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Preface



Climate change, increasing energy demand and resource scarcity not only require a change in infrastructure and industry but also in buildings and cities with smart technologies and systems.

Research and innovation crucially contribute to sustainable and energy-efficient buildings and cities. In the course of the research programme “Building of tomorrow” in the last years my resort has supported many concepts and key technologies for buildings. International co-operations made it possible to successfully disseminate Austrian research results. Today Austria plays an international pioneer role in energy-efficient building.

The new research programme „City of tomorrow“ aims to face coming challenges by funding technological research and development projects of systems and services for the city of the future.

I am therefore very pleased to introduce here at the Sustainable Building Conference 2013 this new research programme to an international audience for the first time. Dedicated to essential questions reaching from renovating buildings and quarters to smart cities, the conference is an excellent platform to present Austrian technologies and know-how in the realms of buildings and cities.

With this in mind I wish those attending the international conference stimulant and exciting discussions!



Doris Bures
Bundesministerin
für Verkehr, Innovation und Technologie

Fotonachweis: bmvit / Peter Rigaud

Preface Minister

The klima:aktiv building standard is Austria´s most prominent quality label for buildings



Sustainable building and renovation are essential instruments of climate protection and represent an important step towards energy autonomy. About one third of our energy consumption results from private and public buildings and from service buildings. Due to space heating and their demand for electricity buildings cause a substantial part of the greenhouse gas emissions.The klima:aktiv building standard is Austria´s most prominent quality label for buildings

Sustainable building and renovation are essential instruments of climate protection and represent an important step towards energy autonomy. About one third of our energy consumption results from private and public buildings and from service buildings. Due to space heating and their demand for electricity buildings cause a substantial part of the greenhouse gas emissions. With comprehensive thermal retrofitting, greater energy efficiency in new buildings and an increase in the share of renewable energy we can protect our climate for the long term. Austria possesses extremely extensive know-how in the fields of environmentally benign and energy-efficient construction and heating technologies. Our country is a frontrunner in the passive house technology and all over the EU one out of three solar energy systems is already from Austria. We must exploit this immense potential.

My ambition is to achieve energy autonomy, meaning that, on balance, Austria produces enough energy from renewable sources to be self-sufficient. To attain this goal until 2050 I am strongly promoting a shift of our system towards renewable energy and higher energy efficiency. With my climate protection initiative klima:aktiv, the subsidisation priorities in the climate and energy fund, the promotion of environmental projects in Austria and vigorous action to foster thermal refurbishment, the Ministry of Life offers concrete advice and financial

support. These investments have also significant economic impacts in Austria: They bring about economic recovery and growth and provide new green jobs.

The klima:aktiv programme "bauen und sanieren" for building and renovation aims at making energy-efficient building and comprehensive thermal-energetic refurbishment an issue of public interest. The klima:aktiv building standard of the Ministry of Life is the most prominent Austrian quality label for residential buildings and service buildings. It is awarded to buildings which satisfy very demanding energetic and ecological requirements. Energy-saving and energy-efficient building is an essential criterion which we have to fulfil to achieve energy autarky. A construction sector which is oriented towards sustainability has positive impacts not only on the environment: With new green jobs it provides promising perspectives on the job market and induces economic advancement.

The Sustainable Building Conference 2013 in Graz comprises highest standards concerning "blue buildings", "green products" and "smart cities". We are convinced that the klima:active building standard will contribute to the high quality of this international conference.

I wish the Sustainable Building Conference 2013 a sustainable success and lots of interesting discussions and insights.

Nikolaus Berlakovich
Minister of the Environment



Ladies and Gentlemen,
dear participants of the “Sustainable building Conference 2013”

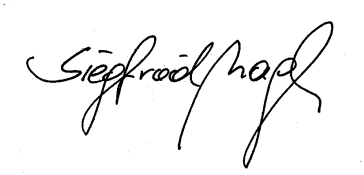
A cordial welcome to Graz, the World Cultural Heritage City, the City of Human Rights and the City of Design!
All three titles have one thing in common: They are all connected to UNESCO.
If we leave out the U-N and O, then it is about Education, Science, and Culture.
We like to think that our city is built on these three pillars, but one pillar is missing here and that is commerce and industry.
But, as you know, this fourth pillar results from promoting the first three.Knowledge is power. Research and the resulting competitive edge form the basis for surviving in today’s global competition.
The ever growing body of knowledge, which is making it more and more difficult to gain an insight into and an overview of specialized fields, means that working in networks is indispensable. These networks between universities provide the foundation for world-class research.

However, networks are a significant factor for progress and development on all levels—both for individuals as well as projects and businesses.

The worldwide growing urban centres need new and creative solutions for ecological and sustainable house building, as well as plant manufacturing. We need also sustainable energy supply, short distances between accommodations, offices, kindergartens, schools and shop centres etc. and we need smart solutions for the traffic.

Therefore, I would like to wish your conference a successful outcome and hope to be able to welcome you again soon in our city!

Yours sincerely,



Mayor Siegfried Nagl
City of Graz

Dear SB 13 participants,



As director of the executive department for urban planning, development and construction of the City of Graz it is a great pleasure to be able to welcome you to Graz, where sustainability in building has long been an important topic. We understand the importance of communicating with other cities and other regions in order to be able to compare the best examples, both in research and in practice. This enables us to discuss their relevance for each city and therefore find optimal solutions. Everyone benefits from being involved in this sort of international cooperation.
The City of Graz has already achieved international recognition for its efforts to find sustainable solutions. This has been made possible through cooperation with numerous experienced partners such as the University of Technology in Graz, Province of Styria and also with outstanding companies working within the research and energy sector. For this reason our concept for a Smart City, the sole flagship project in Austria, has been awarded with a financial sponsorship from the federal running into millions.
This means that we are now able to begin the detailed planning phase of building a sustainable, futureproof, energy self-sufficient district which will be built on an old industrial brownfield near to the main train station in Graz.

Concerning the project “Energy City Graz-Reininghaus”, an overall energy concept including energy networks will enable sustainability for this district. The first steps of the implementation can already be seen.

At SB 13 internationally renowned experts will highlight all aspects of sustainable construction in numerous talks and lectures. The topics range from sustainable, energy self-sufficient urban technologies and the building of new, futureproof buildings to environmentally friendly building materials and sustainable renovation as well as the development of whole districts in such a way that resources are conserved and the observation of the entire lifecycle of buildings.

The fact that young researchers have been invited to come and present new research methods shows that we do not want to simply be satisfied with that which we are building now, but that we want to focus on the future. I have high hopes that the International Sustainable Building Conference 2013 in Graz will represent an important milestone in the development of sustainable building!

I wish you every success and best wishes for a sustainable future!

DI Mag. Bertram Werle
Director of the executive department for urban planning, development and construction
City of Graz



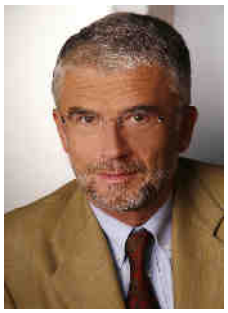
As most visible elements of our built environment, buildings satisfy a deep rooted human need for protection, comfort and well-being. Be it on the workplace, at home, or the public sphere, constructions most strongly determine our quality of life.
But construction and operation of buildings also form part of highest primary resource consumption, energy intakes and environmental pollutants. With 30 to 40 % of pollution and energy consumption within the industrialized world being associated with our buildings, quality and efficiency improvements can provide profound contributions to a more balanced and ecologically sound society.
Therefore all constructive disciplines, civil engineers, architects, infrastructure planners- as well as socio-cultural scientists and political representatives need to be interlinked in order to make a difference by implementing new and innovative technologies. With life cycles that last over decades, generations and often centuries, application of newest technologies and standards is paramount when it comes to ecologically sound and economically efficient buildings.

Being a powerhouse of sustainability, Graz University of Technology is the perfect place to host this “International Sustainable Building Conference”. Through our Field of Expertise “Sustainable Systems”, as well as via the “European sustainable energy innovation alliance” (esaia), we form part of a highly dynamic global sustainability network. Your conference participation most clearly displays the successful path this institution has taken. The coming days will provide you with ambitious intellectual, scientific as well as social inputs. All this is needed to help implement long lasting solutions – and develop new ideas – on how to reduce our primary and secondary resource consumption in building and construction. I hope that after the coming days you will associate Graz with visions, ideas and solutions on how to make our planet a better place!

Yours

Harald Kainz
Graz University of Technology

Foreword





Meanwhile sustainable development has got to a place in the building and construction sector. Therefore it is time to transpose the paradigm change into practice on an overall basis. Whereas in Austria energy efficiency, use of renewable energy or reduction of greenhouse gas emissions were synonyms for sustainable construction we can notice today an increasing acceptance of the holistic approach, the necessity of considering ecology, economy and sociocultural aspects in the building sector simultaneously over the entire life cycle.

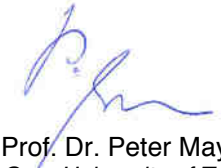
The European Commission enforced this development by releasing numerous strategies, directives and regulations such as e.g. the Energy Performance of Buildings Directive, the Lead Market Initiative Sustainable Construction or the new Construction Products regulation with the new Basic Requirement 7 (*Sustainable Use of Natural Resources*). Parallel to these mandatory regulations, a suite of standards (e.g. European standards for sustainable construction) and non-mandatory building certificates particularly in the area of office and retail buildings emerged. This intensive supply of information, however, leads to many more questions from clients and practitioners, especially on how buildings can be constructed and maintained in a sustainable way.

With these facts in mind, we highly appreciate the initiative of CIB, UNEP, iiSBE and FIDIC of having established the series of SB conferences and are very happy to host the last one of the central European SB conferences in 2013 here in Graz.

One of the most important starting points is the sustainable handling of the existing building stock therefore the SB conference in Graz addresses not only new buildings but also restoration and refurbishment. Hence, we combined the SB13 Graz conference with the ökosan conference, which is normally hosted by AEE INTEC (Institute for Sustainable Technologies). Ökosan is a symposium on ecologically sound refurbishment technologies and best practice examples and together with AEE INTEC we have a strong partner, which offers the possibility to merge theory and practice.

Graz University of Technology and particularly the Faculty of Civil Engineering Sciences acted always as an interface in technology transfer between all stakeholders. Therefore, we do hope to contribute with this conference to a knowledge transfer in the scientific community, but especially with commercial partners from industry, planners and public authorities, in order to realise a sustainably sound built environment without overflow of rules and regulations. Standards and assessment tools should be accepted as support and assistance, not as a restraint.

We are looking forward to your vital participation in the sessions and workshops and wish you a pleasant stay in the green heart of Austria.





Prof. Dr. Peter Maydl
Graz University of Technology

Ass.Prof. Dr. Alexander Passer
Graz University of Technology

Dr. Karl Höfler
AEE INTEC



Dear Participants of the “Sustainable Building Conference 2013”,

The global issues we are all currently facing are multiple. A central one is certainly the continuously rising global demand for sustainable solutions and the building sector is playing a key role in this area.
The supply of future oriented building material solutions and optimized production processes of building materials are consequently the core of the Wienerberger sustainability strategy.
Our target is the delivery of building concepts for tomorrow today. Our long-lasting, resource-conserving building materials as well as our energy-efficient house concepts help our customers make a substantial contribution to environmental protection. Our e4-Brickhouse 2020 for example has a positive energy and CO_2 balance and in this way makes an active contribution to climate protection.

Wienerberger sees also an important potential in the education of young people in the field of sustainable building solutions. Therefore, Wienerberger provides an international education program dedicated to Masters Students of Architecture, Civil and Environmental Engineering who are outstandingly motivated in the field of sustainable building and wish to extend their knowledge and experience in this area. Within the first round of the Wienerberger’ s Sustainable Building Academy (WISBA 2013/2014) we invite 12 students from three different countries for a fully financed one semester training together with experts from science and economics in the field of sustainable building. We start the program of WISBA 2013/2014 in cooperation with the Sustainable Building Conference 2013 in Graz because it guarantees our scholarship recipients the scientific exchange on a high level with the most important experts in Europe. The 3-day kick-off event of WISBA will then be followed by four international workshops during the next months and a final conference in spring 2014.

Sustainable management has been a key part of the Wienerberger corporate culture for many years and is fully integrated in all areas of the company. In order to make our sustainable management activities even more transparent, we have decided to announce our sustainability goals for various areas in the sustainability report 2012 and will report regarding our progress in the future. I invite you to form your own opinion of our efforts with respect to sustainability management and to join us on a sustainable course into the future. For the Sustainable Building Conference 2013 in Graz I wish you all interesting discussions and a promising outcome.

Yours,

Heimo Scheuch, CEO

A1

Legal and economic frame conditions for ecological high quality refurbishment

Chair: Robert Schwertner
FFG – Austrian Research Promotion Agency, Austria

Comparison between energy usage and thermal comfort of typical masonry houses in Ireland before and after receiving retrofit



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Short Summary

This research project examines the efficacy of typical insulation and building fabric upgrade works of residential buildings in reducing energy and greenhouse gas emissions, as well as their affect on the perceived thermal comfort of the occupants. This is achieved by monitoring 19 houses in Ireland and assessing the internal environment, energy consumption, comfort and occupant behaviour, before and after typical residential insulation improvements. A full economic and environmental lifecycle analysis is conducted, which considers both the energy consumption and carbon emissions embodied in the retrofit works together with those associated with the operation of the home. The houses are typical masonry construction used in Ireland. The retrofit provisions included pumping the cavity walls with insulation and increasing the level of insulation in the attic above the ceiling joists. The heating systems in the homes are a central heating system using an oil-fired condensing boiling and a solid fuel open fire in the sitting room. The mix of fuel type employed varied in the different houses. So did the level of satisfaction expressed by the occupants in relation to the thermal comfort conditions before and after the upgrade works? As expected, the upgrade of insulation of the houses lead to increased internal temperature, but also in most instances an expected decrease in overall energy consumption over the lifecycle of the building. However, deeper retrofitting is required on houses in Ireland if the Sustainability Energy Authority of Ireland's target to reduce CO_2 emissions of buildings by 90% by 2050 is achieved. This is a similar target set by the European Commission for reductions in emissions associated with buildings in Europe.

Keywords: Lifecycle assessment; Retrofit; Embodied energy; Embodied carbon; Residential buildings.

1. Introduction

As Ireland aims at limiting greenhouse gas (GHG) emissions to 113% of 1990 levels through Kyoto Protocol commitments by 2020 [1], national GHG emissions associated with the residential built environment will have a significant role to play. Due to recent deceleration in new EU construction activity [2], it is widely expected that national retrofitting strategies of existing housing stock will require significant investment if legal binding targets are to be successfully achieved, especially in Ireland where a significant portion of Ireland's total housing units were completed in the last decade (see Figure 1). Considering the majority of existing housing units will still be active in 60 years time, a lifecycle perspective strongly suggests domestic energy performance retrofitting or refurbishment schemes will be vital in achieving energy efficiency targets [3]. Hence, the

importance of a lifecycle analysis study, in terms of energy and carbon, for retrofitting projects is authenticated. Over a 60 year lifespan it is important perceived operational energy savings of retrofit options are not outweighed by indirect embodied properties of installed materials or services. Studies have highlighted challenges associated with examining retrofit options in Ireland over a lifecycle period [4, 5].

93% of Irish housing units granted planning permission between 1977 and 2011 have initial energy performance requirements compliant to 2005 Irish building energy performance regulations [6] or earlier from collected Central Statistics Office (CSO) data [7], equating to an equivalent Building Energy Rating (BER) [8] of 'B3' or lower upon construction assuming no subsequent renovations or retrofitting. A BER is an independent national certification system used in Ireland to assess how energy efficient a home is. An alphabetical rating scale from 'A-G' is utilised with an A rated home being the most energy efficient [8]. A BER is based on the characteristics of major components of the dwelling (wall, roof and floor dimensions, window and door sizes and orientations) as well as the construction type and levels of insulation, ventilation and air tightness features, the systems for heat supply (including renewable energy), distribution and control, and the type of lighting. It covers annual energy use for space heating, water heating, ventilation, lighting and associated pumps and fans, calculated on the basis of a notional standard family with a standard pattern of occupancy [8]. It is important to note that a BER is only an indication of the energy performance of a house. For example, a rating of B3 equates to a primary energy usage of between 125 and 150 kWh/m^2/yr. Hence, logical conclusions suggest retrofitting packages (small, medium and deep) will play a vital role in landscaping Ireland's future housing stock. Previous Sustainable Energy Authority of Ireland (SEAI) retrofitting scheme take-up has been welcomed in Ireland [9].Therefore, implementation of the SEAI's residential roadmap targets to sizeably reduce domestic residential energy usage and carbon consumption by 2050 is imperative [10]. Various scenarios have been developed with retrofitting to varying degrees of up to 1 million Irish homes in order to achieve substantial Irish residential sector decarbonisation. Targets are in accordance with European Commission 2050 goals to cut EU CO_2 emissions by 90% and energy consumption by 50% [11].

However, it is important appropriate investigation into perceived operational saving benefits is carried out assessing the true effect of residential retrofit financial grant packages offered by SEAI [12]. Issues such as occupant and physical 'take-back', energy usage offsetting, tenant thermal comfort level and internal temperature changes require attention. A 2008 SEAI residential sector report mentioned data on comfort levels or internal temperatures for residential dwellings was unavailable for Ireland with UK values assumed [13]. Without substantial quality thermal comfort and internal temperature data on retrofitted residential buildings in Ireland, it is difficult to truly assess the impact of future national retrofitting schemes.

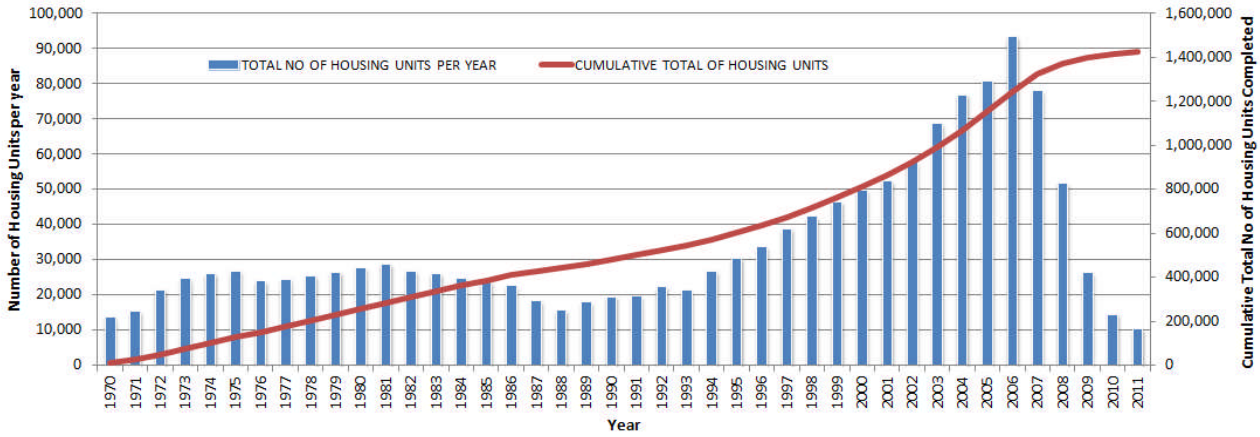


Fig. 1: Housing unit completions from 1970-2011 according to Central Statistics Office data [14].

Improvement of the energy efficiency of the existing housing stock is a core element of Ireland's National Energy Efficiency Action Plan [15]. 199 ktCO_2 (CO_2 emissions) of the currently proposed reductions target relates to state incentivised insulation and heating system upgrades to existing houses, over the life time of the plan. These savings accounts for 8% of the overall reduction forecast for the residential sector. The *Better Energy Homes* and *Better Energy Warmer Homes* are the primary grant schemes in operation in Ireland at present, targeting houses constructed prior to 2006 and 2002, respectively [9, 12]. Anticipated energy savings are the primary motivating factor for individuals part-taking in such state incentivised schemes with comfort gain forming the second most important factor influencing any investment. Previous studies have highlighted possible mean energy savings (21%) of natural gas demand through the SEAI Home Energy Saving (HES) energy retrofitting scheme for a sample of homes when observed over a two year period [16]. Interestingly, a lifecycle analysis retrofit study conducted as part of Rebound initiative on common house types retrofitted to various degrees highlighted client 'take-back' as a concern for residential retrofit project [17, 18]. In that study, the observed before and after works mean temperature data was used to develop specific Dwellings Energy Assessment Procedure (DEAP) [19] models to assess the impact of temperature take back on CO_2 emissions savings resultant from the works, determining the level of direct rebound effect, i.e. the amount of potential CO_2 emission reductions taken back as additional warmth in the properties. Unexpectedly high levels of 'take back' were predicted, if the observed short range temperature increases were to be sustained in the longer term [17, 18]. Furthermore environmental life cycle assessment (LCA) studies on residential case study buildings highlighted the importance of actual operational energy (OE) and carbon (OC) usage in home as a true carbon footprint indicator instead of current BER system limitations [8, 20]. Therefore, before the largest national retrofitting scheme is undertaken in Ireland it is imperative the true potential of retrofitting project initiatives is carefully assessed.

This paper presents findings from a case study set of typical masonry residential buildings in Ireland to determine the efficacy of typical insulation and building fabric upgrade works of residential buildings in reducing energy and greenhouse gas emissions, as well as their affect on the perceived thermal comfort of the occupants. This is achieved by monitoring 19 houses in Ireland and assessing the internal environment, energy consumption, comfort and occupant behaviour, before and after typical residential insulation improvements. These houses are located in a residential housing estate in Ballyshannon, Co. Donegal, Ireland. Operational monitoring started from November 2012 with upgrade retrofit works completed in December 2012. This paper contains provisional case study results as monitoring is ongoing. However, a full economic and environmental lifecycle analysis is presented, which considers both the energy consumption and carbon emissions embodied in the retrofit works together with those associated with the operation of the home.

2. Case study retrofit project overview

2.1 General information

The Highfields residential housing estate in Ballyshannon, Co. Donegal consists of 19 masonry housing units constructed in 2004. The estate is managed by the Cluid Housing Association, which aims to deliver affordable homes to people on housing waiting lists all over Ireland [21]. Housing estate building topology consists of the single-storey and two-storey units, as presented in Table 1. The two-storey 3-bedroom semi-detached homes in this estate have typical average total floor area (110m^2) of semi-detached houses constructed in Ireland, according to CSO data [7]. The two-storey dwellings contain on the ground floor a hallway, living room, combined kitchen and dining room, utility and WC. On the first floor, they contain a landing, bathroom, hot-press (with hot-water storage cylinder) and three bedrooms, The single storey dwellings contain a hallway, one bedroom, bathroom, living room, combined kitchen and dining room, hot-press (with hot-water storage cylinder) and a utility. All of the dwellings have an attic space. The heating systems in the homes are a central heating system using an oil-fired condensing boiling and a solid fuel open fire in the living room.

Table 1: A breakdown of the Highfields Cluid housing estate by house type and total floor area.

House Type	House Number	Total No of Houses	Total Floor Area (m^2)
Two-storey semi-detached	7,8,9,10,16,17,18,19	8	110
Two-storey mid terrace	2,3,12,13,14	5	110
Single-storey end-of-terrace	1,4,11,15	4	67
Single-storey semi-detached	5,6	2	67

Located north east of Ballyshannon, house orientation varies through the estate site layout, as seen in Figure 2. Houses numbered 5 through to 10 are orientated in a north-south direction with the front of the houses southerly facing. House numbers 11 to 15 are opposite in orientation. House numbers 1 to 4 have front openings facing easterly, as seen in Figure 2, with Highfields 16 to 19 are not aligned with the other 15 homes. Their front openings are in a predominantly south-westerly direction. A photo of houses 7 to 10 is also provided in Figure 2.



Fig. 2: Highfields estate orientation layout map and photo of sample masonry estate homes.

2.2 Upgrade retrofit works

Thermal upgrade retrofit works were completed in mid-December 2012 on all 19 estate homes. A basic upgrade in thermal cavity wall and ceiling insulation was conducted in accordance with the Better Energy Homes scheme offered by SEAI [12]. Theoretical U values of building fabric ceilings and walls in all homes were improved as a result.

2.2.1 Pre-works BER

As seen in Figure 3, average pre-works BERs ranged from D2 to C3 for estate houses. BER results are expressed in terms of annual primary energy consumption ($kWh/m^2/yr$) and annual carbon dioxide emissions ($kgCO_2/m^2/yr$) based on input data to the Dwelling Energy Assessment Procedure (DEAP) software calculation tool [19]. Depending on the intensity value achieved an alphabetical grade rating is assigned to the assessed dwelling. For the Highfields estate pre-works, annual primary energy consumption and carbon dioxide emissions varied from 185-294$kWh/m^2/yr$ and 47-75$kgCO_2/m^2/yr$, respectively, according to the collected BER certificates shown in Figure 3.

2.2.2 Post-works BER

As depicted in Figure 3, an expected improvement in BER is recorded in all homes post-works following retrofitting. Average post-works BERs ranged from D1 to C2. For the Highfields estate post-works, annual primary energy consumption and carbon dioxide emissions varied from 169-267$kWh/m^2/yr$ and 43-67$kgCO_2/m^2/yr$ respectively, according to the collected BER certificates as shown in Figure 3. As a result, it would be expected that client perception of internal thermal comfort would improve and average internal temperature increases would be experienced as a result of insulation works.

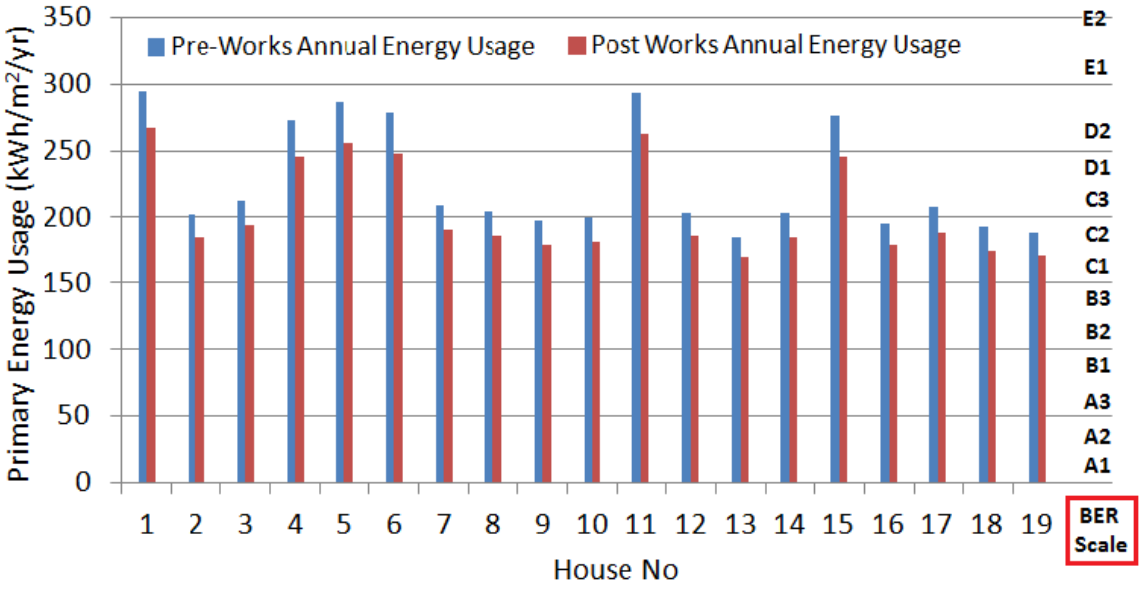


Fig. 3 Building Energy Rating (BER) of Highfields estate pre and post insulation upgrade works.

2.3 Data instrumentation/inventory

Pre-works residential analysis required installation of oil, temperature and relative humidity (RH) recording devices. They were installed in selected estate homes, as indicated in Figure 4. Lascar electronic temperature and RH sensors EL-USB-2 and EL-USB-2-LCD were installed in 15 estate houses on November 22nd 2012. Devices were planned to be left onsite in all 15 homes for the duration of the heating season and beyond. Intermediate downloading of data occurs on subsequent site visits. 10 Apollo smart oil monitors were installed onsite in 10 houses that utilised oil-fired central heating and water systems. Sensors to obtain real-time electricity usage were also installed to obtain electricity usage in selected homes. A thermographic camera was utilised to perform thermography both pre- and post-works on selected estate houses. Digital cameras and camcorders were also used onsite were necessary.

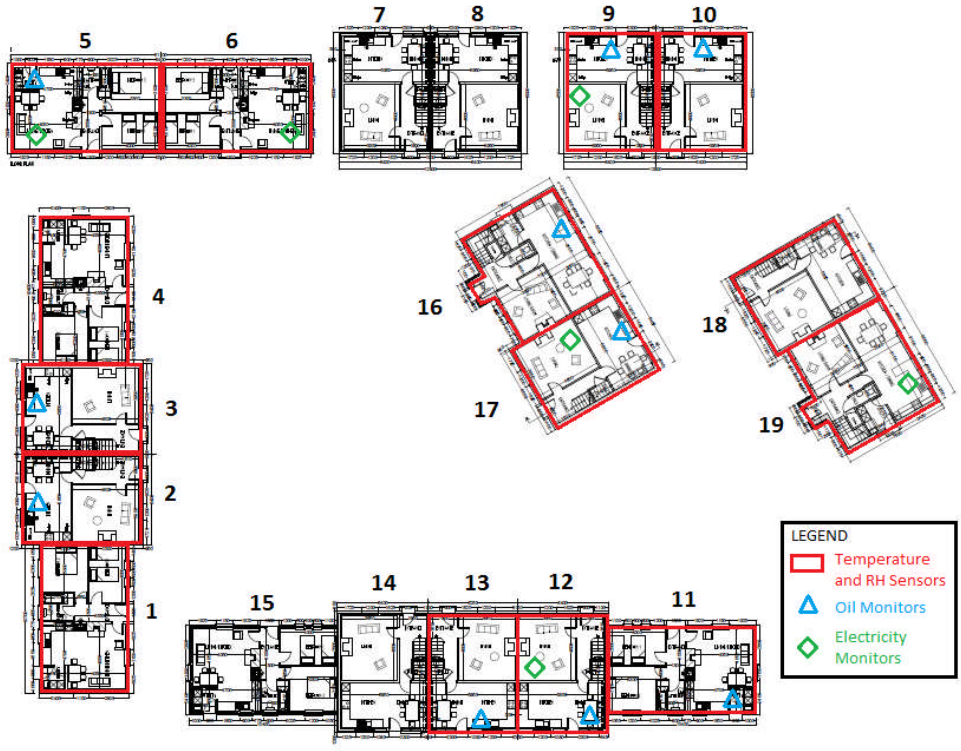


Fig. 4: Location of temperature and relative humidity sensors, oil and electricity monitors.

2.4 Occupants surveys

As part of the study, strategically designed surveys were conducted on tenants both pre- and post-insulation works. Information was gathered with respect to number of residents per house, number of years living at the dwelling, average time spent at home, average energy spending expenses per house and existing appliance usage is collected. Other important issue such as internal thermal comfort perception and relative tenant behaviour is regularly recorded. Continuous thermal comfort surveys are carried out at every site visit to maintain a database of tenant internal comfort levels.

2.5 Weather data

Weather data was gathered from a Met Eireann operated weather recording station at Ballyshannon for daily rainfall, maximum and minimum temperatures for the available period from January 2011 to January 2013, as seen in Figure 5. External temperature and/or rainfall, as well as other external environmental conditions, may influence final result interpretation. Thus, further data, such as relative humidity and global radiation, will be obtained from another weather station operated by Met Eireann in the locality (Finner, Bundoran, which is 5km from the site).

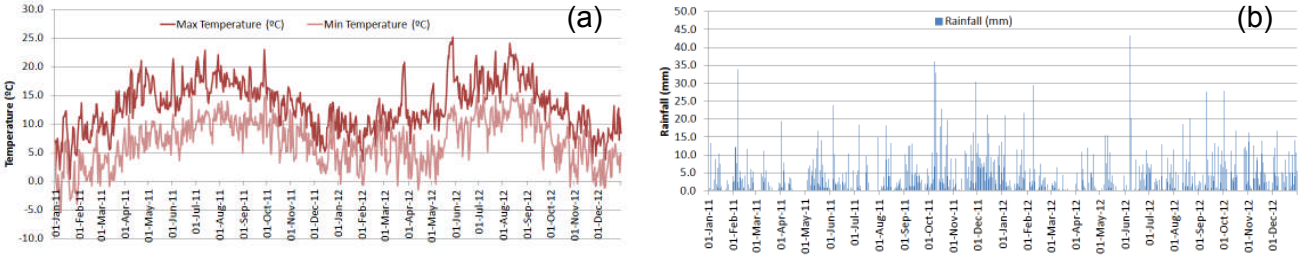


Fig. 5: (a) Maximum and minimum daily temperature data and (b) rainfall (mm) from a Met Eireann Ballyshannon weather station from January 2011 until January 2013

3. Results and discussion

Provisional results from the installed data equipment and tenant surveys are presented in this section.

3.1 Internal thermal comfort and temperatures

Figure 6 presents data from installed temperature and relative humidity sensors pre- and post-retrofitting works from a number of case study homes. Three sets of results (kitchen, living room and bedroom) are presented from a three bedroom two-storey semi detached house (House No 9). Comparative kitchen and living room results are extracted from the adjoining two storey house (House No 10), while a bedroom from House No. 3 (a two-storey semi-detached bungalow is also displayed. The location and orientation of these dwellings can be seen in Figure 4.

Initial observation of provisional results suggests a slight immediate increase in internal temperatures following insulation upgrade works completion. External temperature data corresponding to period of analysis time suggests maximum values rarely exceeding 10 ºC and minimum recordings peaking below 0 ºC. It is assumed home space heating requirements were required during this period with home space heat retention an important building fabric factor. Following retrofitting, relatively stable pre-works house internal temperatures are displayed in many houses, such as all rooms in House No. 6 (see Figure 6 (a), (c), (e)), as well as the living room in House No. 10 (see Figure 6 (d)), with peaked rises in internal temperature following retrofitting. On the other hand, the internal temperature of the kitchen in House No. 10 has larger fluctuations (Figure 6(b)), as well as the bedroom in House No. 3 (Figure 6(f)), as these houses rely more on solid fuel heating in the open fire in the sitting room during the day, whereas the occupants in House No. 9 have the oil-fired central heating on throughout most of the day. Furthermore, these

rooms typically have lower internal temperatures, which is due to low space heating being used by the occupants in these rooms. In some houses, internal temperatures reduce after a period, which may be caused by user behaviour or external influences (for example, in House No. 9 – see Figure 6(a),(c),(e)). Thermal space heat retention building fabric properties improved after retrofitting. Thus, after an initial increase in internal temperature in the house post-works, some occupants reduced the amount of space heating they used (i.e. had the central heating system for shorter periods of time or less often).

Average internal temperature, relative humidity and dew points vary substantial for individual case study homes as Figure 6 demonstrates. Two similarly designed rooms can have significant differences in internal temperature and relative humidity, as Figure 6 demonstrates. Therefore, significant variations in user behaviour cannot be ignored when estimating actual energy and carbon savings following retrofitting. Future analysis will investigate this effect further.

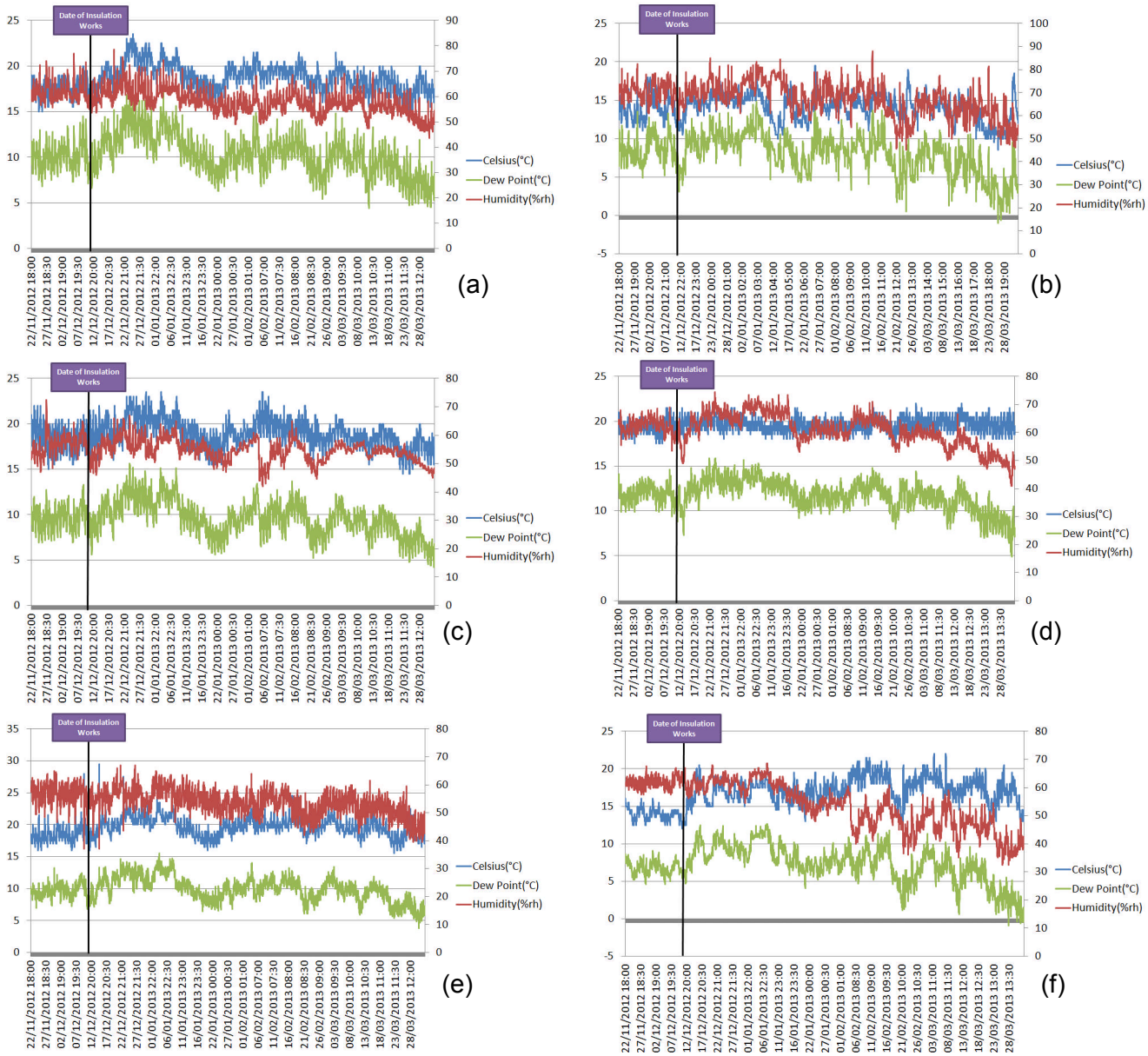


Fig. 6: Provisional temperature and relative humidity results recorded in case study homes. Results are taken from the following locations: (a) House No 9 Kitchen (b) House No 10 Kitchen (c) House No 9 Living Room (d) House No 10 Living Room (e) House No 9 Bedroom (f) House No 3. Bedroom.

Tenant perception on the internal thermal comfort of their homes pre- and post-retrofitting reflects favourably on the perceived benefit of retrofitting to the internal environment of houses. A perceived general increase in internal thermal comfort standards by the occupants following completion of the insulation upgrade works can be clearly seen in Figure 7. When residents were asked post-works if the insulation upgrade works would be of thermal comfort benefit, 90% surveyed felt the works would be of thermal comfort benefit.

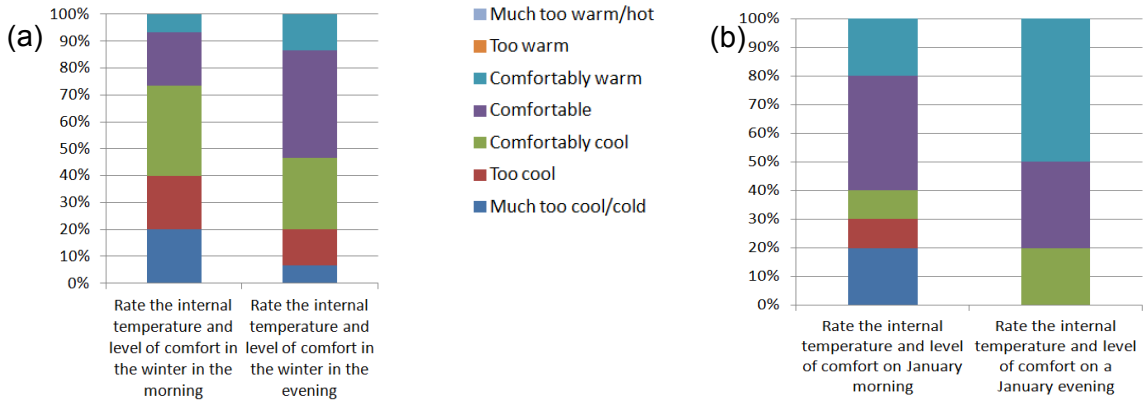


Fig. 7: Results from an occupant survey rating house internal comfort level (a) pre-works and (b) post-works

3.2 Energy and carbon usage

One important energy and carbon usage analysis area is occupancy electricity usage habits and trends. Estimated rationalised electricity usage data pre- and post-retrofitting works was collected from all estate homes and is presented in Figure 8, where the average daily electricity usage is given in kWhr per m^2 of floor area of the dwelling. Three scenarios are outlined in Figure 8 – pre-works, post-works and post-works excluding the three week Christmas period. Average daily electricity usage for a period pre-works and average daily usage post works are calculated from electricity usage data recorded. In some dwellings, electricity usage over the Christmas period would not be typical of other periods during the winter. Thus, a special compensation period of 3 weeks over Christmas is excluded in the third scenario, which was post-retrofitting works.

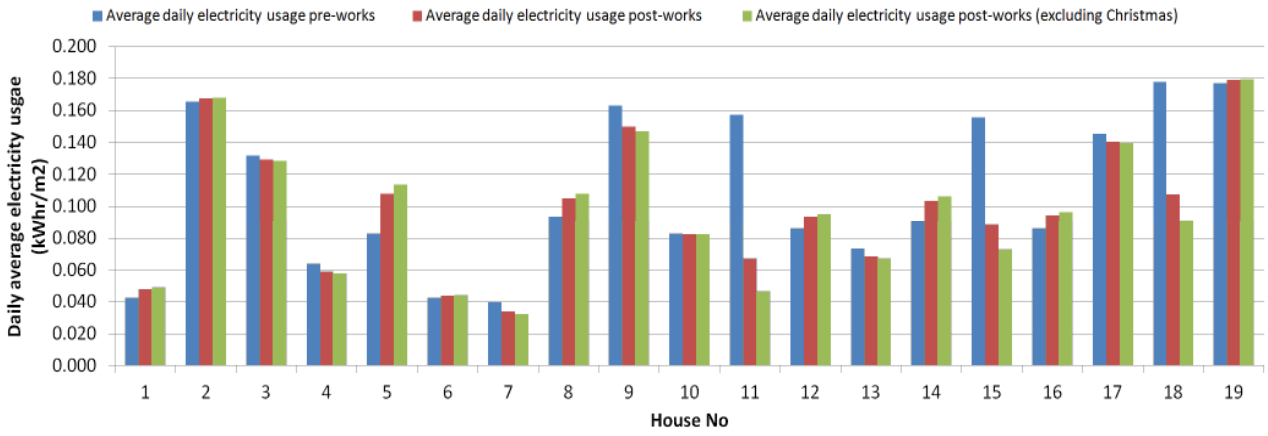


Fig. 8: Average estimated daily electricity usage in each estate house for the period from November 2012 to April 2013 per m^2 of floor area.

As can be seen from Figure 8, the average electricity daily usage varied significantly between dwellings in the estate, even for the same house type and occupancy level. For example, for the one-bedroom single-storey dwellings (i.e. Houses 1,4,5,6,11,15) there was a difference of over

3.75 times the average daily electricity usage between House no. 1 and 11 prior to retrofitting of the houses. The reason for the significant differences is that some houses used personal electric heaters for additional space heating in addition to the oil fired central heating systems and/or solid fuel open fire (e.g. House 11 and 15), whereas others had a back boiler behind the solid fuel open fire in the sitting room, which connected to the central heating system, and did not use additional personal electric heaters (e.g. House no. 1 and 4). It is noteworthy that both House 11 and 15 had significantly lower average electricity usage post-retrofitting works, which was due to lower use of personal electric heaters.

From Figure 8, nine of the case study houses (Houses 3, 4, 7, 9, 11, 13, 15, 17 and 18) experience decreases in average daily electricity usage per m^2 of floor area according to collected data. This represents half the assessed estate homes. It is not possible to assume electricity usage decreases are caused solely by retrofit works although its impact on electricity usage cannot be ignored. A pre-works survey noticed 40% of assessed estate dwellings used electric heaters in the preceding week to the survey. No mention of electricity based heaters was recorded in post-works surveys. Significant average daily electricity usage per m^2 of floor area increases is recorded in certain estate homes (House No 11, 15 and 18). No significant change in household appliance was recorded in any assessed home after the works.

Estimated economic annual energy spending analysis for space heating in Highfields estate homes is based on tenant survey answers and heating season assumptions both pre- and post-works. Average estimated monthly and weekly spending was recorded before and after the works. A heating season assumption of 6 full months and 6 half months of fuel spending is assumed. Improved accuracy of monetary spending on fuel is ongoing with the continuous collection of data through ongoing resident survey studies and increased fuel usage data recordings. Nevertheless, some trends emerged with respect to estimated annual energy spending per m^2 of floor area according to the two housing unit types, as shown in Table 2. For example, an average estimated annual spending reduction of €9 per m^2 of floor area is estimated for the one-bedroom semi-detached bungalows from recorded answers before and after upgrade insulation works. Little or no spending estimation savings are recorded for the larger semi-detached houses assessed based on assumptions and gathered energy spending data. However, there are large variations in monetary spending on each fuel type between similar homes, as indicated in Table 2 by the large coefficient of variation (COV) values.

Substantial savings were recorded in coal usage amongst one-bedroom semi-detached bungalows before and after the works. Slight decreases in average annual heating oil, peat and briquettes and biomass are also recorded in the semi-detached bungalows assessed following retrofitting. A 22% reduction in heating oil average estimated spending per m^2 of floor is recorded for the larger estate homes as seen in Table 2. However, a counterbalance exists with an increase in coal and biomass usage in these homes according to data recorded. Such an offsetting of energy spending can often not be represented in perceived operational energy or carbon savings.

Ongoing analysis aims to improve result validity. 60% of assessed estate tenants had found noticeable savings in energy usage following the upgrade insulation works, while 30% had not according to survey results. The remainder were unsure. Such results favourably represent the client perceived residential retrofitting approach.

Table 2: Average estimated annual spending by fuel type per m^2 of floor area according to the two predominant estate housing unit types.

House Type	Fuel Type	Pre-Works		Post-Works		Difference
		Average	COV	Average	COV	Average
Semi-detached bungalows ($67m^2$)	Heating Oil	€6.6	0.93	€5.1	1.07	-€1.50
	Coal	€11	0.8	€5.4	0.87	-€5.7
	Peat	€0.5	2.24	-	-	-€0.5
	Briquettes	€0.9	1.37	€0.4	1.73	-€0.5
	Biomass	€1.2	1.63	€0.6	1.18	-€0.6
	Total	**€20**	**-**	**€9**	**-**	**-€9**
Semi-detached two storey ($110m^2$)	Heating Oil	€7.9	0.56	€6.40	0.2	-€1.60
	Coal	€5.6	0.69	€6.10	0.72	+€0.5
	Peat	-	-	-	-	-
	Briquettes	€0.2	3.16	€0.1	2.65	-€0.10
	Biomass	€0.7	1.51	€1.80	1.19	+€1.10
	Total	**€14**	**-**	**€14**	**-**	**€0**

Environmental lifecycle assessment (LCA), in terms of energy and carbon, found average initial embodied energy (EE) and embodied carbon (EC) of installed building materials according to acquired bills of quantity to account for 9% and 12% of lifecycle energy and carbon over a 60 year lifespan pre-retrofitting works, respectively. Average operational energy (OE) and operational carbon (OC) accounted for the majority of lifecycle energy and carbon of the estate homes.

Based on post- and pre-retrofitting works BER results, perceived annual OE savings (16-27kWh/m^2) and OC savings (4-8kgCO_2/m^2) in the estate houses should benefit residential occupants financially in the long term. Theoretical annual energy savings should equate to between 1696-2113kWh and 1769-2079kWh for larger and smaller estate homes, respectively. Therefore, assuming a domestic delivered energy cost of 26 cent for electricity [22], annual estimated energy savings range from €438-549 and €467-541 for larger and smaller estate homes, respectively. Similarly, assuming a domestic delivered energy cost of 9 cent for oil [22], annual estimated energy savings range from €151-190 and €162-187 for larger and smaller estate homes, respectively. Over a 60 year lifespan, perceived financial operational savings are substantial.

Average estimated annual spending reductions estimated from surveys of occupants of the semi-detached single-storey dwellings amounted to €9 per m^2 of floor area for fuel requirements as a result of retrofitting. All semi-detached single-storey dwellings have a total floor area ($67m^2$). According to Table 2 results, average estimated annual spending savings as a result of the retrofitting works will equate to approximately €603, which is substantially higher than the estimate obtained using the assumptions in the Dwellings Energy Assessment Procedure (DEAP), which is the Irish official method for calculating and rating the energy performance of dwellings. Thus, BER retrofitting estimations are relatively conservative according to these results for the semi-detached bungalows. An over-estimation in perceived operational savings for the semi-detached two storey estate dwellings is recorded. Care must be taken with regard to perceived OE and OC results as a result of retrofitting domestic buildings. Provisional results highlight the significance of perceived operational energy savings when used as a benchmark. Issues such as physical and occupant 'take-back' and energy usage offsetting may have an impact in retrofitted results. Further analysis over a longer period will highlight such issues.

4. Conclusions

In-depth analysis into the efficacy of residential retrofitting packages for Irish residential building

was conducted on a residential housing estate in Ballyshannon, Co. Donegal. Noticeable improvements in internal temperature and occupant perception of internal thermal comfort was recorded in many homes following completion of basic cavity wall and attic (ceiling) insulation upgrade works in December 2012. Provisional results recorded half the assessed homes held a noticeable average daily electricity usage decrease per m^2 of floor area following completion of works. Provisional findings from occupancy surveys recognised the significance of perceived operational monetary savings as a result of retrofitting compared to actual or relative occupant savings. Care is needed when utilised as a retrofitting energy benchmark. The study presented in this paper involved only short span monitoring of the houses before and after works, so it is difficult to determine if the observed internal temperature and energy usage trends will be sustained in the longer term. Future Irish retrofitting strategies may need to account for the actual operational savings impact compared to the perceived for various retrofitting packages on Irish residential buildings. Methods of engagement and more sustainable consumption behavioural models need to be developed, including the communication of the link between behaviour and actual energy bill reduction, which is the primary driver for individuals participating in home energy efficiency schemes in Ireland [18]. Further research in this area is required and may help reduce the direct rebound effect of occupants taking excessive levels of increased comfort. Such measures may be beneficial in ensuring net CO_2 savings are achieved after insulation works and that Ireland's national commitments in terms of CO_2 emission reductions are met.

5. References

1. UNFCCC, *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, http://unfccc.int/resource/docs/convkp/kpeng.pdf, Editor. 1998.
2. European Commission (2012) *Construction: unleashing the potential of low energy buildings to restore growth*.
3. DCENR, *Delivering a Sustainable Energy Future for Ireland White Paper*, D.o.C.E.a.N. Resources, Editor. 2007, http://www.dcenr.gov.ie/Energy/Energy+Planning+Division/Energy+White+Paper.htm.
4. Hernandez, P., et al., *The challenge of refurbishing recently built apartments. A life cycle perspective*, in *Sustainable Building Conference 2010*. 2010: Madrid.
5. Ahern, C., P. Griffiths, and M. O'Flaherty, *State of the Irish housing stock—Modelling the heat losses of Ireland's existing detached rural housing stock & estimating the benefit of thermal retrofit measures on this stock.* Energy Policy, 2013. **55**(0): p. 139-151.
6. DECLG, *Building Regulations 2005 - Technical Guidance Document L - Conservation of Fuel and Energy - Dwellings*, Department of Environment Community and Local Government, Editor. 2005: Dublin, Ireland.
7. CSO. *Central Statistics Office (CSO) - StatBank*. 2012; Available from: http://www.cso.ie/px/pxeirestat/statire/SelectTable/Omrade0.asp?Planguage=0.
8. SEAI, *A Guide to Building Energy Rating (BER)*. 2010, Sustainable Energy Authority of Ireland Dublin, Ireland.
9. SEAI, *Economic Analysis of Residential and Small-Business Energy Efficiency Improvements*. 2011, Sustainable Energy Authority of Ireland Dublin, Ireland.
10. SEAI, *Residential Energy Roadmap 2010-2050*. 2010, Sustainable Energy Authority of Ireland Dublin, Ireland.
11. Energy Efficient Buildings Association (E2BA), *Energy Efficient Buildings European Initiative*. 2011.
12. SEAI. *Better Energy Homes Scheme*. 2013; Available from: http://www.seai.ie/Grants/Better_energy_homes/.
13. SEAI, *Energy in the Residential Sector*, E.P.S.S. Unit, Editor. 2008, Sustainable Energy Authority of Ireland
14. CSO. *Housing Completion Statistics*. 2012; Available from: http://www.cso.ie/px/Doehlg/Dialog/Saveshow.asp.
15. DoCENR, *Ireland's second national energy action plan to 2020*. 2013, Department of Communications, Energy and Natural Resources: Dublin.
16. Scheer, J., M. Clancy, and S. Ni Hogain, *Quantification of energy savings from Ireland's*

Home Energy Saving scheme: an ex post billing analysis. Energy Efficiency, 2012. **6**(1): p. 35-48.
17. McElmeel, H., *rebound project: Preliminary findings*, in *RIAI 3Twenty10 Research Competition*. 2012, RIAI: Dublin.
18. McElmeel, H., *Impact of temperature take back on CO2 emission reductions achieved after insulation upgrades to two detached Irish houses*, in *MSc Architecture: Advanced Energy and Environmental Studies*. 2013, Centre for Alternative Technology: Wales.
19. SEAI. *Dwelling Energy Assessment Procedure (DEAP) - Irish Official Method for Calculating and Rating the Energy Performance of Dwellings*. 2007; Available from: <http://www.seai.ie/Your_Building/BER/BER_Assessors/Technical/DEAP/>.
20. Armstrong, A. and J. Goggins, *The assessment of embodied energy and carbon of residential buildings in Ireland*, in *BCRI 2012*. 2012: Dublin.
21. Cluid Housing Association. *Cluid Housing Association,*. 2013 [cited 2013 8th May]; Available from: http://www.cluid.ie/.
22. SEAI, *Domestic Fuel Comparison of Energy Costs*. 2012, Sustainable Energy Authority of Ireland

Collaboration Models for Industrialised Renovation Methods and Prefabrication – Experiences and Outlook on Organizational and Legal Frame Conditions



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Short Summary

Today building renovation in Europe is characterized mainly by on-site processes, which may be inefficient with regard to cost and time. The E2ReBuild project aimed to further develop, investigate, evaluate and promote new cost-effective and energy efficient retrofit strategies. [1]
Within the seven Demo projects, innovative industrialised renovation methods and prefabricated façade and roof elements were developed and implemented. The evaluation of their realization process provided feedback from practice, identified dependencies and causal motives and showed needs for future actions of policy makers and stakeholders.
A key aspect for successful renovation within the E2ReBuild demonstrations was the quality of the applied collaboration model. Appropriate team set up, coordination in early planning stages and joint development guaranteed optimization and a smooth workflow for renovation. Further the choice of the *Design-Bid-Build* or *Design-Build* approach influenced the collaboration on how responsibilities and risks were handled and thus the contractual situation among owners, planners and contractors.
However, neither the *Design-Build* nor the *Design-Bid-Build* approach could sufficiently meet the requirements of an optimized team set up. Within both approaches stakeholders struggled with uncoordinated actions, misunderstandings, lack of knowledge-sharing within the team and the interface between planning and construction. A lot of know-how got lost due to changed actors or the missing know-how of relevant actors (e.g.: the timber element manufacturer) in early planning stages.
However, current procurement legislation hinders early collaboration and appropriate team set up. In future, actions within legislation and changes of traditional renovation routines are necessary. Procurement legislation should enable teams to offer their services for planning and construction together or to integrate relevant know-how in early planning stages. In future, the influence of appropriate team set up and communication as driving forces for joint development and optimization regarding quality, costs and time have to be recognized. Finally, all interviewed stakeholders within E2ReBuild stated a high replication potential of the applied technologies, processes and models – provided that framework conditions would facilitate their implementation.

Keywords: Building Renovation; Energy-efficiency; Industrialization; Prefabrication; Collaboration;

1. Motivation and objectives

Facing the demand of renovating buildings constructed between 1945-1980 more efficient construction methods, processes and models with regard to quality, cost and time are urgently needed. New technologies such as prefabrication have been developed and applied in several demonstration and pilot projects in Europe, but they haven`t been implemented on the market yet. The vision of the FP7 project E2ReBuild (2011-2014) is to facilitate, promote and support the transformation of the retrofitting construction sector from the current craft and resource based construction towards an innovative, energy-efficient industrialised sector [1]. E2ReBuild aims to further develop, demonstrate and promote cost-effective, energy-efficient retrofit strategies for broader application on the market. A better understanding of obstacles that hinder a broad implementation of new renovation methods, processes and models on the market should be created.
First feedback from practice showed that industrialised methods and prefabrication were especially sensitive regarding collaboration among actors. Uncoordinated actions, misunderstandings and unclear responsibilities were reported. Beside that, building owners claimed that procurement legislation restricted their choice of planners and contractors.
What is needed are appropriate collaboration models supporting the development of cost-efficient solutions and their application within building renovation. Thus, the analysis and evaluation of collaboration models within E2ReBuild aimed to:

- Identify framework conditions that influence appropriate collaboration.
- Uncover barriers and risks that hinder successful team set up.
- Identify necessary actions within legislation and traditional construction routines.
- Present key aspects for successful collaboration models.

2. Methodological approach

Based on a dialogue between researchers, developers and owners the seven Demonstration projects served as source for analysis and evaluation of the applied collaboration models.

In a first step, interviews, site-visits and stakeholder discussion panels were held to collect experiences of practioners, stakeholders, authorities and residents. This empirical “Bottom-up” approach provided new insights and a better understanding of causal relations of motives and operative forces in practice. Due to varying national and project specific framework conditions, each project was analysed beyond its own background.

In a second step, this information was processed in collaboration charts and action line diagrams in order to allow comparison and crosscutting analysis of the seven Demo projects. The collaboration chart showed the groups of involved actors along with their specific role in the project. Communication and relationship were displayed with line thicknesses correlating to the intensity. The different colours of the ellipses showed the group an actor was assigned to (e.g.: owner, planners, contractor, residents, authority, etc.).

The action line diagram showed the different actions of actors in relation to the project progress. The groups of actors and colours used in the action line diagram are similar to those in the collaboration chart in order to enable a comparison between organizational diagram and the sequence of actions, process steps and milestones in the action line diagram. The adjustment of groups and colours and additional milestones helped to understand their influence on time and timeslots in the project.

3. Definition

While the term collaboration model could not be found in literature and was wrongly interpreted as a business model, the definition in E2ReBuild goes beyond the description of an architecture for value creation. *“It describes coordinated and cooperative processes that enable an entire project*

team with all involved actors and stakeholders to achieve target-oriented concerted actions for the common goal of successful building renovation with industrialized methods and/ or prefabricated components. The structure of communication channels with defined interfaces and the definition of clear responsibilities, rights and obligations are crucial for smooth process chains and successful collaboration." [2] p. 10.



Figure 1: Demo project Augsburg, Grüntenstrasse (DE). The residential area with 2 building blocks (in total 60 units), was renovated with the TES Energy Façade[1] – a prefabricated timber element system. The renovation solution convinced due to the innovative character and the possibility to enlarge the building envelope by enclosing of balconies with the same system. Source pictures: lattkearchitekten, Gumpp&Maier, CCTP;

4. Experiences: Design-Bid-Build vs. Design-Build approaches

The analysis of the collaboration charts and action line diagrams showed differences and similarities within the applied models. Two basic models for the planning and construction process applied in the E2ReBuild project were identified and analysed:

- The *Design-Bid-Build* model (*Figure 2*, *Figure 3*) applied in Augsburg and Munich (DE), in Roosendaal (NL) and Voiron (FR).
- The *Design-Build* (*Figure 4*, *Figure 5*) model applied in Halmstad (S), London (GB) and in Oulu (FI).

Generally the *Design-Bid-Build* model (*Figure 2*, *Figure 3*) was characterized by the „Bid" as an own clear step between design and construction and the resulting individual contracts between planners (architects, engineers), contractors (builders, manufacturers) and the building owner.

[1] "TES" is the abbreviation for **T**imber **E**lement **S**ystem (www.tesenergyfacade.com)

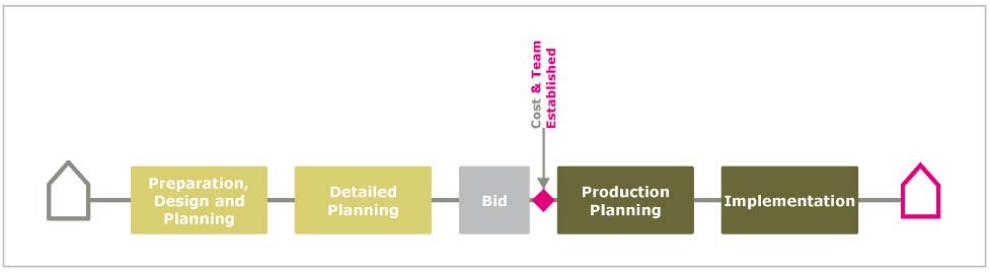


Figure 2: Simplified action line diagram. Within the Design-Bid-Build process all contractors were chosen by the tender process („Bid“).Therefore the timber element manufacturer as contractor was integrated into the team after planning and detailed planning phase and was not able to influence design and planning to optimize the solution according to the manufacturing capabilities. Source figure: [1] p.45;

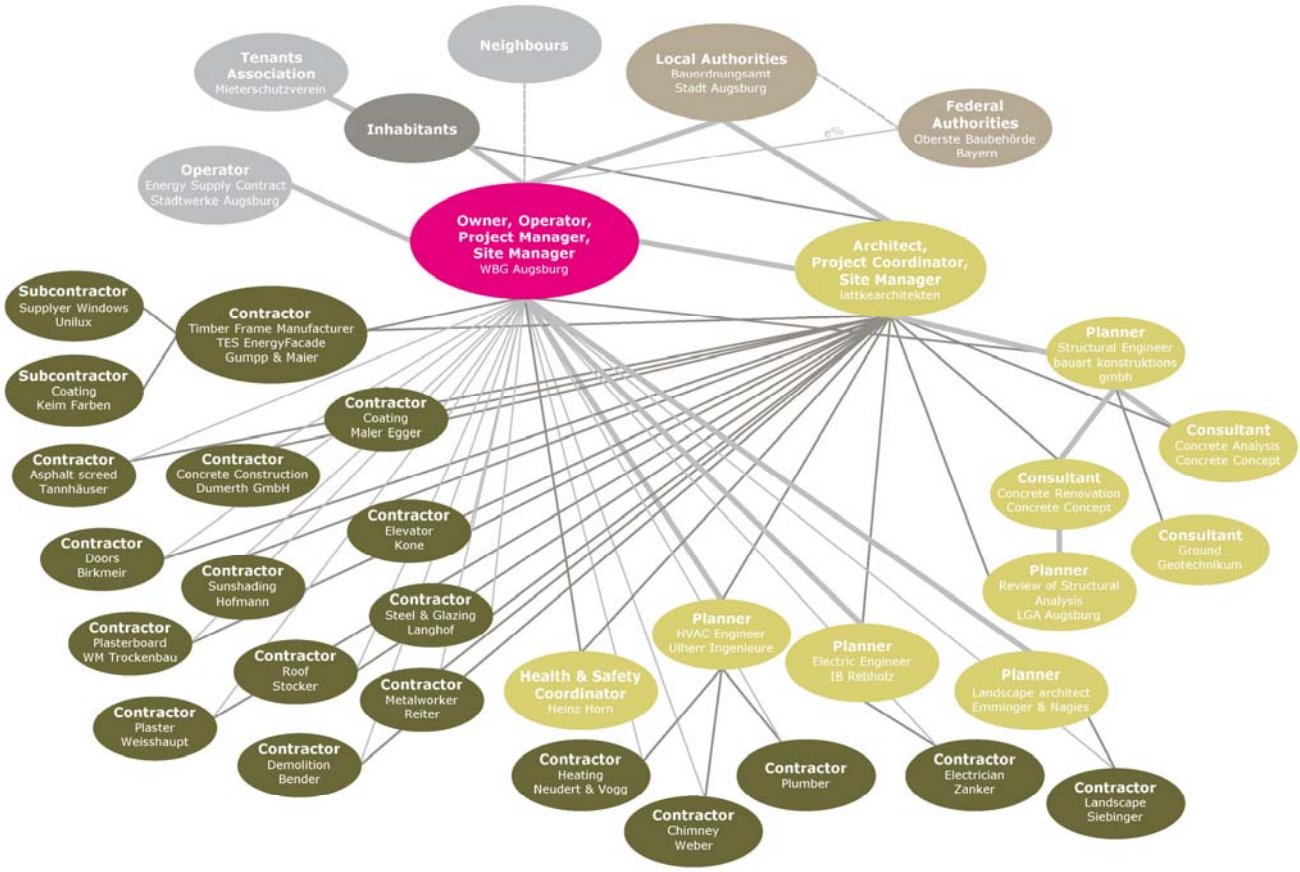


Figure 3: Collaboration chart. The Design-Bid-Build model applied in the Demo project Augsburg, Germany. The architect and the owner shared responsibilities. The contractors were appointed by the tendering („Bid“) and were bound with individual contracts to the owner. Responsibilities (for example for tenants claims) were shared between owner and architect. Source figure: [1] p.21;

The *Design-Build* model (*Figure 4, Figure 5*) is based on one *Total Contractor* who is responsible for design and construction and who has in-house departments for planning or is allowed to recruit subcontractors for design and planning. This model avoids tendering of individual trades, the planners and contractors are chosen by the *Total Contractor* with reference to the costs fixed in the global contract with the client. Basically, the partners in the team are selected by the *Total Contractor*. Within the E2ReBuild Demo project, the clients were able to object individual subcontractors. However, the pressure to keep costs is a determining factor of this model. ([1], p. 44, 48-49)

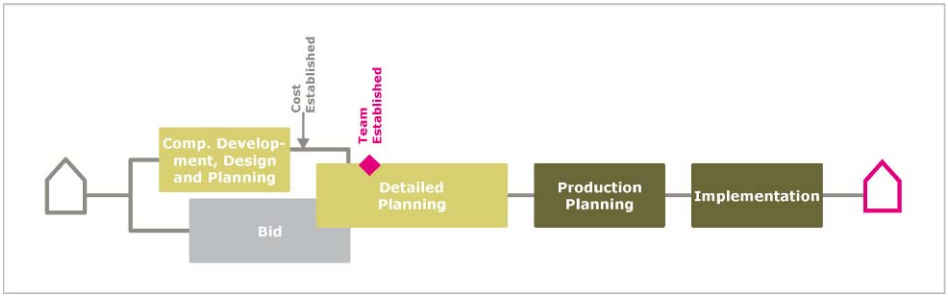


Figure 4: Simplified action line diagram. Within the Design-Build process the Total Contractor delivers a „ready-made“ building renovation to the owner. The contracting can be based on a tender or a negotiation process. The principle of the Design-Build models is based on merging planning and construction under the umbrella of one responsible contractor. The selection of possible subcontractors is determined by the costs fixed in the contract. Source figure: [1] p. 44;

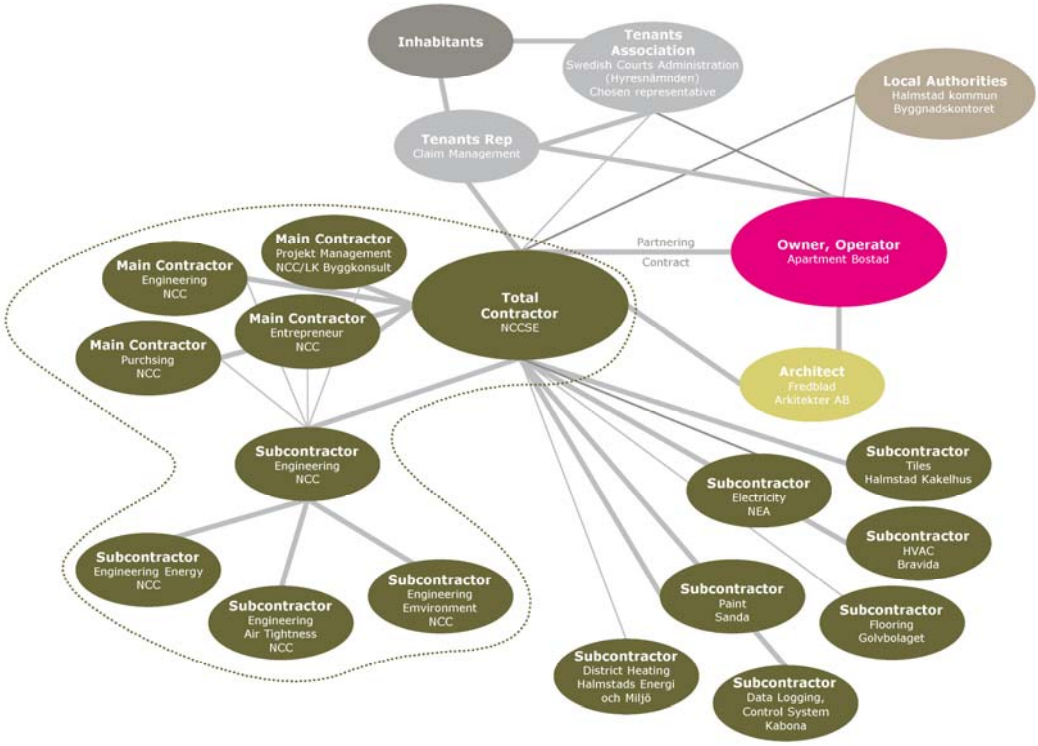


Figure 5: Collaboration chart. Basically the chart of the Demo project Halmstad (Sweden) shows a typical Design-Build model. But the new approach of a so-called Partnering Contracting between the Total contractor and the owner targeted to share the risk and success equally between both partners. Nevertheless the communication and claim management was handled by the Total Contractor. Source Figure: [1] p.25;

In some Demo projects, variations of the basic models such as the *Partnering Contracting (Figure 5)*, a team of *Main Contractors* (*Figure 6*) were tested. For example, the *Partnering Contracting* in the Halmstad Demo (*Figure 5*) where the owner and the *Total Contractor* acted as a partner was a variation of the *Design-Build* model. Here, the range of works was developed in cooperation, but the client made the final decision. Despite the financial risk and success were shared equally, responsibilities for communication and claim management lay in the hands of the *Total Contractor* and he had to guarantee energy savings within the first two years of operation. ([1], p. 23 and 48)

The Demo in Roosendaal (The Netherlands, *Figure 6*) followed the *Design-Bid-Build* model, but the four *Main Contractors* (HVAC, external façade cladding, timber manufacturer and builder) were obliged by the owner to act as a team in order to optimize joint development and share knowledge.

While the builder was informally commissioned to act as a coordinator – the owner wanted to avoid additional charges necessary to employ a *Total Contractor*. ([1] p. 36 and 48)

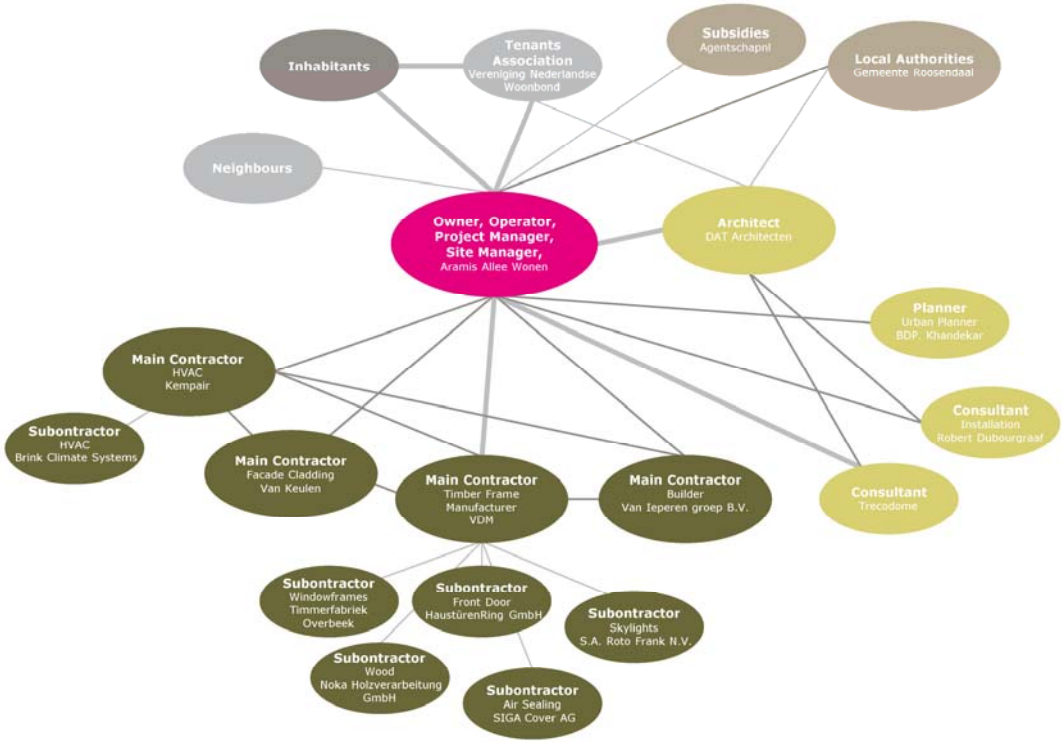


Figure 6: Collaboration chart. In the Design-Bid-Build model applied in the demo project Roosendaal, The Netherlands, the four Main Contractors were obliged to act as a team. Source figure: [1] p. 37;

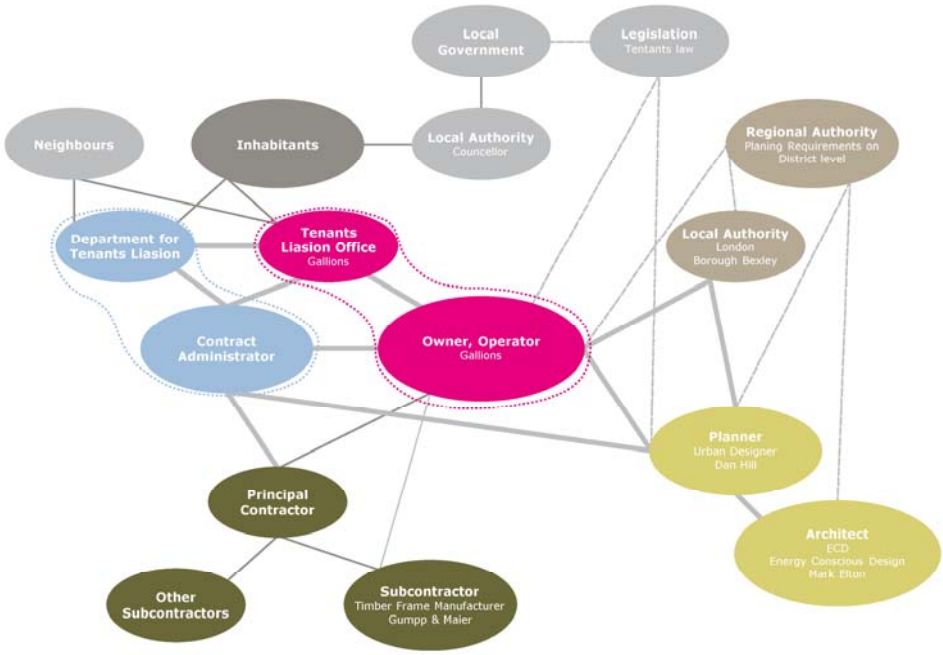


Figure 7: Collaboration chart. In the Design-Build model applied in the Demo project London, Great Britain, the Contract Administrator established and supervised the compliance with contractual and legal conditions. Source figure: [1] p. 42

A specific approach of the Design-Build approach was identified in Great Britain. The *Design-Build* model is common for renovation works performed by owners such as the housing owner of the London Demo project (*Figure 7*). But this *Design-Build* model was influenced by the approach how building permission is granted in Great Britain. The procedure was divided in two parts, the *Planning Permission* and the *Building Regulation Approval*. The *Planning Permission* was used to evaluate the aesthetic and functional aspects of the building renovation without considering technical specifications. However, it enabled the city authorities to influence and determine how the building will fit it in its surroundings. The subsequent *Building Regulation Approval* relied on a positive *Planning Permission.* Hence, the effort of the first step could be kept very low. After the positive *Planning Permission* was granted a separate architect had to be designated[2]. Therefore, actual design and planning (of technical specifications) could only start afterwards. The contractors in Great Britain are not bound directly to the owner. They are bound by subcontracts to the assigned *Principal Contractor.* An additional *Contract Administrator* provided a clear contractual relation (and distance) between the *Principle Contractor* and owner. ([1], p. 40 and 48)

In Munich (*Figure 8*) the housing association had been accustomed to choose out of a pool of planners they knew. For about 10-12 years, they worked with this so-called *Design team* model. Since regulations (*VOF*[3]) have changed they were obliged to tender design and planning services in many cases (depending on the threshold) and report mixed experiences (good ones and bad ones in terms of collaboration and quality of design and planning).

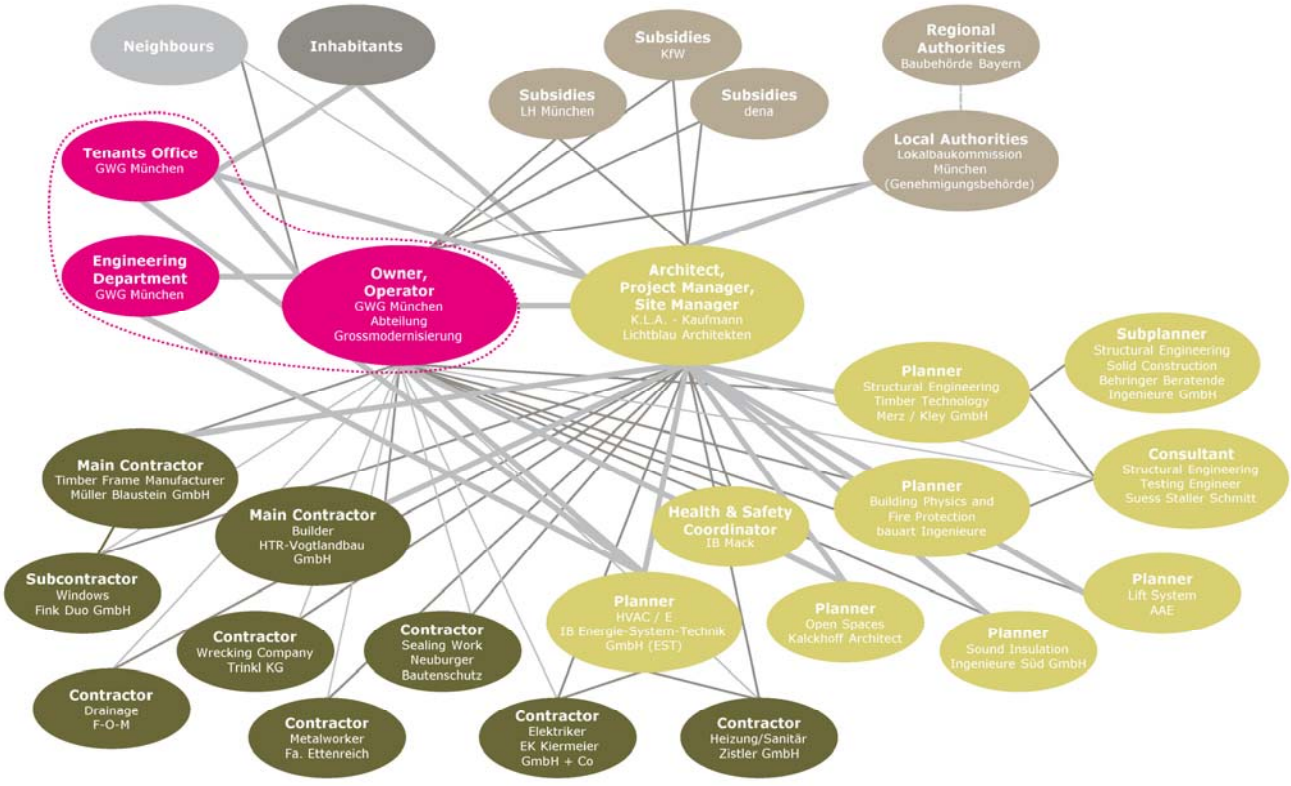


Figure 8: Collaboration chart. The Design-Bid-Build model applied in the demo project Munich, Germany. The housing owner had in-house departments for engineering and tenants affairs. Due the renovation in an unoccupied situation the communication during planning mainly targeted on new tenants. First contact person was the Tenants` office of the housing association; detailed wishes were forwarded to the architect. Source figure: [1] p. 17;

[2] While within the first phase an urban designer was needed, the architect for the *True Design Phase* had to be experienced in structural design and construction planning. Within the Demo in London this architect was a sub-contractor of the urban designer.

[3] The *VOF* „*Vergabeordnung für freiberufliche Leistungen*" rules procurement for supplies and services for freelancers.

The strong commitment of the housing owner of the Demo in Augsburg (Figure 3, Figure 9) to try new renovation methods (the *TES Energy Façade*) and the many years of experience were visible in his active role within the entire process. The specific action line diagram (Figure 9) shows the interconnections of the owner to all other groups of actors, as well as plenty of milestones that marked starting points for actions (contract, agreement, fixed planning, etc.). The process steps are very clearly divided according to the specific skills and know-how of the partners in the project team.

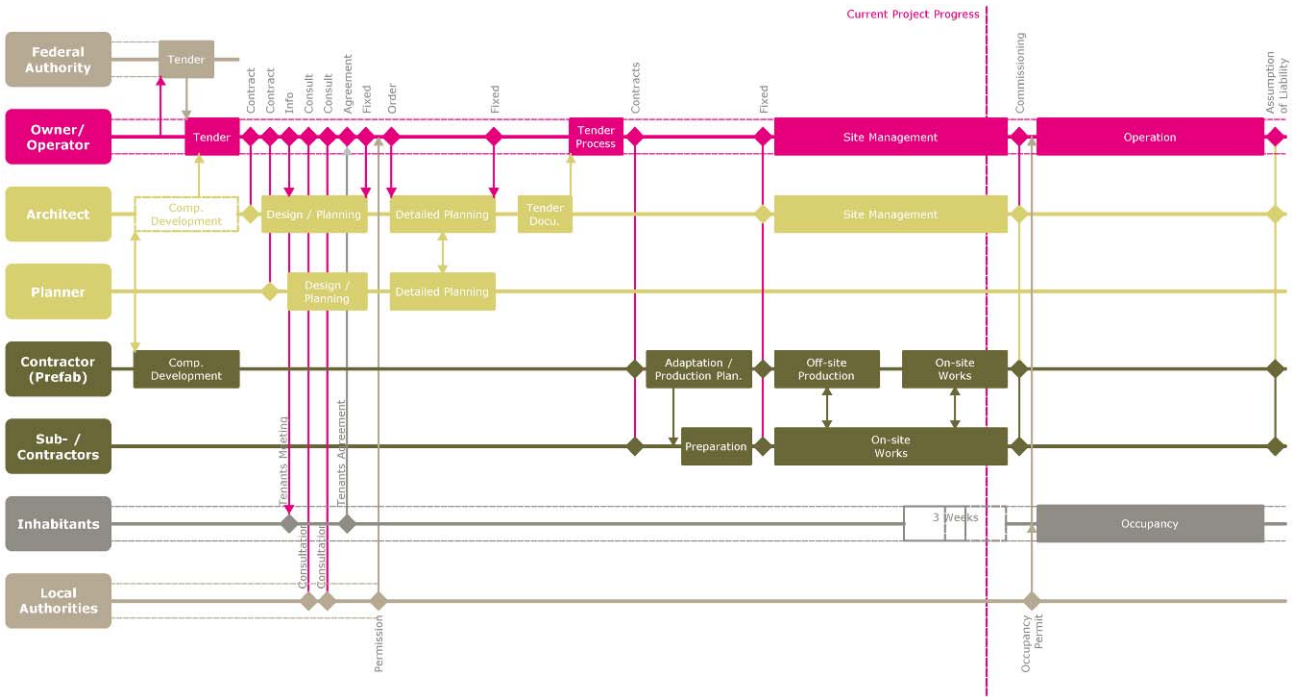


Figure 9: Action diagram Demo project Augsburg. The active role of the owner is visible by the connections to the action lines of other actor groups (magenta lines). Beside steering and controlling the renovation, he took responsibility for the communication and claim management for tenants, the communication towards city authorities and the site management for the entire renovation inside the building. Source figure: [1] p. 22;

4.1 Communication

All Demo project stakeholders showed high awareness of communication with residents and regarded it as a key factor for successful renovation. However, each stakeholder had a different approach on how to handle it. Some addressed tenants personally, were in charge of the communication and claim management and built upon long years` relationship and trust[4]. Others transferred the responsibility to the contractors and the site-manager[5].
However, whether owner or contractor, a high personal effort was necessary in any way in order to keep residents informed and to take care about quick and efficient reactions on their claims. Especially renovation measures in occupied apartments were very sensitive regarding sufficient and careful communication towards tenants.
In contrary, communication among professionals as a tool for joint development within building renovation was a rather neglected aspect despite the fact that the interface between planning and construction was very sensitive. Within the Demos it was seen that know-how from planning phases got lost due to teams planning without manufacturer or insufficient communication and information structures. Frictions in the knowledge chains caused delays and failures in construction and implementation. Misunderstandings and lacking coordination reduced the implementation quality.

[4] This situation was valid for all Design-Bid-Build approaches in the E2ReBuild project.
[5] As claims are seen as a risk, the claim management is shifted to the contractor. This was characteristic for all *Design-Build* approaches in the E2ReBuild project.

Finally, the full potential of industrialised renovation methods could not be exploited as planners were not informed about the ranges of possible cladding materials or 3D nodes were forgotten to be developed carefully, etc.

4.2 Responsibilities and risks

The question of risks and responsibilities dominated the collaboration in the Demos and this was handled differently in the *Design-Bid-Build* and the *Design-Build* approaches. Within the *Design-Build* approaches, the risks and responsibilities were generally shifted to the contractors. Claims concerning renovation, voiced by residents, were seen as "risk" and therefore nearly the entire responsibility for communication[6] and claim management was transferred to the contractor. In this point, the Demo in London was an exception. As within the first phase until *Planning Permission* no *Principal Contractor* was appointed at this time, the housing association took the sole responsibility for the initial information to residents.

4.3 Role of the owner

The choice of model based on the traditional models of the building owners and was influenced by their policy and the role they wanted to take (or could take) in the renovation project.

Hence, housing associations with no or little in-house knowledge (or departments) in the field of construction and renovation choose the *Design–Build* model. Due to the outsourcing of responsibilities and risk to the *Total Contractor*, internal personal effort was reduced.[7] Demos, such as Halmstad and Oulu recognized the advantage of planning and implementation beyond the umbrella of one responsible *Total Contractor* who provided a "ready-made" building renovation in the requested quality with fixed costs. Thus, within the *Design-Build* models clients and owners had less effort, but also less influence on processes, methods and the choice of partners. And the extended responsibilities led to higher costs. For example the owner of the Demo project in London refers to 15-18% of costs for planning and construction ([1] p. 48).

In contrary, owners with many years of experience in construction and renovation choose the *Design-Bid-Build* model. In most cases they had own in-house departments (Augsburg, Munich) and many years of experience in supervising building renovation. Not only precisely defined targets but also a clear picture of methods, processes and materials influenced their role in the process. They stated clear renovation objectives, expected results and executed measures. They stated the importance to steer and control the entire process to guarantee the quality of the construction works and a very quick and efficient reaction to upcoming trouble. They recognized the advantage to influence processes, methods, results and the ability to supervise actors and with it the final success. The more active role of the owner saved costs and provided a bigger range of influence within the process and the team set up (as far as possible regarding procurement regulations).

4.4 Procurement framework

The common way of tendering restricted the owners to work with planners or contractors they knew and trusted. They would have preferred to work with regionally anchored companies which ensured in their opinion higher implementation quality, quicker reaction on the removal of defects and easier liability handling. Further-on changes of manufacturers doubled the work: For instance, a re-design of the prefabricated modules was necessary after the change of the manufacturer due to the result of the tendering process ([1] p. 35). All stakeholders stated the importance of an early selection of planners and contractors and recognized advantages in a harmonized team set up suitable for the specific renovation task and the skills and capabilities of the professionals and

[6] Except initial tenants meetings to inform about renovation.

[7] For example, only one employee of the building owner was required to handle renovation affairs for the Demo Halmstad.

manufacturers. But selecting planners, contractors and putting a team together was often hindered by public procurement legislation – either if the owner was a "*body governed by public law*" ([5] Art. 1 (9) c) or if public money was used for financing the renovation (e.g.: public subsidies). While this European Directive [5] was the common basis for subsequent national legislation, it was interpreted slightly differently in the Member States. However, the new application thresholds regulation EC 1251/2011 published on Jan. 2012 state that contracts above 200.000 EUR for all service contracts, design contests, etc.[8] require public procurement and thus restrict target-oriented selection of planners and contractors.

5. Conclusions and Outlook

The experiences and the feedback from the E2ReBuild stakeholders showed future efforts in policy and decision making to close existing gaps within legislation concerning public procurement. The establishment of teams after the detailed planning phase (by public tender) did not support joint development and collaboration urgently needed in early planning stages. Design and construction teams should be motivated and enabled (on legal basis) to offer services for collaborative design, planning and realization within public tendering. Only teams set up according to their know-how, skills and manufacturing capabilities will facilitate high quality renovation and keep up with time and costs.

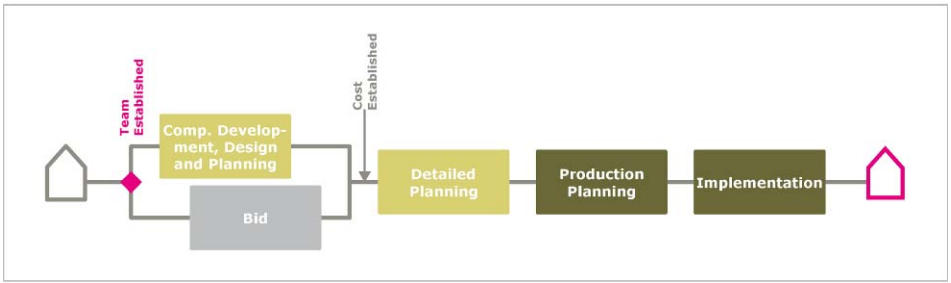


Figure 10: Simplified action line diagram. Within a Team model an entire consortium is founded on a partnership basis. All relevant planners, professionals and manufacturers are included in the team. They offer services within tender or negotiation procedures together. Source figure: [1] p. 68;

In future, teams based on equal partnership of independent companies should be allowed to offer services for planning and implementation of renovation solutions together. Clients would be able to choose between different options and could opt for the most convenient solution for their specific needs. The process to optimize the renovation strategy solution, the quality and finally the costs would start right after the team establishment. As such, knowledge and skills could be kept in the team, and manufacturing capabilities would be available.

That kind of tender process cannot be done with detailed technical specifications. However, this could be solved with functional descriptions for tender. The subsequent procurement would be based on negotiated procedures. However, current legislation does not provide the appropriate framework.
A few models following similar approaches have been realized already[9], but their implementation required special arrangements with authorities and chambers. For example, the *Construction Team* model applied in the German Federal State of Baden-Württemberg based on an establishing a cooperation of the design and construction team before the public tender process. The *Chamber of Architects* developed these models and a lot of projects already used this approach successfully. In the project realized in *Mainz-Grossberg* ([6] p.75-125) the owner (a non-profit housing association) launched a public tender targeted for so called C*ompetition Consortia*. Every consortium needed prescribed participants from planning and building. A series of other contractors could be part of the team or the services were covered with a subcontracting party. The owner arranged the

[8] www.ec.europa.eu/internal_market/publicprocurement/rules/current/index_en.htm
[9] For example the "Bauteammodell" in Baden-Württemberg. See [6] p.75f.

framework with the *Chamber* and arranged information campaigns. They committed themselves to award only the entire consortium - a split between design and implementation was not possible. In the end this *Construction Team* model[10]) brought cost-advantages by exploiting synergies between technical and economical optimization, ensured a highest reliability in terms of quality and time.

The experiences of the E2ReBuild project showed efficient industrialised retrofitting required collaboration models based on teams or partners working together and coordinated centrally by an experienced actor. In future, efficient team set up will depend on how partners` skills, know-how and manufacturing capabilities can be considered. Sufficient communication and information structures collaboration models will have to ensure know-how and information sharing – a precondition for joint development and optimization of solutions regarding costs and time.

As seen in this project, neither the current traditional *Design-Bid-Build* nor the *Design-Build model* could sufficiently meet the requirements for industrialised renovation methods. The feedback from stakeholders showed that all Demo project teams struggled to sustain continuous and smooth workflow and to keep up with time and costs. Depending on the specific project framework and national conditions, each Demo project team had to tackle various obstacles and barriers. Nevertheless, similar requirements on organizational level and obstacles within legislation were identified:

- Communication and know-how exchange among professionals was crucial for industrialised renovation methods and the application of prefabricated façade and roof elements.
- The linkage between the planning team and the contractors. Early and good integration of relevant contractors (e.g.: the timber element manufacturer) ensured optimization of workflow, costs, renovation time and implementation quality.
- Procurement framework restricted owners to compose teams according to project specific requirements and hindered collaboration of planners and contractors in early planning stages.

Finally, traditional renovation routines have to change. Awareness for early integration of relevant know-how carriers (such as manufacturers) and sufficient communication among professionals as driving force for the optimization of renovation solutions is necessary.
Nevertheless, all stakeholders within the E2ReBuild reported a high replication potential within the applied solutions that should be exhausted in future.

[10] A so-called “Bauteam” in German.

6. Further information

This paper reports the legal and economic aspects identified and evaluated within the Workpackage "*Innovation in Planning and Design*" in the E2ReBuild project. Further aspects concerning opportunities, barriers and risk in general and with a special focus on tenants' perspective is shown in the paper "*Collaboration Models for Industrialised Renovation Methods and Prefabrication – Opportunities, Barriers and Risk"* [3]. The detailed report "Evaluation of Collaboration Models" [1] is available as download on the E2ReBuild website: www.e2rebuild.eu

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8. References

[1] FP7 - E2ReBuild. Industrialised energy efficient retrofitting of residential buildings in cold climates. Theme EeB-ENERGY.2010.8.1-2; Grant Agreement No. 260058. 2011-2014. DOI: www.e2rebuild.eu.

[2] GEIER S., EHRBAR D., SCHWEHR P. *"Evaluation of Collaboration Models". Public Report. FP7 - E2ReBuild – Industrialized energy efficient retrofitting of residential buildings in cold climates"*, DOI: www.e2rebuild.com/en/links/deliverables/Sidor/default.aspx; 2013.

[3] GEIER S., EHRBAR D., SCHWEHR P. "*Collaboration Models for Industrialised Renovation Methods and Prefabrication – Opportunities, Barriers, Risk".* In: Proceedings Passivhus Norden Conference 2013. Göteborg, Sweden, 15.-17.Oct. 2013

[4] PARKER P.M. "*Extended Definition: Collaboration*".
DOI: www.websters-online-dictionary.org/definitions/collaboration [Download: 02.08.2012]

[5] EUROPEAN PARLIAMENT. "*Directive 2004/18/EC of the European Parliament and of the Council of 31 March 2004 on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts*". Official Journal of the European Union; L114/134.

[6] ARCHITEKTENKAMMER BADEN-WÜRTTEMBERG (ED.) "*Bauteam – ein Leitfaden für Architekten und Handwerker*". Stuttgart, 2010. DOI: www.akbw.de/nc/berufspolitik/neue-maerkte-und-berufsfelder/bauteam.html?sword_list%5B0%5D=bauteamverfahren

Cost optimal building standards – evidence based! The case of Austria



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Short Summary

The new EPBD requires that the cost optimum over the life cycle of buildings is taken into account when requirements for the energy performance of buildings are established. National minimum standards should be set by the Member States based on the cost optimum for construction costs and operational costs. Therefore, the European Commission has submitted the regulation No. 244/2012.

A crucial question regarding the cost-efficiency of nZE buildings is whether calculated energy demand and costs assumptions are corresponding with measured energy consumption and real cost data from buildings in use. Up to now there is little empirical evidence to answer this question on a broad basis, even in those countries where a considerable number of nZE is already realized.

This paper is based on recent research results based on a broad empirical survey by e7 together with the Austrian Federation of Limited-Profit Housing Associations (gbv). The survey was launched in order to collect energy consumption AND cost data from innovative multi-family-residential buildings which can be regarded as nZE buildings in order to analyze the cost-effectiveness of those buildings. The paper presents results derived from a broad sample of about 90 buildings.

Based on this survey, there is empirical evidence that the measured energy consumption for heating in nearly zero energy buildings is lower than for low-energy buildings. However, the difference in practice is significantly lower than expected from design values.

Whether passive house or low energy standard: there is a broad range of factor three, in the actual energy consumption, depending on accurate construction, proper operation of the building and user behavior. It would be misleading to draw conclusions from studying only small numbers of buildings. On the other hand, this provides a high potential for the optimization of the buildings operation and thus to reduce running costs for the users.

Maintenance costs vary widely and those buildings with ventilation systems tend to have higher maintenance costs. The lower energy costs of passive–house and lowest-energy building types therefore tend to be partly compensated for by higher maintenance costs.

In general, the lower costs for heating energy do not compensate for the higher investment costs for the passive-house standard of building. At least for the specific situation in Austria it seems, that lowest-energy standard (energy heating demand about 20-30 kWh/m².a) turns out to be the range for cost-optimal building standards. This is well in line with theoretical calculations on cost-optimal building standards for multi-family-residential buildings in Austria, carried out independently in 2012.

Keywords: Cost-optimality, residential buildings, energy use, cost-optimal building standards,

nearly zero energy buildings

Abstract

A crucial question regarding cost-optimal buildings standards and the cost-efficiency of nZE buildings is whether calculated energy demand and costs assumptions are corresponding with measured energy consumption and real cost data from buildings in use. Up to now there is little empirical evidence to answer this question on a broad basis, even in those countries where a considerable number of nZE is already realized.

This paper is based on recent research results based on a broad empirical survey by e7 together with the Austrian Federation of Limited-Profit Housing Associations (gbv). The survey was launched in order to collect energy consumption AND cost data from innovative multi-family-residential buildings which can be regarded as nZE buildings in order to analyze the cost-effectiveness of those buildings. The paper presents results derived from a broad sample of about 90 buildings.

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This is well in line with theoretical calculations on cost-optimal building standards for multi-family-residential buildings in Austria, carried out independently in 2012.

Keywords: Cost-optimality, residential buildings, energy use, cost-optimal building standards, nearly zero energy buildings

1. Cost optimality: Legal and methodical background

The recast of the Energy Performance of Buildings Directive (EPBD) introduced, in Article 9, “nearly Zero -Energy Buildings” (nZEB) as a future requirement to be implemented from 2019 onwards for public buildings and from 2021 onwards for all new buildings. The EPBD defines a nearly zero energy building as follows: A nearly zero energy building is a “building that has a very high energy performance […]. The nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby.”[1]

Acknowledging the variety in building culture and climate throughout the EU, the EPBD does not prescribe a uniform approach for implementing nZE Buildings and neither does it describe a calculation methodology for the energy balance. To add flexibility, it requires Member States to draw up specifically designed national plans for increasing the number of nZE Buildings reflecting national, regional or local conditions. The national plans will have to translate the concept of nZE Buildings into practical and applicable measures and definitions to steadily increase the number of nZE Buildings.[2]

Furthermore, the new EU Directive requires that the cost optimum over the life cycle of buildings is taken into account when requirements for the energy performance of buildings are established. National minimum standards should be set by the Member States based on the cost optimum for construction costs and operational costs. Therefore, the European Commission has submitted the regulation No. 244/2012 in accordance with the objective clause of the EPBD in March 2012. Within the scope of this EU regulation, the methodological approach for the analysis of cost optimality of requirement levels is determined bindingly.[3]

The cost optimality principle acts as a bridge between the standard energy performance – as it is usual on today's markets – and the intended goal of reaching nearly zero energy buildings by 2020 (at least for new construction). In this sense the period between now and 2020 can be interpreted as a "transition period" during which the markets are forced to adapt and to apply a life-cycle cost perspective instead of the usual construction cost perspective.[4]

It has to be stressed, however, that the cost optimality principle as defined in the EPBD offers high degrees of freedom when it comes to applying it in the building regulations. Although the EU regulation on cost optimality provides uniform regulations in some respects – e.g. concerning included cost elements, calculation algorithms and analysis period – it allows room for national stipulations in many key areas, such as:

- Definition of the reference building related to important assumption such as size, form, compactness, share of window areas etc.,
- Selection of variants (packages of measures) which are assessed,
- construction costs (and most important construction cost differences for different qualities),
- maintenance costs of relevant building elements and related inflation rates,
- the assumed (technical resp. economical) life-time of building elements,
- discount rates,
- starting level of energy prices,
- energy price trends (although the regulation includes a recommendation to use the "official" EU forecast member states are allowed to use other forecasts for their assessments).

According to a survey done in the frame of the EPBD concerted action in 2011 (before the EU regulation was submitted in March 2012) most of the member states intended to follow a microeconomic approach instead of or together with a macroeconomic approach (which would mainly include GHG emissions as externalities).[5] Up to now, the number of available cost-optimal calculations for different reference buildings according to the EU regulation is quite limited, although considerable work has been done during the last years in developing the application of life-cost-analysis in building practice.

At present, cost-optimal calculations are available only for a limited number of countries, e.g. for residential buildings in Estonia[6] and Austria[78]. The first comparative study with practical examples of cost-optimal calculations for Austria, Germany and Poland was only recently carried out by BPIE in cooperation with The Danish Building Research Institute (SBi), the German Institut Wohnen und Umwelt (IWU) and e7 Energie Markt Analyse (Austria).[9] Although these countries had not announced officially their nZEB definitions, within the cost-optimal calculation performed in this study, packages of measures leading to very low energy buildings have taken into consideration (primary energy demand between 30 and 70 kWh/m².a). The results of this study show, that the difference between actual and cost-optimal energy performance is between 10 and 20% in Austria and Germany, according to different assumptions on input factors and heating systems, whereas there is still a "very big gap" between current requirements and cost-optimal levels in Poland.

2. nZE Buildings in a total cost perspective – the case of Austria

A crucial question regarding the cost-efficiency of nZE buildings is whether calculated energy demand and cost assumptions are corresponding with measured energy consumption and real cost data from buildings in use. Up to now there is little empirical evidence to answer this question on a broad basis, even in those countries where a considerable number of nZE is already realized. If any, it is mostly data for single objects, primarily focusing on measured energy consumption.

Even worse is a reliable data basis when it comes to real costs: so called “additional investment costs” for nZE buildings depend on the actual building standard in the respective country and the availability of cost competitive building components like triple glazing windows. Costs for energy consumption, maintenance and replacement costs are further the crucial elements when it comes to the question of life-cycle-costs.

Regarding the question of actual energy consumption compared to theoretical consumption, it is documented for a sample of 200.000 cases in the Netherlands that there is a considerable difference in both directions, due to the fact that “in very bad performing dwellings the energy use is not as high as expected due to a lower comfort level (behavior) and in very high classified dwellings not as low as expected due to lacking performances of the buildings and services (building control) and the rebound effect (behavior)”.[10] Earlier and fundamental research regarding the rebound effect was already published by Haas and Biermayr (2000)[11] based on a sample of 12 thermally retrofitted buildings in Austria and Berkhout et al (2000).[12]

A considerable number of nZE demonstration projects is well documented in the R&D program “Building of Tomorrow” in Austria. However, the evaluations of these buildings focus on energy consumption and give little or no indication on running costs or life-cycle-costs.[1314] Therefore, in 2011 the Austrian Federation of Limited-Profit Housing Associations (gbv) together with e7 launched a broad survey in order to collect energy consumption AND cost data from innovative multi-family-residential buildings. The aim of this study was to analyze the cost-effectiveness of nZE buildings compared to “normal” low energy buildings.[15]

The following figure 1 shows the distribution of energy heating demand categories within the sample of 128 buildings from the survey carried out. The major part of the buildings within the sample were built between 2006 and 2010, thus securing that consumption data and actual data on running costs are available at least for 2-3 years.

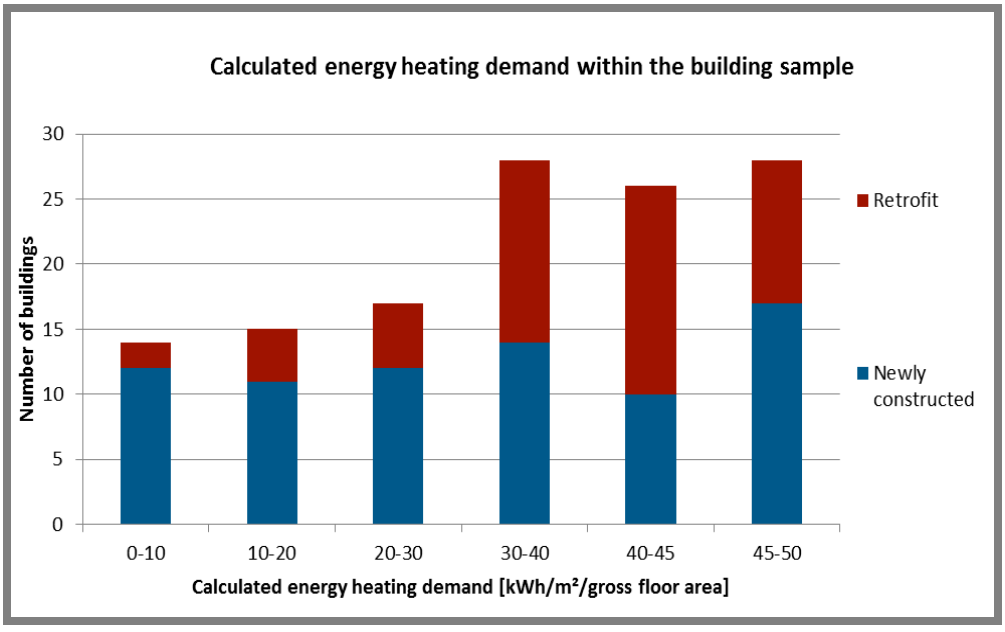


Fig. 1: Calculated energy heating demand in the Austrian multi-family residential building sample (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

The focus of this project was on multi-family-residential buildings with (calculated) heating energy demand lower than 50 kWh/m².a, covering the range from low-energy buildings to lowest-energy buildings to passive-house standard.[16] Energy consumption data were provided by the housing associations for at least two or three years for each building. Results derived from a broad sample of about 60 buildings indicate that the measured energy consumption for heating in NZE-buildings is in reality significantly lower than in low-energy-buildings. However, data show also a broad

variance of real consumption data of about factor three within each group (appr. 15-50 kWh/m².a passive-house / 20-70 lowest-energy / 30-90 low-energy-buildings). Therefore, it could be quite misleading to draw far-ranging conclusions from single objects or a small sample of (selected) buildings.

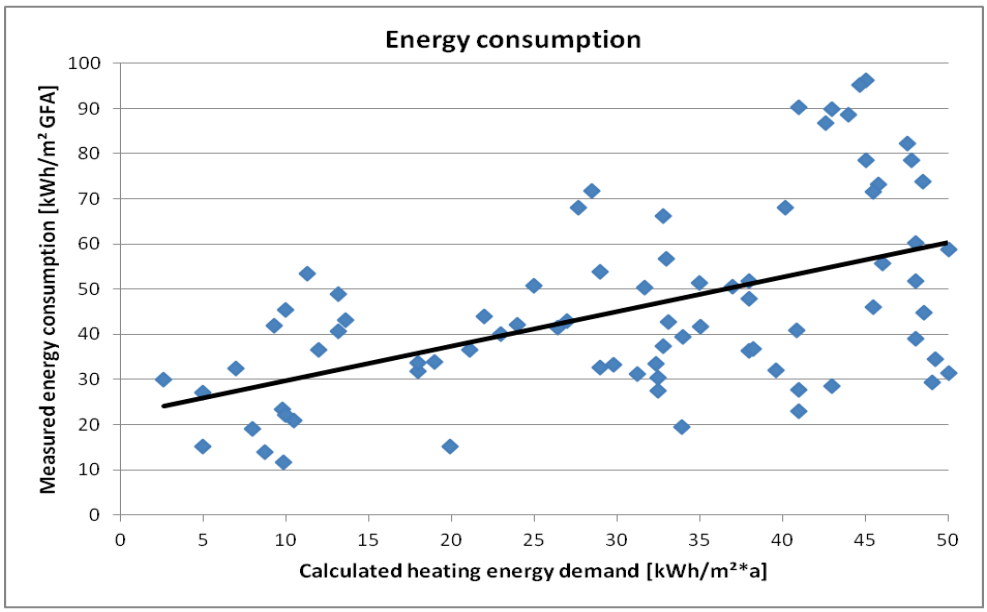


Fig. 2: Energy consumption for heating vs. calculated heating energy demand in nZE multi-family-residential buildings (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

Costs for energy consumption for heating are easily available only for those buildings with central heating systems. Furthermore it has to be differentiated between heating and hot water. Maintenance costs were becoming an increasingly important issue mainly due to mechanical ventilation systems, which are a crucial element of the passive-house-concept but also more and more frequently installed in lowest-energy buildings due to air-tight construction.

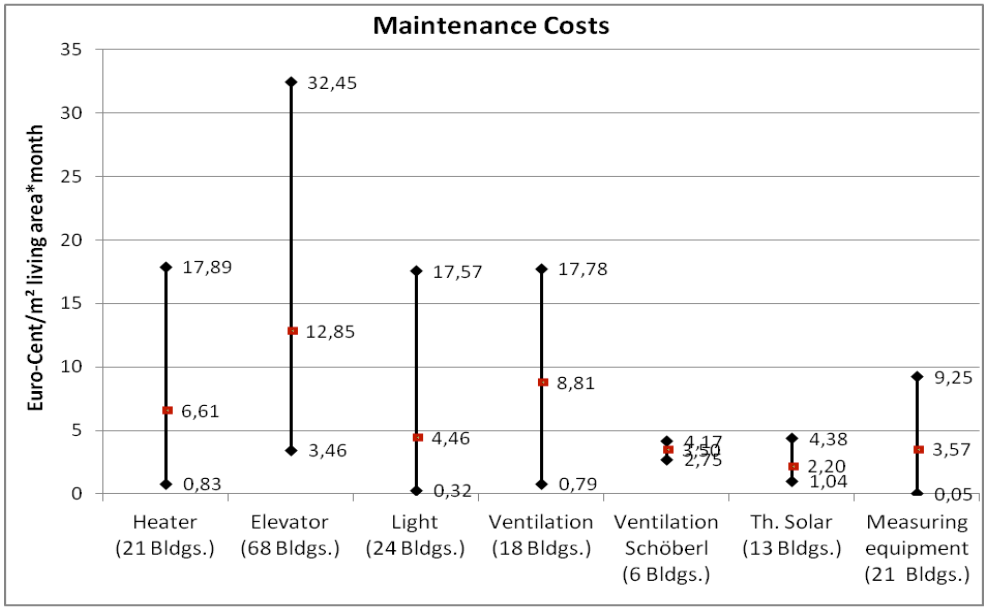


Fig. 3: Maintenance costs in nZE multi-family-residential buildings (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

Not surprisingly there can also be observed a broad variety of maintenance costs in practice. Maintenance costs for ventilation systems range from 0,8 till 18 ct/m².month with an average of about 9 ct/m²m.month, depending mainly on the system (central or decentralized ventilation, frequency of filter exchange, quality of filters and adequate contracts with external maintenance contractors. Best practice studies for a limited number of 6 buildings show that the maintenance costs for central mechanical ventilation systems can be limited to a range from 3 to 4 ct/m².month, whereas decentralized ventilation systems result in maintenance costs of 10 ct/m².month on average.[17]

Buildings with ventilation systems trend to have higher maintenance costs compared to buildings without ventilation systems. Consequently, lower energy costs for heating which can observed in lowest-energy and passive-house-buildings are tending to be partly compensated by higher costs for maintenance.

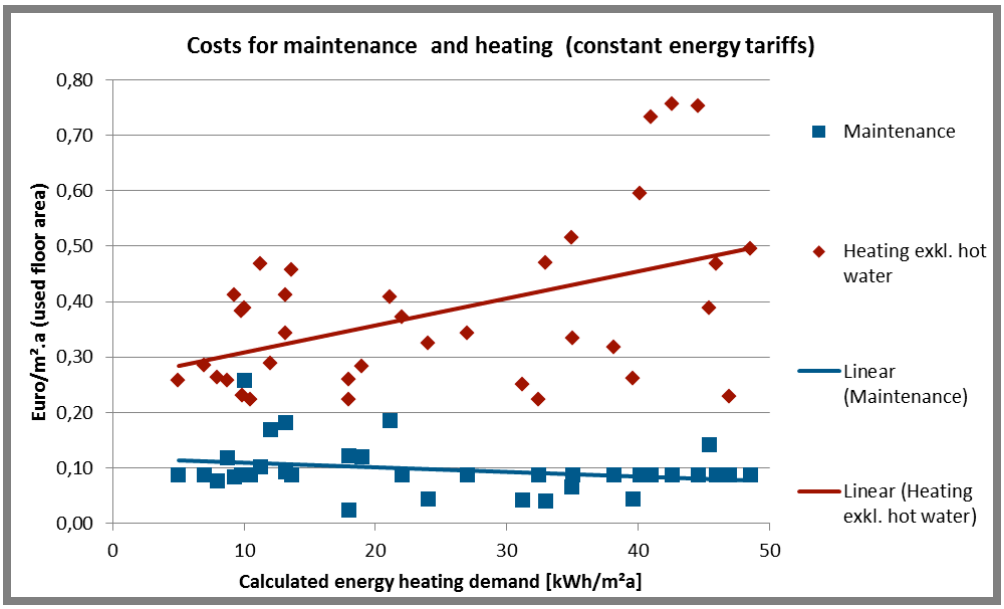


Fig. 4: Energy costs for heating and maintenance costs in nZE multi-family-residential buildings (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

Specific investment costs (€/m² used floor area) are depending on different factors: most important of them the size of a building, since small and less compact buildings have significantly higher specific costs than large and very compact buildings. Further cost components which influence the comparability of building costs are the number of elevators and if there is an underground garage for each dwelling or not. Furthermore regional differences in building cost levels can be generally observed. So one has to be very careful when it comes to comparison of investment costs with regard to different energy standards.

The following graph shows a sample of 40 nZE buildings with (calculated) energy heating demand lower than 50 kWh/m².a. Whereas the specific investment costs for individual buildings vary considerably due to factors mentioned above (regional cost differences etc.) the trend line results in additional specific costs for passive-house buildings of about 100 €/m² compared to low-energy standard (which is mandatory in Austria since 2012). A more detailed analysis show, that the additional costs for passive-house standard seems to be significantly lower for large and compact buildings (appr. 40-80 €/m²) compared to additional costs for small and less com pact buildings (appr. 120-200 €/m²).[18]

One has to mention that the economic ratio of the passive-house according to the (initially) strictly reduced concept based on the idea that additional investment costs for the improved building shell and mechanical ventilation are partly compensated since there is no need for a conventional heating system. This has been successfully proven in practice for a number of buildings but it

turned out that in practice (at least in Austria) most of the multi-family-passive houses are built with mechanical ventilation AND a more or less conventional heating system. Decoupling heating and ventilation allows lower air-change rates and reduces the risk of unhealthy dry air indoor conditions during the winter and is therefore state of the art in passive-house technology. Consequently, to have both mechanical ventilation AND a conventional heating system is questioning the initial idea of cost-effective passive-houses.

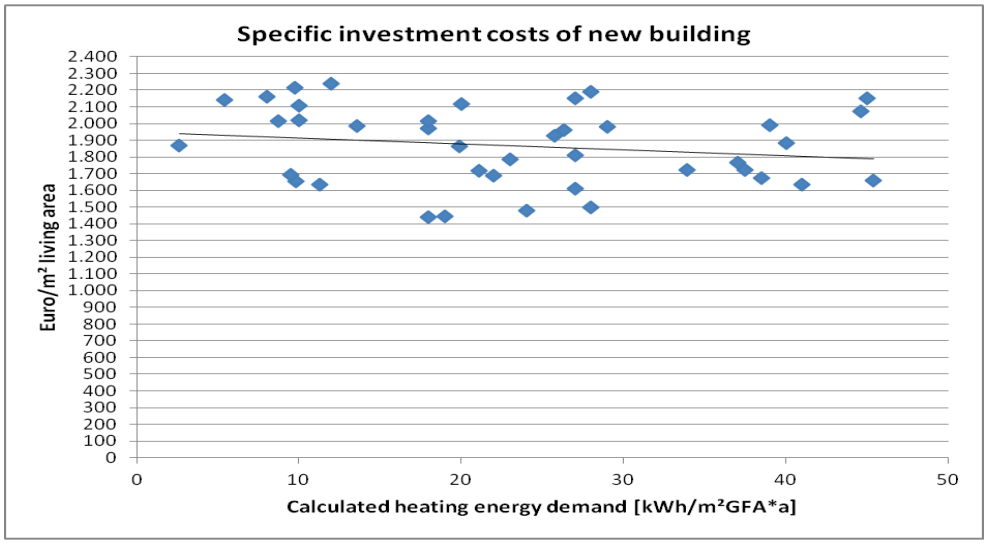


Fig. 5: Specific investment costs for nZE multi-family-residential buildings depending on the energy standard (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

Finally, putting together the data on running costs and investment costs in a simplified total cost calculation over 20 years (net present value, without reinvestments for technical installation and without declining-balance, 3% energy cost increase per year) the results show that lower costs for energy heating do not compensate the higher investment costs for passive-house standard in general. At least for the specific situation in Austria it seems, that lowest-energy standard (energy heating demand about 20-30 kWh/m².a) turns out to be the range for cost-optimal building standards.

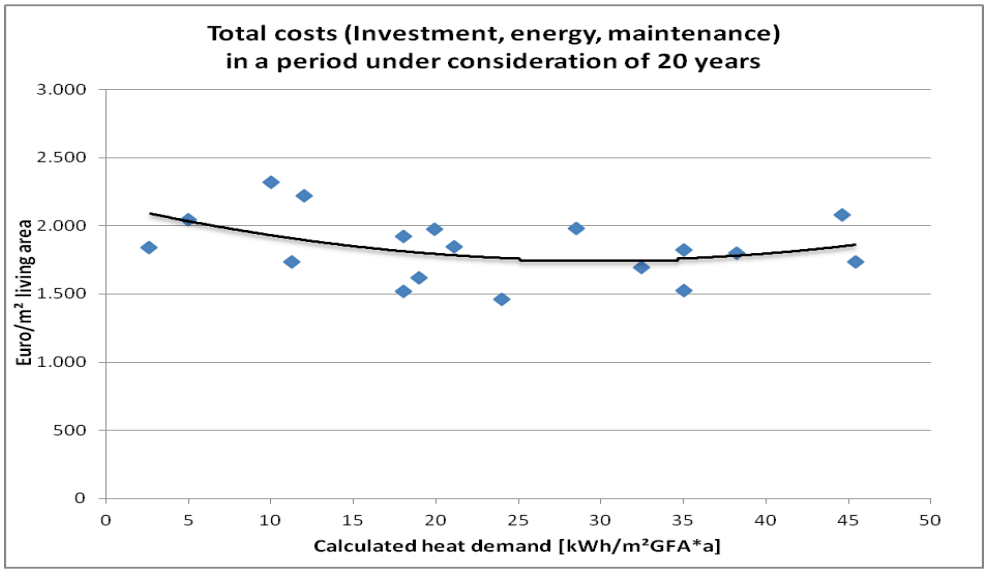


Fig. 6: Total costs (investment, energy, maintenance) in nZE multi-family-residential buildings depending on the energy standard (simplified calculation without reinvestments for technical installation, 3% energy cost increase per year) (Source Hüttler, Rammerstorfer, Tudiwer, 2013)

Approximately, this is quite in line with theoretical calculations on cost-optimal building standards for multi-family-residential buildings in 2012[19]. Results from different organizations based on three different data sets lead to comparable results.

The results of Bednar et al. from the Technical University Vienna was made for two different reference buildings and show an “cost-optimal” heating energy demand of about 20 kWh/m².a for large residential buildings (80 dwelling) whereas the “cost-optimal” heating energy demand for a small residential buildings (6 dwellings) is about 40 kWh/m².a.

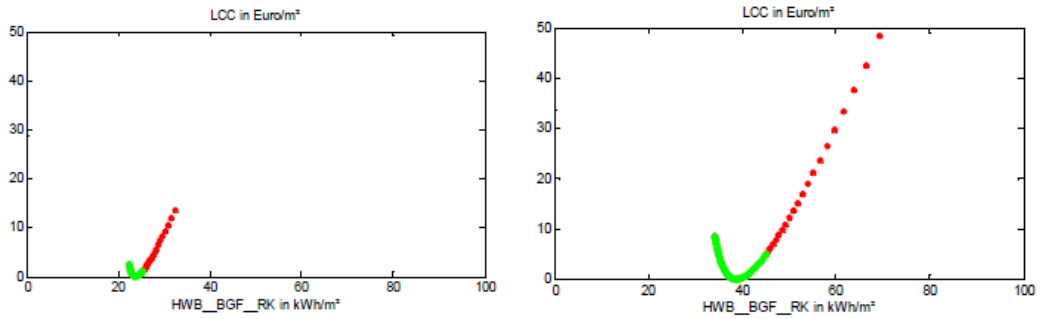


Fig. 7: Cost-optimal building standards for multi-family-residential buildings: large (80 dwellings) left and small building (6 dwelings) right graph. The y-axis describes the global cost difference between the different standards in €/m² (Source Bednar et al., 2012)

Cost-optimality calculations for a residential building with 30 dwellings done by e7 show a cost-optimum range between 20 and 30 kWh/m².a (heating energy demand) (Fig. 8). This is in line as well with the cost-curve derived from our empirical data (Fig. 6) and with the calculations of the Technical University Vienna (Fig. 7).

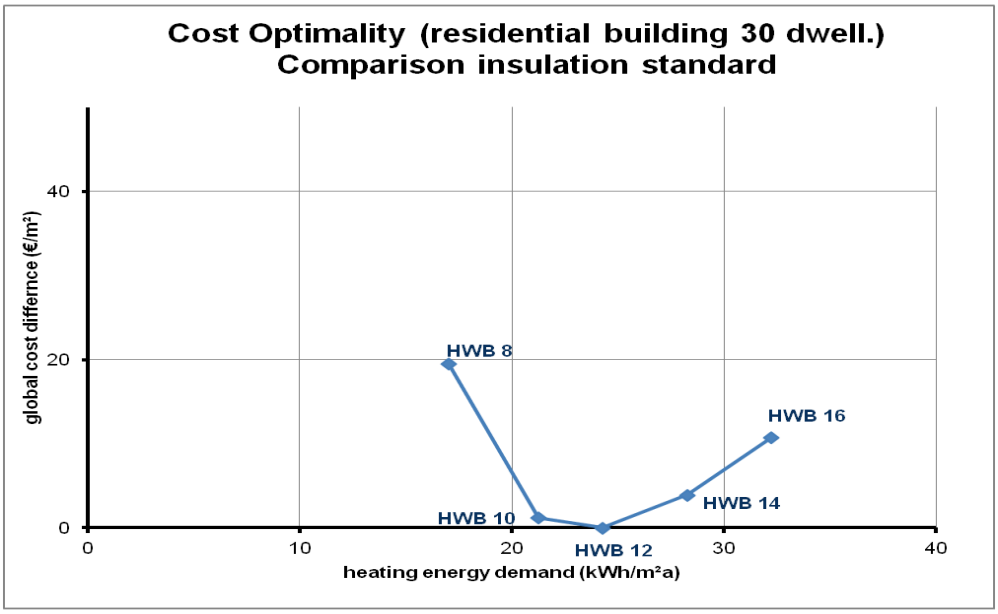


Fig. 8: Cost-optimal levels for multi-family-residential buildings (30 dwellings). The y-axis describes the global cost difference between the different standards in €/m² (Source Leutgöb and Rammerstorfer, 2013)

Based on these calculations it is obvious that the passive-house standard seems actually not to be the cost-optimum for residential buildings. One of the main reasons, why a considerable number of passive-house buildings in Austria were realized during the last years is financial incentives

integrated in the housing subsidy schemes of the federal regions. For example, the additional subsidy for building a residential passive-house is 120 €/m² in Tyrol. Consequently, the housing association "Neue Heimat Tirol" is able to offer dwellings in passive-house standard at the same rent conditions as usual low-energy buildings for their tenants.[20]

3. Conclusions

Based on both theoretical calculation and the analysis of evidence based cost and consumption data from buildings already in use for 3 to 5 years a plausible range for cost-optimal building standards could be identified for Austria. The combination of different approaches carried out independently seems to be a promising way to define nZE buildings based on cost-optimal levels. Furthermore, this reflects only the sheer economic perspective, not including other important parameters like living comfort or practical usability. The results of this analysis may be applied in general to other countries, results in details are very country specific. Therefore, theoretical calculations and analysis based on real data from practice have to be done for each country.

4. References

[1] [1] EU Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD)

[2] [2] BPIE (2011) Principles for Nearly Zero Energy Buildings – Paving the way for effective implementation of policy requirements.

[3] [3] COMMISSION DELEGATED REGULATION (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

[4] [4] LEUTGÖB K, PAGLIANO L, ZAHGHERI P (2013): Cost optimality – Brake or accelerator on the way towards nearly zero energy buildings. Proceedings eceee 2013.

[5] [5] Cost-optimal levels for energy performance requirements - The Concerted Action's input to the Framework Methodology. April 2011.

[6] [6] KURNITSKI J, SAARI A, VUOLLE M (2011): *Cost optimal and nZEB energy performance levels for buildings. Sitra, the Finnish Innovation Fund, Aalto University and Equa Simulation Finland Oy.*

[7] [7] BEDNAR T, NEUSSER M, DESEYVE C. (2012): *Studie zur Analyse der österreichischen Anforderungen an die Gesamtenergieeffizienz von Gebäuden in Bezug auf das kostenoptimale Niveau. Technical University Vienna.*

[8] [8] LEUTGÖB K, JÖRG B, RAMMERSTORFER J, AMANN C, HOFER G (2012): *Analyse des kostenoptimalen Anforderungsniveaus für Wohnungsneubauten. e7 Energie Markt Analyse GmbH, Wien.* http://www.e-sieben.at/de/download/CostOpt_WOHN_Endbericht.pdf

[9] [9] ATANASIU B, KOULOUMPI I, THOMSEN KE, AGGERHOLM S, ENSELING A, LOGA T, LEUTGÖB K, RAMMERSTORFER J, WITCZAK K (2013): *Implementing the cost-optimal methodology in EU countries – Lessons learned from three case studies. Buildings Performance Institute Europe (BPIE), Brussels.*

[10] [10] VISSCHER H, MAJCEN D, ITARD L (2012): *Effectiveness of energy performance certification for the existing housing stock. RICS COBRA 2012, Las Vegas, USA, p 130-148.*

[11] [11] HAAS R, BIERMAYR P (2000): *The rebound effect for space heating. Empirical evidence from Austria. Energy policy 28/6, June 2000, p 403-410.*

[12] [12] BERKHOUT PHG, MUSKENS JC, VELTHUIJSEN JW (2000): *Defining the rebound effect. Energy policy, 28/6, June 2000, p 425-432.*

[13] [13] *Innovative Buildings in Austria – Austrian demonstration buildings and flagship projects within the research programme "Building of tomorrow"* *http://download.nachhaltigwirtschaften.at/hdz_pdf/innovative_gebaeude_in_oesterreich_2012_technical_guide.pdf.*

[14] [14] TREBERSPURG M, SMUTNY R (2009): *Nachhaltigkeitsmonitoring ausgewählter Passivhäuser in Wien.* http://www.wohnbauforschung.at/de/Projekt_Namap.htm.
[15] [15] HÜTTLER W, RAMMERSTORFER J, TUDIWER D (2013): *InnoCost – Cost-effectiveness of innovative multi-family-residential buildings in Austria. e7 Energie Markt Analyse GmbH, Wien. Final report within the R&D program „Building of tomorrow", Vienna.*
[16] [16] According to heating energy demand: passive house < 10 kWh/m²a (gross floor area!), lowest energy < appr. 25-30 kWh/m²a (depending on compactness of the building) low energy standard < 40-50 kWh/m²a.
[17] [17] SCHÖBERL H (2011): *Wartungskosten Minus - Reduktion der Wartungskosten von Lüftungsanlagen in Plus-Energiehäusern. Final report within the R&D program „Building of tomorrow", Vienna.*
[18] [18] Eva Bauer, Austrian Federation of Limited-Profit Housing Associations (gbv), January 2013.
[19] [19] BEDNAR et al. (2012) and LEUTGÖB et al. (2012) see above references [7] and [8].
[20] [20] SPISS E (2012): The Tyrolean path in social housing: from low-energy to passive housing. Neue Heimat Tirol. Symposium: CECODHAS Housing Europe meets Solar Decathlon Europe 2012 - 26 September 2012, Madrid, Spain.

Comprehensive Assessment of Refurbishment of Existing Buildings in China



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Abstract

There are about 54 billion square metres existing buildings in China. In the wake of structural degradation and the enhancement of China's building energy saving standards, large numbers of China's existing buildings need to be rehabilitated.

A comprehensive assessment system for the existing building's refurbishment in China is developed to evaluate the necessity and the specific direction of strengthening and renovation of the evaluated buildings, considering the structural safety, energy saving, indoor and outdoor environment, local content and cost with three-level indicators. In addition, an assessment to forecast the remaining life of the existing buildings after retrofitting which reflects the effectiveness of the refurbishment and the technical economic analysis of the retrofitting is also presented in the system. Finally, a public building in Liaoning province of China is analysed as a case study to demonstrate the feasibility and validity of the system.

Keywords: Existing Building; Refurbishment; Comprehensive Evaluation; Energy Efficiency; China

1. Introduction

Currently, the total area of existing buildings has increased to more than 54 billion square meters in China. More than 11 billion square meters in the old buildings have problems with respect to safety and inner environment. Instead of rebuilding, taking strengthening and retrofitting measures for the old existing buildings are more reasonable. China's construction industry has begun to enter the period of renovation and strengthening from the period of construction [1]. Hence, integrally, comprehensive, and reasonable evaluation of the refurbishment of the existing buildings in China is of great importance.

Most developed countries had formulated their own evaluation systems according to their own state of development [2] in the aspect of assessment of residential building. For example, the Housing Quality Indicators System (HQIS) of England evaluates the residential buildings from 10 partial evaluation indexes of the location, design and performance key factors; Department of Housing and Urban Development (HUD) of America presents the objects of Housing Quality Standard (HQS) including all the independent housing types and collective housings, and the main certification contents of this system have 13 main aspects of health, safety of the residential performance; In the Residential Quality to Ensure the Promotion Law (RQEPL) of Japan, the application area of the industrial building performance's system is extended to all residential buildings. The benchmark of the residential performance of Japan set part performance index instead of comprehensive indexex,

which mainly includes 9 aspects for the evaluation of the new residential content and includes evaluation, repair and recycling for the evaluation of residential points.

The previous works concerns economic indicators (revenue, profit, and depreciation), technical indicators (safety, applicability, durability) and environmental indicators (pollution) of existing buildings [3] separately. The assessment result of existing building may be segmentary and leading to a deficient refurbishment decision. In this study, a comprehensive evaluation of strengthening and retrofitting for existing buildings consider the technical and economic indicators integrated with environment index [4] , making the existing buildings in accord with the sustainable development and people-oriented objectives. Accordingly, a multi-objective and multi-level comprehensive evaluation system for the existing building strengthening and retrofitting in China, which is conducted as elements of building renovation for existing buildings, is developed. A public building in Liaoning province of China is analysed as a case study to demonstrate the feasibility and validity of the system.

2. The comprehensive assessment index system

In order to guarantee the objectivity of assessment result, a series of quantitative indexes are established along with some traditional qualitative indexes, while, the social and humanistic ecology are taken into account.

In the process of the establishment of the index system, we also refer to some developed countries' existing assessment index systems of building performance and green building assessment systems, such as the British BREEAM, American LEED [5], Australian NABERS and Japanese CASBEE [6]. Considering the current situation of China, we also made reference to the Technical Standard for Residential Performance Evaluation (GB/T50362-2005), which was implemented on March 1, 2006, and Green Building Evaluation Standard of China (GB/T50378-2006), enforced on June 1, 2006 (referred to as the "standard"), which is used for evaluating residential and office buildings, shopping malls, hotels and other public buildings.

The evaluation index system includes six indexes as follows: 1) land saving and outdoor environment; 2) energy saving and energy utilization; 3) water saving and water resources utilization; 4) materials saving and material resources utilization; 5) quality of indoor environment; 6) operation management (residential construction), the whole life cycle comprehensive performance of the buildings (public buildings) [7-9].

A Comprehensive Assessment System for the Strengthening and Retrofitting of Existing Residence (CASSRER) is designed with 3 level indicators as shown in Figure 1. Level one includes 6 indicators, such as architecture and structure, indoor environment, energy saving, outside environment, regionalism and economy. Level two includes 23 indicators, such as architectural design, noise and sound insulation, material energy-saving, distribution of buildings, Level three contains 100 marking criteria.

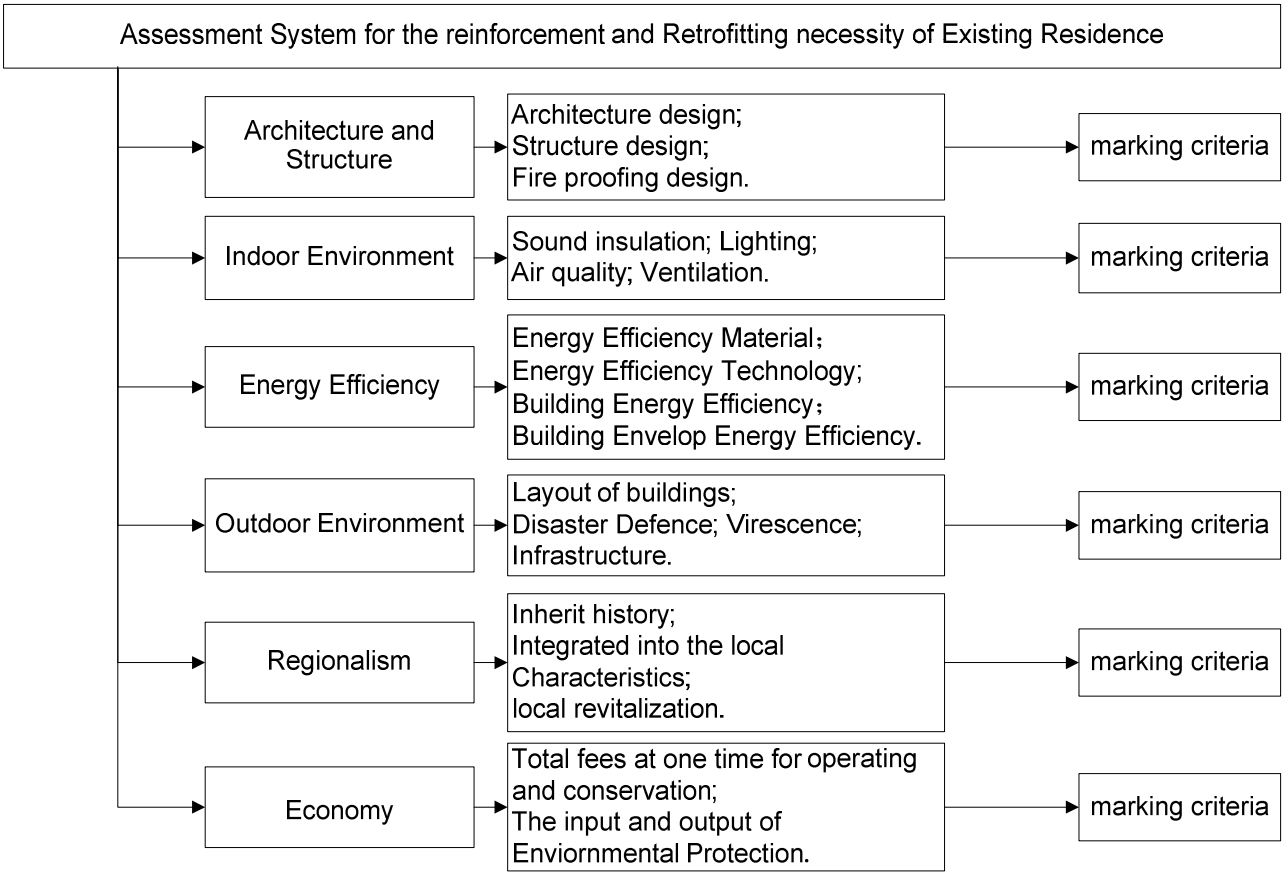


Fig. 1 Assessment System for Strengthening and Retrofitting necessity of Existing Building

3. Weights system

3.1 Method for determining weights

This paper adopted the analytic networks process (ANP), which use comparison matrix function in the super decision software (1.4.2), to determine the weight system based on a questionnaire survey of experts.

Through the questionnaire survey, the relative importance of the 6 level one indicators and 23 level two indicators was determined, which was consistent with the AHP. According to the principle of stakeholders, this survey mainly referred to the people worked in building research institutes, design institutes, real estates, residential construction, construction consulting companies and residents. A total of 200 questionnaires were issued. 188 effective questionnaires were taken back and 12 questionnaires were invalid. Finally, the weights system of the comprehensive evaluation system for the strengthening and reconstruction of existing buildings in China was established, as shown in Table 1.

Table 1 Weights System

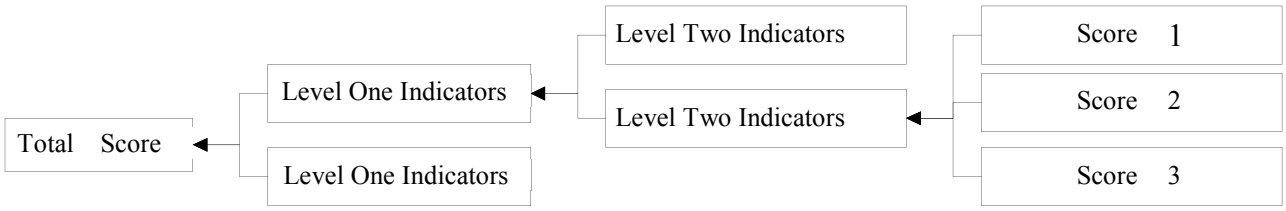
First level index	First level weights	Second level index	Second level weights
Architecture and Structure	0.416	Architecture design	0.220
		Structure design	0.434
		Fire-proofing design	0.345
Indoor Environment	0.113	Noise and sound insulation	0.228
		Sunshine and lighting	0.240
		Air quality	0.277
		Ventilation	0.255
Energy Efficiency	0.313	Building energy efficiency	0.197
		Energy efficiency technology	0.120
		Energy efficiency material	0.193
		Building envelope energy efficiency	0.339
		Water-saving	0.248
Outdoor environment	0.066	Distribution of buildings	0.162
		Disaster protection	0.283
		Vegetation and green	0.253
		Infrastructure	0.301
Regionalism	0.050	Inherit history	0.325
		Integrated into the local Characteristic	0.217
		Local revitalization	0.458
Economy	0.042	Total fees at one time	0.143
		Operating and maintenance fees	0.344
		Environment protection investment	0.245
		The production of environment protection	0.268

3.2 Scoring Method

The comprehensive evaluation system for the strengthening and retrofitting of existing buildings obtains a score through the evaluation of each indicator. As weight grade method has advantages

for the multi-level evaluation index system, the evaluation system for strengthening and retrofitting of existing buildings adopted the weight grade method to calculate each indicator score and the total scores. Firstly, we calculate the actual score of each level-two indicator. Then, all level-two indicator score is multiplied by the corresponding weight and accumulated the results. Finally, we obtain level one indicators' scores, as shown in Fig. 2. According to the indicator score of the evaluated level one indicator for the existing building, the classification modification necessity can be further obtained. Also according to the score of the appraisal object, we can make a comprehensive evaluation on the necessity of building's refurbishment.

Fig. 2 Scoring Method



In this paper, the architecture and structure, indoor environment, energy saving and outdoor environment of four level-one indicators are divided into as objective indicators, meanwhile, the regional and economic indicators of two level-one are divided into as subjective indicators, and we used different scoring methods for different characteristics of the subjective and objective indicators. The objective indicators uses 0/1 scoring method, namely the score is 1 for meeting the criteria, or scores 0. Five grades that scoring points for the subjective indicators are excellent, good, fine, qualified and bad, and respectively correspond to 1, 0.8, 0.6, 0.4 and 0.2 of the five scores. Evaluation grade is decided according to the evaluation scores, and the preliminary rating standard is set for: 1. Being in urgent need of refurbishment (0 ≤score ≤ 30); 2. Being in need of refurbishment (30 < score< 60); 3. Being in no need of refurbishment (60 < score < 100).

4. Case Study

4.1 Project Profile

A laboratory building located in Liaoning Province of China (Fig. 3), which was constructed in 1992, was evaluated by the proposed system. The main characteristics are as follows: five-story brick structure of the body, 3882 square meters in building area , the shape coefficient is 0.28, window to wall ratio are 0.218 (East), 0.051 (South), 0.219 (West), 0.226 (North). Under the barriers of economic condition and policy, there were virtually no energy efficiency and thermal insulation measures were token when constructed, energy-saving construction was conducted on April, 2007.

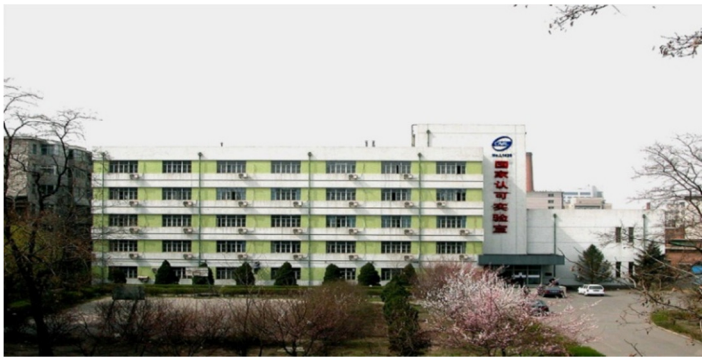


Figure 3 The Laboratory Building Before Strengthening

4.2 Evaluation of the Building Before Refurbishment

Evaluation of the building before refurbishment was implemented through the Comprehensive Assessment System for the Strengthening and Renovation of Existing Residence(CASRRR) developed based on the proposed method of the paper, the result is shown in figure 4. It can be seen from the figure that: the comprehensive score of the building is 43, the total rating is "modification", the comprehensive performance is low. The outdoor environment and regional score is 66 and 76 respectively, which indicate that the two aspects are well behaved. Other three scores in building and structure, indoor environment and economy are between 30 to 60 points, which need appropriate strengthening and appropriate renovation; but the score of energy efficiency is 24, which exposed some problems like high energy consumption, low efficiency. It is shown obviously in radar map that the whole score of the area is lesser due to the various uneven scoring, and affects the comprehensive performance of the building.

The Indicator Scores

Total Score	43.00	Renovation
Building and Structure	46.00	Renovation
Indoor Environment	54.00	Renovation
Energy efficiency	24.00	Urgent Renovation
Outdoor Environment	66.00	No Renovation
Regional	76.00	No Renovation
Economy	45.00	Renovation

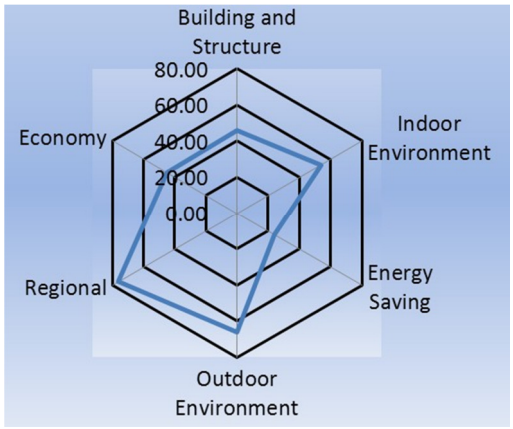


Figure 4 Evaluation Results of the Building Before Refurbishment

4.3 Building Refurbishment Scheme

In the process of refurbishment of the laboratory building, some new technologies of energy efficiency, new materials and integrated application of solar energy technology, water reuse, wind power generation technology were adpoted. Table 2 is a list of the adpoted renovation technologies. Figure 5 is the building after reburbishment.

4.4 Evaluation after the Refurbishment of the Building

Evaluation of the building after refurbishment was conducted through the CASRRR. The result is shown in Fig. 6，in which the comprehensive score of the building is 65, indicating that no renovation is needed.

By comparing the Fig 4 and Fig 6, we can see that the three terms of the building and structure, indoor environment and economy increase slightly, while the building and structure and the rating of economy still need to be improved, but it has been close to the requirements; at the same time the energy efficiency increased significantly, the effect of refurbishment is remarkable.

Table 2 Energy Efficiency Refurbishment Scheme of the Laboratory Building

The serial number	Renovation project		Technical elements
One	Outer renovation	Outer wall	Increase the thermal insulation layer on the basis of the outer original wall which is 370mm thick.
		Outer window	Change the side-hung steel windows with double glazing by the side-hung plastics-steel single frame windows with double glazing, in some floors with low-E glass.
		Roof	Use polystyrene board 120mm thick keeping insulation
		Floor and ground	Increases the phase change heating storage floor in apart of room.
Two	The renovation of inner system	Heating system	Replace one-pipe uplink system with a dual-pipe system, increase the heat flow and temperature control valve, replace the radiator.
		Air condition system	Removal of the split type air conditioner, and using modular air cooled chiller.
		Water supply system	Use water-saving appliances and purified water
		Power supply system	Itemized metering
		Intelligent system	Integrated wiring technology
Three	Apply new technologies	The application of solar technology	Using solar water heating system; Using the solar air heating technology; Using the natural ventilation technology.
		Reclaimed water reuse technology	Collect domestic sewage for water recycling, then through the high efficient bacteria strengthen BAO technology, make the treated water used for flushing and landscape irrigation water.
		Wind generation technology	According to energy conversion principle, through the wind turbine converts wind energy into electricity. It will supply power to street lamp, lawn lamp ahead the building.



Figure 5 The Laboratory Building after Refurbishment

After the comprehensive refurbishment, the score of different aspects of the building tend to be equal, the area of radar chart expands considerably, in that way we can get a great benefits with less economic cost through scientific and reasonable planning for the refurbishment work.

The Indicator Scores

Total Score	65.00	Renovation
Building and Structure	50.00	Renovation
Indoor Environment	62.00	Renovation
Energy efficiency	85.00	Urgent Renovation
Outdoor Environment	66.00	No Renovation
Regional	76.00	No Renovation
Economy	51.00	Renovation

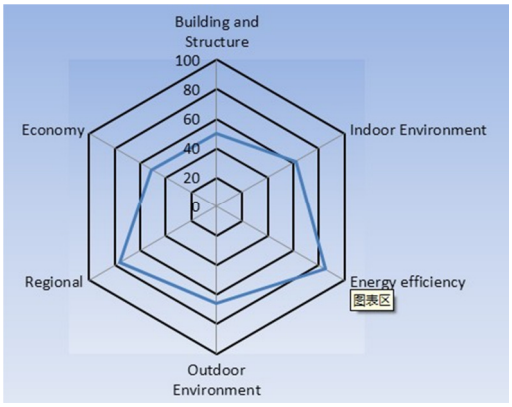


Figure 6 Evaluation Results of a Building after Refurbishment

5. Conclusion

An existing building strengthening comprehensive evaluation system, including 6 level one indicators, 23 level two indicators, is developed in this paper. The evaluation system provides a useful tool for assessing the performance of existing buildings, the grade of strengthening and reconstruction necessity as well as the specific direction of strengthening and reconstruction can be determined. The method can figure out the refurbishment potentiality of existing buildings in 6 aspects regarding the architecture and structure, the indoor environment, energy saving, environment, regional and economic. A case building evaluation verified the feasibility of the proposed system.

6. References

[1] LONGWU WEI, ZHITAO LV, DAN GUO. *"The Evaluation, Strengthening and Retrofitting of building"* [M]. Nanjing: Science and Technology Press of Jiangsu Province, 2006.
[2] GEORGE BAIRD. *"Building Evaluation Techniques "* [M]. New York, 1996.
[3] THE UNITED STATES GREEN BUILDING COUNCIL. *"The Second Edition of Green Building Assessment System, LEEDTM"* [M]. Beijing: China Building Industry Press, 2002.
[4] ASSOCIATION FOR SUSTAINABLE DEVELOPMENT OF JAPAN. *"Comprehensive Environmental Performance Evaluation System for Building-- Green Design Tools (CASBEE) "* [M]. Beijing: China Building Industry Press, 2005.
[5] BUILDING RESEARCH GROUP OF GREEN OLYMPIC. *"Building Assessment System of Green Olympic"* [M]. Beijing: China Building Industry Press, 2003.
[6] ZHIYONG ZHANG, YONG JIANG. "Interpretation of Green Building Assessment System from

the Perspective of Eco-design" [J]. Journal of Chongqing Jianzhu University, 28(4), 2006: 29-33.
[7] GB50096—1999(2003 EDITION). *"The Norms of Residential Design"* [S]. Beijing: China Building Industry Press, 2003.
[8] GB 50352—2005. *"Code for Design of Civil Buildings"* [S]. Beijing: China Building Industry Press, 2005.
[9] GB50180. *"Planning and Design Standards for City Residential Area"* [S]. Beijing: China Building Industry Press, 2005.

A2

Life cycle perspectives in a high quality refurbishment - Part 1

Chair: Christian Hofstadler
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Critical Issues in Application of New European Standard EN15978 in building refurbishments



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Short Summary

This paper focuses on the specification of critical points in the assessment of a chosen building to be elaborated according to EN 15978 [2] and EN 15804 [3]. It is based on the scenario for a specific building refurbishment – underground part of the building was maintained, upper part was deconstructed and built as new re-using the most of the deconstructed building materials possible. The calculations of environmental performance are not part of this paper, but are planned as a next step of the future work of the authors.

Keywords: Life cycle assessment; refurbishment; building assessment; environmental performance of buildings

1. Introduction

Life cycle assessment of buildings is nowadays used first of all for new buildings. The situation is quite different in assessment of existing buildings and their refurbishments. There are only quite few LCA analysis for existing buildings in the world, and most of them are only simplified versions. It is clear that we should focus on LCA of existing buildings because it is generally known that new buildings represent just a minor portion of the total number of buildings (for example the annual growth rate of new buildings added to the housing stock is 1.5%) [1]. From this point of view, we are able to influence the overall environmental performance of buildings more efficiently if we also focus on improvements of the existing ones.

It emerged from the background research that there is not a sufficient number of relevant examples of life cycle analysis of refurbishments of existing buildings. Furthermore, the assessment method according to the European Standard EN15978 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method [2] is quite new and no LCA studies have been done so far. It has been decided to create a detailed LCA of a typical Czech existing building intended for refurbishment. Detailed scenarios are modelled for individual modules of life cycle of the building and particular and problematic issues are defined within the process.

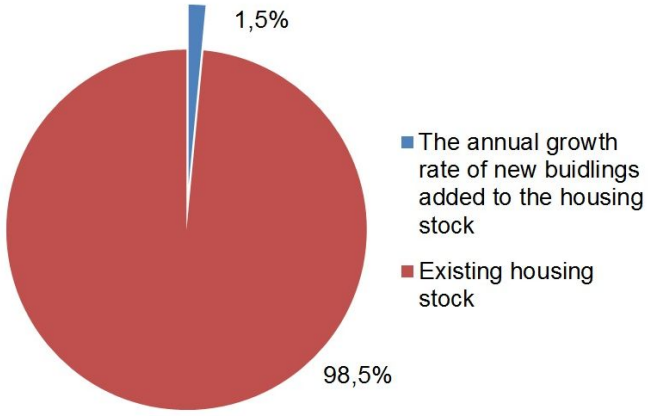


Fig. 1: The annual growth rate of new buildings added to the housing stock [1].

2. Methods

As a model case serves a residential building which went through a refurbishment process. The building is in the first part described according to the requirements of the norm [2]. The second part of this paper addresses the problematic issues and uncertainties that emerge during creating a model and scenario of the building life cycle assessment.

2.1 Building model

"The purpose of the building model is to enable the quantification of the mass and energy flows. This quantification should be organised in a structured way according to the norm" [2].

Our building is a one family house in Pilsen (Czech Republic) which went through a refurbishment process which was finished in 2010 (Fig. 2). The original floor space was 81,7 m2 and 142,8 m2 is the floor area after refurbishment. New living space with rooms for children was created in the attic.



Fig. 2: LCA subject - family house in Pilsen (Czech Republic) which went through a refurbishment process (left – original state, right – after refurbishment).

The basic constructional principals of the refurbishment were:

- Keeping the original built-up area;
- Using parts of the original foundations;
- Deconstruction of the walls;
- Using the original bricks for the new construction of the walls (hand cleaned);

- Rising up the roof to create new rooms;
- HVAC DUPLEX unit used for ventilation and heating (runs on gas boiler) ;
- Fire place with heat accumulation reservoir;
- Solar collectors;

2.2 Purpose of the assessment

The purpose of the assessment is defined by the goal, the scope and the intended use of the assessment. In our case, the intended use of the assessment is according to the norm [2] following:

- Assistance in decision making process (for example comparison of the environmental performance of different design options);
- Documenting the environmental performance of the building;

2.3 Specification of the object of assessment

2.3.1 Functional equivalent and reference unit

As the results of this case study are to be used for comparisons with another scenarios of the building construction, the functional equivalent is the family house for 4 persons, meeting the requirement of the heat transfer coefficient for low energy house (the same coefficient as will be defined for other scenarios), and all fire protection and static requirements of Czech building laws. The required service life of the building will be the same for all scenarios as well (e.g. 50 years, see chapter 2.3.2).

In case of comparison of different building design assessments (e.g. new building will have larger floor surface than the refurbished one), the reference unit per $1m^2$ or per 1 person will be used.

2.3.2 Reference study period

"The default value for the reference study period shall be the required service life of the building. Any deviations from this (see below) shall be clearly stated and reasons explained" [2].

There are several problematic issues regarding the service life of the building or a particular building component. Service life can be divided into **moral service life** or **technical service life**. Moral service life is not usualy identical with the technical service life. It is common that buildings reach their moral service life limit before reaching the real technical service life limit. Such buildings do not fulfil the needs of building operation and they are being demolished although the technical condition of their construction is good.

It is more or less possible to determine the technical service life of a building or its component but the moral service life is quite unpredictable. It is impossible to define future social or urban changes that would influence the building use and its moral service life.

2.3.3 System boundary

"The system boundary determines the processes that are taken into account for the object of assessment. In this context, the object of assessment is the building and its site. This includes all the upstream and downstream processes needed to establish and maintain the function(s) of the building, from the acquisition of raw materials to their disposal or to the point where materials exit the system boundary either during or at the end of the building life cycle" [2].

The building assessment process was studied according to the system boundaries and modules given in [2] and [3]. The results are given in chapter 3.

2.3.4 Scenarios of the building life cycle

In this case, the scenario of a specific building refurbishment was determined. It included the deconstruction of the existing above-ground part and maintenance of the underground part of the

building. Large part of the deconstructed building materials (e.g. bricks), were re-used in the new construction. In a different point of view, this scenario could be taken as a new construction with re-use of existing materials, but as the foundations were maintained, the refurbishment is more likely (at least according to the Czech building law system).
Other scenarios as possible renovation of existing building (without the deconstruction of the upper part) or completely new construction including demolition of the old building were not part of this study, but will be studied in the future work of the authors.

3. Results

The building refurbishment assessment process according to the modules A-D given in [2] and [3] was studied. The critical points expected during the assessment were stated and summarized in tables (Tables 1, 2, 3 and 4)

3.1.1 Product and construction process stages – A modules

Table 1: Product and construction process stages of building assessment and definition of critical issues in assessment of particular processes.

Module	Process	Relevant for the case study	Critical Issue / uncertainty
A1 Raw material supply		Yes	These data for building products should be gathered from **EPD**s [3]. However, in Czech Republic there are almost no EPDs for building products. Generic data should be used in that case, but as stated in [4], this could lead to incomparable and unreliable results. Another problem is the inclusion of **re-used materials**, e.g. bricks. Since they are not transported anywhere and used as they are, only some cleaning should be included. No further environmental impacts are caused by the re-used products. For that, no EPD should be needed. Another question is the **cut-off rules**. According to EN 15804 [3], 1% of energy or materials flow is allowed for a process, and 5% in total for modul A1-A3. Regarding the new materials, the 1% impact could be equal to the impact of the cleaning of the re-used product. But as the impact of the re-used product will only be the cleaning, it needs to be included. Therefore, the question is, if it must be included or excluded.
A2 Transport		Yes	
A3 Manufacturing		Yes	

Module	Process	Relevant for the case study	Critical Issue / uncertainty
A4 Transport (of final product)	Transport from manufacturer	Yes	The calculation of product transport from manufacturer or from the last storage is possible. But the knowledge of any other transport or intermediate storage and distribution impacts is very unlikely. The detailed tracking of each product would be needed. These impacts could be used on average data from producer statistics, but even this is very complicated.
	Transport of the construction equipement	Yes	The transport of the construction equipment will in this case include only scaffolding.
	Losses due to transportation	Yes	Impacts related to losses due to transportation need to be based on some statistics, which probably will bring more uncertainties into the assessment.
A5 Construction – installation process	Ground works and landscaping	Yes	-
	Storage of products	No	-
	On site transport	No	-
	Temporary works	No	-
	On site production and transformation	?	The on-site production and transformation of the product is a question in this case. For instance as the bricks need to be cleaned, should the cleaning be included in this module?
	Heating, cooling, ventilation etc,	Yes	Based on practical experiences and assumptions or simplified calculations if made in the design stage. Can bring uncertainties.
	Installation of products and ancillary materials	No	-
	On site water use	Yes	Based on practical experiences and assumptions or simplified calculations if made in the design stage. Can bring uncertainties.
	Waste management		Waste management impacts are considered minor in this scale, but their inclusion will be very complicated considering the data quality and availability. The cut-off rules should maybe be defined.

3.1.2 Use stages – B modules

Refurbishment is a term that describes a building intervention into a construction object. In the Czech Republic, it is not clearly defined where lies the line between building alternations, refurbishment or a new building which is reusing old constructions.

There is also possibility of building addition or on the other hand demolition of its part. It is impossible to predict these actions in the LCA model of a building. This brings a huge uncertainty into LCA model and scenarios that are used in it.

Another problematic issue is a possibility of future change of building use. This can have a large impact on its overall performance and the LCA assessment.

Table 2: Use stages of building assessment and definition of critical issues in assessment of particular processes.

Module	Process	Relevant for the case study	Critical Issue / uncertainty of / unpredictable change of
B1: Boundary of the installed products in use	Impacts and aspects arising from the normal (i.e. anticipated) conditions of use of components of the building	Yes	- Defined by standard CEN/TC 351 which has not been published yet (current status: drafting process).
B2: Boundary of maintenance	The production and transportation of the components and ancillary products used for maintenance	Yes	- Transportation distance, methods, effectivity and technology
	Cleaning processes in interior and exterior, processes for maintaining the functional and technical performance of the building fabric and technical systems	Yes	- Cleaning technology - Interior and exterior - Building adaptations - Building use - Technical systems
B3: Boundary for repair	Production of the repaired components	Yes	- Production of repaired parts
	Transportation of the repaired part	Yes	- Transportation distance, methods, effectivity and technology
	Waste management of the removed part	Yes	- Recyclation process - Legislative changes
	The end of life stage of the removed part	Yes	- Determination of operation life (durability) of particular components or the whole building

Module	Process	Relevant for the case study	Critical Issue / uncertainty of / unpredictable change of
B4: Boundary for replacement	Production of the replaced component	Yes	- Production technology of replaced components
	Transportation of the replaced components	Yes	- Transportation distance, methods, effectivity and technology
	Waste management of the removed components	Yes	- Recyclation process - Legislative changes
	The end of life stage of the removed component	Yes	- Determination of operation life (durability) of particular components or the whole building
B5: Boundary for refurbishment	Production of the new building components	Yes	- Production technology of changed components
	Transportation of the new building components	Yes	- Transportation distance, methods, effectivity and technology
	Construction as part of the refurbishment process	Yes	- Construction technology - Legislative changes
	Waste management of the refurbishment process	Yes	- Recyclation process - Legislative changes
	The end of life stage of replaced building components	Yes	- Determination of operation life (durability) of particular components or the whole building
B6: Boundary of the operational energy use	Energy used by building-integrated technical systems during the operation of the building	Yes	- Technical systems - Building use - Legislative and norms - Difference between calculated and real energy demand - Operational life of building - Technological and scientific progress
B3: Boundary of the operational water use	Operational water use	Yes	- Technical systems - Building use - Difference between calculated and water demand

3.1.3 End of life stages - C modules

“The end-of-life stage of a building starts when the building is decommissioned and is not intended to have any further use. At this point, the building’s demolition/deconstruction may be considered as a multi-output process that provides a source of materials, products and building elements that are to be discarded, recovered, recycled or reused” [2].

The building is decommissioned when it reaches its moral or technical service life. It can be very difficult to reach reasonable results in C modules as well as in D modules. Processes that are being described in this module happen in distant future (50 - 60 years) so it is very complicated to determine technologies and energy demands for their execution. Therefore it is necessary to come

out from presumptions and estimations and this fact has to be stated in the scenario of LCA.

C module describes also the way how processes connected to recycling or further reuse of materials should be involved in the assessment. Although the description is quite detailed it is not entirely clear. Correct interpretation of this process will be more and more important in the future because the tendencies aim rather to reuse and recycling than disposing materials to dumps.

Table 3: End of the life stages of building assessment and definition of critical in assessment of particular processes.

Module	Process	Relevant for the case study	Critical Issue / uncertainty of / unpredictable change of
C1: Boundary for the deconstruction	Processes on deconstruction site	Yes	- Deconstruction/demolition technology - Temporary buildings on site - All deconstruction processes after decommissioning - Primary on- site sorting
C2: Boundary for transport	Transportation connected to deconstruction process until the end-of-waste state is reached	Yes	- Transportation distance, methods, effectivity and technology - Amount of transported material
C3: Boundary for waste processing for reuse, recovery or recycling	Processes before the end of life cycle of a material or a product	Yes	- Problematic determination of point when a waste becomes a product intended to be reused
C4: Boundary for the disposal	Possible post-transportation treatment that is necessary before disposal	Yes	- Environmental loads resulting from final disposal of materials - Technology progress - Disposal methods

Table 4: Assessment of benefits and loads beyond the system boundary and definition of critical issues in assessment of particular processes.

Module	Process	Mandatory Assessment	Critical Issue / uncertainty of / unpredictable change of
D: Boundary for the benefits and loads beyond the system boundary	Environmental benefits or loads resulting from reuse, recycling and energy recovery	Yes	- Reuse / recycling methods may change in future

4. Conclusions

This study of problematic issues during creation of LCA model of a building is a beginning of a complex project of LCA assessment of existing building.

The results of this preliminary study show us several critical issues that influence the overall LCA result. The common feature of the critical issues is their **unpredictability in the future**. This unpredictability should be always taken into account when creating LCA scenarios and interpreting their results.

The major uncertainties that influence most of the modules and are hard to be predicted are following:
- Service life (moral and technical) of building and particular parts;
- Change of building use;
- Social and urban changes;
- Technological progress in transport methods, construction processes, ways of disposal, recycling etc.;
- Legal changes;
- Insufficient data on environmental performance of materials and building components.

The resulting LCA will always be accurate only within a certain **probability measure** which is hard to be determined as well because the number of possible development scenarios may be infinite.

5. Acknowledgement

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6. References

[1] AD-HOC INDUSTRIAL ADVISORY GROUP. *"Energy-efficient Buildings (EeB) PPP, Research priorities for the definition of a Multiannual Roadmap and longer term Strategy"*. Brussels, 2009, European Economic Recovery Plan.
[2] CEN (2011), EN 15978 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method.
[3] CEN (2012), EN 15804 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products
[4] Hodková, J. - Lupíšek, A. - Mančík, Š. - Vochoc, L. - Žďára, T.: National Platform for LCA Data on Building Elements in the Context of the Czech Republic. International Journal of Sustainable Building Technology and Urban Development. 2012, vol. 3, no. 4, p. 277-284. ISSN 2093-761X.

Environmental and economical assessment of refurbishment concepts



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Short Summary

This paper summarises the results of the recent research Methods and Concepts for Sustainable Renovation (MECOREN) carried out at VTT. The project aimed at creating new understanding about

- sustainable refurbishment concepts for residential buildings.
- environmental and economical impacts of alternative refurbishment concepts
- suitable methods for the environmental assessment of refurbishment concepts.

Alternative refurbishment concepts were studied on the level of the Finnish residential building stock. Different refurbishment concepts were compared by assessing the impact in terms of energy and greenhouse gases.

When assessing the greenhouse gases (GHGs) of buildings and the effect of refurbishment on GHGs, it is important to choose a right method with the help of which the emissions of energy are calculated. This is especially important when district heat and electricity are used as sources of energy.

The paper also assesses the significance of embodied environmental impacts in sustainable refurbishment projects. The environmental impact of renovation materials was compared to the saved environmental impact due to the energy saving achieved with the help of refurbishment. The demolition and building a new building was also considered as an alternative.

The assessment of the economical potentials of refurbishment concepts was carried for cases where an extensive refurbishment is needed for an out-dated building. However, also separately done refurbishment measures such as changes of windows, refurbishment of facades etc. should lead to a reasonable improvement of energy performance. The economical life cycle impacts of refurbishment depend on the investment cost and the reduction of energy consumption. However, a successful refurbishment also affects the resale value of the building. A significant increase in the value (market value) by means of extensive refurbishment can be achieved when the building is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. Compensation can also be achieved by increasing the density of the area (with the help of extensions such as an additional storey or building).

Keywords: Sustainable renovation

1. Introduction

This paper presents the main results of the research project Methods and Concepts for sustainable Renovation (MECOREN) carried out at VTT in 2009–2012 (Häkkinen 2012). The overall research project was a Nordic collaboration. The project had the following research partners: VTT in Finland, SINTEF in Norway, SBI in Denmark and KTH in Sweden.

The paper analyses the impacts of alternative renovation scenarios on the Finnish building stock in terms of greenhouse gases (GHGs). The study focused on residential buildings. The calculations were carried out for years 2010, 2020 and 2030. In addition to the assessment of the renovation concepts of building stock, the objective of the paper is also to

- discuss and give recommendations about the use of environmental data for energy sources
- discuss and make conclusions about the significance of building materials in renovation projects from the view point of greenhouse gases and total energy use
- assess and make conclusions about the economic impacts of building renovation.

Information on total floor area of the Finnish housing stock was used as the basis for the analyses. The total floor area of the Finnish housing stock was first divided into age groups based on the available statistical information on residential housing stock.

In the next phase, the size and performance of buildings in different age groups were defined. The defined performance includes the types of structures, floor height and volume of a building, number of inhabitants, and heating energy, electricity and water consumption. These defined figures were then used as an input for creating exemplary buildings which were dealt with by the energy calculation program WinEtana.

By using the information of the exemplary buildings and the composition of the current housing stock, a theoretical maximum energy saving potential for the Finnish residential stock can be calculated. This was done by applying different energy saving measures to the exemplary buildings. The measures under study were: additional thermal insulation, replacement of windows, replacement of ventilation system and implementation of solar heating.

Based on the assessed energy savings, also savings in GHGs can be calculated. These calculations were based on energy production profiles in Finland.

The housing stock develops and changes over time. Thus the estimation of the current housing stock is not sufficient for estimating the situation in 2020 and 2030. New construction adds the floor area of the housing stock and obsolescence, deterioration and finally demolishment decreases it.

The degree of building degradation was taken into account, since energy renovations are often feasible only in the connection of other renovation. The study used an assumption that energy renovations are made only when the buildings would need renovation in any case.

2. Environmental profiles for electricity and district heat

In order to assess the environmental potential of different renovation concepts the environmental profiles for heat and electricity was calculated as an average value for 2004–2008.

The models built for the calculation of the average electricity supply and heat production include fuel extraction (heavy fuel oil, hard coal, natural gas extraction, greenhouse gas emissions from peat manufacturing), electricity and heat production both in electricity and combined heat and power (CHP) plants, net imports and transmission losses. The used allocation methods for CHP are energy allocation and benefit distribution. Due to lack of data, separate heat production is taken into account only for heavy fuel oil (78% of heat produced with oil is from separate production in 2008). Other fuels are mainly used in CHP plants (75–95% of heat produced in CHP) and the shares of separate production are smaller.

Table 1: LCA based environmental profiles for average Finnish electricity (considering net imports).

	Benefit		Energy	
	Electricity	**District heat**	**Electricity**	**District heat**
CO2 fossil, kg/MWh	309	236	222	273
CO2 biogenic, kg/MWh	121	134	67.5	160
CH4, kg/MWh	0.821	0,364	0.709	0,424
N2O, kg/MWh	0.000654	0.000397	0.000523	0.000448
GHG, kg/MWh	330	245	240	283

The GHGs of electricity produced in condensing power plant has been earlier assessed to be 966 g/kWh (Holopainen et al. 2010).

The newest prediction made by the Finnish Ministry of Employment and Economy was done in the connection of the new climate and energy strategy. On the basis of preliminary information and in accordance with the newest base scenario the predicted emissions for district heat and electricity are as follows:

Table 2: Predicted emissions for district heat and electricity

Characteristic emission, g CO2/kWh	**2010**	**2020**	**2030**
Electricity delivery	230	179	36
District heat	243	216	191

The base scenario takes into consideration the measures already decided such as feed tariff for electricity delivery, subsidies for renewable energy and nuclear power plants already received positive decisions in principle. The allocation of fuels in CHP district heat and electricity was done on the basis with energy method. The scenario also assumes that all electricity is produced in Finland in 2020 and 2030. The scenario considers the assumed decrease of energy demand for heating of buildings. This scenario takes into consideration the impact of energy performance regulations and the impact of changes in building stock (demolition of building and building of new buildings). In addition, the scenario assumes that the use of heat pumps is increased so that those contribute to 7 TWh of the use of primary energy. It also assumes that oil heated houses change the heating system and make use of ground heat pumps and the houses heated by electric air heat pumps.

3. Environmental impact of materials in building refurbishment

The objective of this part of the study was to assess the significance of building materials in building renovation in terms of GHGs. The environmental impact of renovation materials was compared to the saved environmental impact due to the energy saving achieved with the help of renovation. This study considers:

- Two refurbishment methods
- External insulation – with new additional insulation, new façade and roof
- Replacement renovation – with replaced and additional insulation and with a new façade of the same type
- Demolition level
- Partial demolition and renovation (cases M1 and M3) (see Table 4)
- Total demolition and new construction (cases M2 and M4) (see Table 4)
- Two refurbishment targets
- Low energy building structures,
- Passive energy building structures.

Environmental impact for renovation materials was based on VTT's database. The assessed operational energy (Table 3), the renovation cases (Table 4) and the assessed GHGs for the different cases (Table 5) are presented in the following tables.

Table 3: Operational energy for the studied case (existing multi-storey building, 29 apartments), for renovation and for new construction.

	Existing building	Renovation, Low energy envelope	Renovation, Passive structure envelope	New, Passive energy building
	MWh/a (kWh/m^2)	MWh/a (kWh/m^2)	MWh/a (kWh/m^2)	MWh (kWh/m^2)
Heating energy (district heating)	241 (130)	93 (50)	70 (38)	18 (10)
Service water heating	94 (51)	94 (51)	94 (51)	94 (51)
Electricity	82 (44)	55 (30)	55 (30)	55 (30)
Total	417	242	219	166

Table 4: Refurbishment cases for concrete multi-story building

Structure	Low energy structures		Passive energy structures		
	Case M1	Case M2	Case M3	Case M4	Case new
Demolition	–	Outer concrete layer	–	Outer concrete layer	Existing building
Exterior wall	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	W1 (3 layer rendering façade)	W2 (100 mm concrete with tile façade)	concrete element with tile facade
Base floor	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	B1 (EPS + parquet)	(EPS + parquet)
Roof	R1 (asphalt mastics cover)	R1 (asphalt mastics cover)	R1 (asphalt mastics cover	R1 (asphalt mastics cover)	asphalt mastics cover
Window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window	Quadruple pane window

These cases indicate that the increased material consumption because of refurbishment to the level of low-energy and passive-level structures causes an increase in GHGs but this is significantly lower compared to the saved GHGs because of saved operational energy.

4. Energy consumption of the current housing stock and energy saving potential

The heating energy use and electricity use were calculated for all residential buildings by using model buildings. An exemplary building was created to present each of the different age-type groups in the building stock as explained earlier (Section 1), and these model buildings were then used for calculating the energy consumption of the housing stock.

When buildings exit the housing stock, savings in heating energy and electricity consumption take place. This also results in a decrease in GHG emissions, assuming that the emissions for the different energy types remain unchanged over time. Buildings also undergo energy renovations, which decrease their energy consumption, and result in reduced GHG emissions. Finally, the heating method of buildings may be changed causing changes both in energy consumption and GHG emissions.

The results show the total energy consumption of the building stock, after all buildings in renovation need have been renovated with a certain renovation method. Results are for all residential buildings; the year of consideration is 2030.Table 6 shows that the assessed GHG saving potential of different renovation alternatives ranges from 3% (solar heat installation) to 27% (a combination of renovations). In addition to energy renovations, buildings may also undergo renovations related to their heating systems. The study focused on detached houses, since

changes in their heating systems are relatively easy to implement, and, for example conversions from electrical heating to geothermal heating has already become quite popular. Table 7 shows the assessment results for GHG emissions, if all the detached houses with electric heating and oil-heating changed their heating method by 2030.

Table 5: GHGs for a multi-storey building (operation period 50 years)

	Existing building, no renovations	Refurbishment to low energy building Case M1	Low energy building new construction Case M2	Refurbishment to passive structure Case M3	Refurbishment to passive structure Case M4	Passive structure building, New construction Case M New
Demolition			342		342	21 702
Exterior wall		13 028	59 867	18 245	65 408	152 045
Base floor		8 735	8 735	8 735	8 735	41 273
Partition wall		0	0	0	0	86 832
Roof		16 650	16 650	21 314	21 314	45 024
Partition floor						107 566
Window		9 776	9 776	9 776	9 776	9 776
TRP to site		237	857	268	889	7 066
Heating	2 533 770	979 879	979 879	736 359	736 359	185 472
Electricity	915 327	606 095	606 095	612 279	612 279	612 279
Hot water	991 475	991 475	991 475	**2,673,676**	991 475	991 116
Total	**4,440,572**	**2,625,874**		**2,398,452**	**2,446,578**	**2,260,151**
Total/m^2	**2,400**	**1,419**	**1,445**	**1,296**	**1,322**	**1,222**

Table 6: GHG-emissions of buildings, no-renovation scenario compared to scenarios where different energy renovation methods are applied.

	CO2-equ emissions from heating			CO2-equ emissions, electricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy renovations	9.30	0	0%	2.00	0	0%	11.30	0	0%
Passive-level envelope	7.43	1.88	20%	2.00	0	0%	9.43	1.88	17%
Ventilation renovation	8.52	0.79	8%	2.07	-0.07	-3%	10.59	0.72	6%
Solar heat installation	8.96	0.35	4%	2.00	-0.01	0%	10.96	0.34	3%
Window renovation	8.78	0.52	6%	2.01	-0.01	0%	10.79	0.51	5%
Renovation combination	6.13	3.17	34%	2.07	-0.07	-4%	8.21	3.10	27%

Table 7: Effect of the assumed change in heating method on GHGs

	CO2-equ heating			CO2-equ electricity use			Total CO2-equ emissions		
	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %	Total Mt	Saving Mt	Saving %
2030, no energy renovations	5.169	-	-	1.204	-	-	6.373	-	-
2030, electric heating changed to ground heating	3.721	1.448	28%	0.852	0.352	29%	4.573	1.800	28%
2030, oil heating changed to wood heating	2.718	2.451	47%	1.198	6	1%	3.916	2.457	39%
2030, electric heating changed to ground heating, and oil to wood heating	1.270	3.899	75%	0.845	0.359	30%	2.116	4.257	67%

The change in heating methods may not necessarily cause energy savings, but it may lead to significant GHG emission savings. If all the detached houses with electrical heating changed their heating method to ground heating, and all houses with oil-heating to wood heating, estimated GHG savings would equal to about 4.3 Mt, or 67%, compared to the baseline case.

5. Effect of calculation rules

As there is a rapid change in the assessed CO_2 values of electricity and district heat between the years 2010, 2020 and 2030, the possible consideration of this change in LCAs of buildings has a significant effect on final results. It is here recommended that especially when making building level and stock level life cycle assessments over 50 years' period, the assessed change in emission values should be considered. An example of the significance of the issue is given in the following.

When the GHGs because of total operational energy use during 50 were calculated (section 3) by using the emission values of 2010, the result is significantly bigger (1.99Mt CO_2e) than when the total GHGs are calculated considering the predicted change in the emission values of electricity and district heat (the assessed result falls to1.44 Mt CO_2e). Thus also the share of building materials from the total GHGs increases (in this example it increases from below 20% to roughly 25%). The share of materials in the latter case roughly equals to the combined share of heating and electricity while the heating of water is responsible for roughly 50% of the assessed GHGs.

However, when making building stock based analyses about the significance of renovation scenarios, it is also important to take into account, whether a particular decrease in the demand for delivered electricity is actually needed as a partial measure in order to make the change (decrease of GHGs) to happen. The ability of building sector to react to the challenge is an important prerequisite for Finland in order to be able to respond to the requirements of decreasing GHGs. The role of building sector is double in such a way that it is first important to decrease the GHGs of the building stock with help of improved energy performance and indirectly to enable the better power generation (in terms of GHGs) with the help of reduced demand for delivered electricity.

Section 4 shows assessment results for the final energy use and related GHG emissions of the Finnish residential building stock in 2020 and 2030. According to the results the total final energy demand in 2030 would be 29 TWh including 29 TWh for heating spaces and 9.2 TWh because of the use of electricity. This assessment takes into account the assessed outgoing share of the current stock and the share of buildings needing either light or thorough renovation during the coming years. It is also based on assumption that an effective combination of energy renovation measures would be done for those buildings that need thorough renovation. The share of electricity

from the assessed 29 TWh is 27% (7.8 TWh). However, the total use of electricity could be further decreased by roughly 4 TWh with help of ground heat pumps of detached houses. Assuming that the energy is produced with help of district heat and electricity and by using either 2010 values or predicted values for GHGs, we receive different results for the assessed impact of building stock in 2030:
The assessed GHGs of the existing building stock is 9.1 Mt by using the present values
The assessed GHG of the existing building stock s 4.7 by using the predicted values (2030)
If we further consider the assessed savings in demand for delivered electricity because of the change of attached houses from electrical heating to ground heat pumps, we receive the following results:
The assessed GHGs of the existing building stock is 8.1 Mt by using the present values
The assessed GHG of the existing building stock in 2030 is 4.5 by using the predicted values.

6. Economical assessment of renovation concepts

The potentials to remarkably and economically improve the energy performance of buildings are linked to the cases where an extensive renovation is needed for an out-dated building. However, also separately done changes of windows, refurbishment of facades etc. should lead to a reasonable improvement of energy performance. On the basis of the study, the life cycle impacts of successful renovation concepts can be summarized as follows:

- significant reduction of energy consumption and related GHGs
- reasonable increase of investment cost
- reasonable savings in life cycle costs
- increase of resale value.

The most significant increase in economic value (market value) with the help of extensive renovation can be achieved when the building or the block of buildings is located in a relatively valuable neighbourhood and when the whole neighbourhood is renovated at the same time. In these cases the costs of renovation can be compensated with the help of the increase of market value. This can also be realised by increasing the density of the area. Effects on economic values of houses and buildings and departments may sometimes be significant because of improved performance and because of aesthetical improvement.

The economic and environmental impact of the renovation of certain building types and groups was also assessed. The assessment was done for detached buildings from 1940–1959, detached buildings from 1980–1989 and for residential blocks of flats from 1960–1069 and 1970–1979. These groups of building were selected because of their big share from the whole building stock. Alternative renovation concepts were as follows: Renovated with 100mm thermal insulation, Renovated with 100mm thermal insulation and ventilation renovation, Renovated with passive level envelope, Renovated with a combination of renovations. On the basis of economical assessment results the following recommendations are given:
All studied alternative energy saving methods are favourable in the case of detached houses from 1940-1959 as the effect of the improved insulation of envelope is very high. Also almost net zero energy level may be achieved in an economical way when connected to an extensive renovation and when there is a need to improve the quality of indoor climate.
In the case of relatively new detached houses (1980-1989), almost net zero energy target is the most economical when there is a need for extensive renovation and need to improve the quality of indoor climate.
In the case of detached houses the target of almost net zero energy building is recommended while in the case of residential blocks of flats passive level envelope and possible renewal of ventilations are the most economical when there is a need for extensive renovation and need to improve the quality of indoor climate.
The economic impact studies were also made regarding the whole existing building stock. In the case of required renovations it was assumed that 75% of all buildings which need thorough renovations shall be renovated with 100mm additional thermal insulation and 25% of them with 100mm thermal insulation and ventilation renovation. The total volumes, cost savings, investment costs, needed annual support and labour effects of renovation concepts in the whole residential building stock in Finland were assessed to be as follows:

Table 8: The assessed total volumes, cost savings, investment costs, needed annual support and labour effects of renovation concepts in the whole residential building stock in Finland

Whole residential building stock Total area 266 000 mill. m^2 (2010), renovated area 140 000 m^2 by 2030.	**Renovated area in year mill. m^2/y**	**Corresponding annual heating cost savings in average mill. €/y**	**Corresponding extra investment costs mill. €/y**	**Annual need for public support (10-15% of investment) mill. €/y**	**Labour effects Person years/y**
Renovated totally with required energy savings	7.0	-45	+650	65 100	9 000
Renovated totally by new ventilation and passive level envelope	7.0	-70	+1 350	150 200	17 000
Renovated totally to almost net zero energy buildings	7.0	-140	+2 750	270 400	31 000
Renovated 50% by new ventilation and passive level envelope and 50% to almost net zero energy buildings	7.0	-105	+2 050	150 200	26 000

7. References

[1] HÄKKINEN T., RUUSKA, A., VARES, S., PULAKKA, S., KOUHIA, I., HOLOPAINEN, R. *"Methods and concepts for sustainable renovation of buildings"*. VTT Technology 26. Espoo 2012. 266 p. + app. 51 p.

[2] HOLOPAINEN, R., VARES, S., RITOLA, J. & PULAKKA, S. 2010. *"Maalämmön ja viilennyksen hyödyntäminen asuinkerrostalon lämmityksessä ja jäähdytyksessä"*. Espoo. VTT Tiedotteita – Research Notes 2546. 56 p. (In Finnish)

LCA and LCC based Energy Optimization of Building Renovation Strategies



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Short Summary

The aim of the paper is to evaluate the efficiency in retrofitting the built asset in order to choose the most sustainable strategies. Generally, this topic has not been afforded in a building life cycle prospective [1,2] and only few authors faced the problem in a systematic way [3,4]. Nowadays, although new European Standards are under publication, a method to assess the environmental impacts (LCA) and economical costs (LCC) from renovations and refurbishments activities along the service life of a building still needs to be developed [5,6]. From these considerations, this work aims to give a contribution in defining a practical LCA and LCC-based method applied to a specific case study.
A multi-storey residential building located in Northern Italy was analysed in order to evaluate different renovation alternatives. This reference building has a very high refurbishment potential: indeed, it has quite low energy efficiency (despite connected to a high efficiency district heating system), an insufficient robustness against actual seismic standards and a very poor acoustic insulation.
The approach here adopted is based on the evaluation of a wide range of possible refurbishment alternatives. Then, an optimization matrix was developed combining the optimal elementary activities and defining a mix of beneficial renovation actions: substitution of external windows, increase in envelope insulation, etc. Improvements of the heating system efficiency were not taken into account among the alternatives. Finally, the most sustainable renovation alternative (Option B) was identified and compared to a second scenario (Option A): full demolition and reconstruction of a new building with the same volume, but a primary energy consumption for heating of 13.92 kWh/m^2-year.
The results clearly point out that Option B is the most sustainable choice, both in terms of energy and GHG saving as well as economical costs reduction. The demolition activity, both in terms of environmental impacts and economic costs, does not significantly affect the results.

Keywords: Renovation; Housing; Sustainability; LCA; LCC; Retrofitting; Carbon Footprint.

1. Introduction

During the Italian economic boom of 50s-70s sustainability and end of life scenario were not taken into account in the building sector. In the following years a social and environmental conscience on sustainability and refurbishment has spread among the stakeholders.
A research carried out by Cresme (Center for Economic, Social Market and Construction Research) in the 90s stated that, in the last years, 55% of the building stock has been

affected by maintenance and refurbishment activities, unlike what was happening in 60s-70s when new buildings amounted to 70-80% of all construction works. Nowadays, the trend towards the quest of technical solutions aiming at a sustainable development with a look at future generations is a growing phenomenon.
In the building sector, resources exploitation, energy consumption and harmful gas emissions have to be taken into account and cannot be neglected in order to obtain an improvement in energy and environmental efficiency.
ENEA (Italian National Agency for New Technologies, Energy and Economic Sustainable Development) stated that energy exploited for domestic hot water and heating in Italian residential buildings is about 30% of national energy consumptions and is the cause of 25% of national carbon dioxide emissions. To restrain this growth, refurbishment strategies have to be studied alongside the research of recyclable and sustainable materials.
As European environmental policies aim to reduce energy consumptions and environmental impacts (Blengini et al [8]), Italian standards look at energy strategies, from national to local scale, with a perspective mainly addressing, through direct and indirect statements, the decrease of operational primary energy (and focusing more specifically on heating).
Thomsen et al. [9] consider the good potential of building refurbishment strategies thanks to the environmental sustainability and energy efficiency that could be reached, as stated in Kyoto protocol, compared to the resource exploitation involved in a demolition. These refurbishment activities concern adaptation to standards, environmental sustainability, envelope energy efficiency and improvement of usability and building quality.
On the basis of these issues, an economical and environmental analysis has been carried out (LCC and LCA) on a case study to compare a building energy refurbishment and a complete demolition followed by a new building reconstruction. The case study is a social housing linear building in Brescia, Italy.
From the merely environmental point of view a refurbishment prevents the soil consumption, the energy exploitation to produce new materials and the economical and energy costs if compared to demolition and new building construction (Schultmann et al. [10]).
The analysis has underlined the economic and environmental advantages both of refurbishment and demolition plus new construction in a scenario in which building energy efficiency and operational performances and consumption have been improved.

2. Methodology

2.1 System boundaries and functional unit

The aim of the research is to compare two building refurbishment strategies, through an LCC and LCA, and to identify the one that gives the greatest economical and environmental advantages.
Building service life is an important parameter to evaluate life cycle impacts (ISO 15686 [24]). A 50-year service life has been taken into account, agreeing with Itard et al. [11], to make a comparison between demolition plus new construction (Option A) and refurbishment (Option B) activities.
Option A consists of, in the present case study, building demolition and subsequent construction of a more efficient building, comprising its operational phase in the service life. The evaluated steps, following UNI 15978 [12], are:

- "END OF LIFE" (C 1-4): end of life of materials, components and technological plans of the building;
- "BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARY" (D): materials' recycling, such as steel and mixed waste from demolition. Allocation methods are not considered because the avoided impacts have been already taken into account and the construction of the existing building is not included within the boundaries of the system [13];

- "PRODUCT" and "COSTRUCTION PROCESS" (A 1-5): construction of the new building, including the site's management in terms of electric energy and machinery's fuel consumptions;
- "USE" (B1-B6): consumption for heating, domestic hot water, gas for eating and electric energy during the building's service life. Maintenance (B2) and requalification-recoveries (B3-5) phases have been neglected because they are the same either for Option A and Option B, so, for the sake of comparison, they don't affect the results. Moreover, maintenance can be considered independent from technology solution, excluding the surface finishes, which are the same in both Options analyzed.

Option B comprises only some energy refurbishments:

- "USE" (B1-B6-B5): implementation of energy performances and evaluation of the consumptions for heating, domestic hot water, gas for eating and electric energy during the building's service life. Maintenance (B2) and repair (B3-B4) phases have been neglected as in Option A.

In Option B "END OF LIFE" phase (C 1-4) has been neglected because information about the sequence of activities for dismantling and recycling or for disposal of construction and demolition waste [8] are difficult to foreseen and are subjected to great variability due to the hand work and to the complexity of disposal system.
Moreover, the study of Option B is focused only on energy refurbishment, neglecting the benefits that could be generated from acoustic insulation, anti-seismic features or architectural upgrading.
The functional unit considered for LCA and LCC is 1 m^2 of living area, to compare the obtained values with similar analysis [13-16] either in performances and in service life.

2.2 Impacts and database

The environmental impact indicators considered for the analysis are the Cumulative Energy Demand (CED) and the CO_{2eq} emissions into the air.
Only non-renewable CED is considered, because the renewable CED is negligible.
The emissions of CO_{2eq} have been divided in different contributions, according to ISO 14067 [17] and PAS 2050: 2011 [12].
Amounts of materials are primary data relative to the case study, while materials production and other processes are secondary data taken from Ecoinvent 2.0 database and calculations performed with Simapro 7.3.3 Software.
Besides, in the economical analysis only the technical costs of the building operations have been taken into account and the overheads, the charges related to safety, business profits, VAT and the increasing of price of money during the life cycle have been neglected.
The unitary costs evaluation has been conducted according to Italian building price list [19], considering material costs and not finished works.
Some Italian building companies have provided primary data both for environmental impacts and for costs of some activities, such as demolition works or insulation addictions.

3. Case Study

The building case study is located in the Casazza neighbourhood of Brescia (Italy) and was built in the 60-70s. The six-storey building, with also an underground floor, has a rectangular plan and the main orientation follows the axis NE-SW.



IDENTIFICATIONE OF TIME	Contemporary (1964-1975)
CONSTRUCTION MATERIALS	Brick-Cement
TYPE OF CONSTRUCTION	Beams and columns
BASEMENT DIMENTIONS	11m x 42m
TOTAL ELEVATION	22,5 m
GROSS VOLUME	12781 m^3
TOTAL NET AREA (usable)	2046 m^2
PERIMETER WALLS	2296 m^2
ROOF	400 m^2
FRAMES EXTERNAL	351 m^2

Figure 1: Characteristics of the building case study.

The building has a concrete frame, brick walls and a sloped bitumen waterproof covering, with fiber-cement slabs. The windows frame is in PVC and has PVC shutters not isolated.
From the decay analysis, the envelope doesn't seem to have particular problems. In this way, both a complete demolition of the building (Option A) and an energy envelope refurbishment (Option B) could be supposed. The demolition with the hypothesis of a new construction would have the goal of improving thermal, acoustic, seismic performances as well as obtaining a better architectural shape also in terms of flexibility with a wide variety of flat layouts.
The building is served by district heating, used exclusively for heating, while domestic hot water is produced by electric water heaters located in every apartment.
An energy analysis was done to evaluate the existing building's consumption, following the Lombardy Region calculation procedure (DDG 5796 of 11th of June 2009 and UNI-TS 11300): the primary energy need is 169 kWh/m²-year.
Gas consumptions for eating have been chosen on the basis of a "mean family" composition (4 people in each flat).
Finally, yearly electric energy consumption for the "mean family" was evaluated, using a tool suggested by ENEA and the city of Bologna [20] (*Table 1*).

Table 1: COSTS, CO_{2eq} and CED of the existing building (50-year service life).

STEP	COSTS	IMPACTS	
	COSTS [€/m^2]	GWP [kg CO_{2eq}/m^2]	CED [MJ/m^2]
USE Heating	515	1.457	25.450
USE Domestic Hot Water	309	798	12.026
USE Gas Kitchen	68	22	2.450
USE Eletricity	421	1.065	16.400
TOTAL	**1.883**	**3.158**	**44.961**

4. Inventory analysis

Option A, i.e demolition and new construction with better performances, provides an evaluation of end-of-life scenario. The most suitable demolition technique used for the operation is the use of excavators equipped with tongs and shears (De Angelis et al [24]).
Demolition plays the highest contribution in terms of economic costs, whereas waste disposal is crucial for environmental impacts because of the length of treatment processes. To cut down on environmental and economic impacts connected to waste treatment, an in-situ treatment of mixed construction wastes (CER 17.09.04, waste type classification according to the inventory introduced by European Directive n. 2000/532/CE) has been evaluated instead of landfill disposal. This kind of in-situ C&D waste processing produces secondary raw materials using a mobile press. With this machine gravel is obtained and the impacts, which would be generated from the extraction of raw material from the pit, are avoided (De Angelis et al [24]).
The new building has a wooden structure because the aim of the analysis is to focus on innovative systems. This new building has the same living area of the existing building and better energy performances, with a primary energy need of 13,92 kWh/m^2-year. Heating pumps are used both for heating and for domestic hot water, but their construction costs and the corresponding environmental impacts have been neglected. Thanks to 26 m^2 of solar

panels, 60% of domestic hot water request has been ensured, reducing heating pumps electricity consumption.
Gas and electric energy consumptions are evaluated following the same procedure adopted in the existing building, obviously considering a better efficiency.
In *Table 2* the three steps of Option A scenery are summarized.

Table 2: COSTS, CO_{2eq} and CED of Option A (demolition plus new construction) over a 50-year service life.

STEP	COSTS	IMPACTS	
	COSTS [€/m²]	GWP [kg CO_{2eq}/m²]	CED [MJ/m²]
DEMOLITION	116	21	817
CONSTRUCTION	1.090	962	13.087
USE Heating	62	161	2.429
USE Domestic Hot Water	128	331	4.990
USE Gas Kitchen	68	22	2.450
USE Eletricity	347	878	13.526
TOTAL	**1.811**	**2.375**	**37.299**

From the economic point of view, construction costs are higher than the ones of operational phase. The operational phase of the new construction has a lower cost because the primary energy needs are reduced thanks to the higher envelope performances. Operational electric energy consumptions play an important role in GWP and CED impacts. Demolition phase is only responsible of 6% of the total economic costs and of 1% of the environmental impacts; the operational phase is the crucial phase of the building life cycle, as proved by Adalberth et al. [15].
Option B consists in an envelope energy refurbishment aiming at obtaining a reduction of building life cycle consumptions. Some basic activities on envelope have been studied from the economic and the environmental point of view, varying the insulation thickness and the kind of insulation material.

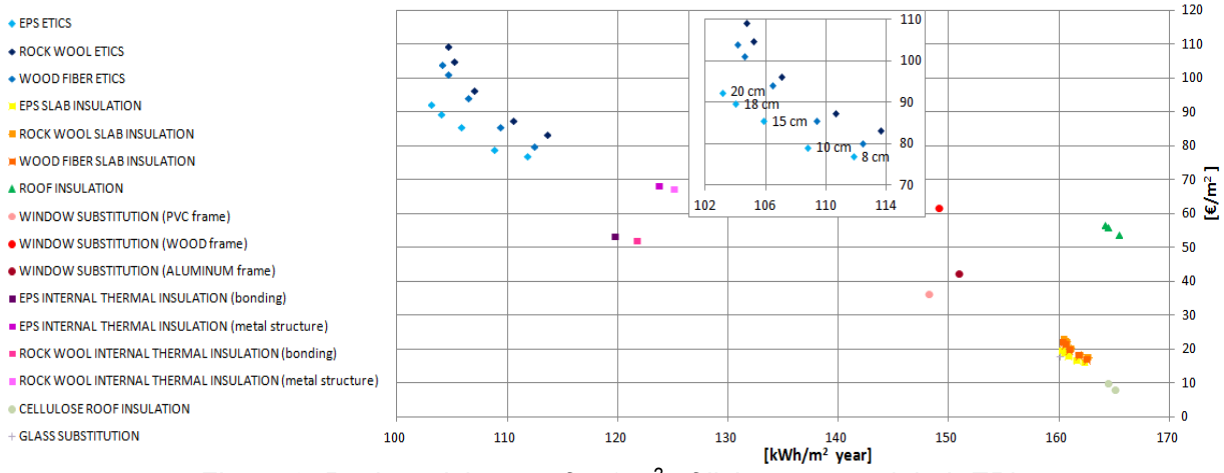


Figure 2: Basic activity cost for 1 m^2 of living area and their EPh.

The basic activities analyzed are:

- External Thermal Insulation Composite System (ETICS), in EPS, or rock wool, or wood fiber, with a thickness of 8 cm, 10 cm, 15 cm, 18 cm and 20 cm;
- Slab insulation, in EPS, or rock wool, or wood fiber, with a thickness of 8 cm, 10 cm, 15 cm, 18 cm and 20 cm;
- Roof insulation, providing the demolition of existing sloped covering and insulating with loose fill cellulose, with a thickness of 15 cm or 20 cm, or with XPS, with a thickness of 10 cm, 16 cm e 18 cm;

- Window substitution, providing a frame in PVC, wood or aluminum and a low-e glass 4-16-4 filled with argon. Glass substitution is also analyzed separately because the existing frame maintain good thermal performances;
- Internal thermal insulation, in EPS or rock wool and plasterboard, varying construction technology (metal structure or bonding).

These basic activities can be applied to other buildings with similar technology. In *Figure 2* primary energy consumptions considering each basic activity are associated to the cost over the life cycle for 1 m^2 of living area in order to identify the optimal energy and economical solution.

The basic activities were combined to find the best set of interventions able to guarantee environmental, economic and energy savings. Moreover, the choice among the basic activities has been done considering those that would have created to inhabitants the less discomfort as possible, so focusing on external interventions. Therefore, internal walls thermal insulation has been avoided.

Furthermore, slab or roof insulation interventions are not able to guarantee an important EPh improvement either varying thickness or material (*Figure 2*). However, in roof insulation a great environmental and economic contribution is given by roof demolition processes that could be otherwise avoided if loose fill cellulosic insulation was used.

From the economic point of view the optimal solution resides in a combination of those basic activities which use the least amount of materials as possible. In addition, aiming at an energy refurbishment, the savings achievable decreasing EPh needs have to be taken into account.

Summing up the construction processes relative to the basic activities and the operational consumption over 50 years is easy to find out the best group of choices that could lead to the optimal economic and environmental refurbishment.

EPh values have been calculated multiplying the energy needs by a coefficient 0.85 to consider the technological plants. Building real energy consumptions have been obtained considering 70% of EPh calculated.

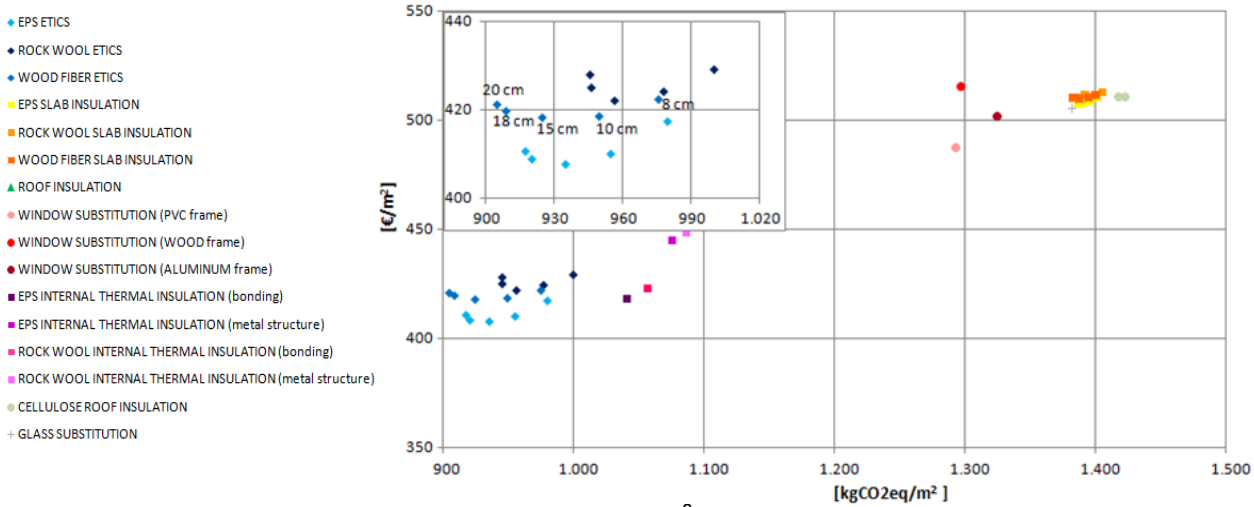


Figure 3: Basic activity cost and their CO_{2eq} for 1 m^2 of living area over a 50-year service life.

In *Figure 3* basic activity cost and their CO_{2eq} for 1 m^2 of living area over a 50-year service life is shown; the same trend is obtained with CED (MJ/m^2), with values ranging from 16'000 to 25'000 MJ/m^2. Heating economic savings with an insulation thickness higher than 15 cm and considering both construction and operational phase are very low. A higher insulation thickness will be an economic loss if compared with the energy savings that could be obtained.

Roof insulation with 20 cm-thick loose fill cellulose the cheapest and the most suitable activity that could be applied. Window substitution involves high costs, but relatively scarce EPh and environmental impacts optimization, even using different materials for the frame.

Anyway, a PVC frame with low-e glasses filled with argon seems to be the most suitable option.
Some combinations of basic activities have been studied in order to find out the mix that is able to guarantee the best economic, energy and environmental performances.
Five combinations have been analyzed and for each of them EPh value of the whole refurbishment has been evaluated *(Table 3)*. These combinations include the activity with the highest, the medium and the lowest performance among the basic activities.
On the basis of the EPh consumptions calculated, the total energy consumptions and environmental impacts over 50-year service life have been assessed. These operational values were added to those of the construction phase.
The basic activities mixes to reach best ratio between performances and costs are summarized in *Table 3.*

Table 3: COSTS, CO_{2eq} *and* CED *of the basic activity combinations over a 50-year service life.*

COMBINATION 1 - EPH 60 kWh/m²-year (EPS ETICS 8cm + CELLULOSE ROOF INSULATION 15 cm + GLASS SUBSTITUTION)	**COSTS [€/m²]**	**GWP [kgCO_{2eq}/m²]**	**CED [MJ/m²]**
CONSTRUCTION	157	24	520
USE	738	1.593	34.017
TOTAL	**895**	**1.617**	**34.537**
COMBINATION 2 - EPH 49,6 kWh/m²-year (EPS ETICS 10 cm + XPS ROOF INSULATION 16 cm + WINDOW SUBSTITUTION PVC)	**COSTS [€/m²]**	**GWP [kgCO_{2eq}/m²]**	**CED [MJ/m²]**
CONSTRUCTION	212	49	1.015
USE	712	1.517	32.697
TOTAL	**924**	**1.566**	**33.702**
COMBINATION 3 - EPH 48,5 kWh/m²-year (EPS ETICS 15 cm + XPS ROOF INSULATION 18 cm + WINDOW SUBSTITUTION PVC)	**COSTS [€/m²]**	**GWP [kgCO_{2eq}/m²]**	**CED [MJ/m²]**
CONSTRUCTION	219	60	1.228
USE	709	1.509	32.546
TOTAL	**928**	**1.569**	**33.774**
COMBINATION 4 - EPH 34,2 kWh/m²-year (EPS ETICS 15 cm + CELLULOSE ROOF INSULATION 20 cm + WINDOW SUBSTITUTION PVC)	**COSTS [€/m²]**	**GWP [kgCO_{2eq}/m²]**	**CED [MJ/m²]**
CONSTRUCTION	188	46	958
USE	672	1.404	30.717
TOTAL	**860**	**1.450**	**31.675**
COMBINATION 5 - EPH 31,6 kWh/m²-year (EPS ETICS 20 cm + ROOF XPS 18 cm + WINDOW SUBSTITUTION PVC)	**COSTS [€/m²]**	**GWP [kgCO_{2eq}/m²]**	**CED [MJ/m²]**
CONSTRUCTION	228	68	1.416
USE	665	1.385	30.385
TOTAL	**893**	**1.453**	**31.801**

The best basic activities mix used in Option B is:

- ETICS in EPS with a thickness of 15 cm;
- Slab insulation in EPS with a thickness of 15 cm;
- Roof insulation with loose fill cellulose with a thickness of 20 cm;
- Window substitution with a frame in PVC and low-e glasses 4-16-4 filled with argon.

Table 4: COSTS, CO_{2eq} and CED of Option B (refurbishment of existing building) over a 50-year service life.

STEP	**COSTS**	**IMPACTS**	
	COSTS [€/m²]	**GWP [kg CO_{2eq}/m²]**	**CED [MJ/m²]**
REFURBISHMENT	188	46	958
USE Heating	89	250	4.374
USE Domestic Hot Water	93	67	7.493
USE Gas Kitchen	68	22	2.450
USE Eletricity	421	1.065	16.400
TOTAL	**860**	**1.450**	**31.675**

Table 4 shows the life cycle costs and impacts of Option B over 50 years after envelope refurbishment. Domestic hot water boilers have been replaced because the existing ones were obsolete. In each apartment a condensing boiler has been installed, neglecting the environmental impacts generated by their construction. In Option B operational phase is predominant on construction both from the economic and environmental point of view.

5. Results

The comparison between Option A (demolition plus new construction) and Option B (refurbishment) has been developed focusing on economic costs, which affect primarily customers requirements, and environmental impacts, evaluating CO_{2eq} emissions and CED. In *Table 5* costs and environmental impacts are shown.

Table 5: Option A and Option B comparison: COSTS, CO_{2eq} *and* CED over a 50-year service life.

OPTION A			
STEP	COSTS	IMPACTS	
	COSTS [€/m²]	GWP [kg CO_{2eq}/m²]	CED [MJ/m²]
DEMOLITION	116	21	817
CONSTRUCTION	1.090	962	13.087
USE	605	1.392	23.395
TOTAL	**1.811**	**2.375**	**37.299**

OPTION B			
STEP	COSTS	IMPACTS	
	COSTS [€/m²]	GWP [kg CO_{2eq}/m²]	CED [MJ/m²]
REFURBISHMENT	188	46	958
USE	672	1.404	30.717
TOTAL	**860**	**1.450**	**31.675**

Demolition plus new construction (Option A) leads to higher life cycle costs than building refurbishment activities (Option B); if only environmental aspects are considered, this gap is significantly reduced: CED values are really similar. Building envelope refurbishment seems to be the cheapest and the most environmentally friendly activity that could be faced on existing building that need recovery. This refurbishment aims at improving energy performances, decreasing operational consumptions, which are the cause of the highest impacts over the entire building life cycle.
The energy refurbishment studied involves exclusively envelope, neglecting comfort and other performances that could be reached with a new construction. Acoustic performances, seismic behavior and internal flat flexibility guaranteed in a new construction give a further comfort value to inhabitants and cannot be compared with the intervention activities applied in Option B. If, besides energy, these other aspects were analyzed in Option B, maybe the results would be sensibly different. However, among others, operational phase with its heating, domestic hot water, gas and electric energy consumptions are always the main responsible of environmental emissions.

6. Conclusions

Existing building recovery could lead to the choice between energy refurbishment and complete demolition followed by new construction with better performances. These aspects, however, do not consider architectural value or restraints of the existing building.
A new construction assures better performances from the point of view of acoustic and seismic behavior, or internal flexibility and variability of flat layout.
In the Brescia case study analyzed, as confirmed by other studies, i.e. Sartori et al. [21], operational phase is the most impacting phase over a building life cycle, either economically and environmentally. The envelope insulation is one of the easier refurbishment activities on existing building that could assure the decrease of energy consumptions. In this case, the performances that could be attained will never be the same as the ones achievable in a new construction, but significant savings can be obtained upon decreasing heating needs in operational phase.

Life cycle phases other than the operational one can contribute as well to reduce economic and environmental impacts. For instance, the materials choice can strongly influence the final outcomes either positively, especially if recyclable or reusable [8], or negatively, is assembled not carefully (for instance, thermal bridges can lead to an enormous increase in energy needs). In Option A it is the new construction that most contributes to the environmental impacts, while demolition is almost negligible (about 1%). Envelope refurbishment only (Option B) is certainly more advantageous than new construction, at least in terms of energy and money saving as well as of CO2eq emissions reduction.
In conclusion, on existing buildings that still save good architectural and structural characteristics, energy refurbishment seems to be the most suitable and cheapest solution, both from an economic and environmental point of view. Anyway, a careful economic and environmental assessment on the existing building stock has always to be done before acting on it, in order to select the most appropriate intervention solution.

7. Acknowledgements

Authors are thankful to General Smontaggi Spa for their support in collecting information about demolition activities.

8. References

[1] Adalberth K., "*Energy use during the life cycle of single-unit dwellings: examples*", Building and Environment, 1997, Volume 32/4.
[2] Citherlet S., Defaux T., "*Energy and environmental comparison of three variants of a family house during its whole life span*", Building and Environment, 2007, Volume 42.
[3] Erlandsson M., Levin P., "*Environmental assessment of rebuilding and possible performance improvements effect on a national scale*", Building and Environment, 2005, Volume 40/11.
[4] Blengini G. A., "*Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy*", Building and Environment, 2009, Volume 44/2.
[5] Fawcett W., Hughes M., Krieg H., Albrecht S., Vennstrom A., "*Flexible strategies for long-term sustainability under uncertainty*", Building Research & Information, 2012, Volume 40/5.
[6] Flourentzou F., Brandt E., Wentzel C., "*MEDIC: A method for predicting residual service life and refurbishment investment budgets*", Energy and Buildings, 2000, Volume 31.
[7] ENEA, "*Risparmio energetico nella casa*", in Sviluppo sostenibile, settembre 2009.
[8] Blengini G. A., Di Carlo T., *"The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings, Energy and Buildings 42",* 2009.
[9] Thomsen A., Van der Flier, K. *"Updating the housing stock; the need for renovation-based approaches"*, in Proceedings of the International Research Conference on Housing Cultures, Convergence and Diversity, ENHR & Europaforum Wien, 2002.
[10] Schultmann F., Sunke N., *"Energy-oriented deconstruction and recovery planning"*, Building Research & Information, 2007.
[11] Itard L., Klunder G., *"Comparing environmental impacts of renovated housing stock with new construction*", Delft University of Technology, OTB Research Institute.
[12] UNI EN 15978, *"Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method"*, 2011.
[13] Nicholson A.L. et al. *"End-of-life LCA allocation methods: Open loop recycling impacts on robustness of material selection decisions"*, Sustainable Systems and Technology, 2009.
[14] Blengini G. A., *"Life cycle of buildings, demolition and recycling potential: a case study in Turin-Italy"*, Building and Environment 44, 2009.
[15] Adalberth K., Almgren A., Petersen E. H., *"Life Cycle Assessment of four multi-family buildings"*, International Journal of Low Energy and Sustainable Buildings, 2001.
[16] Ortiz O., Castells F., Sonnemann G., *"Sustainibility in the construction industry a review of recent development based on LCA"*, Construction and Building Materials 23, 2009.

[17] ISO 14067, *"Carbon Footprint of Products"*, 2012.
[18] PAS 2050:2011, *"Specification for the assessment of the life cycle greenhouse gas emissions of goods and services".*
[19] "*Prezzi informativi dell'edilizia. Recupero, ristrutturazione, manutenzione*", DEI, tipografia del Genio Civile, 2011.
[20] Tonini G., Caponio R., *"Strumento di calcolo sviluppato nell'ambito del progetto TREAM"*, ENEA Bologna in collaborazione con l'Ufficio Energia del Comune di Bologna, Settore Ambiente e Verde Urbano, 2009-2010.
[21] Sartori I, Hestnes AG., *"Energy use in the life cycle of conventional and low-energy buildings: a review article",* Energy and Buildings, 2007.
[22] Regione Lombardia, *"Regolamento per l'istallazione di valvole termostatiche obbligatorie",* in force from 1st August 2014.
[23] ISO 15686, "*Buildings and constructed assets. Service life planning*", 2000.
[24] De Angelis E., Dotelli G., la Torre A., Pansa G., Pittau F., Porcino C., Villa N., "*LCA ed LCC di un intervento di demolizione totale*", Atti del VII Convegno della Rete Italiana LCA, 27 - 28 giugno 2013, Politecnico di Milano, Milano, in press, 2013.

Nearly Zero Energy Renovation of houses: Life cycle costs and environmental impact



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Short Summary

This paper describes the results and conclusions from an LCC and LCA analysis performed on a case study. An actual deep energetic renovation example in Torhout, Belgium was studied on its cost efficiency and environmental impact, comparing it to different other renovation scenarios: standard renovation – in which measures were applied to obtain an energy consumption level similar to the minimal energy requirement (EPB) for new houses and NZE or Nearly Zero Energy renovation, where the as built (or as renovated) situation was used as starting point and additional renewable energy systems were installed to strive to zero energy consumption. This allows on the one hand to verify which scenario is the most interesting in terms of costs and environmental impact, and on the other hand to gain insight in the feasibility of obtaining a NZE level in renovation of houses.

Keywords: Deep Renovation; NZE; Life cycle assessment (LCA); Life cycle costing (LCC)

1. Introduction

In the renovation of single houses the ambitions on energy savings grow, as in the whole building market. The ERACOBUILD One Stop Shop project [1] was aimed to create a larger market for deep renovation of houses and investigated ways to motivate clients to do an integral holistic retrofit. In general, the motivation and reasons for renovating a house are related to comfort improvement, quality of living and the necessity of certain replacements and improvements, and is less about energy savings and cost benefits [2]. Nevertheless, the budget and long term perspectives (return on investment) are important parameters in the decision process in many projects. In a broader frame, also environmental issues gain importance.

Within One Stop Shop several existing ambitious renovation projects ('low energy' or 'passive house') were analyzed on their cost efficiency and environmental impact. The main question was 'how far to go in the energetic renovation in order to be beneficial?'. Next to the costs and environmental loads of the 'as built' project over 30 and 60 years, the costs and impacts of other renovation scenarios with different ambition levels were compared: On the low end, a 'Standard Renovation' is considered, defined as an integral retrofit, but with limited efforts (measures to save energy, comparable to current new building standards in Flanders, Belgium). On the high end, the feasibility to obtain a Nearly Zero Energy (NZE) building by applying additional measures to the *as built* situation is investigated.
In this research, the NZE-level was defined based on the considerations from a BPIE report [3], with (1) a very low primary energy consumption in kWh/m²a on a yearly basis including heating, cooling, ventilation, lighting and aid energy, using nationally defined conversion factors, and (2) renewable energy production on-site, nearby and off-site, where 50-90% of the energy demand is

covered by renewable energy. This definition was translated in practice by 'getting as near to zero energy consumption as possible within the project's site boundary' for the projects under study.

2. Case study

2.1 As built (post renovation) situation



Fig. 1: Retrofit of 2 row houses from the 1970s. Before (left) and after (right) © Benergie.be – Architect L. Dedeyne

Architect Luc Dedeyne renovated and transformed two neighbouring houses, dating from the early 1970s, into a single family house with private practice. As *Fig. 1* shows, one of the goals of the architect was to achieve an 'architectural' façade with all elements (doors, windows, façade finishing) within the same vertical plane. The most important measures in the actual renovation are:

- Replacement of the floor slab on the ground floor and installation 15 cm EPS insulation;
- Replacement of the roof and installation of 32 cm additional mineral wool;
- Renovation of the street façade by demolishing the external part of the cavity wall and installing 24cm of cellular glass with a ceramic materials as finishing layer;
- Replacement of old windows by triple glazed aluminium windows;
- Addition of Vacuum Insulation Panels (VIP) to the aluminium doors and garage door;
- Installation of a large (25m²) solar boiler, floor heating, heat pump and PV-installation (3.4 kWp).

2.2 Considered alternative scenarios

The as built 'Low Energy' renovation with a Heat Pump (coded **LE-HP**) as energy source for heating & hot water is compared to several alternative scenarios:

- A case where the same measures for the envelope were taken, but a condensing boiler on natural gas is used for heating & hot water (**LE-CB**)
- Based on the LE-HP scenario, additional PV panels and a larger solar boiler are added, in order to obtain the **NZE-HP** alternative – this is the most ambitious scenario, striving for Nearly Zero Energy consumption.
- A Standard Renovation scenario is defined, based on minimalistic insulation measures and a condensing boiler (on natural gas) system, coded **SR-CB**. Attention was paid that the same degree and type of façade finishing are kept, in order to be able to compare the costs for the different scenarios.

A summary of the measures in each scenario are given in *Table 1*.

	SR-CB	LE-CB	LE-HP	NZE-HP
Roof	20 cm mineral wool between existing battens	2x16 cm mineral wool on top of existing roof structure (16 cm MW)		
Walls	External insulation: 12 cm cellular glass & glued ceramic tiles	Demolition of external cavity wall, 2x12 cm cellular glass & glued ceramic tiles		
Floor	6 cm sprayed PU foam	15 cm EPS		
Doors & gates	Alu with PU-core	Alu with VIP-core		
Windows	Alu with 1.1 glass	Alu with triple glazing		
Thermal bridges	Not remediated	All solved		
Heating & hot water production	Condensing boiler on natural gas + radiators & floor heating		Heat pump (water/air) + radiators (LT) & underfloor heating	
Solar boiler	/	5 m²	5 m²	25 m²
PV panels	0.9 kWp	0.9 kWp	0.9 kWp	3.4 kWp
Ventilation	Natural ventilation	Mechanical ventilation + heat recovery (system D)		
Air tightn. (v50)	7	2		

3. Cost efficiency

3.1 Methodological approach

The cost efficiency evaluation of the different renovation scenarios considers the relevant life cycle costs over a period of 30 years. The investment costs are based on the real costs documented by the architect and include 6% VAT. Cost data for alternative solutions was obtained from similar projects and reference books, and include all relevant works to the envelope and the technical systems.
The Flemish EPB-software was used to determine a typical energy consumption. This software gives a characteristic value of the primary energy consumption for heating, cooling, hot water production and aid energy. The effects of air tightness and thermal bridges are taken into account. No cooling energy was considered, given that no real overheating risk was present. The same energy consumption data is used for the cost as for the environmental analysis.
For the economic analysis, a cost of 0.2 €/kWh for electricity and 0.08 €/kWh for natural are assumed. A yearly increase of prices of 2.25% is considered.
Maintenance & replacement costs are included, mainly for the technical systems, since these require the most annual maintenance and have a service life shorter than 30 years, and thus will need to be replaced.
The influence of financial incentives is taken into account, but in a way that allows the analysis to be done with or without the influence of subsidies. The subsidy mechanisms available in Flanders on April 1st 2012 are taken into consideration.

3.2 Investment cost

Fig. 2 shows the investment cost for the considered alternatives. The cost for the walls is very significant, because of the special solution chosen (cellular glass & glued ceramic tiles) and the bad condition of the bearing wall when the outer façade wall was demolished, which needed considerable reparation and preparation works.

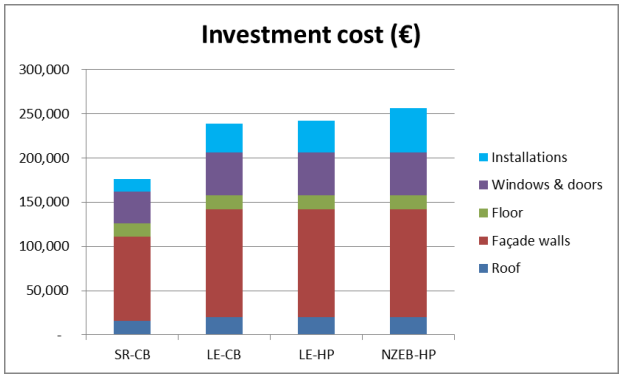


Fig. 2: Investment cost of different renovation scenarios investigated (SR=Standard Renovation, LE= Low Energy Renovation, NZEB = Nearly Zero Energy Building Renovation, CB = Condensing Boiler on Gas, HP = Heat Pump)

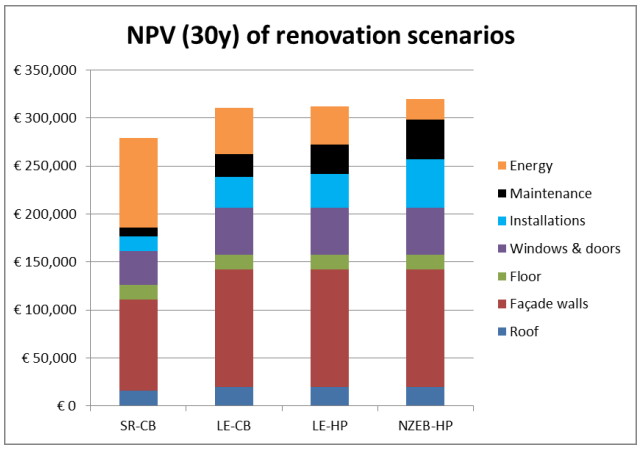


Fig. 3: Life cycle costs over 30 years of different renovation scenarios – without incorporation of subsidies

3.3 Life cycle costs

The energy and maintenance costs are discounted to Net Present Value using a real discount rate of 1.96%. If financial incentives and subsidies are not taken into account, the SR-scenario, which consists of insulating the considered case study house to the required minimal insulation level of new houses shows to be the most interesting in terms of Net Present Value over 30 years.
Fig. 3 clearly shows that the investment costs of the walls are very high, higher than the NPV of the energy consumption accumulated over 30 years. The combined cost of insulating the walls, triple glazing and adding more installation technology is not compensated by the lower energy use.

When taking subsidies anno 2012 into account, the SR-scenario remains the most interesting. The other three scenarios, that have the same envelope, are in the same range of NPV over 30 years. The additional energy savings & the (large) subsidies for PV panels to achieve a “NZE” level do weigh up against the higher maintenance and replacement costs of the larger system, and the NZE-alternative becomes competitive with the LE-scenarios.

4. Environmental impact

4.1 Methodological approach

The environmental impact of the different renovation approaches is analyzed using life cycle analysis (LCA). This technique considers the input (resources, energy) and output (emissions, waste) of the renovation process over its life cycle to quantify its contribution to several environmental issues, such as global warming, the depletion of the ozone layer, or particulate matter. This study makes use of the Ecoinvent life cycle inventory database (version 2.0) [4] and defines the environmental impact using the ReCiPe Mid/Endpoint method (version 1.06) [5]. This method allows to quantify various environmental indicators (each with their proper unit) as well as to determine a global environmental score (expressed in points - Pts) after a process of normalization, grouping and weighting (for this analysis ReCiPe Endpoint (H) / Europe ReCiPe H/A)[6].

The life cycle of the building renovation is set to 60 years for the analysis. Building elements with a shorter life span (like windows and installations) are considered to be replaced during this period. Whereas several interior materials (eg. wall finishes, bathroom or kitchen) are renovated in the *as built* renovation project, these are not considered in the environmental analysis. *Table 1* provides an overview of the different materials and installations included in the study. In addition, the energy

consumption required for heating, ventilation and aid energy during the building's life cycle is considered in the environmental analysis and estimated as described for the cost analysis.

4.2 Impact of materials & installations

The aggregated scores show that the environmental impact of the materials (initially used) for the envelope is 28% higher for the LE (& NZE, since the same materials are used for the envelope) scenario compared to the SR scenario. The largest environmental impact originates, for all scenarios, from the materials used for the floor (*Fig. 4*). The environmental impact of the floor is slightly higher for the SR where sprayed PU foam is considered, than for the LE scenario which applies EPS panels. The large impact of the floor results from both the concrete floor slab and the ceramic tiling used as finishing material.
The global environmental impact of the installations also increases for scenarios with increasing energy performance. This is largely because of the larger number of photovoltaic panels in the NZE scenario. Windows are replaced once in 60 years, the installations are replaced every 15 or 20 years. The NZE-scenario has the highest environmental impact in terms of replacements, because of the large amount of installations (*Fig. 4*).

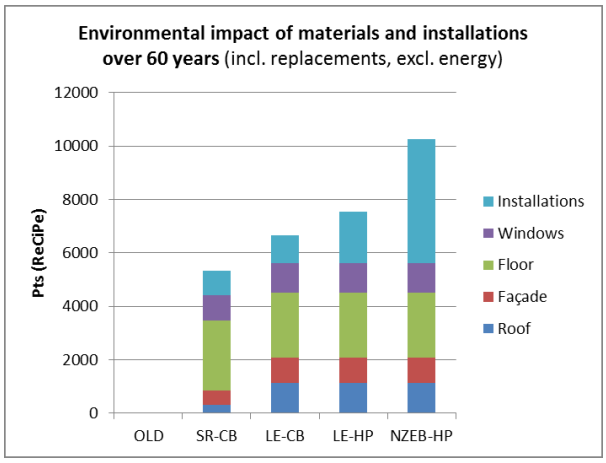


Fig. 4: Environmental impact of the materials and installations over the total life cycle of the building (60 years) for different renovation scenarios. Method: ReCiPe Endpoint (H) V1.06 / Europe ReCiPe H/A / Single score

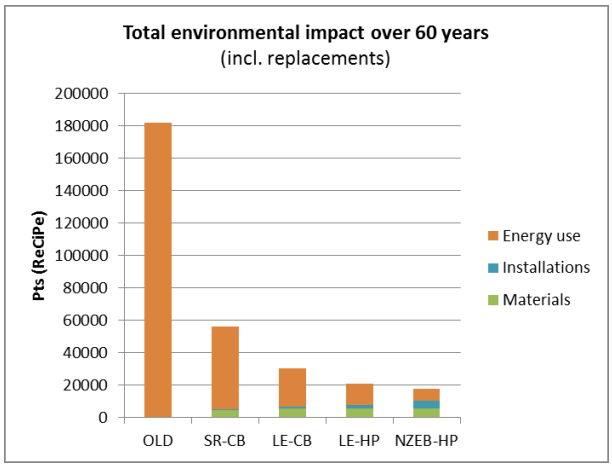


Fig. 5: Total environmental impact of different renovation scenarios over their life cycle. Remark: Different scale than Fig. 4! Method: ReCiPe Endpoint (H) V1.06 / Europe ReCiPe H/A / Single score

4.3 Impact of energy & total impact

The scenarios defined with better energy performances will use less energy for heating, ventilation and hot water. Next to the differences in amounts of energy used per year, also the energy carriers vary between the scenarios. The environmental impact related to the energy use diminishes for scenarios with increasing energy performance: from SR to NZE: -86%. A comparison between LE-CB and LE-HP (where the heating demand is the same) shows the environmental impact is smaller when using a heat pump for heating compared to a condensing gas boiler.

Adding the environmental impacts of materials, replacements and energy use over 60 years together, provides further insights in the total environmental impact of the different renovation measures. The impact related to the energy use clearly determines the total impact (*Fig. 5*). As a result, the environmental impact of the renovation measures decreases for renovations with increasing levels of energy performance (from SR to NZE: -68%).

For illustration, the impact 'over time' of the different scenarios is given in the figure below. It shows that the added materials to achieve lower energy consumption have a small 'environmental pay-back time'.

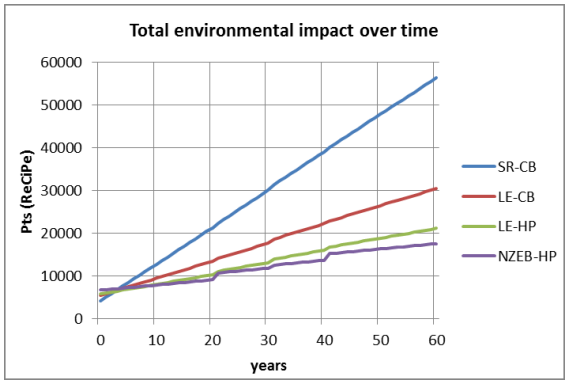


Fig. 6: The environmental 'impact over time' for the different scenarios

5. Discussion of results

5.1 Other case studies

Within the One Stop Shop project, another Flemish renovation case was studied using a similar approach: a renovation of row houses from the 1970s to passive house standard in Wachtebeke, see [7] & [8] for detailed information. The results of this case study lead to similar findings for both the cost and environmental analysis, which enforces the general trend from other research [9][10]. In the Wachtebeke case, the 'Standard Renovation' scenario (SR & K40 - with an insulation level similar to new construction anno 2012) is the most cost efficient over a period of 30 years. In both cases, some insulation was present in the 'old situation', which makes investing in extra insulation measures less efficient. Financial incentives, such as grants for investment and green power certificates for renewable energy, tend to flatten the differences between the more ambitious scenarios and the standard renovation.

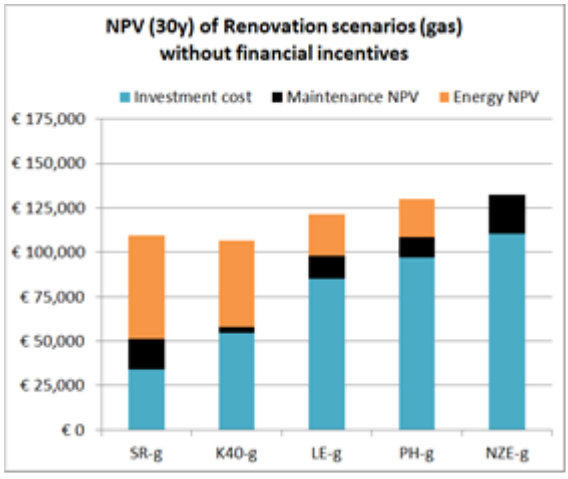


Fig. 7: Life cycle cost of renovation scenarios for Wachtebeke case(all on natural gas) without financial incentives – SR=Standard Renovation – only necessary measures, K40 = renovation to new build minimal standards, LE = low energy, PH = as built Passive House, NZE = Nearly Zero Energy [8]

In terms of total environmental impact, the Wachtebeke case also illustrates that the scenarios with the highest levels of energy performance have the smallest environmental impact over the renovation's life cycle. The global environmental impact of materials and installations increases when going from SR to LE to NZE, but the impact related to the energy use diminishes spectacularly and determines the overall results.
The individual results and more detailed information of both cases can be found in the report that is available on the project website [7].

5.2 Feasibility of NZE level

The results presented in the previous paragraphs show that in the 'NZE' scenario for the Torhout case, where the whole roof surface is used for PV (3.4 kWp) and solar boiler panels (25 m²), it is not feasible to reduce the average annual energy consumption to zero. This is due to the relatively large surfaces of windows and garage doors, with a much higher thermal conductivity than the opaque façade parts. This makes it very hard to reduce energy demand for heating very significantly.
In the Wachtebeke case however, the NZE-level is achievable: covering the roof with PV panels leads to a yearly energy consumption cost of 44 €.

6. Conclusions

In terms of cost efficiency, striving for a very low energy consumption is not cost efficient, due to the high initial investment. Also the elevated maintenance and replacement cost for more sophisticated installations gives the advantage to less complex and less ambitious solutions.
Starting from the as built situation, achieving NZE level is possible using renewable energy techniques, on the condition that the energy demand can be reduced substantially and thus that wall openings are limited – which becomes clear from the comparison between Wachtebeke & Torhout.

In terms of environmental performance, higher levels of energy performance lead to lower environmental impacts. Whereas bringing more materials and installations to a renovation project inevitably leads to higher environmental impacts, this is easily compensated by the reduction of the energy use. The energy use dominates the environmental impact for standard and low energy renovations. The impact of the materials and installations gains importance when striving for the passive house or NZE level. This is related to the strong decrease in energy use, but also to the increase in amount of materials and installations needed to achieve these levels. From this point of view it would be interesting to investigate the environmental impact of different material applications for reaching NZE-level.

It can be concluded that there is still a trade-off to make between cost efficiency and the best option for the environment, within the chosen boundary conditions.

7. Acknowledgements

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8. References

[1] One Stop Shop website, Available: www.one-stop-shop.org. Consulted: [01 July 2012].
[2] MLECNIK, E. et al, *Low Energy Housing Retrofit (LEHR) Final Report*, Belgian Science Policy (Belspo), Brussels, 2010
[3] BPIE – Building Performance Institute Europe, *Principles for nearly Zero-energy Buildings*, 2011
[4] Ecoinvent data v2.0, Swiss Centre for Life Cycle Inventories, www.ecoinvent.org
[5] ReCiPe methodology for Life Cycle Impact Assessment, www.lcia.recipe.net
[6] GOEDKOOP, M. et al., *ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and endpoint level, Methodology report, First edition (revised)*, July 2012, Ministerie van VROM. Den Haag.

[7] VRIJDERS, J., et al., *One Stop Shop WP2 report*, 2012, http://www.one-stop-shop.org.
[8] VRIJDERS, J. et al., *Costs, benefits & environmental impact of achieving NZE-level in renovation: A case study*, PassiveHouse 2012 proceedings, Brussels, 2012.
[9] RISHOLT, B. et al., *Zero Energy Renovation Strategies for a Single Family House in a Life Cycle Cost Perspective*, Technoport 2012
[10] DELEM, L., et al., *Milieu-impact en kostenanalyse van een renovatie tot passiefhuisstandaard*, Passiefhuissymposium 2009.

Retrofitting solid wall buildings: carbon costs and savings



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Short Summary

Regulations and technological advances over the last decade have led to improved energy efficiency for new buildings. However much of the existing European building stock has poorly insulated fabric leading to low energy efficiency and high carbon emissions. In the UK we have a particular problem with homes built prior to 1930 with un-insulated solid walls. This paper briefly reviews the multiple barriers to retrofitting solid wall insulation in the UK. It then quantifies the whole life (operational and embodied) carbon of a solid-walled dwelling, first in its original state and then retrofitted with one of four solid wall insulation products. The results show that all of the products modelled repay their cradle to grave embodied energy and carbon costs within 13 months of installation through the operational savings achieved. The authors conclude that retrofitting with solid wall insulation can result in considerable whole life carbon reductions. While the barriers remain considerable, greater understanding of the issues will help contractors, home owners and developers to make informed design choices.

Keywords: retrofit, whole life energy and carbon, life cycle assessment, solid wall insulation

1. Introduction

According to the International Energy Agency [1], buildings account for close to 40% of the energy used in most countries, with space heating still the main factor. The IPCC have suggested that buildings have the highest potential for cost-effective reduction of energy among all sectors and in all countries [3]. Reducing heating demand through energy efficiency measures could reduce energy use in the domestic sector alone by 50% or more [1].

Regulation and technological advances over the last decade have led to increasing improvements in the energy efficiency of new buildings, with net zero energy due to become the norm in the UK by 2019. However much of the existing European building stock which will still be standing in 2050 has poorly insulated fabric leading to low energy efficiency and high carbon emissions. In the UK we have a particular problem with homes built prior to 1930 with un-insulated solid walls; 31% of existing dwellings fall into this category [2] and these are responsible for over 30Mt CO_2 emissions per year. The option of demolishing and rebuilding these homes with more energy efficient designs would not only lose our cultural and social heritage, it would also have a high embodied carbon cost.

The Climate Change Act of 2008 committed the UK to reducing carbon emissions by 80% by 2050. A number of policy instruments have been developed to achieve this target, including increasingly stringent Building Regulations for new buildings. In 2013 a financial instrument, the Green Deal, was launched to encourage the retrofit of existing homes. This is expected to increase the up-take of solid wall insulation in particular with the result of reducing carbon emissions, as well as energy use, from existing dwellings. However the process and materials involved in retrofit also have a carbon impact which needs to be included in any calculation of savings. The Government Low Carbon Innovation and Growth Report of 2010 recommended that embodied carbon should be assessed at the feasibility stage of construction projects to inform design decisions [4], and this also, necessarily, applies to retrofit projects.

The multiple reasons for the current slow uptake of external insulation installation are discussed in the following section. The paper then describes a theoretical model simulating the performance of a solid wall house with four options, each with a different insulation product as part of the building's wall construction. For each option, the operational energy and carbon saved during the building's lifetime is compared with the embodied energy and carbon of the product.

2. Barriers to solid wall insulation

Energy efficient technologies can be attractive investment opportunities, not only at governmental and industrial levels but also at household level; they can be net present value (NPV) positive, they have low time payback period, and are most likely to remain competitive in the future (Reddy 1990). Cavity wall insulation and loft insulation programmes have been encouraged by the UK Government for many years, with widespread uptake in both social and privately-owned housing. Solid wall insulation systems have also existed for many years – however, these systems have had very poor uptake, for a number of reasons.

Many of these reasons are technological. One important issue for traditional buildings is that they are "breathing" structures, made of permeable materials and without the vapour barriers and membranes which are standard in modern construction. This permeable fabric tends to absorb more moisture, which is then released by internal and external evaporation. Inappropriate application of impermeable solid wall insulation products can lead in some cases to problems with damp ingress [5]. Other technical challenges can be problems with thermal bridging and the creation of cold spots [6].

Further barriers arise from social and cultural considerations. External insulation systems can change the appearance of the building, while internal systems reduce room sizes. Both are disruptive to the daily activities of the occupants. Economic concerns are also considerable, with not only the cost of installing the insulation and applying finishes and redecoration, but often considerable further building work, such as extending window sills and eaves, needed as a secondary effect of adding the insulation.

In addition, in the UK there is little previous experience of this type of work, either by builders or by home-owners. In a traditionally risk-averse industry this is a considerable barrier to implementation.

These barriers are summarised in Table 1 below.

Table 1: Barriers to growth of solid wall insulation sector

Classification	Barriers to implementation of solid wall insulation
Technological	i. Embodied energy and carbon emission savings in contrast with U-value.

	ii. U-value varies significantly between each type of insulation. The thickness of insulation plays a role in decision making iii. Technical challenges including thermal bridging, the creation of cold spots and potential damp inducement.
Economic/ Financial	i. The need for grants and other financial support as the cost of solid wall insulation can be a market inhibitor. ii. There is a lack of consistency and clarity on the direct and indirect costs of solid wall measures and payback times
Socio-cultural/ Behavioural	i. Change of appearance of the dwellings, especially when implementing external solid wall insulation ii. The reduction in the total area of the living space when using internal wall insulation, as well as the need for redecoration. iii. Both internal and external solid wall insulation disrupt the activities in the household.
Information/ Awareness	i. There is a lack of robust, detailed data on the size of the domestic solid wall insulation market in terms of value, number of installations, trends and forecasts. ii. A low public awareness especially on the options availability and the benefits each option introduces.

3. Whole life energy and carbon for five scenarios

The Energy Saving Trust states that 'where products are very similar in terms of operational performance, then embodied energy aspects should also be taken into consideration' ([6] p.32). The authors have calculated the whole life energy and carbon of a typical solid wall masonry UK domestic building, first in its original state and then retrofitted with one of four solid wall insulation products, in order to assess the carbon payback times for each product.

The tool used to model the building is a whole life cost, energy and carbon tool called 'Butterfly' [7], developed as part of an industrial-academic research consortium led by BLP Insurance and including the Centre for Sustainable Development (CfSD) at the University of Cambridge, the Energy Institute at UCL and UK major contractor, Wilmott Dixon.

The embodied energy (EE) and embodied carbon (EC) are calculated over the whole life of the building ('cradle to grave'), following the methodology and boundary conditions set out in the recently published CEN TC 350 standards on Sustainability of Construction Works [8-10]. Figure 3 illustrates the modules of the Life Cycle Analysis framework as set out in these standards; those which are outlined in blue/bold form the embodied impacts. Only module B1, Use, incorporating B5 and B6, are currently the focus of regulation in the UK.

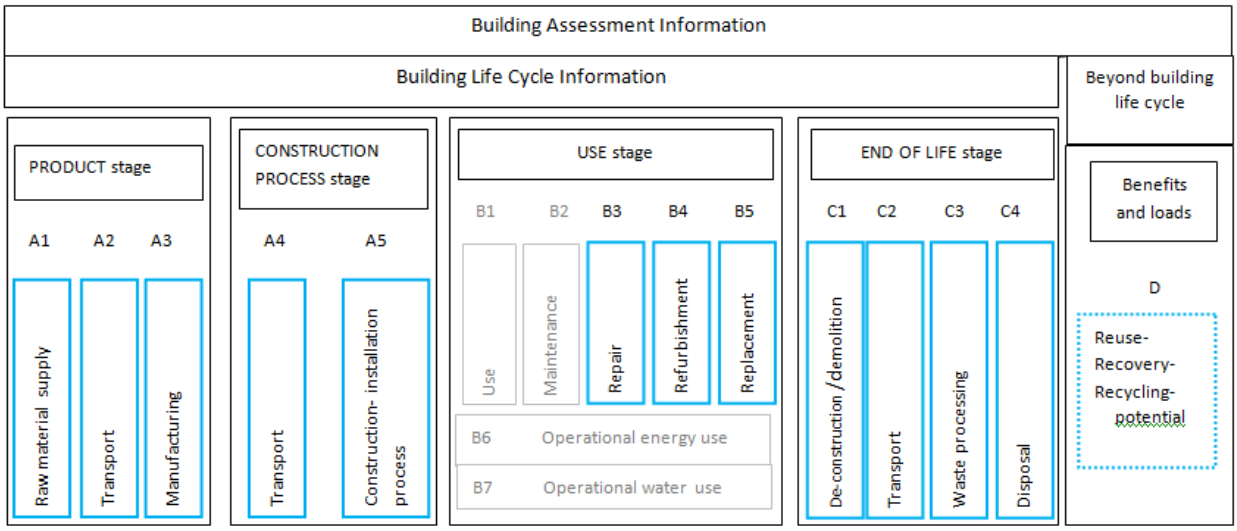


Fig. 1: Life cycle stages from BS EN 15978:2011 Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method [8]

The model considers the building broken down into assemblies (external wall, for example), each with their constituent components (plasterboard lining, for example) and the quantities of these are calculated using assumptions of typical construction methods and systems. These can be overruled by the user when actual figures are known. The embodied energy and carbon of each component is calculated for modules A-C and aggregated to give the total 'cradle to grave' embodied energy and carbon for the building. The construction phase is an exception to this method, since the energy and carbon is not easily attributed to each individual component, and so benchmarking data from construction projects has been used [11].

The operational energy and carbon is calculated using a SAP model, which considers the U values of the building fabric, heating systems and other energy use parameters of the building.

The baseline building used in this experiment is a traditional solid wall masonry semi-detached 2 storey house of 76m^2 internal area. The model was run for five different external wall insulation conditions, the first base case with no insulation and the other four cases retrofitted with different products, including two which are used externally and two internally, with one mineral and one oil-derived product in each category. These are labelled options 1-4 and each is described in more detail below [12].

Option 1: ThermoShell rock mineral wool (External use)

> This product incorporates a rock mineral wool slab with thermal conductivity of 0.038W/mK, containing a water repellent additive to ensure that no water is able to pass through the slab and reach the substrate during installation and construction. However mineral renders and rock mineral wool insulation are breathable, allowing moisture to permeate through the system in use.

Option 2: OPTIMA system with ISOVER glass wool product (Internal use)

> The OPTIMA System consists of a metal frame, ISOVER glass wool insulation with a thermal conductivity of 0.035W/mK, a vapour retarder and air tightness layer. To avoid condensation damage in the structure, the vapour retarder and air tightness layer are installed on the inner facing surface of the insulation layer (i.e. the warm side).

Option 3: ThermoShell EPS Board (External use)

ThermoShell EPS Board is a graphite impregnated expanded polystyrene bead board with a thermal conductivity of 0.032W/mK. The boards can be either adhered and mechanically fixed or just mechanically fixed to the substrate and then overlaid with a mesh and a render system.

Option 4: Speedline Thermal Laminate Plasterboard (Internal use)

This is a composite product of 12.5mm tapered edge gypsum plasterboard factory bonded to polyisocyanurate foam (PIR) insulant with a thermal conductivity of 0.022W/mK. The PIR foam is faced on both sides by a multi-layer kraft paper and aluminium foil to create a vapour resistant product which can be either adhered or mechanically fixed to the wall.

The wall build-up modelled for each of the 4 options includes an external cement render layer and an internal plasterboard layer, and all options have a total thickness of 350mm; the difference between the options is therefore only in their thermal performance. Each of the four solid wall insulation options produce a u-value similar to that of a standard insulated cavity wall as shown in Table 2. The full external wall assembly is modelled in the programme under the ID code for each option, with only the external walls changed.

The additional embodied energy and carbon 'cost' of the solid wall insulation was then measured against the operational energy and carbon 'saving' due to the decreased u-values of the building envelope. In each case the carbon payback time was calculated, defined as the length of time from when the building starts operating to the point at which the operational carbon savings surpass the additional embodied energy and carbon.

Table 2: Comparison of external wall options

ID code	U-value (W/m^2K)	Description	Operational carbon (regulated) (tCO_2e/yr)	Total embodied carbon (tCO_2e)	Relative embodied carbon (tCO_2e)	Payback (mths)
2355	2.09	Solid wall, no insulation	3.93	33.23	-	-
2356	0.29	Option 1	2.36	34.41	1.18	9.0
2357	0.28	Option 2	2.35	34.65	1.42	10.8
2358	0.26	Option 3	2.33	34.56	1.33	10.0
300	0.20	Option 4	2.27	35.07	1.84	13.3
200	0.25	Cavity brick and block with 100mm cavity fill mineral wool insulation	2.32	32.31	-0.92	-

The percentage contribution of each life cycle stage to the total embodied carbon of a whole new-build dwelling is given in Table 3 below (from [11]). For the solid wall insulation products, stages B2-5, which include the replacement of components, will be zero for a retrofit design life extension of 60 years, since correctly installed this is also the design life of the insulation systems.

Table 3: Percentage contribution of each life cycle stage to the whole building embodied impacts

TC350 stage	Embodied carbon (%)	Embodied energy (%)

A1-3 Product	50	54
A4 Transport	9	10
A5 Construction	3	5
B3-5 Refurb and replace	17	26
C1-4 End of life	21	5
Total A-C	100	100

4. Discussion and conclusions

As can be seen from the results of the modelling in table 2, all four insulation products have very low payback periods, and are very similar to each other. In particular it is clear that the embodied carbon of external wall insulation is low compared to the operational carbon saved over its lifetime. This is an important finding for both designers and policy advisors interested in influencing retrofit of domestic buildings. While the addition of other energy technologies may appear more exciting and innovative, it is important to assess all options not just on the potential carbon saved but also on the initial carbon cost [13].

It is also important to consider, as the authors have here, the full life cycle impacts of a retrofit product. Here again solid wall insulation is a sensible choice for carbon reduction, since not only does it have relatively low initial embodied carbon, where correctly installed it is expected to last for at least 60 years, the standard extended design life of the building in which it is installed. This means that the repeat carbon costs of reinstallation over the life of the building are not an issue, unlike products which have a shorter design life such as most services components.

However, as discussed in section 2, a number of barriers still exist to the installation of these systems in the UK. The extra cost of installing external systems due to the additional work required, and the loss of space from installing internal systems in already small houses, are both considerable concerns. The lack of expertise and knowledge for both installers and home-owners is important, as are the valid fears of incorrect installation leading to damp problems. The Green Deal should go some way towards alleviating the economic barriers, leading to an increase in uptake and subsequently a greater experience of and confidence in the technology. As demand increases, the focus on manufacturers and specifiers will be to produce thinner systems, without huge increase in embodied carbon.

This paper concludes that the embodied carbon impact of retrofitting solid wall insulation to existing UK homes is very low compared with the carbon saved during the building's lifetime. The carbon payback time is calculated at around one year for each option, with only small variations between the four products studied. Even with the acknowledged variation between actual energy saved compared with that as modelled here by the Standard Assessment Procedure (SAP), the payback is likely to be very much shorter than the lifetime of the product. It is therefore clear that the take up of this insulation should be encouraged for the 31% of UK homes which currently have solid walls, in order to reduce whole life carbon emissions from the building stock. Since the embodied carbon of the four typical products chosen were similar, the choice of product used is likely to be dependent on other issues, such as whether the disruption and loss of space for internal insulation, or the expense and changes to dwelling appearance for external systems, are more acceptable.

This paper concludes that there are undeniable technical arguments for applying solid wall insulation. While the barriers remain considerable, the increase in uptake which is likely to result from

the Green Deal will lead to greater understanding of the issues, which in turn will help contractors, home owners and developers to make informed design choices.

5. Acknowledgements

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6. References

1. International Energy Agency, *Energy Technology Perspectives: Scenarios & Strategies to 2050*, 2006.
2. DEFRA, B.a.E.S.T., *BRE HOUSING Energy Analysis Focus Report: A study of Hard to Treat Homes using the English House Condition Survey - Part I: Dwelling and Household characteristics of Hard to Treat Homes.* , 2008.
3. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The physical science basis*, 2007.
4. HM Government, *Low Carbon Construction Innovation & Growth Team Final Report*, 2010.
5. English Heritage, *Insulating Solid Walls*, 2012: London, UK.
6. Energy Saving Trust, *CE 87 Energy-efficient refurbishment of existing housing (2007 edition)*, 2007, Energy Saving Trust: London.
7. BLP Insurance. *Butterfly*. Available from: http://www.blpinsurance.com/added-services/butterfly/.
8. British Standards Institution, *BS EN 15978 Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method*, 2011, British Standards Institution: London.
9. British Standards Institution, *BS EN 15643 Sustainability of construction works — Assessment of buildings* in *Part 2: Framework for the assessment of environmental performance*2011, British Standards Institution: London.
10. British Standards Institution, *BS EN 15804 Sustainability of construction works.* , in *Environmental product declarations. Core rules for the product category of construction products*2012, British Standards Institution: London.
11. Moncaster, A.M. and K.E. Symons, *A method and tool for 'cradle to grave' embodied energy and carbon impacts of UK buildings in compliance with the new TC350 standards.* Energy and Buildings, (under review).
12. Soulti, E., et al., *Evaluation of Energy Efficient Technologies: Embodied Energy and Carbon Study of Four Insulation Products*, 2013, Centre for Sustainable Development: Cambridge.
13. Sahagun, D. and A.M. Moncaster. *How much do we spend to save? Calculating the embodied carbon costs of retrofit*. in *Retrofit 2012*. 2012. University of Salford, UK

A3

Life cycle perspectives in a high quality refurbishment - Part 2

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Life Cycle in Timber Facade Systems – Robust Design Patterns

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Short Summary

Scope of the paper is the environmental system declaration and improvement of environmental properties of the prefabricated TES EnergyFacade retrofit system on product level. It is the fundamental step towards the description of ecologic quality of a smart envelope refurbishment method. The task is a comparison of various dependencies between the technical requirements and the material effect, which is relevant for the environmental characteristics. The outcome shows a high influence on environmental impact results from different technical and functional requirements to facade elements.

Keywords: Refurbishment; energy efficiency; resource efficiency; system declaration; environmental product declaration; environmental impact; life cycle assessment; reference service life;

1. Objective

Sustainably built and modernized buildings must be economically, socially and ecologically sustainable. In addition to organizational and technical aspects, as well as the optimization of the planning and construction process, fire protection, or the hygro-thermal building physics, is therefore the life cycle-oriented consideration of ecologic quality of vital importance for the development of new modernization solutions [1]. The ageing building stock in Germany and most of Europe is in a change phase. An amount of around 45% of the existing buildings from the age class of 1950 to the eighties of the last century is dedicated to a fairly renewal, that goes beyond ordinary maintenance and repair. The building performance neither fulfils the actual technical and functional requirements nor the demand of owners and tenants.
The currently usual answer to this need for renewal is the application of external thermal insulation compound systems made of mineral fibre or for economic reasons polystyrene hard foam. The installation of these systems is little ergonomic, dependent on weather, will be more difficult with increasing insulation thickness and leads to dust and noise pollution for an extended period of time. These market dominating insulation systems are manufactured from non-renewable raw materials and are energy-intensive in the production and assembly. In polystyrene rigid foam there are risks in terms of the environment and human health, especially by contained hazardous flame retardant which can reach different pathways into the environment.
Energy efficiency measures must be out of social, environmental and process planning considerations carefully considered and compare different solutions; it must be ensured a balance between the environmental impact of the manufacturing phase and the reduction of environmental impacts during building operation. Even if the energy efficiency related refurbishment, mainly targets towards reduction of greenhouse gas emissions in the building operation, so the LCA of a reorganization measure itself, i.e. the primary energy use or greenhouse potential in production, as well as possible risk and hazardous material loads may be considered during production, processing, use and end of life.

Hence it remains a contradiction between improving the ecological properties of existing buildings and the use of fossil based resources to achieve the first goal. In order to realize a better energy efficiency of the building stock there is the need to (1) bring down buildings energy demand by changing the heating system and fuel, (2) improving the building envelope (windows, wall, windows, ground floor, roof) and additional (3) minimize impact from refurbishment by conserving useful substance of the existing fabric, prolonging service life, choice of durable and multifunctional (flexible solution) by consequently use an off-site process before facade elements are assembled and wrapped around the existing fabric.

Scope of the paper is the preparation of basic environmental system declaration and record of environmental properties of the prefabricated TES EnergyFacade retrofit system on product level. TES is synonymous with Timber-based Element System for the energy efficient refurbishment. It is the fundamental step towards the description of ecologic quality of a smart envelope refurbishment method. The task is a comparison of various dependencies between the technical requirements and the material outcome, which is relevant for the environmental characteristics. The main objectives for a practical application of reduced environmental impact are defined by König et al. in [2]. The impact for the most influential life cycle phases – production and end-of-life – has to be quantified for sustainability benchmarks. This information is required in certification systems and supports decision making.
TES EnergyFacade elements consist of a timber-framework construction with highly insulated cavities. The modular framework is produced off-site and assembled with an adaption layer onto existing structures or exterior walls. The cladding material and windows can be chosen as like. They will be mounted onto the wall elements and that should be done off-site as well. Due to the high level of prefabrication, the on-site process is short and inherits minimal waste production.

The dominant parts of the system have not the highest environmental impacts, because they are from renewable resources. Rather, it will be revealed that these parts make a positive contribution to the environmental impact by avoiding a high percentage of carbon. This remains very similar in various construction structures, as the dominant shares are of renewable resources. The disposal can take credits from the energy generation from wood to a substantial extent. The burdens are mainly on the account of the mineral components on the system.

2. Methodology

2.1 Facade Construction Parameters

Life-cycle optimized construction systems have four important basic requirements: the objectives are to maximize the lifespan of important components such as the primary structure [2] [3] [4], minimizing the flow of material [5], increases the possibility to reuse and recycling, as well as maximises the decommissioning. The necessary and variable components of the system are described as input variable. In a poly-hierarchical model, they are networked with the requirements and further the critical dependencies with the impact on the choice of material are derived.

There is a definition of functional properties of layers for TES element and a definition of the essential principles to ensure the design characteristics of this new facade construction [7]. TES is a self-supporting facade structure similar to semi-balloon framed timber structures with support for vertical loads and horizontal anchoring against wind loads on each floor level. Each element has a structural framework and within this framework there is the insulation which improves thermal properties of the existing exterior walls. The enclosure of framework is necessary for structural bracing and functional properties of the element as moisture safety, wind- and airtightness. For safety reasons specific panelling layers for fire safety can be applied. These mineral-based layers encapsulate and protect the insulation and structural parts of the elements.
The compulsory and variable components of the system are set as input dimensions and represent the subgroup of the *TES core* and *Adaption layer* as it can be seen in Figure 4. The structure of the timber framework consists of the wood studs that are positioned in a regular distance and butt-joint perpendicular to sill-beam and wall-plate. On this side of the element oriented towards the interior a panelling is applied for structural and airtightness reasons. Towards the outside a mineral- or a

wood-based panel is fixed. A gypsum fibre board is exemplary for a fire safety layer. The partition cavities will be filled with thermal insulation like cellulose fibre.

2.2 Robust construction model

Robustness in life cycle engineering delivers constructions with minimised environmental impact at full serviceability at appropriate durability and technical functionality.
In a poly-hierarchical model, the technical parameters of the TES construction are connected with the environmental requirements derived from the objectives listed in this specific order:

a) Construction design decision leads to,
b) Differentiation of life span and
c) Influences dismantling behaviour.

For life cycle durability and service life, only qualitative empirical values can be derived from existing structures e.g. lifetime of dry wooden walls. It applies to the composition of the structures that so far no composite materials are provided in rule-compliant elements. Exceptions are the sill and the sealing of the window frame.
A selective dismantling process is possible on the element level on-site, a demolition is not necessary. All joints between the existing building and the TES are done by screws. Entire elements can be disassembled and transported for further waste management. The layers and timber framework of individual elements have to be separated and recycled off-site. The joints between the framework and layers of the element are durable and e.g. staples, nails are reversible only to a limited extent.
All relevant considerations need to be evaluated and optimized for the finding of design patterns. Hence the aim is at demonstration of appropriate layer composition instead of the detailing of smaller parts of the timber facade system. This assumption is explained with the influence of the joint part in relation to the element area. Basic assumption is an average small facade of a 4 storey town house building with eight apartments. The length of all horizontal joints is roughly 320 – 520 meters including the length of the basement and the roof eaves. This sums up to an amount of 2,2 to 3,5 m³ of wood required for all horizontal joints plus ten percent for all vertical joints. Assumed that average facade area is about 450 m² it is only 0,005 m³ of wood per square meter of the facade needed for the joint. The TES element itself requires about 0,036 m³ of wood per square meter.

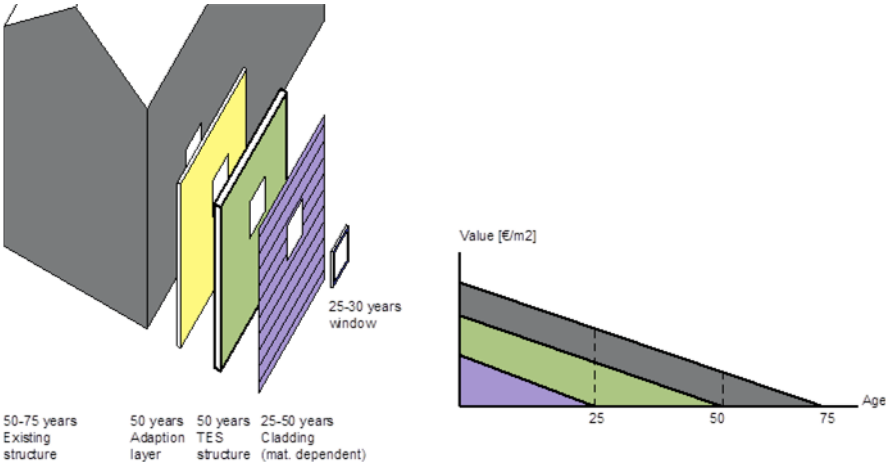


Figure 1 Differentiation of life span of TES element layers.

It is shown as an example that it is more worthwhile from an LCA perspective to optimize the structure of the element. The shape of the joint has an influence on the construction process and the later removal and thus the recovery at the end of life. These other objectives are integral in the whole life-cycle approach, and in particular in the development of the jointing.
Further goals are to maximize the lifespan of important components such as the timber framework structure, and give ability to reuse and recycling, as well as maximizing the dismantling. This is necessary to a higher degree for the exterior parts and layers compare Figure 1. The durability of

the wooden elements and the protection of the structure against climate exposure are done in compliance with hygrothermal requirements and moisture management in closed timber frame components. Thus the TES elements fulfil the requirements of use class 1, in which the wood or wood-based product is inside a construction, not exposed to the weather and wetting [8].

2.3 Life cycle assessment methodology

General LCA methodology is according to the basic rules of building life cycle assessment following the requirements and steps of ISO 14040 and ISO 14044 standard [9] [10].
Functional unit is one square meter of TES element with all layers of the timber framed element but without existing wall, cladding and other integrated components like windows. Up to now the inflow side does not include a more detailed insight in the accompanying parameters, anchoring, tie-back, and gap layer. The core element inventory, which are layers b and c see Figure 3, cuts off negligible secondary materials e.g. tapes, nails, and screws.

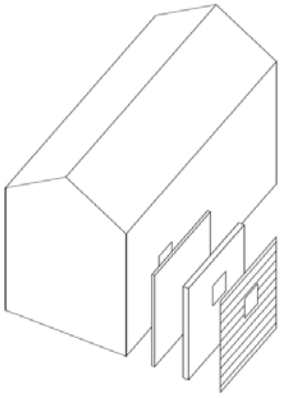


Figure 2 Assembly process of adaption layer, core element and cladding at existing structure (left to right).

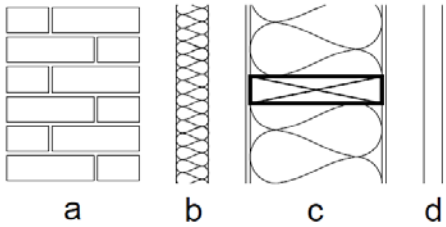


Figure 3 Cross section of existing structure (a), gap layer (b), core TES element (c), cladding layer (d).

System boundaries include the production with raw material extraction, transport, and processing into semi-finished products. The system includes the production of the raw materials and the provision at the factory gate; this is the cradle to gate part according to EN 15804 [11]. The off-site production of the conducted elements is a second factory process, but it is attributable to the construction process and related to phase A5. The transport and assembly flows in A4 are cut off from the “second” factory gate. There is still no data available for life cycle module A4-5 energy and material flows for mounting TES on existing buildings. The subsequent life cycle modules B, C and D are not examined in this article.

2.4 Data for life cycle assessment

The assumptions are set for the entire production phase of TES facade elements. They consist largely of semi-finished products for which already environmental product declarations (EPD) are available. There are so far no detailed data recorded of energy consumption and local material flows in the manufacture of TES elements. Therefore comparative figures from the off-site production of timber frame construction elements will be used, similar to new building off-site processes [12] [13].
Material input flow indicators are divided into the primary energy sources of renewable primary energy content (PER) and non-renewable primary energy content (PENR). A delicate subdivision is not possible here according to the conventions of the EN 15804, because neither the used nor currently available data from the ökobau.dat conform to this standard [14]. Upcoming EPD available on the basis of EN 15804 is also not fully well suited and have only values of the specific products. It is resorted also to EPD for the data base because there are no suitable generic records in the ökobau.dat.

Data for wood-fibre insulation material are selected on an EPD basis [15]. For the wood-fibre insulation material and other wood-based materials, the carbon sequestration is estimated on the basis of the density and the usual humidity and receives a flat-rate reduction of ten percent as either from the manufacturer unspecified base material or necessary glue is included in the final product.
The choice of the impact categories consists of accepted indicators in certification processes. Hence refurbishment will reduce the greenhouse gas emissions, is therefore an important reference value on the material side of the global warming potential (GWP). In addition the carbon sequestration (Cseq) of renewable materials is shown on the basis of the standard TC 175WI [16]. This advantage is evoked already in the global warming potential calculations for cradle to gate. But thermally recycled wood loses this advantage and gets CO2-neutral on the only material side at the end of the entire life cycle. Because the advantage of a CO2 absorption in wood in structure is an essential climate protection contribution, it is included informative in this investigation as a positive environmental impact.

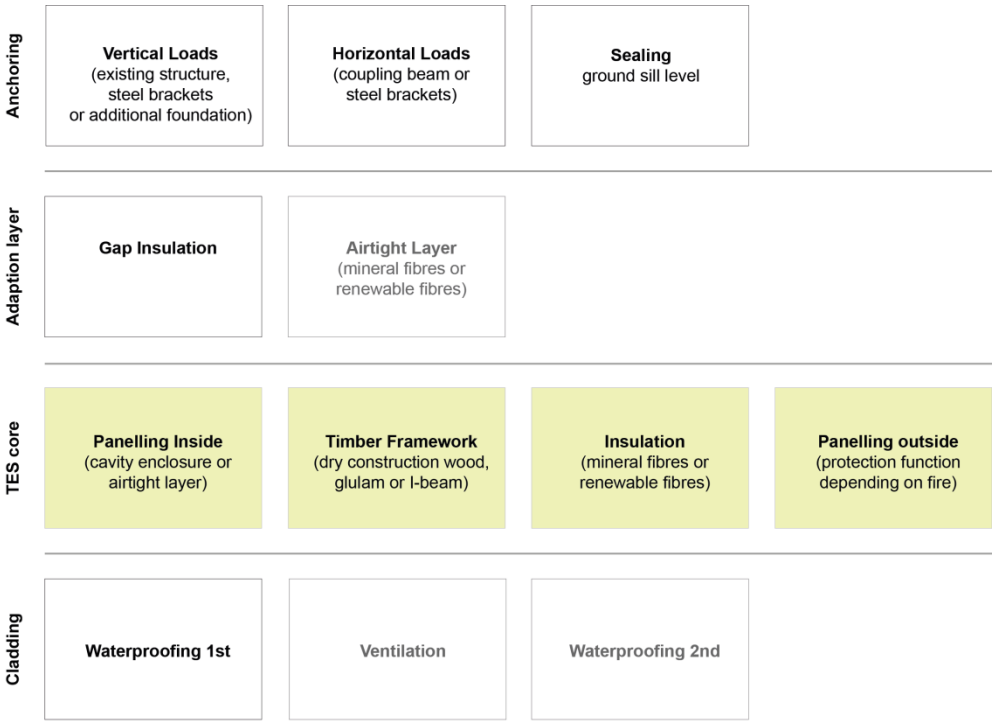


Figure 4 Matrix and basic functional unit description of a general TES system with the core parts highlighted in third row.

2.5 Demonstrators and Examples

The studies are based on nine different wall constructions that are already implemented in different projects. The projects were in Germany, in Norway and Finland. The thickness of the insulation, which is realized with these elements, is between 200 and 300 mm. The thickness of the adaption layer must be added yet, it is between 50 and 80 mm. The TES cross-sections have resulting U values of 0.14 to 0.24 W/m²K. Together with the existing walls thermal properties, total U-values can be reduced thus down to 0.10 W/m²K. By such measure the heat transmission of the facade of existing buildings can be reduced to the level of a retrofit passive house.

Table 1 Properties of TES element case A.

	Position	*Material description*	*Dimension [mm]*
1	functional layer	gypsum fibre board	25
2	gap for adaption	mineral wool	98
3	back_panelling	OSB	12,5
4	insulation	mineral wool	250
5	structure	glue laminated timber, dry	250
6	front_panelling	wood fibre board, soft	12,5

3. Result and discussion

3.1 TES solutions compared to conventional systems

The results focus on the material input and related burdens and benefits. One goal is to compare the full TES systems with the benchmark of conventional retrofit systems for facades. Another objective is taken also on the bandwidth of the inflows of primary energy and the outflow indicators for the global warming potential. Moreover, very good and very bad solutions of a TES facade can be identified and better valued. The averages for the primary content and the global warming potential give important indications of the performance of the entire system. They are also orientation values for the whole spectrum and the degree of deviation.
All TES elements compared in nine cases have the similar layer structure, only the functional layer is not included in all cases. Soft insulation is used for heat insulation and to compensate the gap. The supporting structure is made of solid wood or wood-based materials. The back side panelling requires only airtightness. The front side usually braces the element and additionally meet fire protection requirements on the front in the cases A, D, E, F, G and H.

The primary energy expenditure for TES production is high, if you look at the pure numbers in Figure 5. The ratio of renewable primary energy (PER) versus non-renewable primary energy (PENR) content is 815 MJ to 603 MJ on average. Compared to that, the primary energy content of ETICS are rather small, they have a ratio of 7 MJ PER versus 331 MJ PENR.
The renewable primary energy content of TES contains also the share of the calorific value of wood material in addition to the energy of production; it is therefore similar to or higher than the non-renewable primary energy. The fraction of the calorific value of a square meter of TES is at least 212 MJ or 55 kWh and thus over a quarter of the average renewable primary energy demand.

Table 2 Indicator overview of all nine examples with averages and standard deviation.

	Min	*Max*	*Average*	*SD*
PER	492.21	1318.37	815.38	275.74
PENR	338.27	1191.28	603.38	249.30
GWP	-0.43	-63.89	-33.78	16.67
CSeq	38.32	81.00	50.82	12.16

The benchmark of ETICS is according to the environmental system description (ESD) of the industry. It is therefore an aggregated ESD of German ETICS association and indicates PENR 331.18 [MJ/m²], PER 7.07 [MJ/m²], and GWP +14.48 [kgCO2eq/m²] [17]. The ETIC system compared is from expanded polystyrene insulation material and contains therefore prevailing fossile energy and causes greenhouse gas emissions. Meanwhile, the TES facades have a carbon sequestration potential of an average 50 kgCO2eq that is almost equal between different cases as it can be seen in Figure 6.
The GWP of nine different cases of TES is on average at -33 kgCO2eq. This value is by a factor of four below the reference value of polystyrene-based ETICS.
This shows the low environmental impact of TES facades despite their high resource demand and minor U-values. Despite high primary energy consumption, a result of the reasonable amount of

wood mass with a high calorific value, the remaining GWP of TES is still lower than for ETICS. It should be noted in particular a necessary improvement of resource efficiency in the production of the TES elements and its raw materials. However this universal statement based on the figures lacks a more detailed examination of material properties that cannot be done here.

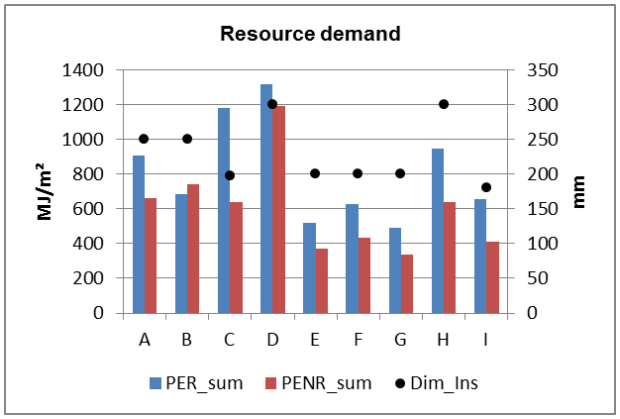


Figure 5 Resource demand of construction compared to thickness of insulation and TES element.

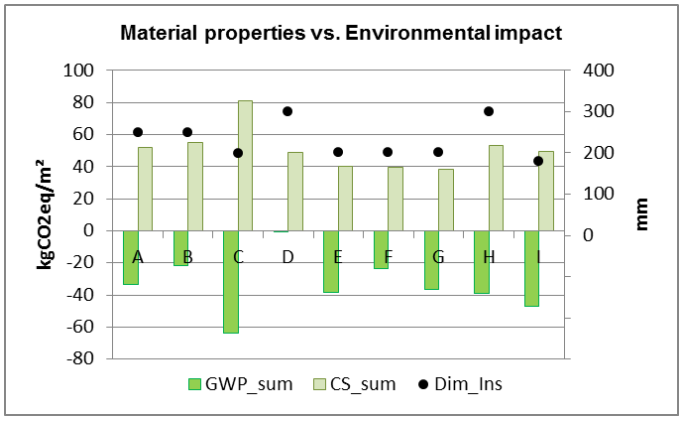


Figure 6 Environmental impact versus the carbon sequestration related to thickness of insulation in a TES cross-section .

3.2 TES layers environmental impact en detail

The analysis of the element layering is most suitable as a method and applied here. The inflow indicators by PER, PENR and carbon sequestration together with the outflows or emissions of GWP are individually calculated for each component layer. The correlation between the insulation dimension and the GWP is assessed. The sensitivity of the influence of layer materials is checked in a dominance analysis. Finally the evenness of material compositions graphs show how important certain layers are for the total amount and to the degree of environmental impact.
In principle, all layers are variable, with regard to the dimension as well as with regard to the materiality. In order to handle the possible diversity it is necessary to consider the requirements matrix and to ensure the correct choice of environmentally-friendly construction of the system. The choice of the layers in the context of the design principles makes it possible to evaluate them separately and to assess environmental impact of layers. By comparing the individual inflows and outflows makes clear, this parameterized layer affect the result of each indicator. On one hand facades such as TES can avoid or replace materials with high environmental impact in contrast to other constructional parts of a building like foundations. This is not always a simple task for wood-based materials because fasteners, adhesives, or encapsulating materials can influence the outcome (structural, safety). If the influence can be reduced the overall result will get more stable in relation to the environmental impacts. Further research will be done on this topic and first results are show in the presentation.

In Table 1, the review of the TES is given as an example element in case study A. By the global warming potential be considered it is apparent that there are positive and negative values in case A. The functional layer and the insulation are on the positive ordinate axis because they do not have carbon storage in cradle to gate phase. The wood based materials from the back panels to the front panels are on the negative ordinate axis due to their carbon storage, see Figure 6 and Figure 9. They avoid carbon emissions and contribute to a reduction of global warming therefore they have a bonus expressed in negative values for the cradle to gate phase.

It is expected that the insulation and the studs have the highest proportions and the strongest influence on the distribution of primary energy. This can be confirmed from a general perspective with the numbers in Figure 7 to Figure 8. There is also a correlation expected between the insulation thickness and the primary energy parameters. Regression of the insulation thickness with the PER and PENR is available (Lin. R-squared = 0.62). Further it is expected that there is a strong negative CO2eq for GWP as mostly wood and wood-based materials are in use. This is true

for almost all investigated facade cases; compare Figure 9 to Figure 10. Mainly a mineral based panelling of the TES front side will have influence as well as non-renewable insulation. The GWP scattering at the Back_Panel layers is very low. The Back_Panel layer is only thin regard the entire cross section. Greater deviations rise with the front panelling, the Front_Panel layers, because technical requirements for fire protection or bracing reduce variability of material and dimension parameters. The carbon sequestration information will behave similarly to the GWP.

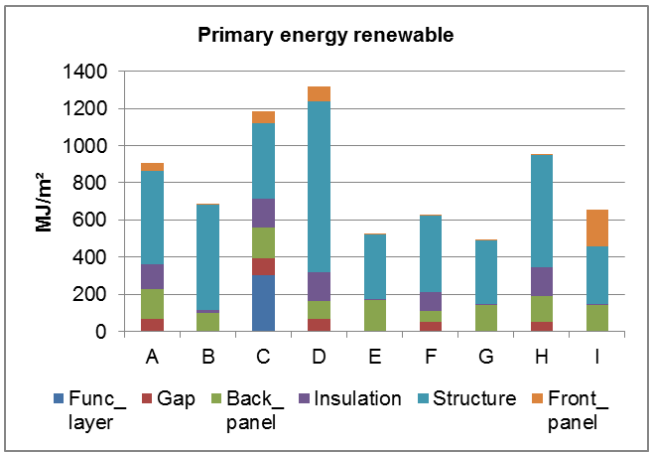


Figure 7 Renewable primary energy content of nine different TES facades, separted by layers.

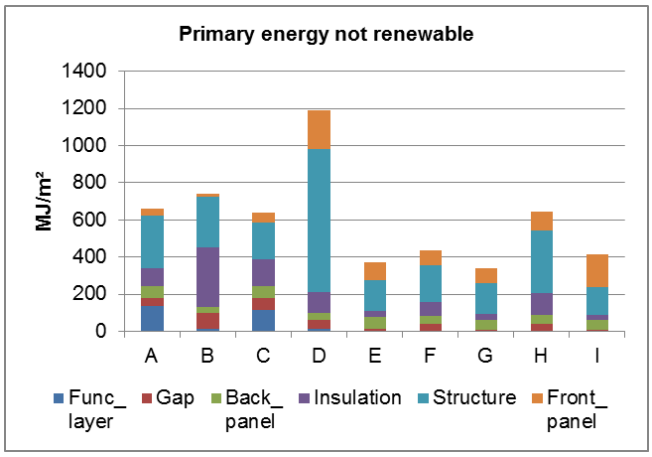


Figure 8 Non-renewable primary energy content.

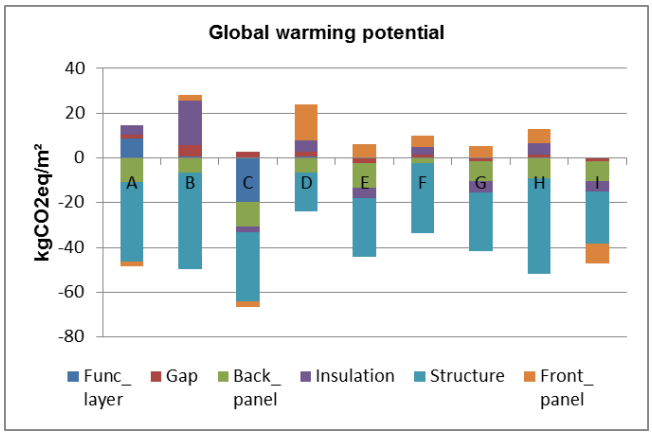


Figure 9 Global warming potential.

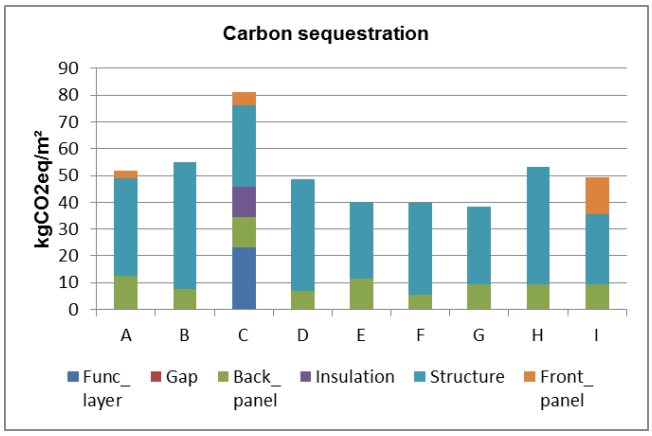


Figure 10 Carbon sequestration potential.

In the further course this article you look closer to some features. They are related to particular element production techniques and the use of certain materials associated.

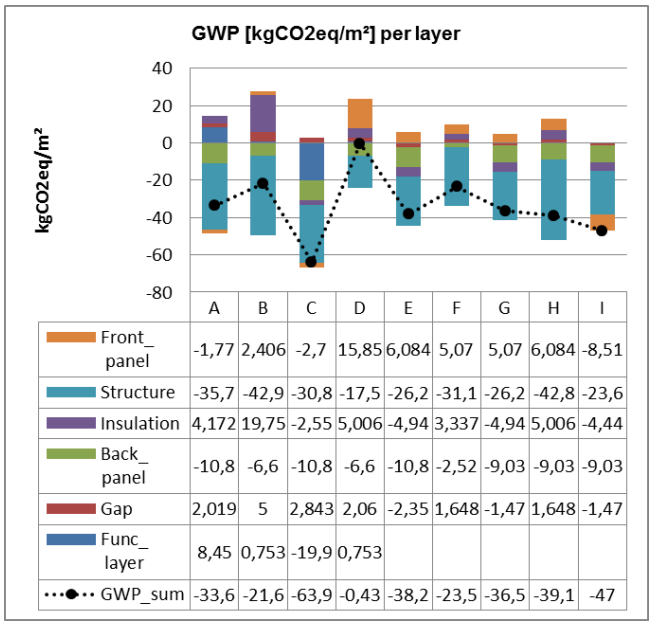
Table 3 Main material groups used in the nine cases.

Functional layer	A; B; C; D	airthightening foil or board
Insulation	A; B; D; F; H	mineral or glass wool insulation
	E; G; I	loose fill cellulose fibre insulation
	C	wood fibre insulation
Front panelling	A; D; E; F; G; H	mineral-based building board (gypsum based or cement bound)
	A; C; I	wood based panelling

In facade case C a functional layer (= shell) is included for airtightening reasons. For this layer, there is a small reinforcing effect of negative GWP, compare Figure 9.
In Figure 9 GWP shows also a distinct greenhouse potential at facade of case D, whereas the

other cases all have a smaller proportion of the positive GWP variants. The same applies to the primary energy content from case D. There is a GWP score of almost zero instead of a negative for case D. It should be noted that the load-bearing structure in this case is laminated veneer lumber (LVL). The used insulation material is mineral-based. In sum, this leads to a below-average score in all impact categories.

For its positive performance the cases C, H and I have low GWP. Another good performance in GWP value has facade case H despite high insulation thickness and not renewable insulation material. This is due to the high proportion of wood in the load-bearing structure. The layers have almost no greenhouse gas emissions with the exception of case H, because it has a mineral based insulation and front panelling. Case I is very balanced over all component layers.
Figure 12 indicates the positive influence of the structural framework on the negative GWP while the front panelling and the insulation do not have this. The structure also has the highest deviation of all scores. The even distribution of the other layers impacts apart from the front panelling is seen also in Figure 12. There is also a spike from the insulation material in this diagram. Reason for this result is a high amount of GWP for the glass wool used.
The influence of insulation and its material is a significant burden while the influence of insulation thickness is comparable low.



	A	B	C	D	E	F	G	H	I
Front_ panel	-1,77	2,406	-2,7	15,85	6,084	5,07	5,07	6,084	-8,51
Structure	-35,7	-42,9	-30,8	-17,5	-26,2	-31,1	-26,2	-42,8	-23,6
Insulation	4,172	19,75	-2,55	5,006	-4,94	3,337	-4,94	5,006	-4,44
Back_ panel	-10,8	-6,6	-10,8	-6,6	-10,8	-2,52	-9,03	-9,03	-9,03
Gap	2,019	5	2,843	2,06	-2,35	1,648	-1,47	1,648	-1,47
Func_ layer	8,45	0,753	-19,9	0,753					
GWP_sum	-33,6	-21,6	-63,9	-0,43	-38,2	-23,5	-36,5	-39,1	-47

Figure 11 Global warming potential in detail compared to the total sum.

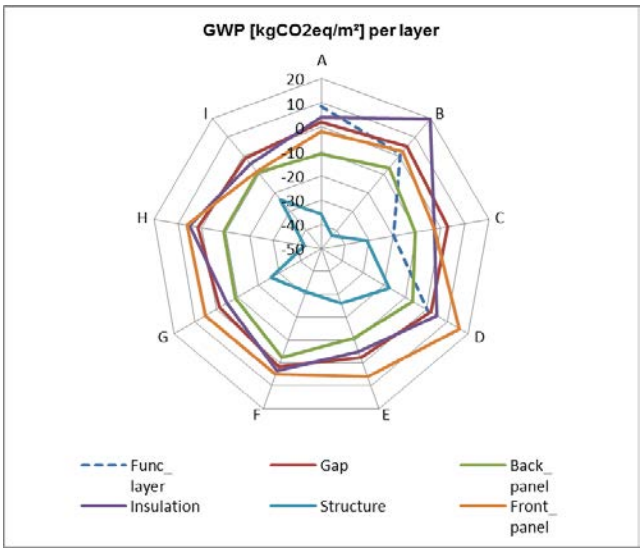


Figure 12 Dominance and evenness of GWP related to layers.

As mentioned before the module A4-5 is based on a very general assumption. It is given that the life cycle module A4-5 holds 20-30% of the total impact of module A1-3. In addition, the module A4 has a relatively high share in the module A4-5, approximately 30%. The other 60% can be allotted to phase A5 construction and phase A5 waste management in equal shares.

4. Conclusions

The TES system is analysed to, which features most of the modernization projects are sustained and what features constitute individual solutions. This inquiry is necessary to be able to use the catalogue of requirements for all projects as universally as possible. The dominant parts of the system have not the highest environmental impacts like the timber framework as structure. Rather, they make a positive contribution to the environmental impact by saving a high percentage of carbon. This remains very similar in various constructions, as the dominant shares are of renewable resources. But right selection of structure and insulation material can influence the positive properties of TES EnergyFacade to a large extent.

To sum up, it can be stated only the front cladding and insulation can deteriorate the GWP balance because they have values on the high emission side of the GWP which is a positive figure. The wood framing and the panelling of the back are renewable materials with negative figures and absorb more CO2 than the production emits. The functional layer is not always required, but it can contribute a slightly negative influence on GWP. The environmental impact of the insulation layer in the adaption layer of the gap is in contrast, constant low and almost negligible.

All TES EnergyFacade solutions are relatively homogenous regarding their global warming potential. The deviations depend severely on the material of the studs and the insulation and are more obvious on the inflow side than on the impact. The panelling has only minor influence.

The TU Munich has developed an eco-balance calculation tool for the TES facade elements and it will be expanded with complementary information. It is an extension to previously disregarded components (e.g. anchoring bolts), as well as characteristic values for the end-of-life scenario have to be captured. The cladding layer as well as integrated elements will be shown only exemplary, because they are individual chosen in each project and they are separate EPD or even ESD and therefore kept outside the system boundary. Another interesting aspect is a deeper insight in the necessary amount of energy and waste for off-site construction and the missing values for flows resulting from on-site processes. The assembly of a TES element wrap around on existing buildings is very different from new building with timber constructions and will cause further environmental impact that has to be diminished.

5. Acknowledgements

TES EnergyFacade, run from 2008 to 2009, and still running SmartTES, from 10/2011 to 09/2013 are funded in the European ERA-Net Woodwisdom-Net by the German federal ministry for research BMBF, represented by PTJ.

6. References

[1] smartTES. smartTES – Innovation in timber construction for the modernisation of the building envelope. http://www.tesenergyfacade.com. Period from 10/2011 to 09/2013, funded by BMBF, represented by PTJ.

[2] KÖNIG H, KOHLER N, KREISSIG J, LÜTZKENDORF T. *Lebenszyklusanalyse in der Gebäudeplanung*. Institut für intern. Architektur-Dokumentation, München, 2009, ISBN 978-3-920034-30-0

[3] ALTING L, LEGARHT JB. *Life Cycle Engineering and Design*. CIRP Annals — Manufacturing Technology, DOI: http://dx.doi.org/10.1016/S0007-8506(07)60504-6; 1995, Vol 44 (2), pp 569–580.

[4] THORMARK C. *A low energy building in a life cycle — its embodied energy, energy need for operation and recycling potential*. Building and Environment, Elsevier, München, DOI: http://dx.doi.org/10.1016/S0360-1323(01)00033-6; 2002, Vol 37, pp 429 – 435.

[5] OTT S, WINTER S. *Parameter Study of a Prefabricated Retrofit Facade System*. Proceedings International Symposium on Life-Cycle Civil Engineering IALCCE, 2012, Vienna, ISBN 978-0415621267.

[6] MOREL, JC, MESBAH A, OGGERO M, WALKER P. *Building houses with local materials: means to drastically reduce the environmental impact of construction*. Building and Environment, DOI: http://dx.doi.org/10.1016/S0360-1323(00)00054-8; 2001, Vol 36 (10), pp 1119–1126.

[7] LOEBUS, S, OTT, WINTER. *Prefabricated Retrofit Facade System – a Systemized Building Construction Detailing*. In: Proceedings of SB13 Graz. 2013. (to be published).

[8] EN 335:2006-10: Durability of wood and wood-based products – Definition of use classes. CEN/TC38 – Durability of wood and wood based products. 2006.

[9] ISO 14040. Environmental management – Life cycle assessment - Principles and framework (ISO 14040:2006). Berlin: Beuth, 2009.

[10] ISO 14044. Environmental management - life cycle assessment - requirements and guidelines (ISO 14044:2006). Berlin: Beuth, 2006.

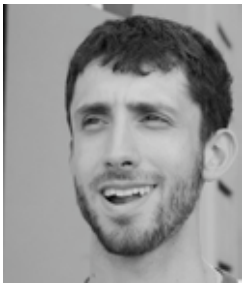
[11] EN 15804:2011. Sustainability of construction works – Environmental product declarations –

Core rules for the product category of construction products.
[12] ECO2-book: www.eco2wood.com; Summer 2013 (to be published).
[13] TAKANO, A, PITTAU, HAFNER, OTT. *Greenhouse gas emission from construction process of multi-story wooden buildings.* In: Proceedings of SB13 Graz. 2013. (to be published).
[14] Ökobau.dat 2009, http://www.nachhaltigesbauen.de/no_cache/baustoff-und-gebaeudedaten/oekobaudat.html?cid=4264&did=1490&sechash=026f9f62. Last access 05.04.2013.
[15] EPD-KRO-2009212-D, Kronotherm Holzfaserdämmung, Hersteller Kronoply GmbH, 2009. http://bau-umwelt.de/download/CY1c67a99eX13aab7d9717X7ba4/EPD_KRO_2009212_D.pdf. Last access 5.04.2013.
[16] TC 175 WI: *Use of wood in buildings and the adventitious potential for the reduction of a building's carbon footprint.* CEN TC175. 2011.
[17] Muster ESD-FVW-2011511-D, WDV Systeme, Hersteller Fachverband Wärmedämm-Verbundsysteme e.V. , 2011. http://bau-umwelt.de/download/C3ddbc477X13042d4a6ffX443e/Muster_ESD_FVW_2011511_D.pdf. Last access 5.04.2013.

Naturwall: active timber wall for renovation of existent buildings



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Short Summary

The renovation of old buildings is actually the challenge to cope with increased effort in order to reduce climate global change, channeling more investment and awareness in this sense, defining more experimentations and find innovative solutions. The difficulty of carrying out an intervention on the existing buildings necessarily arise from the lack of information on the existing structure and the lack of coordinated processes between the multidisciplinary skills involved, as well as a difficulty to optimize the process that would make it even more competitive on the renovation work instead on the new construction.
Naturwall is an innovative energy saving system for existent buildings by using wood in multifunctional components able to mitigate the environmental effort in building management. The project meant to introduce an industrialized design method in the renovation of existing build environment that highlights opportunities gave by "off site" production and parametric design approach, without neglecting the aesthetical values and the possibility to change the architectural image of residential and non residential constructions. The project aims to create a representative model of solution that will be promoted in Italy and widespread in other similar context.

Keywords: wood, prefabrication, retrofit, building, urban renewal, renovation,

1. Introduction

The renovation of existing buildings is driven by new European rules and projects on energy efficiency. The recent Smart City program, EU climate action "20-20-20" or the last EPBD directive 2002/91/EC are promoting initiatives in the field of renovation, introducing new issues and perspectives in the use of materials and components performed for this goal.
The aim to achieve energy saving in buildings is a complex process, especially if buildings are very ancient. From the last report of Buildings Performance Institute Europe (BPIE), regarding the situation of building sector in EU 27 [1], are shown the performances of the amount of old construction characterized by poor energy saving potential. Our purpose has been the development of a whole process system in the field of renewal strategies to be used in every architectural field. Starting from the relief phase, we would optimize the process detailing envelope with digital data to be used in the entire process to define components that fit perfectly on the existent wall surface, reducing the risk of adaptability of the system and the work during the yard, We meant to achieve the reduction of energy cost optimizing the total cost of the operation, complying actual energy standards and reaching the opportunities related to renovation of social housing and industrial heritage, which needs smart solution in economic terms. In the report made by Copenaghen Economics for Renovate Europe in 2012 is highlighted how “energy savings associated with energy efficient renovation of buildings outweigh the up-front investment costs

needed to under-take the projects" [2]. The reducing of energy demand in public bills for example reflect a decrease in need for subsidies and permit the achievement EU's 2020 energy targets and reductions of greenhouse gases at a lower cost. Renovation opportunities could be a real benefit for EU economies and society, especially using a strategy that maximize the investment in energy saving convey an amount of extra benefits regarding the quality of health and urban climate (air pollution, etc...). Energy efficiency could seen as possibly the most cost effective way of reducing GHG emissions. Energy efficiency measures account for two-thirds of the 3.8 GT of abatement in 2020, with renewable energy contributing about 20 % [3]
Some economical studies [4] believed that efficiency offers an enormous "win-win" opportunity. Thus means that through an appropriate and strict energy conservation policies, it's possible both save money and reduce negative issues. This approach refers to the amount of externalities such as harm to human health, climate change and constraints on the foreign policy objectives of energy-importing countries that could be amplify with correct investments in energy efficiency. A true retrofit requires a fact-based, benchmarked, quantitatively oriented, energy efficiency retrofit with a clear payback analysis on an integrated multicomponent effort with performance guarantees. [5]

1.1 Renovation problem in Italy

In Italy, the introduction of energy regulation, within standards coming from European energy legislation, has led to further actions oriented towards buildings retrofit. This approach is not well sustained by a renewal claim about functional and formal features, but only considering faster energy saving strategies. In the most case this has solved by installing a thermal insulation on the building envelope, which permit to fulfil the target points without valorise the economical and architectural value of building heritage.
The situation of built environment in Italy could be understood by the outcomes of two national studies. The first is an outline from ISTAT (National Institute for Statistic) survey in 2001, which shows the highest number of existing houses built before the energy crisis of the '70s (more than half of the total amount) and how much is the consumption of those buildings (about 250 kWh/m2 compared to 100 kWh/m2 of buildings built in the '90s).
Considering the improvement of energy efficiency of residential buildings built among 1950 - 1980 (resulting from a widespread housing development), may suggest the obvious benefits about reduction of climate-altering gases in Italian urban areas through retrofit strategies and the reduction of management cost for public administration.
The second important data coming from an EU project called TABULA [5], in which Italian part was conducted by Politecnico of Turin, it displays for Italian country an existing built environment not efficient, wide and varied to be tackled through redevelopment actions. This research defines the typology of Italian buildings heritage and their features, explaining some furthering action to improve their supply and energy performances.The last frame is a research conducted by Legambiente, and called "Tutti in classe A", which present the top level in Italian energy rating, confirming the worse insulation of buildings actually made in Italy.
All those documents explain us how much wide is retrofitting field of work in our country. Thus was highlighted by first international convention Re- Build, held in Riva del Garda (TN) in September 2012, which has shown the huge percentage of heritage to be restored and re-used, promoting governments initiatives in the recovery and regeneration assets, emphasizing the need to revise intervention processes on urban areas, stimulating the research of structured path between governance, business and local communities.

2. Naturwall – a sustainable way for the envelope retroffitting

The target of the Naturwall method is primarily focused on the building's energy efficiency improvement and, as direct consequence, the reduction of GHG emissions. "Energy efficient buildings poses special demands on the quality and performance capabilities of the facade" [6] In the field of renovation and refurbishment high energy retrofitting results and greenhouse gases reduction could be achieved by using multifunctional facade systems. Smart facade solutions using the surface of the building envelope as "active skin" confirm the increasing number of experience in this sense (TES EnergyFacade, enVELOP system, PHI-Wood façade, GAP façade system, etc..). The last number of Zuschnitt [7] shows some innovative way to recover buildings with wood prefab systems. Thus permit to reach to achieve high energy performances and sustainable features on existing buildings.

Our system would recover power from sun by using PCM systems or simple strategy to overstock renewable energy (PV, water, etc..). We verify the behaviour of Naturwall system with mathematical models by using energy evaluation software; after tested it on laboratory, we will prompted it on a real case study. The first application will be upon an industrial building envelope, which needs to be recovered and insulated. Finally, we study its application on a residential multi-storey building located in Turin (Italy) to verify the efficiency of the solution in terms of architectural renovation and energy saving.

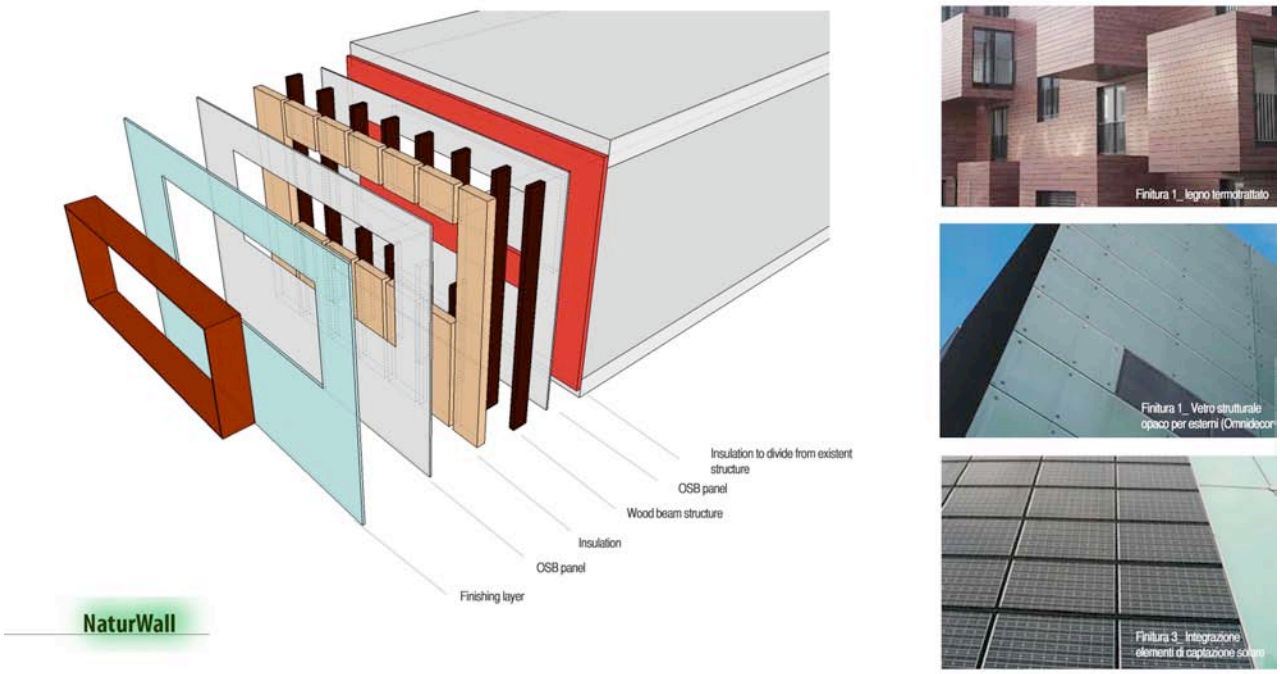


Fig 1: Naturwall facade system schematic design

The main target of that element are:

- Self supporting timber frame structure, coming from local forestry management
- Precision and quality of a customized prefabricated building system
- Application of different cladding materials – especially use of solar active systems (PCM, Photovoltaic, etc..
- Spatial intervention or expansion in a coherent modular system
- Integration of technical systems and sensor for monitoring performances
- Static behavior: wood elements are lighter than other construction material and guarantee better seismic performances.
- Responsive design to project objectives, an off-site process permit to control the quality of the final result, elements are industrialized products (made by using CNC machinery);
- Management of the yard: the setting in construction phase is more simple and there is the possibility to work, in the case of retrofit projects, without move outside the users, reducing implementation cost.
- Use of local material, especially wood coming from certified forest

A core task of energy efficient building design is to reach the required indoor environmental quality with a minimum of primary energy demand and a simple energy supply system. [8] Naturwall have several advantages, especially in the use of natural and local material, which reduce the embodied energy in the process and the carbon footprint of the products.

2.1 Multidisciplinary integrated workflow

Naturwall research meant to introduce a new settlement in renovation design approach maximizing benefits of integrated design and off-site production. This means achieving energy requirements

paying attention on the whole process. It is almost different from simple "recovering" strategy, Naturwall aims to define housing components able to activate dynamic and adaptive processes referred to the stresses coming from the external environment.
Facades play a fundamental role in the city renovation projects especially if the intervention runs up on buildings without remarkable architectural meaning and poor energy saving quality.
Naturwall prefab elements combine a self-supporting structure with insulation infill and panelling, which can be made by wide range of cladding materials (e.g. timber boards, timber panels, glass, aluminium etc.). High precision components like windows are easily integrated due to the modularity.

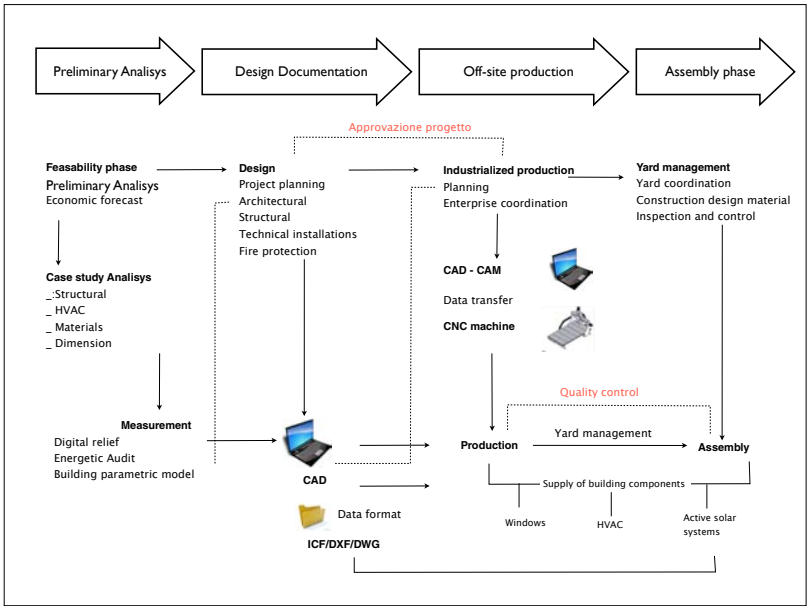


Fig 2: Naturwall workflow process (A. Spinelli, 2012)

Despite the use of wood in construction is increasing in Italy, the use of lightweight components in the intervention on the built environment remains an area of interest and research in our country. The aim of this project it's to propose a reflection about the opportunity gave by using industrialized system in the retrofitting approaches in urban spaces. permitting a deep renovation of the heritage that now shows problem of maintenance. The situation of the context, especially in urban dense areas, is very important to define a strategy that conceive the operative condition and time costing of the retrofit operation. One of the purpose of this research is the connection among design phase and construction, through the re-organization of the whole process with: digital measurement, planning off-site fabrication, on-site assembly, defining the instruments and phase necessary to bring the renovation to the end, evaluating all the issue and pay-back return. The Naturwall project take into account different ways for the application of that innovative component on the building. In particular, three main installation type have been considered: components applied on exiting envelope, components applied instead the existing envelope or components added to extend the building. All these types of installation request a preliminary survey of the building in order to put in evidence the critical points and study the best solution for the building renovation.

2.1.1 The role of relief phase

A specific relief phase, based on a dedicated methodology able to investigate in details the starting condition of the building, is necessary in order to collect important features and parameters necessary to conceive the component with respect to its performance, but also in order to reduces cost, resources and times in the whole design and fabrication process. During the production phase is important the availability of reliable and detailed measurements regarding the building. Since precision and reliefs devoid of errors are at the base of each solid design and correct inventory of the current state of a building, nowadays the simple 2D representations are no longer sufficient to serve the purposes of the field of architecture especially in the detailed metric measurement of the external facades. In the last few years, the employment of 3D laser scanning systems for the survey of exiting building - also complex - have been considerably increased due

to the advancement achieved by the recent hardware and software solutions. This technical improvements has boot a consequent decrease in the laser scanning services cost, that today are almost comparable with the traditional survey techniques. In addition, comparing the traditional survey techniques, the high level details achieved by laser scanning survey permits the correct dimension of the components during the off-site production phase achieving high precision (as an example, technical compartment for windows could be measured with a total error less than 5mm). Because the digital fabrication process based on CAD/CAM programs work mainly in two-dimensional mode, the 3D scan data allows the generation of any number of 2D representations such as plans, sections or views to understand the possible critical points during the fabrication process and design the component correctly. It is therefore possible to compare the measured data with the desired renovation project, detecting early warning of potential design errors and eliminating them even before the construction phase. This reduces the high liability risk of the requalification project, while the stringent requirements in terms of accuracy and profitability become calculable. In addition, the relief data could be directly imported in CAD/CAM programs and directly charged into CNC production machine, reducing the time necessary for the fabrication. Another advantage of the adopted method is given by the deformation analysis conducted on the façade, which allows to extract different important parameters in order to plan the most suitable installation program and conceive the proper support structure devoted to the component installation (bracket, trestles, etc.) with a consequent reduction in terms of resources and time

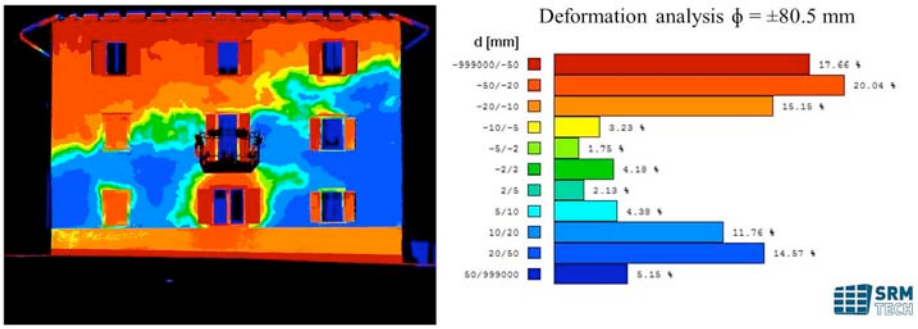


Fig 3: Deformation analysis of the west façade of an existing building (traditional '900 architecture) in Trentino, Italy.

during the place on the yard due to unforeseen critical points. As an example, in figure 3 is reported the deformation analysis on an existing building in Trentino Region where façade planarity error is higher than 20 mm in the 84% of the total surface.

2.1.2 The role of design phase

The designing phase could be focused as the main part of the process; the modern methods for measuring described above (i.e. Photogrammetry and 3D laser scanning) generate precise data of the target buildings in 3D-models, which could used for designing prefabricated components for renovating, and finally, for maintenance program. The dataflow matches the requirements of the digital process chain, from site measuring, planning to prefabrication. To exploit the best value of industrialized process we need to improve our instruments of investigation and communication. BIM method, for example, is an intelligent model-based process that helps professionals and enterprises achieving business results by managing more accurate, accessible, and actionable insight throughout project execution and lifecycle.

"The digital age has radically reconfigured the relationship between conception and production, creating a direct digital link between what can be conceived and what can be built", [7] the use of control machines within help of computer code permit to overcome the limit of standardization, variable information flow coming from design allows the manufacturing of components of various shapes, without any loss of time in production phase. The easy machinability of wood account this material for digitally controlled processes, thus provide an opportunity to incorporate the properties of material and inputs coming from construction and fabrication requirements, as parameters into the process. [8]

Timber design can be defined as the most modern method of construction in the market in terms of contemporary 'information society'. No other systems could explain better the relationship between technology, fabrication methods and architecture. [9] With an integrated design, you not only

evaluate the systems by themselves, but also as part of the overall energy consumption picture so that every action reinforces the others.

2.1.3 The role of production phase

When we manage a retrofit process, a shorter assembly on-site and fewer restrictions due to construction work compared to conventional renovation methods is a valuable quality for owner-occupied flats or buildings under operation. Some case studies made in Europe shows how it's possible to make a renewal project within inhabitants living in the "under construction" building.
In the timber construction sector, advanced methods of prefabrication are very successfully used in a contemporary practice to make new energy efficient buildings, and are consistently gaining market share.
Prefabrication allows the integration of building components such as windows, building services systems and ready-made surfaces of the facade elements in the controlled and ergonomic working environment of the factory. A flexible workflow from design to production allows for customised fabrication of single building parts to take into account the specific needs of individual buildings, e.g. size, unevenness etc.
Builders are actually prepared to achieve higher work productivity and manage rapidly the entire process, especially the assembly that is controlled from a strict design phase, which define the dimension of all pieces and modules. All parts of the system could be optimised in the workshop, e.g. material flow and efficiency, machine employment, etc . The work load on-site is minimised to the handling of just-in-time provided parts. This avoids organisational work, unproductive time, preparation work and enhances the productivity of the whole process.

2.1.4 The role of monitoring phase

In combination with an accurate metric measurement and deformation analysis of the building façade, a thermal analysis is conducted in order to evaluate environmental condition and characterize the building from the energy point of view. These analysis is important not only for the proper refurbishment of the façade in order to improve energy saving performances of the building, but also to realize a measurement campaign that characterize the performances of the installed components during their lifecycle. The survey methodology combines the most recent techniques for survey and modelling of the existing buildings with the thermal analysis (eventually merged on the 3D data volume), giving a sort of structural analysis and performance estimation of the building that will be suitable for a correct production of the components as cited before. By this way, a continuous improvement of the product in function of the different building environment conditions and landscape characteristics could be done.
In the economics of the operation, get feedback on the functioning of these modules and their performance, in order to improve their features on subsequent projects, is a key point; through the insertion of sensors it's possible to evaluate the parameters in a dynamic and active way, changing the characteristics of the housing envelope and the management system refer to geographical site and also provide real-time assessments of behaviour in various situations of intervention. This would ensure a performance audit of the housing within dynamic systems, allowing managing more accurately the service life of the building.

3. A refurbishment case study in Piedmont



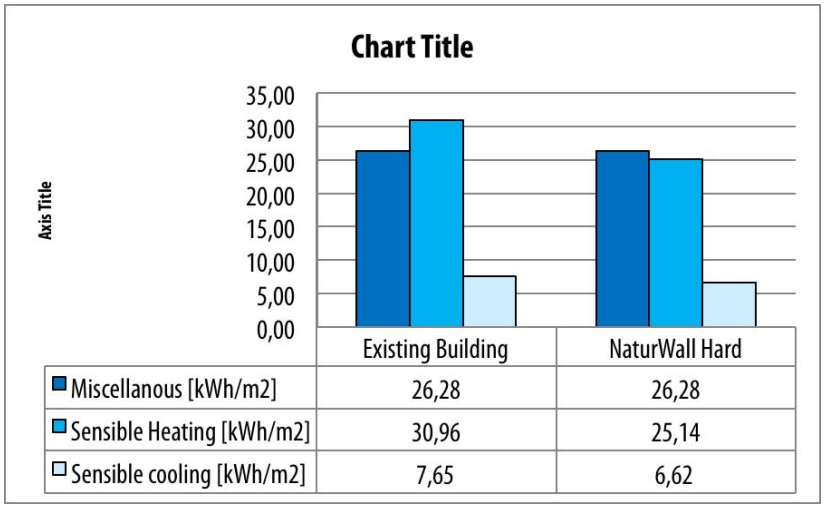
Fig 1: 4 Naturwall Case study model. Located in via Pietro Cossa in Turin. On the right the plan of the main floor.

Naturwall becomes a real program of intervention within Territorially Agency of Home (ATC) endorsement that has sustained our initiative permitting to develop some case study models to verify the feasibility of this retrofit strategy. Choosing a building more responsive to the average characteristics of the buildings made in the post Second World War period, we define a smart requalification process that combine Naturwall with other renewable systems to reduce the impact of those buildings towards "Net Zero Energy" home goal. The building is part of an expansion project in the suburbs of Turin in the '60 and are characterized by a poor energy saving envelope and low architectural value. By using Autodesk Design Builder© software tool we put in the baseline data coming from a preliminary energy audit and we studied the behaviour after introducing our new envelope system. The scope is to analyse how it works before and after the application of the Naturwall façade system. Evaluating the apartments of one floor, after calculating their annual consumption related to heating, cooling and electricity consumption, we simulated the addition of the new facade.
We use in this Naturwall system composed with local timber structure, cellulose insulation and ventilated glass facade (for external layer). Our intervention as be considered as a passive way to reduce consumption without using active systems, like as new technical installations or renewable energy.

The main results shows immediately a considerable percentage reduction of heating and cooling consumption and the increase of performances in energy saving envelope.

	Without retrofit	With Naturwall = Transmittance= 0,138 W/m^{2}K)
U_ Wall 1	0,486	0,11
U_ Wall 2	0,563	0,113
U_ Wall 3	0,561	0,113
U_ Wall 4	0,49	0,113

The table above shows the differences between transmittance values of the walls (that define the perimeter of the apartment) before and after installation of Naturwall system, the new partition have a behaviour in line within standards of new energy regulations in Italy.



The table above shows instead the reduction in term of energy consumption for square meter before and after the installation of Naturwall system. The amount of decrease it's around 15% of total energy consumed for square meter. Considering only the annually cost referred to heating and cooling consumption it represents an added value gain of 321 € for apartment. If we consider

electrical costs (Miscellaneous) the percentage drops to 6%.

4. Conclusion

Naturwall is a retrofit technological system that means to achieve energy savings requirements and restore contemporary building architectural aspect. Our building needs a restoration process to upgrade their performances and reduce the management costs and impact on the environment. With a deep preliminary study on the existing it's possible to make a detailed frame for the requalification process, inside of which can be define some work scenarios, finding the best solution for restoring quantifying the added value of regeneration. Materials, products, components and building techniques used in new buildings need to be further developed and adapted to the constraints of existing buildings. In terms of added value, the new envelope introduce a permanent solution that can be evaluate on a long financial term and achieving some incentives from Government, like as photovoltaic installations, we could widespread that practice of intervention. Multifunctional elemnts, including energy production installations, distribution and storage technologies, shall be integrated into the envelope system for building retrofitting.
For the final step of this research we are defining the cost of the component and its assembly phase on the yard, to develop a real payback return plan of the investment. Naturwall is an eco sustainable system, by using local wood materials to increase the ecological amount of the product and give new opportunities for woodworking local chain on out territorial land and develop a model for other country and define new business for enterprises in retrofit programs.

5. Acknowledgements

The outcome of the work had been possible thanks the work of Natural House (an italian PMI which offers wood construction services) and SRM TECH S.R.L (an Italian PMI which offers innovative solutions for real estate retrofit and refurbishment). The work was co financed by Fondazione Goria (Master dei Talenti della Società Civile).

6. References

[1] ECONOMIDOU M. *Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings*. Brussels: Buildings Performance Institute Europe, 2011
[2] COPENHAGEN ECONOMICS, Multiple benefits of investing in energy efficient renovation of buildings. Brussels: Renovate Europe. 2012.
[3] INTERNATIONA ENERGY AGENCY. World Energy Outlook. OECD/IEA. 2009
[4] ALLCOTT H., GREENSTONE M. Is There an Energy Efficiency Gap? In *Journal of Economic Perspective* Vol. 26, (1). 3–28, 2012
[5] Lockwood C. Building retro. Urban Land. November/December. 2009
[6] www.tabulaproject.com_ EU project TABULA - _ last viewed 11-5-2013
[7] BILOW M, "*International Facades - CROFT: Climate Related Optimized Facade Technologies* "TU Delft, 2012
[8] HEGGER M, FUCHS M, STARCK T, ZEUMER M, *Energie Atlas, Institut für internationale Architektur-Dokumentation,* München, 2007
[9] KOLAREVIC B, Information master builders, Architecture in Architecture in the Digital Age: *Design and Manufacturing*, Washington, DC: Taylor & Francis. 56-62, 2005
[10] Buri H, Weimand Y, " The tectonics of timber architecture in the digital age", in Kaufmann H, Building with timber- Paths into the future, Prestel, Munich, 2012
[11] SCHEURER F, SCHINDLER C, BRAACH M. From Design to Production: Three Complex Structures Materialised in Wood. In 6th International Conference Generative Art. Milan: ed. Celestino Soddu, 2007
[12] SPINELLI A, CALLEGARI G, Naturwall© - timber multifunctional systems in refurbishmentsustainable process. in Cruz P. Structures and Architecture: Concepts, Applications and Challenges Taylor & Francis Group. London. 2013

Finding the Balance between Measures Reducing Energy Demand and Measures Based on Renewable Energy Sources in Building Renovation



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1. Short Summary

Calculations carried out for renovations of generic single family buildings in Austria, Denmark, Norway, Portugal, and Switzerland show that the most significant reductions on greenhouse gas emissions and primary energy use are obtained by switching to a heating system based on renewable energies, yet that significant synergies exist when combining this with energy efficiency measures on the building envelope.

Keywords: Building renovation; cost-effectiveness; greenhouse gas emissions; energy efficiency; energy need; renewable energies; reference buildings; life-cycle-costs; insulation measures; renovation packages

2. Abstract

Energy use in existing buildings is a major source of energy consumption and greenhouse gas emissions in Europe. Until now related standards and regulations have mainly focused on energy efficiency measures reducing energy need; however, measures based on renewable energies might to some extent reach environmental objectives more cost-effectively. Consequently, there is a need to investigate the balance between these two types of measures, and related implications for design of and target setting in standards and regulations.

Calculations were carried out with a tool taking into account generic building characteristics of residential buildings in Austria, Denmark, Norway, Portugal, and Switzerland, related climate conditions, prices and emission factors of different energy carriers, as well as costs and effects of different renovation measures comprising both measures reducing energy demand and measures to use renewable energy. Results of these calculations show that a combination of measures reducing energy demand with measures to use renewable energies does not lead to large differences in terms of cost-optimal efficiency levels of the building envelope, compared to a situation when the energy carrier remains unchanged. At the same time, calculations show that the number of building elements included in building renovation determines energy performance of the building and cost-effectiveness of the building renovation more than the efficiency level of a single building element. Furthermore, a switch to renewable energy sources has been found to reduce emissions more strongly than energy efficiency measures.

As heating systems based on renewable energies usually have lower energy costs, it could be expected that the cost-optimal energy efficiency level of the building envelope is already reached at a lower ambition level, if a switch to renewable energies is carried out. However, the results

show that if measures reducing energy demand are combined with a replacement of the heating system, there are to a large extent synergies and not trade-offs between measures reducing energy demand and renewable energy measures, as demand side measures reduce peak capacity of the heating system which reduces initial investment costs more strongly for renewable energy systems than for conventional heating systems. At the same it can also be shown that in order to reduce the impact of buildings on primary energy use and greenhouse gas emissions, it is advisable to promote the renovation of several elements of the building at the same time and in particular to switch also to renewable energies, rather than setting higher energy efficiency levels for individual building elements.

3. Introduction

Standards and regulations for building renovations have focused until now mainly on energy efficiency measures reducing energy needs; however, measures based on renewable energies might to some extent reach environmental objectives more cost-effectively. Consequently, there is a need to investigate the balance between these two types of measures, and related implications for design of and target setting in standards and regulations for building renovation.

4. Method

4.1 General approach and framework conditions

Calculations are carried out with a tool taking into account generic building characteristics of residential buildings in Austria, Denmark, Norway, Portugal, and Switzerland, related climate conditions, prices and emission factors of different energy carriers, as well as costs and effects of different renovation measures comprising both energy efficiency measures reducing energy needs and measures based on the use of renewable energies. Calculations of energy needs take into account energy performance of the building envelope, outdoor climate, target indoor temperature and internal heat gains. Greenhouse gas emissions and primary energy use are calculated by taking into account conversion efficiencies of the heating systems and emission factors as well as primary energy factors of the energy carriers including up-stream emissions or energy use. The life-cycle-cost and cost-effectiveness calculations are carried out dynamically with the annuity method.[1],[2]

Table 1 shows the energy prices used in the calculations. Prices refer to assumed average prices over the next 40 years. The table contains empty cells, as only data actually used for calculations is indicated. By default, a 30% price increase for energy prices was assumed for the 40-years period compared to prices from 2010, if no official national projections on energy prices were available which is compatible with the price increases suggested to take into account by the EPBD regulatory framework.[2] A real interest rate of 3% per year is used.

Table 1: Assumed energy prices for households, including taxes.

Parameter	Unit	Austria	Denmark	Norway	Portugal	Switzerland
Oil	EUR/kWh	0.12	0.15	-	0.13	0.1
Natural gas	EUR/kWh	-	-	-	0.09	-
Wood pellets	EUR/kWh	0.08	0.08	0.1	0.3	0.08
Electricity	EUR/kWh	0.21	0.33	0.24	0.18	0.2

Emission factors and primary energy factors used include upstream emissions associated with the production, transport and delivery of these energy carriers. Country mixes for electricity are based on the sources of electricity consumed and not on the national production mix.

4.2 Reference buildings

Generic reference buildings which were investigated refer to single family residential buildings with a relatively low energy performance before renovation. Table 2 summarizes the assumptions made related to the generic reference buildings.

Table 2: Assumed characteristics of reference buildings for Austria, Denmark, Norway, Portugal, Switzerland before renovation.

Parameter	Unit	Austria - SFH	Denmark – SFH	Norway - SFH	Portugal – SFH	Switzerland SHF
Gross heated floor area (GHFA)	m^2	242	108	113	156.2	210
Façade area (excl. windows)	m^2	185	90	146	114.94	206
Roof area pitched	m^2	181	130	54	80.63	120
Roof area flat	m^2				5.43	
Attic floor	m^2		108			
Area of windows to North	m^2	10	5.86	2	2.66	3.3
Area of windows to East	m^2	9.1	1.3	1.7	8.6	8.3
Area of windows to South	m^2	10.0	13.92	13.6	5.55	13.2
Area of windows to West	m^2	9.1	3.2		10.69	8.3
Area of ceiling of cellar	m^2	145	108	51.1	74.4	80
Average gross heated floor area per person	m^2	60	27	28.3	31.24	60
Typical indoor temperature (for calculations)	°C	20	20	20	min 20 winter / max 25 summer	20
Average electricity consumption per year and m^2 (excluding heating, cooling, ventilation)	kWh/ ($a*m^2$)	22	44	26.5	23.51	22
U-value façade	$W/(m^2*K)$	1.4	0.46	0.5	1.1	1
U-value roof pitched	$W/(m^2*K)$	0.9	0.386	0.4	2.5	0.85
U-value attic floor	$W/(m^2*K)$		-			1
U-value roof flat	$W/(m^2*K)$		-		2.5	1
U-value windows	$W/(m^2*K)$	2.9	2.6	2.7	3.9	3
g-value windows	Factor 0.0 – 1.0	0.76	0.75	0.71	0.88	0.75
U-value ceiling of cellar	$W/(m^2*K)$	0.97	0.9	0.5	1.56	0.9
Energy need for hot water	kWh/m^2	14	22	26.5	24.5	14
Energy need for cooling	kWh/m^2				1.8	

4.3 Renovation packages

For each of the reference buildings investigated, series of measures are defined and applied in calculations as renovation packages.[1],[2],[3] Starting from the reference case, which implies some rehabilitation measures without improving the energy performance, nine renovation packages are investigated denominated M1 to M9 which have progressive ambition levels related to the resulting energy performance of the building. Renovation packages distinguish themselves both by the number of building elements included in improvement of energy performance, and in the thickness of the chosen insulation or in the U-value of the chosen window. A replacement of the heating system is assumed in all cases. For each reference building, combinations with three different types of heating systems are considered.

For the generic calculations in Austria, the following renovation packages on the building envelope are investigated:

- Reference: In the reference case, the wall and the windows are repainted, and the pitched roof is refurbished. These measures do not improve the energy performance of the building.
- Renovation package M1: The wall is insulated with 12 cm of mineral wool.
- Renovation package M2: The wall is insulated with 20 cm of mineral wool.
- Renovation package M3: The wall is insulated with 40 cm of mineral wool.
- Renovation package M4: Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 14 cm of mineral wool insulation
- Renovation package M5: Additionally to M3, the roof is refurbished including membrane, roof battens, shuttering, gutter and 30 cm of mineral wool insulation
- Renovation package M6: Additionally to M5, the cellar ceiling is insulated with 8 cm of mineral wool.
- Renovation package M7: Additionally to M5, the cellar ceiling is insulated with 12 cm of mineral wool.
- Renovation package M8: Additionally to M7, the windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.0.
- Renovation package M9: Additionally to M7, the windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.7.

For the generic calculations in Denmark, the following renovation packages on the building envelope are investigated:

- Reference: In the reference case, the joints in the wall are repaired and windows are repainted. These measures do not improve the energy performance of the building.
- Renovation package M1: The cellar ceiling is insulated with 8 cm of rock wool.
- Renovation package M2: The cellar ceiling is insulated with 12 cm of rock wool.
- Renovation package M3: Additionally to M2, the roof part of the building is insulated with 14 cm of granulate on attic floor.
- Renovation package M4: Additionally to M2, attic floor is insulated with 30 cm of granulate on attic floor.
- Renovation package M5: Additionally to M4, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.6.
- Renovation package M6: Additionally to M4, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.
- Renovation package M7: Additionally to M4, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.7.
- Renovation package M8: Additionally to M7, the wall is insulated with 12 cm of rock wool.
- Renovation package M9: Additionally to M7, the cellar ceiling is insulated with 30 cm of rock wool.

For the generic calculations in Norway, the following renovation packages on the building envelope are investigated:

- Reference: In the reference case, the wall is refurbished and windows are repainted and repaired. These measures do not improve the energy performance of the building.
- Renovation package M1: Windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.2.

- Renovation package M2: Windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.8.
- Renovation package M3: Windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.7.
- Renovation package M4: Additionally to M3, the cellar ceiling is insulated with 8 cm of mineral wool, plasterboard.
- Renovation package M5: Additionally to M3, the cellar ceiling is insulated with 12 cm of mineral wool, plasterboard.
- Renovation package M6: Additionally to M5, the roof is refurbished by insulating the ceiling of the attic floor with 20 cm of mineral wool.
- Renovation package M7: Additionally to M5, the roof is refurbished from the outside with an insulation of 43.5 cm in an airtight construction.
- Renovation package M8: Additionally to M7, the wall is insulated with 15 cm of mineral wool in a ventilated construction.
- Renovation package M9: Additionally to M7, the cellar ceiling is insulated with 40 cm of mineral wool.

For the generic calculations in Portugal, the following renovation packages on the building envelope are investigated:

- Reference: In the reference case, the wall is refurbished by cleaning with vapour and preparing the surface to apply a new coating system, the pitched roof is repaired by replacing the cover material (clay tiles) and the wood windows are repainted. These measures do not improve the energy performance of the building.
- Renovation package M1: The roof is insulated with 5 cm of XPS.
- Renovation package M2: The roof is insulated with 8 cm of XPS.
- Renovation package M3: Additionally to M2, the cellar ceiling is insulated with 4 cm of XPS.
- Renovation package M4: Additionally to M2, the cellar ceiling is insulated with 5 cm of XPS.
- Renovation package M5: Additionally to M4, the compound wall is refurbished with 4 cm of ETICS – EPS.
- Renovation package M6: Additionally to M4, the compound wall is refurbished with 6 cm of ETICS – EPS.
- Renovation package M7: Additionally to M4, windows are replaced with new windows with a metal frame and a U-value for the entire window of 2.7.
- Renovation package M8: Additionally to M4, windows are replaced with new windows with a metal frame and a U-value for the entire window of 2.5.
- Renovation package M9: Additionally to M4, windows are replaced with new windows with a metal frame and a U-value for the entire window of 2.3.

For the generic calculations in Switzerland, the following renovation packages on the building envelope are investigated:

- Reference: In the reference case, the plastering of the wall is restored, the wall is repainted, and the roof is refurbished, yet all those measures do not improve the energy performance of the building.
- Renovation package M1: The wall is insulated with 12 cm of mineral wool.
- Renovation package M2: The wall is insulated with 30 cm of mineral wool.
- Renovation package M3: Additionally to M2, the roof is insulated with 12 cm of mineral wool.
- Renovation package M4: Additionally to M2, the roof is insulated with 36 cm of mineral wool.
- Renovation package M5: Additionally to M4, the cellar ceiling is insulated with 10 cm of mineral wool.
- Renovation package M6: Additionally to M4, the cellar ceiling is insulated with 16 cm of mineral wool.
- Renovation package M7: Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.3.
- Renovation package M8: Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 1.
- Renovation package M9: Additionally to M6, windows are replaced with new windows with a wooden frame and a U-value for the entire window of 0.8.

5. Results

The following graphs summarize the resulting cost effectiveness, greenhouse gas emissions and primary energy use of renovation packages with different heating systems. For each reference building investigated, graphs show the relationship between greenhouse gas emissions or primary energy use and life cycle costs, on a yearly basis and specific per m^2 heated area. In each graph, three different curves are shown, representing the application of the different renovation packages on the building envelope in combination with the installation of different heating systems. Each dot in the curves represents the application of a different renovation package. The point with highest emissions or highest primary energy use represents the reference case. As more measures are added to the renovation packages, emissions and primary energy use decrease.

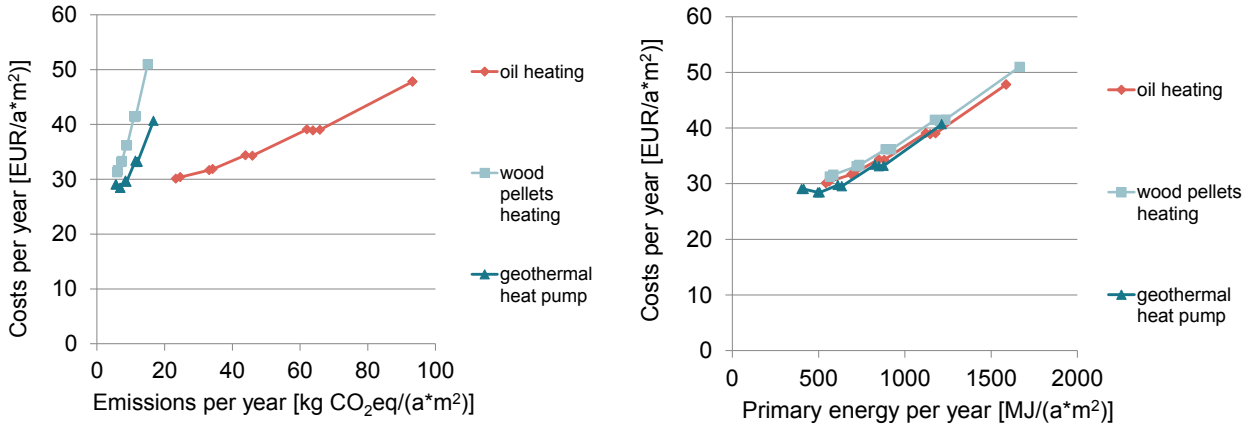


Fig. 1: Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions and primary energy use in Austria

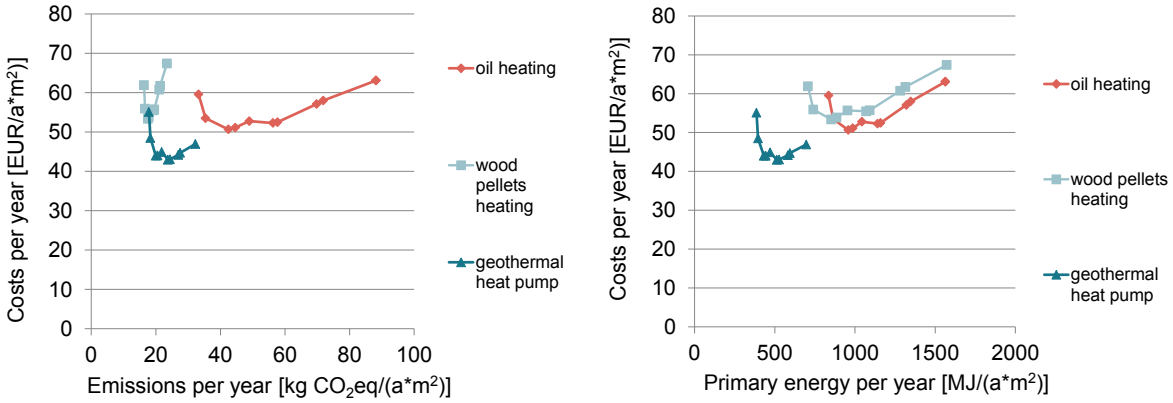


Fig. 2: Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions and primary energy use in Denmark

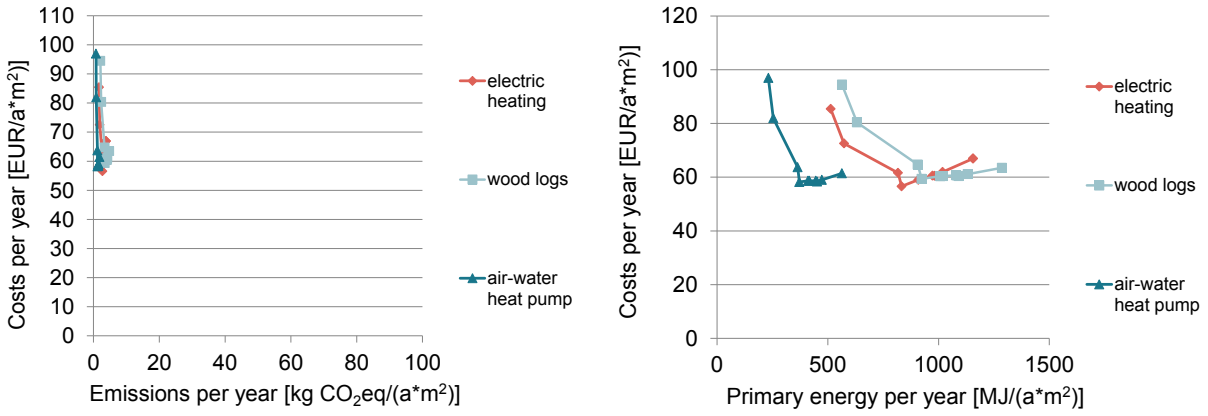


Fig. 3: Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems (note: the systems here are electric heating, wood logs and air-water HP) and related impacts on greenhouse gas emissions and primary energy use in Norway

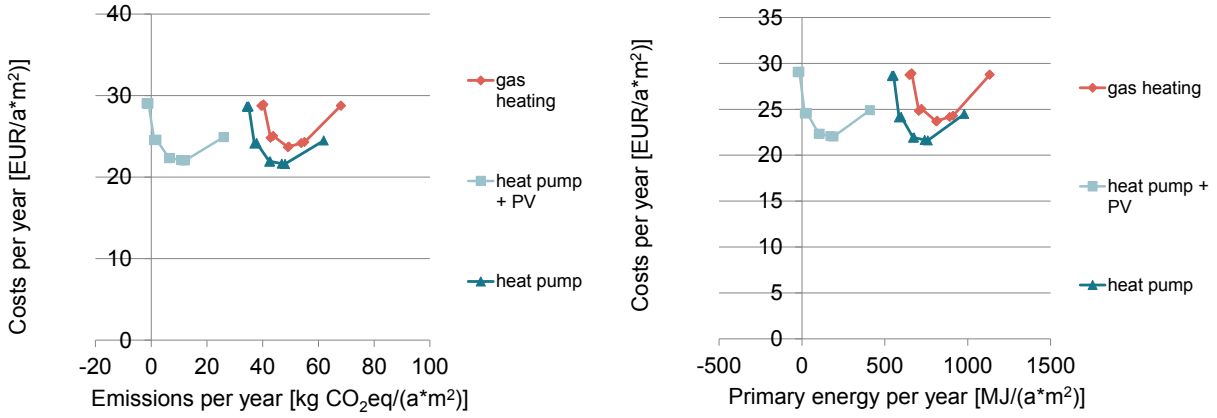


Fig. 4: Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems (note: the systems here are gas heating, heat pump + PV and heat pump) and related impacts on greenhouse gas emissions and primary energy use in Portugal

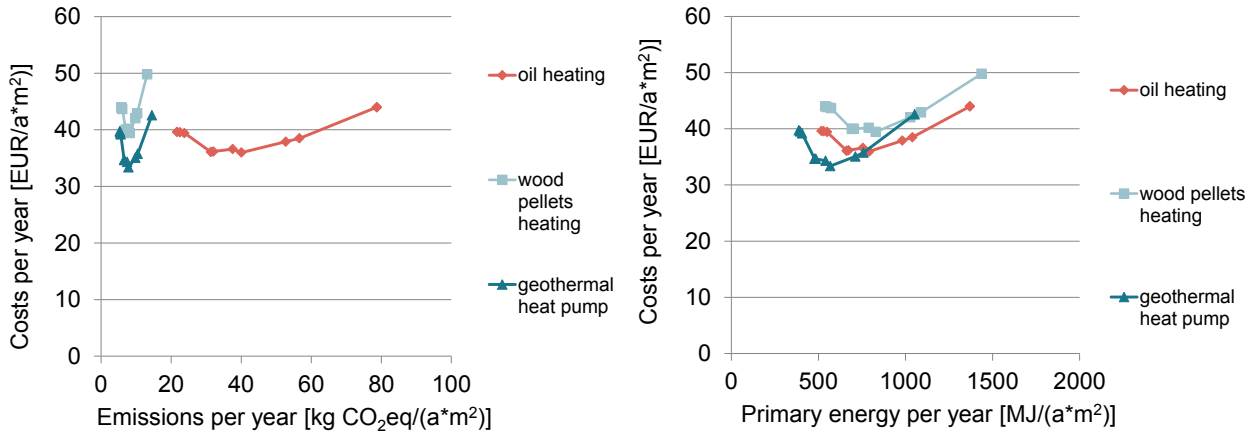


Fig. 5: Comparison of cost effectiveness of energy efficiency renovation measures for different heating systems and related impacts on greenhouse gas emissions and primary energy use in Switzerland

In the graphs as shown in Figures 1 to 5 it can be recognized that a change of the heating system shifts the curves significantly towards lower primary energy consumption and greenhouse gas emissions. The effect is more pronounced for greenhouse gas emissions than for primary energy use if switches from fossil fuels and renewable energy systems are considered. It is observed that a switch from fossil fuels to renewable energy sources reduces emissions more strongly than energy building envelope efficiency measures. However, as compared to a switch to renewable heating systems building envelope efficiency measures might have a larger effect on the reduction of primary energy consumption. As a particular case are the low greenhouse gas emissions for all curves for the building in Norway, because in Norway the electricity mix is mostly free of greenhouse gas emissions, and for the calculations in Norway no fossil fuel based systems have been taken into account. Instead electric heating is assumed as conventional energy system.

When looking at the shape of the curve, it can be seen that they are similar for all curves for a given building. If a renovation package is cost optimal, i.e. if the related dot is closest to the minimum of one of the curves, it is usually also close to the minimum in the other curves. This shows that the cost-optimal ambition levels for energy efficiency measures on the building envelope do not differ strongly for different choices of heating systems. However, note that the cost optimum may be quite different across the different heating systems, particularly with regard to greenhouse gas emissions as well as with regard to primary energy consumption.

At the same time, it can be seen that within a single curve, there are usually some renovation packages, as symbolized by individual dots, which are close together in the curve, whereas between others there are larger differences. The large differences refer to changes in the number of building elements taken into account by the renovation packages, whereas changes in the thickness of insulation or in the U-values of the windows lead only to small differences for the related renovation packages both in terms of costs and greenhouse gas emissions or primary energy use. This shows that the number of building elements included in building renovation determines energy performance of the building and cost-effectiveness of the building renovation more strongly than the energy efficiency level of a single building element.

6. Discussion

As heating systems based on renewable energies usually have lower annual operational energy costs than conventional heating systems, it could be expected that the cost-optimal energy efficiency level of the building envelope is already reached at a lower ambition level, if a switch to renewable energies is carried out. However, the results show that if measures reducing energy need are combined with a replacement of the heating system, there are to a large extent synergies and not trade-offs between energy efficiency measures reducing energy need and renewable energy measures. This can be explained by the fact that demand side measures reduce peak capacity of the heating system which reduces costs more strongly for renewable energy systems with higher initial investment costs than for conventional heating systems. For heat pumps, there is an additional synergy between energy efficiency measures and renewable energy measures, as heat humps work more efficiently if the energy need is lowered by energy efficiency measures on the building envelope. It could also be shown that in order to reduce the impact of buildings on primary energy use and greenhouse gas emissions, it is advisable to promote the renovation of several elements of the building at the same time and also to switch to renewable energies, rather than setting high energy efficiency levels for individual building elements. The results underline in particular the importance of changing to a renewable energy based heating system and to combine this with energy efficiency measures on the building envelope in order create synergies.

The findings are specific to the reference buildings investigated, yet these reference buildings are drawn from different countries and take into account different framework conditions, which strengthens the conclusions derived. Nevertheless, the results remain sensitive to several assumptions, in particular to energy prices and the energy performance of the buildings prior to renovation. The results could be further tested and refined by pursuing the research on the input data, by extending the comparisons to more reference buildings for other building types, energy characteristics, countries, or climate zones, and by taking into account also other renovation

measures which are not investigated here, for example ventilation, solar thermal energy, building automation or energy efficient devices.

7. Acknowledgements

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8. References

[1] EUROPEAN COMMISSION, "*Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012, supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings",* 2012/C 115/01; Official Journal of the European Union, C 115/1 - C 115/28, 19.4. 2012

[2] OTT W., BOLLIGER R. "Cost Effective Energy and Carbon Emissions Optimization in Building Renovation. Basic Methodological Guidelines." Report for the Annex 56 meeting in Copenhagen. May 2013, IEA ECBCS Annex 56, http://www.iea-annex56.org/

[3] BUILDINGS PERFORMANCE INSTITUTE EUROPE, "*Cost Optimality – Discussing methodology and challenges within the recast Energy Performance of Buildings Directive*", Brussels, 2010

[4] JAKOB M., GROSS N., NÄGELI C., UNTERHOLLENBERG S., OTT W., BOLLIGER R., VON GRÜNIGEN S. *"Integrierte Renovationsstrategien und Politikinstrumente zur Reduktion von Primärenergieverbrauch und CO_2-Emissionen"*. Proceedings 17. Status-Seminar «Forschen für den Bau im Kontext von Energie und Umwelt», Zürich, 2012, http://www.brenet.ch/statusseminar.php

[5] JAKOB M., OTT W., BOLLIGER R., VON GRÜNIGEN S., KALLIO S., CHOBANOVA H., NÄGELI C., *Integrated strategies and policy instruments for retrofitting buildings to reduce primary energy use and GHG emissions (INSPIRE)*, Zürich, 2013 (forthcoming).

[6] OTT W., PHILIPPEN D., BAUMGARTNER A., VOGEL U. *"CO_2–Vermeidungskosten bei der Erneuerung von Wohnbauten"*, Swiss Federal Office of Energy Energy Research Database, 2011, http://www.bfe.admin.ch/dokumentation/energieforschung/index.html?lang=en

Management and financial tools for housing regeneration

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Short Summary

Social housing stock in Italy is actually in a profound state of decay; it shows multiple critical elements that range from poor overall energetic performance, to traditionally lower class occupants with related difficulties in solvency to the scarcity of available economic resources needed to act on it in adequate manner.
The concept of a building as an energy consumer is well understood and has been ingrained in all plans linked to energy saving. Limiting energy consumption has become the key point of all policies, laws and regulations issued in the past ten years. We can add to this the paucity of available economic resources.
Based on what I have outlined, is important to identify the possible economic and managing tools that can generate usable resources to requalify social housing. This becomes possible by linking together the building's potential characteristics switching from an energy consumer to an energy producer view, analysing the technical capabilities that come from the exploitation of renewable energy sources (i.e. photovoltaic). The revenue that comes from the sale of the energy produced by the building can create an interesting investment opportunity, albeit without the profit margins that come with traditional investments, and with a longer ROI.
The concept of the building as an energy producer is one that generates a worthwhile reflection in the search for new paradigms needed to close the gap between the need to intervene and the scarcity of economic resources for residential housing.
Due to the evolution of technical solutions for building envelope ever more performing in terms of thermal comfort, and building systems (in particular for thermal and electrical photovoltaic systems), the possibility of having surplus energy with respect to the building's consumption resalable on the market has grown. This surplus (there are a number of case studies on the subject in Italy and abroad; we mention here the pilot study in the town of Reggio Emilia in the FRESH European framework) represents the keystone to radically change the concept of all that purports to the production and management of the housing. The operators who will be capable of working in this revolution are, thus, companies that deal with energy. Escos (Energy Service Companies) in particular come into play both in new developments and in requalification through third party financing operations, bearing the full cost of the operation and obtaining a revenue from the energy bill before and after the operation.

Keywords: Social housing, energy management, economic and financial processes, public-private partnership

1. Introduction

The research, policies, strategies and operational tools that revolve around the theme of "social housing" are going through a period of profound change in Italy. The term "social" is changing its meaning in relation to both the building stock of reference, and to the target users, and to any operational possibilities for the planning and implementation of interventions.
The term is used to indicate housing designed and built to satisfy the basic need of housing in

relation to a user group that is not able to access the free market. They are traditionally houses built by the state using non-repayable economic resources.
Because of the conditions of low solvency of the user group, and the inability for the public administration to make a return on rents, blocked by the fair rent mechanism, social housing is usually considered in terms of the budget as an item of expense necessary to cope with a social emergency.
It is necessary, however, to distinguish between the interventions of Economic and Popular Construction (Edilizia Economica e Popolare - ERP) and those that are more generally referred to as social housing, intended for the poorer part of the population, constructed by a special agreement between the builder (usually a cooperative) and the public administration. In this case, the rents are still controlled, but provide higher figures than those of the ERP.
Most ERP interventions took place in the period of economic boom in the years '50-'70, in an age of widespread speculation and employed technical solutions aimed at solving a problem of quantitative emergency rather than directed towards quality building. The urgent need to renovate this heritage to make it functional at least with respect to the starting conditions of use is strongly felt and necessary today.
To this situation is added the need to deal with the environmental emergency, with the demand for evermore efficient performance parameters relating to fuel economy, the performance of the building shell in terms of thermal insulation, and the operation and building organism in both winter and summer.
Welfare policies in Italy in recent years have come to a grinding halt because of the ongoing economic crisis. The public administration presently does not have access any more to its traditional channels of procurement; non-repayable resources are disappearing, and, again because of the economic crisis, the portion of the population that might require accommodation in a subsidised rent setting is constantly growing. The central problem today is therefore the difficulty in redeveloping and managing the social housing assets; the reasons for this difficulty have to do not only with the need to improve technical performance, but above all with the scarcity of available economic resources.

2. The crisis in the social and economic sector

2.1 From the lower-middle and middle classes to the grey users

Until a few years ago the target users for social housing were made up exclusively of people belonging to social categories at risk, with no income, who accessed ERP rankings more easily the more their general living conditions were considered to be precarious. It was a social class that, all things considered, was homogeneous and stable, in which the conditions of poverty and lack of cultural education went hand in hand, very different from the lower-middle and middle classes who could usually access the private building market.
The crisis and the ongoing economic uncertainty has impoverished and rendered unstable segments of the population that previously formed the backbone of the Italian social fabric, creating a new category of user and one that is difficult to place within well-defined boundaries.
It is a group of "grey" users, with changing and undefined characteristics, no longer economically stable, borderline, which can live in relative economic ease at times and at others slip below the poverty line. This user category has features in common with the bourgeoisie from which it comes as well as with the target users of affordable and popular housing, among which the most significant is the lack of economic stability required in order to gain access, for example, to a traditional bank loan.
The presence of this group of users, which is so fragile and numerically increasing, makes the question very complex and problematic. The crisis affecting the social housing sector is closely connected to the crisis that is affecting the construction industry in general, also with respect to the private housing market.
The marked difference that existed one time between users who took advantage of lodgings at controlled rents and those who turned to the free market of renting and buying is no longer so clear. The separation between the lower middle class and 'grey' users is increasingly blurred, because entering into crisis is the whole area of the middle class, increasingly devoid of fixed points and security with respect to the labour market.
The data for the annual CENSIS report on the situation of the country in 2012 show a worrying and

widespread situation. The collapse of the economic capacities of the middle class is evident (there has been a collapse of the share of wealth of the middle class of between 50,000 and 500,000 euros, and including real estate, which declined from 66.4% to 48.3%.), and this occurred in favour of the already well-off segments of the population (the proportion of households with a net financial wealth of more than 500,000 euros in fact doubled, from 6% to 12.5%). The social divide has increased at the expense of middle-income classes. Over the past ten years, in fact, net financial wealth has gone from 26,000 to 15,600 euros per family, a reduction of 40.5%.
It is important to consider that one of the characteristics of the grey band is a capacity to produce income albeit in a discontinuous manner. So it is not only the population that is traditionally not solvent that is the recipient of affordable and popular housing, but people who are working on a casual basis, that is, not constantly enough to gain access to the free market (for example, to get a bank loan), but at the same time with an economic power that exists even if it is variable depending on the labour market. The grey band is the place where we find the “jobseekers”, identified by Censis 2012 as a segment of the population that is increasing (+34.2% between the first half of 2011 and the first of 2012), active, relatively young (between a quarter are 35 and 44 years old, another quarter in the older brackets, while the others are under 35) which is currently being pressed by the current economic situation due to the lack of job prospects.
The expansion of this user category is also invading segments that up to a few years ago were destined for the private market, broadening the question to what is defined as current residential construction, i.e. the portion of the housing stock typically allocated to the main house of the middle class.

2.2 The collapse of public and private investment in the construction industry.

Everything that has to do with building in Italy, and not only social housing, has suffered a sharp decline in recent years in terms of the economic resources available and possible investments. The collapse of the private housing market has affected a sector that traditionally was able to drive the overall economy of the country in a very strong way, contributing significantly to the stagnation of the current economic crisis. This situation is fully described at various territorial levels. The European Commission Communication to Parliament and the Council of 31/07/2012 (COM2012 433 final) on the Strategy for the sustainable compatibility of the construction sector and its enterprises underlines (referring to the Eurostat press release 169/2011) the presence of a severe crisis in the construction sector, with a drop in the carrying out of building and infrastructural works of 16% occurring between January 2008 and November 2011. At local level, referring to the city of Rome, a relevant indicator of this situation is provided by the decrease recorded within the private housing market. From the note published by the Territorial Agency for the Valuation of the Real Estate Market in the first quarter of 2012, a decline of 20% in sales compared to the data of the previous quarter was witnessed.
If the construction market is in crisis, equally in crisis is the situation regarding access to public resources that can be spent on housing and in particular on social housing.
Public resources currently available and in the process of disbursement cannot alone solve the problem because they are not sufficient to put in place extensive programs of intervention on the housing stock. The concept is disappearing of the disbursement of resources in the form of non-repayable grants, because those provided are not sufficient. These resources also, where available, are not always adequately used. Given the conditions of low solvency in the user group, both in relation to that which traditionally was the recipient of ERP housing and considering the grey band, more solvent but variable, it is not possible to consider the construction and management of social housing as a profitable investment in relation to the absorption of rents. In some cases, the resident population in social housing is not only not able to bear the cost of the rent, however reduced, but not even able to pay energy costs, generating the complex phenomenon of fuel poverty.
One of the key issues is therefore related to the possibility of attracting investors interested in operating in a segment of the housing stock that traditionally has been unprofitable; the very investors plunged into a comprehensive crisis by the economic crisis. If the public administration is no longer able to bear the costs for the redevelopment of social housing, it is equally complicated to turn to forms of public-private partnership. It is necessary to attract the interest of someone willing to invest in a sector that does not pay, a supposed “cold work” to use the term from project financing, destined, that is, at least apparently, to not produce income.

3. Energy management as a resource

3.1 From consumption to energy production

To the question of the possibility of having a space to live, we have to add that of lowering the consumption, and therefore the costs, related to the energy management of the building. In Europe, social housing is made up of approximately 25 million housing units, of which more than half have an energy consumption of over 150 kWh/sq.m/year. In Italy, the social housing stock is traditionally "dated" in time and built between the early 1900s and the '50s and '60s. 80% of this stock needs energy upgrading.
The policies of the last decade have made great strides in this direction dealing with the issue of limiting consumption, with the aim of creating building structures that are as self-sufficient in terms of energy as possible, all the way to considering the building not as a consumer but a possible energy producer.
Because of changes in the energy market in fact, the ability to produce energy independently of the networks of national production has been made possible by the spread of large-scale technologies related to solar energy. The spread of procedural and economic mechanisms for the autonomous management of energy, the presence of state incentives for the diffusion of these same tools, and a growing widespread awareness of environmental issues, is leading to an increasingly large number of individuals choosing to operate in this field.
The concept of energy sustainability is now closely linked to economic sustainability; we assume the cost of installing plant capable of producing energy because this has advantages at an economic level that are perceptible albeit in the medium and long term. The market also is rapidly absorbing the growth and spread of new products able to operate in this way.
At the basis of the concept of economic sustainability is that of self-financing; creating a building structure that is autonomous in terms of its needs regarding plant operation means becoming independent of the traditional channels. It is precisely the energy market operators, primarily the ESCOs (energy saving companies), private companies which invest by paying the costs relating to the intervention, in the expectation of a financial return that comes from the management of the same, that are able to offer possible solutions as regards it.
Thinking in terms of energy production may represent an element of interest for those who are able to make a profit from the management of the same, freeing themselves from the condition of being resident users. A structure with high energy efficiency also improves its functioning (and therefore its performance in economic terms) if the general conditions of the same, the shell and plant, are optimal.
This kind of operation is possible through the use of appropriate management and budgetary tools. The intervention of the ESCOs is in this sense a great opportunity. They have an interest in improving the energy functioning of a building because they can achieve a profit from the management of the same, through instruments (such as energy performance contracts) that guarantee the ESCO a profit that comes directly from the collection of the energy saving. In layman's terms, the more a building consumes less and produces more, and the more the energy bill is lowered, the more the ESCO is able to earn. The redevelopment of the building stock, with the consequent increase in technical and energy performance, offers, in this sense, an interesting perspective.

3.2 The European Project FRESH and the pilot case in Reggio Emilia

A case study in this sense is represented by the European Project FRESH (Financing Energy Refurbishment for Social Housing), which has just ended and whose results are being evaluated, which in Italy was carried out through a pilot case in the Municipality of Reggio Emilia.
The project opened up a discussion whose aim was precisely that of reflecting on the relationships between the various parties involved in operations of third-party financing with the help of an ESCO. In particular it has used, analysed and implemented the forms of contract that can be stipulated in these cases. The EPC (Energy Performance Contract) contract is proposed as a large-scale solution (but applicable and improvable in line with specific cases) for energy upgrading in social housing.
The project was carried out with a number of experiments that took place through contracts in

several states of the European Union on upgrading the energy efficiency of buildings destined to social residential use. In particular, the countries involved were France, Italy and the UK. The buildings chosen as pilot projects were built in the ‘80s, with the prevailing construction technology based on the use of concrete with a high consumption of resources in the phase of use.
The Italian pilot project consisted in entrusting the provision of energy services in a building for public residential use under the management of the Reggio Emilia ACER located in the Municipality of Reggio Emilia. It is a small building (a total of 13 apartments), built in the ‘80s. The building envelope was made with precast concrete panels with an interposed insulating panel; the air conditioning plant, run on natural gas, did not ensure adequate performance in energy efficiency.
The call for tenders involved the renovation of the heating system in order to obtain enough savings in fuel consumption that could repay the intervention itself as well as the cost of the energy service made up of the conduction of the air conditioning systems (inclusive of extraordinary maintenance) and the operation and maintenance of heating systems, as well as ancillary services including the provision of fuel for the heating plant in winter.
The main objective of the intervention was to achieve in the first year of activation energy consumption savings of 35% in terms of primary energy use as well as a reduction in energy costs of at least 35% of the expenditure currently incurred. The project is now finished, with satisfaction on the part of the users both in terms of savings and quality of life.
The profit for the service contractor, in this case, comes from the retention of a portion of the energy savings achieved through the redevelopment. From the collection of that fee, which occurs for a given number of years stated in the contract, also comes the coverage of costs incurred in the intervention. It is obvious that the success of such operations depends on the ability to use the technologies available on the market and to organise both technical and managerial competences.

4. Open issues and possible strategies

4.1 Self-reliance and economic sustainability

The goal of economic sustainability, understood as self-reliance, can be pursued only through a careful reflection on the instruments currently able to operate in this way.
The open questions on the subject, which have to be answered in the near future for this revolution to become feasible at the operational level, involve various aspects.

4.1.1 The operators in the energy market: problems and potential

The first aspect concerns the operational difficulties encountered by those working in the energy market.
The problems deriving from the spread of forms of partnership involving the intervention of ESCOs are of a different nature. On the one hand, a low diffusion of the phenomenon corresponds to a lack of knowledge of the same. The disbursement of a loan granted to an ESCO by a bank, for example, can no longer be connected to the existence of any guarantees (as is the case in traditional lending mechanisms), but to the obtainment of the promised results in terms of improvement in energy performance. The evaluation of this type of factor presupposes the presence of adequate technical knowledge, not yet possessed by the operators present in the market.
The skills required of an ESCO, on the other hand, range from the technical to the managerial and financial, since the ESCO proposes to manage the operation overall. The purely technical and financial aspects, moreover, are more closely connected than in the past for other management operations of the housing stock, given the close connection between the savings achieved and the use of technical equipment capable of generating precisely those savings. To this is added the difference in performance compared to operations carried out in the construction market. In the phase prior to the start of the economic crisis there was a period of great speculation, with very high earnings for builders and investors. Currently the instruments connected to third-party financing with the help of ESCOs provide longer payback times with earnings that are lower and diluted over time.
To this is added the relationship with users; they, while no longer entering the game as potentially paying customers, are the recipients of the interventions, and have to be assisted in order to work together to make the right choices. Given that users traditionally resident in social housing do not

have the appropriate skills to fully understand such complex interventions, there is a need for great transparency and simplicity in communicating what is actually being accomplished.

4.1.2 Possible public resources to guarantee private investments: the Funds

The need to entice ESCOs to enter a market that is traditionally unprofitable led to the birth of funding mechanisms through Funds, particularly the funds of the Cassa Depositi e Prestiti (Deposits and Loans Fund). The ESCOs are considered, in this case, as possible beneficiaries such as private citizens and condominiums, or as public bodies, for certain types of intervention relating to the improvement of the building shell and plant through appropriate and/or innovative technologies.
The Cassa Depositi e Prestiti is a joint-stock company 80% controlled by the Ministry of Economy and Finance. It is subject to minimum reserve requirements by the European Central Bank as all banks are. The resources it channels through the funds therefore are not grants, but real investment arrangements that foresee the interest of a bank and the possibility of a return, through which it is possible to finance the fund itself. Such a return, albeit non-speculative and with low margins, must be present. Since 2009 the operations of the Cassa have extended to the possibility of financing projects of public interest such as those related to social housing.
Among the available and active funds and the financing channels promoted by the Cassa Depositi e Prestiti is the revolving Kyoto fund. This fund has an initial budget of 600 million euros. The fund is called “revolving” insofar as it is fed with the instalments of the repayment of loans, and has been available and operational since 16 March 2012. It can be used and combined with other incentives, such as those relating to the issuance of Green Certificates, Third and Fourth Energy Account, and incentives for the production of electricity and heat. Between 2012 and 2013 the objectives of the fund have remained essentially the same with a few variations. The request for funding in the years 2012 and 2013 was very high, and exhausted very shortly after the activation of the requests, which could be made through an IT portal.
The same concept forms the basis of the European Energy Efficiency Fund (EEEF), connected with the European objectives of 202020. In this case too, possible recipients are the ESCOs but also the social housing associations. The concept behind this type of instrument is that of attracting public and private capital to promote partnership initiatives aimed at solving environmental problems.
The importance of this modus operandi is fundamental from the point of view of seeking to create forms of guarantees for investors operating in sectors of high risk and collective interest; the impulse coming from the public administration in terms of incentives is very important to create the initial lever to trigger a mechanism of this sort. The same concept is at the basis of the operation of the incentives for the production of energy from renewable sources, which have increased energy production from photovoltaic sources enormously in recent years. The report “Statistical data on electricity in Italy in 2011,” by Terna shows, in terms of net production, a decline in thermoelectric production (218.5 TWh against 221, -1.1%) and hydroelectric (47.2 TWh against 53.8, -12.3%), and a significant increase in the contribution of the other renewable sources of wind, solar and geothermal (25.8 TWh against 16, +61.2%).
Among these photovoltaic is the most relevant technology, because of the enormous increase of production recorded which is equivalent to +499.2% (10.7 against 1.9 TWh) which has far exceeded the already very considerable result of 2010 (+177%). In 2011 the number of operating photovoltaic systems reached 330,306 (of which 174,329 were connected to the grid in the last year of reporting).

4.2 From the building to the city

The idea of energy self-production involves not only the operative possibilities on single buildings, but more widely the satisfaction of a need of a collective character.
The analysis carried out on the possibilities of intervention on a building stock that is problematic both in terms of the intrinsic characteristics and the conditions of the users, such as those of social housing, reveals potential for use by reasoning on a different scale, that of the city.
Going up in scale, in fact, and considering the possibilities for energy production no longer from the single building but from the block, the sector, the small size of the neighbourhood, we enter into the logic of the smart city understood as a set of individuals working collectively to solve single

problems.
From the point of view of energy production adding together the energy production of groups of houses rather than focusing on the efficiency of individual buildings is undoubtedly more productive in terms of the amount of energy produced and possibly residual energy as a surplus to be placed on the market. If it is this surplus that acts as a lever to move from the concept of a building as energy consumer (with the resulting energy savings in various forms), to a building as a structure that is energetically as independent as possible (aiming for the solution of the passive house at zero consumption), to a building as producer of energy (deciding how to use the energy produced) and as a producer of economic resources, it is necessary to find a way to develop collective strategies to help this become possible. The conditions of the built heritage in Italy involve an urban core that often is very compact, and for this reason concentrating on the production efficiency of a single building is not always convenient precisely because it operates within a built context in which the technology linked to solar collection cannot always be effective. The energy efficiency of a technological solution can be influenced by the relationship with other buildings, in terms of orientation, shadows, management issues, the shape of the building itself. The same house if transported to an empty space with the right exposure could make much more energy if it were not wedged in a built-up area that is often very compact; but at the same time the presence of a compact built-up area, with buildings similar in their original constructive technology, and numerically significant, allows choices to be made that are more convenient by adding together the energy production of a number of units.

5. Conclusions

Thinking in terms of buildings as potential producers and not just as consumers of resources, and using the earnings resulting from the management of the energy produced from the buildings for the redevelopment of the social housing stock, can bring benefits both in terms of the quality of life of the resident users and in terms of new investments to be made on the market, generating a potentially effective economic induced activity.
The social housing sector has been, in recent years, the subject of numerous research projects in Italy and abroad, mainly aimed at the development of innovative solutions especially at the technical level. These solutions, without adequate financial resources to allow their large-scale diffusion, risk remaining examples of an excellent technological level but destined to have a low take-up in practice, limiting themselves to the development of prototypes of a very high technological quality and high-impact innovation, but without the possibility of becoming widespread on a large scale. Within this framework, it is important therefore to consider the connections between technical possibilities and the management-economic ones that can be used to promote the redevelopment of the social housing stock in a concrete way.
To summarise and conclude, the two main issues that need to be developed in the near future relate to:

- The need to make interesting and appealing to the eyes of a private investor possible redevelopment interventions on the existing. This need might be addressed by linking redevelopment to the introduction of systems and technologies for the production of energy. The ultimate goal is that of redeveloping in a sustainable manner, considering the economic aspect, above all related to energy production linked to the introduction of photovoltaic systems. At the basis of this type of intervention is the overturning of the common way of thinking about the house as something that consumes resources, focusing rather on the fact that through the introduction of appropriate technologies it is possible to produce energy resources which, if managed correctly through the use of appropriate management tools, can be transformed into opportunities to produce economic resources. These opportunities range from the possibility of using the energy produced for the running of the home and the services related to it, in order to create a structure that is as independent as possible from the point of energy.
- The need to think in a collective way rather than stopping at the individual instances of the single case. This request comes from considering the request for energy/economic production collectively, no longer being interested in the single building but in groups of houses arranged in blocks, sectors, larger groups than a single building. This is how possible solutions to a problem like the apparently limited one of social housing can be used for the redevelopment of a building and social fabric that is numerically much more

significant and complex. This involves on the one hand the possibility of producing energy in a more rational and efficient way, but the other leads to problems both from the point of view of the management of the service and from the point of view of the management of possible initiatives.

A reflection undertaken to solve a social emergency can be transformed, if properly managed, into a resource capable of generating mechanisms that can also be used elsewhere with potentially beneficial effects for the rest of society.

6. References

[1] DELERA, A. (a cura di), Ri-pensare l'abitare, Politiche progetti e tecnologie verso l'housing sociale, Hoepli 2009 ISBN 978882343781

[2] CLEMENTE, C.; DE MATTEIS, F. (a cura di), Housing for Europe, DEI - Tipografia del Genio Civile, Roma,2010. ISBN 9788849625110

[3] PIERMATTEI, P., Resources for regeneration: economic and financial processes for social housing in Italy, Proceedings International Conference "World Building Sustainable Conference SB11, Helsinki, Finland, 18-21 ottobre 2011 ISBN: 978-951-758-534-7

[4] PIERMATTEI, P., Recupero del patrimonio di edilizia pubblica esistente: aspetti economici e sociali" In: Ponte n. 9/2011, DEI Tipografia del Genio Civile, Roma 2011 ISSN: 1129-3918

[5] PIERMATTEI, P., Riqualificazione edilizia ed urbana sociale sostenibile. Il recupero del quartiere Compagnoni Reggio Emilia in Ponte n. 9/2011, DEI Tipografia del Genio Civile, Roma 2011 ISSN: 1129-3918

[6] LANNUTTI, C., CORSETTI M., "Sostenibilità energetica ed economica negli interventi di riqualificazione dell'edilizia residenziale pubblica", in TECHNE, n.3 2012, Firenze University Press, Firenze, 2012. ISSN 2239-0243

[7] PIERMATTEI P (2012). La gestione dell'energia come strumento per l'edilizia residenziale sociale. Proceedings International Conference: Abitare il nuovo, abitare di nuovo ai tempi della crisi., Napoli, 12-13 dicembre 2012 ISBN: 9788884972361

[8] PIERMATTEI p. (2012). Componenti invisibili per la gestione energetica ed economica della residenza. In: B. Todaro con A. Giancotti e F. De Matteis. HOUSING. Linee guida per la progettazione dei nuovi insediamenti. p. 202-207, ROMA:Prospettive Edizioni, ISBN: 9788889400821

[9] ARBIZZANI E, CLEMENTE C, CIVIERO P, PIERMATTEI P(2012). Strumenti di pianificazione come dispositivo integrato di controllo della qualità del progetto urbano sostenibile. Il caso dei nuovi Piani di Zona di Roma. In: C. Clemente. Pluralità Tecnologica. Papers. p. 27-41, ROMA:Rdesignpress, ISBN: 9788889819333

[10] Commission of the European Communities, Strategy for the sustainable competitiveness of the construction sector and its enterprises, Brussels, COM(2012) 433, 2012.

[11] Dati statistici sull'energia elettrica in Italia nel 2011, nota di sintesi, Terna, Direzione Relazioni Esterne e Comunicazione, www.terna.it



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Catalogue of passive house details for refurbishments

1. SYNOPSIS

The IBO catalogue of passive house details for refurbishments [1] is a comprehensive resource for solutions for refurbishments tasks. Construction and connection details, checked for their physical, ecological and technical properties are offered to designers, the building trades and producers of building materials.
Typical refurbishment tasks like roof space conversion, basement drainage, façade renovation are treated systematically.
Ecological and hygienic aspects are pivotal for the evaluation of innovative solutions. This paper uses examples of façade and basement renovation to demonstrate the comprehensive approach used in [1].

2. INTRODUCTION

Refurbishment of existing buildings to comply with the passive house standard or refurbishments using passive house components may lead to savings in terms of heating demand from 75 % to 90 %. Conventional refurbishment will realize less than half of this potential. Refurbishment with passive house components guarantees a marked improvement of physical safety in terms of condensation and mould development. Most notable benefits are comfortably high temperatures of inner surfaces and good indoor air quality.
The catalogue is structured according to

- building tasks – encountered in buildings from the 19th century to the 80s of the 20th century, mainly in central Europe with a focus Germany and, especially, Austria. In this paper we present two solutions for renovation of base and basement slabs presented
- regular cross section – items are ordered according to building components, detailled as regular cross sections and connections and evaluated. In this paper we present a façade renovation with passive house qualities.

- recurring problems of thermal renovation with passive house components like moisture or harmful substances in existing buildings, basement climate and slab foundations in contact with ground without moisture seal. In this paper we present an climate optimization for a basement

For details of methodology see [1]

3. RESULTS

3.1 Building tasks

Treated are buildings from the 19th century to the 1980s, mainly in central Europe with a focus Germany and, especially, Austria.

Buildings are listed in order of age:

- buildings built before 1918
- buildings built between 1920 to 1950
- buildings of the 1950s and 1960s
- buildings of the 1970s
- massive buildings of the 1980s
- prefabricated lightweight buildings of the 1980s

Fig 1. shows an example of a refurbishment detail in 2 variations for a building built before 1918 with solid brick outside wall and vaulted ceiling.

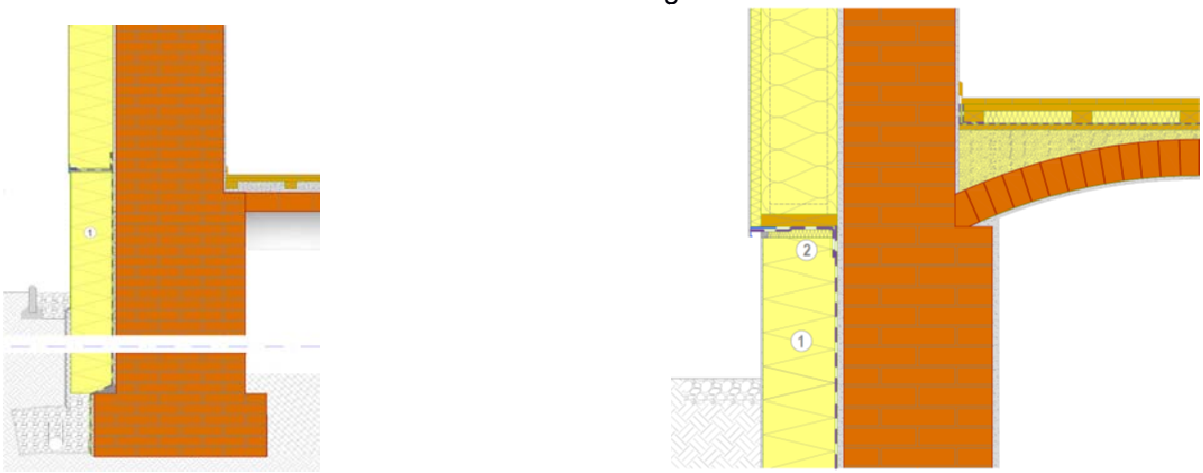


Fig 1. Example of a refurbishment detail: detail with 2 variants for a building built before 1918 with solid brick outside wall and vaulted ceiling (Notice: Variant basement floor insulation is insulated on the perimeter only at those parts of the basement wall which are in contact with outside air)

3.2 components of passive house retrofit

Overview

Items are listed according to building components and detailed as cross sections and connections

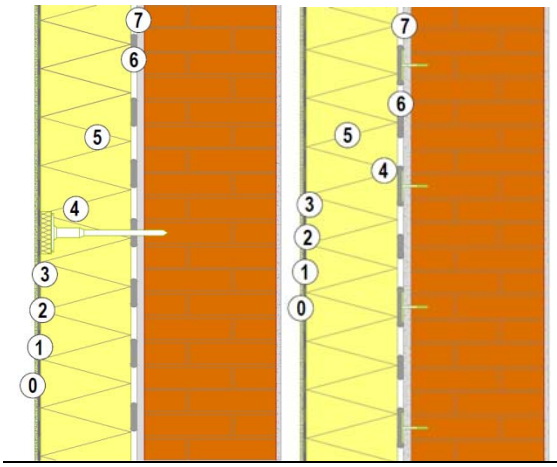
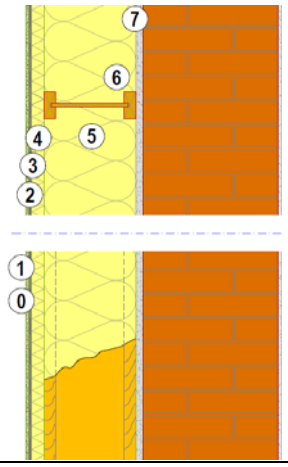
- Insulation materials – Overview and ecological evaluation
- Outside thermal insulation of outside walls

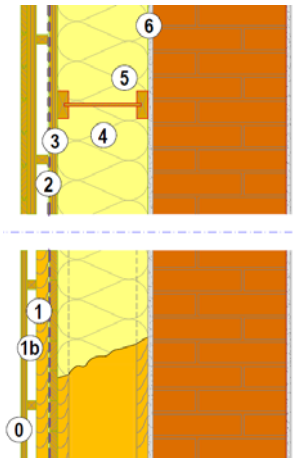
- Inside thermal insulation of outside walls
- Thermal insulation of steeply pitched roofs
- Thermal insulation of flat roofs
- Thermal insulation of uppermost floors
- Basement slabs thermally insulated upper side
- Basement slabs thermally insulated lower side
- Thermal insulation of foundation slabs
- Outside thermal insulation of basement walls in contact with ground
- Balconies and loggias
- Windows
- Ventilation systems

Example: Ecological amorisation in façade renovations

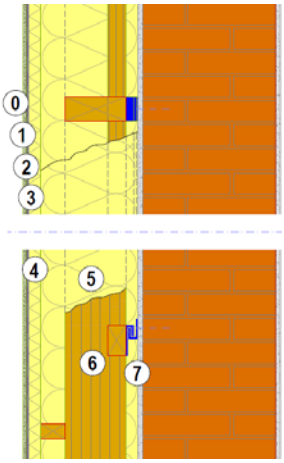
For an outside wall thermal insulation one may consider rear ventilated or composite (ETICS) systems, plastered or non-plastered systems, glued ot mechanically fastened systems (Fig 2). Systems may differ in

- level of prefabrication
- fastening technique (glued or screwed)
- flatness tolerance and tolerance for adhesiveness of existing surface

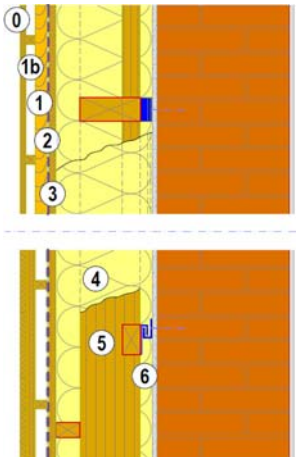
ETICS	Wood construction built on-site, plastered
	
Wood construction, built on-site, rear ventilated	Prefabricated wood construction, insulation material inserted on-site, plastered



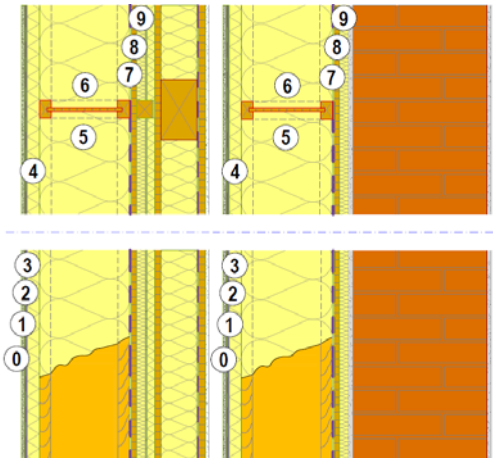
Prefabricated wood construction, insulation material inserted on-site, rear ventilated



Wood construction. Prefabricated including insulation material, plastered



Wood construction, prefabricated including insulation material, rear ventilated



Anchored on-site

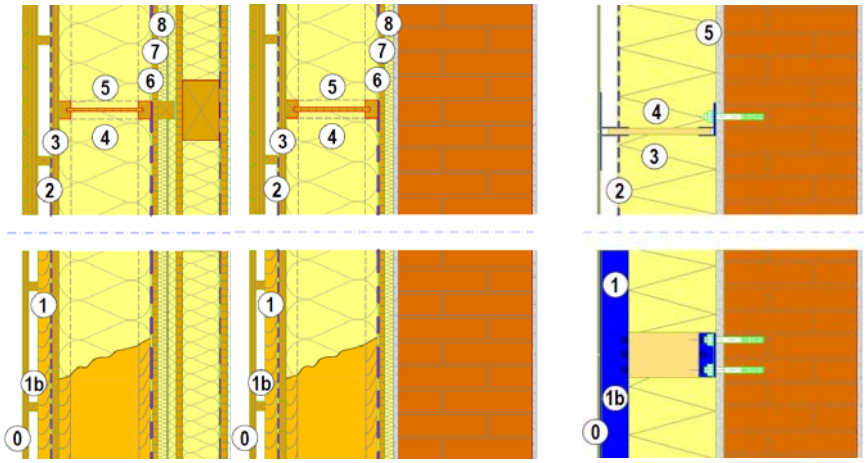


Fig 2: Regular cross sections analysed in detail in [1]

Summary of physical considerations

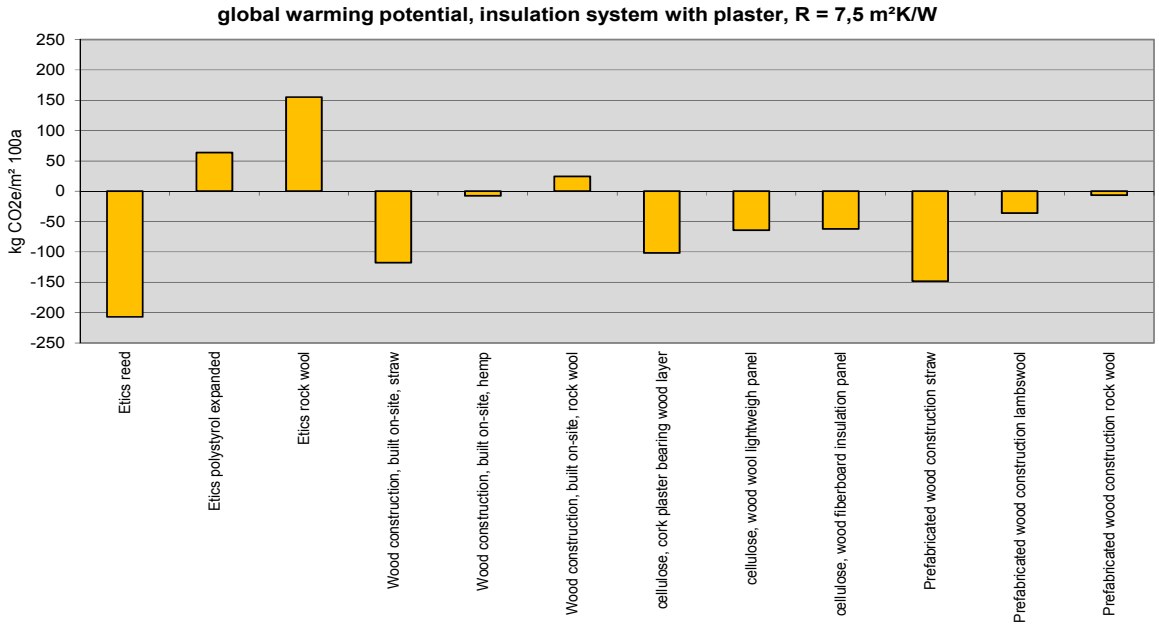
Thermal insulation must not be ventilated with cold air at the rear side. No cracks or clearances must connect warm and cold areas. As existing walls may not be flat, their surfaces must prepared according to norms and regulations.

Air-injected insulation materials will fit to uneven surfaces. Systems with inflexible insulation materials (ETICS) or prefabricated insulated constructions require filling of rear air gaps which is a disadvantage. Sound insulation will be improved in almost all cases, depending on properties of the existing wall and flexibility of the surface layer. ETICS systems may with inflexible insulation materials may reduce sound insulations properties in some cases. Using thicker layers of plaster or choosing more flexible insulation materials may prevent such problems. Moisture protection of insulation systems is dependent on the finishing/quality of outer surfaces:

- plastered systems allow for high moisture diffusion and hydrophobic properties against driving rain at the same time if modern coatings (silicate or silicate resin plasters) are applied
- rear ventilated systems separate both functions with advantages in moisture diffusion properties

Summary of ecological considerations

Ecological impacts of production of refurbishment components are dominated by impacts resulting from thermal insulation material production (Fig 3). All other required building materials have comparably small impacts resulting from production. Systems produced with minor processed insulation materials show favorable low values.



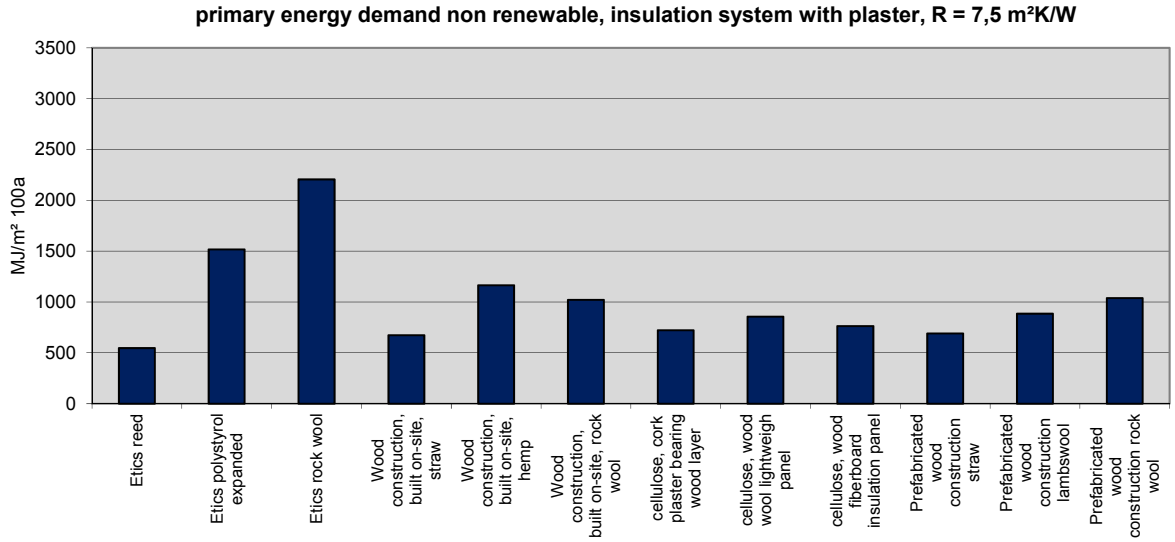


Fig 3: Global warming potential and primary energy demand non renewable of production and maintenance of different insulation systems an different insulation materials, with plaster, 100a

Expenditures for production of refurbishment components are to be balanced against achievable heating energy savings resulting from minimized heat transmission losses.

Fig 4 balances expenditure in terms of global warming potential (GWP100) of production and maintenance of an ETIC system with EPS-F panels (λ = 0,04 W/mK) against heating of a building with natural gas to a level of 20 °C in a typical central European climate varying thickness of insulation

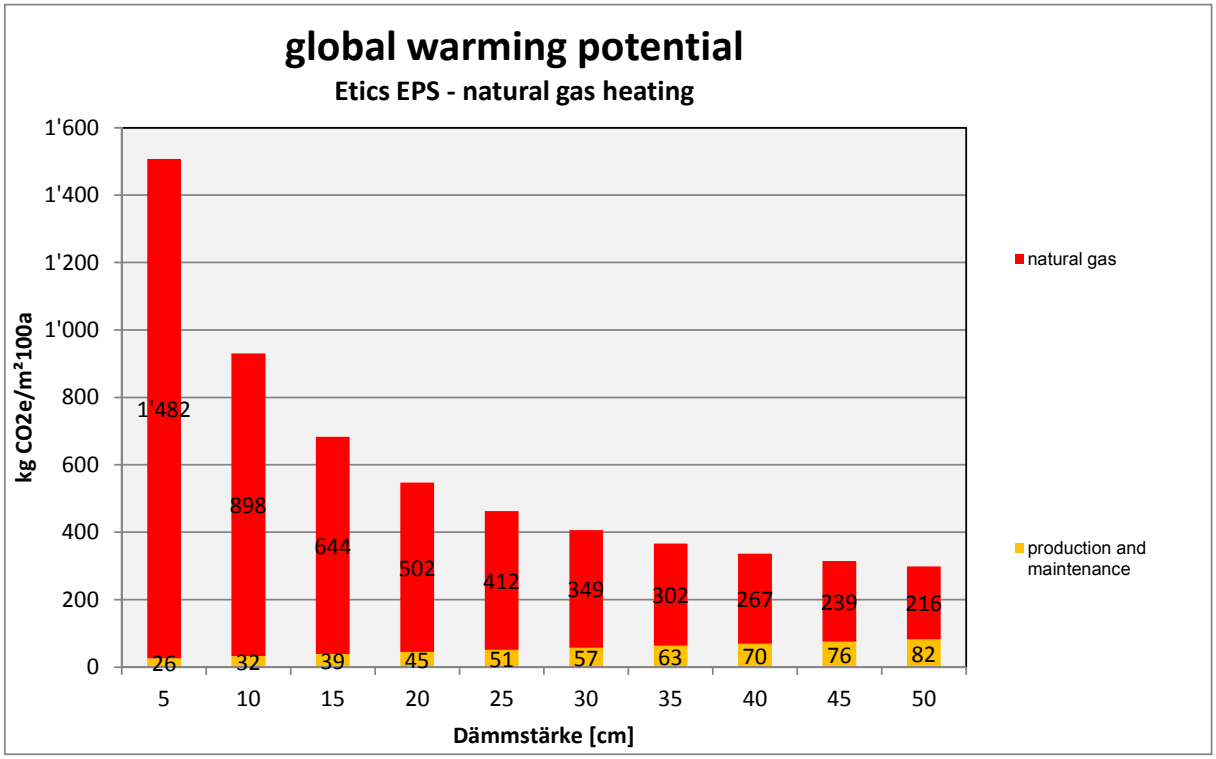


Fig 4: Global warming potential of production of an ETIC system plotted against layer thickness (incl. Exchange of materials within 100 years) assuming heating with natural gas to compensate heat transmission losses

Fig 5 shows decreased values of global warming potential (GWP100) as result of refurbishment depending on thickness of insulation material layers and heating system

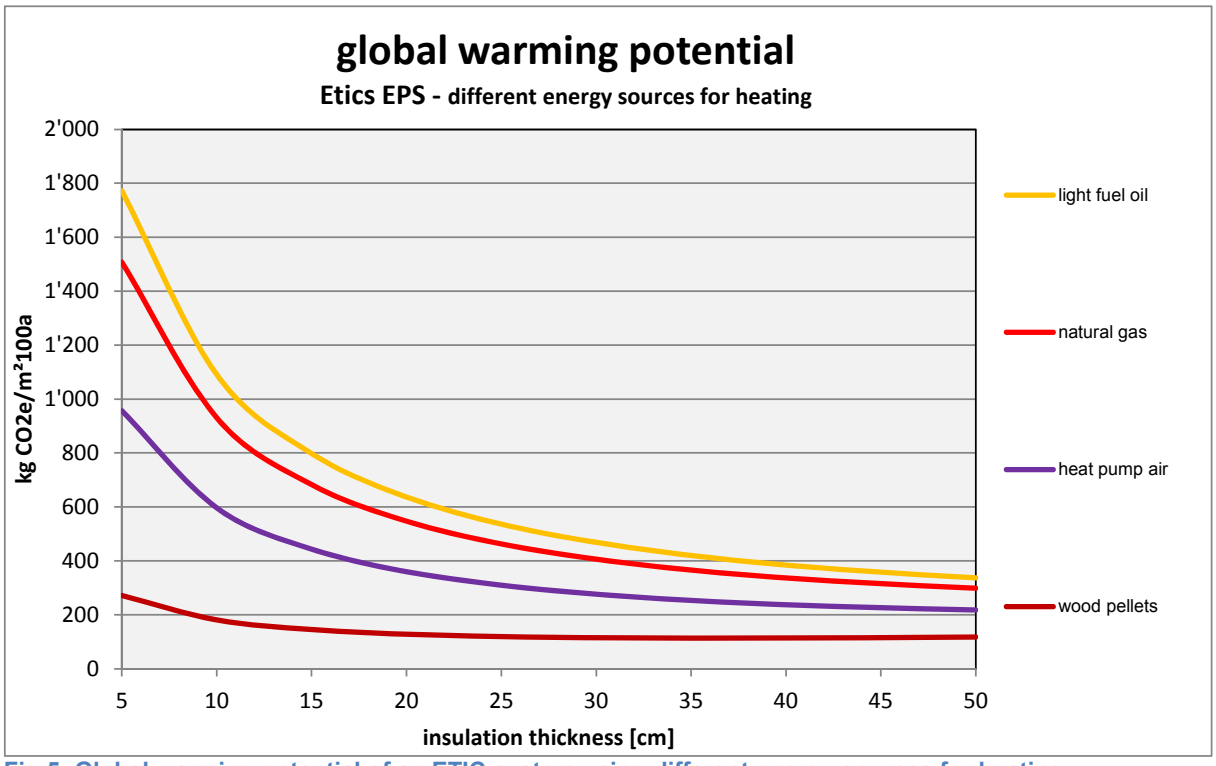


Fig 5: Global warming potential of an ETIC system using different energy sources for heating

Optimum values of insulation material thickness in EPS ETICS are beyond 50 cm in most cases. Only with wood pellets heating and CO_2-neutral combustion there is a minimum of expenditure at 35 to 45 cm insulation material thickness. Thermal insulation with EPS, an ecologically less favorable insulation material, should be applied with thicknesses required for the passive house standard. Optimum thickness is even higher with insulation materials that carry more favorable ecological expenditures of production.

Building site workplace exposure is the sum of exposures resulting from individual components. Protection measures are mandatory especially for air injection of insulation materials incurring considerable dust emissions. Prime coatings may emit large quantities of solvents.

Disposal properties of a construction differs with separability into its components and with their suitability for material and energetically use.

Construction details are evaluated regarding deconstruction, recycling and disposal according to methods developed in [2]. The following table shows results of a disposal rating of selected variants of an outside wall outside thermal insulation. A 30 cm brick work (dressed stone of brick) with inside lime cement plaster is assumed as outside wall.

Insulation material variants listed are installed to this wall:

Plastered insualtion system	**Note**
30 cm ETICS with EPS panels (disposal of brickwork due to contamination)	6,7
30 cm ETICS with EPS panels (recycling of brickwork despite of contamination)	4,9
34 cm ETICS with meineral foam panels	3,3
30 cm I-beam with cellulose fibre, plaster on 4 cm wood wool lightweight panel	3,0
30 cm wood frame with wood fibre insulation, plaster on 4 cm wood wool lightweight panel	1,2
Rear ventilated insulation system	**Note**
30 cm cellulose fibre between I beams with wood shuttering, wood façade on wood lathes	2,6
30 cm cellulose fibre between wood construction1	1,1
30 cm EPS panels fixed with anchors, mounted with dowels in the brickwork, aluminum facade on aluminum substructure	2,0

General topics of thermal refurbishment with passive house components

- Moisture in existing buildings
- basement climate and floor slabs in contact with ground without sealing
  inside insulation in refurbishment
- microbial fouling on façade surfaces
  design aspects
- harmful substances in existing buildings
- disposal options of typical demolition waste

Example: High grade refurbishment with improvement of basement climate

Problems of thermal and hygric conditions in basements can be described as:

- If an insulation is applied to basement ceilings, temperatures in the basement will decrease by several degrees depending on ventilation and thermal bridges
- With absolute humidity remaining constant, relative humidity will increase steeply, mould may develop in certain conditions.
- Moisture contents at the surfaces may vary with sources of humidity (surface water (pavement!) ground water, soil conditions, use-specific sources like laundry including drying) and with ventilation intensity.

Two variants of thermal refurbishment of a base in a building built before 1918 are used to demonstrated our comprehensive evaluation procedures (Detailed drawings see above).

- Variant 1 Umbrella-type insulation. Basement wall insulated until down to the foundation slab, basement ceiling slab is not insulated
- Variant 2 Insulation of basement ceiling slab, base is insulated only partly where in contact with outside air

Technical and physical evaluation

Technical effort for the variant „umbrella-type insulation“ is large

- the whole basement wall has to be excavated, securing of the excavation pit is dependent of soil conditions
- in many cases an excavation of the foundation for insulation and sealing work is not feasable

In the case of the variant „basement ceiling insulation“ the perimeter insulation and the sealing extends only 50 cm above the part of the wall in contact with outside air. The basement ceiling slab is insulated upper side (alternatively: lower side):

- Technical effort is considerable for removing the existing floor in order to install insulating fills and to reinstall a new floor
- Effort to insulate the base at the outside is small

In the variant with basement ceiling slab insulation downward heat transfer ist reduced significantly. In the variant with umbrella-type insulation vertically intruding water can be kept away.

Calculations of hygrothermal behaviour were made using a 3dimensional simulation program Ham4D, which was developed at the Technical University of Vienna, and which is capable of reproducing all relevant humidity and heat flows (simulation period is 100 years). Water content and relative humidity of the umbrella-type insulation variant in a settled state is shown in Fig. 6 and 7:

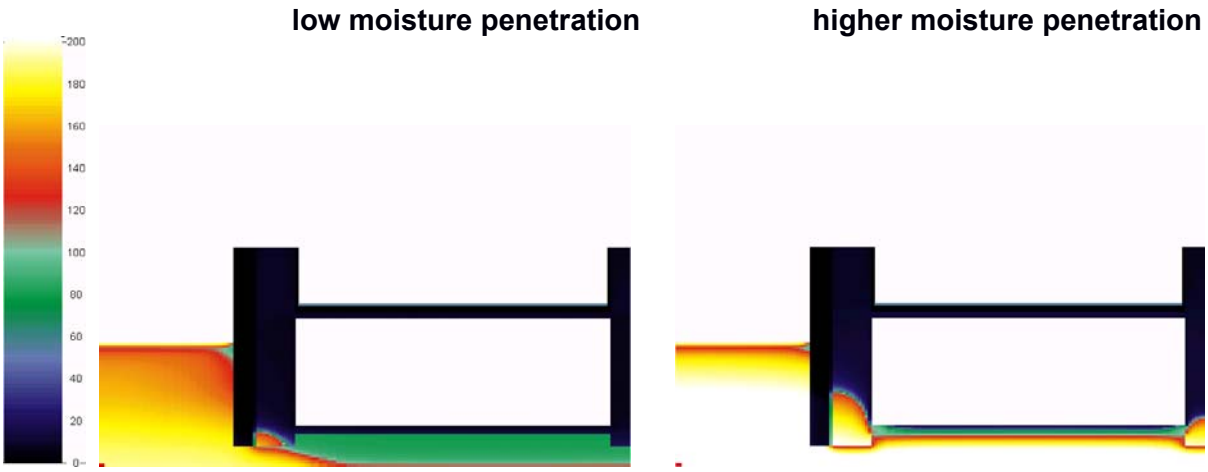


Fig 6: Water content [kg/m³] with lower or higher moisture penetration and an air exchange of 0.1/hr (1 January)

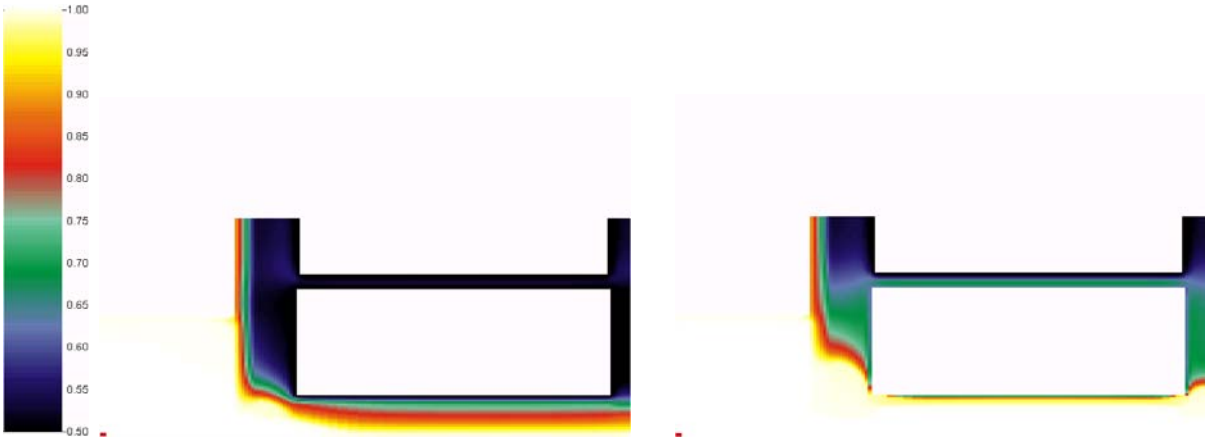


Fig 7: Relative humidity with lower or higher moisture penetration and an air exchange of 0.1/hr (1 January)

In principle relative humidity is directly dependent of brickwork moisture penetration and of air exchange. The refurbishment variants have similar effects on the room climate independent of the level of moisture penetration. In principle thermal improvements of the thermal envelope of the building should be preferred to achieve an increase of temperature in the basement and thus a reduction of relative humidity. All kinds of thermal refurbishments of a basement will increase humidity problems and need to be combined with accompanying measures like an adjusted ventilation of the basement.
An optimal thermal refurbishment of a basement is not only dependent on insulation thickness but also on moisture penetration in the floor in contact with ground and in the brickwork and dependent also from air exchange rates with outside air.
The following comparison (Fig 8) shows relative humidity of a basement at different air exchange rates and different degrees of moisture penetration.

low moisture penetration **high moisture penetration**

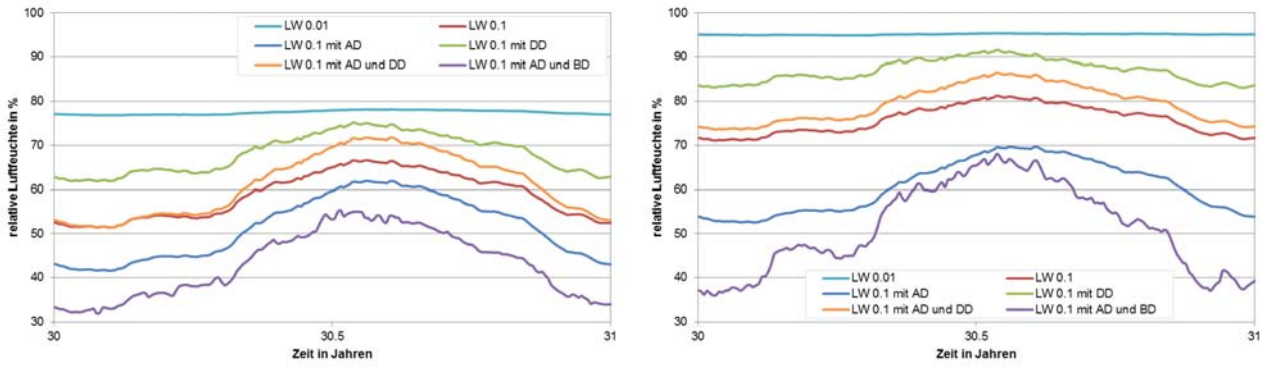


Fig. 8: Relative humidity at different degrees of moisture penetration comparing all refurbishment variants (LW = air change cellar; AD: exterior wall to outside and to ground insulated; DD: basement ceiling slab insulated; BD: cellar slab insulated)

Moisture penetration in a construction has no marked effect on temperature distribution. Only in the variant with floor insulation, with reduced moisture input on account of the additional floor construction, temperature follows a slightly different curve.
The following figure 9 compares temperature curves at different moisture penetration levels in the basement wall

low moisture penetration **high moisture penetration**

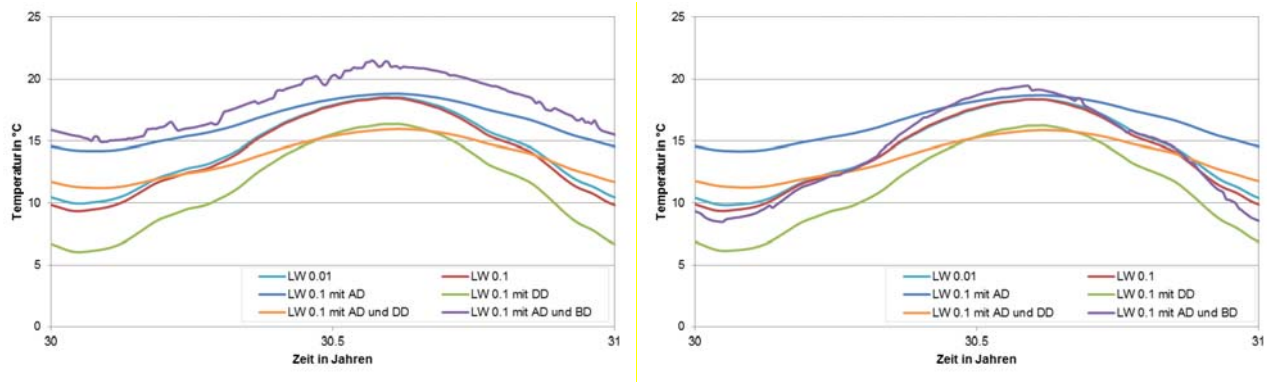


Fig 9:temperature distribution at lower and higher moisture penetration comparing all refurbishment variants (LW = air change cellar; AD: exterior wall to outside and to ground insulated; DD: basement ceiling slab insulated; BD: cellar slab insulated)

Heat flow is calculated for ecological comparisons on the basis of ÖNORM EN ISO 13370 (PHPP 2007) – see fig 10. Balancing expenditures for heating via the basement ceiling against expenditures for production and maintenance of the insulation system, the following environmental expenditures result in a period of 100 years, expressed as primary energy input, non-renewable.

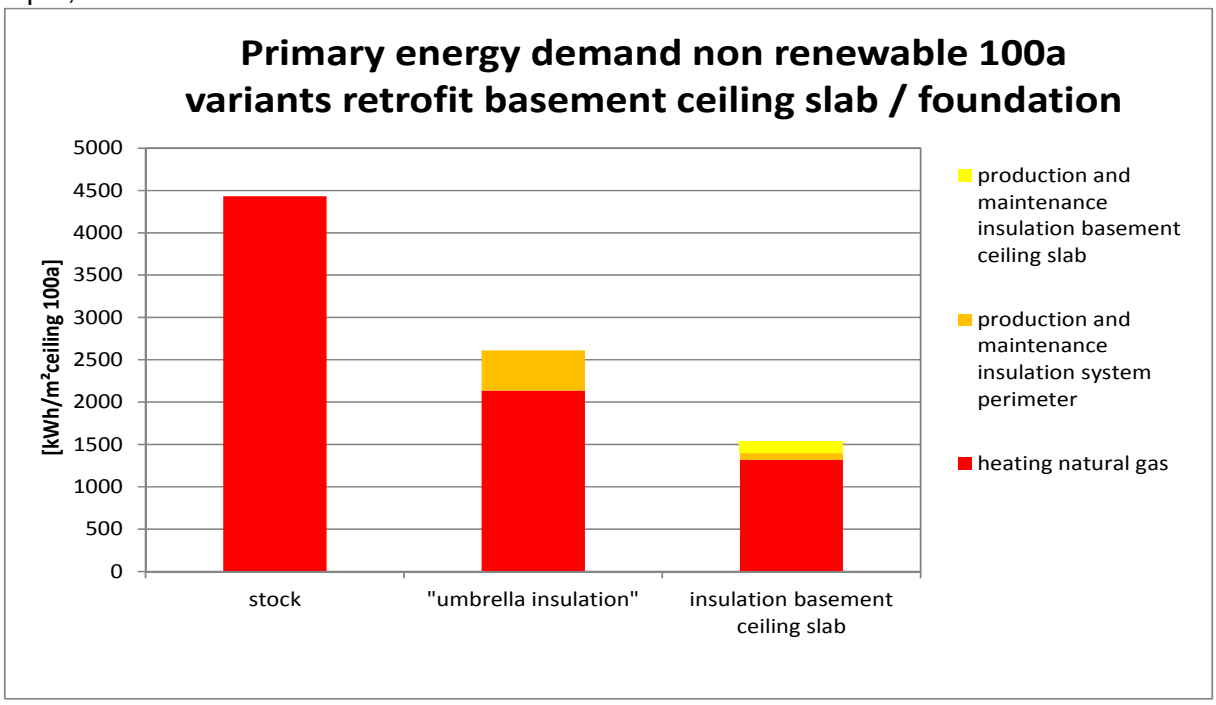


fig 10: Expenditures for production of insulating systems and for heating in order to compensate for heat losses via the basement ceiling

By reference to primary energy demand, non renewable, insulation of the basement ceiling slab plus thermal insulation of the base parts in contact with outside air more favorable than an umbrella-type insulation. Both systems, however, have big advantages compared to the unrefurbished state.
Capabilities of a cellar to store goods and also regarding risk of mould development the variant with umbrella-type insulation is preferable. The variant with basement insulation is most unfavorable, the unrefurbished initial state is in a middle position.
These results give clients a well founded position to choose refurbishment options by ecological and hygrothermal criteria.

Conclusions

On the way to an energy self-sufficient (or energy independent) Austria in 2050 high grade refurbishments of the existing building stock take a crucial role. In the future not only refurbishments with passive house components are relevant but also integration of energy-collecting systems. Integration in the existing building stock and reliable energy yield forecasts also in dense urban settings seems as one of the promising solutions.

Literature

[1] ZELGER TH, WALTJEN T et al: „PH-Sanierungsbauteilkatalog: Zweite Ausbaustufe PH-SanPlus“ Herausgeber: bmvit. Schriftenreihe 48/2012- Deutsch, 527 Seiten DOI: http://www.hausderzukunft.at/results.html/id6072

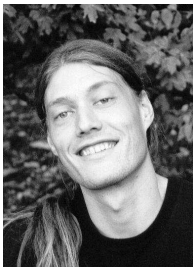
[2] SCHNEIDER U., BÖCK M., MÖTZL H. et al: Recyclingfähig Konstruieren. 2010

A4

Technologies and aspects of high quality refurbishment in non-residential constructions

Chair: Vanessa Gomes
University of Campinas, Brazil

Requirements and solutions for high performance school renovations



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Keywords: School renovation; energy-efficiency; ventilation; passive cooling; indoor environment quality

1. Introduction

Schools were mostly built from the 1950ies to 1980ies. Beside educational aspects the existing school buildings are mostly in high need of renovation. While in rural areas an increasing number of schools are closed down, the urban areas lack of space for the increasing numbers of pupils in consequence of growing populations in the cities. So school renovations often are municipality driven projects, they claim governance and expert advice. The renovation process should raise both energy efficiency by high performance retrofit strategies and thermal comfort by proved solutions for ventilation and protection from heat. School owners and users demand short renovation time, high indoor environmental quality and summer comfort of school renovations.
A transnational research approach to strategies and solutions for school renovations was made by the European ERACOBUILD-project School*Vent*Cool. Some results of this project will be presented in the paper.

2. School renovation strategies

Comprehensive and holistic renovation strategies follow an “Integrated Design” approach that covers all relevant aspects. The regularly applied and accustomed procedures of municipalities to retrofit their building stock should be scrutinised. They mostly lead to a typical package of renovation measures setting priorities on the single building level, there on the appearance of the building secondly on insulation or energy relevant measures. In many cases the influence of the location and infrastructure, the indoor air quality, overheating challenges or even educational aspects are not included or discussed within the renovation process. This is suited for a change and was one of the outcomes of School*Vent*Cool as shown in *Figure 1* [1] – renovation of the school building stock starts with the Scope and ends up with Best Practice school renovations.

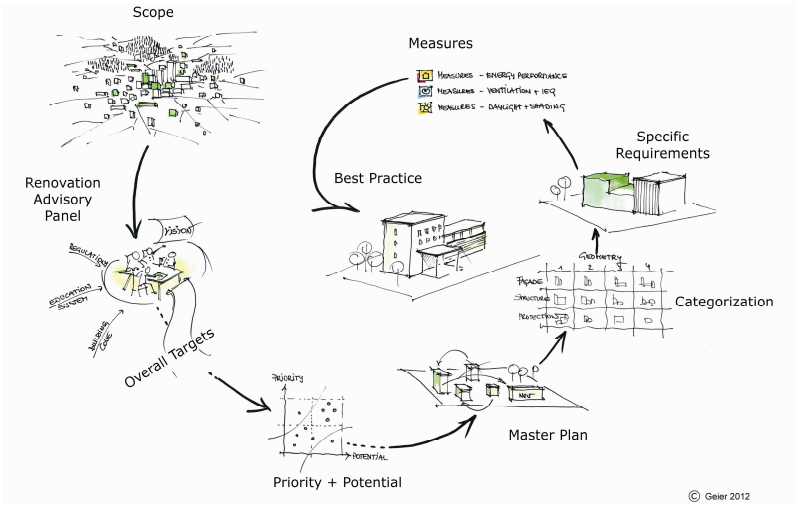


Figure 1 The SchoolVentCool methodology approach

2.1 Scope

The change of the scope from the single building to the entire portfolio avoids measures and investments in a non-selective way. Sustainable property management and development needs a profound knowledge on the existing building stock and is therefore based on a sufficient building stock documentation.

2.2 Renovation Advisory Panel

A future-oriented education system needs sufficient building and organizational structures. A Renovation Advisory Panel with experts and stakeholders from all affected aspects enables a multi-disciplinary perspective for the development of sustainable strategies of school building portfolios.

2.3 Overall Targets

Targets have to be defined in a clear, quantifiable and achievable way. They should address the buildings' functional usage, possible options for educational building utilization, performance, the Indoor Environmental Quality and the outlook to the life-cycle of the buildings. The overall targets provide the „Big Picture“ and general guidelines for all school buildings within the portfolio.

2.4 Priority and Potential Assessment

Target-oriented strategies on the level of the entire portfolio facilitate achieving the “Big Picture”. It is necessary to choose suitable school buildings for renovation that can be made „fit for future“ with feasible means. The degree of priority (urgency and pressure) together with the level of potential (good location, easy to adapt and renovate) shows ranking scenarios for scheduling and expenditures of measures (see Figure 2).

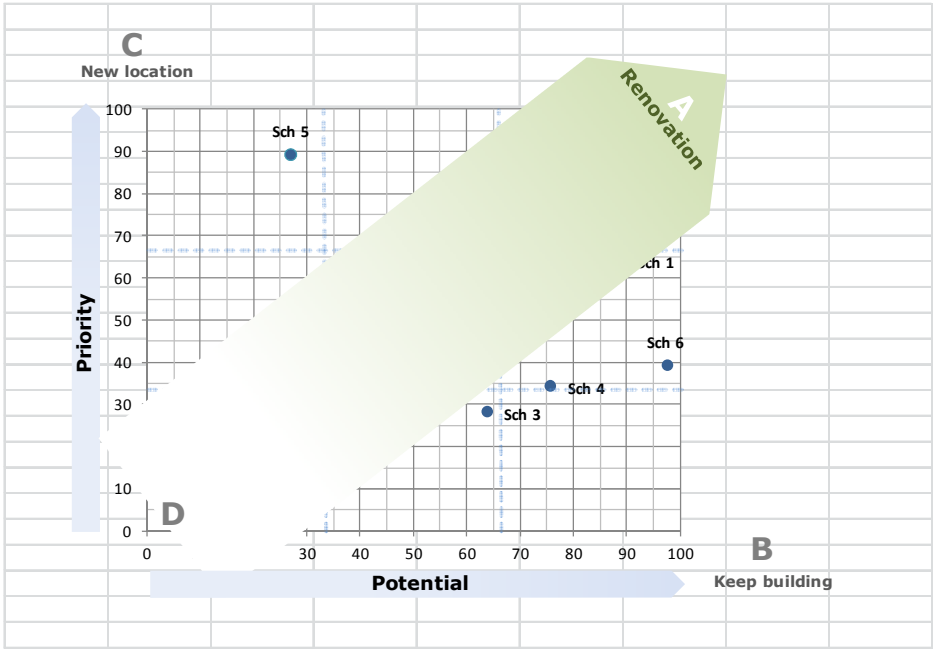


Figure 2 A “Potential-Priority Matrix” supports decision-making within a building portfolio

2.5 Masterplan

The development of a master plan is focused on a cluster of school buildings and the set-up of the

most efficient renovation strategy. That comprises reorganization or switching of buildings, functions or space supply for optimized operation. Additions of stories or annexes, even to sell, to let or to demolish buildings are possible options. Based on the strategic master plan that optimizes space structures and functional use of building structures from a bird's view, it is also necessary to (re-)structure the buildings due to the interior structure – for example a zoning due to the orientation (corridors on the west-side, classrooms on the east-side), the user's needs (comfort temperatures are higher in classrooms than they are i.e. in corridors), the difference of usage profiles and other influencing factors for interior space and room planning.

2.6 Categorization

Every renovation has to tackle the pre-settings of existing buildings that cannot be changed easily. Relevant key characteristics of buildings are indicators for executable or non-executable strategies and measures. The categorization of existing buildings due to a few but relevant key characteristics facilitates the choice of appropriate strategies and measures. (see chapter 4.1)

2.7 Specific Requirements

Now the strategy for the specific school-building with its own environment and conditions has to be developed. Having the vision of the „Big Picture" for the entire building stock very clearly in mind it is easy to deduct the specific targets for single buildings. So the overall targets have to be brought down and interpreted: What does it mean for that specific single building?

2.8 Measures

Basically measures can be separated into: „Passive" ones, like the improvement of the thermal envelope, efficient shading or optimized use of daylight, „active" ones that include efficient mechanical ventilation or heating systems, lighting control or others. Besides constructional or technical options organizational measures are an option too – they have to be planned in strong cooperation with all building related measures and the intended users. But anyhow the point is not to use the best measures, but the most suitable ones.

2.9 Best Practice

The best way to prove theories is to show that they had been realized already. Although every project has its own specific approach – the pattern of the strategy and the subsequent success is always the same. So every best practice example provides the chance to learn and the motivation to keep it up. Last but not least the pupils and teachers benefit from them!

3. Quality Requirements

Following requirements regarding best classroom indoor environment and learning ability are crucial:

- Visual comfort
- Thermal comfort
- Humidity comfort
- Air quality (olfactory comfort)

Beside design quality of the classrooms and functionality regarding educational and social use these four quality requirements have to be taken seriously. For each of them guidelines are existing in nearly all European countries as investigated in the School*Vent*Cool project, but often these guidelines neither are legal obligatory nor put into practice of renovation measures. So these overall quality requirements (see also chapter 2.3) are very important parameters to be considered before single renovation planning.

4. Solutions – prefabrication, ventilation, passive cooling

Based on the knowledge of the specific Integrated Energy Design and so the overall strategy of the renovation process, the quality requirements and the analyses of typological features, a set of solutions could be determined for the single building level.

4.1 School building typology

Analysing the typology of school buildings, a lot of similar constructions appear.[2] Conformities exist in facade structure, floor number, classroom dimension, window areas, entrances, staircases, other facilities. The typology work distinguishes general from focus types, whereas the general types are mainly characterised by the number of stories and the type of façade (see *Figure 3*), the focus types by e.g. window areas, parapet, lintel and room heights regarding a specific interest like space for ventilation ductwork etc.

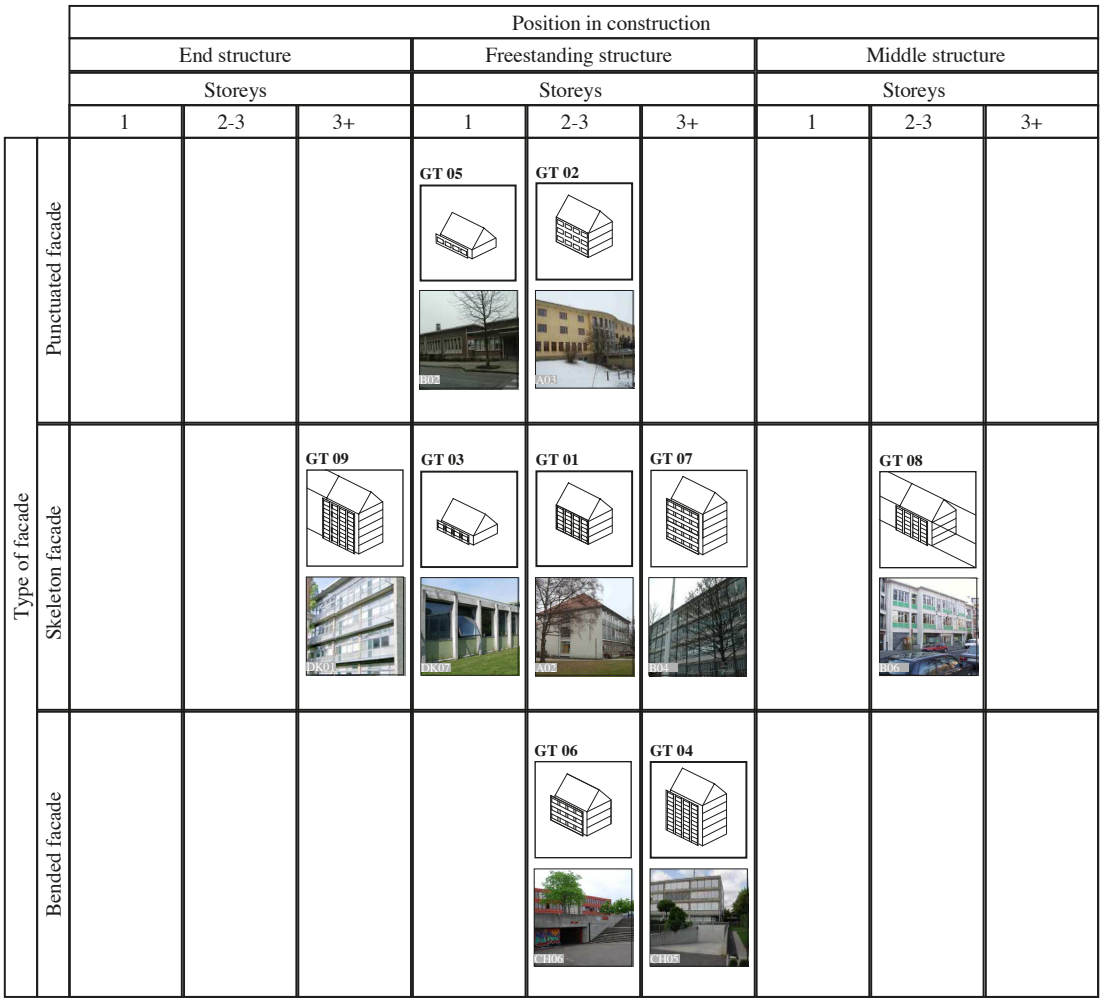


Figure 3 Categorisation of general types regarding the defined key features type of façade, number of storeys and position in construction, visualized with case study buildings (Source: FHNW)

The aim of this categorization work is creating detailed knowledge on pre-conditions of the school buildings leading, for example, to the design and production of prefabricated façade and roof modules. These thorough investigations help to find appropriate renovation measures for the:

- Module system and dimensioning
- Access to and storage space of building site
- Process of transportation and mounting
- Construction of foundation

- Roof adaption
- Renewable energy integration
- System and distribution of ventilation
- Cooling system
- Orientation and size of façade openings

4.2 Prefabrication

Renovation often means disturbance of the building's users, individual and error-prone construction works and dependence on weather conditions. Prefabrication is a very interesting aspect to overcome this challenge. The module manufacture is weather-independent, the construction works on site are short and can be made during summer when pupils are out. The critical path for school buildings is the air ducting system because of the high air volume needed in the classrooms.[3]

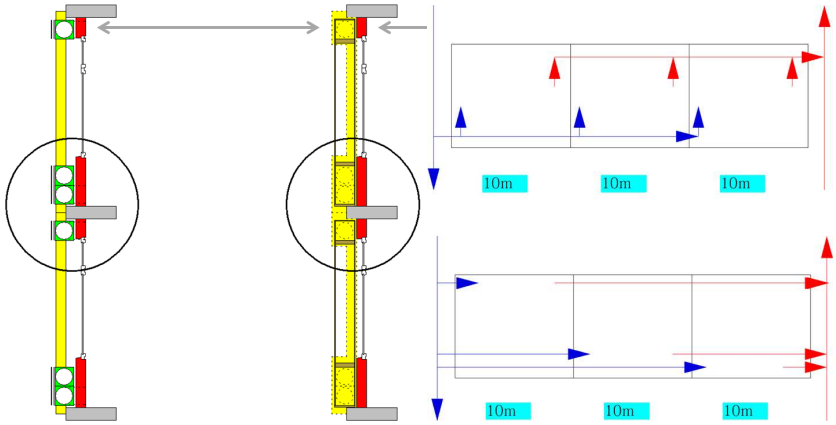


Figure 4 Central ventilation with horizontal air distribution and smaller effect on architecture; Left: Cross section of two façade-Storeys; Right: Elevation of two façade-storeys with horizontal ductwork (Source: FHNW)

Dependent on the existing façade structure the modules can be mounted onto or placed in front of the façade. But in every case the system and distribution of the ventilation seems to be the crucial point regarding school renovations. The question is, how the ductwork could be included in prefabricated modules mounted onto the façade (roof) without disturbing the users and the architectural appearance of the building.

4.3 Passive Cooling

Existing school building stock is mostly equipped with big window areas without acceptable thermal and shading standard.

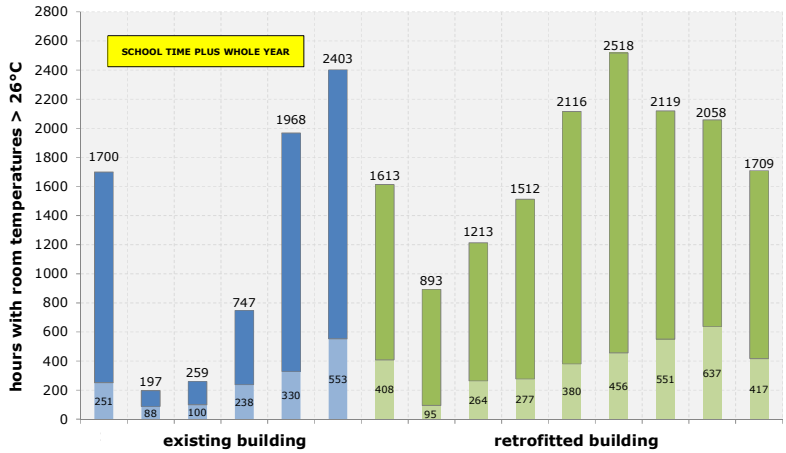


Figure 5 Different scenarios of shading and ventilation systems in an existing and a thermal-energetic retrofitted classroom of the same building

Thermal analyses have shown that thermal standards for summer comfort will be very important in future especially thinking of “summer- / all day schools” [4] – see *Figure 5*. Calculations have shown that the worst case in renovated schools could be one quarter of a year with temperatures above 26℃ in the classrooms, including summer holidays. Passive cooling concepts have to include “intelligent” shading control and (night free) ventilation systems to avoid overheating. At the same time an innovative shading and lighting concept is relevant for the optimal use of daylight and an effective protection from glare. The shading system as underestimated component of the energy system controls both comfortably cool rooms and intelligent usage of daylight.

4.4 Ventilation

A big challenge mostly is the implementation of the right ventilation system for school renovations. Manifold studies during the last decades have shown that ventilation is a vital aspect in getting classrooms to high indoor air quality (IAQ) standards, ensuring pupil’s health and their ability to concentrate during lessons. The way to appropriate ventilation solutions is again determined by the existing school building typology and IAQ criteria. A design criteria list, visualised as design cart (see *Figure 6*), weather centralized or decentralized mechanical or hybrid / natural (including night-) ventilation is best, helps for the decision making process.[5] Important is to think of both, fresh air during lessons and increased free ventilation during the night for cooling down the heat storage mass.

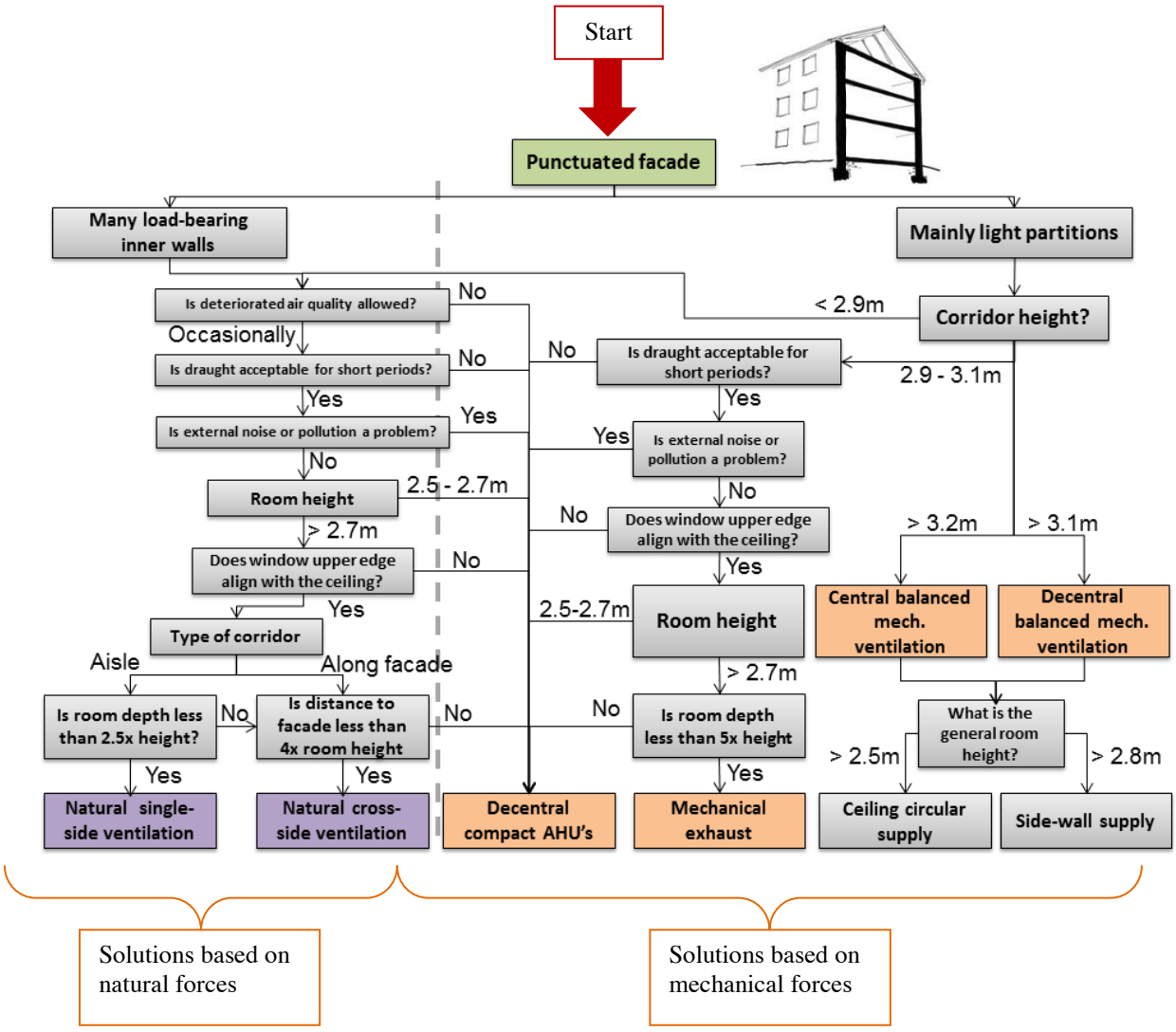


Figure 6 Visualization of the criteria that each solution must fulfil in order to be the recommended solution for a given building typology (Source: DTU)

5. Conclusion

If the scope is clear and the master-plan for the existing school sites done, a range of solutions for school renovations based on typology can be found. Prefabrication or the use of modular design components is a very promising of that. In near future there will be more research activities like concept and component development in this field. As there is very low energy demand for heating in high performance modernized school buildings the importance shifts towards their cooling demand. Passive cooling with (night-/free-)ventilation, intelligent shading and daylight use will raise the indoor environment and educational quality for pupils. These measures should be integrated in the prefabrication processes as far as possible to avoid individual installation mistakes on site and keep the renovation works in schools as short as possible.

6. References

[1] GEIER S. et al. “The way towards your cool school – A guideline to high performance school renovations in Europe”. Brochure, Antwerp May 2012

[2] HEIM T. “Evaluation of Focus Features”. Overview-paper for the international “schoolventcool” project workshop, Graz Sept. 2011

[3] KOBLER L.R, DOTT R, HEIM T. „Erneuerung von Schulgebäuden mit modular vorfabrizierten Fassadenelementen inklusive Lüftung“, Paper for the „17. Statusseminar“, ETH Zürich Sept. 2012

[4] KNOTZER A, VENUS D. “Thermal comfort analyses in classrooms”. Paper for the AIVC-TIGHTVENT 2012 conference, Copenhagen Oct. 2012

[5] HVIID C.A, PETERSEN S. “Implementation of ventilation in existing schools – a design criteria list towards passive schools”, Paper for the Passive House Symposium, Brussels Oct. 2012

All these papers and the brochure have been elaborated in the frame of the ERACOBUILD-project School*Vent*Cool – www.schoolventcool.eu.

Indoor Environment Quality in Riga City Kindergarten Buildings: Actual Data, Problems and Solutions

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Abstract

In the present article we have reflected and compared the results of our investigations on indoor air quality (IAQ) in relationship with heat energy consumption in unrenovated, renovated and newly erected kindergarten buildings. Latvian Energy Development Guidelines for the years 2007-2016 define that heat energy consumption should decrease by 28%, but by 40 % in the time period up the year 2020. Big heat energy demand in buildings is part of Latvia's heritage from the Soviet era. The majority of buildings do not have energy saving mechanical ventilation systems. Our analysis shows, that partial renovation: heat insulation of buildings with windows change, does not give heat energy consumption economy as established. Another target of this study was to evaluate indoor air pollution in kindergartens. Various indoor air pollutants such as volatile organic compounds (VOC) and biological pollutants, emitted from furniture, cleaning agents and floor covering materials, are responsible for respiratory diseases and allergies.

Keywords: Kindergartens; IAQ; VOC.

1. Introduction

For the most part, people live in buildings; thus IAQ is an obviously important determinant of health and wellbeing. To provide IAQ framework (Fromme et al. 2007; Santamouris et al. 2008) requirements are on the footing. Local Latvian laws are based on significant decisions of the European Parliament and European Council, for example, Directive (2002/91/EC) of 16 December 2002 on the energy performance of buildings and Directive (2006/32/EC) of 5 April 2006 on energy end-use efficiency and energy services and the repeal of Council Directive 93/76/EEC. Based on these documents, the Republic of Latvia Cabinet of Ministers created laws for local use. The main ministry that deals with energy issues is the Ministry of Economics. Building and reconstruction must also be provided by the IAQ framework requirements. But does this apply to all cases? We will provide the answer in the present article. We have reflected and compared the results of our investigations on the IAQ in relationship to heat energy consumption in unrenovated, renovated and newly erected kindergarten buildings. Heat energy consumption in public buildings has been explored very little in Latvian scientific research. After partial renovation, the IAQ slowly begins to deteriorate because outdoor air infiltration has stopped. Reconstructed, old natural ventilation and mechanical systems do not provide the necessary air exchange and quality. Residential buildings have the same problem. This unpleasant fact was overlooked for a very long time. Buildings get "sick building syndrome" after some time.

Having clean air indoors is very important for the health of the population as a whole and becomes particularly important for vulnerable groups like babies and children. Various indoor air pollutants (volatile organic compounds, biological pollutants, etc. emitted from furniture, cleaning agents, floor covering materials) are responsible for respiratory diseases and allergies (Wolkoff, 2006; Bernstein, 2007; Carslaw, 2009; Tanaka-Kagawa, 2005). One of the aims of this study was to evaluate indoor air pollution in kindergartens.

2. Materials/Methods

The aggregated information total contained more than 60 000 data indications from the relative humidity of the air, the temperature and indoor concentration of carbon dioxide. IAQ parameters have been defined in the Republic of Latvia Cabinet of Ministers Regulations No. 359, adopted 28 April 2009, as shown in Table 1.

Table 1. Requirements for the Microclimate of Work Premises Depending on Physical Load

No.	Time of the year	Work category	Air temperature (^{0}C)	Relative air humidity (%)	Air movement rate (m/s)
1.	Cold time of the year (average air temperature outside work premises + 10°C or lower)	I[1]	19,0–25,0	30–70	0,05–0,15
		II[2]	16,0–23,0	30–70	0,1–0,3
		III[3]	13,0–21,0	30–70	0,2–0,4
2.	Warm time of the year (average air temperature outside work premises exceeding + 10°C)	I[1]	20,0–28,0	30–70	0,05–0,15
		II[2]	16,0–27,0	30–70	0,1–0,4
		III[3]	15,0–26,0	30–70	0,2–0,5

These Regulations contain legal norms arising from Council Directive 89/654/EEC of 30 November 1989 concerning the minimum health and safety requirements for the workplace. IAQ parameters for kindergarten buildings have also been defined in the Republic of Latvia Cabinet of Ministers Regulations No. 596 “Hygiene requirements for educational institutions when implementing preschool programmes”. They stipulate that the air temperature minimum for children younger than three years is +20.0ºC and older than three years air temperature is +18.0ºC. This requirement does not indicate the boundary of the two indoor environment parameters as relative air humidity and carbon dioxide concentrations indoors, as described in the Minnesota Department of Health Fact Sheet (MDH, 2010).

In this study we used MINILOG GSOFT 40K V7.80 (air temperature logger), EASYLOG 40RF GSOFT 40K V7.80 (air relative humidity logger) and Wöhler CDL 210 version 1.1.6 (air temperature, relative humidity and carbon dioxide quantity) loggers. Loggers have been used in kindergarten rooms approximately 1.5 m above the floor. The gas chromatographic (volatile organic compounds – VOC expressed as carbon) and high-pressure liquid chromatography (aldehydes) method was used for the air pollution investigation. The air polluting substances were absorbed in charcoal tubes in the case of VOC and silica gel cartridges treated with 2,4-dinitrophenylhydrazine (DNPH) in the case of aldehydes. The indoor air concentration levels recommended by the World Health Organization (WHO) were used for the evaluation of indoor air quality: formaldehyde – 0.1mg/m^3 and of VOC – 0.3mg/m^3 (WHO, 2000).

3. Results

We detected indoor air polluting substances – aldehydes (formaldehyde 0.023±0.005mg/m^3; acetaldehyde 0.015±0.003mg/m^3; benzaldehyde 0.004±0.001mg/m^3; propylaldehyde 0.003±0.001mg/m^3) and volatile organic compounds expressed as carbon 0.56±0.11mg/m^3 in kindergartens in the case of floors covered with linoleum and with plastic windows without a ventilation system.

Figures 1, 2 and 3 presents the outdoor and indoor air temperatures, relative humidity and CO_2 concentration level in kindergarten buildings. The horizontal axis presents data of times and date. Minor gridlines disclose the time: first 2:00; second 5:00; third 8:00; fourth 11:00, etc. Major gridlines, for example, zero to eight is the first datum, achieved on 21 February; nine to sixteen is

the second datum achieved on 22 February; seventeen to twenty four is the third datum achieved on 23 February, etc.

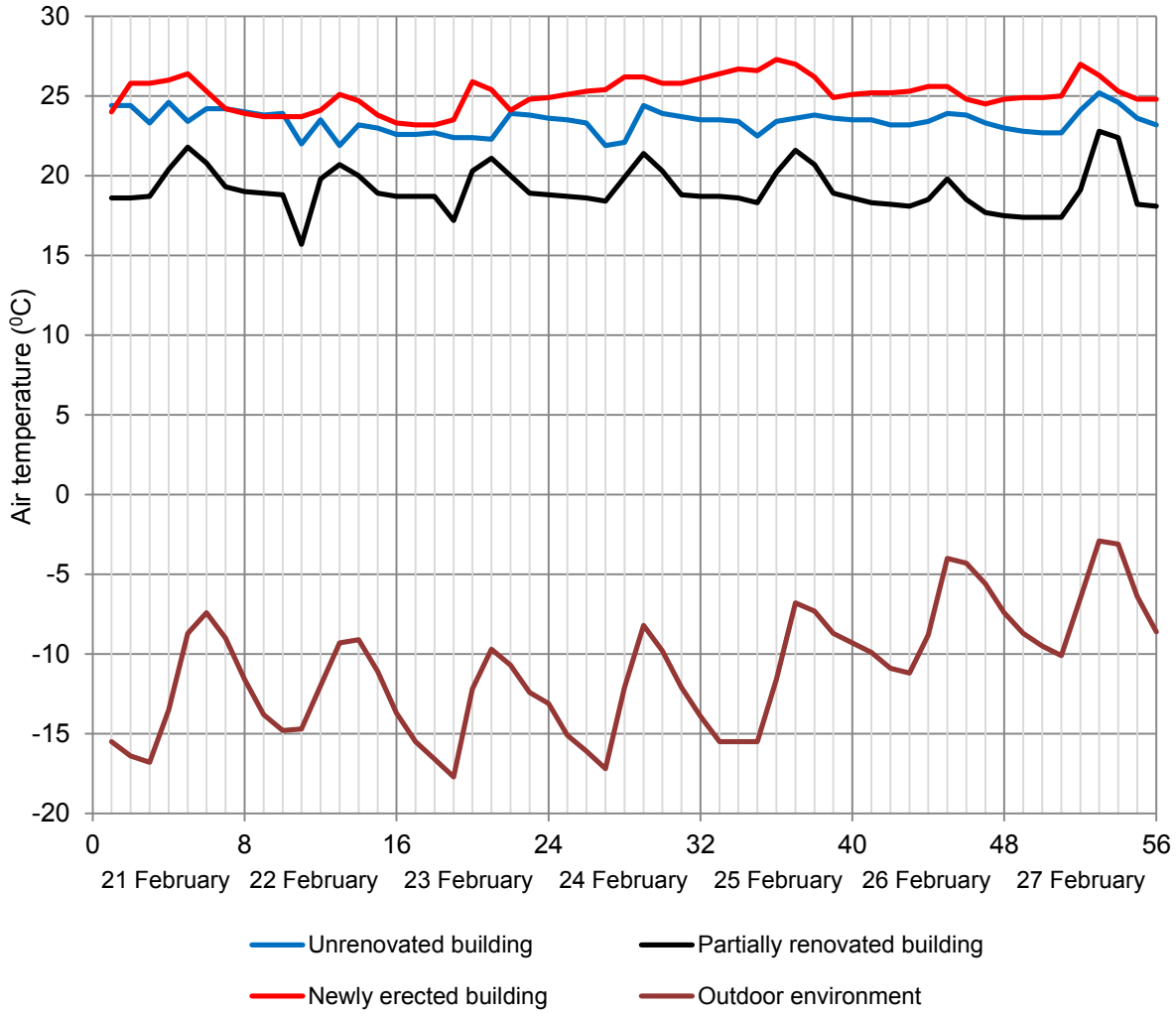


Figure 1. Air temperature in the different conditions of kindergarten buildings and outdoor environment in the year 2011

The newly erected building was built in 2007 and had a heat consumption 339kWh/m^2 in 2008; the partially renovated kindergarten building was renovated in 2004 and had a heat consumption 237kWh/m^2 in 2008; the unrenovated kindergarten building had a heat consumption 130 kWh/m^2 in 2008.

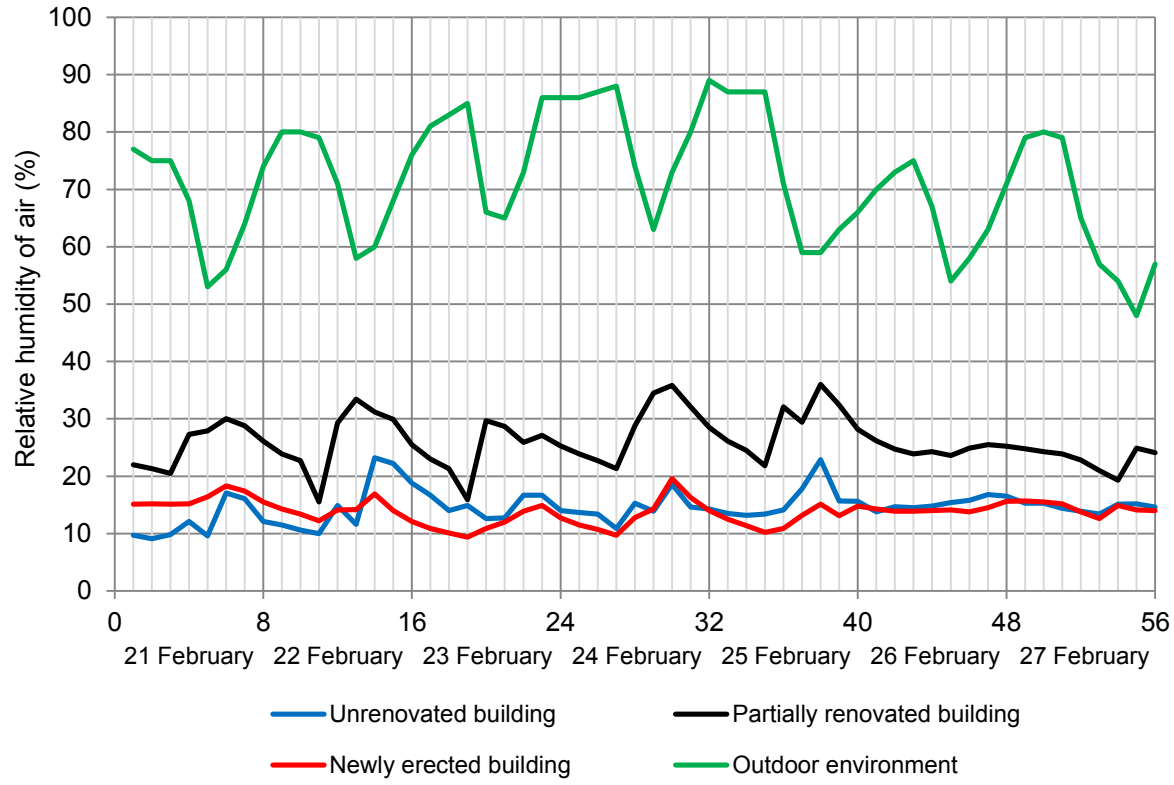


Figure 2. Air relative humidity in the different conditions of kindergarten buildings and outdoor environment in the year 2011

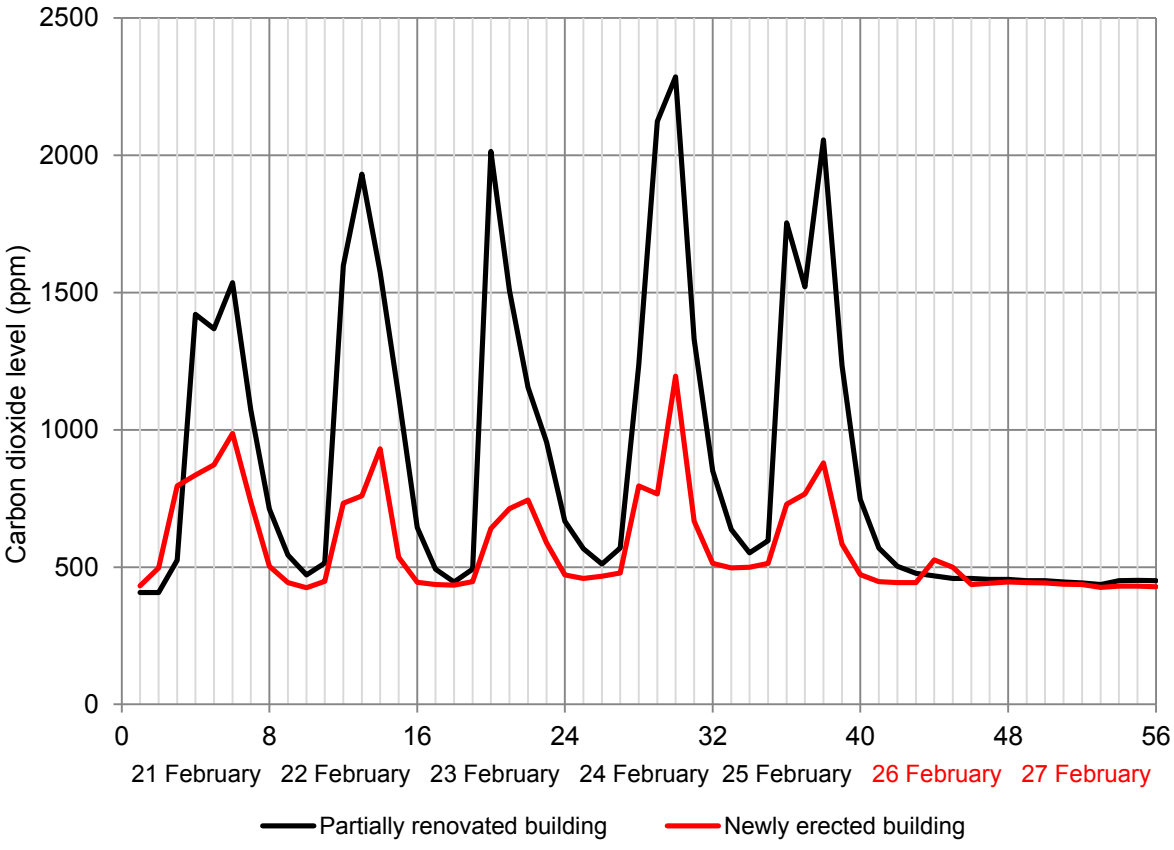


Figure 3. Carbon dioxide level in the indoor environment in partially renovated and newly erected kindergarten buildings

4. Discussion

Heat energy consumption to one square metre per annum in unrenovated kindergarten building is less than in the other conditions of buildings. The thermal comfort zone is defined between 19.0–25.0ºC. As shown in Figure 1, the partially renovated kindergarten building has an indoor air temperature that is lower than defined in many cases. In all cases, indoor air temperature has the property of mimicking changes in outdoor air temperature. This has been indicated on an unbalanced heating control unit. Indoor relative air humidity, as reflected in Figure 2, is for the most part lower than the set standards. Ventilation systems without air humidifiers are responsible for the cause and effect. Figure 3 also reflects the inadequate supply of fresh air in a partially renovated building.

“The outdoor concentration of carbon dioxide can vary from 3500-400 ppm or higher in areas with high traffic or industrial activity” (MDH, 2010). Our fixed outdoor concentration of CO_2 level varied from 410 to 440 ppm in February and March 2011 in Riga city. Table 1 reflects conditions that have an influence on the IAQ.

Table 2. Conditions of kindergarten buildings

Building	Year	Total floor area (m^2)	Heat consumption in the year 2008 (kWh)	Children/ Personnel	Achieved data rooms floor area (m^2)	Remarks
Newly erected	2007	1901	645 000	21 February – 16/2 22 February – 12/2 23 February – 11/2 24 February – 13/2 25 February – 13/2 26 February – 0/0 27 February – 0/0	88	With mechanical ventilation system
Partially renovated	2004	2054	486 000	21 February – 12/2 22 February – 14/2 23 February – 13/2 24 February – 12/2 25 February – 11/2 26 February – 0/0 27 February – 0/0	60	1.New heating system 2. New PVC windows 3. Without mechanical ventilation system

The investigations revealed the presence of various polluting substances in indoor air. The optimal concentration of aldehydes does not exceed the WHO-recommended limit for formaldehyde, which is the more toxic of aldehydes. In turn, indoor air pollution with VOC is higher than the recommended limit.

5. Conclusions

The personnel of kindergartens and children have complaints of smells and stuffy air. There is the possibility of poor IAQ in the case of plastic windows and rooms without ventilation, as well as kindergarten rooms with synthetic indoor materials. The project also aims to establish a common protocol for the evaluation of the IAQ.

Increased heat energy consumption in kindergarten buildings indicates that partial renovation was done with inadequate project solutions.

The main solution to these problems is to take an integrated approach to the IEQ and to establish energy-saving, quality ventilation and air condition systems.

Poor and unconformable IAQ indicate the necessity to make ventilation systems according to current building legislation.

Partial renovation of buildings has not decelerated heat energy consumption and has not enhanced the IAQ to the required level.

6. Acknowledgement

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7. References

[1] BERNSTEIN J. A, ALEXIS N, BACCHUS H. et al. 2007. The health effects of nonindustrial indoor air pollution // J Allergy and Clinical Immunology. pp. 585 – 591.

[2] CARSLAW N, LANGER S, WOLKOFF P. 2009. New Directions: Where is the link between reactive indoor air chemistry and health effects? // Atmospheric Environment. pp. 3808-3838.

[3] FROMME H, TWARDELLA D, DIETRICH S, HEITMANN D, SCHIERL R, LIEBL B, RUDEN H. 2007. Particulate Matter in the Indoor Air of Classrooms – Exploratory results from Munich and Surrounding Area, International Journal of Atmospheric Environment, Volume 41, Issue 4. pp. 854-866.

[4] SANTAMOURIS M, SYNNEFA A, ASSIMAKOPOULOS M, LIVADA I, PAVLOU K, PAPAGLASTRA M, GAITANI N, KOLOKOTSA D, ASSIMAKOPOULOS V. 2008. Experimental Investigation of the Air Flow and Indoor Carbon Dioxide Concentration in Classrooms with Intermittent Natural Ventilation. International Journal of Energy and Buildings, Volume 40, Issue 10, pp.1833-1843.

[5] TANAKA-KAGAWA T, UCHIYAMA S, MATSUSHIMA E. et al. 2005. Survey of volatile organic compounds found in indoor air and outdoor air Samples from Japan // Bull. Nat. Inst. Health Sci.. pp. 27-31.

[6] WHO. 2000. Air quality guidelines for Europe, 2nd ed. Copenhagen, World Health Organization Regional Office for Europe. WHO Regional Publications, European Serries No. 91.

[7] WOLKOFF P, WILKINS C. K, CLAUSEN P. A, NIELSEN G. D. 2006. Organic compounds in Office environments: sensory irritation, odor, measurements and the role of reactive chemistry // Indoor Air. pp. 7 – 19.

[8] Directive 2002/91/EC of the European Parliament and the Council of 16 December 2002 – on the energy performance of buildings. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0065:EN:PDF

[9] Directive 2006/32/EC of the European Parliament and the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC (Text with EEA relevance). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0064:0064:en:pdf

[10] The Cabinet of Ministers of the Republic of Latvia in Regulation No. 596 “Hygiene requirements for educational institutions, implementing preschool program”. http://www.likumi.lv/doc.php?id=69951

[11] Labour Protection Requirements in Workplaces. http://www.likumi.lv/doc.php?id=191430&from=off

[12] Minnesota Department of Health Fact Sheet April 2010.
http://www.health.state.mn.us/divs/eh/indoorair/co2/carbondioxide.pdf

SB13 Graz - Re-Commissioning Services: Immediate Savings and Triggering Building Refurbishment Measures in Non-Residential Buildings



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Short Summary

In many cases the question arises, how and where to start with the energetic optimisation and high quality rehabilitation of complex, large-volume non-residential buildings like hospitals, universities etc. Usually, an energy audit is carried out, measures are defined by an expert and a decision making paper for the management is worked out.

A completely different approach offers Re-Commissioning: a systematic approach to examine existing building equipment systems, their operation and maintenance procedures and – highly important – communication and interactions with facility building management staff and occupants. Through Re-Commissioning the first 10% of the energy bill can be saved without immediate investments. Staff is trained in energy efficiency and the users are motivated to change their behaviour and contribute with own ideas to smart energy savings. The process and the first successes lead to a higher energy consciousness and the desire for greater savings. Investments into comprehensive refurbishment measures as a result of an internal evaluation process are more likely to follow.

The process follows a standard Plan-Do-Check-Act management cycle; it is compatible with energy management systems as described in ISO 50001 and builds on 5 key components:

1. Establishing an energy information system
2. Data analysis and selected measurements
3. Optimisation of existing building technologies
4. Information and motivation of building occupants
5. Monitoring and quality assurance instruments of the project results

In the "Re-Co.eu" project[1], energy efficiency engineers, economists and marketing experts from 10 partners are joining forces to develop Re-Commissioning services and markets in 8 European countries and test the feasibility of the concept.

[1] Supported by the Intelligent Energy Europe program of the EU

In our speech we will summarise Re-Commissioning services, components and tools (e.g. process flow, pilot project log, data base for measures implemented and the measurement and verification approach). We will report on preliminary results of selected pilot projects implemented in hospitals and universities, show examples of successful measures and strategies and how these results are communicated to stakeholders.

We will conclude with the lesson learned that for the achievement of sustainability in large-volume, non-residential buildings a comprehensive approach is necessary. Besides high-performing building technologies the continuous adaption and optimisation of the technology, the communication with the staff and the integration of energy efficiency in management routines are important elements.

Keywords: Re-Commissioning; www.Re-Co.eu; large-volume buildings; energy management system; energy efficiency

1. Why Re-Commissioning?

In many cases the question arises, how and where to start with the energetic optimisation and high quality rehabilitation of complex, large-volume non-residential buildings like hospitals, universities etc. Usually, an energy audit is carried out, measures are defined by an expert and a decision making paper for the management is worked out. Evaluations of this procedure show that only a few of the proposed measures are carried out due to different reasons:

- the audits often concentrate on high investment measures with long payback periods
- managements tend to implement measures with short payback first before considering longer payback periods
- the proposed measures are often not embedded into a holistic concept including energy monitoring, information of users and quality assurance

A completely different approach offers Re-Commissioning: a systematic approach to examine existing building equipment systems, their operation and maintenance procedures and – highly important – communication and interactions with facility building management staff and occupants. Through Re-Commissioning the first 10% of the energy bill can be saved without immediate investments. Staff is trained in energy efficiency and the users are motivated to change their behaviour and contribute with own ideas to smart energy savings. The process and the first successes lead to a higher energy consciousness and the desire for greater savings. Investments into comprehensive refurbishment measures as a result of an internal evaluation process are more likely to follow.

2. Approach of Re-Commissioning

The process follows a standard Plan-Do-Check-Act management cycle; it is compatible with energy management systems as described in ISO 50001 and builds on 5 key components:

1. **Design:** The Re-Co Services Consultant (Re-Co SC) creates an overview of the owners building stock and works out the individual strategic objectives for the building owner and corresponding success indicators. E.g. improving energy efficiency, reducing operating cost or improving user comfort.

2. **Investigation:** The Re-Co SC investigates the building stock, identifies high potentials and defines specific measures of improvement and a plan for their implementation. The owner recieves a clear calculation of costs and benefits of each measure to decide about the implementation. A concept for evaluation – usually a suitable technical metering system – is defined and installed.

3. **Implementation:** The measures are being implemented. All cost and timelines are documented.Operations are actually starting to improve.

4. **Evaluation:** All measures are evaluated using individual approach according to success indicators. The evaluation shows the individual cost effectiveness of each measure and the amortization of the whole Re-Co Service.

5. **Continuity:** Re-Co Services are intended to come and stay. The metering concept and the success indicators are great tools to continuously monitor the performance of your buildings, to maintain the savings and to even indentify further measures of improvement.

The similarity of the process to energy management systems (as shown in the graph X) entitles the scheme of re-commissioning to be used as a preparation for the implementation of an energy management system: Depending on the individual design of the project a high number of the elements to be necessary for an energy management is already been implemented during the re-commissioning-process.

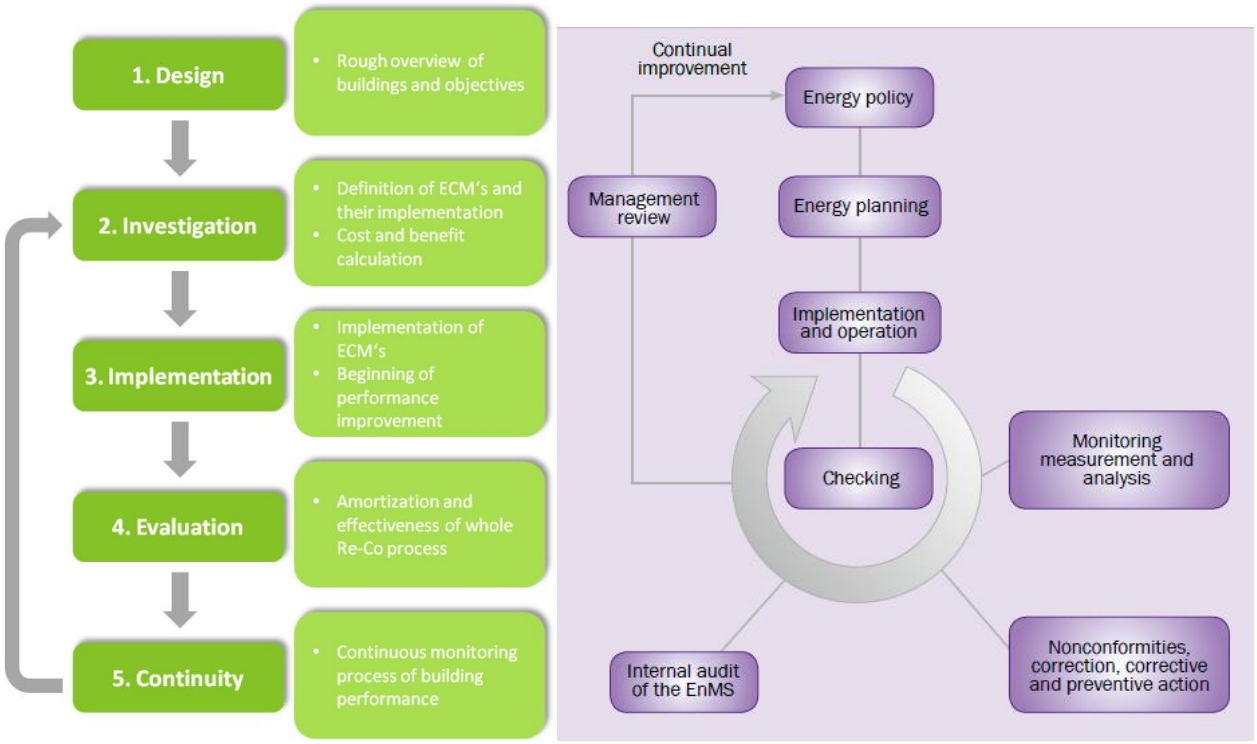


figure 1: similarity between the process of re-commissioning and ISO 50001

3. IEE-project Re-Co

In Re-Co 10 partners from 8 countries join their forces and experience to develop a common understanding of re-commissioning in Europe. As the individual approaches of all partners regarding technical appliances, tools and communication strategies are quite different, the common structure has been identified and experiences – whether strategies or tools work out or not – are exchanged between experts.

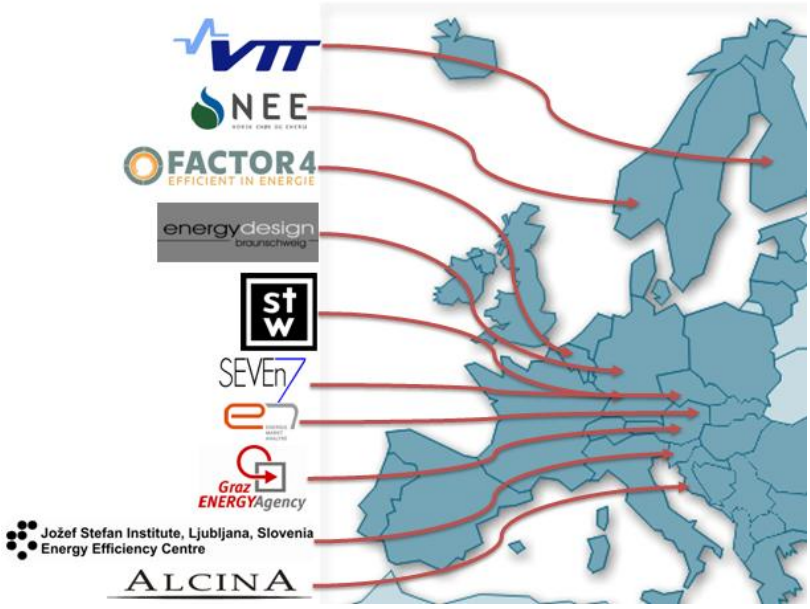


figure 2: partners of the IEE-project Re-Co

4. Two best practice examples to demonstrate that different technical approaches can be successful

4.1 BGU Ludwigshafen, hospital in Germany

In this pilot project the experts concentrated on the optimization of the ventilation system after the analysis of the energy consumption showed that 45% of the overall energy consumption is used by these systems.

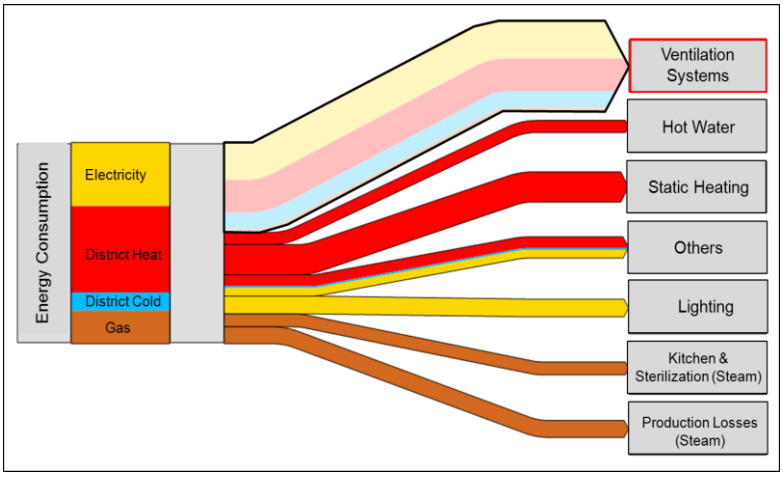


figure 3: sankey diagram BGU Ludwigshafen

Consequently a simulation of the 5 ventilation system has been performed, showing saving potential in the systems in respect of usage and time on the one side and pressure and volume on the other side. The optimization avoided a loss of comfort and a violating of hygienic standards, so the implementation of the proposed measures – pressure reduction, air volume reduction and runtime reduction – was only a technical issue and not an organisational. An unexpected saving benefit has been that one of the ventilation systems could be turned off completely as it turned out that the respective building has been out of use as a whole, a situation which is not a one-time-occurrence but can be found quite often.

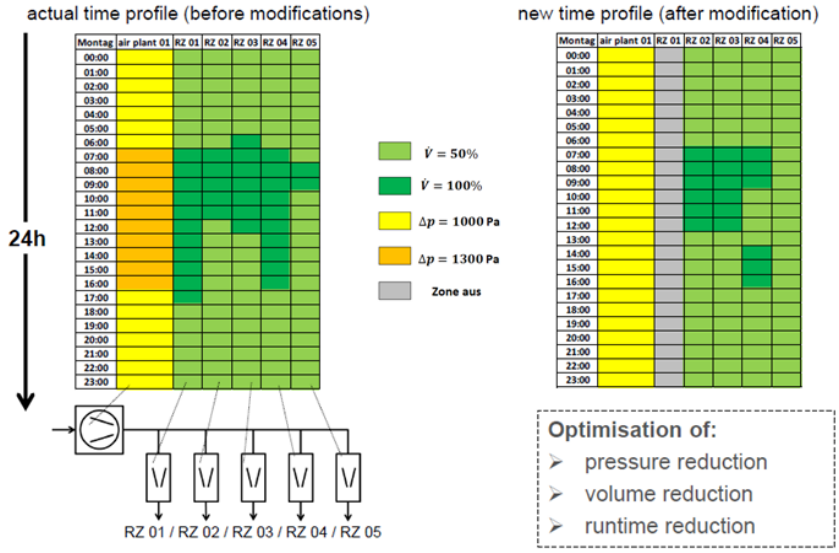


figure 4: BGU Ludwigshafen: optimization of ventilation system

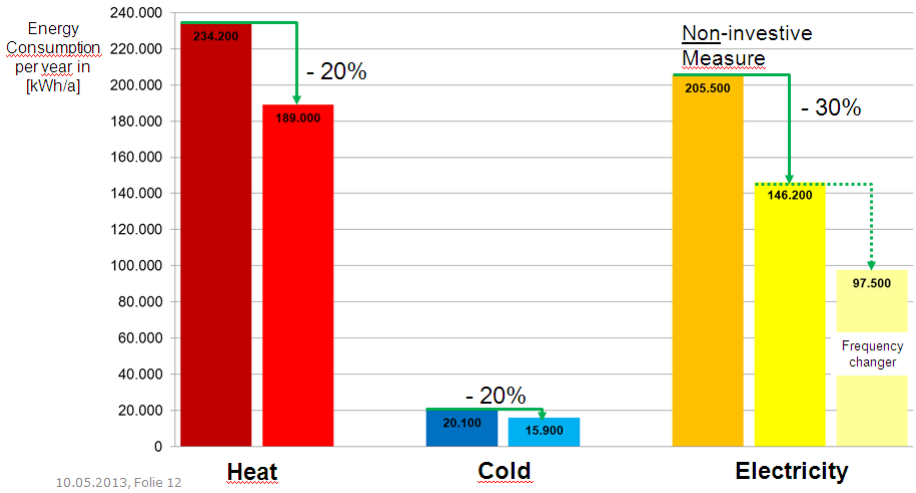


figure 5:BGU Ludwigshafen:saving potentials of ventilation system

The gained savings through pure optimization without investment are 20% for heat and cold and 30% for electricity, whereas in the process an investment measure – the implementation of frequency converters – has been developed, which should reduce the electricity consumption by another 30%.

4.2 KH Güssing, hospital in Austria

the focus in this pilot project has been on technical optimization, user motivation and training of technical staff. To enable an optimized output of ideas for measures a special communication structure has been set up: The group of users chose a team of energy coaches, who were determined to develop measures in their range of influence, i.e. the hospital units, administrational offices, surgery rooms. On the other side the technical staff has been invited to perform the same in their range. Both groups created these measures but also created measures to be enabled by the respective other group. These measures have been reported by the experts to the other groups, so a interactive dialog developed, which not only created innovative and individual measures but also a better understanding for the needs and way of thinking of the counterpart.

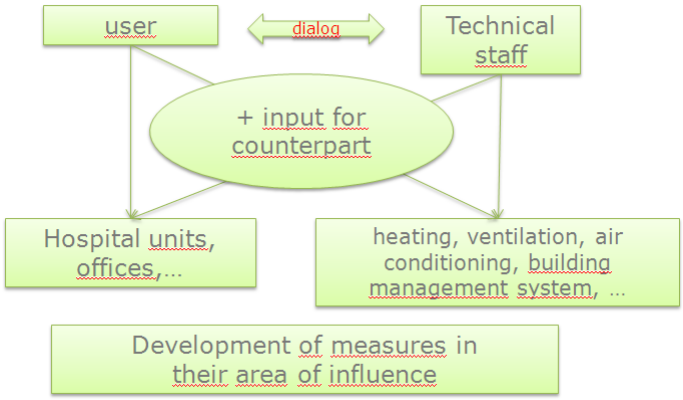


figure 6: a.ö. KH Güssing: communication structure

In this scheme a number of 26 technical and 30 user behavior measures have been developed, the staff has been empowered by the management to enable measures themselves, while the

experts acted more like mediators, giving advice and technical background to the members of the discussion groups and preparing communication means for the client, i.e. posters, stickers and manuals for technical issues and communication. A selection of measures of these 56 measures:

1. optimisation of ventilation system
2. reduction of room temperatures (25°C → 22°C)
3. training of technical staff in control system
4. information and motivation campaign for users regarding cooling, lights, elevators, stand-by,…

5. Conclusions

The evaluation of the pilot projects shows that the targeted 10% of end-energy savings are realistic to achieve – even in modern buildings and organizations with professional and well-educated building-staff.
Re-commissioning is especially suitable for clients with a high level of internal technical know-how and with need for high operating safety (i.e. hospitals) and it can act as a door opener for high investment measures after the implementation of low-cost-measures in the re-commissioning-project.
Re-commissioning can and has to be adjusted to the individual needs of the client depending on the desired access and involvement for the consultant to technical settings in respect of security reasons and depending on the individual know-how-level of the internal staff.
In the end the similarity of the re-commissioning-process to energy management systems suggests to use re-commissioning as a preparation for the implementation of an energy management system, i.e. ISO 50001.

The advantages for the client are that

1. through re-commissioning he reduces his energy consumption and related energy costs,
2. he can but doesn't have to use internal resources for the planning phase,
3. the implemented measures show sustainable effect due to the conversion into an PDCA-cycle
4. the implementation of the measures happens in ongoing operational business
5. the part of user-motivation can also be seen as team-building
6. as "side-effects" reasonable investment measures can be evaluated and prepared for further decisions

6. References

[1] PLESSER S; GÖRTGENS A; "Re-Co pilot project process scheme" www.re-co.eu
[2] RIEGER U; HEMMINGER U; MAHLER B *"Optimisation of Ventilation Systems in the BG Klinik Ludwigshafen"*. Presentation on expert meeting on 7.3.2013 at BG Klinik Ludwigshafen
[3] UNGERBÖCK R; KAURAN K; PAPOUSEK B; *"User Motivation in Hospitals"* Presentation on expert meeting on 7.3.2013 at BG Klinik Ludwigshafen
[4] UNGERBÖCK R; PAPOUSEK B; "Re-commissioning:Energy Efficiency without Investment" conference speech on 3.4.2013 at EU-China Conference on Policies for the Benchmarking of Lafge-scale (Commersial) Buildings on 3.4.2013 in Beijing, China

Risk Assessment for Energy Efficient Refurbishment of 19th Century Townhouses Using Interior Insulation



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Short Summary

The paper deals with the thermal rehabilitation of 19th century townhouses using interior insulation. It presents the latest research results of two ongoing projects of the Research Centre of Building Physics and Sound Protection of Vienna University of Technology. Essential details concerning the renovation – focusing on the thermal rehabilitation of an exterior wall, e.g. interior insulated wooden beam connections – are discussed. It is shown, how the risk of damage of an inside insulated construction can be assessed by hygrothermal simulations and the analysis of certain issues.

A planning example of an internally insulated exterior wall with wooden beam connections is presented. The worst case scenario is described by variation of certain boundary conditions. It is shown how selective tempering of the joist bearing can minimize the risk of damage as well as the energy expenditure. Besides the description of the technology of wooden beams' temperature controlling, a patent is introduced which is currently being further developed in an ongoing project of the Research Centre of Building Physics and Sound Protection of Vienna University of Technology.

Keywords: Interior insulation; building component tests; wooden beam head; risk assessment; life cycle costs

1. Introduction

Increasing energy consumption in buildings was leading to greater awareness of energy conservation and to rising energy efficiency. The highest potential for thermal optimization lies in renovating existing buildings. Due to the fact that many buildings are listed worthy of preservation renovating the historical façade with a thermal insulation system is obsolete. Therefore interior insulation is gaining tremendous importance and many research institutes, planers, executives and consulters are busily engaged with the process.
Hereafter the planning process of interior insulation systems and related questions are discussed. At the beginning the correlation of significant planning parameters are analysed. Subsequently the theoretical planning process is demonstrated by a case study. The approach is based on the specifications of the "Framework for Probabilistic Assessment" according to the IEA Annex 55.

For planning an interior insulation several parameters must be observed. These are referred to as “framework” and represent all relevant parameters that are required for designers and contractors of interior insulation systems.

2. Considerations for the framework

2.1 Definition of the scope

The planning and evidence of internal insulations can be divided into different **levels of complexity**. This ranges from the entire building to individual components and specific connection details.

1. Whole building
2. Nonsteady state calculation of a detail with multidimensional heat and moisture transport including airflows (4D HAM)
3. Nonsteady state calculation of a detail with multidim. heat and moisture transport (4D HM)
4. Building component with 1D layer structure (1D HM)

In section 3, examples are given how the ideal calculation model can be selected. It is shown how a construction with low potential of risk can be created and it is demonstrated by calculations with appropriate planning tools. A proof of a damage-free construction is currently used rarely used in practice. With the help of the framework a comprehensive verification can be implemented.



Fig. 1: Parts of a building on the example of a 19th century building

Depending on the level of complexity, there are different aspects that must be taken into consideration when designing the framework. For instance, considering the entire building the renovation and maintenance costs may constitute a relevant variable. In contrast, if focusing on a ceiling connection detail for example the maintenance costs are negligible. The planning and execution costs must already be compared to the potential of maintenance procedure costs during the planning phase. Considering the risk of damage of a certain construction the retrofitting costs and the consequential costs of damage have to be evaluated.

At the beginning of a project the **targets and the performance criteria** as well as the consequences of these criteria must be considered. The central goal of thermally renovating an existing building using interior insulation is to increase the energy efficiency of the property. This is achieved by minimizing the heat losses. The effectiveness of a thermal retrofitting can be described by the maintenance of a certain U-value of an external wall structure. At the same time it must be ensured that the renovation does not cause any structural damage. This can be done by evaluating specific performance criteria of a certain construction, e.g. the moisture behaviour of the materials and the permeability or the air-tightness of a construction. The goal is to demonstrate the functionality of the interior insulated wall section. Moreover, it has to be proved that the construction shows a long-term damage-free condition. This verification is based on defining various influencing parameters.
These parameters are based on the **existing conditions and the general information** about the building to be retrofitted. As shown in [1], the detailed planning process starts with a building survey. For this purpose a detailed assessment of certain issues concerning the renovation project is necessary. The questions must include all relevant influence parameters in order to make an object-specific statement. The following checklist shall help to identify the dangers and the relevant parameters within the given object.
The first part of the checklist deals with outside influences on the structure. Here the effects of weather and other constructive material-related features are revealed that – combined with internal insulation – may cause a problem.

		Testing Option			Limit	
Influences	Basic Questions	Y	N	T	L	Detailed Parameters
Outside Boundary Conditions	Are there any climate data of the location?					Which minimum temperature is to be expected in winter? In which climate region is the restoration object situated?
	Is there a driving rain?					Which driving rain group does exist? Which side is stressed the most? Is a functioning rain protection available?
	Is there a risk that the façade dries very slowly?					Can the facade dry fast enough after a driving rain event? Does the facade have parameters that facilitate the drying process? • coloring • surface roughness etc.
	Was the façade hydrophobized?					Are there any defects in the hydrophobing?
	Is there rising moisture?					Is it • constant humidity or • temporary humidity?
	Can the facade absorb moisture at a driving rain event?					How much moisture is absorbed? What happens to it? Can the consequences be estimated, or even seen?
	Is there solar irradiation to the facade?					May it come to reverse diffusion? Is the location of the building • freely and exposed or • in a built-in area?
	Is there existing damage on the facade due to effects of moisture?					Do the effects of moisture come • from the soil? • by driving rain? • by water damage?
	Are there areas on the facade where rainwater can easily penetrate into the construction?					Are • joints, • cracks

Fig. 2: Questions for the survey based on the outside boundary conditions (Part 1 of the checklist)

The second part of the checklist deals with the boundary conditions on the inside of the wall construction and the user-specific conditions. Here the focus lies on existing damage due to moisture and constructive defects on the wall's surface.
Further sections of the questionnaire are dealing with constructive and component-dependent influences on an interior insulation. The whole questionnaire is described in [1]. By using the questionnaire the retrofitting object can be analyzed in detail. In this way problems which could be potentially overlooked in a rough planning process can be detected. The checklist gives further information on the objectives and design possibilities and provides clear knock-out criteria for certain variants.
From the results of the building survey **retrofitting strategies** can be assumed. If the possibilities of renovating a building thermally are already limited to applying an interior insulation the selection of alternatives is very small. It is, however, possible to raise the comfort with the help of special building services like under-floor- and wall-heating-systems.
A basic calculation of an interior insulation can be performed using different **limitations and assumptions**. Especially material properties have to be estimated partially, because historical materials can have wide differences in their key parameters. External climatic conditions can be received by weather stations, thus providing very realistic input parameters for the calculation method. The internal climate conditions must be selected depending on the usage. The indoor climate is described in ÖNORM B 8110-2 or in the WTA data sheet 6-2-01.

2.2 Identification of benefits and hazards

The execution of an interior insulation system requires an intensive and detailed planning process. A lot of object-specific parameters must be investigated. These influential parameters and their uncertainties must be considered when choosing the right insulation system. The following figure shows the essential boundary conditions and divides them into four main groups, each with two sub-groups as shown in Fig. 3.
The uncertainties of the individual parameters can be determined in several ways:

- approximation of parameters (climate data of the location, moisture load of the interior

climate etc.)
- measurements of parameters in the laboratory (material data, flow resistance etc.)
- measurements of parameters of existing properties or demonstration buildings (moisture content of the existing structure, climate conditions etc.)

In ongoing projects calculations of the construction are mainly based on assumptions about material parameters whereas measurements of individual parameters are only made in some



Fig. 3: Influencing parameters

specific cases.

2.3 Importance of parameters

The efficiency of the internal insulation can be evaluated and limited by different variations of the parameters. Thereby one can determine the importance of the individual variables. It is shown that many parameters are object-specific. Thus, the boundary conditions can be sorted by importance for a particular rehabilitation project.

2.4 Implementation of risk assessment

Once the systematic building survey has been completed and the different influencing parameters have been weighted by importance the risk assessment can be carried out. Thus the risk of damage of a construction is recognized. On the basis of life-cycle costs different alternatives of renovations and interior insulation systems can be compared. For constructions with a high risk potential higher restoration costs have to be assumed. These higher costs will negatively affect the life-cycle costs.

In order to determine the risk of damage of an internally insulated construction the combination of

different boundary conditions and influencing parameters has to be taken into account. In addition to the uncertainty of climatic boundary conditions especially material parameters vary significantly, as shown in [2]. These uncertainties can be visualized in probabilistic functions. The calculation of the risk of failure is based on probabilistic calculations incorporating individual parameters. This approach corresponds to a probabilistic safety concept. The research activities in IEA Annex 55 are focussed on implementing a probabilistic verification method in building physics – similar to the verification concept in the statics.

3. Choice of simulation geometries and boundary conditions

Considering the hygrothermal assessment of construction parts, the Glaser-method was the standard of knowledge up until the 1990s. As described in [3], this method, however, works solely with stationary constraints und does not take into account all thermo- and moisture technical storage phenomena and moisture transport through capillary conduct. Since the 1990s methods for a non-steady-state calculation of heat and moisture transport in construction parts are being developed in various research institutes.
As mentioned in 2.1, various calculation models can be used. Thereby the results differ significantly. The simplest way to calculate an interior insulation is a **1D simulation**. Hereby a homogeneous layer structure and a one-dimensional heat flow are assumed. This model corresponds to a flat wall cutout.

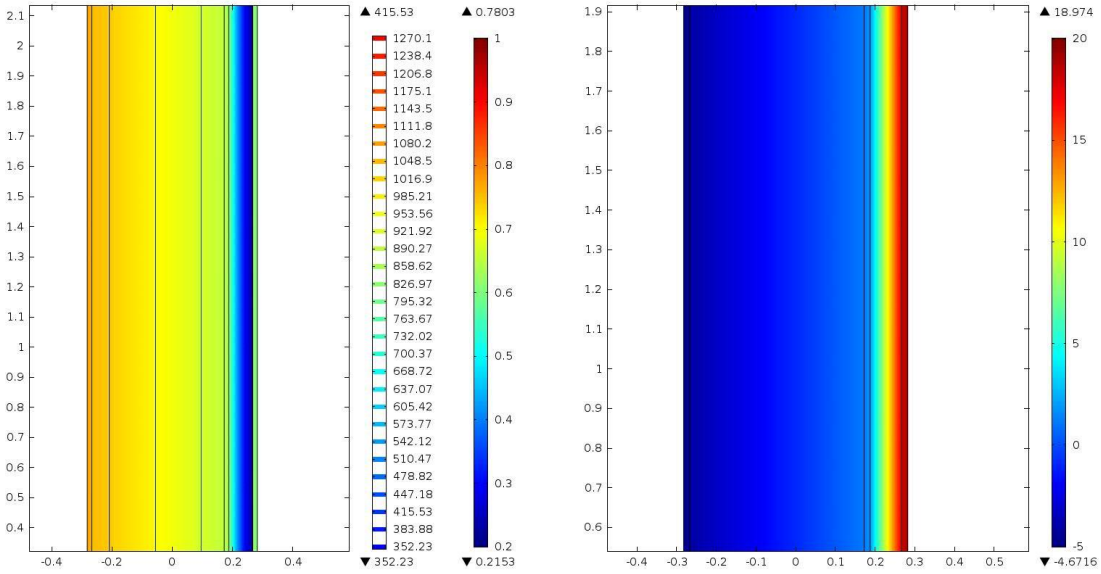


Fig. 4: 1D-Simulation of an inside insulated construction
left: partial pressure and relative humidity; right: temperature

The next complicated model includes a **2D geometry** for calculating two-dimensional heat fluxes. By using these models thermal bridges can be easily displayed. Thus surface condensate or the risk of mould growth can be proved.
For calculating some specific details a **3D simulation** is absolutely essential. Critical thermal bridges are usually three-dimensional and must be calculated accordingly. When planning an interior insulation especially ceiling and interior wall connections as well as window reveals are important three-dimensional details which have to be proved for their proper functioning.
Furthermore, it is essential that liquid water transport and air flows are taken into consideration when hygrothermal simulations are carried out. As shown in [4] and [5] air flows have a significant influence on the functioning of an interior insulation system. This fact is demonstrated in section 4 on the basis of a wooden beam connection. Water entering is relevant especially in the case of facades which are subject to driving rain.
The planning process of an interior insulation should always start with the simplest way of simulations. After clarification of all essential parameters simulations must be continued with the verification of three-dimensional thermal bridges.

4. Influence of calculation methods – Case study of a wooden beam head

The following case study of a wooden beam head shows the impact of different 3D-simulation methods. The beam is situated in a brick wall. At the bearing the wood is surrounded by air. The interior insulation system consists of mineral wool with an air-tight layer on the inside. The simulations were carried out with COMSOL Multiphysics. Temperature, relative humidity, partial pressure and the air flow were evaluated. In three different calculations the same model was simulated using different boundary conditions.
Fig. 5 shows the easiest way to calculate the 3D model. Only vapor diffusion and heat transfer are taken into account.

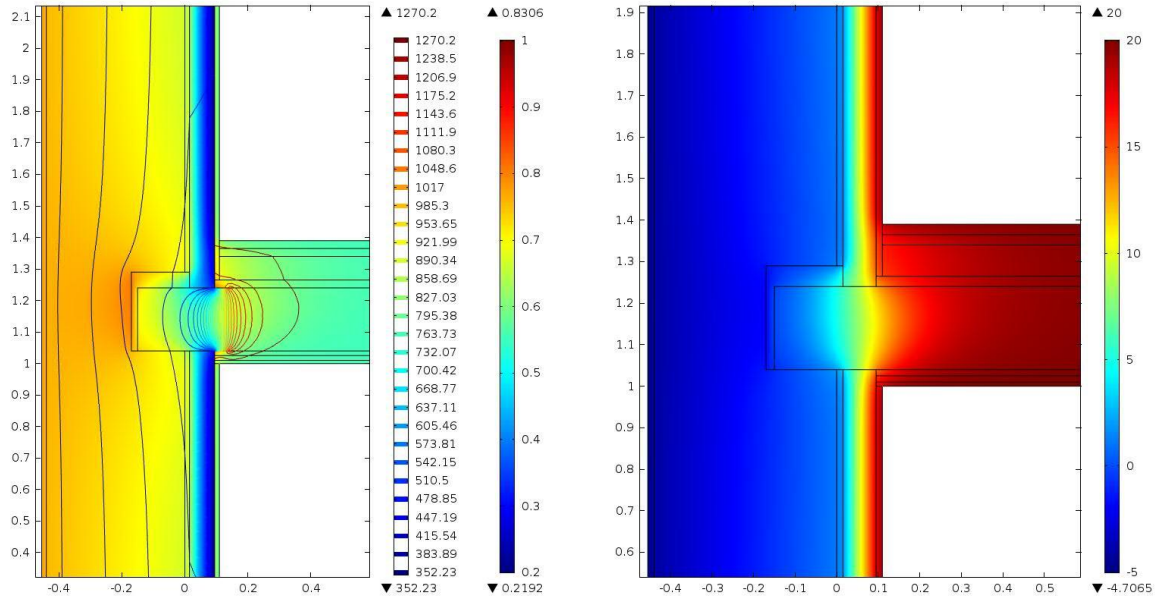


Fig. 5: 3D-simulation of a wooden beam head without airflow;
left: partial pressure and relative humidity; right: temperature

In Fig. 6 vapor diffusion, heat transfer and airflow are taken into account.

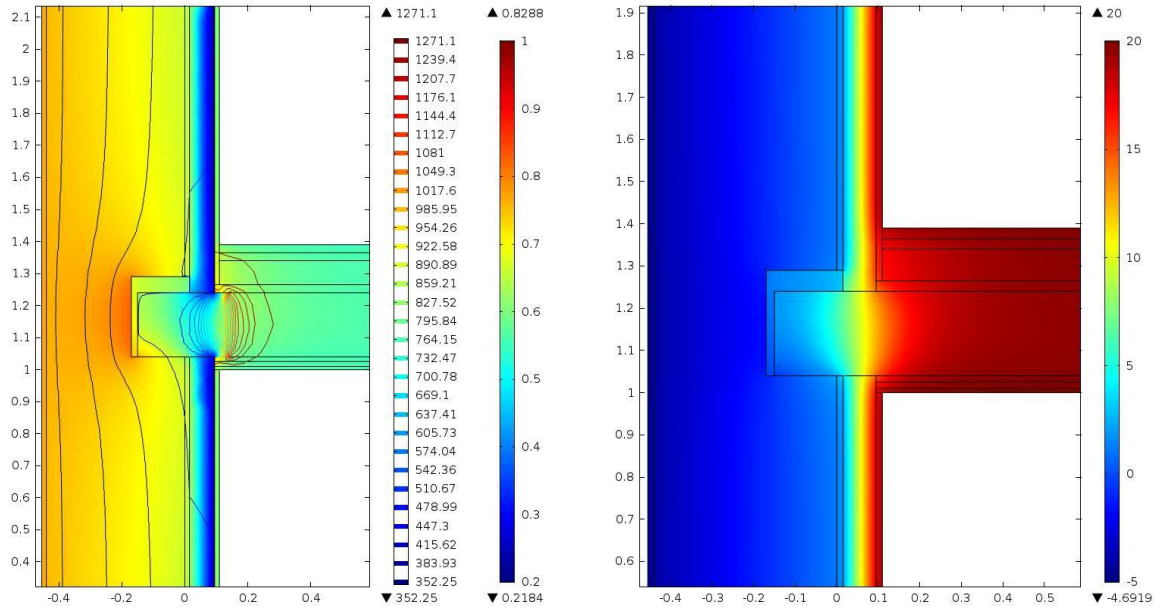


Fig. 6: 3D-simulation of a wooden beam head with airflow;
left: partial pressure and relative humidity; right: temperature

In Fig. 7 vapor diffusion, heat transfer, airflow and a leakage in the construction with a pressure difference of 0,5 Pascal are taken into account.

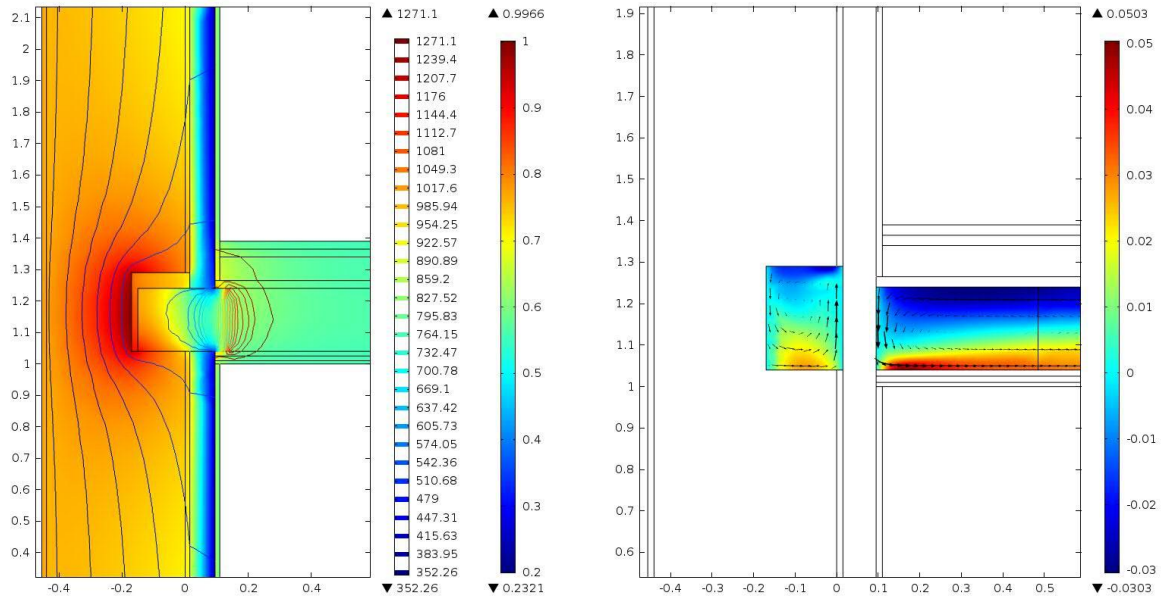


Fig. 7: 3D-simulation of a wooden beam head with airflow, leakage and pressure difference;
left: partial pressure and relative humidity; right: temperature

Comparing the three models one can see the impact of air-flows through constructions and the wide range of simulations' results. It shows that considering or neglecting a single parameter in a simulation can cause completely different results. Therefore it is very important to evaluate all parameters.

5. Conclusions and look-out

The risk of damage of inside insulated wooden beams can be described by the temperature and the relative humidity at the beam head. As shown, these parameters depend on the considered boundary conditions.

The risk for rotting and mould growth can be minimized by selective temperature control in the joist's bearing. A mechanism for temperature control of the wooden beam's end is described in [6]. Fig. 8 shows the effect of the temperature control. The temperature level is raised at the joist's bearing. So the relative humidity can be kept low in order to avoid rotting. Zelger described in [7] a simplified estimation of the additional energy costs.

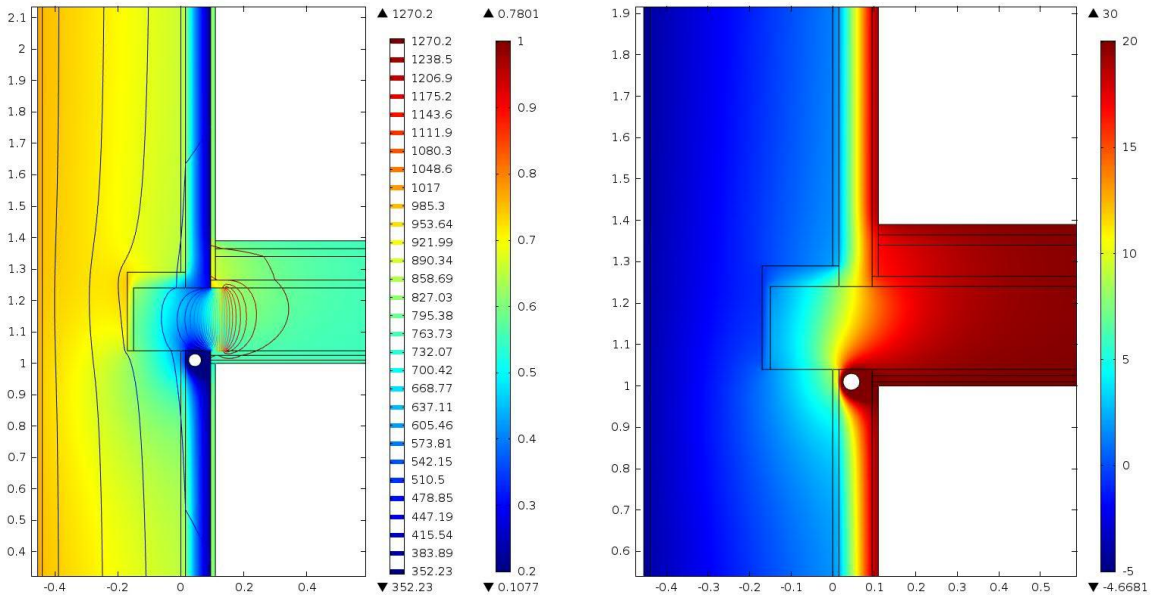


Fig. 8: 3D-simulation of a wooden beam head with airflow and local temperature control; left: partial pressure and relative humidity; right: temperature

It has been demonstrated that using hygrothermal simulations in which worst-case scenarios are assumed can provide results on the safe side. As shown in [7], the estimated costs for planning and quality assurance for specific constructions (with / without leakage) and outdoor climate conditions can be calculated. The evaluation is performed by comparison with limits such as for example, the Isopleth's model to assess the mold growth [8].

In the future, the evidence of the durability and the functionality of interior insulation systems should be based on a probabilistic safety concept. The basics such as the formation of probability distributions of material parameters and climatic boundary conditions are currently being processed. By using probabilities the retrofitting costs and life-cycle costs can be estimated in a better way.

6. References

[1] WEGERER P. *„Beurteilung von Innendämmsystemen – Langzeitmessung und Hygrothermische Simulation am Beispiel einer Innendämmung aus Schilfdämmplatten.*“ Diplomarbeit, TU Wien 2010.

[2] BEDNAR T. *„Beurteilung des feuchte- und wärmetechnischen Verhaltens von Bauteilen und Gebäuden – Weiterentwicklung der Meß- und Rechenverfahren.“* Dissertation, TU Wien 2001

[3] KÜNZEL H.M. *„Dampfdiffusionsberechnung nach Glaser – quo vadis?“* IBP Mitteilung 355, 1999

[4] WEGERER P, NEUSSER M, BEDNAR T. *„Auswirkungen der Luft(un)dichtheit auf die Feuchtebelastung von Konstruktionen mit Innendämmsystemen*.“ 7th International Symposium on Building and Ductwork Air Tightness in Practice May 11 – 12, 2012, Stuttgart, Germany

[5] STRANGFELD P, STAAR A, TOEPEL T. „Das hygrothermische Verhalten von Holzbalkenköpfen im innengedämmten Außenmauerwerk (Teil1).” In Bausubstanz, Heft 2, 2012

[6] WEGERER P, BEDNAR T. *„Anordnung und Vorrichtung zum Temperieren von Tramköpfen*“ Patentnummer AT 510 965

[7] ZELGER T, WALTJEN T, et al. *„PH-Sanierungsbauteilkatalog: Zweite Ausbaustufe PH-SanPlus”*. Berichte aus Energie- und Umweltforschung 48/2012

[8] SEDLBAUER K. *„Vorhersage von Schimmelpilzbildung auf und in Bauteilen*.“ Dissertation, Universität Stuttgart 2001.

Analysis of the thermal behavior of historical box type windows for renovation concepts with CFD



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Short Summary

The box type window (BTW) is a typical craftsmanship's construction for European buildings until the mid of the 20th century, so that there still is a high amount of such windows. While their design is quite complex (as a double window), their assembly is rather simple for a skilled joiner. Therefore they can easily be reconstructed or renovated which – instead of replacing them with new windows – saves embodied energy. Improving their thermal performance is nevertheless crucial nowadays and a deeper understanding of their thermal behavior as well as their flow characteristic is required. This paper sets out to show the outcome of a comprehensive study of the thermal behavior of BTWs´ inner cavity and close surrounding regarding some of the most promising renovation concepts.
Climatic preconditions as well as window geometry had to be considered. Results of in situ measurements of two identically designed and differently refurbished historic box type windows had been used for validating the outcome of Computational Fluid Dynamics (CFD) simulations. The simulations demonstrate effects of heat transfer, buoyancy driven air flow and radiation for the window cavity, interior room and immediate external environment and are consistent to the measurements to a great extent.

Keywords: Computational Fluid Dynamics, Historical Box Type Windows, Renovation Concepts, Thermal Performance, Flow Behavior

1. Introduction

Today Europe´s cities still consist to a notable extent of buildings established from the early 19th century to the mid of 20th century. Several of them are heritage buildings. The box type window was a typical construction at that time for a temperate climate. In Germany and Austria more than 100 million BTWs can be found on buildings´ facades [1], [2].
Because of their simple assembly BTW can be reconstructed or renovated easily and thus fulfill current requirements of heritage protection. Renovation of BTW, especially improvement of their thermal performance reduces heating demand and energy consumption as well as embodied energy otherwise spent on new windows. The huge amount of BTWs requires a detailed understanding of thermal behavior and flow characteristic inside BTWs. Beside briefly touching on convective flow this paper concentrates on simulation of the most promising renovation concepts for traditional BTWs.

BTWs consist of an interior and an exterior casement with an air filled cavity of 150 to 200 [mm] thickness in between. These casements are mounted on a wooden frame so that a box is formed by the frame and the inner and outer casements covering the cavity. Sometimes BTWs also include a shutter box on the top (Fig. 1 and Fig. 2). Normally they have air permeable joints between casement and frame with a gap-width of 1 to 2 [mm] for the inner and 3 to 4 [mm] to the outer layer. The air permeability of the joints allows vapor from the interior to flow to the exterior thus preventing condensation in the cavity which might damage the wooden parts. Furthermore it provides natural air change.

Weathering causes an increase of the air permeable joints' width. As a result convective flow inside the window increases and leads to higher heat loss from the interior to the exterior. Consequently a higher risk of condensation in the cavity and uncomfortable air-speed near the window arise. Several concepts of improvement have been developed to avoid these situations, most of them in agreement with guidelines of Austrian organizations for monument protection. The renovation concepts (Fig. 1) based on the standard BTW (A) which were analyzed in this study are: (B) a gasket frame for the inner casement, (C) insulated glass for the inner casement and thermal insulation for the shutter box, (D) an additional interior casement and (E) a vertical airproof divider within the cavity.

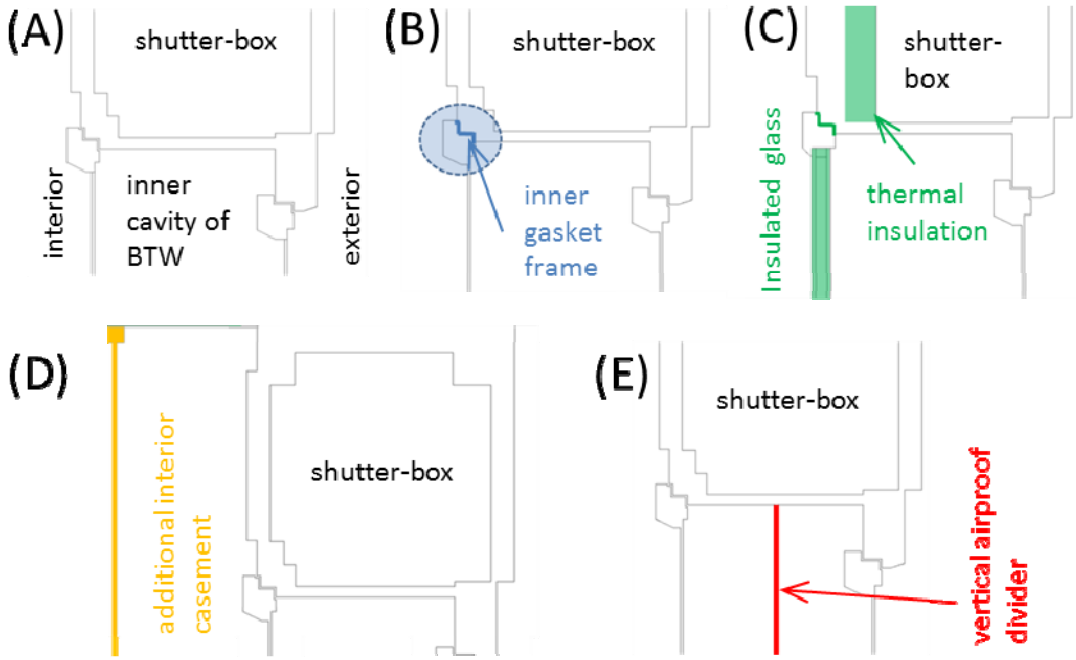


Fig. 1: Schematic of considered renovation concepts for BTWs: (A) refurbished (traditional), (B) gasket for the inner casement, (C) insulated glass for the inner casement and thermal insulation for the shutter-box, (D) additional interior casement, (E) vertical airproof divider.

To improve the level of knowledge on thermal behavior and flow characteristics of BTW the Institute of Building Construction conducted in situ measurements of two similar designed BTWs in combination with hygrothermic simulations. One window (A) was renovated and painted, the other one was additionally improved by adding a gasket frame to the inner casement and changing the inner single glass panes with low-e-coated glass panes (B). The attained data from standard BTW (A) were used for validating the results of Computational Fluid Dynamics (CFD) simulations which are the main focus of this research.

2. Literature research

Current literature shows several studies regarding natural convection in a closed cavity of double windows as well as double-skin façades [4], [5], [8] and [10]. The aspect ratio (Eq. 1) of height and length of the inner cavity is at more than 20 in all these studies.

$$A = \frac{H}{L} \tag{1}$$

The aspect ratio for a typical BTW´s inner cavity is approximately 8. Moreover Wright et al. [3] published results from an analysis of natural convection in a tall cavity between a hot and a cold wall at different Rayleigh numbers (Eq. 2). The aspect ratio was around 40 and the distance between hot and cold side was much smaller than it is in BTWs.

$$Ra_x = \frac{g \cdot \beta}{\nu \cdot a} \cdot \left(T - T_\infty\right) \cdot x^3 \tag{2}$$

A related study was conducted by Alawadhi [5] to determine the effects of window integrated phase change materials (PCM) on thermal and flow behavior of the window and the PCM. The PCM was implemented as a shading device in between the window panes.
A number of studies cover the thermal behavior of open joint façade systems as laboratory experiments in combination with numeric simulations [9] and [10]. Different measurement methods for flow characterization were used as well as several CFD simulations for validating the experimentally achieved data.
Coussirat et al. [11] investigated different numerical models for natural and forced convection in a double-glazed rear ventilated façade. The results by using different turbulence and radiation models were compared with conclusions from Manz et al. [21], resulting in SKE and RNG turbulence models being most suitable. The P1 model showed best agreements for compared radiation models.
Further more accurate flow characteristics could be achieved by using velocimetry measurements. Mortensen et al. [7] analyzed the microclimate inside a box with Particle Image Velocimetry (PIV) technique. A chiller attached at the top wall provided enough cooling power to enable natural convection inside the box.
Bhamjee et al. [12] experimentally monitored natural and forced convection within an air-supply window with the Laser Doppler Velocimetry (LDV) measurement method.
Natural convection has been covered by many studies coping heat transfer in double-glazed facades with integrated shading devices having a notable influence on convection [15] - [17], [19] and [21]. All of these studies used either two or three dimensional geometry for the CFD simulations. An alternative for investigating thermal behavior inside double-glazed facades and windows is a full scale experimental set-up, as in the studies of Pappas et al.[20], Kuznik et al. [22] and Peeters et al.[23].
Almost all of these studies concentrated an overheating on hot summer days in warmer climate. In colder climate the effort on heating for providing comfortable climate indoors in winter is significant higher than the cooling effort in summer. As no literature was found on this subject, this research at first copes with measurements for a typical BTW and the validation of simulations by measurement data followed by a theoretical reflection of four different renovation concepts.

3. In situ measurement

3.1 Measurement build up

Multiple measuring approaches are known to investigate the thermal quality of windows.

One of the most important laboratory test-sets for rating the thermal behavior of windows under controlled boundary conditions [12] is the hot box method [13], where two boxes at different temperature levels are positioned on either side of the façade or window.
In huge outdoor test facilities full scaled façade elements can be integrated and their thermal behavior under the influence of the external climate can be observed [19].
Integrating all sensors in a window in a building is called “in situ” measurement. This method was used for monitoring the thermal behavior of the renovated BTW (A) and improved BTW (B) mentioned in this paper. The windows are installed in one of the reference objects of the research project “denkmalaktiv I”: Schönbrunngasse 30, 8034 Mariatrost in Graz, Austria, a former mental home built in 1885, now a public kindergarten.

The right BTW (A) on picture (1) in Fig. 2 was used for validating the simulation results. The main dimensions of the window are 1.63 x 1.76 x 0.28 [m] (W x H x L). Each of the two BTW´s casements consists of three window parts, two of which can only be opened simultaneously. A shutter box is the upper enclosure of the inner cavity. The dimensions of the inner cavity are 1.36 x 1.49 x 0.21 [m] (W x H x L), adjacent masonry is about 0.55 [m] thick. The joints between casement and frame are varying about 0.5 and 5.0 [mm]. Several sensors were installed to measure temperature, humidity, air flow and global radiation. For the validation of the simulation results the following four temperature sensors were needed:
Sensor T-top (picture (3), Fig. 2, highlighted by a red circle) was mounted 0.2 [m] below the wooden plate forming the upper cavity enclosure and in the horizontally canter.
Sensor T-bot was also fixed in the center of the BTW´s cavity about 0.2 [m] above the base plate (highlighted by a magenta circle, picture (2), Fig. 2).
Two more sensors were attached to the window 0.34 [m] above he base, one sensor on the inner surface of the exterior (T-ext) and the other on the outer surface of the interior (T-int) glazing (picture (2),Fig. 2).

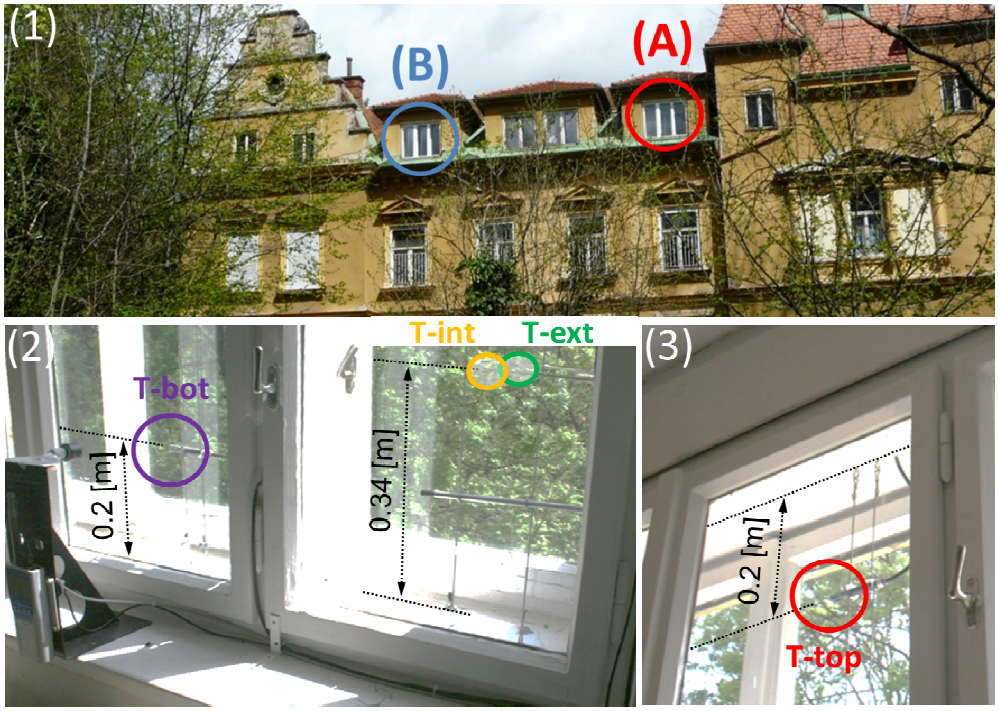


Fig. 2: (1) the south façade of the historical building Schönbrunngasse 30, Graz, including a refurbished (A) and an improved (B) BTW, (2) and (3) pictures of the BTW and details about temperature measurement build up.

3.2 Measurement results

Fig. 3 gives a sectional view on the temperature, monitored in 2012 for the refurbished BTW (A) from February 2nd to 22th. The figure also shows room temperature (T-room) as well as the external temperature (T-out) close to the window. The external temperature was ranging between -15.0 and 10.0 [°C] while room temperature was approximately between 20.0 and 30.0 [°C]. Temperature peaks in the inner cavity were resulting from the influence of solar radiation.

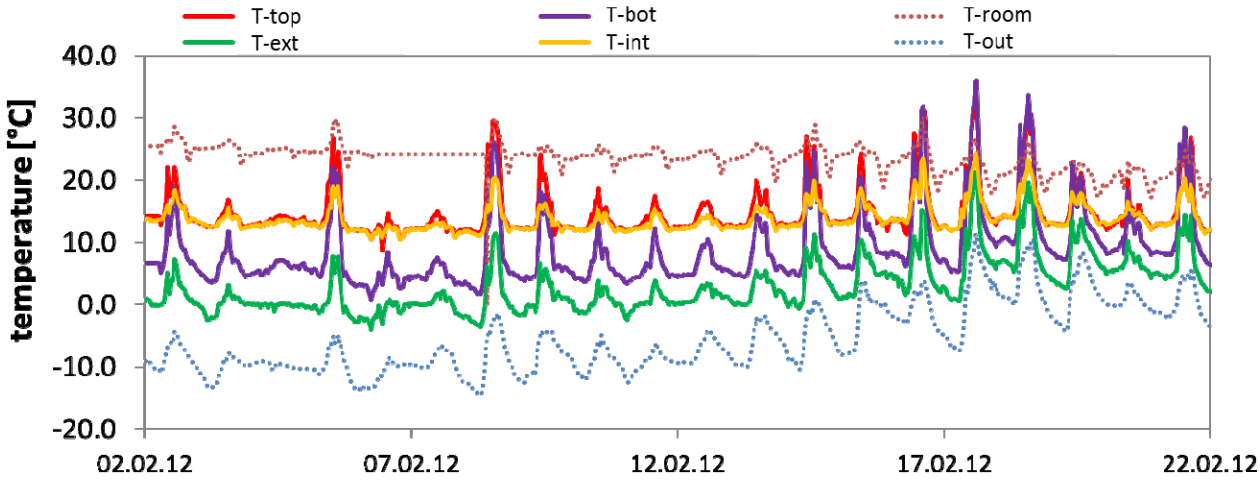


Fig. 3: Temperature measurement from February 2nd to 22th, 2012 for refurbished BTW (A).

4. Computational Fluid Dynamics (CFD)

4.1 Numeric approach and required parameter

While in-situ measurements provide only sample values for validation, Computational Fluid Dynamics can give a deeper view inside the thermal behavior of BTWs. Main goal was to reproduce the physical behavior for the inner cavity of the BTW. All simulations of this study were accomplished by the use of special CFD software called ANSYS Fluent [25]. This software provides a broad range of model-equations for description of fluid flow, thermal considerations, radiation, chemical processes etc. which are described very detailed by the theory- and user-guide [25]. Good quality in simulation results required numerical reproduction of air flow, buoyancy effects, energy consumption, thermal conductivity as well as consideration of long wave radiation. For CFD-Software available turbulence models, which have significant influence on the behavior of air flow, were derived from Reynolds Average Navier-Stokes (RANS) equations (Eq. 3).

$$\rho \cdot \overline{u}_j \cdot \frac{\partial \overline{u}_i}{\partial x_j} = \rho \cdot \overline{f}_i + \frac{\partial}{\partial x_j}\left[-\overline{p} \cdot \delta_{ij} + \mu \cdot \left(\frac{\partial \overline{u}_i}{\partial x_j} + \frac{\partial \overline{u}_j}{\partial x_i} \right) - \overline{\rho u_i' u_j'} \right] \tag{3}$$

For all simulations in this study the realizable k-ε (RKE) turbulence model was used. This simulation model was very suitable for complex flow which occurs in the BTW cavities, interior room and external environment. The extension of the enhanced wall treatment was necessary for better solution of thermal effects close to the solid surfaces. Further required was to enable gravity force and to implement full buoyancy effects in order to generate natural convection in the simulations. The air permeable joints could be defined as laminar zones, because the calculated Reynold numbers (Eq. 4) did not exceed the critical value that indicates turbulence.

$$\mathrm{Re}_x = \frac{\rho \cdot u \cdot x}{\eta} = \frac{u \cdot x}{\nu} \tag{4}$$

The discrete ordinate (DO) model was applied to involve the effects of radiation between air space adjacent walls. The input value for the Theta and Phi Divisions as well as for the Theta and Phi Pixels was 5. During the simulation radiation was calculated every 25th time step. Moreover in simulations air was treated as an ideal incompressible gas because of low Mach number (Eq. 5) with values far below 0.2.

$$Ma = \frac{u}{c} = \frac{u}{\kappa(T) \cdot R_S \cdot T} \tag{5}$$

The thermal conductivity λ for wooden components was 0.13 [W m^{-1} K^{-1}], 1.0 [W m^{-1} K^{-1}] for the window glass and approximately 0.38 [W m^{-1} K^{-1}] for the masonry wall. All simulations were performed for steady state condition by using an implicit pressure based solver. The solution method SIMPLE was used for the pressure-velocity coupling. Further the body forced weighted pressure method was used for discretization of pressure. Method for discretization of the gradients was the least squares cell based. Method of second order upwind scheme was used for convective, radiation and energy term discretization.

4.2 Geometry and boundaries

A two dimensional CFD-model geometry was developed (Fig. 4) for simulations, according to the dimensions of the BTW and the room from in-situ measurement in the building Schönbrunngasse 30 (Fig. 2). For the air permeable joints a simplified assumption with a width of 2 [mm] was made. One study from recent literature research [17] showed how important it was to consider the external environment in simulations of natural convection and ventilation effects for double-skin facades.

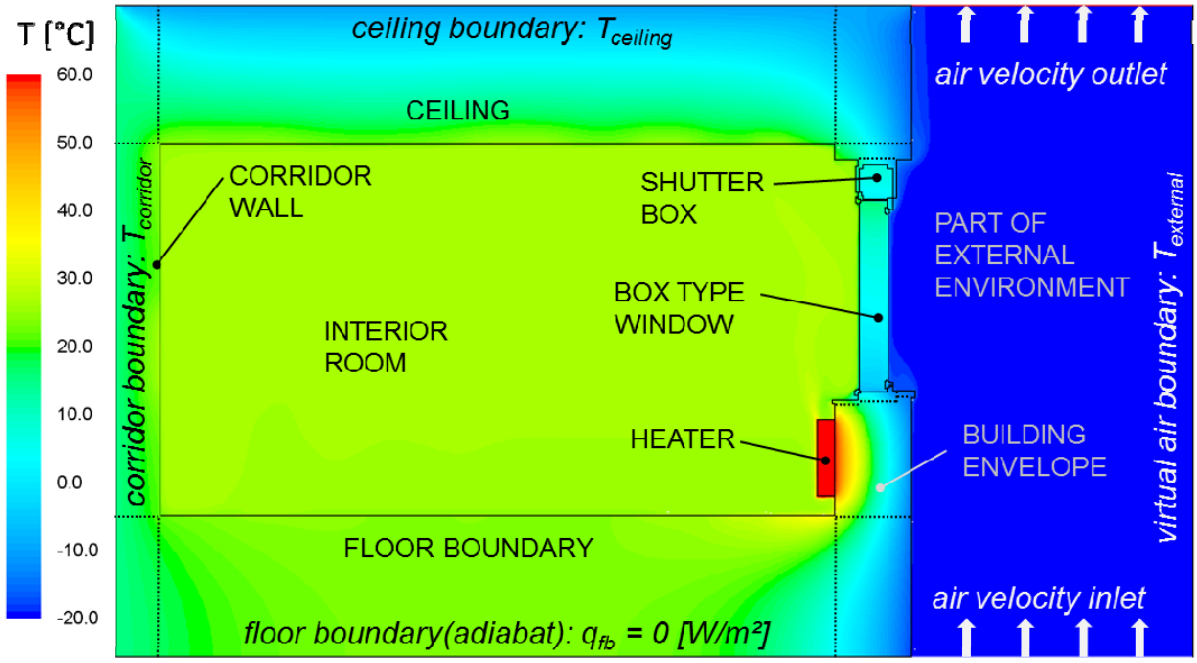


Fig. 4: Simulation model including zones and boundaries.

Main dimension of the interior room was a height of 2.67 and a length of 4.8 [m]. The room was enclosed by the ceiling, the floor and the corridor boundary as well as the building´s envelope. For the floor boundary no heat exchange to the room below was defined. The influence of external wind was included in simulation by definition of a velocity outlet at the top and a velocity inlet at the bottom of the external environment zone. Below the BTW bench a radiator was attached that supplied heating energy to the room by predefinition of the heater´s surface temperature.

4.3 Grid for CFD simulations

For the grid generation of the BTW simulation geometry the “pave” method was used. The grid nucleation was initialized at the air permeable joints at a starting cell size of about 0.5 [mm]. The grid generation was accomplished with the help of the software Gambit [25]. Afterwards the grid had to be adapted by considering the wall function. For the adaption process the generated grid was imported to the CFD Software Fluent ANSYS. The boundary conditions in adaptation process were the same as in the CFD-analysis of the thermal behavior for a cold winter day (5.1). The adaptation process was completed when turbulence rating y^+ had reached a value smaller than 1.0 [25]. After adaptation process the grid consisted of approximately 600.000 linked cells. Fig. 5 gives a sectional view of the grid structure by showing the region of the bottom located inner air joint. The grid´s cell size varied between 0.05 x 0.05 and 64 x 32 [mm].

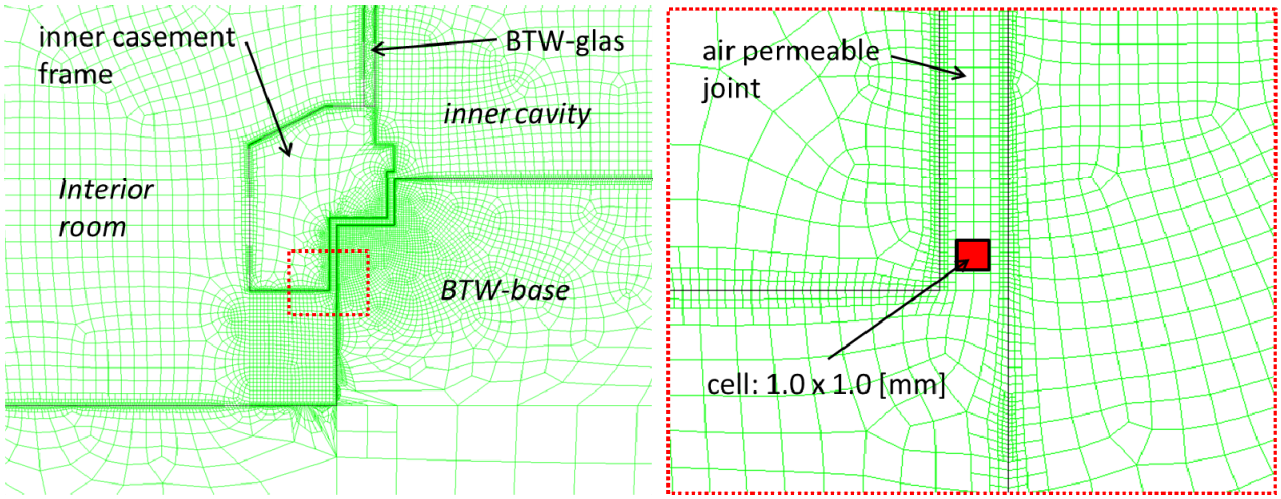


Fig. 5: Sectional view of the grid structure for the BTW simulation geometry at the region of bottom located inner air joint.

5. Results and Discussion

5.1 Thermal and flow behavior for a cold winter day

The first analysis was the examination of convective flow during a winter day in the region of Graz in Austria. The external temperature was -20 [°C] at a wind speed of 0.1 [m/s] along the façade of the building. This wind speed input was resulting from the most prevalent horizontal wind loads occurring at this location of the building. The ceiling boundary temperature was -10 [°C] for consideration of heat loss through the roof of the building. The corridor boundary temperature was 15 [°C], assuming that the buildings´ corridors were held at moderate temperature. The effect of heating was defined by a heater´s surface temperature of 60 [°C].
Fig. 6 and Fig. 7 give a sectional view of the temperature distribution and convective flow inside and close to the BTW. The red arrows highlight the main flow characteristic for the inner cavity. At the bottom located exterior joint infiltration of air from outside was detected. In the region close to the exterior casement frame at the bottom of the BTW cavity several air vortices were obtained. The air streamed from exterior to the interior casement at the bottom of BTW cavity. A jet of cold air flowed inside to the room through the bottom located interior joint. This cold air was mixed up with the upwards streaming, by the radiator heated air and caused a reduction of the room temperature. Additionally the air streamed upwards due to buoyancy effects. Along the whole interior window glass a thin natural convective flow could be observed. At the top temperate air from the interior room streamed into the BTW´s cavity and got mixed up with the upwards streaming air along the interior window glass. This mixed air streamed from interior to exterior casement along the upper edge of the cavity. Through the upper exterior joint temperate air flowed to the external environment. A rest of air was streaming around the upper exterior casement frame. Close to the

exterior window glass the air was cooled down and flowed downwards. Furthermore occurred a small partition of air that was recirculated at the top of the BTW cavity.

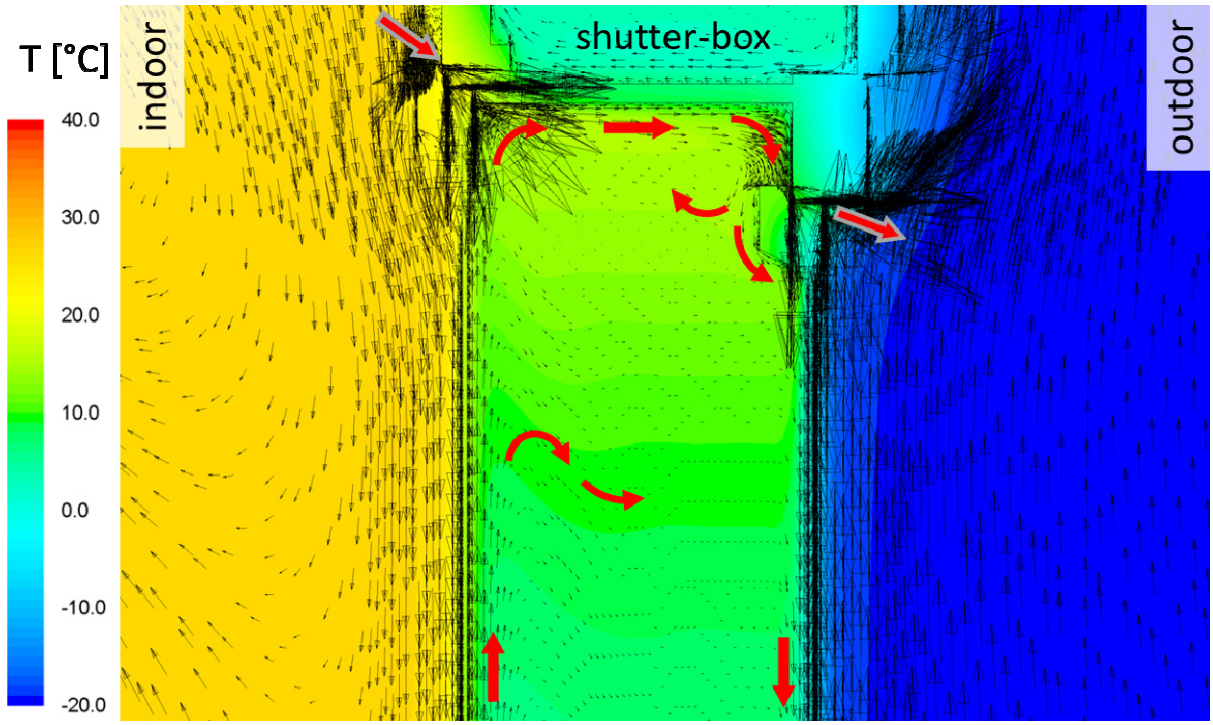


Fig. 6: Illustration of temperatures and air vectors for the upper region of the inner cavity of the refurbished BTW (A).

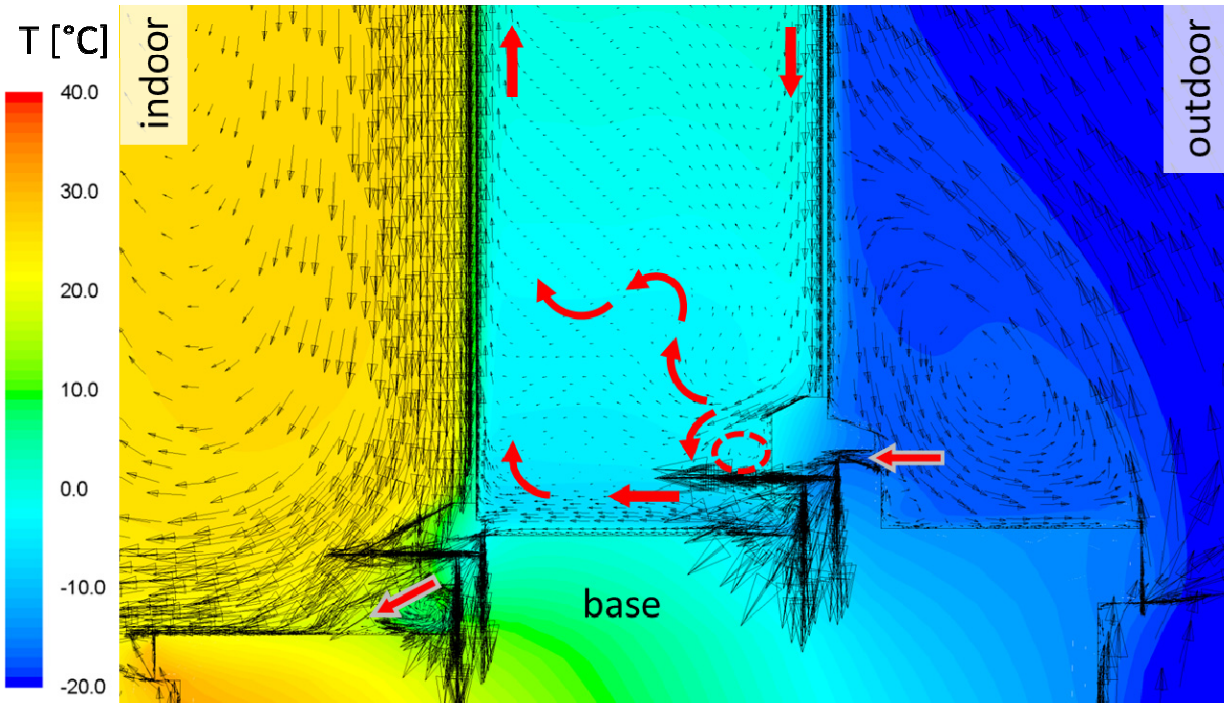


Fig. 7: Illustration of temperatures and air vectors for the lower region of the inner cavity of the refurbished BTW (A).

More details about the temperature and buoyancy velocity for inner cavity are shown in Fig. 8 and Fig. 9. Fig. 8 includes temperature and velocity profiles along the length of the BTW cavity at the middle of the BTW´s height (A-center), 20 [mm] distanced below the upper cavity edge (A-0.2-top)

as well as 20 [mm] in distance above the bottom edge of the cavity (A-0.2-bot). Fig. 9 contains three sections of temperature and buoyancy velocity profiles along the BTW height (at the middle position (A-middle) of BTW-length and in 10 [mm] distance to exterior (A-0.1-ext) and interior (A-0.1-int) window glass).
The temperature profiles showed a stratification of temperature along the height of window´s cavity where temperature was increasing upwards. The profiles indicated fluctuations of temperature near the air permeable joints. The buoyancy velocities of convective flow along the window glasses reached a maximum in the middle of the BTWs´ height. The thickness of these flows varied between 3 and 12 [mm]. In the middle of the BTW´s length a zone was obtained, that showed almost no buoyancy velocity.

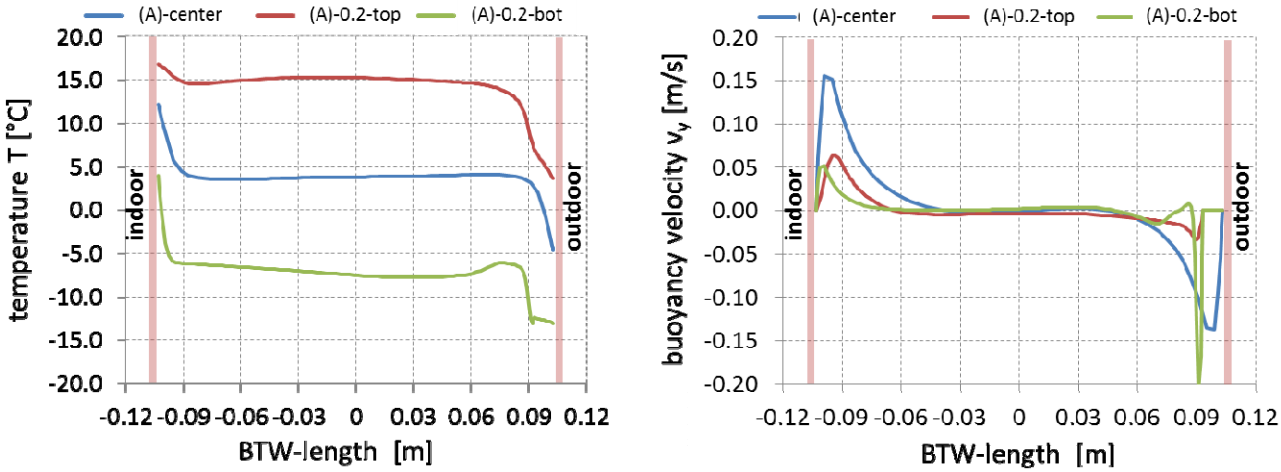


Fig. 8: Profiles of temperature and buoyancy velocity along the inner cavity´s length for the refurbished BTW (A) at different BTW heights.

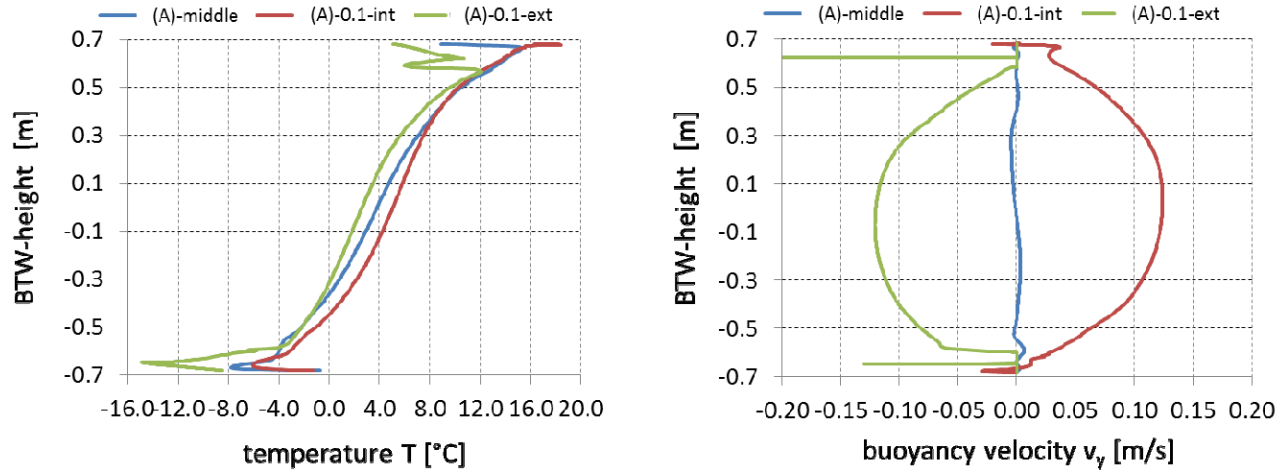


Fig. 9: Temperature and buoyancy velocity along the inner cavity´s height for the refurbished BTW (A) at different BTW length.

5.2 Comparison between measurement and simulation

This chapter shows a comparison of the computed temperature profile with the data from measurements for the refurbished BTW (A). On 6th February between 9 and 12 p.m. almost constant temperature was indicated which was perfectly qualified for the validation of the steady state simulation´s results. At this point of time external measured temperature was -9.96 [°C]. The corresponding measured room temperature was 24.2 [°C].
In the CFD simulation the measured external temperature was used as input for the virtual air boundary. During simulation process the surface temperature of the heater had been changed until

the room temperature had reached the measured value. The results of the computed temperature profiles from this simulation compared with measurement data are shown in Fig. 10. This diagram contains the computed temperature profile along the BTW-height (A-middle) at the cavity measurement sensor´s position (T-top, T-bot, also shown in Fig. 1) as well as the temperature profiles along the cavity-oriented surface of the external (A-ext-pane) and the internal (A-int-pane) pane. Measured (T-int, T-ext) and simulated temperatures at the window glasses showed good agreement. The computed values underestimate the measured temperatures inside the BTW. The difference at the upper sensor position was 1.54 [°C], the measured temperature at the lower sensor position was 2.57 [°C] higher than computed. These deviations could be explained because of the two dimensional simulation geometry and simplifications in form of the assumption of a uniform width for the air permeable joints.

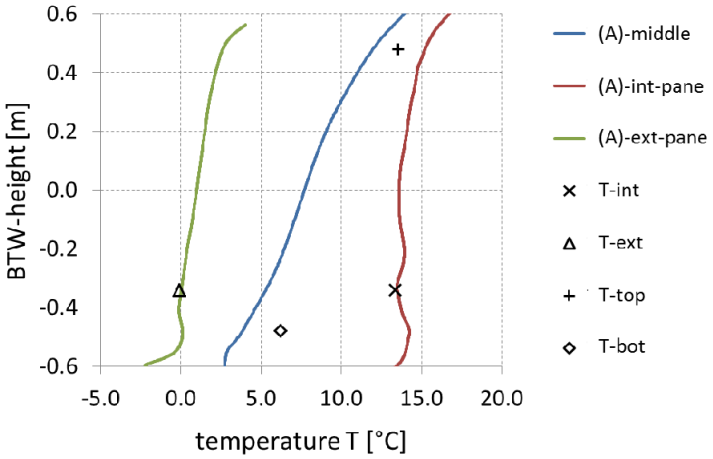


Fig. 10: Comparison between in situ measurement and the computed temperature profiles at corresponding positions in the cavity of the refurbished BTW (A).

5.3 Comparison of renovation concepts

After determination of air flow and validation of simulation data for the refurbished BTW (A), the comparison of the before mentioned renovation concepts (Fig. 1) follows. By the reason, that for renovation concept´s simulations the boundary conditions were inherited from the refurbished BTW simulation of a cold winter day (chapter 5.1) a cross-comparison was possible. Resulting temperature profiles of the renovation concepts are shown in Fig. 11. This figure also includes the comparison of the average room temperature for all renovation concepts. A higher averaged room temperature indicates better quality for the corresponding renovation concept. Therefore a specially expression of the BTW rating (Eq. 6) was developed:

$$rating_{BTW(i)} = \frac{T_{average,BTW(i)} - T_{average,BTW(A)}}{T_{average,BTW(A)}} \cdot 100\% \qquad (6)$$

Concerning to this evaluation method the application of an insulated glass as inner pane and thermal insulation for the shutter-box (C) effected highest average room temperature and thus received the best BTW rating (21.6 %). The renovation concept with the integrated vertical airproof divider (E) showed an improvement of 6.9 %. The concept with the additional casement at the interior room side (D) followed with 4.4 % in improvement ranking. The implementation of the interior gasket frame (B) also showed a slight improvement (1.24%).

The influence of each renovation concept on the air temperature of the inner cavity as well as on the temperature profile close to the interior casement is shown in Fig. 12. Temperature profiles for the interior room close to the window confirmed the results of average room temperatures. The temperature profiles inside the cavity showed inverse behavior to the room temperature with the exception of the renovation concept (E) with the vertical inner divider.

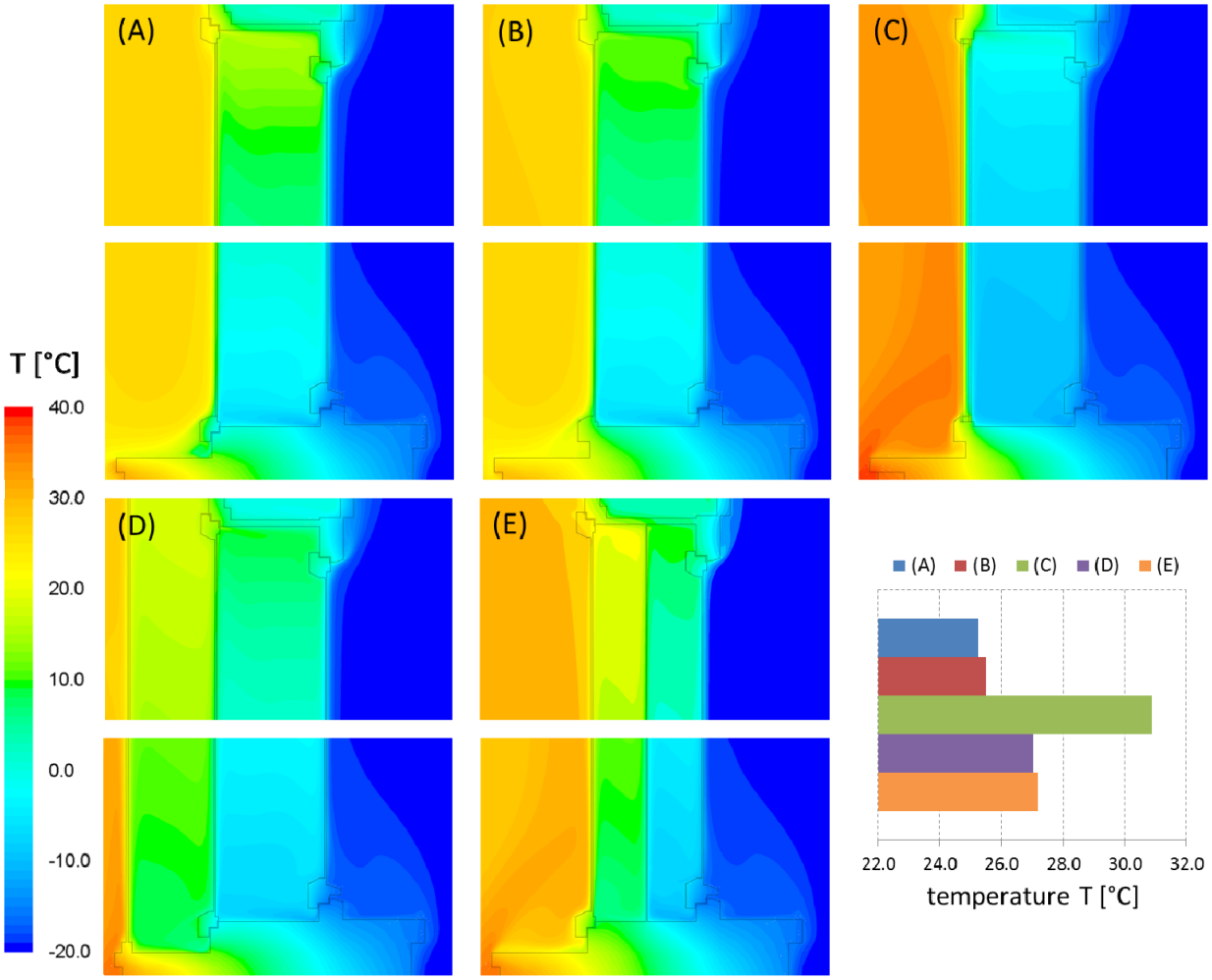


Fig. 11: Temperature distribution at the bottom and top region of the inner cavity for (A) the refurbished BTW, (B) the BTW with implemented interior gasket frame, (C) BTW containing an insulated glass and insulation for the shutter-box, (D) BTW with additional interior casement and (E) BTW with an vertical airproof divider. The diagram shows a comparison of average room temperature of the five BTW types.

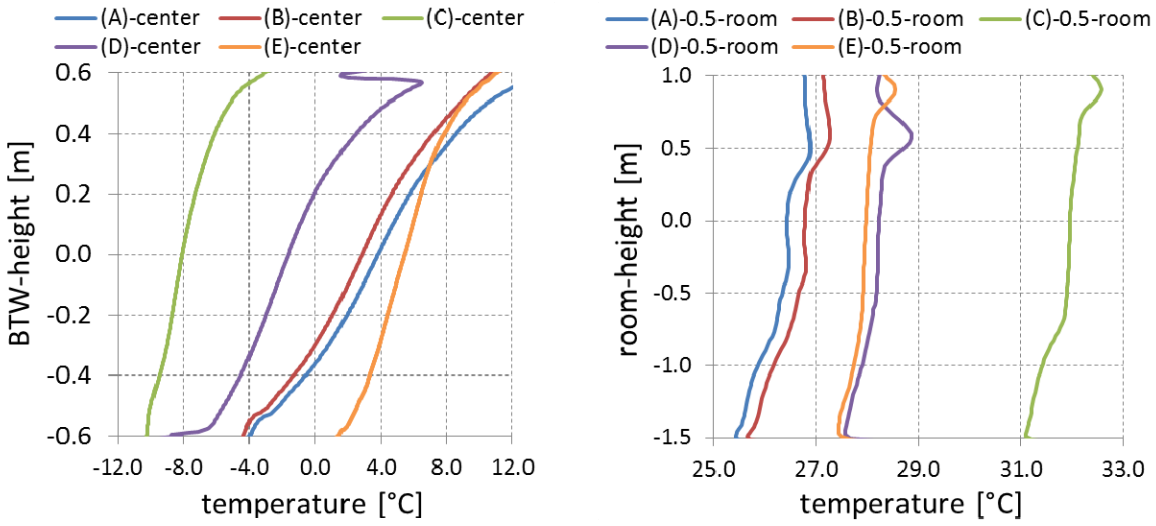


Fig. 12: Left diagram shows the comparison of temperature profiles along the BTW cavity height, right diagram shows the temperature profile along the room height at a distance of 0.5 [m] to the interior window glass.

6. Conclusions and Outlook

This paper covers a detailed prediction of the thermal behavior of a traditional BTW´s (A) inner cavity and close environment by use of Computational Fluid Dynamics. Boundary conditions were those of a cold winter day in a temperate climatic zone. Flow characteristic of the inner cavity as well as effects of infiltration and natural ventilation have been discussed.
Sectional profiles of temperatures and buoyancy velocity described shape, stratification and magnitude of the convective flow along the windows casements at the inner cavity. Maximum buoyancy effect occurred in the middle of the BTW´s height.
The validation with results from in situ measurements showed good accordance between simulation and measurement data at the window glasses while the computed temperature inside the BTW cavity was too low. The influence of solar radiation on convective flow for the inner cavity was indicated by high temperature peaks.
Differences in thermal behavior between four different theoretical renovation concepts were simulated by CFD and compared with the results from the refurbished BTW. The BTW (C) containing an insulated glass and insulated shutter-box achieved the best rating concerning thermal performance. All other renovation concepts also showed improvement.
Further experiments and measurement set-ups with controlled boundary conditions would produce a higher level of data and validation quality.
As a summery it can be assessed that investigations of the transient behavior of BTWs as well as consideration of three dimensional simulation models improve the quality of the simulation results.

7. Acknowledgement

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8. References

[1] GAMERITH H, HÖFLER K, VABITSCH G, FERK H, REITERER E. *“Historische Fenster: Untersuchungskriterien zur Bestimmung der Erhaltungswürdigkeit historischer Fenster”*. 1997, Graz. (historical windows: investigational criteria to determine the conservation of historical windows)
[2] MÜLLER R. *“Holzfenster: Konstruktion, Schäden, Sanierung, Wartung”*. 2011, Korr. Nachdr. Köln: Rudolf-Müller. (wooden windows: structure, damage, renovation, service)
[3] WRIGHT J, JIN H, HOLLANDS K, NAYLOR D. *“Flow visualization of natural convection in a tall, air-filled vertical cavity”*. International Journal of Heat and Mass Transfer, 2006, volume 49, pp. 889-904.
[4] MANZ H. *“Numerical simulation of heat transfer by natural convection in cavities of façade elements”*. Energy and Buildings, 2003, volume 35, pp. 305-311.
[5] ALAWADHI E. *“Using phase change materials in window shutter to reduce the solar heat gain”.* Energy and Buildings, 2012, volume 47, pp.421-429.
[6] AYDIN O. *“Conjugate heat transfer analysis of double pane windows”.* Building and Environment, 2006, volume 41, pp.109-116.
[7] MORTENSEN L, RODE C, PEUHKURI R. *“Investigation of airflow patterns in a microclimate by particle image velocimetry (PIV)”.* Building and Environment, 2008, volume 43, pp. 1929-1938.
[8] XAMAN J, ALVAREZ G, LIRA , ESTRADA C. *“Numerical study of heat transfer by laminar and turbulent natural convection in tall cavities of façade elements”.* Energy and Buildings, 2005, volume 7, pp. 787-794.
[9] SANJUAN C, SUAREZ M, BLANCO E, M HERAS M. *“Development and experimental*

[1] denkMALaktiv I - Restoration of old heritage buildings to standards of active houses?, Neue Energien 2020 2. announcement, project number 821 201

validation of a simulation model for open joint ventilated facades". Energy and Buildings, 2011,volume 43 pp. 3446-3456.

[10] SANJUAN C, SANCHEZ M, HERAS M, BLANCO E. *"Experimental analysis of natural convection in open joint ventilated facades with 2D PIV".* Building and Environment, 2011, volume 46 pp. 2314-2325.

[11] COUSSIRAT M, GUARDO A, JOU E, EGUSQUIZA E, CUERVA E, ALAVEDRA P. *"Performance and influence of numerical sub-models on the CFD simulation of free and forced convection in double-glazed ventilated facades".* Energy and Buildings, 2008, volume 40 pp. 1781-1789.

[12] BHAMJEE M, NURICK A, MADYIRA D. *"An experimentally validated mathematical and CFD model of a supply air window: Forced and natural flow".* Energy and Buildings, 2013, volume 57 pp. 289-301.

[13] APPELFELD D, SVENDSON S. *"Experimental analysis of energy performance of a ventilated window for heat recovery under controlled conditions".* Energy and Buildings, 2011, volume 43, pp. 3200-3207.

[14] COLLINS M, TASNIM S, WRIGHT J. *"Numerical analysis of convective heat transfer in fenestration with between-the-glass louvered shades".* Building and environment, 2009, volume 44, pp. 2185-2192.

[15] COLLINS M, TASNIM S, WRIGHT J. *"Determination of convective heat transfer for fenestration with between-the-glass louvered shades".* International Journal of Heat and Mass Transfer, 2008, volume 51, pp. 2742-2751.

[16] DALAL R, NAYLOR D, ROELEVELD D. *"A CFD study of convection in a double glazed window with an enclosed pleated blind".* Energy and Buildings, 2009, volume 41, pp. 1256-1262.

[17] PASUT W, DE CARLI M. *"Evaluation of various CFD modeling strategies in predicting airflow and temperature in a naturally ventilated double skin façade".* Applied Thermal Engineering, 2012, volume 37, pp. 267-274.

[18] SAFER N, WOLOSZYN M, ROUX J. *"Three-dimensional simulation with a CFD tool of the airflow phenomena in single floor double-skin facade equipped with a venetian blind".* Solar Energy, 2005, volume 79, pp. 193-203.

[19] ZÖLLNER A, WINTER E, VISKANTA R. *"Experimental studies of combined heat transfer in turbulent mixed convection fluid flows in double-skin-facades".* International Journal of Heat and Mass Transfer, 2002, volume 45, pp. 4401-4408.

[20] PAPPAS A, ZHAI Z. *"Numerical investigation on thermal performance and correlations of double skin facade with buoyancy-driven airflow".* Energy and Buildings, 2008, volume 40, pp. 466-475.

[21] MANZ H. *"Total solar energy transmittance of glass double façades with free convection".* Energy and Buildings, 2004, volume 36, pp. 127-136.

[22] KUZNIK F, CATALINA T, GAUZERE L, WOLOSZYN M, ROUX J. *"Numerical modeling of combined heat transfers in a double skin façade - Full-scale laboratory experiment validation".* Applied Thermal Engineering, 2011, volume 31 pp. 2043-3054.

[23] PEETERS L, BEAUSILEIL-MORRISON I, VOVOSELAC A. *"Internal convective heat transfer modeling: Critical review and discussion of experimentally derived correlations".* Energy and Buildings, 2011, volume 43, pp. 2227-2239.

[24] BAIRI A. *"Transient free convection in passive buildings using 2D air-filled parallelogram-shaped enclosures with discrete isothermal heat sources".* Energy and Buildings, 2011, volume 43, pp. 366-373.

[25] ANSYS FLUENT 14.0. Userguide/Theoryguide.

Nomenclature

a	thermal diffusivity [$m^2\ s^{-1}$]
A	window aspect ratio
c	speed of sounds [$m\ s^{-1}$]
f	external forces [$kg\ m\ s^{-2}$]
g	gravity acceleration [$m\ s^{-2}$]
H	window height [m]
L	window length [m)
Ma	Mach number
p	pressure [$kg\ m^{-1}\ s^{-2}$]
q	heat flux [$W\ m^{-2}$]
Ra_x	Rayleigh number
Re_x	Reynolds number
R_S	specific gas constant [$kJ\ kg^{-1}\ K^{-1}$]
T	(characteristic) temperature [K]
T_∞	quiescent temperature [K]
u, v	velocity [$m\ s^{-1}$]
W	window width [m]
x	Characteristic length [m]
y^+	turbulence rating

Greek symbols

β	thermal expansion coefficient [K^{-1}]
κ	isentropic exponent
λ	thermal conductivity [$W\ m^{-1}\ K^{-1}$]
η	dynamic viscosity [$kg\ s^{-1}\ m^{-1}$]
μ	viscosity [$kg\ s^{-1}\ m^{-1}$]
ν	kinematic viscosity [$m^2\ s^{-1}$]
ρ	density [$kg\ m^{-3}$]

Subscripts

i	
j	

A5

Opportunities and potentials for an energy efficient modernisation of syndicates of municipalities

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Selection of refurbishment construction solutions to improve the Indoor Environmental Quality and Sustainability of buildings



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Summary

Building rehabilitation is essential to achieve the targets defined by the EPBD recast regarding energy efficiency, reduction of carbon emissions and use of on-site renewable energy sources. Besides the energy efficiency the Indoor Environmental Quality of Buildings (IEQ) and environmental impact must also be considered when planning a refurbishment project. Thus to propose an effective building rehabilitation is necessary select the adequate construction solutions taking into account their impact on the energy performance, thermal and acoustic comfort, indoor air quality and environmental impact of the building. In this work a multi-criteria decision analysis method, ELECTRE III, is applied to balance all these aspect, during the design phase of a refurbishment project, in order to assist the design team on the selection of construction solutions. Throughout the multi-criteria analysis performed, it was possible to verify that the rehabilitation solutions with lower embodied energy were the best refurbishment options.

Keywords: Refurbishment; Thermal behaviour; Acoustic performance; Energy efficiency; Multi-criteria decision analysis

1. Introduction

Energy efficiency and indoor environmental quality of buildings are nowadays major concerns as European Union (EU) buildings account for 40% of the total energy consumption and the population spend about 90% of their time inside closed spaces [1]. Thus, it is mandatory to control the energy consumption in the building sector, while maintaining, or even improving, the indoor environmental quality (IEQ), to reduce these needs and, consequently, reduce the EU energy dependency as well as the greenhouse gas emissions, in accordance with what is pre-scribed in the Energy Efficiency in Buildings Directive (EPBD) and reinforced with the "EPBD recast" [1, 2].

The rehabilitation of the building stock is an opportunity to achieve these goals. In Portugal, 80% of the building stock was built before 1990, year of the publication of the first Portuguese thermal regulation, leading to high levels of thermal discomfort and excessive energy consumption, as the majority of the existing buildings was built without any thermal concerns and shows very high energy consumptions even when minimal comfort conditions are required [3].

To correctly select the rehabilitation construction solutions it is necessary to consider their contribution to the energy efficiency, thermal and acoustic comfort, daylight conditions and the indoor air quality, its environmental impact (considering the embodied energy, for example), but also their contribution to the thermal inertia of the building, the weight of the solution and its effect on the structural project of the building and the thickness as the useful area might be reduced.

However, these goals are often in conflict and there is not a unique criterion that describes the consequences of each alternative solution adequately and there is not a single solution that optimizes all criteria. In many cases, the best solutions to accomplish different comfort requirements are not compatible, especially in what concerns natural ventilation and daylighting strategies and the acoustic and thermal performance. For instance, the type of window used can have a strong and opposite influence on the thermal and acoustic performance of the building, just not to mention its interference with the indoor air quality (IAQ). It is, then, necessary to have an integrated approach to ensure the best overall behaviour taking into account all of the, sometimes incompatible, comfort and energy efficiency requirements.

Thus to propose an effective building refurbishment is necessary to select the adequate construction solutions and materials taking into account their impact on the energy performance, thermal and acoustic comfort, indoor air quality and environmental impact of the building.

Therefore, thermal quality, acoustic behaviour and energy reduction strategies, that are mandatory, should be meshed at an early stage of the rehabilitation process with the other requirements to ensure the buildings overall comfort conditions and energy efficiency. To do so, it is necessary to select the correct materials, and construction solutions, among a large number of options to improve the occupants overall comfort and, at the same time, reduce the energy costs. Furthermore, to make a conscious selection of the possible alternatives, it is necessary to balance the positive and negative aspects of each solution into the global behaviour of the building trough a multi-objective optimization. The correct comparison of the solutions is difficult as the behaviour of some are affected by imprecision (design phase) and it is also necessary to take into account the constraints of the project and the decision maker point of view.

Multi-criteria decision analysis (MCDA) is, in this way, an important tool in such problems, since it can be used in any location and employs mathematical models that evaluate alternative scenarios, taking into account both their objective characteristics (acoustic insulation, U-Value, etc.) and the preferences of the decision makers regarding the objectives and constraints of each project.

The aim of this study was to select the materials and construction solutions to refurbish the façade walls of a building, based on criteria that are mandatory (U-value and acoustic insulation) and the designer must conciliate. The embodied energy, superficial mass and thickness of the construction solutions were also considered as they are a designer concern, affecting the environmental impact, the thermal inertia and the useful area of the building. The MCDA method ELECTRE III was chosen to assist the design team in the selection of the most adequate refurbishment solutions [4].

2. Methodology

To achieve an adequate behaviour of the buildings it is necessary to consider the indoor environmental quality, the environmental impact as well as energy efficiency. It is then essential to optimize the building envelope, by improving construction solutions and insulation levels, glazing type, optimizing the thermal and acoustic behaviour, the natural ventilation and daylighting techniques through an appropriate refurbishment. In this study several construction solutions for the façade walls were studied.

2.1 Retrofit Building Characteristics

The case-study building to be refurbished is a detached single family house (Figure 1), from the 1980s. The building is a single residential unit with two bedrooms, north oriented, with 54.42 m^2 and 2.44 m of floor to ceiling height. The construction system is a low cost construction system based on a steel reinforced concrete pillars and beams structure, single pane hollow concrete block walls (CMU) and clear single glass with aluminium frame windows with PVC (Polyvinyl chloride) roller shutters. The window to wall ratio is approximately 20%. Table 1 lists the main characteristics of the building envelope.

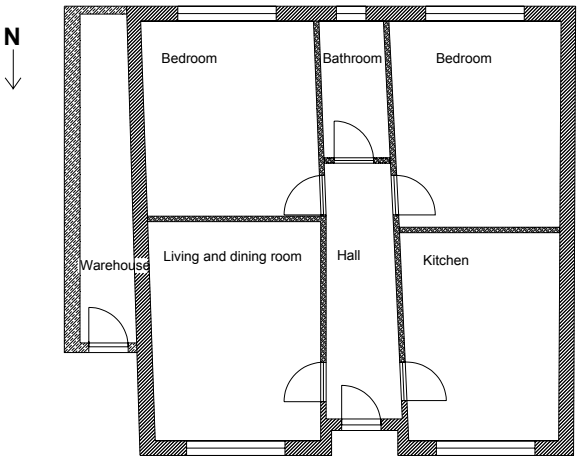


Fig. 1: Floor plan of the building

Table 1: Characteristics of the building

Building element	Construction solution	U-value [W/(m^{2}ºC)]
Structure	Concrete pillars and beams	-
Floors	concrete	-
Roof	Pitched roof	2.35
Ceiling	Beam and pot slab	3.08
Façade walls	Single pane hollow concrete block	1.90
Roller shutter boxes	concrete	2.85
Windows (window to wall area of 20%)	Single clear glass with aluminium frame	5.14
Partition walls	Hollow brick	-

2.2 Multi-criteria analysis

The multi-criteria decision analysis (MCDA) defines flexible approach models to help the decision maker, and/or the design team, perform a multi-objective optimization to select the most adequate solutions to optimize the building IEQ and energy efficiency among a large number of options and possibilities. The MCDA methods can be applied when there are several decision agents, each one with different objectives and criteria, sometimes with opposite visions. The problem of the decision makers is a multi-objective optimization problem characterized by the existence of multiple, and in several cases competitive, objectives that should be optimized, taking into account a set of parameters (criteria) and constraints [5].

This kind of analysis is able to reflect the objectives and limitations of each one of the alternatives to be studied, but it is necessary to be thorough on selecting the criteria that should be exhaustive but not redundant (it is recommended to use no more than 12, which represents an acceptable compromise between feasibility and detailed description) and must be coherent (which are the criteria to be maximized and to be minimized) [6, 7].

The multi-criteria methodology selected in this work to help the decision maker selecting the most adequate solutions to optimize the building indoor environmental quality, was the ELECTRE III (ELimination Et Choix Traduisant la REalité - ELimination and Choice Expressing the REality) model as it may be considered as a decision-aid technique suited to the appraisal of complex civil engineering projects [4, 8].

2.2.1 The ELECTRE III method

ELECTRE III is a multi-criteria decision analysis method that takes into account the uncertainty and imprecision, which are usually inherent in data produced by predictions and estimations [4]. The construction of an outranking relation amounts at validating or invalidating, for any pair of

alternatives (a, b), the assertion "a is at least as good as b". This comparison is grounded on the evaluation vectors of both alternatives and on additional information concerning the decision maker's preferences, accounting for two conditions: concordance and non-discordance.

The ELECTRE III method is based on the axiom of partial comparability according to which preferences are simulated with the use of four binary relations: I, indifference; P, heavy preference; Q, light preference and R, non-comparability. Furthermore, the thresholds of preference (p), indifference (q) and veto (v) have been introduced, so that relations are not expressed mistakenly due to differences that are less important [4].

The indifference threshold (q) defines the value beneath which the decision maker is indifferent to two option valuations, the preference threshold (p) defines the value above which the decision maker shows a clear strict preference of one option over the other, and the veto threshold (v) where a ‘discordant’ difference in favour of one option greater than this value will require the decision maker to negate any possible outranking relationship indicated by the other criteria. The indifference (q) and preference (p) thresholds of any criterion can also be interpreted as the minimum imprecision and the maximum margin of error respectively [9].

The ELECTRE III method does not allow for compensation, which may occur when using methodologies based on performance indexes, due to the use of the veto threshold. Using this method, an option which shows too poor results in one criterion cannot be ranked in a higher position [10]. The model permits a general ordering of alternatives, even when individual pairs of options remain incomparable or when there is insufficient information to distinguish between them [11]. Also, the technique is capable of dealing with the use of different units, the mix of both quantitative and qualitative information and when some aspects must be maximized and others minimized.

This method allows, in an easy and quick way, to outrank construction solutions options according to a set of criteria pre-established and based on criteria weights and thresholds assigned to each one. The criteria, criteria weights and thresholds are selected by the design team according to the objectives and constraints of each project which enable the use of this methodology to a vast set of possibilities (selection of materials, construction solutions, design alternatives, rehabilitation scenarios, etc.), based on different criteria (U-value, acoustic insulation, embodied energy, weight, heating and cooling needs, etc.). This methodology is not specific to a country and can be used in an early stage of the design phase of a new building or of a refurbishment project, when not all the characteristics are defined.

2.3 Prediction Tools

The prediction of the building thermal behaviour, related to thermal comfort and energy efficiency, was done using the U-value, determined using the publication ITE50 – U-Values of Building Envelope Elements [12]. All the solutions selected respect the minimum requirements defined in the Portuguese Thermal Regulation [13].

The acoustic performance of the building elements the weighted standardized level difference of the façade ($D_{2m,\,nT,\,W}$) was estimated using the Acoubat Sound Program [14, 15]. All the solutions selected respect the requirements defined in the Portuguese Acoustic Regulation [14].

The embodied energy was assessed using the Cumulative Energy Demand 1.04 method from the Life Cycle Assessment (LCA) software, SimaPro 7.1.8 [16, 17, 18].

3. Results

3.1 Criteria, Criteria Weights and Thresholds

In the study performed, the ELECTRE III method was applied to the evaluation of several alternative solutions for the façade walls on the basis of five criteria: thermal and acoustic

insulation, superficial mass, weight and thickness. Table 2 lists the different criteria, thresholds and criteria weights that were selected, by the design team, for this case-study.

Table 2. Criteria, criteria weighting and thresholds (criteria to: ↓ - minimize; ↑ - maximize).

Criteria	Units		Criteria Weight	Threshold		
				Preference	Indifference	Veto
Thermal Insulation (U-Value)	W/(m^{2}ºC)	↓	25	0.25	0.10	0.50
Acoustic Insulation ($D_{2m, nT, W}$)	dB	↑	25	5	2	10
Embodied Energy (EE)	MJ/m^2	↓	20	200	50	400
Superficial Mass (Msi)	kg/m^2	↑	20	50	10	100
Thickness	cm	↓	15	10	2	30

The criteria selected to outrank the construction solutions options are related to the most important characteristics of the IEQ, the thermal and acoustic comfort and influence the energy efficiency of the building. These criteria were also selected because it is possible to define them in a non subjective way, it is possible to predict them in an early stage of the design phase, they are under the designer scope and they are the issues that are also the most valued by the users of the buildings. The minimum thermal and acoustic insulation values are also defined in the Portuguese thermal and acoustic regulations and are mandatory [13, 14].

The embodied energy, the superficial mass and the thickness of the construction solution were also selected. The embodied energy is considered to account the environmental impact of the construction solution, as this is nowadays a concern of the building sector. The superficial mass is considered to account the impact of the construction solution in the thermal inertia of the building, as this is essential to the correct behaviour of the building. The thickness of the solutions was selected as it influences the useful area and is an important factor, valued by the designer.

The U-Value, the embodied energy and the thickness of the construction solution are criteria to be minimized to improve the thermal comfort conditions, energy efficiency and environmental impact and to increase the useful area available. The Façade acoustic insulation, $D_{2m, nT, W}$, and the superficial mass are criteria that should be maximized, to improve the acoustic comfort and the thermal inertia of the building.

As the definition of criteria weights and thresholds must take into account the objectives and constraints of the project and capture the points of view of the decision makers, to select them, a sensitivity analysis was performed and the visualization of the outcome impacts was assessed.

The criteria weights were defined taking into account the relative importance of each one of the criteria. The criteria weighting established for the thermal and acoustic insulation criteria, associated to the thermal and acoustic comfort, were defined according to the relative importance of each one to the occupants based on studies performed in Portugal and according to literature [19, 20, 21]. These studies showed that the thermal and acoustic comfort are the most valued criteria. The embodied energy, superficial mass and thickness of the solutions are essentially a concern of the designer.

The thresholds were defined according to the criteria characteristics, for example a 2 dB difference is the threshold at which human beings can perceive differences in noise levels and 5 dB is the noise difference at which clear preference can be expressed for one option over another [22].

3.2 Construction Solutions

The first step of the refurbishment process was the replacement of the existing single glass windows and PVC roller shutters by windows with double pane glass with air inlets in the aluminium frame with thermal break (U_w = 2.50 W/(m^{2}ºC)) and insulated roller shutters (considering the thermal resistance of the window, during daytime and the thermal resistance of the window and of the roller shutter during the night-time, U_{wdn} = 2.00 W/(m^{2}ºC)). The air inlets were introduced to improve the air change rate and the indoor air quality. Additionally 20 cm of mineral wool were

placed in the roof (0.21 W/(m^{2}ºC)) to improve its thermal performance.

The rehabilitation construction solutions selected (shown in Figure 1 and listed in Table 3) cover the solutions most used in Portugal (External Thermal Insulation Composite Systems, ETICS, ventilated wall, insulation and plasterboard or hollow brick panes). The study was done considering four insulation materials (expanded polystyrene, EPS, expanded extruded polystyrene, XPS, mineral wool, MW and cork, ICB).

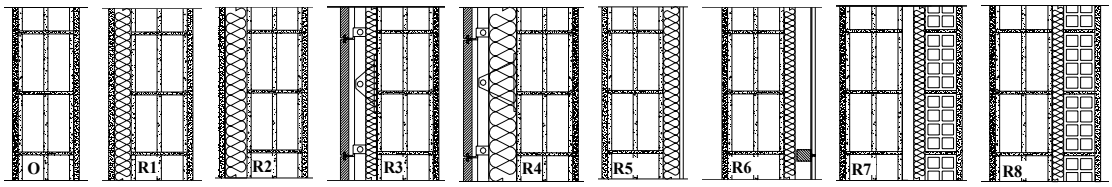


Fig. 2: Vertical cross-section of the existing and rehabilitation construction solutions of the façade walls

Table 3. Construction solutions studied for the façade (as represented in Figure 1).

Option	Wall	U-Value [W/(m^{2}ºC)]
O	Hollow concrete block with 20 cm	1.90
R1	Hollow concrete block wall, 20 cm and ETICS system with 4 cm of EPS	0.65
R2	Hollow concrete block wall, 20 cm and ETICS system with 8 cm of EPS	0.40
R3	Hollow concrete block wall, 20 cm and ventilated wall with stone with 5 cm with 4 cm of XPS	0.67
R4	Hollow concrete block wall, 20 cm and ventilated wall with stone with 5 cm with 10 cm of XPS	0.34
R5	Hollow concrete block wall, 20 cm and plasterboard wall (1.3 cm) with 4 cm of MW	0.57
R6	Hollow concrete block wall, 20 cm and plasterboard wall (1.3 cm) with 6 cm of MW	0.48
R7	Hollow concrete block wall, 20 cm, air gap and hollow brick (11 cm) with 4 cm of MW	0.48
R8	Hollow concrete block wall, 20 cm and hollow brick (11 cm) with 6 cm of ICB	0.42

* EPS – expanded polystyrene; XPS – expanded extruded polystyrene; MW – mineral wool; ICB – Insulation corkboard.

Table 4 lists the results of the prediction of the façade walls behaviour according to the five criteria selected to outrank the design alternatives. The U-Values are weighted averaged values taking into account the opaque, the glazing part of the façade and the roller shutter box.

Table 4. Criteria for the different design alternatives studied for the façade.

Options	U-Value (weighted averaged values) [W/(m^{2}ºC)]	$D_{2m, nT, W}$ [dB]	EE [Mj/m^2]	Msi [kg/m^2]	Thickness [cm]
O	2.23	30	0	150	24.0
R1	1.09	35	61	150	30.0
R2	0.90	35	145	150	34.0
R3	1.10	37	2018	150	35.0
R4	0.86	38	2184	150	41.0
R5	1.04	35	161	75	29.3
R6	0.97	37	205	75	32.2
R7	0.97	38	261	150	41.5
R8	0.93	39	262	150	39.4

The credibility degree matrix and the results of the outranking using ELECTRE III method are presented in Table 5. The credibility degree matrix gives a quantitative measure to the force of the statement “a outranks b” or “a is at least as good as b”. Number 1 indicates the full truthfulness of the assertion and 0 indicates that the assertion is false.

The ranking of the alternatives can then be determined based on the credibility degree matrix through a distillation procedure, where the alternatives are located firstly following their qualification going from the best to the worse one and then inversely, from the worse to the best one, defining two pre-ranks. Finally, the final ranking is achieved by using the results of these two pre-ranks.

Table 5. Credibility degrees matrix for the alternative solutions selected for the façade walls.

Options	O	R1	R2	R3	R4	R5	R6	R7	R8	Non-Dom		Ranking
										A	m(A)	Options
O	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	O	0.09	R2
R1	0.91	-	0.85	1.00	0.70	1.00	0.97	0.88	0.73	R1	0.93	R1
R2	0.72	0.92	-	1.00	0.92	0.95	1.00	0.92	0.83	R2	0.99	R8
R3	0.00	0.00	0.00	-	0.77	0.00	0.00	0.00	0.00	R3	0.00	R5
R4	0.00	0.00	0.00	0.77	-	0.00	0.00	0.00	0.00	R4	0.00	R7
R5	0.64	0.78	0.78	0.85	0.63	-	1.00	0.77	0.67	R5	0.78	R6
R6	0.53	0.72	0.84	0.85	0.83	0.98	-	0.85	0.85	R6	0.75	O
R7	0.65	0.65	0.81	0.92	0.98	0.78	0.86	-	1.00	R7	0.77	R3, R4
R8	0.65	0.66	0.85	0.95	1.00	0.78	0.89	1.00	-	R8	0.93	

Table 5 shows that option R2 (refurbishment with the ETICS system with 8 cm of EPS) is ranked as the best action and is “at least as good as” options R3 and R5 in all criteria, as the number 1 in columns 4 and 7 indicates. This refurbishment solution has one of the lower U-Value, the second lower embodied energy and is one of the solutions with the higher superficial mass and is also one of the thinner solutions.

Solutions R1 (4 cm of EPS ETICS), with the lower embodied energy, acoustic insulation and thickness and one of the higher U-values and superficial mass, was ranked second. Option R8 (6 cm of ICB and hollow brick pane with 11cm) was ranked third. This option has the third best thermal performance and the best acoustic behaviour, has a high superficial mass but is also the third thicker solutions and has the third higher embodied energy.

The existing solution (O) with the worst thermal and acoustic performance and the ventilated walls, option R3 and R4 (with the lowest U-value), with high thermal mass, with the second and third best acoustic insulation, but with the higher embodied energy were ranked last.

4. Conclusion

Throughout the multi-criteria analysis performed, it was possible to verify that the refurbishment solutions with ETICS system, with low U-value and embodied energy and higher superficial mass were ranked the best rehabilitation options.

The solution with ICB and a second hollow brick pane, that presents the second lower U-value, the higher acoustic insulation and a high thermal mass, was ranked third.

The existing solution with the worst thermal and acoustic performance and the ventilated walls, with the lowest U-value, high thermal mass, with the second and third best acoustic insulation, but with the higher embodied energy were ranked last.

The best ranked options were not the ones that had the best performance in the criteria with highest weights. This example shows that applying this methodology, due to the use of weights and thresholds, the best action is not the one associated to the highest weight, even if it is the one that has the best performance in that criterion.

5. References

[1] DIRECTIVE 2002/91/EC, “Directive of the European Parliament and of the Council on the Energy Performance of Buildings (EPBD)”, from 16 of December, 2002.

[2] DIRECTIVE 2010/31/EU, “Directive of the European Parliament and of the Council, on the Energy Performance of Buildings (recast)”, from 10 of May, 2010.

[3] CENSUS 2011, “XV Recenseamento Geral da População, V Recenseamento Geral da Habitação”. INE - Instituto Nacional de Estatística, 2012.

[4] ROY, B., "ELECTRE III - Algorithme de classement base sur une représentation floue des préférences en présence de critères multiples“. *Cahiers de CERO*, 1978.

[5] EHRGOTT, M. and WIECEK, M.M., “Multiobjective programming“, in: J. Figueira, S. Greco, M. Ehrgott (Eds.), *Multiple Criteria Decision Analysis: State of the Art Surveys*, Springer. New York.

[6] ROY, B. and BOUYSSON, D., “Aid multiple a la decision: methods et cas“. *Económica*. Paris, 1993.

[7] ROULET, C.-A., FLOURENTZOU, F., et al., “ORME: A multicriteria rating methodology for buildings“. *Building and Environment*, Vol. 37, 2002, pp 579-586.

[8] PAPADOPOULOS, A. and KARAGIANNIDIS, A., “Application of the multi-criteria analysis method ELECTRE III for the optimisation of decentralised energy systems“. *Omega - The International Journal of Management Science*, Vol. 36, 2008, pp 766-776.

[9] MAYSTRE, M., PICTET, J. and SIMOS, J., “Methodes multicriteres ELECTRE“. *EPFL Presses Polytechniques et Universitaires Romandes*. Lausanne,1994

[10] ROULET, C.-A., et al., “ORME: Office Building Rating Methodology for Europe“. *Office Project Report*, University of Athens, Athens. 1999.

[11] ROGERS, M., “Using ELECTRE III to aid the choice of housing construction process within structural engineering“. *Construction Management and Economics*, Vol 18 No. 3, 2000, pp. 333-342

[12] PINA DOS SANTOS, C. and MATIAS, L., “U-Values of Building Envelope Elements“, *LNEC*. Lisbon, 2006.

[13] DECREE-LAW Nº 80/2006 2006. “Portuguese Building Thermal Legislation“ (In Portuguese), RCCTE 2006, April 4th, Lisbon.

[14] DECREE-LAW Nº 96/2008 2008. “Portuguese Building Acoustics Legislation“ (In Portuguese), RRAE 2008, July 9th, Lisbon.

[15] EUROPEAN STANDARD EN 12354-3, “Building acoustics - Estimation of acoustic performance of buildings from the performance of elements - Airborne sound insulation against outdoor sound“, CEN, Belgium. 2000.

[16] ASIF, M., DAVIDSON, A. and MUNEER, T., “Embodied energy analysis of aluminium-clad windows”. *Building Services Engineering Research and Technology*, Vol 22 No 3, 2001, pp. 195-199.

[17] FRISCHKNECHT R., et al., “Implementation of Life Cycle Impact Assessment Methods”. *Final report ecoinvent 2000*. Duebendorf. Swiss Centre for LCI, 2003.

[18] PRE CONSULTANTS BV, “SimaPro 7 User's Manual”, Netherlands, 2008.

[19] MONTEIRO SILVA, S., “Building sustainability and Comfort“ (in Portuguese). PhD Thesis. *Universidade do Minho*, Guimarães. 2009

[20] ROHLES, F. H. WOODS, J. E. and MOREY, P. E., “Occupant Perception of the Work Environment“. *Human Factors and Ergonomics Society Annual Meeting Proceedings*, Vol. 31, No. 10, 1987, pp 1105-1108(4).

[21] KIM, SUN-SOOK; et al., “Development of a housing performance evaluation model for multi-family residential buildings in Korea“. *Building and Environment.* Vol 40, 2005, pp 1103-1116.

[22] ROGERS, M. and BRUEN M., “Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE“. *European Journal of Operational Research*. 107, 1998, pp. 542-551.

The uncertainty of the energy demand in existing Mediterranean urban blocks.



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Short Summary

The objective of the paper is to describe a stochastic model that has been developed to obtain load profiles for household electricity. For the study, several profiles have been generated in order to simulate the electrical demand of a residential building block or neighbourhood and evaluate the uncertainty of its energy use. The paper is divided in three different parts: development of the model, validation and determination of the uncertainty demand. In the first parts the basis of the model and how it works is explained. The second one represents the validation of the model, the input data and its results. The last step is focused on a statistical analysis of the electricity demand of a block of dwellings to evaluate minimum number of dwellings needed to estimate the average demand representative of the Mediterranean dwelling with different levels of accuracy.

Keywords: stochastic model; electric load; residential building; Mediterranean regions; cluster of buildings

1. Introduction

In the last years, the increased interest on energy efficiency and on the use of renewable energy technologies in residential buildings has produced the need to improve the knowledge of all the factors that take part in the energy balance. In addition to the technological improvements, an important progress has been the increased availability and use of energy simulation tools. The simulations tools allow realizing building model to test and optimize the energy efficiency measures and energy renewable systems in the design stage. Therefore, detailed load profiles for domestic energy use are important as input to simulations of energy systems such as distributed generation or Net Zero Energy Buildings (NZEB). The heating and cooling load can be calculated by physics models, because these loads are mainly forced by external phenomena. However, the DWH and electric loads of appliances depend on the user behaviour and must be pre-determined, with assumptions, profiles and statistical studies. On the other hand, if the objective is to analyse a cluster of buildings having information of each individual building, it is not realistic to use the same electric load profile for all dwellings. For these reasons are needed to have tools that reproduce real and random electric load.

The objective of the study is to develop a stochastic model to obtain high resolution load profiles for household electricity in Mediterranean climate. Several profiles have been generated in order to simulate the electrical demand of a building block or neighbourhood and evaluate when the

uncertainty demand is low enough. Moreover, this paper wants to share information to the Energy Services COmpanies (ESCOs) about the uncertainty in the energy demand in the residential sector. The rate of energy efficiency refurbishment of the buildings is low, especially in the Mediterranean regions [1]. High investments are needed to carry out the renovations, and the ESCOs are the entities that could afford this investment. However, there are aspects that restrain the ESCOs to carry out this kind of projects, as the uncertainty of the energy demand in residential dwellings.

In the last decade, occupancy and behaviour models have been developed with different motivations, but all of them with the need to obtain realistic profiles of the energy use of buildings. Widen [2] has worked in an occupancy model based on Markov-chain transition probabilities and Time Use Data (TUD) of Sweden. TUD gives the information about the occupancy and their activity, which should be translated to end-uses. Widen uses the Markov-chain method to produce realistic patterns and to produce realistic load profiles for household electricity. The model has been adapted to generate different load profiles: electricity, hot water and lighting. Richardson [3] has developed a model of domestic electricity use based on a combination of patterns of active occupancy and daily activity profiles, using Markov-Chain Monte Carlo techniques. The statistical information used is from the United Kingdom. Dar [4] has used the Richardson's model in the field of the NZEB design for a case study in Norway. All of these aspects are related to the Demand Side Management (DSM), where Paatero [5] has been working on. Paatero has built a model for generating electricity load profiles for a dwelling using representative data sample and statistical averages from Finland. The randomness has been included using stochastic processes and probability distribution functions (starting probability function based on the seasonal, hourly and social factors). Another key element is the high influence of the occupancy activity with the heating and cooling loads and in consequence with the size of the systems. Baetens [6] has simulated in Modelica the user behaviour and the use of lighting and appliances. The use of appliances has been implemented by a semi-Markov-process based on the presence of an occupant and the activity profiles. In the paper the results of the model have been compared with deterministic approach proposed by the ISO 13790 [7], obtaining important differences in the demand peaks.

The models described above are based on statistical data of equipment stock of dwellings and user activities or habits in Northern European countries and UK. Recently, "Instituto para la Diversificación y Ahorro de la Energía" (IDAE) has been carried out the SECH-SPAHOUSEC project [8], where a detailed characterization of the energy use of the residential sector in Spain. This study has been used as basis information for the model presented in this paper.

2. Method

All the study has been carried out using mainly the detailed data from the SECH-SPAHOUSEC project. This project characterizes the energy consumption of the residential sector in Spain. The dwelling description includes detailed information about the equipments stock and different energy uses. The information is divided by regions (Atlantic, Continental and Mediterranean) and building type (detached houses and block of apartments). In this paper, the results are related to Mediterranean region and for block of apartments.

The model is divided in two sub-models: electrical appliances (refrigerator, freezer, washing machine, dish washing, television, tumble dryer, microwave, PC, lighting and others which includes a group of small appliances) and kitchen devices (gas and electrical stove and oven).

The model has been developed as a component of TRNSYS 17.1 and gives the possibility to simulate more than one dwelling at the same time. The time resolution is one hour. Each equipment has to be characterized with the parameters described in the Table 1. In addition, general parameters are needed to carry out the simulation: number of simulated dwellings and seeds for the random number generators.

Table 1 Description of the parameters and inputs of the stochastic model of electrical load profiles of dwellings

Data type	Parameter	Units	Description
Stock characterization	Penetration rate (Pr)	%	Fraction of dwellings with at least one equipment. The input of the model is its complementary (1-Pr).
	Multi-equipment probabilities (Mp)	%	These values represent the probability to have 1, 2, 3 or 4 equipments in a dwelling. The multiequipment is defined with 4 probabilities (probability to have 1 equipment, to have 2...). At the same way of the penetration rate, the input of the model is its complementary (1-Mp).
	Fraction of electric devices (FE)	%	In the case of the kitchen devices, it is necessary to include the fraction of electric devices. The gas devices are calculated as the difference of the electrical ones.
Technical data	Power (P)	kW	This power has reference to the nominal power. This information is available in the technical sheet of the equipment. This power could be different to the used power when the equipment is working.
	Power Fraction (PF)	%	PF is the hourly mean power when the equipment is ON divided by the power (P) of the equipment. This parameter is constant over time.
	Cycle Length Fraction (CF)	%	CF is the relation between the cycle length and the integer hours. For example, the duration of the cycle of a washing machine is 1.5 hours, then the integer hours is 2, and CF is 1.5/2. This parameter represents the fraction of the hour when the equipment is spending energy. This parameter is constant over time.
	Power of Stand-by (Pstb)	kW	Pstb is the power of the stand-by mode. If the equipment does not have stand-by, the value should be 0.
Statistics of use	Hourly profile of probabilities of use (prob(t))	%	The probabilities of use represent the probability to use one equipment at each hour. There are hourly profiles for each season (summer, winter and mid season) and type of day (weekday and weekend). It means that there are six hourly profiles of probabilities of use.

The simulation is divided in two steps: dwelling characterization and simulation process. The dwelling characterization is done only at the beginning and consists in the selection of which equipments are in each dwelling. The selection is done by a random number that is compared with (1-Pr). After that, how many equipment there are has to be defined. To do that, the same random number is compared with the multi-equipment parameters. In the equation (1) is represented the conditions to choose the equipments of each dwelling.

$$\left.\begin{array}{ll} RNE_e^d < (1-\mathrm{Pr}_e) & \rightarrow \text{There is no equipment } e \text{ in dwelling } d \\ RNE_e^d \geq (1-\mathrm{Pr}_e)\begin{cases} (1-Mp_{e1}) > RNE_e^d & \rightarrow \text{There is 1 equipment } e \text{ in dwelling } d \\ (1-Mp_{e1}) \leq RNE_e^d < (1-Mp_{e2}) & \rightarrow \text{There is 2 equipments } e \text{ in dwelling } d \\ (1-Mp_{e2}) \leq RNE_e^d < (1-Mp_{e3}) & \rightarrow \text{There is 3 equipments } e \text{ in dwelling } d \\ (1-Mp_{e3}) \leq RNE_e^d < (1-Mp_{e4}) & \rightarrow \text{There is 4 equipments } e \text{ in dwelling } d \end{cases} \end{array}\right\} \quad (1)$$

Where RNE_e is the random number for each type of equipment e and dwelling d. Pr_e is the

penetration rate for each type of equipment. Mp_{e1}, Mp_{e2}, Mp_{e3} and Mp_{e4} are multi-equipment probabilities for each type of equipment.

The selection of the equipments in the sub-model of the kitchen devices is different. First, it is necessary to define the presence of the kitchen devices in each dwelling. After that, it has to be chosen if the device uses electricity or gas. It can be represented in the following equation:

$$\begin{cases} RNE_e^d < (1-\mathrm{Pr}_e) & \rightarrow \text{There is no equipment } e \text{ in dwelling } d \\ RNE_e^d \geq (1-\mathrm{Pr}_e) \begin{cases} FE_e < RNE_e^d & \rightarrow \text{There is an electrical equipment } e \text{ in dwelling } d \\ FE_e \geq RNE_e^d & \rightarrow \text{There is a gas equipment } e \text{ in dwelling } d \end{cases} \end{cases} \quad (2)$$

The second step starts after setting the equipments of each dwelling: the simulation process. In each time step of the simulation period, in our case an hour, the model has to define which equipments are ON or OFF (or Stand-by) to be able to calculate the energy consumption for each dwelling. Then, in each time step another set of random number has been generated ($RNP(t)_e$) in order to be compared with the probabilities of use of each equipment type. In the following equation the comparison done at each time step is shown:

$$\begin{cases} RNP(t)_e^d \geq prob(t)_e \rightarrow E(t)_e^d = Pstb_e \cdot \Delta t & \rightarrow \text{The equipment is OFF or in Stand-by} \\ RNP(t)_e^d < prob(t)_e \rightarrow E(t)_e^d = P_e \cdot PF_e \cdot CF_e \cdot \Delta t & \rightarrow \text{The equipment is ON} \end{cases} \quad (3)$$

Where $RNP(t)_e$ is the random number generated for the equipment *e* of the dwelling *d* at time *t*. $prob(t)_e$ is the probability of use at the time *t* of the equipment *e* (*t* refers to the season, type of day and hour of day). $Pstb_e$, P_e, PF_e and CF_e are the parameters of the equipment e described in the Table 1. Δt is the time step (1 hour). Finally, the $E(t)_e$ is the energy consumption for the equipment *e* of the dwelling *d* at time *t* (in kWh). The probabilities of use have been obtained after post-processing work using the database of the project SECH-SPAHOUSEC.

As can be seen in the model description, there are two sources of stochasticity: the random selection of the type and the number of equipment in each dwelling and the random selection of which equipment are ON or OFF (or stand-by) in each time step.

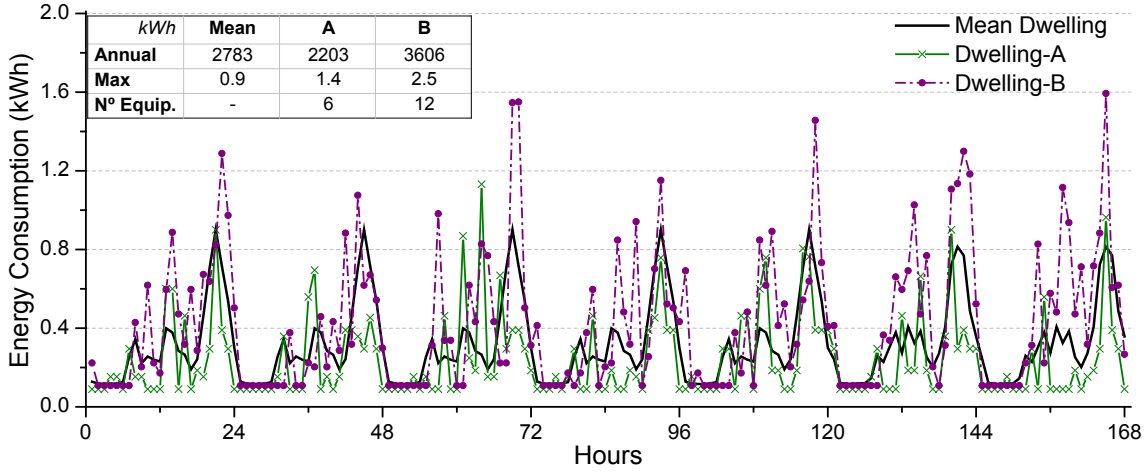


Fig. 1 Hourly electric consumption for a winter week. Example output of the model, two random dwellings and the mean dwelling (reference data).

In the Fig. 1 an example of the output of the model is shown, plotting the hourly electric consumption of two random dwellings during one winter week. In addition, the hourly consumption of a mean dwelling has been included in the graph, in order to view that the simulated dwellings

have random profiles. One of the most important advantages of the outputs is to catch the peak values of the load profiles, which are different between days and dwellings.

3. Model validation

The validation of the model is done in two levels: energy consumption of individual equipment and energy consumption of a dwelling. To validate the model, 1000 dwellings of Mediterranean region have been simulated (multi-dwelling building). In the Table 2, the used technical parameters of the equipment in the simulation are shown. The parameters have been obtained from the database of the project SECH-SPAHOUSEC, where there are measurement data of equipments of 200 dwellings over Mediterranean regions of Spain. These parameters has been compared and adjusted with reference studies. However, the following assumption has been done in the case of gas kitchen and gas oven due to the absence of data: the efficiency of the gas kitchen and gas oven is lower than the electrical ones (60% for gas and 75% for electrical ones).

Table 2 Technical data of the equipments used in the simulation

Equipment	P W	PF %	Cycle Length Min	E_{ON} Wh	E_{STB} Wh
Refrigerator	180	96	27	77	-
Freezer	130	96	24	50	-
Washing machine	2200	23	91	380	6
Dish. Washing	2200	94	82	350	-
Television	125	99	48	100	5
Tumble dryer	2000	30	90	450	-
Microwave	1100	50	6	55	3
PC	200	99	36	120	5
Others	3000	22	6	65	1.4
Lighting	200	100	60	200	-
Kitchen (electric)	5000	28	22	510	-
Kitchen (gas)	6176	28	22	630	-
Oven (electric)	2500	27	31	340	-
Oven (gas)	3162	27	31	430	-

Table 3 Annual Energy Consumption for each equipment. Comparison of the results of 1000 dwelling simulation with reference data.

	Annual energy consumption for (single) equipment (kWh/yr)					
	Simulation		SECH-SP [8]	Smart-App[9]	Remodece[10]	Richardson[11]
Geographic area	Med area ON	 STB	Spain	EU-15	EU-12	UK
Refrigerator	674	-	550-700	403	344-575	426
Freezer	438	-	400-750	414	256-634	271
WashMach	247	53	250-450	150	92-377	191
DishWash	246	-	250-350	241	132-330	273
Television	196	34	100-250	-	61-456	242
Dryer	249	-	250-400	251	211-393	314
MWave	36	24	50-100	-	16-54	77
PC	311	31	200-300	-	31-368	349
Others	75	11	50-150	-	-	-
Lighting	479	-	300-500	-	68-1013	715
Kitchen (ele)	435	-	450-550	300	138-287	276
Kitchen (gas)	545	-	-	-	-	-
Oven (ele)	163	-	150-350	225	138-287	236
Oven (gas)	202	-	-	-	-	-

In the Table 3 the average annual energy consumption for equipment is shown. In addition, reference data are included in order to be compared with the model results. Comparing the results, in general terms the model fits to the reference data. There are differences in some equipment

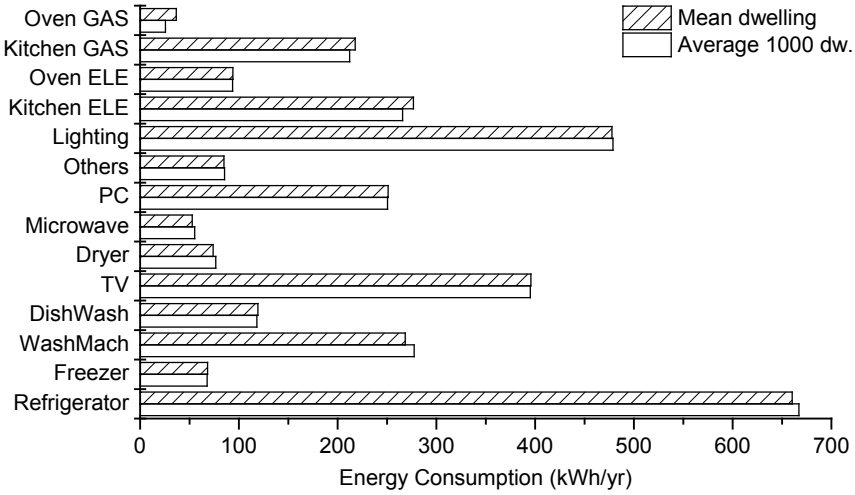
although they are coherent with the SECH-SPAHOUSEC. The input data of the model are based on the equipment stock of Spain, where approximately 40% of the equipments has an energy labelling equal or higher than A-label [8]. Reference data in Table 3 (Smart Appliances [9], Remodece [10] and Richardson [11]) are from other European countries with cultural and climate differences which affect to the energy use. Both aspects could be the cause of differences between the simulation results and the reference data.

Once the equipment parameters have been checked, a validation of the energy consumption of dwellings is presented. In the Fig. 2 the annual energy consumption for a mean dwelling are represented, broken down by energy uses. The bar diagram compares the average of 1000 simulated dwellings with the mean dwelling. The graph shows a good performance of the model, having differences lower than 5%.

Moreover, in the Fig. 2 the normalized root mean square error (NRMSE) has been included (equation 4) in order to evaluate goodness of fit of the model. The great part of the elements has an acceptable value of residual variance, lower than 20%. Particularly, there are four elements, washing machine, dishwasher, electric oven and electric kitchen that are lower than 10% of residual variance, which means that the 90% of the variance observed in the these elements are reproduced by the model. However, there are two equipments, refrigerator and freezer, which NRMSE is considerable high, comparing with the other equipments. The reason is that, despite the nearly constant profile over the year, in the reference data there are small variation between seasons, and the model uses a constant value. This variation does that difference between the maximum and minimum value is very small, and then the normalization is done with a low number (denominator). Comparing the diagram with the NRMSE, it is possible to see that a good annual performance not involve a good hourly behaviour. In the section 5, the sources of error that could influence in the results are discussed.

$$NRMSE = \frac{1}{\left(E_{mean}^{\max} - E_{mean}^{\min}\right)} \cdot \sqrt{\sum_{t}^{n} \frac{\left(E_{sim}(t) - E_{mean}(t)\right)^2}{n}} \tag{4}$$

Where the $E_{sim}(t)$ and $E_{mean}(t)$ is the hourly energy consumption simulated and the reference data, t is the time and n are the 8760 hour of the year. E^{max} and E^{min} are the maximum and the minimum value of the reference data over the year.

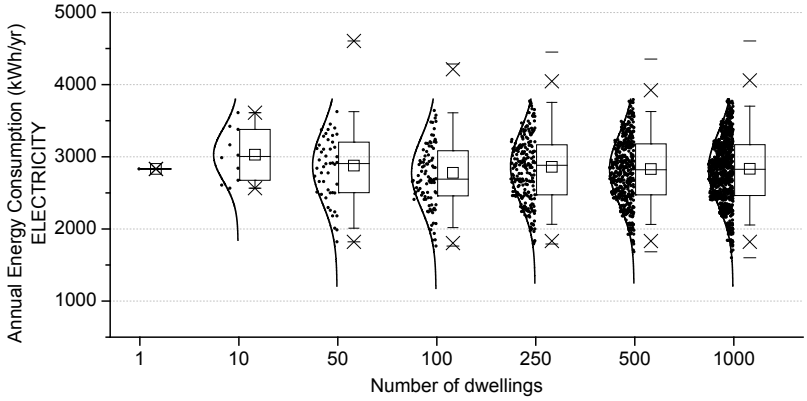


	NRMSE
Oven (ele)	8%
Kitchen (ele)	9%
Lighting	10%
Others	15%
PC	17%
Microwave	13%
Dryer	14%
TV	19%
DishWash	9%
WashMach	7%
Freezer	56%
Refrigerator	31%

Fig. 2 Annual energy consumption for equipment type. Comparison of the average consumption of 1000 simulated dwellings with the mean dwelling (reference data).Right: Normalized root mean square error (NRMSE) of hourly energy consumption for each equipment for the year.

4. Sample size analysis

The objective of this section is to analyse the sample size needed to characterize the buildings during the design process of energy efficiency measures. For this scope, the empirical distribution of the annual energy consumption is analysed. The Fig. 3 represents the distribution of the annual energy consumption simulated for different sample sizes. It can be seen that over 100 dwellings, the two main parameters of the distribution converge; the mean is around 2850kWh/yr and the standard deviation around 500kWh/yr. The distribution of the annual energy consumption is slightly left-skewed but it performs quite similar to a Normal distribution.



nº DW	STATISTICS (kWh/yr)			
	Mean	SD	MIN	MAX
10	3028	364	2565	3611
50	2877	513	1822	4606
100	2777	492	1763	4287
250	2861	495	1791	4452
500	2829	484	1683	4354
1000	2834	499	1600	4606

Fig. 3 Distribution of the annual energy consumption for dwelling, increasing the number of dwellings. Description of the box plot parameters: mean by square; median by horizontal line; 25% and 75% percentile by box; 5% and 95% by whiskers; 1% and 99% percentile by cross; minimum and maximum by dash. In the right table, the statistical values of each sample (mean, standard deviation (SD), minimum and maximum).

Based on the data from the SECH-SPAHOUSEC project and the simulations performed the sample size for two different scenarios are calculated. As previously, the decision variable in this analysis is the total annual energy consumption of a dwelling. The first scenario is designed with the objective to characterize of a population; it wants to determinate the number of dwellings that are required to estimate the mean annual energy consumption of the total population, with different levels of accuracy. The following equations define the sample size for this scenario:

$$n = \frac{N \cdot \sigma^2 \cdot Z_{\alpha/2}^2}{(N-1) \cdot e^2 + \sigma^2 \cdot Z_{\alpha/2}^2} \tag{5}$$

$$n = \frac{N \cdot \sigma^2 \cdot Z_{\alpha/2}^2}{e^2} \tag{6}$$

Where (5) is the equation used for a known target population size and (6) for an unknown one. $Z^2_{\alpha/2}$ is the normal distribution value for a confidence level α, σ^2 is the variance of the variable, e^2 represents the error corresponding to the defined level of accuracy, and N is the target population size.

Table 4 shows the value for different levels of accuracy. It can be seen that with a sample size of 48 and 12 the mean annual energy consumption can be estimated for any set of Mediterranean dwellings with an accuracy of 5% and 10% respectively. For lowers values of accuracy, the sample size depends on the target population size.

Table 4 Sample size to estimate the mean annual energy consumption for different targets of population size (α =0.05).

Target population size	Accuracy		
	1%	5%	10%
20	20	14	8
100	92	33	11
500	354	44	12
1000	548	46	12
3000	862	48	12
10000	1079	48	12
Unknown	4839	194	48

Table 5 Sample size to reflect the annual energy saving in the electric consumption after to apply energy efficiency measures (paired test, α = 0.05, β = 0.9).

Energy saving	Sample size
5%	265
10%	66
15%	29

The second scenario wants to define the sample size for an energy efficiency measures in a set of dwellings. Given an expected energy saving, the sample size needed for observing differences between the annual yearly consumption before and after the action is calculated.

$$n = \frac{2 \cdot \sigma^2 \cdot \left(Z_{\alpha/2} + Z_{\beta}\right)^2}{\Delta^2} \tag{7}$$

Where Δ^2 represents the expected energy saving after the energy efficiency improvement. The Table 5 shows the value for different levels of energy saving, applying different energy efficiency measures. It can be seen that for greater values of improvement, smaller sample sizes are required. This is because, when comparing two values (mean energy consumption before and after the measure), the greatest is the difference, the easiest is to find it statically significant.

5. Discussion

Regarding the validation process, the model is able to generate random profiles of electric consumption for a dwelling or several dwellings, with preservation of important qualitative features. The load profiles are realistic and their annual consumption is consistent in comparison to Spanish data and from other European countries. However, analysing the results in detail there are slight differences between the simulation and the reference data. The reasons could be due to the limitation of the model, where the following approximations have been done. 1) The technical parameters of FP and CF for each equipment are constants over time. For a refrigerator and for a freezer, it may be a good approximation because their variations during the year can be lower. However, in the case of the other equipments, such assumption could not be justifiable, as for example that the power of lighting is the same during the whole day or the programme of the washing machine or dryer is always the same. 2) Although the input data (hourly consumption of each equipment) takes into account the length of the cycle, in the model there is no relation with the previous hour and the duration of the cycle is not simulated.

In the section 4 a statistical analysis of the annual energy consumption distribution for the simulation results of Mediterranean dwelling is done. The objective has been to evaluate how to reduce the uncertainty in the energy consumption choosing the adequate sample of dwellings. For the first test, it is observed that in the measure that the target of dwellings increase, the size sample needed is proportionally smaller. The second test shows that the energy efficiency measures with high impact are not necessary to be applied in a high number of dwellings to obtain the expected energy savings.

6. Conclusion

The model developed in this study is able to reproduce the hourly and annual patterns of the electric consumption for a residential building or a block of buildings of the Mediterranean region. A general validation has been done in this paper. However, there are aspects that should be tested and improved. A sensitive analysis has to be done to analyze the influence of the variation of technical parameters of equipments, now constants during the simulation. The validation of the model results is done at annual level. It would be interesting to validate the model at hourly level, in order to verify the hourly peaks. At the moment, the model is not related with the occupancy level neither with the user behaviour. These parameters could be included in the model to increase the range of possibilities to adapt the model to each situation and necessity. The use of this type of models is a good tool that could help to reduce the uncertainty of the energy consumption of the residential sector, improving making decision process in the early stage of refurbishment projects.

7. Acknowledges

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8. References

[1] CUBÍ E, ORTIZ J, SALOM J. *"Potential impact evaluation: an ex ante evaluation of the Mediterranean buildings energy efficiency strategy"*, International Journal of Sustainable Energy, DOI: 10.1080/14786451.2013.796945; 2013, Volum 1-17.

[2] WIDÉN J, MOLIN A, ELLEGÅRD K. *"Models of domestic occupancy, activities and energy use based on time-use data: deterministic and stochastic approaches with application to various building-related simulations"*, Journal of Building Performance Simulation, DOI: 10.1080/19401493.2010.532569; 2011, Volum 5, pp. 27-44.

[3] RICHARDSON I, THOMSON M, INFIELD D, CLIFFORD C. *"Domestic electricity use: A high-resolution energy demand model"*, Energy and Buildings, DOI: http://dx.doi.org/10.1016/j.enbuild.2010.05.023; 2010, Volum 42, pp. 1878-1887.

[4] DAR UI, SARTORI I, GEORGES L, NOVAKOVIC V, *"Evaluation of load matching and grid interaction index of a Norwegian all-electrical Net-ZEB under stochastic user loads"*, Proceedings Eurosun 2012, Rijeka, 2012.

[5] PAATERO JV, LUND PD. *"A model for generating household electricity load profiles"*, International Journal of Energy Research, DOI: 10.1002/er.1136; 2006, Volum 30, pp. 273-290.

[6] BAETENS R, SAELENS D. *"Integrating occupant behaviour in the simulation of coupled electric and thermal systems in buildings"*, 8th Int. Modelica Conf., March, 2011, Volum 20-22.

[7] AENOR. *Energy performance of buildings - Calculation of energy use for space heating and cooling*. ISO 13790. 2008.

[8] IDAE, *"PROYECTO SECH-SPAHOUSEC: Análisis del consumo energético en el sector residencial en España",* Instituto para la Diversificacion y Ahorro de la Energía, 2011, http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_Informe_SPAHOUSEC_ACC_f68291a3.pdf

[9] STAMMINGER R, *"Synergy Potential of Smart Appliances",* Smart Domestic Appliances in Sustainable Energy Systems (Smart-A), IEE Project, 2008,

[10] GRINDEN B, FEILBERG N, *"Analysis of Monitoring Campaign in Europe. REMODECE",* Intelligent Energy – Europe (IEE), 2010, http://remodece.isr.uc.pt/

[11] RICHARDSON I, THOMSON M. *"Domestic Electricity Demand Model - simulation example",* Centre for Renewable Energy Systems Technology (CREST), Loughborough University, 2010, https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/5786

PV integration in the open urban space redevelopment of historical villages in Italy



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Short Summary

In a contemporary perspective, the building refurbishment is no longer indifferent to technological innovation and energy efficiency goals. The photovoltaic (PV) integration becomes a possible way for design in "sensitive contexts". The research proposes, within a wider strategy of sustainable reconstruction, some experimental projects for urban voids rehabilitation in minor historic villages hit by earthquake. The developed case-studies demonstrate possible and affordable ways for integrating PV within urban/architectural innovative zero-energy concepts in sensitive areas.

Keywords: BIPV, historical centers, refurbishment, reconstruction, photovoltaic.

1. Introduction

The refurbishment of many historical villages abandoned or hit by earthquake, is today an issue of vital relevance in Italy and it is a complex and multidisciplinary field of research, in which the focus on sustainability can be recognized as a potential scenario of common development [1]. Despite the current background often directed to demagogic "in style" interventions, an innovative way of research is aimed to rethink these settlements in relation to a "sustainable" return to life in next years that can't neglect the topic of energetic efficiency, both at building and urban scale. Unfortunately the less physiological "measurability" of some factors involved and the greater disciplinary complexity are an actual barrier and too often the premises are discouraged, determining an inactive and dangerous tearing between sectors. The first objective of the ongoing research path, begun some years ago, has been a definition of the main forms of compatibility among PV systems and the wide range of environmental, landscape, historical and material values of these places [2]. In a contemporary perspective, no longer uncaring of environmental topics, so, PV integration can be recognized as one of the key-aspects for a more responsible design in "sensitive contexts". The goal of the presented research, following other studies already made about methodology of BIPV (Building Integrated Photovoltaic) [3], is to experiment the real PV compatibility (in historic villages hit by earthquake of 06.04.2009 in Italy) through the development of case-studies regarding the urban voids rehabilitation. The study takes into account 3 different areas within a village, considering different historic and landscaping scenarios. The use of PV is conceived not only as an energy goal but also as a part of a wider and more complex refurbishment project that is characterized by architectural distinguishability with ancient, technological reversibility/temporality/lightness and energetic autonomy. Outcomes of these case-studies show as PV may become, within a careful and aware project, a compatible and characterizing factor within an innovative logic of reconstruction, demonstrating a possible and effective co-existence with historical and landscaping values of these places. Furthermore the complex reality typical of these areas requires a "controlled transfor-

mation" variable case by case. Following these experiences, the believed scenery of the research is a real applicability in the reconstruction process, through knowledge transfer, development of guide-lines, tools, criteria and advices to be implemented in urban planning and building rules in next years. PV will require to be considered as an architectural and urban opportunity as well as an innovative challenge to be deepened, introducing the perspective of Nearly-Zero Energy Villages in the contexts concerned. Future prospected works along this path will be other case-studies in margin areas (valley, green areas) and in urban grids (streets) aimed to extend the PV integrability concept from building to a wider scale. This general topic will also match some new international Task related to "Solar Energy and Urban Planning" [6].

2. Perspectives: PV towards new urban and landscape scales

2.1 From Nearly-Zero Energy Building (NZEB) to Nearly-Zero Energy Clusters (NZEC)

The recast of the European Directive 2010/31/EU establishes that starting from 2020 new buildings will have to become Nearly Zero Energy (Nearly ZEBs). According to this Directive, a *Nearly Zero-Energy Building* has a very low energy consumption, which can be achieved by both high energy efficiency as well as by renewable energy produced *on-site* or *nearby* [4]. In the perspective of "Nearly-Zero" Energy Buildings (NZEB), PV has already today a basic role, thanks to its ability to be integrated everywhere within the building envelope, to produce renewable energy and thanks to a rapid prices falling that allow by now to consider PV as an ordinary building material. If incorporating some module, just to respond to the "minimum standard", has so far often relied on a tacit and shared culture of architectural (and constructive) "camouflage" excluding the solar systems by specific design thinking (like a television antenna or a chimney), the raising of energy level and the significant increase in quantity, will put inevitably the need of a more conscious assumption of responsibility by designers and other stakeholders at widespread scale. From this point of view, the design potential of PV could turn from a legal constraint into a new challenge for architects. From a cultural perspective, PV is rarely perceived as a creative challenge, but rather as a necessity that cannot be postponed. From the technical point of view, moreover, the building envelope today might not be sufficient to produce all the energy required [5]. In the near future, therefore, the design of Nearly-ZEB will have to evaluate, in addition to the space considered so far (the "footprint" of the building), the need to extend the available area for solar power generation systems "beyond the envelope" that is at the scale of the site, neighborhood, city and landscape. Even at the international level, after several experiences on Building Integrated Photovoltaic (BIPV), this awareness is leading to startup of specific research aimed to develop processes, tools and case studies on the integration of solar systems on an urban and landscaping scale, both for new complexes as well as for the refurbishment of existing settlements [6]. With the objective of quickly converting new and existing housing stock within a stronger energy efficiency logic, in addition to the standard Nearly-ZEB that today is already an accessible and feasible reality, the main challenge of the coming years will be a broader perspective (eg. Nearly-Zero Energy Clusters/Cities). The building is no longer seen as a closed an self-referential unit, but as an integral part of a more complex system (clusters, grids, city) in turn piece of a smart eco-sustainable city on a wide scale, where energy efficiency is not given just by the sum of many efficient buildings but, contrariwise, by an innovative interaction among urban areas, mobility, transport, industry, agriculture, waste ... etc..

2.2 Landscape Integrated Photovoltaics (LIPV): from solar fields to land art

The enlargement of perspectives from building to sustainable urban areas for the coming years, certainly opens up the research towards new fields putting in relationship PV and landscape. For some time, with the progressive spread of the "solar fields", this investigation path has become increasingly paradigmatic and has not yet saved the photovoltaic by several criticalities, even tough. There is no doubt that large installations are a real mark on the territory, characterizing the

perception of the landscape on a wide scale: in variuos cases, often forced by the logic of the economic investment, PV has caused damages to agriculture, soil, vegetation and wildlife as well as to the landscape. Beyond instrumental positions, it is clear that in the planning of such interventions becomes necessary to develop specific investigations of "environmental compatibility" for the evaluation of the different and complex environmental systems interacting. In response to a recognized need of environment protection, however, it is unquestionable that a new and controversial search for a balance between the natural values to be preserved and the energy issue emerges by the contemporary debate, creating a major complexity than in the past and putting in conflict aspects linked for the first time, in some way, to the same goal of rational use of resources and environmental protection. The acceptability and compatibility of photovoltaic implementation respect to the context, of course, are sent on a case by case investigations aimed to analyze the contextual characters (geomorphological data, microclimate, settlements, characters of vulnerability ...), the legislative, natural and anthropic constraints, and the landscaping impact analysis (eg. with an environmental impact assessment). Therefore in areas with particular worth, as the minor historical centers, the solar implementation requires to carefully investigate the compatibility issue that, , through a deep and sensitive design phase aimed to find the ways of a high acceptability, in alternative to the zero hypothesis. Even in such contexts, the research has shown the possibilities to overcome aprioristic positions, also thanks to a new "craft technology" able to meet, in a flexible way, the project demand in every specific context, respecting environmental and historical values [7]. Despite legislative instruments of territorial planning not yet diffusely updated to these topics, the best practices of international projects offer innovative visions as reference. A new way of thinking about renewable energy in our landscaping environment is shown, for instance, by movements and initiatives of Land Art which have demonstrate a creative and artistic way to use renewable sources and technologies in harmony with nature [8].

2.3 PV and historical heritage: a new possible way

The presence of several research sectors that, under various titles, are linked to the heterogeneous field of the “historical built”, can be considered a consequence of the complex character of this matter. In a contemporary perspective of “sustainability” in architecture and in urban planning, even the field of PV integration has recently entered this sector showing, both on a research level and with some real interventions, the possibility to implement renewable energy. Some first BiPV guiding-cases of refurbishing historical neighbourhoods in Europe mark this new season [9], where PV implementation within historical consolidated environments becomes a reality. Even some interventions on historical protected heritage (medieval churches, towers, etc.) show a possible shift from the research field to the real one [3]. Despite the “ordinary” heritage opens the project to the opportunity of re-shaping the pre-existing bringing a new character and a higher quality, in historical contexts many values need to be preserved (historical, landscaping, environmental), requesting a more "conservative" and “compatible” way of intervention. In particular, in the "minor" historical centres hit by earthquake, new methodological challenges related to the control of energetic demand are required, at different scales. After the earthquake of 2009, the need to rebuild and rehabilitate the wide urban area in the crater of L'Aquila, with its several historical centers, poses relevant questions for these topics and defines an innovative objective for the reconstruction process in following years that will have to be faced in a challenging way.

3. New goals: PV in urban systems of minor historical centres

Minor historical centres appear as a whole crossed by roads, streets and squares, which together form the unitary image of the historic built, closely linked with topography, morphology and surrounding natural environment. The PV implementation within these contexts, as opposed to the ordinary heritage, moves in a complex and peculiar relationship with *"the overall environmental value"* charachterizing these areas. The study of PV integration strategies, so, before to refer to individual building envelopes, requires to investigate new ways of thought on a *"urban"* scale which includes open-relation spaces and landscape areas as following explained. The building-scale, futhermore, must be expanded towards the size of the *building "aggregate"* defined by a homogeneous built unit, "autonomous" from the rest of the historic settlement [3]. The research, after introducing the whole discussion, is addressed to the topic of urban voids refurbishment.

3.1 Built tissues: roads and urban networks

A possibility in the refurbishment of minor centers, especially in the post-earthquake reconstruction, could be a different use of streets and roads of urban settlements: though, on one hand, this theme converges on the planning of underground services (technological tunnels, service networks ...), to a broader and ambitious view it could be declined in an innovative concept of "sustainability" networks. The streets could be re-thought as passive urban bioclimatic tunnels/spaces between the houses (a kind of buffer zone), able to interact with the local weather conditions for controlling of microclimate and lighting, and to be inhabited during different seasons, carrying a new functional, urban and social role. In an active way, moreover, they could be used as energetic grids both offering a location to solar (or wind) systems, where this appears compatible, and integrating technological underground tunnels (water, electricity, optical fibers, pressure waste systems, etc.) with a network of other services linked to an energy-efficiency policy at urban scale (e.g. pipes of district heating linked among houses and power stations, smart grids coming from energy fields, etc.).

3.2 Relation areas: squares and open spaces

Relation and open areas of historic villages are generally the centrality and the representative places of the entire settlement, as the “square”. Around these urban areas are typically collected the most symbolic monuments such as the church (with any convents, cloisters ...), the town hall, stately palaces and other important buildings, often examples of high historical value of premodern architecture or art. Within these historic cores, even in cases where the earthquake has caused serious damages, there is a low degree of transformability and consequently the introduction of "energy systems" is linked to specific compatibility analysis and evaluations. However important possibilities of "micro-intervention" aimed at energy efficiency of these spaces has not to be excluded, such as the upgrading of lighting scenarios and urban furnishing, in which a careful and "customized" use of the PV can establish a new possibility for the rehabilitation of these spaces as well as a demonstrative important symbol [1] [7]. Some examples of Anglo-Saxon and European integration of solar systems on medieval churches or on historical buildings show us even wider opportunities [3]. We have not to forget then, especially in contexts of reconstruction, the chance to reintegrate or rebuild historical artifacts completely collapsed with contemporary distinguishable interventions, could offer another way to re-think at renewable sources as a vital means of design.

3.3 External areas: energy towards the landscape

The historical centers concerned are usually connoted, as already said, by a special relationship with the surrounding nature of which they form an integral part. Many centers of Abruzzo, built on rocky ridges, appear as huge blocks of stone crossed by streets and squares, immersed in a landscape system in which the natural and the artificial become one. Defensive strategies of the time are still readable in the walls around the built boundary. Beyond this perimeter, in cases still intact

by the wild post-war building, the nature marks the contour with a mountainous landscape punctuated by valleys, orchards, fields, and ancient paths. In this border areas, now abandoned and disused, is frequently hidden a great potential for restoration and enhancement of these places, if we think about the possibility to open new routes (pedestrian, cycling, horse trails, sustainable mobility ...), natural parks and waterways or other scenarios of sustainable re-use, which should become the distinguishing values of their return in life. In a perspective of organic re-planning of the territory after the earthquake, this network between the villages could become an important occasion for introducing parks and energy fields (biomass, solar, wind, hydro), as well as power plants for the built centers or a new sustainable mobility system (bikes and electric cars).

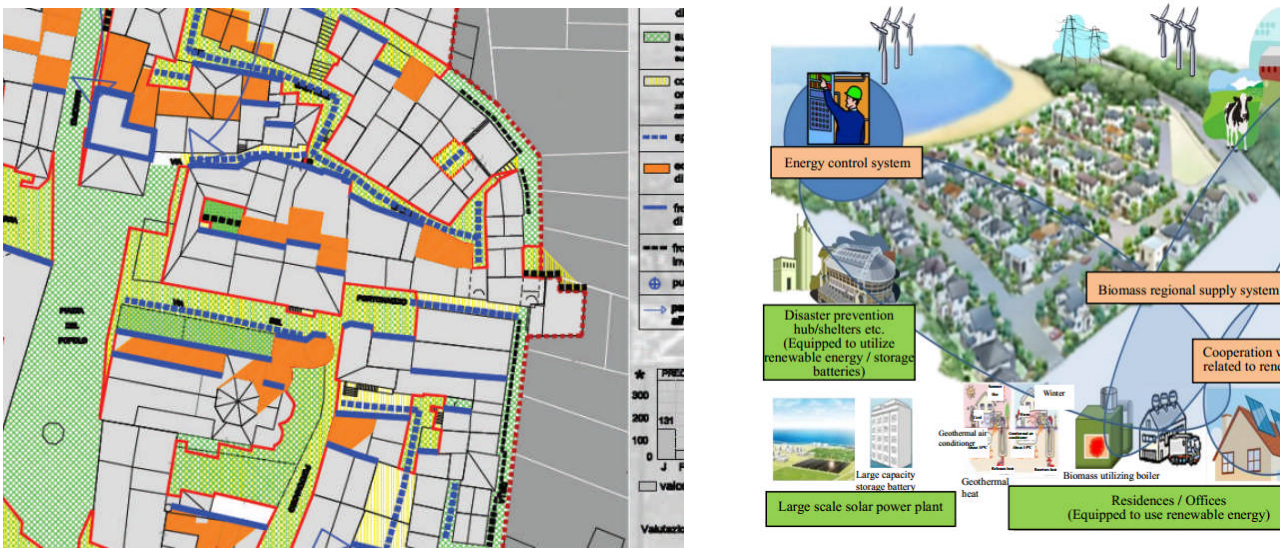


Fig. 1: (Left) Bioclimatic analysis and guide-lines for active and passive strategy in the reconstruction plan of S.Eusanio Forconese –Italy, after 2009 earthquake (DAU-University of L'Aquila). (Right) "Sanriku eco-town". Reconstruction plan after 2011 Japan earthquake and tsunami.



Fig. 2: Energy service and landsape. (Left) Energy Plant. Dok Architekten. Utrech University. (Right) Windstalk for Masdar City. Concept and Design: Darío Núñez Ameni and Thomas Siegl, with Atelier dna (landartgenerator.org)

3.4 Refurbishment of urban voids as a new challenge: method and case-studies

Refurbishment design and accordingly PV integration in reconstruction contexts, will have to face with the voids of the urban system. Just visiting any of the historical villages around L'Aquila there is the perception of a "negative of the original" with the overthrow of full and empty due to the "voids" created by collapse and the rubbles within the original open spaces (streets, squares ...) [9]. From this state of art, the presented research experiments possible ways for recovering these urban spaces through an approach aimed to environmental and material lightness, energy self-sufficiency and a controlled distinguishability from existing historical matter. Although the main topic was PV integration in sensitive areas, the presented case-studies cannot give up a wider design sensibility as well as the need to realize more general goals for the life return of these villages, for providing services during the reconstruction process or for introducing memory signs of the tragic event. Projects has been developed with Building-Engineering/Architecture students within a specific lecturing module at University of L'Aquila, and concerns one of the most hit centres due to the 2009 earthquake that is Sant'Eusanio Forconese nearby L'Aquila in Italy. The small village, born between XII and XIII centuries, has about 400 inhabitants and is located in a very meaningful natural environment: after the earthquake it was completely abandoned. Hoping in a quick re-born, despite the hard and complicated reconstruction process waited for the following years, the presented study has been directed to experiment a new coexistence between memory and hope, through the proposal of urban elements designed either for nowadays than for next years. The chosen areas are located either within the historical centre than at the edge with landscape, representing different design possibilities in dissimilar kinds of urban voids.



Fig. 3: Pictures of the 3 different urban voids in the post-earthquake status

3.4.1 A sensible media box in the central square

This first project is located in the central historic square of the village, and its goal is to replace a building collapse happened between the church and the stately building beside to the main entrance of the historical village. The site conserves some traces of the old walls and is bordered by a building just on one side while the other ones overlook the square. Considering the high sensitiveness of the place, historical hearth of the town, the main goal was offering a memory of the event: the concept is, so, an insertion of an interactive box thought as a broken cube whose pieces becomes parts of the square. The external vertical envelope of this urban element is completely made by a media shell, made with a special PV thin-film glazed module. PV glazed panel is frontally printed with a local stone pattern that, partially reducing the energy yield of about a 20%, allows an aesthetic integrability during the day. At night the envelope becomes a kind of lighted lantern thanks to rear LED hot spots that form a grid of pixels onto the facades. The inner space, separated by a double skin, is characterized by electrochromic glazed walls on which are electronically shown movies, pictures and stories. The roof is also conceived as a semi-transparent PV glazed double-skin. Piezoelectric internal and external floors allow both producing energy as well as to self-light, internally, as a smart touchscreen sensible to people feet steps. A transparent opening obtained in a corner of the cube, looking towards the square allows in each moment to view from interior towards outside and to compare the story internally told with the external reality. The energy concept allows to entirely provide the energy demand with BiPV and piezoelectric systems also offering public services as a media screen, urban lighting, wi-fi zone, etc.



Fig. 4: The "memory" box in the central square. Conceived as a media urban system, it is characterized by a PV media skin patterned as a stone wall and self-lighted by led (Bucci, Santoro, Troia).

3.4.2 An autonomous temporary laboratory for the reconstruction

This project is aimed to redevelop an urban void located between the square and the east boundary of the historic village within the urban tissue. This area, at the edge with historical walls, is essentially enclosed by built volumes (or ruins), though overlooks towards the landscape on the east side. Due to this strategic location the project proposes an immediate recovery through a temporary structure useful as a laboratory for the reconstruction process. This solution could allow a fast life return thanks to the location of a strategic research centre to be lived by actors of reconstruction in the current years within the abandoned village. Due to its temporary character and to the absence of energetic grids it's conceived as a self-sufficient system with the use of recycled materials (coming from nearby construction areas, rubbles and building ruins), the rain water storage and with completely electric devices powered by an integrated stand-alone photovoltaic systems. The structure is conceived by a 4 storeys scaffolding frame with the insertion of completely reused containers. At the top, a semi-transparent customized PV surface provides a peak power of nearly 10 kW and the sun protection of the laboratories below. Internal services are just conceived for lighting, pc work stations and electrical heating in winter to be provided by solar energy storage system. The specific study of containers location, the lightness of the scaffolding frames and the glazed roof allow preserving a sight towards the landscape without entirely refilling the void. On the east façade some vertical flexible PV tents provides further 2 kW peak energetic power besides to protect from sun the container glazed openings avoiding overheating in summer.

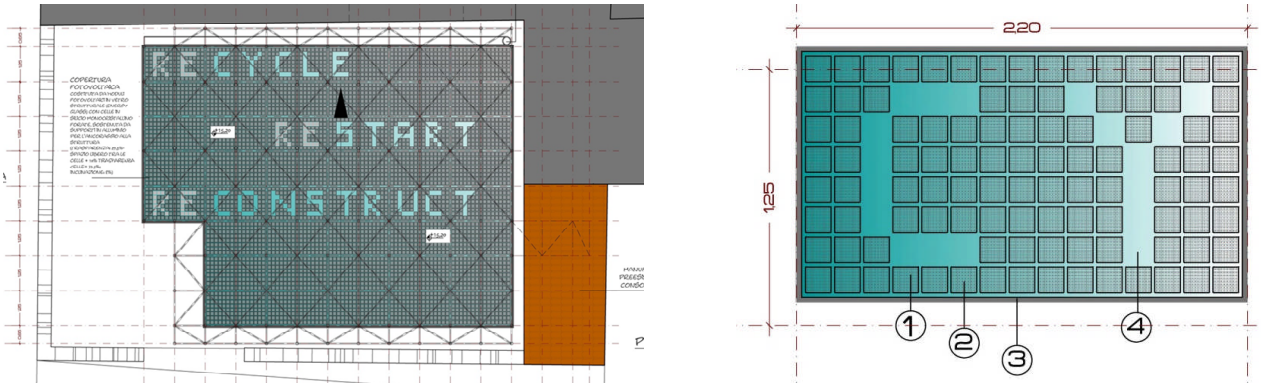


Fig. 5: The PV glazed roof is partially made by customized module (De Michelis, Cortellini, Pacini).

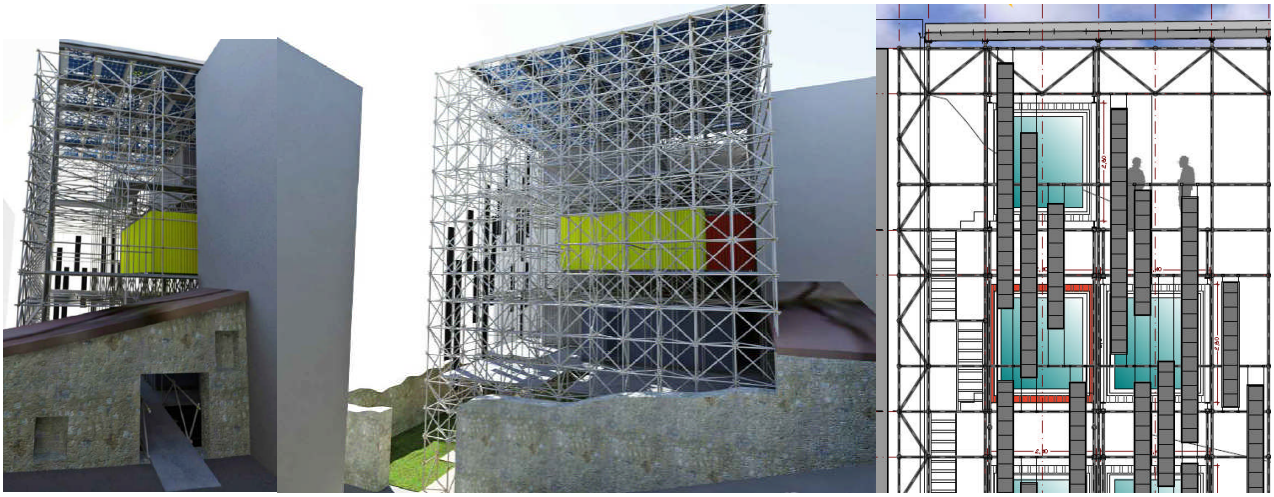


Fig. 5: The temporary laboratory is built with recycled components and is energetic autonomous

3.4.3 A sight towards the landscape: a sustainable urban library

This third chosen area is the most external, being located just at the boundary of the ancient perimeter in south position overlooking the valley and the landscape. The project, in this case, is aimed to imagine a new public function for the residents, in the perspective of the post-reconstruction status, thinking to a new urban life of the village. The void is partially replaced with a built volume that seems embedded to the earth and appears as a photovoltaic black object really distinguishable from the nearby stone walls. It is a public library room with a small park below where are placed, on the ground, some other PV modules characterized by green cells, introducing a landscape solar challenge able to be replaced in wider areas outside the centre. The building, inserted within a crater generated by a collapse, is conceived like a spyglass with the sight directed from the centre towards the landscape. It is designed with a wood skeleton cantilevered by the foundation, and it's entirely made with dry envelope technologies above a concrete basement. The envelope is externally cladded by PV thin film glazed modules on each side, including roof, east and west ones, apart from the surface below the volume or some edge elements which are similar black glazed panels. Plants, lightings and internal services are supplied by PV skin defining a plus-energy building that could be grid-connected. The estimated yearly energy surplus is more than 20.000 kWh, allowing to satisfy the electric demand of about 5 houses.



Fig. 6: The building is inserted within a crater as a spyglass opened towards the landscape. The skin entirely use a PV thin film cladding (Dell'Orso, Poliandri).

4. Conclusions

In a contemporary perspective, the building and urban refurbishment cannot longer be indifferent to technological innovation and energy efficiency goals. Despite some current background and barriers often directed to demagogic “in style” interventions especially in historical areas, an innovative way of research and practice is beginning to rethink these settlements in relation to a “sustainable” return to life that can’t neglect the topic of energetic efficiency and renewable energies, both at building and urban/landscape scale. The photovoltaic (PV) integration is by now a possible way only if PV is conceived, not simply as an energy device, but also as a part of a wider and more complex refurbishment project linked to an aware contemporary approach. Outcomes of above mentioned case-stories show as PV may become, within a careful design method, a compatible and characterizing factor useful for an innovative logic of reconstruction, demonstrating a possible co-existence with the many historical and landscaping values of sensible areas. Also it emerges as the complex reality typical of minor historical centers requires a controlled transformation variable case by case due to the several and dissimilar values involved. From these first studies the footprint of urban voids, thanks to the small scale of the old surrounding buildings (generally of 2 or 3 storeys), seems to be able to satisfy the own energetic demand and to offer energetic surplus to several nearby houses. It means that the implementation of solar systems just in strategic open areas, controlling the urban density and the balance between buildings and voids in the reconstruction urban planning, could be a way to supply the energetic demand (or anyway a significant part) of the entire historical centre, enhancing the urban liveability with more open areas and avoiding the challenging solar integration on historic building roofs. Also the refurbishment of old buildings, futhermore, will have to follow energy efficiency principles dramatically reducing the energetic demand. Therefore, considering the lower energetic demand, the small scale of these settlements and the presence of several voids able to be strategically re-used, these first research findings show that a premeditated re-planning of urban settlements could allow a significant solar implementation, satisfying a main part of the energy request, also improving the urban quality and, not least, offering a medium term economical payback. Following these experiences, the believed scenery of the research is a real applicability in the reconstruction process, through a transfer of skills, guide-lines and criteria to be implemented in urban planning and in building rules in next years, considering PV as an architectural and urban opportunity, an important design resource and an innovation challenge for the energy efficiency. Future prospected works are, also matching broader international goals on this topic, other case-studies in margin landscape areas and in urban networks with the goal to experiment and extend PV integrability from building to a wider scale and with the hope to introduce, in the contexts concerned, the future challenge of Nearly-Zero Energy Villages.

5. References

[1] DE BERARDINIS P. “*The sustainable refurbishment.The open relation spaces”*, in C. Aymerich, *Architettura di base*. Alinea, Firenze, 2008, pp. 37-48

[2] DE BERARDINIS P, DI GIOVANNI G, BONOMO P. *“PV integration in the minor historical centres of Abruzzo. An opportunity for a sustainable reconstruction”*. Energy Forum on Solar Building Skin–Brixen 06-07/12/2011, Proceedings book. ISBN: 978-3-981205343

[3] DE BERARDINIS P, BONOMO P., “*BIPV in the recovery of minor historical centres. The project of integrability between standard and customized technology”*, Zero Energy Mass Customisation Home 2012– Glasgow 12-14/09/2012, Proceedings book.

[4] EPBD recast, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast), 2010.

[5] SCOGNAMIGLIO A., RØSTWIK H.N., “*Photovoltaics and Zero Energy Buuildings: a new opportunity and challenge for design”*, Progress in Photovoltaics: research and applications,

Wiley Online Library 2012.

[6] SHC Programme- INTERNATIONAL ENERGY AGENCY: task 51 “Solar Energy in Urban Planning”: http://task51.iea-shc.org/

[7] HERMANNSDÖRFER, I., RÜB, C., 2005,. *“PV ACCEPT. Final Report”*. www.pvaccept.de.

[8] FERRY R., MONOIAN E., “*A field guide to renewable energy technologies”*, Land Art Generator Initiative, 2012, www.landartgenerator.org.

[9] DE BERARDINIS P, BONOMO P., “*BIPV and refurbishment of historical minor centres”*, 39th IAHS World Congress– Milan 17-20/09/2013, Full paper accepted for Proceedings book.

Energy efficient roofs retrofit for communist prefab concrete blocks



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Short Summary

An elaborate survey over one of the most used type of standardized collective housing units erected during the socialist regime, called 770, revealed a great opportunity for roof retrofitting as a sustainable action in order to revive the “grey” dormitory districts. The use of existing infrastructure to create new and contemporary “penthouse” apartments is basically the starting point for larger actions, including thermal rehabilitation with refurbished facades, introducing elevator as comfort upgrade and last, but not least, innovative structural solution and energy efficient construction materials. The project called 770 [1], was created and improved during the passing years by the Centralized Institute for Standardized Building. It’s wide spread implementation all around Romania makes him a perfect candidate for a sustainable study regarding improving comfort measures together with a new and better exterior look of the whole (old building plus new “attic”). The real estate market shows a great demand for better housing units with good position in the city almost central areas. But the existing similar works are dealing only with maximum saleable area and, in most cases, doesn’t care about construction aesthetics or urban image. The psychological idea of having a “penthouse apartment” is neglected in these new houses without any exterior private spaces – balconies or terraces. The mixture between thermal rehabilitation and a complete new level (an attic, according the national legislation) led in the last ten years to several alterations (not always good) and unaesthetic buildings. The solution proposes a switch from nowadays works, on all layers: structure, enclosing materials, roof type, functional improvements (elevators, terraces and open space apartments), respect to existing inhabitants and private property (access to the upper level through the existing staircases, extended). The structure is represented by multiple light prefabricated concrete frames, placed exactly over the old structural grid, with exterior columns that offer a rhythmic exterior design. The enclosing elements, along with the flat roof are energy efficient lightweight materials [2] of composite type with rigid foam polyurethane as thermal insulation. For the existing three layers exterior concrete panels, mineral wool was the insulation chosen for the bonded thermal system (BTS). In order to show the good energetic performance of the whole proposal, an energy certificate was made for the existing construction and the refurbished one.

Keywords: flat roof retrofit; concrete prefabricated blocks; energy efficient composite materials

1. Introduction

During the communist regime, Romania had a similar evolution in construction field with the other soviet influenced European countries. All projects were designed by the National Institute of Standardized Buildings, then erected all over the country. There were few types with many subtypes. Because Romania has serious seismic movements, the great openings used by other states in prefabricated housing construction were not available. Norms, regularly updated, together with maximum usable areas and price limitations lead to constant improvements of same type of

concrete blocks. As general features, 30 cm modulation and maximum weight of panels limited to 5.5 tons were used everywhere. Some local details enriched the usually “grey” and monotonous facades, but the use of prefabricated elements (from large scale to small pieces) and construction details are all the same (Fig. 1).



Fig. 1: Romanian communist prefabricated housing blocks

Most of these buildings are used at their full capacity even today, when big cities are (still) magnets for a consuming society [3]. But the infrastructure and facilities are inadequate to such big number of cars (each family has at least one vehicle) with not enough socializing or playground areas nearby.

2. Project type 770

2.1 Communist existing buildings

One of the most extensively used projects, called 770, with its twelve subtypes (Pa1, Pa2, Pa3, Pa4, Pb1, Pb2, Pb3, Pb4, Pc1, Pc2, Pc3 and Pc4), can be found all around the country (Fig.2).

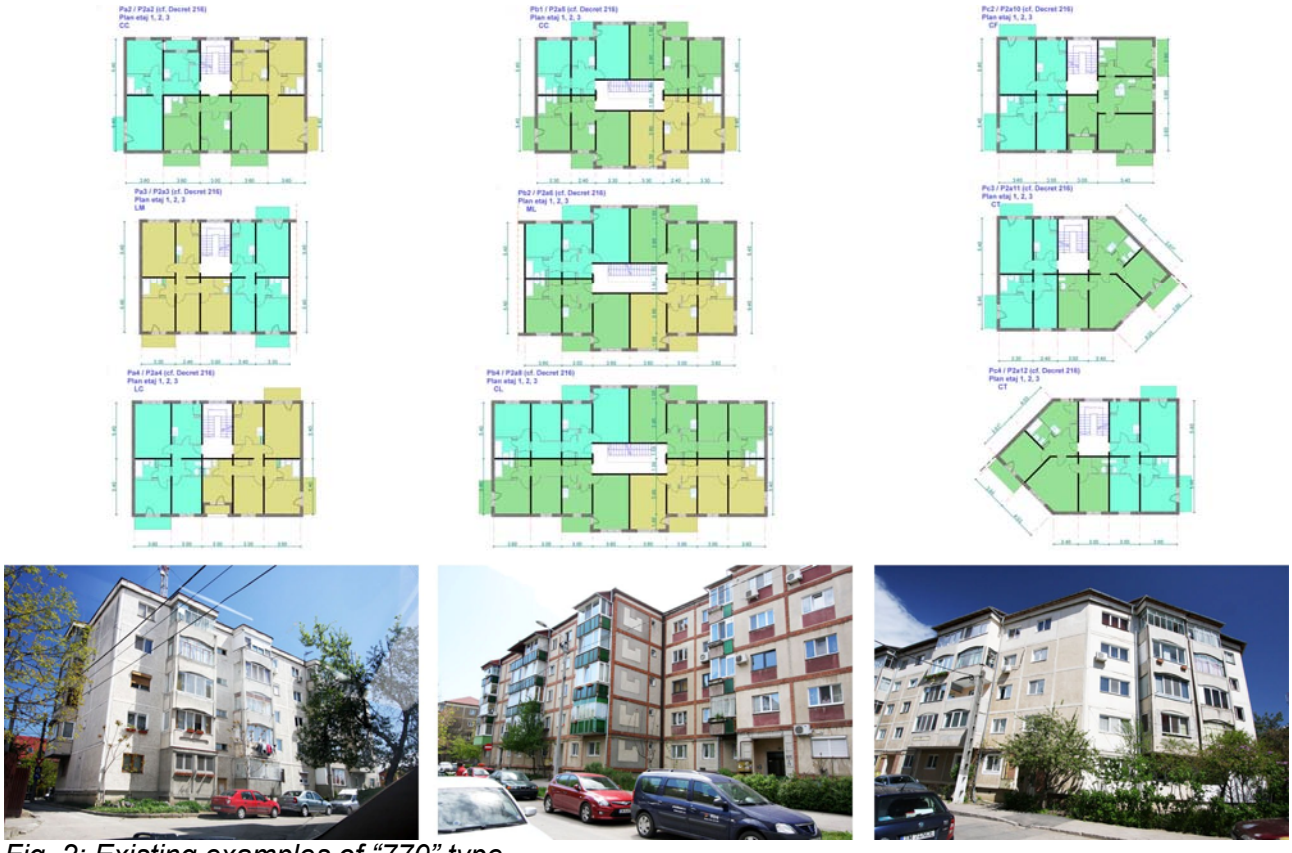


Fig. 2: Existing examples of “770” type

The last improved variant was designed in 1983 (the year of its application) developing rectangular “matchboxes” with 6 types of apartments (with 2, 3 or 4 rooms), small structural cells (2.4 m, 3.0 m,

3.3 m, 3.6 m or 5.4 m) and a standard coupling width of 11.2 m. All the five levels with apartments have the same height (2.7 m) while the technical basement has just 1.7 m. The different ending block panels (opening on long / short side) offer 88 sections of buildings and 72 types of concrete panels, with 1 to 4 staircases.

Most of construction elements were prefabricated. The structure is made out of concrete, with exterior panels made out of three layers and 30 cm thickness, the interior walls and slabs also from reinforced concrete. The flat roof has a thick thermal insulation (expanded clay or autoclaved aerated concrete), usually deteriorated by the poorly executed waterproofing works and many uncontrolled leaking. The plumbing features were also prefabricated as well as the carpentry elements (apartment windows and doors), the common spaces having metal doors.

2.2 Post revolutionary small scale interventions

Once the capitalism started (after 1989's Revolution), the new owners of formers exclusive State's ownerships started to improve their own comfort and develop small scale interventions, interior and also exterior. The diversity of construction works – replacement of wood fenestration with white PVC double glazing, closing balconies, exterior units of HVAC, outside enlarging ground floor apartments, single apartment exterior insulation – show that the great liberty offered by the switch of political regime was, in most cases, badly understood (Fig.3). The financial power and knowledge of each occupant was reflected in these small scale interventions, especially those regarding exterior aspect of the entire building. The change of thermal system, from district heating to individual unit was randomly done.



Fig. 3: Small scale interventions

Some more general alterations were developed for each staircase's apartments or Owner's Associations by changing the roof. The main idea was a traditional aspect with small price and no concern for the whole building image, together with a general rejection for flat roofs. Due to a bad original execution or the materials' aging, the architectural appearance was completely changed and sometimes, the result was worse than the primary conformation. Because one building has usually 2/3/4 staircases and each of it could receive a local and different "hat" (form, material, colour, etc.), the results were very peculiar.

2.3 National Rehabilitation Program

Started in 2002, the National Program for Thermal Rehabilitation of collective dwellings reached its peak in 2009. The whole program included for 2004-2014 25.000 multi-storey buildings and 0.8 million apartments. Later it comprised 3 million apartments and the necessity of 11 billion euro [3]. Some of the selection criteria were: older buildings, greater number of apartments, construction envelope type (preference for concrete prefabricated panels), technical conditions, mildew or dampness, climatic area [4]. No urban reasons and other exterior / social / public works were considered. The rehabilitation measures (only for housing) included: thermal insulation, pitched roof (but no attics), the replacement of exterior doors and windows and the replacement of common mechanical features. Financially, the costs were shared between the state, the local authorities and the owners' association [3]. Due to the global economical crisis, stating from 2010, the State switched to bank credit with governmental guarantee.

From an architectural point of view, the final "product" doesn't show a contemporary aesthetic

attitude, just vivid colours on facades, white PVC windows and improved comfort inside - less money for energy costs with individual heating system. The use of cheap materials, together with the lack of specialists' involvement (the constraints were always financial), different difficulties encountered during the process and the small interest for a unitary district aspect led to an erratic and colourful ensembles (Fig. 4).



Fig. 4: Thermal rehabilitated blocks through the National Program

2.4 Attics and real estate market

A combination between thermal exterior insulation and pitched roof was developed by real estate agencies or contractors in exchange of new attic apartments with maximum saleable area. In fact, a whole new level, even if not completely legal because of a missing elevator (according to nowadays legislation) offered the opportunity of having extra housing units in the same urban area, already too crowded and suffocated by cars. Because of the city position of original blocks (sometimes quite central), some of these new apartments were highly appreciated on real estate market. More problems occurred: legal aspects concerning private and collective property (the flat roof is by law common property and every owner has to sell its share to a third party), fire and structural resistance maintained, inevitable long time disturbance of existing people, insufficient mechanical features and even more parking spaces needed. Other important architectural aspect concerns the different solutions applied on the same building, each staircase (sometimes equivalent with the owners' association) is having a distinct look.



Fig. 5: Attics with maximum saleable areas

3. Proposed roof retrofit

3.1 Description of selected building

A sustainable solution applied on this prefabricated "commieblocks" should consider, first of all, the great opportunity of applicability all over Romania. This is why the choice of a widespread building type and uniform intervention treating problems like comfort, social all ages areas and even parking, together with the use of energy efficient composite materials and a complete approach of exterior design to provide contemporary comfortable new plus old apartments could be a possible retrofit.

Leaving from the 12th basic sorts of 770 type, the study case considers a building with three staircases, apartments with single or double orientation, no settlement joint and three different subtypes (Pa1, Pb3 and Pc1). Because the coupling possibilities of different construction where

related with site conditions, the hypothetical building allows another (similar) block to be urban related with the studied one (Fig. 6).



Fig. 6: Current level and section of analyzed building

3.2 Self imposed constraints

As a reaction to other contemporary similar designs, this study was developed considering that an example should be done, as a reaction to the actual interventions. This means: less interference with the residents during construction works through a quick execution, respect for actual legal constraints, a new and aesthetical image for old blocks.

The legal constraint of an elevator (starting from more than 4 stories) combined with the small cellular structure doesn't give too many possible solutions: an exterior position, detached from the façade, in order not to disturb the private windows or balconies. Another legal problem regards fire resistance. The actual buildings, made out of reinforced concrete, have a very good fire behavior. Any addition to it should maintain the same degree of fire resistance – most of the existing interventions don't comply with this rule. Another major constraint was the weight of new attic construction that has to be similar with the removed components of the former flat roof.

3.3 Architectural innovative solution

The old apartments, with different owners, cannot be treated as a whole and the respect of private property was a key target. If someone wanted to do some interior and personal arrangement, some variants with very small structural but controlled damages have been proposed. The minimum things possible to do were exterior thermal insulation with mineral wool, changing of wood windows with efficient double glazing together with controlled ventilation, all representing improvement of inside existing conditions along with outside picture. Extra measures – insulations of basement ceiling and flat roof insulation (thermal and hydro) plus new plumbing features – can accomplish the basic needs with less to 0 mixing in private property. Different treatment of balconies (open, partially or completely closed) allows diversity, but still unanimous treatment of exterior architectural elements (Fig.7).



Fig. 7: Architectural solution for extended and rehabilitated building

The new level uses an existing infrastructure, so there is no need for foundations, utilities and accesses. The same staircase space, together with an exterior detached elevator provides the vertical connection between new and old. The elevator, connected with the common staircase, can be also used by the actual occupants from the last floors (3rd and 4th). Its detachment from the main building gives privacy to the rooms with exterior openings oriented to this vertical element. At the corner of two buildings with two staircases, a single elevator can serve the both accesses. The interior design is open space and has no structural barriers, due to the chosen system, with identical and repeated light concrete frames consisting of 3 columns (2 exterior and one interior – in the middle) and 2 beams. The recessed closing vertical elements, completely separated from the structural frames, offer a continuous terrace to the new apartments (fig. 8).



Fig. 8: Architectural solution for extended and rehabilitated building

The facades are usually an urban image that relates a building with its public space nearby, being very important in rehabilitation process. Along with square proposal, regarding parking places and playing / socializing spaces, all together in the middle of the plot, surrounded by the “back” facades and new erected elevators – the image of urban vicinity is completely changed. A demi-basement parking with social areas above can replace the nowadays boring and concrete panels garages randomly erected. The pedestrian area, surrounded on all sides by rehabilitated blocks, is a combination between parking alleys with sitting areas and playground equipments

3.4 Energy efficient measures and EPC

The whole solution of roofing retrofit was developed using only energy efficient composite materials, light, good fire behaviour and quickly erected. The use of only prefabricated elements reduces execution time and the interference with occupants beneath is minimized. The nowadays construction materials have different characteristics and the smart combination between them can help to achieve every goal (Fig. 9).

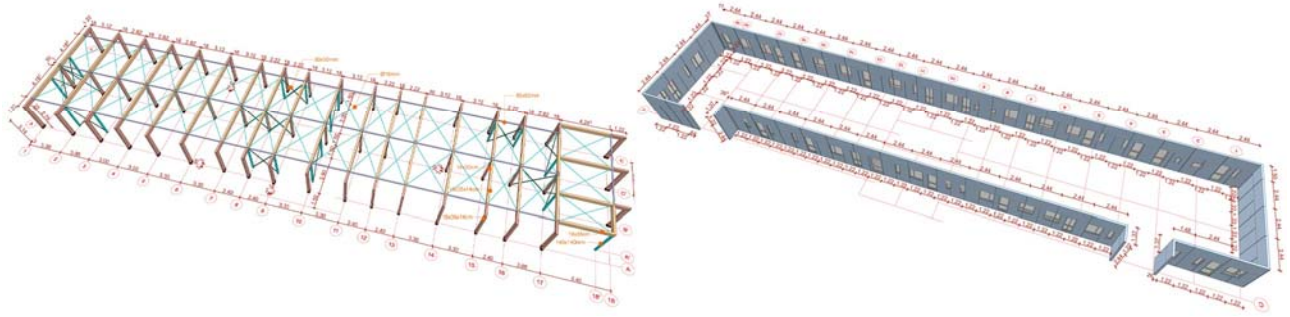


Fig. 9: Structural grid with light concrete frames and modelled exterior closing panels

The reinforced concrete as a structural solution was used for light prefabricated frames – 3 to / frame (with trapeze section, overlapped exactly above the existing structural grid. It was proven that concrete reabsorbs during its lifetime the CO_2 produced during its fabrication process [5]. Light triple layer walls called Glupan 125 (Glulam producer [6]) with Vidiwal fibre reinforced interior gypsum board, rigid polyurethane foam (PUR) in the middle and OSB board outside has 125 mm width, U=0.022 W/mK, 27.55 kg/sqm and the vertical elements (including openings) were modelled after its dimensions. The outside protection for these elements was made with Baumit Thermoputz plaster. The flat roof uses Kingspan KS1000x-dek steel panels also with 100 mm PUR insulation and PVC Sikaplan as waterproof material, U=0.19 W/mK and 24.6 kg/sqm [7]. The whole building received new PVC doors and windows from Internorm type Kunstoff Passion 4-16-4. The same PUR insulation, in situ applied was a choice made even for existing terrace new insulation, and instead of polystyrene or rock wool (because it's U value is almost twice smaller) [2]. 10 cm of Rockwool insulation was used for existing exterior prefab concrete panels and basement ceiling.

For the existing analyzed block and the extended one, a thermal and energetic expertise was done, concluded with an Energy Performance Certificate (EPC) (Fig. 10). The old block, erected in 1983, the minimum thermal resistance corrected (R'M) with thermal bridges of envelopes' each element is lower than the admissible values (sanitary – R'nec and energy efficiency conditions – R'min) and condense appears inside exterior panels and flat roof (table 1). The extended and rehabilitated block, with all new materials enumerated above, exceed the admissible values and there is no mildew (table 2).

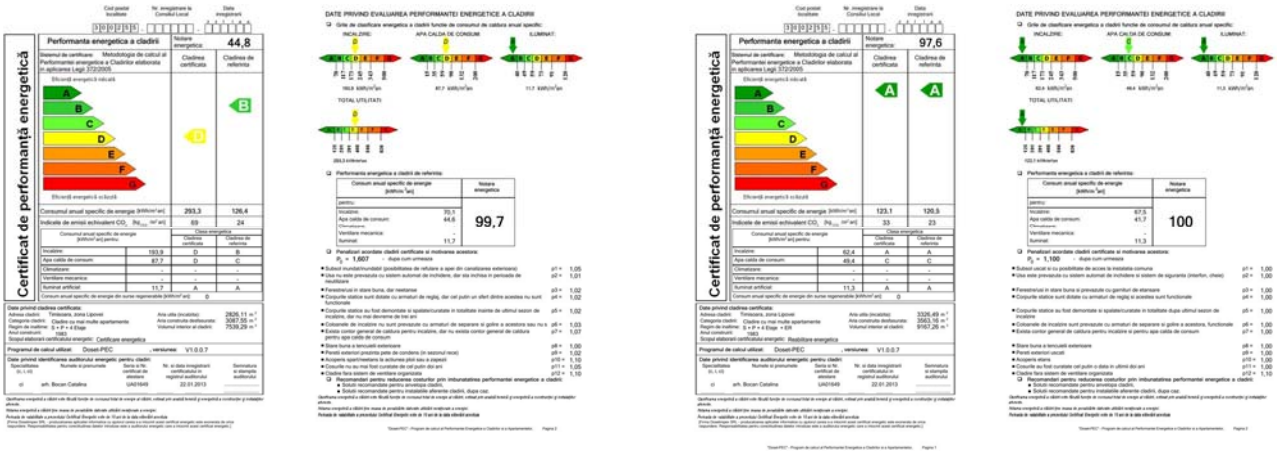


Fig. 10: EPC for existing and extended + rehabilitated building

Table 1 Thermal resistance for each envelope element on existing building

Construction element	**Area**	**R'M**	**R'nec**	**R'min**
	[m²]	**[m²K/W]**	**[m²K/W]**	**[m²K/W]**
Exterior wall	1465.87	0.606	1.188	1.4
Flat roof terrace	570.06	1.132	1.583	3
Slab over basement	560.36	0.244	1.416	1.65
Exterior fenestration	352.31	0.369	0.39	0.4

Table 2 Thermal resistance for each envelope element on rehabilitated building

Construction element	**A**	**R'M**	**R'nec**	**R'min**
	[m²]	[m²K/W]	[m²K/W]	[m²K/W]
Exterior wall	1732.39	2.619	1.188	1.8
Flat roof terrace	577.54	5.146	1.583	5.0
Slab over basement	560.36	3.045	1.416	2.9
Exterior fenestration	448.48	0.833	0.39	0.77

The nowadays rehabilitations are using only cheap materials, like polystyrene for thermal insulation. The use of mineral wool instead is recommended even for fire safety reasons, not just sustainability. Again, the use of PUR insulation allows minimal width when is needed (existing terrace – new attic floor). The use on concrete as ain structural material has never been used in this manner because of a psychological rejection for prefabrication and flat roofs. The structural details (the connection between old and new) is also a novelty for our country.

4. Conclusions

The innovation of this attic solution is given by a mixture of: new attic / penthouse design adverse to general adopted solution with pitch roof; new prefabricated materials used for structural and enclosing part, opposite to wood / masonry/metal/small tiles; different joint type between the original concrete walls and the new reinforced concrete frames instead of monolith solutions; little structural elements inside the new apartments; large covered terraces for the penthouse apartments; the new elevator used as a dynamic element for the back/inner court facade (with less balconies). As a reaction to other interventions (made out of materials enumerated above) I consider it normal to have a large scale operation due to a great interest of real estate market for 3 million apartments. The relocation is not a viable solution and construction works with residents in the building can be very difficult.

All enumerated above contribute to a daring roof retrofit by creating an attic, combined with a thermal retrofit, and may represent a challenge for Romanian people, running away from flat roof, prefab concrete structures and small spaces. Some arguments from a sustainable point of view are: the reuse of existing infrastructure, good energy quality prefabricated materials, quickly erected design solution and smaller disturbance, opportunity for large scale applicability. By using the existing terrace to create new living spaces, the actual apartments' inhabitants pay less money for building rehabilitation and the energetic performance of the whole construction is much better than without the new attic (Fig. 11).



Fig. 11: 3D images of the improved building

Other former communist countries have experienced similar measures, with attics on one, two or even three levels [8], but one of the main characteristic that allows such "liberty" is the lack of seismic constraints or movements - **SuRE-FIT European Program** (Sustainable Roof Extension Retrofit for High Rise Social Housing in Europe.

Acknowledgements

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5. References

[1] ***, "*Large panels living units P+4. Project 770 – 83*" Short description Brochure, 1983
[2] HEGGER, M. & AUCH-SCHWELK, V. & FUCHS, M. & ROSENKRANZ, T. "*Insulating and sealing".* In Edition DETAIL. *Construction Materials Manual*. Munich: Birkhauser; pp.132-141, 2005, ISBN-10: 3-7463-7570-1, ISBN-13: 978-3-7643-7570-6
[3] ***, National Institute of Statistics, *"People and Housing Census"*, 2002
[4] ***, excerpts from National Government Programs and Legislation regarding the Program of Thermal Rehabilitation.
[5] DENCSAK, T. "*Sustainability of construction. Special aspects of concrete structures", PhD Thesis*", 2012, Politehnica University of Timisoara, Chapter 5
[6] ***, Thermal Insulation Panel Glupan. *"Glulam Company Presentation Brochure* " 2009
[7] ***, Kingspan X-dek KS1000 XD − Longspan Roofpanel. *"Kingspan Company Brochure",* 2010.
[8] ***, (2010). „*Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe*" SuRE-FIT, European supported project, number: EIE-06-068 - SuRE-FIT

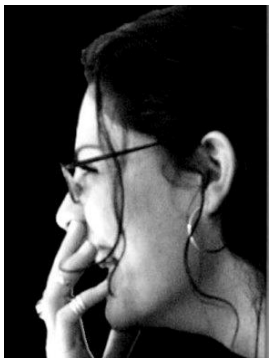
Methodology for improving and testing the quality of renovation actions: a case study application



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Short Summary

This paper presents a synthesis of some results obtained from an on-going national research program carried out at the University of Bologna, Department of Architecture, focusing on sustainable renovation processes and effective solutions for increasing the energy efficiency of the existing housing stock. The proposed methodological approach is based on a step by step retrofit strategy, tested by a simulation model, aiming to reduce the energy demand from the current significant present value to at least 15 kWh/m^{2}y. This performance level was assumed as the target of the retrofit action that has been developed by assessing the effectiveness of the different technological solutions adopted. This methodology and simulation set are going to be used for a further development of the retrofitting solution that foresees the use of pre-fab wood panels.

Keywords: retrofitting; volumetric additions; energy savings; quality; housing renovation

1. Starting position and objectives of the research

With the Directives 2010/31/EU and 2012/27/EU, the European Parliament and the EU Council promoted a wide range of improvements in the energy performance of buildings within the EU, proposing a methodology that takes into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. Specific targets are provided for new constructions and existing buildings. In order to meet these targets and exploit the construction sector growth and employment opportunities (including the production of construction components, services rendered by professional studios of architecture and engineering), the Member States are required to establish a long-term beyond 2020 strategy for pushing investment in the renovation of residential and commercial buildings. This intervention strategy should address significant cost-effective renovations leading to refurbishments that can reduce both the supplied and final energy consumption of a building by a significant percentage when compared with the pre-renovation levels, therefore resulting in a very high level of energy performance. Such renovations could also

be carried out in different stages. Since the existing residential building stock represents the single biggest potential sector for energy savings, not only for its dimension and widespread presence on the territory, but also for its related behavioural implications, the expectation of the EU is that the rate of renovation interventions are going to increase in the very near future.
The housing sector plays a key role in this field and several research programs [1] dealt with the sustainable renovation and energy efficiency improvement of the existing stock erected between the '60s and '90s, covering over 65% of the urban fabric of several European cities. This stock is affected by relevant technological obsolescence (both physiological and functional), furthermore, at EU level, the annual consumption per m^2 for residential buildings is around 200 kWh/m^2. Additionally, a large number of these buildings has resulted not suitable for meeting the ever changing needs of todays families and their lifestyle.
This paper presents a synthesis of some results of an on-going national research program, carried out at the University of Bologna, Department of Architecture, focusing on sustainable renovation processes and effective solutions to increase the energy efficiency of the existing housing stock [2]. Based on the significant demand, on a national scale, for high quality residential units – which, following the financial crisis of 2008, is very hard to meet – the research program investigated the impact of volumetric additions to existing buildings in terms of densification.
Starting from a theoretical matrix of strategies for volumetric additions [3;4], this research studied specific topics concerning the re-dimensioning of the units, and increase in energy efficiency and the installation of equipment applying them on some case studies involving Italian residential buildings.
In order to make effective and sustainable the process of retrofitting (not only in financial terms), some topics of strategic importance are pointed out:

- A reduction in operating energy demand;
- Meeting the need for new space arrangement and level of quality;
- An introduction of passive or active solutions to exploit renewable sources;
- The optimization of the energy balance.

All of the above are considered strategic factors in the definition of the design approach for interventions and in addressing the methodology.

2. Research methodology

The research mainly considered multi-family housing (as they represent the greatest part of the residential stock in modern city) and selected several case studies, located in the main Italian and European cities, built from 60's to 90's, in order to obtain an index of the construction techniques originally adopted and a diagnostic analysis of the main pathologies and damages. Following the collection and analysis of the data, a synthesis of the most recurring obsolescence phenomena were associated to the distinctive construction characteristics of each typology [5]. Subsequently, the research focused on the Italian situation with the aim to offer effective design solutions capable of supporting renovation initiatives which – in the current economic climate – seem to be the only viable strategy to meet the housing demand and the increasing request for energy savings measures.
The methodological approach, proposed by the Research Unit of UNIBO, focuses on a step by step retrofitting strategy, to be tested on several case studies, with the aim to reduce the current very high energy demand to a value of at least 15 kWh/m^2y. This performance level is assumed as the target of the retrofitting action that was developed by assessing the effectiveness of the different technological solutions adopted. The methodology foresees the following steps:

- A definition of the simulation models;
- A definition of boundaries conditions;
- A definition of pathologies;
- A definition of renovation targets;
- An intervention scenario;
- An evaluation of the technological choices;
- An assessment of performances.

2.1 Definition of simulation models and boundaries conditions

The main typology adopted in Italian cities for multi-family housing is the one based on a concrete

skeleton with brick blocks closures, narrowly followed by concrete pre-fab panel systems or ones made on site. In order to test the performance of several technological solutions, aiming at drastically reducing energy consumption through a retrofitting action, some simulation models – one for each recurring typology – were set up for the definition of the specific deficit and lack of performance to create the foundation for the further steps of the analysis. In this way, different solutions can be compared (starting from the same basic conditions and targeting the same level of performance) and specific topics can be evaluated. In this paper the model referring to the most recurring typology is described.
Starting conditions were set as follows: the bearing structure is a reinforced concrete skeleton made of 25 x 25 cm pillars with a distance of 4 meters (which can be considered the facade module) and of lightweight concrete slabs with a thickness of 20 cm with reinforced concrete edge and internal beams. The building is assumed to be seven floors, including the ground floor; each floor is 9 Mt in depth and 2.70 Mt in height. Part of the floor slabs extends outside the edge beam in order to obtain the structural support for the terraces. Railings are made of pre-fab concrete panels.
The vertical closure (between the concrete pillars) is assumed to be for the first 1/2 in a double wall of brick blocks with different thickness plastered on both sides. The thermal insulation is provided by a polystyrene panel 3 cm thick between the two bricklayers. The remaining 1/2 of the module is a ceiling to floor clear wall. The windows are assumed to be of wood and single glass. The overall estimated thermal transmittance coefficient of 5.25 W/m^{2}K is well above the values established by law. Doors and windows, even when dealing with very large surfaces, have no protection against solar radiation. The roof slab is insulated (12 cm), protected by a waterproof membrane and covered by a metal sheet coat.
The heating system is assumed to be replaced with a new one in order to provide a more efficient behaviour and avoid heat losses deriving from a non insulated distribution system.
Even though many differences may be present, most of the typological, technological and construction experiments characterizing the recent history of the Italian building sector can be recognized in this model. The model allows to test different layouts for residential units of 45-70-90 m^2 considered the typical measurements of that period. The presented case is one of 70 m^2, with two units on each floor accessed through a staircase. The building is north south oriented and the layout foresees the living room and kitchen facing south side and the bedrooms facing north. The building is located in Bologna and the climate conditions assumed as boundaries for simulations are summarized in table 1.

Table 1: Conditions assumed as boundaries for simulations.

Geographical data			
place	altitude	latitude	longitude
Bologna (BO)	54 m	44°29'	11°20'
Thermal data			
Reference outside temperature: -5,0 °C			
Degree day: 2259		Climatic area: E	
Average heating period temperature: 7,3 °C		Average solar radiation on an horizontal plane during the heating period: 7,92 MJ/m^2	
Summer data			
Mounth of max solar radiation: July		Average monthly summer max temperature: 25,4 °C	
Summer max temperature: 33,0 °C		Difference in temperature during the hottest day: 12,0 °C	
Solar radiation on an horizontal plane during the month of max daylight exposure: 296,19 W/m²			

2.2 Deficits detected and retrofitting targets

The model reflects the high energy losses affecting most part of the existing building stock due to the construction system originally adopted: several thermal bridges are detected between the bearing structure and the building closures especially in correspondence of the terraces. Furthermore most part of these losses are due to a poor quality of glazing and frames. According to the starting conditions set, the primary energy demand is calculated in 160 kWh/m^{2}y (134 kWh/m^{2}y for heating and 26 kWh/m^{2}y for hot water production).
The quality of the units finishing, doors and windows and systems is quite poor. The poor indoor

conditions are related to the low quality of insulation and to a lack of any suitable climate control device. In addition to the above the related operating costs are very high. The current economical crisis does not favour a replacement of the existing buildings with new ones; consequently the only feasible solution seems to be a renovation intervention, also in terms of volume densification, to upgrade the building and limit costs. This solution seems to be the one more readily accessible to small and medium households.
Initial costs and running costs of the different strategies should be taken into consideration during the design activity, since the energy and financial aspects are strictly connected: a high energy performance solution usually needs higher investments, but savings generated during the life cycle are enough to repay the amount invested.
Consequently, the possible solutions analyzed take into consideration the savings generated in the long term, highlighting the economical sustainability of the intervention, in reference to an expected period of time. The main goals of the proposed renovation strategy can be summarized as follows:

- a reduction of operating energy demand by implementing the building envelope;
- an upgrade of the size and the dimensions of the units;
- a densification of the building as a whole;
- an introduction of passive solutions to improve indoor comfort;
- an integration of active solutions to exploit renewable sources;
- an introduction of a lift for each stair case;
- an optimization of technological choices to reduce energy investments
- a construction within budget.

Some supporting initiatives have been promoted in Italy at local and regional level with the aim to encouraging private investments for renovation and refurbishment actions. Unfortunately, the results are far from the expected ones since no planning activities have been put in place.

3. Renovation scenario

A renovation intervention should have an impact on two main aspects: first of all a reduction in the current energy demand in order to obtain a more sustainable behaviour of the building and a drastic decrease in operating costs, and then an upgrading of the units layout and dimensions to meet the new needs. Both of these could be achieved without having to move the residents out by reducing the impact of the intervention inside the unit and the building as a whole.
The analyses performed on the model showed that most of the heat loss occurs through the building envelope. Therefore, during the first stage of this research, a new insulation layer on the façades and a replacement of the windows were considered.
However, this conventional approach doesn't represent an effective answer to all the needs and doesn't offer any economic advantage since a relevant part of the costs are still due to the construction phase. Consequently a different approach was adopted [6; 7].

3.1 Intervention concept

In order to increase the performance of the building envelope and obtain additional surface for the units, two additions (1.40 Mt in depth) were introduced on both the main façades (see fig. 1). This strategy involves all the façade, allowing to introduce an addition on each floor and providing a simple structural solution.
On the north side this volumetric addition offers the opportunity to enlarge a single room to a double one and to provide a new bathroom for the existing double room. The loss of the terrace is balanced by the introduction of a new lodge.
The priority on the north side is to strongly reduce heat losses and for this reason the size of the windows of the added volume has been reduced when compared to the original ones (from 150x150 cm or 70x220 cm to 70x150 cm). Insulation is provided through the implementation of the envelope and the existing walls are transformed in internal partitions.
High performance insulation solutions are needed for the winter period, while a more complex behaviour of the envelope is required during summer time, when the main problem is reducing the heat indoors deriving from solar radiation. On the south side, the addition acts as a large lodge with an openable glass working as a greenhouse during the winter maximizing passive solar gains. Some PV panels are integrated on this glass envelope in order to obtain from renewable sources

part of energy needed. During the summer, a section of the glass envelope can be opened to favour natural ventilation and the PV panels can be oriented and adjusted to act as shading system. The objective is to minimize the interventions for the modification of the existing space and put all the economic resources and concentrate all efforts in the new volumes that provide new comfortable living spaces at minimum cost and optimize the overall energy performance.
On the south side, a thermal buffer zone is obtained through the addition of a lodge, which can be used as living space during summer and winter garden during the cold season. Furthermore, an additional room can be obtained through the modification of the configuration of the living room and the kitchen with a small increase in the budget.
Additions provide a 25 % increase in the unit surface therefore servicing a higher number of users. Figure 1 shows the main effect of the renovation strategy simulated in the model.

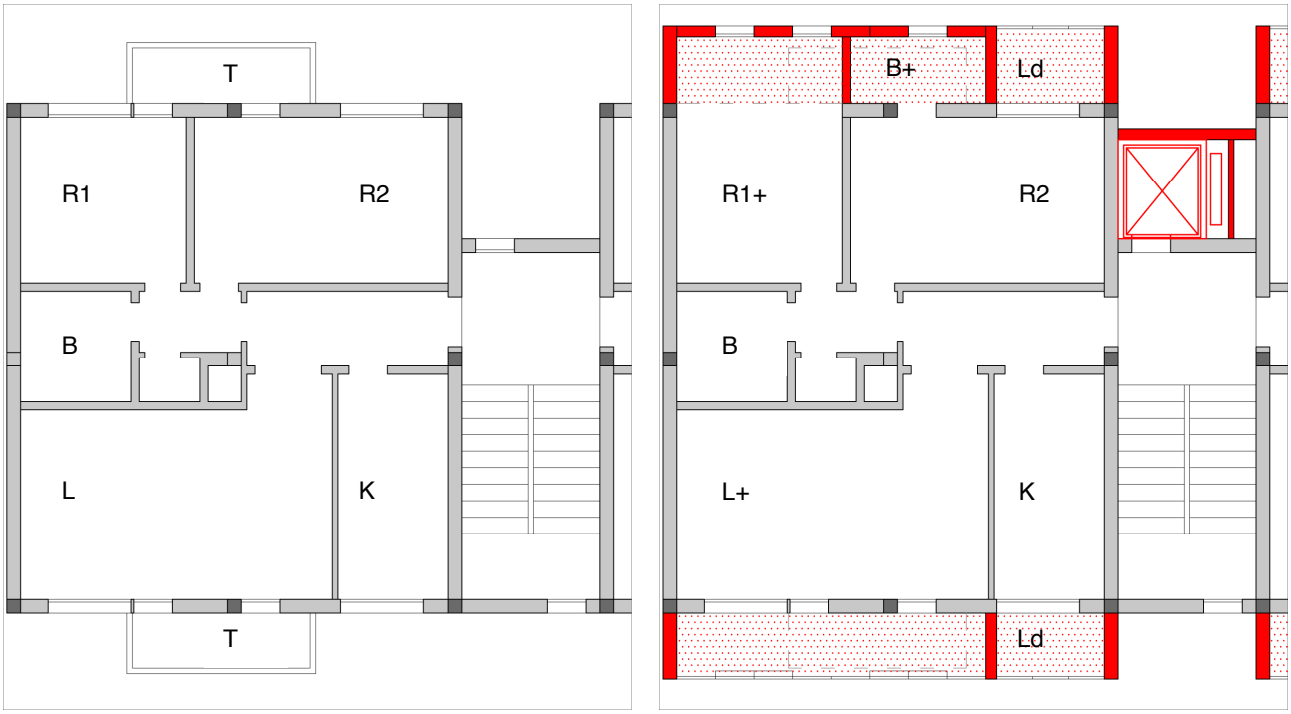


Fig. 1: plan of the typical unit considered in the model. On the left before intervention and on the right after renovation [R1-single room, R2-double room, B-Bathroom, L-Living room, K-Kitchen, T-Terrace, Ld-Lodge, + Addition]

The additions imply a reconfiguration of the main facades (north and south side) and provide a new image to the blocks. In order to increase the quality and the accessibility of the building as a whole, a lift is introduced on each staircase.

3.2 Technological choices and performance evaluation

In order to optimize the energy balance of the renovation action, several technological solutions were evaluated considering also LCA implications. The first requirement was to find a lightweight solution to reduce structural interventions and avoid significant consolidation works on the existing building. In this case the choice favours pre-fab panels of cross laminated timber which are used as support for the additions throughout each façade elevation. A horizontal panel (9.00 meters per 1.20) is used to extend the floor slab: this element is partially supported by the existing terraces slab, and mainly supported by vertical panels extending from the ground floor to the roof. The construction phases foresee a removal of the pre-fab panels, composing the terraces railings and their flooring, and then an installation of the new wood deck and vertical elements to be connected to each other and to the existing structure by steel joints. The vertical wood elements are pre-fab integrating the insulation layer, the condensation and waterproofing membranes as well as the cladding (which can be chosen according to morphological and technological criteria).

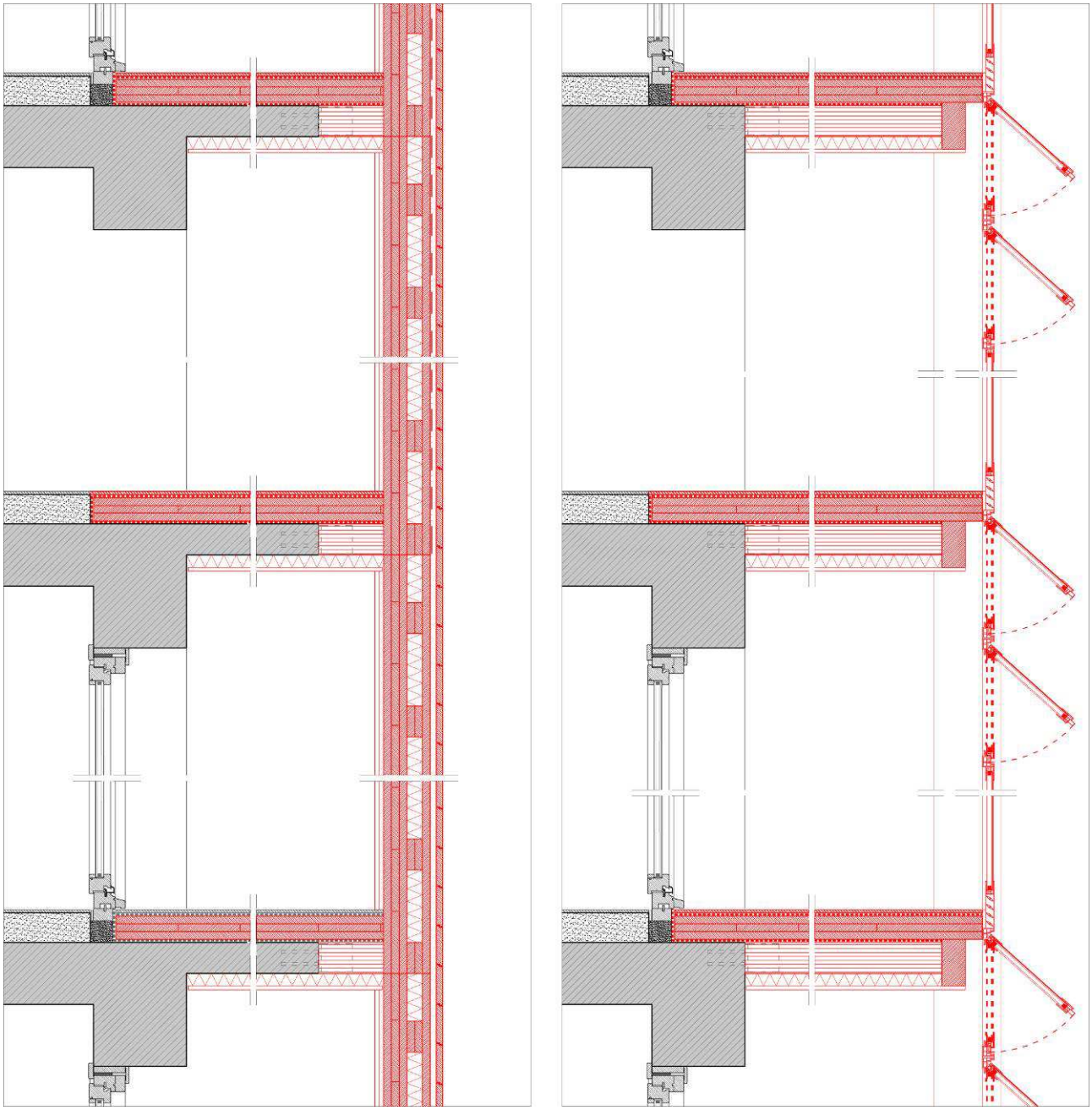


Fig. 2: detailed cross section of the addition on the north (left) and south side (right). The new deck is obtained using cross laminated panels while the vertical elements are pre-fab wood panels with integrated insulation layer. PV elements are installed on the glazing of the south facade to exploit renewable energy sources and provide a shading system, supporting natural ventilation therefore mitigating the indoor conditions during the summer.

This technological choice produces a very high performing envelope, which reaches in its typical section a thermal transmittance value approximately equal to 0.22 W/m^{2}K meeting the requirement of a significant performance increase of the envelope on the north side. The new wooden windows with double-glazing and the glazed modules on the south side reach a transmittance equal to 1.5 W/m^{2}K (the limit by law is 2.2 W/m^{2}K). Despite the reduced weight of the closure and the large glazed surface on the south side, the addition operates as an excellent buffer zone both in summer and winter. Simulation performed on the model showed that during winter the buffer effect and the passive solar gains balance the lower insulation level obtained on the south side while the natural ventilation and the PV shading system offer comfortable conditions during summer.

Despite the fact that few studies have been made on this subject and that no conclusive results are therefore available, the current condition of the existing Italian stock shows that the energy demand for cooling is about 2/3 of the one for heating. Consequently, it is important to provide an effective solution to the building energy needs during summer.
Simulations showed that the proposed interventions allow to significantly reduce dispersions and produce remarkable energy savings. In the analyzed model the existing heat generator is replaced with the new one with the aim to increase the efficiency of the system. Furthermore, the refurbishment action also provides the installation of solar panels for the production of hot water, on the addition roof, in order to reach a final EP index value equal to 15 kWh/m^{2}y, this being the value expected.

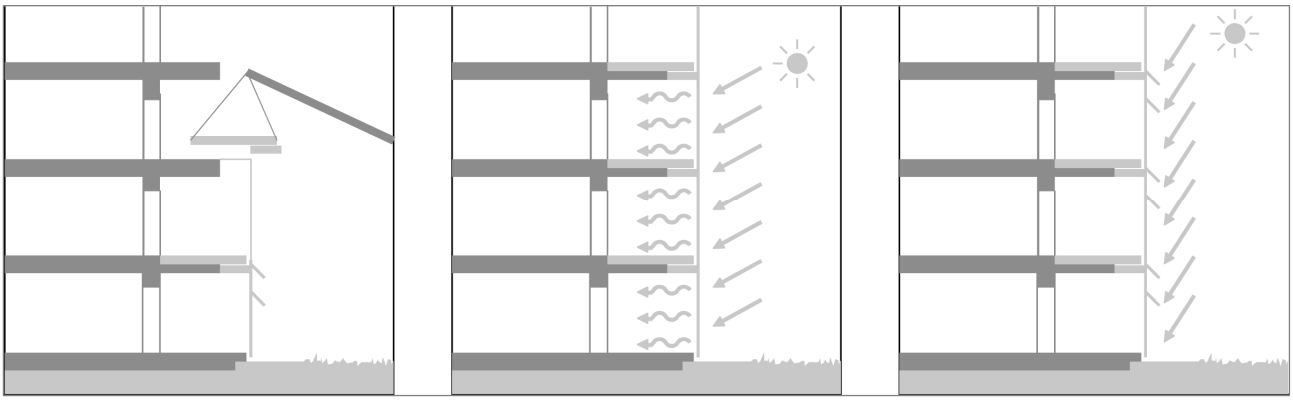


Fig. 3: Pre-fab panels assembled scheme and outline of the behaviour of the addition on the south side during winter (center figure) and summer (on the right).

The advantages of this approach to renovation are not only related to the benefits deriving in terms of energy savings and reduction in operating costs, but also to the optimization of the construction process. The addition can be realized with pre-fab elements ensemble on site without having to move the users out and the very small amount of demolitions and modifications required can be performed in a very short time.
Some further development of the proposed solution, such as the replacement of all the existing windows and radiators and the refurbishment of the building finishing, which would certainly increase the quality and the comfort, have not be considered in this study due to budget constraints. However, the proposed methodology allows to calculate the costs of the possible solutions, by comparing them with the current status.

4. Comments on results

Even if a volumetric addition seems to be much more expensive when compared to an implementation of the building envelope, the scenario proposed above shows a difference of just 9% in terms of construction costs. There is, of course, an additional cost for the new structure, but the choice of using wood elements limits costs in financial terms as well as in energy investments ones. The investment needed for the new glazing is closed to the one needed for the replacement of the original windows, therefore avoiding the need for a much more expensive and complicated solution in terms of insulation of the building envelope. In order to assess the cost effectiveness of the proposed strategy a financial analysis [8] was performed including the initial costs and the energy investment of the solution as well as the energy savings that can be obtained in the expected lifespan. The payback period for the renovation scenario, investigated through the simulation model, is of 12 years.
For what concerns annual management and maintenance costs (which were described in detail in the calculation models) an increase of 3.3% per year (in relation to the Italian trend) is expected while the discount rate was assumed of 5%. The calculation model takes into account a forecast trend in inflation equal to 7% for factors related to energy supplies and costs, as defined by the Electricity and Gas authorities.
A feasibility analysis including a financial evaluation (based on a multicriteria approach and also

including quality and energy issues) seems to be an unavoidable step in the development of any effective and conscious renovation action. The cost/benefit ratio evaluation is an essential tool in order to steer the design phase towards the most effective solution. Therefore sharing the decisional process with the end-users for what concerns the management activities, the functional features and the ordinary use can be a strategic factor to define effective solutions. The evaluation process can also influence the choice of the construction methods and the technological solutions.
From a methodological point of view, the experience tested in the simulation model allowed to point out some fundamental steps for the retrofit actions. The functional program, the typologies and the possible construction systems should be flexible in order to be able to adapt them to the results of the financial evaluation and to ensure a successful results of the project in terms of economic investment, quality improvement, energy savings requirements, environmental standards, etc.
Even if the main goals of the refurbishment are an improvement of the indoor comfort and of the energy performance – by controlling the heat exchange through the envelope – the economic impact of each action initial investment is still one of the first choice criteria potential investors look at. The aim of the proposed methodology and simulation model is a comparison of the costs-benefits ratio for the different solutions.
The simulations run during the research demonstrated the efficiency of the assessment approach even if the results are still affected by a certain degree of uncertainty due to the difficulties in predicting costs, trends of energy costs, tax relief policies and financial aspects.
The obtained results and the adaptable character of the methodology proposed encourage to continue this research through a further development of the proposed technological solution in collaboration with some companies specialized in the production of multi-layer wood panels, pre-fab and customized that can be adapted to the different requirements of the building.
Once the basic components for the construction system are defined further test will be carried out in order to check the actual performances. Therefore the objective is to find a cost-effective and high performance solution.
In conclusion, this research focuses mainly on a series of comparison of different solutions, in terms of an assessment of the cost-benefits ratio.

5. References

[1] DI GIULIO R (edited by), "*Improving the quality of suburban building stock*", Faculty for the built environment, University of Malta, Malta, 2010.

[2] BOERI A, LONGO D, "*Eco-technologies for energy efficient buildings in Italy*", in HERNANDEZ S, BREBBIA C A. DE WILDE W P (edited by), "*ECO-Architecture III-Harmonisation Between Architecture and Nature*", WIT Press, Southampton, 2010.

[3] GASPARI J, "*Architectural and technological additions as strategies to improve urban quality in refurbishment actions*" in DI GIULIO R, (edited by) "*Improving the quality of suburban building stock. Improving the quality of suburban building stock*" - COST ACTION TU0701 international final conference. Ferrara, Unifepress, 2012, vol. 1, pp. 413 – 419.

[4] SIMON P, "*Additions d'architecture*", Pavillon de l'Arsenal, Paris, 1996.

[5] BOERI A, LONGO D, "*High density suburbs redevelopment and social housing retrofitting for cities regeneration*" in BREBBIA C A, PACETTI M, PASSERINI G, LATINI G, "*Sustainable City VII - Urban Regeneration and Sustainability*", Southampton, WIT Press, 2012, pp. 133 – 144.

[6] FORSTER S, "*Radical conversion instead of demolition – from prefabricated panel construction to garden city*", Detail 7/2000.

[7] JØRGENSEN O B, "*Flexren, flexible façade system for energy conscious renovation of European houses*". In *Northsun 2001 Technology meets market in the solar age Proceedings*, Leiden, 2001.

[8] BROWN G, MATYSIAK G, "*Real estate investment, a capital market approach*", FT: Prentice Hall, London, 2000.

A6

Demonstration projects considering new technologies and innovative concepts in rehabilitation of large-volume buildings

Chair: Katharina Kowalski
Federal Ministry of Agriculture and Forestry, Environment and Water Management, Austria

Comparative analysis for the refurbishment of the high-rise concrete building stock based on life cycle assessment scenarios



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Short Summary

The **prefabricated reinforced concrete large-panel construction** method was spreading throughout Europe during the reconstruction work following the World War II in order to decrease the general housing shortage. During the 1970s and 1980s, altogether 510.000 flats of this type were built throughout Hungary, therefore their refurbishment is inevitable and urgent.

This study focuses on **the environmental optimisation of the retrofit** of the existing precast large-panel building stock in Hungary providing **a decision support tool** for the architectural design process by identifying the largest environmental impacts and optimizing the design. During the research a **comparative analysis** was developed for the refurbishment possibilities of existing buildings based on Life Cycle Assessment that studies the environmental aspects and potential impacts throughout the building's lifetime. Different refurbishment scenarios were studied in order to compare their relative environmental impacts.

The **typology of the precast large-panel building stock** was set up by grouping buildings according to their age, architectural and technical parameters. After assessing the environmental performance of the determined types the mitigation potential of the building stock was estimated. The analysis focuses on the most common impact categories generally applied for buildings e.g. the cumulative energy demand, the global warming potential, and the acidification, eutrophication and ozone depletion potential**. Normalization** was applied to understand the relative significance of the impact category results.

The methodology is demonstrated on **a case study area**: the Kelenföld housing estate in Budapest (Hungary) built in 1968-74 was chosen for the analysis and after assessing the environmental performance of the determined types the mitigation potential of the housing estate is estimated.

Keywords: life cycle assessment; scenarios for refurbishment; life time; concrete building; building typology

1. Introduction

The European Union has recently confirmed its commitment towards a sustainable future by adopting the 20-20-20 target: reducing the greenhouse gas emissions at least 20% below 1990 levels, reducing energy consumption by 20% and increasing the share of energy from renewable resources to 20% by 2020. The energy consumption of the building sector is significant all over Europe, accounting for around 40% of the energy consumption in the EU providing a great potential for cost-effective energy savings. There are more options to reduce the energy consumption in case of new buildings but the **sustainable refurbishment of the existing building stock** is an urgent task.
The goal of sustainable rehabilitation is the modernization of the existing building stock meeting the demands of present times and focusing on technical and ecological aspects at the same time, as well as the lengthening of their life-span and the conservation of built heritage. Besides the aesthetical and economical questions, energy efficiency and environmental impacts are important factors of decision making about the retrofitting of an existing building. Life Cycle Assessment (LCA) provides a scientifically sound solution for optimising the environmental performance of building.
The **reinforced concrete precast large panel construction** method was spreading throughout Europe during the reconstruction wave following the World War II in order to decrease the general housing shortage. Today their overall refurbishment is inevitable and urgent. The main problem this building stock presents is that the operational energy use is extremely high, due to design, constructional and structural errors. This paper deals with the question 'What makes the existing reinforced concrete high-rise building stock sustainable in the long term?'.

2. The existing building stock

In Hungary the first initiatives of the prefabricated reinforced concrete large-panel construction method were carried out in 1954, later in 1966, and the large-scale "production" of large wall panel blocks became possible. During the following decades, about 30-35,000 flats were built annually. Altogether 510,000 flats of this type were built throughout the country (nowadays appr. 13.5% of the people live in these high-rise buildings).

Since the primary aspect of designing these so called 'panel buildings' was the large number of production therefore many uniform features can be recognized concerning the geometry and the materials. The typical height of the large-panels is 2.80-2.85m (result in 2.65m headroom), the width of the panels was changed during construction period, in the beginning 2.70m and 3.6m were representative and later the 5.4m width was spread but more types of panels were applied in a single building. Considering the economical requirements of that period, mainly four and ten storey-high blocks were built, in the form of housing estates. The size of windows and architectural form of balconies and loggias were uniformed also.

There are not adequate statistical data available about the determined types of panel building stock but according to their age: almost the 55% of these prefabricated reinforced concrete large-panel buildings were built before 1979. The **typology of the precast large-panel building stock** was set up by grouping buildings according to their age, architectural and technical parameters: the most frequent types based on expert judgements are the detached building with almost a square shape, the 'terraced panel buildings' with more narrow or wide strip blocks and the 'H' shaped multi storey buildings the so called 'building with ears' with internal staircase [1], see Figure 1. Several subtypes can be determined but in this study 3 typical types of **the Kelenföld housing estate** in Budapest were chosen for analysis and after assessing the environmental performance of the determined types the mitigation potential of the housing estate are estimated.

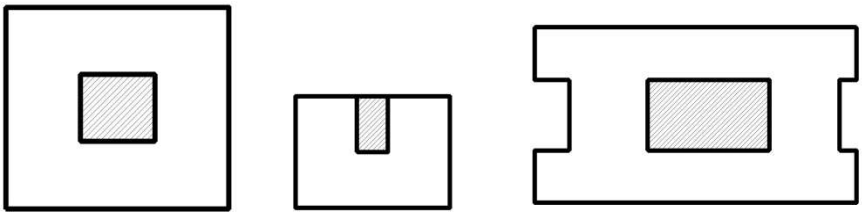


Figure 1: the sketch of the floorplan of the building types (the grey area is the staircase and the corridor) in order: detached building, terraced panel building and 'building with ears'.

3. The environmental evaluation of building refurbishment

During the research **a methodology was developed** for the analysis of the refurbishment options of prefabricated concrete buildings in order to reduce their impact on the environment. The method is based on **Life Cycle Assessment (LCA)** that studies the environmental aspects and potential impacts throughout a building's life from raw material acquisition through production and operation to disposal. A comparative analysis was developed: different refurbishment options were studied in order to compare their relative environmental impacts. The methodology is demonstrated on a case study.

4. Case study area: Kelenföld housing estate

The Kelenföld housing estate in Budapest can be considered to be one of the first realised results of prefabricated panels construction in Hungary, which was developed in the capital between 1966-75, mainly 10-storey, multi-storey, strip blocks with sections consisting of three or six flats of staircases among them 15-storey high-rise buildings, 1 or 2-storey service buildings were attached to the blocks. One of the largest housing estates of this type in Budapest consists of altogether 53 construction blocks roughly with some 8500 flats, that means the homes of about 20.000-25.000 citizens.

The analysed buildings are: the 'terraced panel building' erected in the beginning of this industrialized period, the 'H' shaped building with 6 flats per storey (the code is 'Kf10') and the 'A10' building with 10 flats per storey. All these buildings are 10-11 storey high and widely spread not only in the analysed housing estate but in the whole country.



Figure 2-4. Three typical prefabricated reinforced concrete large-panel buildings in Hungary: building codes in order: terraced panel building, A10 and Kf10.

4.1 General description of the building constructions

The analysed apartment houses were built from 1968 to 1972 by the first Hungarian Construction Factory according to the original Soviet technology located in the Kelenföld housing estate, in Budapest.
Regarding **the building constructions and the building materials**: the one-storey high reinforced concrete wall or floor panels are welded on their edges and assembled by fixing and concreting on the site in order to realise their box-structure, therefore the weak points of the

structure are mostly the **joints**. Considerable attention should be paid to both satisfactory joint sealing (heat-insulation and waterproofing) and the protection against corrosion of joining reinforcing bars.
Outside perimeter wall panels with built-in insulation are made of sandwich-structure: reinforced concrete elements with polystyrene thermal insulation. The thickness of the thermal insulation in the sandwich-panels decreased to 2 cm at the joints resulting in extreme thermal bridge losses on the façade (see Figure 5).

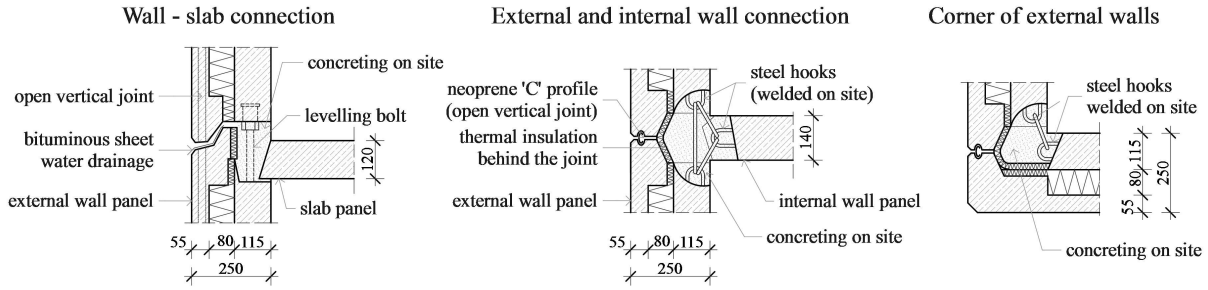


Figure 5: General details of the external panel connections (based on [2])

In the Kelenföld housing-estates a double-shell (ventilated) cold roof covered by bitumen membrane water proofing was generally applied with a low-insulation level, and lots of drainage problem nowadays.
The original wooden windows had obsolete construction, with very poor insulation capacity and high filtration rate. In most cases they were made with reveal shape and installed without any external shading devices.
Regarding **the building services** district heating systems with no possibility of local control were usual until the middle eighties. The heating systems are often unbalanced, resulting in overheating and under heating in different flats of the same building at the same time.

4.2 Methodology

This study focuses on the environmental optimisation of the retrofit of the existing precast large-panel buildings in Kelenföld housing estate. This method provides a **decision support tool** for the architectural design process by identifying the largest environmental impacts and optimizing the design of the refurbishment. The method of life cycle assessment (LCA) was applied, following the norms ISO 14040 [3] and ISO 14044 [4].

The main goal of the study was to evaluate the environmental impacts of the refurbishment of three typical existing high-rise large panel residential buildings in Hungary and the contribution of the different life cycle phases of refurbishment, maintenance, operation and disposal. Seven different scenarios are compared to support the decision making.

The **functional unit** was a high-rise prefabricated reinforced concrete apartment building in Budapest (Hungary) to provide housing for 100 additional years. An **Excel-based tool** was developed for the analysis and the calculations are based on real building documentations.
The reference **inventory database** used for the assessment in this study was the Ecoinvent v2.0 database by the Swiss Ecoinvent Centre, which contains high-quality inventory data of more than 2,500 products and services [5]. Since the sources of this database are mainly the Swiss and German industry the building materials produced in Hungary required certain modifications. The composition of the Swiss and the Hungarian electricity mix differs significantly; hence these modules were changed accordingly. The buildings erected by industrialized technology in Hungary are supplied particularly with district heating, and based on the data given by FŐTÁV (the district heating company of Budapest), the district heating mix of the assessed area was composed. For products absent from the database new datasets were developed based on the material composition [6].

During the research the **non-renewable cumulative energy demand** method the **CML method**

was used to assess the environmental impacts, both are internationally accepted and widely used. The whole remaining life cycle of buildings was considered. The **life cycle was divided into five phases:** production, operation, maintenance, retrofit and disposal.

During the production phase, the **construction** of the building requires energy and building materials transported to the site. In this study 15 MJ/m2 of diesel and 2 kWh/m2 of electricity were assumed for the construction based on the ecoinvent data. Based on the building geometry and composition of the building elements, the built-in weight and the embodied energy of the materials was calculated with an average 5% mass added to account for construction waste.
In the **operation phase**, the energy demand of the building service systems was assessed according to the Hungarian building energy calculation method [7] based on the Energy Performance of Buildings Directive [8]. The user-related components of the energy demand (e.g. the air change rate, internal gains and domestic hot water need) are defined in the Hungarian Government Decree on the energy performance of buildings. The annual energy demand for lighting was neglected, as it is allowed by the regulation in case of residential buildings. The **gross energy demand** including the efficiency and losses of the systems was calculated using the tabulated values of the Decree [7].
Maintenance activities involve small repairs and periodic replacement of building elements and service systems based on their expected life-span, this includes the production of the new elements. No modernisation, thermal performance upgrade or major rebuild, enlargement, conversion etc. were considered during the maintenance phase. For the maintenance works 1 kWh/m2 electricity was assumed. The values for the life-span of the building elements were estimated based on the literature sources [9][10][11].
The **retrofit phase** includes a comprehensive refurbishment reducing the operational energy need for the remaining prolonged lifetime. The phase includes the transport of the new building materials to the site (e.g. the new windows) and the transport of the replaced old elements to final disposal (e.g. the old windows), the production and installation of the new materials and the disposal of the exchanged building structures.
The last life cycle phase includes the **disposal** of the replaced building materials in the maintenance phase and the demolition of the building at the end of the effective life, separation, transport and processing of materials according to their end of life scenario and re-cultivation of the deposit site. For the demolition process itself, 30 MJ/m2 of diesel was calculated based on the ecoinvent data.

According to the literature, **the physical lifetime of large-panel buildings** is assumed to be between 80-120 years in Eastern Europe [1]. The expected lifetime of the building constructions and building service systems are not fundamentally different from traditional building elements. In this study the expected life time of a large-panel building is 80 years.
The case study buildings were built in 1968-72, so in the analysed moment these are 40-45 years old (rounding to 40 years), so the remaining life time is 40 years more.
It is assumed that the retrofit (especially the thermal insulation of the external walls) is expected **to increase the remaining life span of the building.** Due to the additional thermal insulation, the expansion of the external reinforced concrete layer of the sandwich panels' decreases, and the joints between the panel elements are completely hidden eliminating the possibility of moisture penetration. By the new thermal insulation boards on the façade the thermal bridge effect caused by the lower thickness of thermal insulation in the external panel joints is eliminated. Therefore the risk of internal condensation is reduced. Thus, due to the retrofit we assumed that **the expected life time of the building increases** by 20 years (20%).

The scenarios proposed for the retrofit to be compared, in case of a 40 year-old large-panel building:

- *No overall renovation:* retaining the current building in its current state, only maintenance work is done. The demolition is due at the end of the expected life time, in 40 years, when a new building will be erected with lower energy consumption.
- *Retrofit:* undertaking a comprehensive refurbishment, therefore the operational energy need is reduced for the remaining lifetime, the renovation prolongs the life time of the building, hence

the demolition and the erection of a new building is delayed. The different levels of possible refurbishment in point of the energy performance:

- retrofit 1: to achieve the current energy performance regulations in Hungary;
- retrofit 2: increased thermal insulation level of the building envelope;
- retrofit 3: increased thermal insulation level with upgrading the existing heating system and installing heat recovery ventilation;
- retrofit 4: retrofit 3 complemented by installing flat-plate solar collectors on the flat roof.

After 60 years, at the end of life, the renovated building will be demolished and a new one will be erected. Due to the increasingly stringent international regulations on energy performance it is assumed that the erected new one will have 40% lower energy consumption than the 'new building 2' scenario.

- *Demolition followed by the erection of a new building:* demolishing and constructing a new building (of the same shape, of the same size). Two different levels regarding the energy performance were considered:
  - new building 1: high-level thermal insulation and windows with gas heating system and heat recovery ventilation ('A' category)
  - new building 2: high-level thermal insulation and windows, heat recovery ventilation with solar energy use ('A++' category)

The long-term thinking suggests including **the embodied energy of every building component in the calculation,** not only the envelope. Those elements do not influence the operational energy consumption directly, but they account for a significant section of the embodied environmental impacts, especially in case of multi-storey buildings [6].

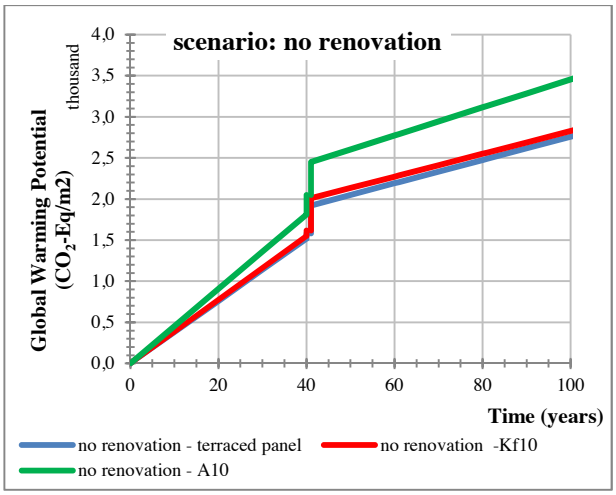
4.3 Results

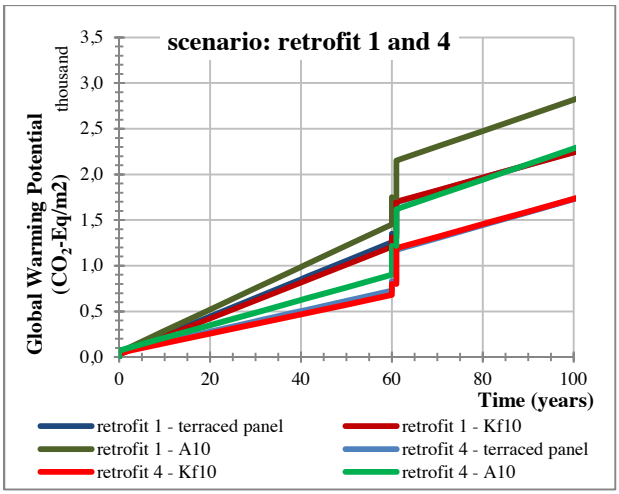
LCA professionals use different impact assessment methods, with several **environmental indicators**. In this study, beside the **non-renewable cumulative energy demand** the **CML method** was used to assess the environmental impacts. The used CML categories were: the global warming potential, 100 a (GWP), the acidification potential, average European (AP), the ozone depletion potential, steady state (ODP) and the eutrophication, generic (EP).

Normalization, an optional step of life cycle assessment was applied to understand the relative significance of the impact category results. In accordance with EN ISO 14044, normalisation is the calculation of the magnitude of the category indicator results relative to reference information. The obtained results of the impact categories are converted to common units; therefore the relative significance of the category results can be compared. In this study, the reference values (normalisation factors) given by Guinée were used referring to the intervention in Western Europe in 1995 [12].

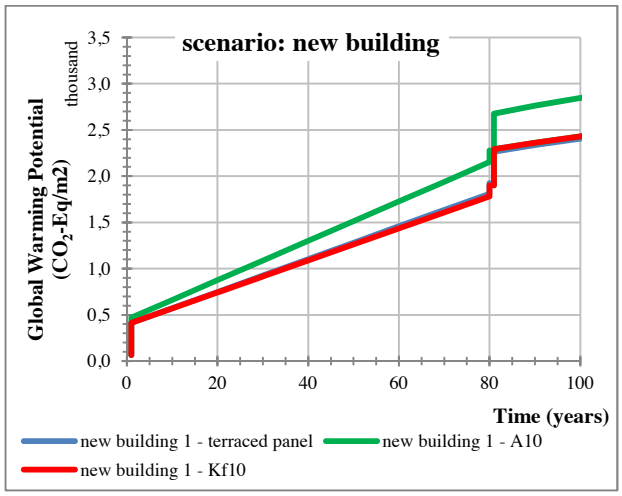
All normalization figures of the 'terraced panel building' (of all the other retrofit scenarios) show that buildings have the most significant contribution in the category of global warming (GWP) and also the acidification potential (AP) is relevant, but the contribution is less than half of the GWP. The normalised ozone depletion and eutrophication caused by the retrofit are insignificant.

According to the results of normalization in this paper the **global warming potential**, as the most significant environmental indicator is demonstrated in more detail. Figure 6-7. and 8 show below the global warming potential of the most significant scenarios of all the analysed buildings, referring to one year and to one square metre of floor area as a function of time.





Figures 6-7: The global warming potential of the three analysed buildings in case of 'no renovation' and 'retrofit 1 and 4' scenarios



Figures 8: The global warming potential of the three analysed buildings in case of demolition followed by the erection of a new building

As the figures above show the results of each scenarios are similar the difference is around 20%, the terraced panel building and the Kf10 building are almost the same only the A10 building differs. In this study the results of 'Kf10' building will be reviewed.

Figure 9 shows that **for the first 2-3 years** after the decision point, the 'no overall renovation' scenario seems to be the best decision. However, after this time, all retrofit options have a lower environmental impact.
Until year 60 after the decision point, the 'retrofit 4' scenario has the lowest global warming potential, which is the high level retrofit of the existing large-panel building. At that moment the retrofitted building will be demolished and a new one will be erected but with a lower energy consumption and lower global warming impact, since many emissions are directly linked to the energy use.
The **steps of the designed 'retrofit 4' scenario are:** increased thermal insulation of the external building envelope (16 cm polystyrene on the external wall, 10 cm wood wool insulation on the basement floor and 24 cm polystyrene on the flat roof); the change of the existing wooden windows in the flats and the staircase for multi-chambered PVC thermally efficient windows with low-e glazing (u=1.1 W/m^{2}K) and the installation of new metal main entrance doors (u=1.1 W/m^{2}K). To avoid thermal bridge effects the insulation of the parapet walls of the loggias, balcony slabs, plinths, and the attic walls will be carried out. Finally in the course of the modernization of the

building services thermostatic valves are fixed to the radiators in the flats in order to be able to control the heat flow and mechanical ventilation is implemented with heat recovery (70% efficiency) completed by flat plate solar collectors installed on the roof (app. 2,0m^2/apartment) and the necessary puffer water tanks in the basement.

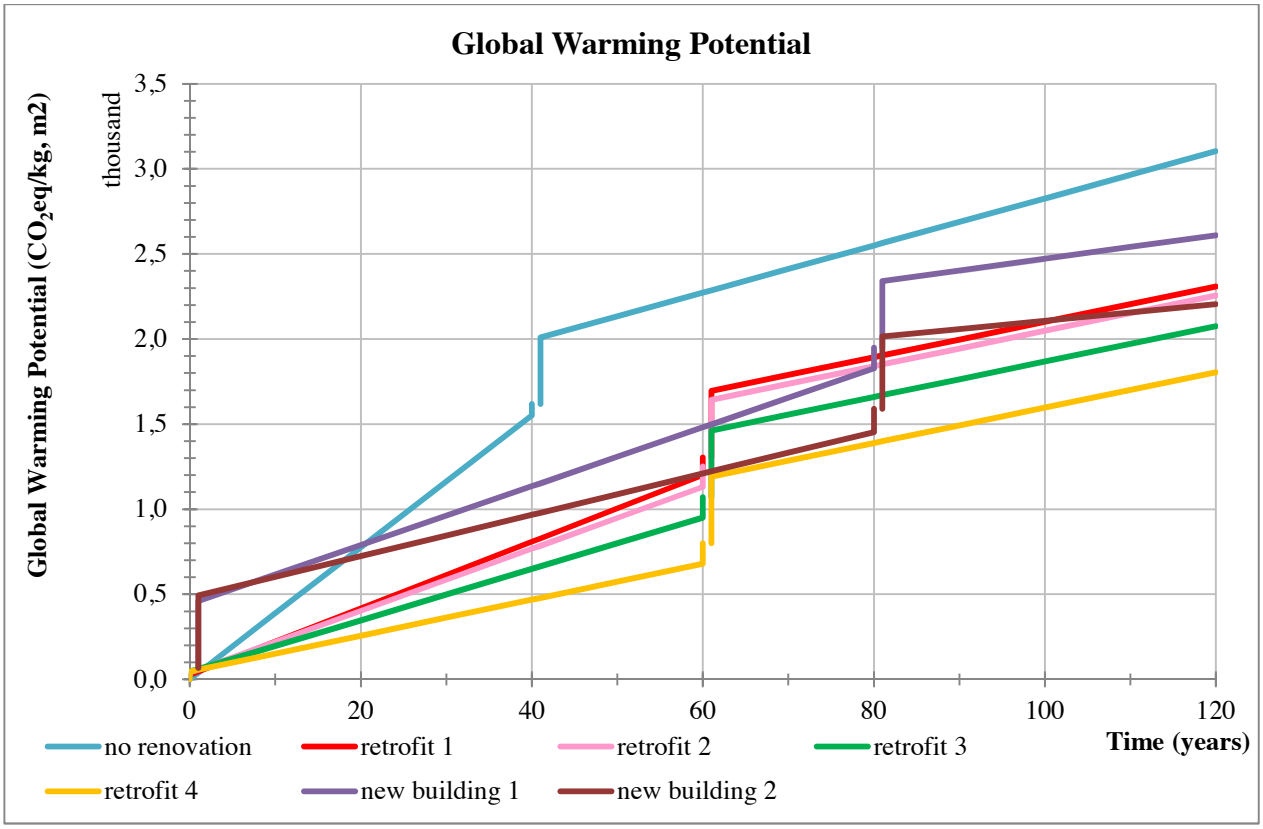


Figure 9: The global warming potential of all the alternatives in case of 'Kf10' building

Analysing **the longer term – 60 to 80 years –** due to the high level of uncertainty in the energy mix and the future regulations about the energy performance of buildings it is difficult to decide whether the immediate demolition of the building and the construction of a new low-energy building (scenario: new building 2) or the retrofit 4 scenario has the lowest life cycle CO_2 eq emission.

The same tendencies can be observed in case of the **ozone depletion potential** of the alternatives, consequently the operation phase is dominant. The 'retrofit 3' and 'retrofit 4' scenarios have the lowest ozone depletion potential during the assessed period of time.
Regarding the **acidification potential**, the production phase is more significant than from the point of view of CED and GWP: the construction of a new building is around 28-31% of the total emission. All retrofit scenarios have lower acidification impact than the new building scenarios.

Similarly to AP, the production phase of the new building scenarios is relatively dominant in the category of the **eutrophication potential**. Production phase of the new buildings is 34-35 % of the life cycle impacts. The **cumulative energy demand** is suitable as a screening indicator in the environmental assessment of buildings. Since the burning of fossil fuels is dominant in greenhouse gas emissions, and the analysed buildings are heated by district heating based on natural gas in the Kelenföld housing estate, the CED and GWP values were highly correlated in this assessment also. The relatively high significance of the end-of-life phase is remarkable; it is around 17-18% of the total.

Altogether 23 of the 'terraced panel buildings' mentioned above are located at Kelenföld housing estate, generally built with 3-4 narrow strip blocks each and some with wide blocks. The number of the so called 'building with legs' (code: A10) is significant, altogether 12 buildings. In addition 3 more 'Kf10' buildings are located around the park in the middle of the area. Altogether there is

approximately 280,000 m^2 area of flats at this residential area.

From the results of the individual buildings the total energy saving and the mitigation potential of the housing estate can be calculated taking into account the number of building types per district.
The **global warming mitigation potential** of the analysed area is 5,2 ktons CO_2 equivalent per year. In average the mitigation potential is 44.4 % that would be achievable if the buildings were upgraded to fit the requirements of the current building code (retrofit 1 scenario). In case the existing large panel buildings were be retrofitted according to the retrofit 4 scenario the decrease of global warming potential would be 64.6%.
Since the energy mix of the district heating is based on fossil fuels the **non-renewable cumulative energy demand and the ozone depletion potential** are quite similar to the global warming indicator.
Concerning the **eutrophication and the acidification potential** the decrease is lower approximately 26.6-26.7% in case of general retrofit measures (retrofit 1) but there is not significant change if the retrofit 4, the high-level refurbishment were taken into account (24.6-27.3%).

5. Conclusions

For energy efficient retrofit, the payback time is usually calculated on the basis of the investment and the savings. But when the question is whether a retrofit is worth doing or not, all relevant aspects have to be considered, not only the payback time.
The 'no overall renovation' scenario has the lowest life cycle CO_2 eq emission in the first 2-3 years, but after this time the retrofit options have a lower global warming potential: the energy and the environmental impact invested into the retrofit is quickly recouped. The **comprehensive retrofit is the most environmental friendly option until about 60 years**, when the renovated building reaches the end of its expected life time. In an even longer term (60-80 years), as it is difficult to predict the future regulations about the energy performance of buildings and the possible changes of the building materials in the long term, there is an increasing uncertainty involved in the assessment.

The analysed time period depends on the decision makers. Investors are generally interested in the very short term. The government or the local governments are able to think 10 to 15 years into the future in case of buildings, but their actions depend on the political decisions.

In order to analyse the mitigation potential in each impact categories during the remaining life cycle of the whole prefabricated large panel building stock more research is necessary: develop further the building typology and make further life cycle assessment calculations.

6. Acknowledgement

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7. References

[1] CSOKNYAI T. „ Energy conscious retrofit of residential buildings built with industrialized technology". PhD dissertation, Budapest University of Technology and Economics, Hungary, 2004

[2] GUINÉE J B (final editor), GORRÉE M, HEIJUNGS R, HUPPES G, KLEIJN R, DE KONING A, VAN OERS L, WEGENER SLEESWIJK A, SUH S, UDO DE HAES H A, DE BRUIJN H, VAN DUIN R, HUIJBREGTS M A J, LINDEIJER E, ROORDA A A H, WEIDEMA B P. „*Life cycle assessment; An operational guide to the ISO standards".* Ministry of Housing, Spatial

Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands, 2001,
[3] GUSTAVSSON L, JOELSSON A, *"Life cycle primary analysis of residential buildings"*. Energy and Buildings; 2010, volume 42, pp 210-220
[4] SZALAY ZS. „*Life cycle environmental impacts of residential buildings"*. PhD dissertation, Budapest University of Technology and Economics, Hungary, 2008
[5] SARTORI I, HESTNES AG. „Energy use in the life cycle of conventional and low-energy buildings: A review article". Energy and Buildings, 2007, volume 39, pp. 249-57.
[6] KÖNIG H, KOHLER N, KREISIG J, LÜTZKENDORF T. „*A life cycle approach to buildings*". München, Edition DETAIL Green Books, 2010, ISBN 978-3-920034-45-4
[7] GOLIC K, KOSORIC V, KRISTIC FURUNDZIC A. „General model of solar water heating system integration in residential building refurbishment—Potential energy savings and environmental impact". Renewable and Sustainable Energy Reviews, 2011, volume 15, pp 1533-1544
[8] KONSTANTINOU T, KNAACK U. „Refurbishment of residential buildings: a design approach to energy-efficiency upgrades". Procedia Engineering, 2011, volume 21, pp 666-675

“Johann Böhmstrasse”: Renovation concept towards energy plus standard with prefabricated active roof and facade elements, integrated home automation and grid interaction"



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Short Summary

The existing building stock in Austria consists of a variety of buildings from the post-war period. Due to their poor quality of construction those buildings consume an enourmous amount of heating energy.
In Kapfenberg one of these bad energy performing social housing buildings from the sixties is being renovated to become net zero building. The sixties bloc will be converted into a futuristic showcase. The house in Kapfenberg has 32 apartments on four floors. 200m2 building integrated solarthermal collectors and up to 1.200m2 photovoltaic modules have been mounted on a large scale solar wing that extends far beyond the existing roofscape. In the annual average energy balance, the building will produce more energy than it consumes on the primary energy level. Johann Böhmstrasse is a „Building of Tomorrow“ flagship project funded by the BMVIT.

1. Introduction

The existing building stock in Austria consists of a variety of buildings from the post-war period. Due to their poor quality of construction those buildings consume an enourmous amount of heating energy.
In Kapfenberg one of these bad energy performing social housing buildings from the sixties is being renovated to become net zero building. The sixties bloc will be converted into a futuristic showcase. The house in Kapfenberg has 32 apartments on four floors. 200m2 building integrated solarthermal collectors and up to 1.200m2 photovoltaic modules have been mounted on a large scale solar wing that extends far beyond the existing roofscape. In the annual average energy balance, the building will produce more energy than it consumes on the primary energy level. Johann Böhmstrasse is a „Building of Tomorrow“ flagship project funded by the BMVIT.

2. Development of prevabricated facade modules

The refurbishment concept of the Johann Böhmstrasse is based on efficiency measures (highly insulated, prefabricated active energy roof and energy facade elements with integrated building services), on a high percentage of renewable energy sources as well as on a smart integration of energy supply towards heat and electricity networks. The concept makes a significant contribution to the achievement of three EU goals:

- 80% energy efficiency – reduction of energy demand
- 80% share of renewable energy in total energy consumption
- 80% reduction in CO2 emissions

The high-quality refurbishment towards the plus-energy building standard is only possible becouse of an integrative refurbishment and energy concept. The high-quality thermal renovation of the building envelope with Passive House components, the interaction of energy-producing active elements – thermal collectors, PV – and a grid integration of electricity and heat. Using existing energygrids for storage and distribution makes it possible to reach plus-energy building standard in the renovation.

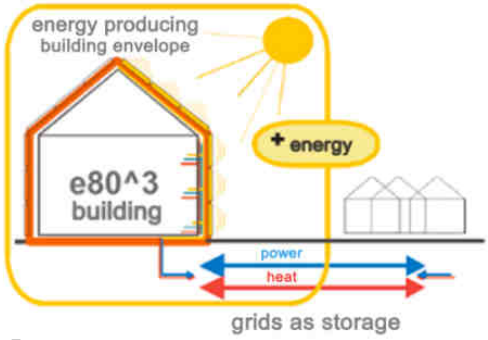


Fig. 1: Principle, source: AEE INTEC

The basis of this innovative and inclusive reconstruction concept is established by a required brief analysis of the status quo. Building typologies, construction characteristics and typical building physics and static standards of multi-family houses (MFH) which were built from 1945 to 1980 provide the preconditions for the further development steps and point out the potential for economic feasibility.
Special attention is given to the overall building systematic and respective inclusion into the considerations. Analyses for an optimal energy-efficient coverage of consumption peaks through renewable energies and usage of synergy effects within settlements have been considered. Concept design mainly focuses on the development of the rearrangement of all the building services – manholes, walls etc. to be moved from the building interior into the new building envelope. During the development of technology and components of prototypes of prefabricated facade elements and supply and disposal systems, the structural engineering and building physics aspects are particularly considered and included in the considerations. Building up on already implemented innovative house of the future projects (such as Linz, Graz and Makartstraße, Dieselweg) these guiding or flagship projects are to be developed, optimized, perfected and thus transferred from individual manufacturing to mass production. Through the evolution of prefabricated facade, as well as new, external home automation modules for up to 4-storey buildings, it is possible, to economically refurbish all the buildings of this epochs. The facade- and basic roof modules incorporate conventional rear-ventilated constructions as well as the new power-generating active elements ("plus" energy producers) such as solar collectors and photovoltaic systems. Thus, the number and arrangements can be adapted and optimized to suit the respective situation given (zero energy or positive energy).

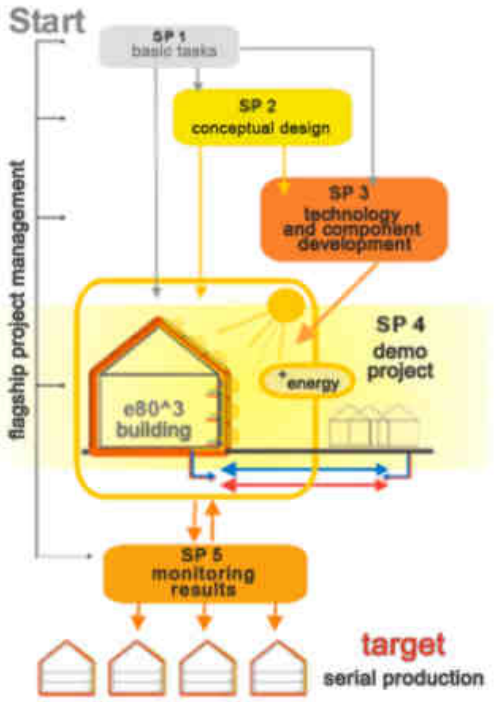


Fig. 2: Project schedule, source: AEE INTEC

3. Energy Concept of Johann Böhmstrasse

The main heat supply is achieved by the district heating system of the Stadtwerke Kapfenberg. This is mainly done by the waste heat of the Böhler-Werken. On the southern side of the building there are solarcollectors (about 200m2) attached which contribute to the heating and the provide warm water. The exhaust fan is equiped with heat recovery and a heat pump. Through these three measurements the energy storage is being supplied. The energy being produced supplies the energy storage and is then passed on to each apartment for heating and warmwater. On the roof of the building, which changed from a steep roof to a flat roof photovoltaics are introduced in a size from about 400m2 / 50kWp. On the eastern and the western facade photovoltaics contribute to the high energy performance of the building. Surplus energy is being transferred to the public net. On the first step the domestic current should be reduced to a minimum. There is a possibilty to introduce even more photovoltaics to the building in further developments.

4. Conclusion

The building envelope as an active rather than a passive element, as an energy converter meets more functions than just the separation of the outer space from the interior with more or less thick insulation. There are still too few approaches and economically implemented examples of prefabricated facade and roof elements.
The implementation of systematic and integrated wiring outside the original facade in combination with the new building envelope would be an innovation for the market. The integration of existing and planned grids as storage and distribution elements allows for future realisation of refurbishments towards energy-plus buildings in settlements.

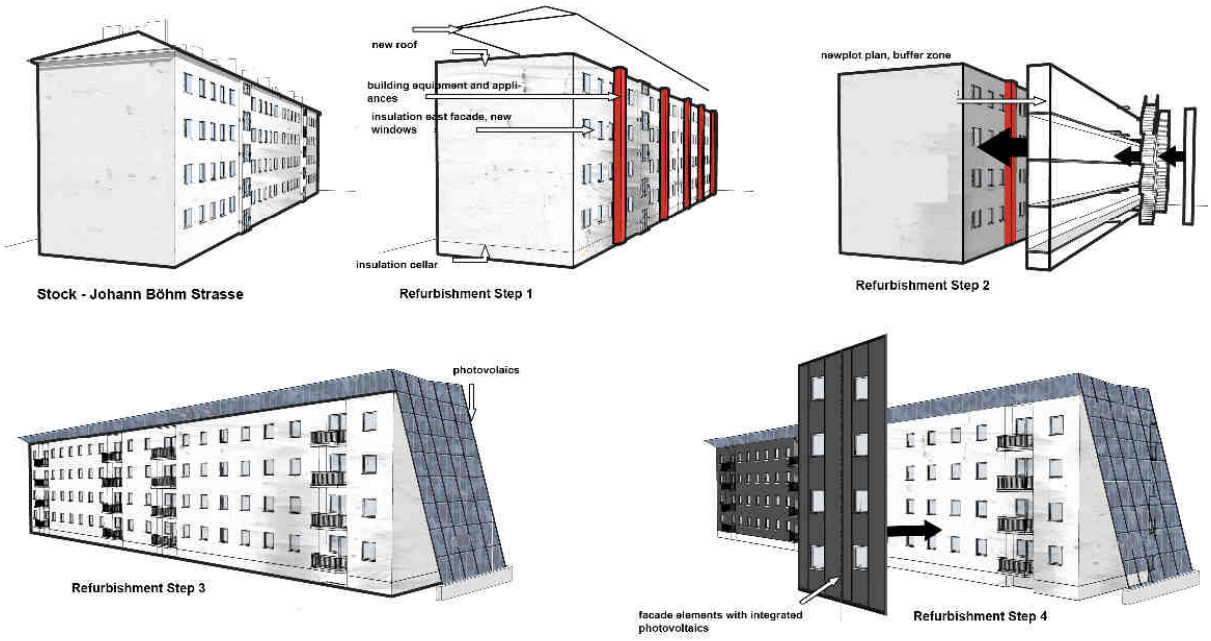


Fig. 3: Schema of the refurbishment



Fig. 4: On the left the newly refurbished building can be seen as a comparison to the old building on the right

To reach Net Zero, not only the large scale solar integration is needed. Also the operational energy of the building will be reduced by 80% after the renovation. Therefore the existing building facade is beeing renovated with forty feet high prefabricated wooden modules. The new building services, active solar elements as well as doors and windows are already integrated into these highly insulated timber façade elements. Thanks to the prefabrication a high precision in the details is achieved, which is needed to exploit the potential for energy improvement which is necessary to reach net zero. Furthermore the construction time on site can be reduced drastically and the building can stay inhabited during the renovation process. The joints and connection details of the completely prefabricated elements are designed in a way that after the assembly on site all the

required building physical functions such as fire protection, air tightness and sound insulation are guaranteed.



Fig. 5, 6, 7: A facade element being attached to the building

5. Project Partners

AEE INTEC - Institut für Nachhaltige Technologien
Dr. Karl Höfler
Ennstal SG
Nussmüller Architekten
Stadtwerke Kapfenberg

Block of Flats from 1958, Rejuvenated with Wood

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Summary
A rundown 1958 post-war housing estate in the west of Munich was first an object of study, then a planning model and finally a showcase project for holistic wood renovation. For an ideal lifecycle balance and overall economy, the following is vital: maintain the carrier substance, rebuild, recompress, passive-building envelope pre-fabricated in wood, timeless design and regenerative energy supply.

Keywords
Solar construction, renew stock, recompress, set of objectives, lifecycle balance, grey energy, wooden construction, pre-fabrication, passive house, solar energy



Fig. 1: Renewal post-war housing estate Munich, arcade view to the west

Location	Munich-Sendling, Badgasteiner-/ Fernpaßstraße
Building owner	GWG Städt. Wohnungsgesellschaft München mbH
Planning+construction management	KLA Kaufmann.Lichtblau.Architekten, München/ Schwarzach
Structural planning	MKP Merz.Kley.Partner/ EST Energie.System.Technik
Funding/ Research	KFW, dena, LH München, E2ReBuild
Construction dates	Original 1958/ Constr. Phase 1 2010-11 (Phase 2 2012-13)
Net dwelling area	3.323 m2 (originally 2.012 m2, + 65 %)
Units	46 flats/ district housing office (originally 36 flats)
Envelope quality Ht'	0.26 W/m2K (originally 1.56 W/m2K)
End energy	22 kWh/m2a (originally 280 kWh/m2a)
Primary energy	22 kWh/m2a (originally 340 kWh/m2a)
Building cost	950 €/ m2 GFA (German DIN cost groups 300/400, gross

How is our ‘big house’ doing?

‘Holistic’ solutions for building restoration – is that just a new name for an age-old problem? We don’t think so. I would like to try to briefly explain why, an idea and a concrete project example. The question here is what does sustainable mean? The answer is to get started with the holistics .. let me start with a very personal story. My children, Leoni, 16, and Lucia, 13, grew up in the south of Munich. Their ecological footprint on the world is still small – and it should stay that way. But if we listen to serious forward thinkers – which we definitely should – by the time they reach our age, their world should be a completely different one than today...

Should we be afraid of that? Well, we probably don’t need to be and fear is never a good starting point when trying to find sustainable solutions. The term ‘respect’ fits better here – faced with the boundless complexity of global events as a result of a burn out of our knocking off economy. The more we think we know, the less we manage to maintain a natural balance. Prof. Radermacher, for example, calls it the boomerang effect. No wonder that there are children who say: we cannot leave the shaping of our future up to the adults anymore. What more can you say to that?

How to handle this ‘seven-headed Hydra’? I have found a suitable approach for myself: it is the daily effort to constantly contribute to a solution instead of the problem. Only by living out that idea can a temporary state of calm be reached. Planning and construction offer a rewarding area of work in this respect. The key functions of energy, material and capital circulation are each approximately half directly or indirectly linked to our building construction and present the highest potential by far for sustainable collaboration with their owners and users. Success solely depends on us, the social skills towards high priorities, strength of character and communication.

Challenge and objective

Buildings are and will remain our most costly and longest lasting commodity. We are faced with the simple fact that with the turn of the millennium, we entered an era in which we need to reflect on those unique key energies and materials, which have always made living even possible: our sun, its light. High-tech on the roof, smart-tech in the house and/ or religious beliefs of divine salvation is not enough. But what is ‘solar construction and restoration’? Integral planning concepts are aimed at a rational, sustainable overall context of:
- Induced energy and land consumption in urban building or landscape preserving credibility,
- energy consumption due to production and transport and the minimisation of synthetic materials in construction,
- of operational energy consumption when using the building and installations, linked to optimised quality of use,
- energy input and problem waste on ‘re-use/ down-cycling/ disposal’ after restoration or demolition,
- and the easing or reshaping of our social, cultural and economic network of relationships.

Energy, anything material and also our culture are not reproducible. Solar architecture is about the complex equilibrium of energy and material balance of our earth. Above all, it is pleasing and works simply, is flexible and long-lasting – three barely perceived, but ultimately decisive multiplier properties for the ecologically rational lifecycle balance. This suggests a decisive turnaround against our political and economic behaviour, our smart and responsible contribution towards an open solution process – as an essential contribution towards peace and the well-being of generations.

The building owners may ask: Who should pay for that? The counter question is: what is the future worth to us? Stay calm, thinking helps. Independent expertise and creative reflection are by far the most cost efficient resources for real sustainable construction. A macroeconomic observation – compiled under ecological cost transparency – leads to extensive different decisions than in today’s building industry. Relevant research results have expressly proven this several times. The simple, comprehensive dynamic CO2 taxation would be a highly effective motor.

Long-term ecology will become long-term economy by the time the overdue internalisation of external costs at the latest. ‘Holistic and sustainable’ will become the only form of building construction we will be able to afford in the future. Good architecture has so much more to offer than low energy demand values, but only when architects and engineers take on this system-changing planning attitude in design realisation and render a backward-looking, knotted sustainability certification redundant, will a substantial economy, new ‘archi-culture’ and genuine quality of life synergistically arise – wouldn’t that be a legacy worth striving for?

The example: From object of study to prototype

A large part of the overall housing stock in Germany is functionally outdated, has high operational costs, is inadequate in terms of energy consumption and does not comply with society’s living standards of today, let alone of the future. That means, that our central construction tasks lie in the renewal of our existing building stock. This necessity poses many dangers, however, when thought through it poses unique opportunities: it calls for a fundamental approach and new interpretation of old housing. Structural sins of the past can be alleviated or even eliminated and the demand for a more sensitive recompression and redesign presents the possibility of sustainable urban corrections linked with high overall economic efficiency and an attractive future orientation.

As an example we present a Munich GWG housing estate in Sendling: Mass commodity in the 1950s, masonry bolts with unit floor plans and individual room heating, after two generations it is still in its original condition for the most part. The heating requirement is approximately at factor 4 above the new construction value according to EnEV2009. It was only the excellent location, that kept the building from permanent vacancy. In 2006/7 we had focused on a study design about sustainable development goals by the chair of wooden constructions at the TU Munich – with remarkable results. A research project ‘TES Energy Facade’ subsequently followed, then the contract for the planning and implementation by the public housing association to our ArGe Kaufmann.Lichtblau – in short: it got serious!



Fig. 2: Renewal post-war housing estate Munich, path of the sun 21 March / Sept.

So the modern engineer’s wooden construction was to become the renovation method of building stock?! Until now, a lot was theory as in architecture. The design, it is said, shows the talent; the art begins with the implementation and realisation. The building owner and our planning team – after detailed preliminary discussions – agreed on a set of objectives. This corresponds entirely with the requirements and, among other things, the widest possible preservation of existing primary structures to the prevention of grey energy and waste from demolition and reconstruction. An upgrade-free economic life expectancy of at least 40 years for complete renovation – 46 flats and new regional administration in the lowest energy standard – essentially covers three areas, our set of objectives:

A / The use: Quantity, quality and environment
- Compress rentable living areas of the 1b site by more than 50 % - use building ground, ensure revenue,
- Create market-conform mix of flats with light, attractive layout – offer new living quality,
- Interlock disabled, elderly and child friendly functional residential use – include demography,

- Make the new living environment spacious, social, close to nature and robust – design urbanity,
- Studies of the sun show daylight quality in each residential area in the quarter.

B / The energy concept: Standard, maintenance, economy
- Lower the energy demand, heating, air and light to under 50 % of a new construction – achieve maintenance security,
- As much as possible, provide regenerative residual energy from heating and electricity – achieve zero emissions,
- 'triple win' – ease the burden of the owner/ tenant/ environment – produce overall profitability,
- Offer simple, safe, long-lasting technology for ease and cosiness – promote health and comfort.

C / The structure: Ecology, process and design
- Perfectly ecological assembly system of high quality and precision – optimise life cycle balance,
- Constructive integration of sound insulation and fire protection, as well as statics, hvac and solar active components – understand flexibility
- Digital on-site measurement and an maximum pre-fabrication, low weight and short construction period – track process efficiency,
- Low maintenance surfaces and many selectable design variations – enable time-less, attractive architecture.

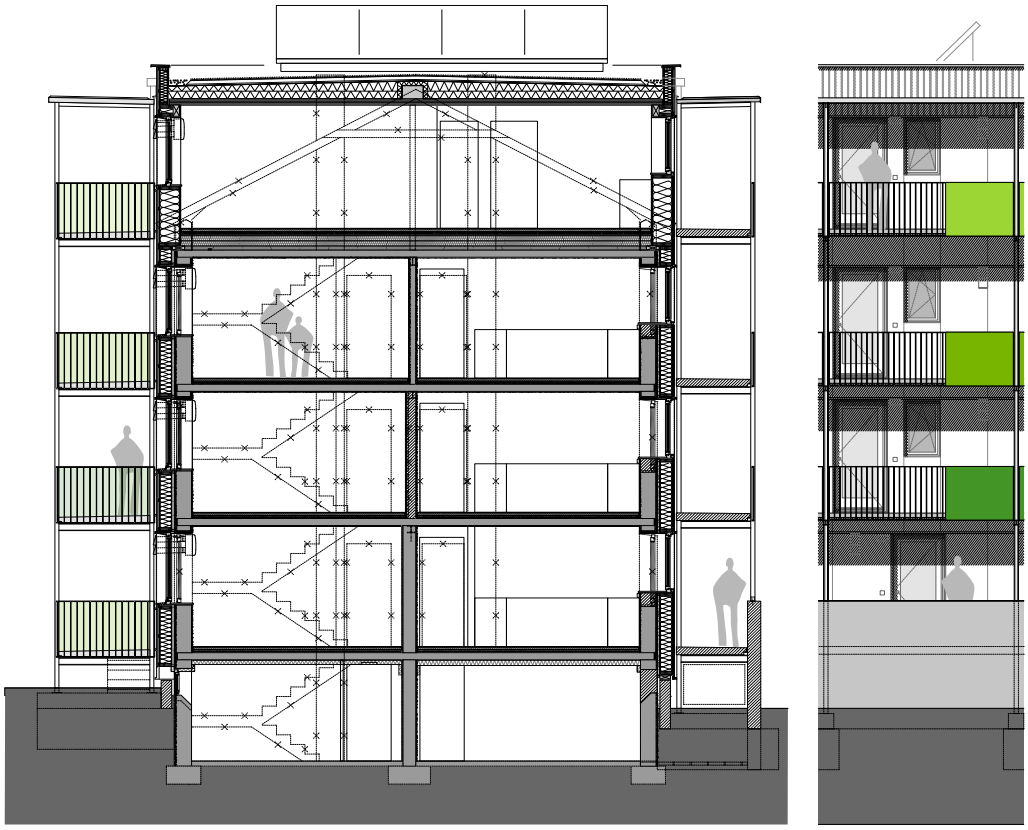


Fig. 3: Renewal post-war housing estate Munich, layout construction in wood

The provocative demand of the building owners to the planners: all aforementioned objectives should be reached cost-neutrally within public housing subsidies. The unavoidable extra costs for prototypes with 'sustainable attributes' must be financed in full by appropriate subsidies for energy renovations and 1 € / m2 rent exclusive of service charges as a user contribution for minimal energy costs. That should occur through the holistic added value as described, and furthermore a new 'league of efficiency' will be reached. Despite obstacles and risks we accepted the challenge.

Almost 3 years' work passed by. The first construction phase of the pilot project is finished, the GWG administration and new construction flats as well as the comprehensive renovation of both

existing buildings along with additional stories are being used, the outdoor areas are almost done. With a widely successful completion of the comprehensive mutual set of objectives, K.L.A. has consciously entered new territory for GWG and in doing so has also reached unforeseeable limits to the affordable input of working time. We owe that to our cause, our building owners and their (happy) tenants. An extensive monitoring for result validation will be carried out by the end of 2013, the second construction phase with the replacement new construction has begun.

Provisional conclusion: The obtained result is an example of the simple fact that the renewal of existing buildings with the title 'real sustainability' – on today's conditions – is achievable, of course not by means of standard planning, standard processes with standard partners and at standard costs. We also had to deal with obstacles and risks, as well as priority struggles and completely new solutions. Follow-up work shows plenty of valuable experience and learning success, which we will hopefully be able to consistently develop. We cannot go back. The reward for all our efforts lies in durable high use and structural quality with unbeatable overall profitability, but with reference to the life cycle – just like in sustainable forestry.

The second chance: Future perspectives...

At this point a discussion about the new planning and construction techniques 'wooden prefabrication' would be appropriate. What systematic wooden construction is really capable of achieving for climate change was first shown at the 'Building with wood – ways into the future' exhibition at the architecture museum in Munich in 2011. It aroused an interest which never existed before in modern wooden construction, our GWG project was chosen as the restoration example in the next exhibition. We urgently demand a policy be issued to duly support planners and building owners on the development of this enormous CO2 reduction potential.

The focus is on attaining industrial cost-saving production and in doing efficiently increase building stocks' slowing restoration rate, using the most natural, healthy and environmentally friendly materials and processes as possible. Only through competently optimised planning under equal observation of effective land use, ecological structural engineering, zero-emission building operation as well as first class use and design quality is macroeconomic, affordable and real sustainability achieved. 'Solar construction and restoration' as we know it does not harm anybody, it presents the basis for personal freedom and in doing so embodies true modernism.

Therefore it should be up to us construction masters to change the attitude from the bottom up, to learn something new, to present results and to tell happy customers: it really works! Wooden construction marks the most sensible way of using raw material, whose abundance and innocence will finally pass. Every well-made, energy autonomous and nice looking wooden construction can become a clear sign of change. Let's protect our riches of timber against foreign desires and wrong usage. With wood as a construction material, warmth returns as a life metaphor, haptic trust creates a new confidence that there are solutions for our problem of the century: sustainability. They grow in the forest and demand nothing more than our sensitivity, fantasy and unity. That is why it is important to endlessly discover new things, rediscover and develop further.

I would like to finish the illustrated boardsheet with this: let me quote what occurred to me when I woke up in the night and luckily found a pencil and paper. I will take the liberty of including our partners and building owners: 'We have not dedicated our lives to architecture to later on have to say: we failed on the most important dimen-sion of construction: a universal sustainability. It may appear quite emotional to some people – nevertheless and now more than ever: we will not stop being nonconformist and controversial until we hand over to our children and grandchildren'. That is what we can do - and what you can do with us.

Thank you all the best ! FL1212

Renovation to plus-energy-standard schools – Rainbach im Mühlkreis/Austria



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Short Summary

The aim is to renovate the whole school complex to a plus-energy-house-standard.
A functional as well as a technical overall view are necessary due to the closeness of the two main structures, the shared facilities such as gym-hall, multi-functional hall, as well as the gas heating facility and water supply, the boarding for pupils and the shared cleaning staff.
With the construction of a new hall which unites elementary, secondary modern schools and gym-hall all different functions of the complex are interlinked. Moreover, the outer surfaces of the secondary modern school are reduced remarkably, and for the elementary school and the gym-hall this fact means that no separate thermal insulation is necessary at all.
To provide sufficient fresh air, the complex will be equipped with a mechanical ventilation system with heat recovery.
All windows will be provided with centrally controlled moveable sunblinds.
The existing water well will be used for the toilets.
Electric lighting is controlled in the same way as the sunblinds.
For the generation of electric current a 50 kWP photovoltaic plant will be established.
After thermal renovation heating will be effected by means of wooden chips.

Keywords: prefabrication, sustainability, comfort, economic efficiency, fire safety, cost effectiveness, recyclability, precision, integral planning, renewable materials

1. Situation

The market town of Rainbach is situated 720 meters above sea level in the north of the Province of Upper Austria. From the climatic point of view this region is characterized by its relatively high altitude above sea level and the frequency of defogged days.

The market town has about 3100 inhabitants. The structural weakness of the region also marks the financial situation of the market town.

The two schools of the market town Rainbach are situated near the market town center on a separate, adequately dimensioned school ground with sufficient open area. The nearby publicly owned sports ground is also used by the schools. The catchment area for pupils exceeds the community boundaries, a fact which shades cross-community importance on the construction of the schools.

1.1 Description of the status quo

The energy indexes of the three existing structural elements are between 104 and 120 kWh/m² per year.

1.1 Educational concept

Due to changes in the Austrian educational system structural adaptations are necessary. Both, the elementary as well as the secondary modern schools, are run with 8 classes. Changes in the numbers of pupils in different subjects call for bigger class rooms, which are not available in the present building and therefore necessitate amplification. Moreover, concepts like “Neue Mittelschule” or all-day-school and new ways of teaching have their impact on the room use and room size and thus require corresponding structural adaptions.
The concept of renovation unites both schools to one building complex which results in better use of room resources, shared facility and property managements. Similar synergies arise from building equipment and appliances and therefore can be used more effectively.

2. Intention

The renovation of the building in an energetic technical way leads to a sustainable reduction of total energy use without consumption of further building land and without construction of new building surfaces. In Austria 70 % of heating energy is used for buildings which are older than 20 years. These buildings mostly possess good structures and therefore the decision to renovate them instead of demolishing and rebuilding is often taken.

On the one hand renovation has a high potential of energy-technical savings and offers on the other the creation of modern room structures with sustainable materials and elaborate planning. A school is the “work-space” for pupils and teachers, the classrooms constitute the different “workshops”. Effective performance highly depends on factors such as ambient room, the materials, lighting, air quality and educational possibilities. It is the responsibility of the planners to consider all these facts and create best possible conditions for the pupils and their education. It is also the responsibility of the planners to leave buildings which can be maintained by generations to come.

An objective of the municipality is to maintain a renovated, optically attractive building. Furthermore the erection of a building should - on the long term – put only little strain on the municipality budget and also involve regional enterprises in the renovation. The building must be and remain affordable over its life time cycle in relation to the costs of reconstruction, energy, cleaning, disposal, etc.

The ecologic fundamental idea of the municipal council and the planners has been the focus for all steps of planning. The municipality is fully aware that by the implemented measures the school site Rainbach achieves an economic advantage. The financing of the ecological sustainable reconstruction is supported by a state-aided model-renovation program “Musterhaussanierung” and a special grant of the Province of Upper Austria.

3. Measures in insulation



3.1 Secondary Modern School and Gym hall

All the surfaces of the buildings were analyzed and the following measures will be implemented: the exterior walls of the Secondary modern school (will be run as “Neue Mittelschule” from autumn 2013 onwards) and of the gym-hall will be renovated with prefabricated wooden-framed-elements. In building projects with short execution times this is

a perfect method to previously transfer work flow to the production hall. The prefabricated wooden elements guarantee high end quality and can be produced independent from weather conditions.

Assembly time at the building site is reduced to a minimum, which is perfect for projects with short setting times.

The use of unified elements results in cost reduction.

Construction waste on the site is reduced as by the prefabrication adjustment work on the site is mostly omitted.

High costs for scaffold can be avoided.

These wooden framed elements have the advantage of separability of the materials when being disposed.
Windows, sunblinds and wires are already integrated in the prefabricated façade elements.

The application of prefabricated elements also means more intensive advanced planning and requires appropriate coordination of individual planners, optimizing of element sizes and compositions, careful examination of the static bearing capacity.

The choice of the best suitable structural grid depends on the sizes of the applied boards.



The sizes of the wooden frame elements depend on the matter of transport as well as the access routes.

3.2 Uppermost ceiling

Another important topic is the thermal losses through the uppermost ceilings and the flat roofs. The uppermost not accessible ceilings will be insulated with fireproof glass wool.

The new flat roofs with wooden bearing structure will be insulated with special mineral wool that can be walked on. This material constitutes also the fire protection for the wooden constructions.

The outer walls of the cellar will be insulated with XPS boards due to humidity.

3.3 Elementary school

The outer walls of the Elementary school will be insulated with an upgraded insulation with wood fibre insulating boards. This material holds the “natureplus” quality seal. The wooden fibre insulating boards are made from grain in a dry process. As the insulation material consists completely out of wood it can be disposed ecologically and easily at the end of its life circle.

On the uppermost ceiling not flammable glass wool will be applied.

Thermal insulation in the basement will be done by XPS boards.

While in the Secondary modern school only a small part of the cellar floor will be removed and newly rebuilt, all the cellar floor in the after-school-care rooms of the Elementary school will be completely thermally insulated. The window openings will mostly remain the same size, except in those rooms where more daylight is necessary for future use, the windows are enlarged accordingly.

4. Transparent facades

Due to the wooden frame façade elements which are used in this project the windows cannot be preassembled.

The windows correspond to passive house standard and are carried out with triple glazing and wooden-aluminium frames – their thermal transmittance (k value) is 0.8 W/m²K.

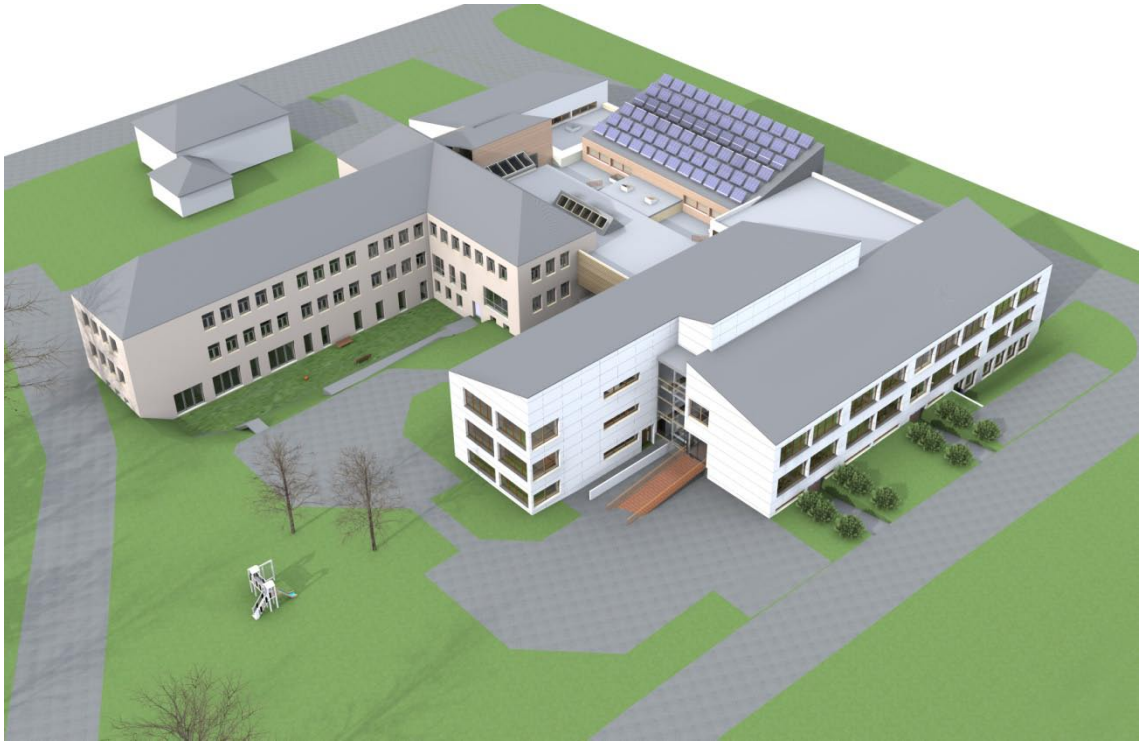
4.1 Glass fronts

The bearing construction elements are made from spruce and aluminium profiles, their thermal transmittance (k value) is 0.8 W/m²K.
The thermal transmittance of all triple glazing itself is 0.6 W/m²K

5. Structural measures

The requested new classrooms will be established in a heightening above the present entrance area on the north side. This is the cheapest way to produce extra room as the necessary fundaments and the base plate can be used. Only two exterior framings and a roof construction are required. With this heightening extra room can be provided without creating new outer surfaces. The same comes true for the extension of the school hall on the south side. A new glass façade is built as closing element of an existing recess. In this extra space the new elevator which provides accessibility for handicapped persons and mechanical maintenance is situated.

The new hall between Elementary school, secondary modern school and the gym-hall unites all the functions of the building complex. In this central hall overall tasks such as library, boarding of the pupils, gym-hall and a nearby function-room are interconnected. By this measure the outer surfaces of the Secondary modern school as well as of the elementary school and the gym-hall are reduced and therefore need not be thermally insulated any more. Once more new extra room is created without producing additional outer surfaces.



Due to effective standards for static load assumptions all the roof constructions have to be reinforced by 100 %.

To guarantee accessibility to the Elementary school an elevator near the existing functional room, which will not be renovated, will be established. In this way both, the elementary school and the functional room, will be accessible for handicapped persons.

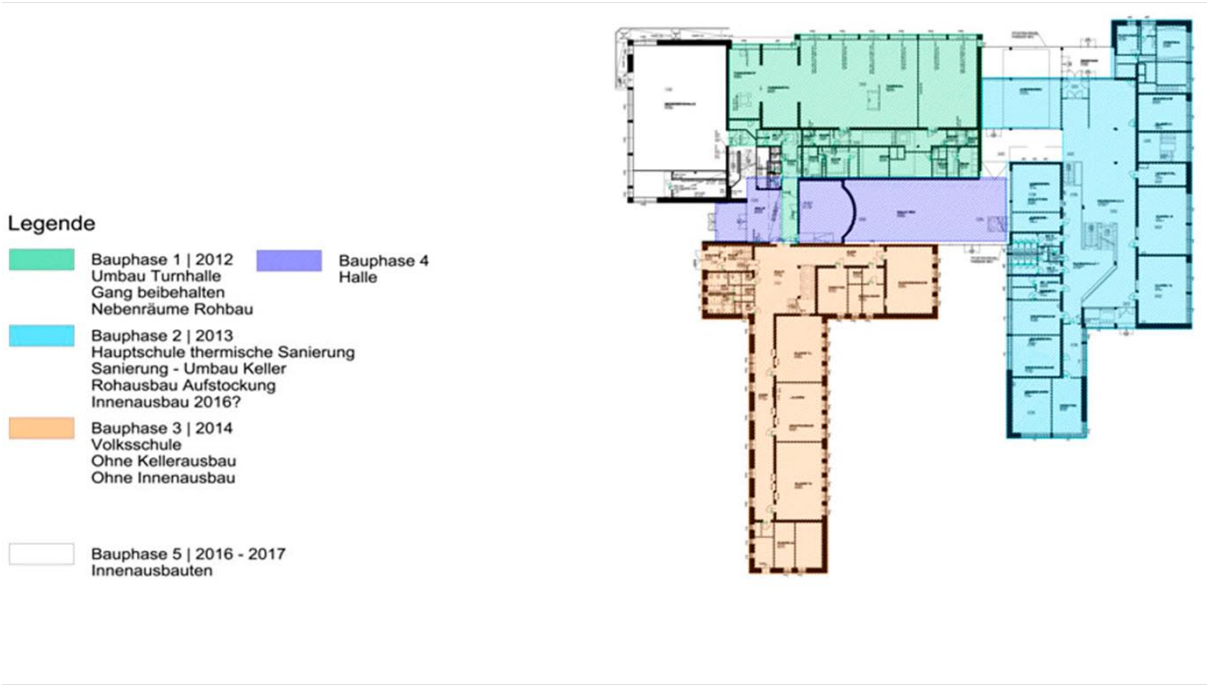
The entrance of the Elementary school will be resituated to the existing entrance of the functional room. This measure means more space between traffic area and the entrance door and moreover provides a porch roof.

Within this new entrance area accessibility to the four parts – Elementary school, function room, Secondary modern school and gym-hall - can be controlled.

All sanitary rooms of the Elementary school as well as all the plumbing need to undergo a complete renovation.

The interior walls separating the class rooms rest on the basement ceiling. Removing these interior walls would imply high cost for underpinnings. Therefore the class-rooms will remain mostly as they are. Through openings in the wall to the new central hall the natural light quality in the corridor of the ground floor will improve remarkably.

6. Technical measures



6.1 Noise control

All classrooms need an improvement in regard to room acoustics. The most important element to achieve this improvement is the mounting of cost-efficient wooden ceiling-liners especially developed for this project. These liners are made of spruce, mostly untreated, as to preserve the naturalness of the material and its positive influence on the indoor climate. These ceiling-liners are also used for the ceiling of the gym-hall.

6.2 Measures for cooling

To prevent overwarming in summer time with the high insulation standard and the high number of persons in the rooms (especially in May, June and September), cooling with the cool night air will be applied. This aspect becomes even more important in regard to the future all-day school.

As Rainbach is situated at about 720 meters above sealevel there are only few nights with temperatures higher than 20°C which is an obvious plus for night cooling and no extra cooling energy is necessary.

The cool night air will be transported by the ventilation system as cooling by opening the windows manually.

Passive measures: Exterior sunblinds combined with an automatic daylight control also prevent overwarming by sunlight of non-populated rooms.

6.3 Hot water

For producing the hot water the biomass heating is used in winter. The existing hot water storage tanks close to the gym-hall and the new center hall are equipped with 16 m² solarcollectors to produce hot water in an ecological way for the there situated sanitary rooms.

6.4 Sun protection

All windows – except on the north side – will be equipped with centrally controlled moveable sunblinds. These sunblinds can be controlled individually, but foremost they are centrally controlled by light sensors.

6.5 Ventilation

Ventilation appliance: It corresponds to the passive house standard regarding energy consumption, heat recovery and tightness. With one single appliance ventilation of the whole complex with its different occupation times can be effectively done. The big advantage of this single unit results in little lower investment costs but above all in considerably lower costs in operation and maintenance.

The installed appliance not only convinces by the high extent of heat recovery (over 90%) but also by the recovery of humidity to reduce drying of the air remarkably which is important for health in winter.

Diffusion in the room: a low speed inlet system is applied as it allows reduction of the flow of air which results in better air quality and less draught.

6.6 Building physics, ecological concept

The mass of concrete in the ceilings is used as thermal storage for excessive heat. Therefore the ceilings in the halls and corridors remain without claddings and in the class rooms 1/3 of the ceiling surfaces can also be used for this aim.

6.7 Light control

Light control is combined with the control of the sunblinds. Dimming, occupation sensors and daylight control can reduce the consumption of electric energy of up to 70 %. The light control depending on the daylight results in a reduction of 30 – 40 % (about 4400 hours of operation) in electric energy consumption. This means a new energy consumption of 20.000 kWh per year compared to about 60.000 kWh for lighting up to now.
With this lighting and sunblinds control system and the modern LEDs and T16 lamps annual savings of about 40.000 kWh can be achieved by lighting alone.

6.8 Photovoltaic plant

As the roof construction of the gym hall had to be renewed anyway, it was redone with an inclination to the south and furnished with photovoltaic elements with a capacity of 42 kWh peak. Further elements with 8 kWh peak will be situated on the roof of the Elementary school.

Near the entrance of the Secondary modern school an ecological electric charging station for the vehicles of the staff and inhabitants of Rainbach will be installed.

7. Energy pass

7.1 energy indexes

Secondary Modern School:	Existing Building – 103,9 kWh/m²a After Renovation – **11,6 kWh/m²a**
Gym hall and new hall	Existing Building (gym hall) – 119,5 kWh/m²a After Renovation (gym hall + new hall) – **16,3 kWh/m²a**
Elementary school	Existing Building – 110,6 kWh/m²a After Renovation – **7,2 kWh/m²**



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E-Office: a prime example for energy efficiency

Summary

The corporate headquarters of Energie Steiermark at Leonhardgürtel in Graz, fully renovated and converted between 2008 and 2010, are now a prime example of an energy-efficient, low-energy office block. These headquarters, which bear the title of "E-Office", replace four previous locations in the greater Graz area.
The building, originally dating from 1961, was fully renovated, expanded to 15,000 square metres of available surface and redesigned by architect Ernst Giselbrecht into an innovative low-energy office block for 620 workers. For anyone interested, a one of a kind, interactive experience exhibition on the ground floor – the "E-Wunderwelt" – offers a fascinating insight into the field of renewable energy. Guided tours can be booked. In total, the investments came to around 36 million euro.

Keywords
energy-efficient office, renewable energy, energy saving

1. History

The corporate development of the company, then known as Steweag, at the end of the 1950s gave rise to the establishment of a central administration office. It was specified that the site of the new administration building should be conveniently located for transport, whilst in an inner-city location. The site at Leonhardgürtel was chosen based on its direct proximity to the sophisticated road network, Ostgürtel, which was still being developed, as well as other development potential. However, as we now know, this road network was never expanded, which would have been a mistake given the routing of roads through high-quality housing developments.
The entire block area between Elisabethstraße and Leonhardstraße and/or Leonhardgürtel and Merangasse was untouched, excluding the construction of late 19th century-style buildings on the block perimeter around Elisabethstraße and Merangasse. Between 1958 and 1961, the Steweag administration building was constructed as a single 10-storey edifice, which was accessible from Leonhardgürtel. The three residential buildings at Merangasse and the associated garage building at Kroisbach were built considerably later, only at the beginning of the 1970s.

1.1 Description of the old administrative building

The building was a well-proportioned 10-storey structure with ground dimensions of approx. 40 x 20 m and had a clear façade design with continuous mosaic banding in three grey tones and flush-mounted aluminium framed windows. This was by all means a high-quality design, which was extremely modern for that time. The structure was built as a reinforced-concrete skeleton construction; the parapet recesses were manufactured with 12 cm masonry and 5 cm thick internal insulation using wood wool insulation board. The reinforced-concrete columns were also internally insulated using 2 cm thick expanded polystyrene sheets.

Significant deficiencies soon highlighted design and technical issues in the installation of flush-mounted aluminium framed windows on the façade. Furthermore, insufficient thermal insulation resulted in damage to the interior plaster of the parapet and the timber cladding on the columns and lintels. The non-insulated aluminium window design led to significant condensation. As the building was equipped with a 2-cycle air conditioning system, this problem could only be brought under control by dehumidifying the incoming air. It was only possible to lower the temperature over holidays and weekends by raising the dehumidification of the incoming air. If the interaction between the temperature inside and outside was not managed properly, the amount of condensation was so dramatic that employees suspected leaks on the flat roof.

The building was constructed before the first Styrian building regulations, the Styrian Building Code 1968, came into force. Otherwise there were no regulations whatsoever for high-rise buildings in Styria.
This may also have been the reason for the insufficient fire protection in the building. Given the lack of fire sections and fire extinguishers, plus a deficient escape route situation, any fire would have had catastrophic consequences. Attempts were made to reduce potential danger by replacing the cellar and stairwell doors, installing rescue hoses, replacing the goods lift with a fire brigade rescue lift, installing escape route illumination and organisational measures.

The mosaic façade itself had already been renovated several times to repair the many small damaged areas.

The building was fitted with an internal sun protection system, which given the large number of windows and the size of the windows, made a considerable contribution to heating the building.



Fig. 1: Façade from 1961



Fig. 2: Building before renovation

2. New administration office of Energie Steiermark

Competition on the electricity market due to liberalisation demands the use of synergies. After the merging of the companies, the fundamental need for a joint administration office for Energie Steiermark was clear. Following the merger of Steweag and Steg, five possible sites in the region of Graz were suggested. These were the Steg sites at Ankerstraße, Triesterstraße and St. Peter; the Steweag sites at Leonhardgürtel and Neuholdaugasse and the Steirische Gas-Wärme site at Gaslaternenweg.

After a decision process, which considered 6 sites in the region of Graz, the site Leonhardgürtel 10 was selected. All sites were compared economically whereby investment costs throughout the entire life cycle of a site, including operational and management costs, were evaluated. A duration of 40 years was set for the evaluation period, with a residual value for the properties.
After the purchase of the new administration office, only the Leonhardgürtel and Neuholdaugasse sites were required, and the other sites were sold. This considerably reduced infrastructure costs and cut the trip times of employees.

After determining the office space requirement for a total of 620 employees, it was clear that an extension in addition to the general renovation of the existing building was necessary. Another requirement was the creation of 250 underground parking spaces.

2.1 Architects competition and idea

Once the planning parameters had been determined, an architectural competition was held based on a feasibility study. The winning project was designed by architect DI. Ernst Giselbrecht.

Giselbrecht placed the necessary extension on the southern side of the existing building. This closes the gap between it and the 2-storey control room building. The extension enlarges the existing building by 50% (ground area of the old building approx. 40 x 20 m, extension ca. 20 x 20 m).

The winning project makes excellent use of the plot as an extension of the existing property and creates an unmistakeable landmark on the Graz cityscape. The entire western part of the plot accommodates the underground garage, however the area above ground could be developed into parkland.

The façade design includes a sun protection system with folding shutters, so the façade can take on a different appearance every day, regulated by the user. The folding shutter shades the window, whilst not obstructing the view outside. The skylights were fitted with LED strips, which enable a colour display of the façade. The interior of the building is based on a colour concept: each floor has a distinctive floor colour, which helps to identify which employees “belong” to which floor. The office space configuration includes individual offices and group office solutions.

3. The new E-Office

In the future, renovation will take up a much larger portion of the construction work. There are various reasons for this. Building conditions have often changed, meaning that similar developments would no longer be approved. The quality of the site is often crucial, often complete demolition and reconstruction is difficult on inner-city sites.

Various ideas for utilising the property were considered for Energie Steiermark's main office building. The decision in favour of the Leonhardgürtel site in the site concept meant building an extension in addition to renovating the existing building.
This includes completely gutting out the building, keeping only the load-bearing reinforced concrete skeleton.

The decisive factor for the general renovation was the absolutely terrible energy performance of the building and the technical ageing of its technical facilities.

The new building shell for the existing building and the extension were developed using the latest knowledge in façade technology.
In addition to an optimal thermal insulation value, particular attention was paid to new technology in the form of a folding shutter made of perforated aluminium that shaded the windows when folded back, thus preventing heat transfer in the summer and minimising the energy requirement for air-conditioning in particular.

One special feature is a specially shaped skylight strip that deflects light. Daylight that comes in through the skylight is reflected onto the ceiling via the window ledge that is fitted with a reflective sheet, and then deflected down into the office.
This, combined with the external sun protection system that both deflects heat in the summer and works as a heat buffer in the winter, creates optimal conditions for the indoor climate. Thus the new offices are bright and the entrance halls are also flooded with natural light thanks to glass walls in the corridor.

On the 10th floor the existing core zone was expanded, creating a conference and seminar area from which you can enjoy a fantastic view across all of Graz.

The façade surfaces in the southern and western area are partially equipped with photovoltaic elements, as is the canopy of the entrance and the flat roof above the 10th floor.

A split-level, underground garage for 250 parking spaces was established in the western part of the plot. This garage stretches directly from the existing buildings up to the western boundary. This has resulted in a difficult construction, including underpinning the existing building and securing the multi-storey buildings on the adjacent site.
A park was created above the underground car park. The paths were laid in "lightning bolt" shapes as a reference to electrical energy. The theme is "park instead of parking", since this area used to house a car park.

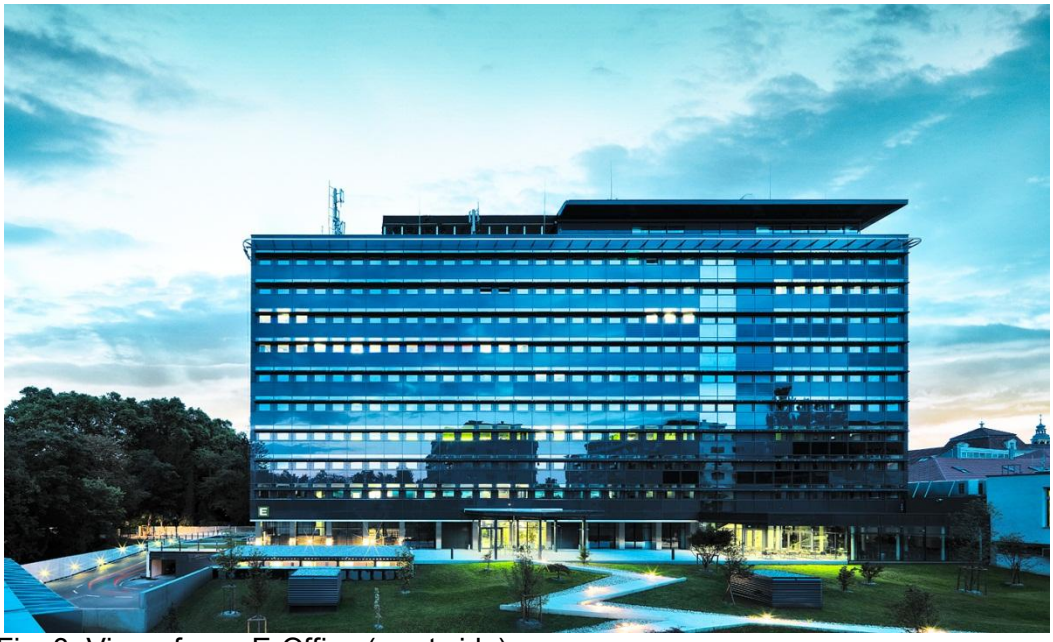


Fig. 3: View of new E-Office (west side)



Fig. 4: View of new E-Office (Elisabethstraße entrance)

3.1 Alternative energies & technical features

- Photovoltaic system with a surface of 550 m², installed on the façade, on the flat roof above the 10th floor and on the canopy of the entrance, which generates a yield of approx. 71,000 kWh/year.

- Heat pump system using geothermal energy as the energy source for supporting the heating and air-conditioning system, operated through deep holes with a total length of 1200 m. The annual yield is approx. 80,000 kWh.

- Use of rainwater for WCs, resulting in an annual saving of approx. 2,240,000 litres of drinking water.

- Solar energy plant for generating warm water for the canteen area and the showers in the workout room.

- Glass and aluminium façade with an insulation thickness of 18 cm using mineral wool. According to the energy certificate calculations of the firm Rosenfelder & Höfler, this generates a heating requirement of 22.8 kWh/m²a. With this value, the E-Office corresponds to Building Class A and can be referred to as a “low-energy construction”.

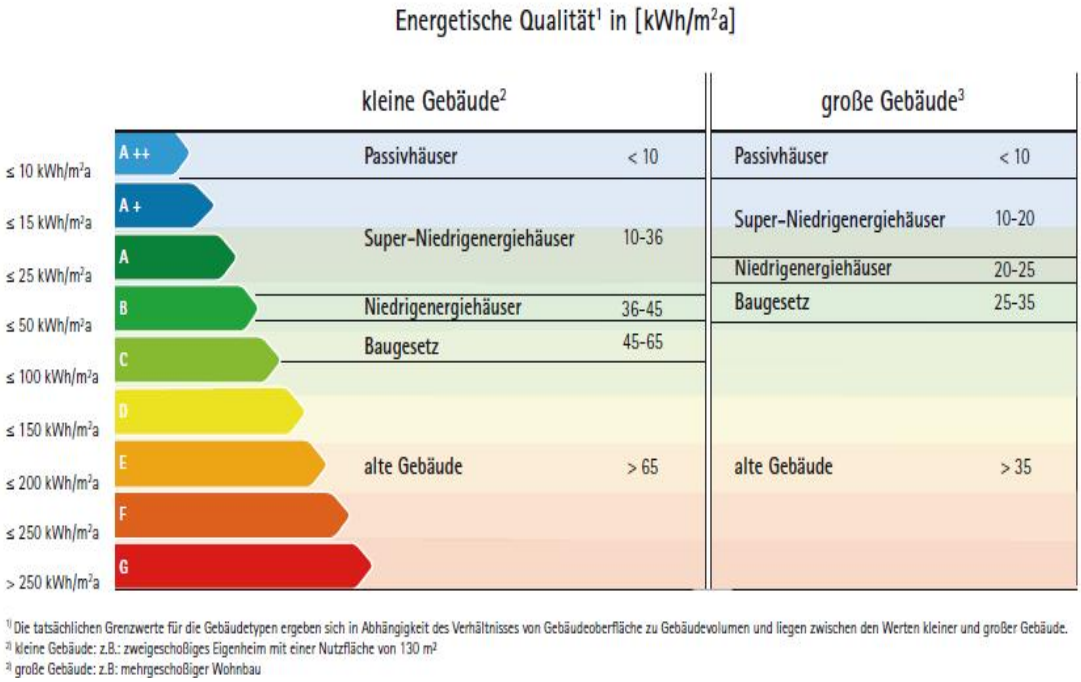


Fig. 5: Energy performance

- Shading system without darkening rooms, the folding shutter system prevents the sun’s rays striking the glass surface of the window. This considerably reduces the amount of heat transferred into the building in the summer, as the need for air conditioning is considerable higher than the need for heating in an office building with high internal heat sources generated by people, equipment (PCs, monitors, etc.).

- The entire heating usage in the new E-Office is 52% lower than in the old building, even though the gross surface area has increased by 50%.

- The total volume of electricity purchased for the new E-Office is 47% lower than for the old building, even though the gross surface area has increased by approx. 50%.

- Off-air management via heat recovery.

- Installation of window contacts that shut down the room technology (heating/air-conditioning) if a window in the corresponding room is open. With the option of being able to open the windows, it’s possible to ventilate the room with outside air. However, the contacts should prevent windows staying open for a long time.

- Office lighting using self-regulating standard lamps. These lights adjust the required light intensity according to the time of day by automatically switching on and off. The savings compared with conventional lighting with an on/off switch are approximately 40%.

- Light deflection through the skylight strip using reflective high-performance film on the skylight window ledge. Daylight is deflected down into the office by reflecting the sunlight onto the ceiling.



Fig. 6: Façade consisting of skylight strip, folding shutters (closed) and parapet glazing

- Elaborate, state-of-the-art fire protection system installed for the first time in Styria as part of the construction of a high-rise building. In addition to a complete sprinkler system, full protection through fire detection, fire dampers, a fire alarm system and fire compartmentalisation, also pressure ventilation systems, extraction systems and electromechanical window opening for evacuating the building and fire fighting were installed by the fire brigade.

- *E-Wunderwelt* on the ground floor is used to illustrate the energy source, alternative power generation and conduction, and demonstrates energy savings. *E-Wunderwelt* is designed for visits by lower secondary school pupils.

Key performance indicators:

- Investment costs totalling €35.1 million, €4.5 million of which for underground garage
- Total net floor space (without underground garage) 15,480 m²
- Investment costs totalling 2,050 €/m² net floor space (incl. costs for alternative energy, *E-Wunderwelt* and demolition of the old administrative building, planning, project management and additional costs (e.g. connection fees for sewage, etc.)

4. Conclusion

The E-Office is a showpiece in the area of energy efficiency, as a total of 550 square metres of solar panels were incorporated into the facade and roof of the building, providing energy for more than 30 households. Furthermore, 12 geothermal energy systems and a solar plant ensure the international low-energy standard is observed. More than 1.8 million litres of precious drinking water can be saved each year through the intelligent use of rain water. Interior motion sensors and the use of LED technology ensure a saving of up to 90 percent in comparison to traditional light systems.

B1

Best Practice in Sustainable Buildings

Chair: Claudia Dankl
ÖGUT, Austria

Best case - plus-energy renovation of a residential building in Kapfenberg assessed with ÖGNB (TQB) and klima:aktiv building standards



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Summary

Building assessment systems can serve as powerful agents of change in efforts to reduce the environmental impact caused by the building sector.

Building assessment systems provide building performance information such as energy consumption, materials used, and operational costs. Assessment systems define various levels of performance within the marketplace, above and beyond the minimum defined by codes and standards. As a consequence, building assessment results can be utilised as a marketing instrument, thus increasing the demand for cost-efficient, user-friendly, and environmentally sound buildings. At the same time, they produce a substantial reduction in environmental impact.
In Austria, the TQB building assessment scheme has been in place since 2001.

This conference contribution describes the development of the TQB assessment scheme, and the successful refurbishment of the lead project “e80^3-Buildings” of the research program “house of tomorrow – plus” will be shown in detail, presenting the development of high-performance retrofitting concepts, focusing on plus-energy buildings with the prefabricated façade elements, built-in building services and net integration.

High-performance refurbishments can only be achieved through an integrated design that includes advanced energy concepts. Specifically, this will require a high-quality thermal refurbishment of the building envelope with simultaneous integration of energy-producing active elements (solar thermal collectors and photovoltaic elements), as well as network integration for electricity and heat.

Keywords: sustainable buildings, building certification, energy efficiency, renewable energy, sustainable development, green building assessment scheme

1. Introduction

Energy consumption in the building sector accounts for more than one-third of energy consumption in Austria. Residential buildings represent the majority of the Austrian building stock: according to statistical analysis carried out by Statistics Austria, in 2001 there were 2.05 million buildings and approximately 3.86 million dwellings. Three quarters of all Austrian buildings are single-family houses and detached houses, and 14% are non-residential buildings. Concerning the number of flats, the distribution is more or less equal between single-family houses and detached houses, and apartment buildings. 21% of residential buildings were constructed before 1919, and 47% were constructed in the period between 1945 and 1981. [1,2,3] The latter portion is most important

in terms of constructed buildings as well as in terms of energy consumption and thus also energy saving potential.

While energy use for space heating and energy use for domestic hot water is predominant in residential buildings, energy consumption patterns are more diverse in non-residential buildings, depending on the purpose of the building: hospitals, shops, offices, schools, etc., and there is little statistical information. However, it is evident, that electricity consumption is increasing dramatically, mainly due to cooling needs. Studies carried out to analyse the impact of climate change on Austrian regions show that the number of days with temperatures above 30°C will increase fourfold in the East of Austria. [4] As a consequence, electricity consumption is likely to skyrocket if no precautionary measures are taken.

In order to reduce heating and cooling energy consumption in the building sector, and to optimise buildings as a whole in terms of sustainability, several policy instruments have been applied in Austria. The social housing scheme is one of these.

The social housing scheme has a long tradition, and has been a driver for sustainable buildings in the residential sector. Criteria have been established so that the majority of Austrians is eligible to apply. For many years, the social housing scheme has been extended towards including energy efficiency criteria, addressing renewable energy systems, and subsequently also to criteria targeting ecological materials. The social housing subsidy scheme provides additional money upon condition that energy and other ecological criteria are met. Heating energy consumption has been decreasing due to defined heating energy indicators required by subsidy schemes, and since 2009 also by the revised building codes, as required by the Energy Performance of Buildings Directive (EPBD).

Green building assessment schemes offer the opportunity to substantially facilitate the transition towards a sustainable building sector by setting up performance requirements regarding energy, materials, water, land, indoor air quality, emissions, and many others. Green building assessment schemes address residential buildings outside the social subsidy scheme, and - even more importantly – also address the non-residential sector. The application is voluntary and requirements are more ambitious than those of the building code and social housing scheme. Therefore, building assessment systems can serve as powerful agents of change in efforts to reduce the environmental impact caused by the building sector.

2. Total Quality Building – development of TQB assessment scheme

In 1997, Austria joined the Green Building Challenge, an international platform for the development of green assessment schemes for buildings (successor organisation IISBE - International Initiative for a Sustainable Built Environment). At that time, the BRE Environmental Assessment Method (BREEAM, developed in UK) was in place and experiences delivered valuable input for establishing an international platform for green building assessment. However, in terms of practical implementation it soon became evident that data generation, collection, and examination had to be adjusted to the Austrian planning and construction practice, in order to avoid high transaction costs. In Austria, small and medium-sized companies are predominant, and it was the objective to provide a cost-efficient tool for widespread application. In 2001 the Total Quality (TQ) assessment scheme was developed, and after a testing phase went into full operation in 2003. [5,6]

In 2009 the system was revised based on lessons learnt and renamed as Total Quality Building (TQB) assessment scheme.

Since 2009, the ÖGNB – Austrian Sustainable Building Council – has run the TQB assessment scheme and the third party certification. ÖGNB also provides a platform for further developing the

criteria framework and a platform for creating innovations that may be necessitated by the performance requirements in the construction sector and associated industries.

Development of the TQ assessment scheme was based on a survey conducted among developers, which clearly pointed out that performance criteria limited to energy efficiency measures, renewable energy technologies, and ecological materials would lack acceptance. However, developers were willing to apply a comprehensive building assessment scheme, which would include aspects such as noise protection, indoor air quality, flexibility, and others besides environment-related criteria. Furthermore, the assessment scheme should be useful as a quality control tool as well as a marketing instrument.

The TQB assessment scheme was therefore developed as a comprehensive set of criteria to be applied at the very beginning of a project to adjust design targets and to achieve a good assessment result.

In order for buildings to pass the TQB assessment, checks are made twice, first at the end of the planning stage and then after completion of construction. The objective is to ensure that the building was constructed in compliance with the design, which will be especially important if the building is designed in an integrated way. In this case, architectural aspects and energy technology aspects are intertwined and small changes during construction to reduce costs may result in substantial problems concerning comfort and energy performance during building operation. After the planning phase, drawings and calculations are checked, and after completion, compliance with the design is examined and measurements are carried out.

The next figure shows the concept of the Austrian building assessment scheme.

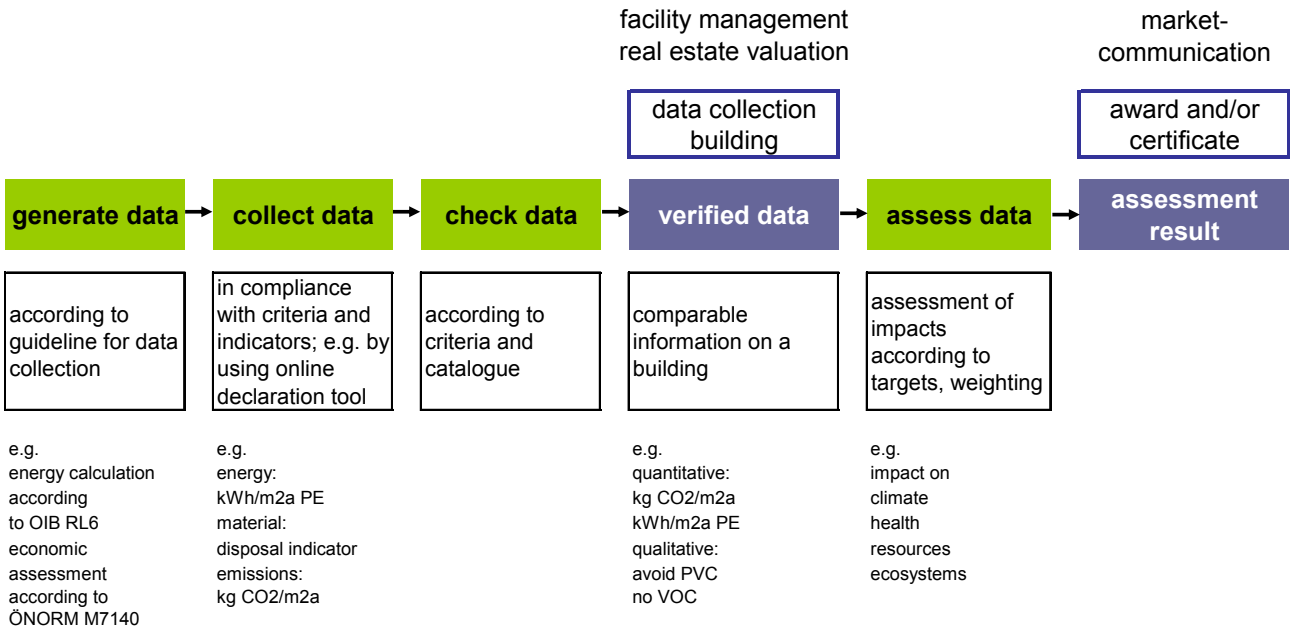


Fig. 1 The concept of the Austrian TQB green building assessment scheme

Since 2010, the TQB assessment is based on an internet tool, which is free of charge and publicly accessible at www.oegnb.net. The tool consists of an assessment framework with a detailed description of assessment criteria, a description of data that have to be provided and a guideline how to achieve the best score. The tool is free because it is the objective to encourage architects, designers and building owners to use assessment criteria for design optimisation and quality control during the design and construction process. Only if the building owner demands a third

party certification will costs arise for the certification procedure.

The TQB system does not assess architectural quality, but technical parameters that have to be taken into account during the process of designing the building. At the beginning of the design process, the design team and the client define the design targets for the building by means of criteria for the assessment framework and the scores they want to achieve; after assessment, a group of independent experts certifies that all the information used for assessment is correct.

The next table shows the latest version of the assessment criteria for residential buildings.

Table 1 TQB-Assessment categories and criteria (overview residential buildings, category and first level criteria, version 2.2, december 2010)

	Category and criteria (German original)	**English translation**
A	**Standort und Ausstattung**	**Location and amenities**
A.1	Infrastruktur	Infrastructure
A.2	Standortsicherheit und Baulandqualität	Security
A.3	Ausstattungsqualität	Amenities
A.4	Barrierefreiheit	Accessibility
B	**Wirtschaftlich und technische Qualität**	**Economical and technical quality**
B.1	Wirtschaftlichkeit im Lebenszyklus	Life cycle cost assessment
B.2	Baustellenabwicklung	Construction site management
B.3	Flexibilität und Dauerhaftigkeit	Flexibility and longevity
B.4	Brandschutz	Fire prevention
C	**Energie und Versorgung**	**Energy and water**
C.1	Energiebedarf	Energy consumption
C.2	Energieaufbringung	Energy production
C.3	Wasserbedarf und Wasserqualität	Water consumption and water quality
D	**Gesundheit und Komfort**	**Health and comfort**
D.1	Thermischer Komfort	Thermal comfort
D.2	Raumluftqualität	Indoor air quality
D.3	Schallschutz	Noise protection
D.4	Tageslicht und Besonnung	Daylight and sun
E	**Ressourceneffizienz**	**Resource efficiency**
E.1	Vermeidung kritischer Stoffe	Avoidance of harmful substances
E.2	Regionalität, Recyclinganteil, zertifizierte Produkte	Quality of products (local production, recycling material, certified products)
E.3	Ökoeffizienz des Gesamtgebäudes	Eco-efficiency of the entire building
E.4	Entsorgung	Demolition and disposal

Although the assessment scheme was developed according to developers' needs, market up-take was quite slow, and assessment results were not generally used in marketing communications. It turned out that estate agents did not know how to use the assessment result in the selling or renting process, largely because they were not trained in aspects such as indoor air quality, primary energy consumption of materials or CO_2-emissions. It seemed as if the barrier for the construction sector was too high, with exception of a few innovators. Therefore, green building assessment was integrated in the climate protection programme "klima:aktiv", launched by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management in 2004. The programme targets a substantial reduction of CO_2-emissions and a substantial increase in energy efficiency in the

building and transport sector, in industry, and households, by funding comprehensive activities such as the production of information material, consulting services, network development, and the elaboration of quality control procedures. [7]

The sub-programme “construction and refurbishment” offers the klima:aktiv building standard for residential and non-residential buildings, and for new build constructions as well as for refurbishments. This standard consists of selected criteria of the TQB standard with focus on outdoor and indoor environment, to communicate individual benefits along with the reduction of CO_2-emissions.

The criteria system comprises the following categories:
- A Design and Construction
- B Energy and Supply
- C Materials and Structure
- D Comfort and Indoor Air Quality

3. To lower the barrier with a step-wise system: energy certificate - klima:aktiv - TQB

Since the full implementation of the EU Directive 2002/91/EC (EPBD) in 2009, a step-wise system has been in place. The combined model was chosen to lower barriers for companies to become familiar with environmentally conscious design and construction. It was the objective to make use of the dynamism stemming from the EPBD, and to facilitate market penetration of eco-buildings by linking the voluntary building assessment schemes with the mandatory energy certificate. [8,9] Therefore, the klima:aktiv category “B Energy and Supply” fully corresponds with the energy certificate. On the way towards a sustainable building, the first step is a good energy performance documented by the mandatory energy certificate. If the developer or building owner seeks good performance beyond the energy sphere, the klima:aktiv criteria “A Design and Construction”, “C Materials and Structure”, and “D Comfort and Indoor Air Quality” can be fulfilled, and after a plausibility check the klima:aktiv label will be awarded. If the building owner or developer is ready to document that the building achieves high quality also in terms of noise protection, flexibility, and other criteria, then there exists the option to build upon the klima:aktiv data and to extend the data collection in order to receive the TQB certificate. As a condition, the building must pass a detailed check of data carried out by authorised staff.

klima:aktiv was developed based on a study commissioned by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management, and TQB was developed based on studies commissioned by the same ministry, the Austrian Federal Ministry for Transport, Innovation and Technology, and the Austrian Federal Ministry of Economy, Family and Youth.

Since 2009, the ÖGNB - Austrian Council for Sustainable Construction has been involved in both building assessment schemes. [10]

4. The role of research and demonstration

The Austrian research programme “Building of Tomorrow” is an integrated research program, which supports the process of change towards sustainability by funding research projects, prototype development, and demonstration building projects. Since 1999, numerous projects have been funded, among others the development of the TQB building assessment scheme. The building assessment scheme has served as a guideline on performance criteria and how to achieve them, and as a tool to make the building quality visible in the form of a building certificate.

Sustainability requirements resulted in development of new products and technologies, such as: [11]

- Thermal flat collectors to be used as 'facade collectors', which can be installed without any back ventilation onto facades. The new component represents a high architectural quality and style element for facades, and can be recycled after the lifetime has ended.
- Photovoltaic modules for building integration. PV-modules provide energy and at the same time take over additional functions such as building covering or shading. They can be manufactured on demand in various sizes, and due to their “break-through security” the modules are applicable for facades as well as overhead glazings.
- Single-stage adsorption chiller working with water as cooling agent and silica gel as adsorbent agent for a low range of performance (2 to 50 kW refrigerating capacity), and based on energy supply with hot water, provided by solar panels or district heating.
- Product development for the inside thermal insulation for houses designated as having special historic status, with restrictions concerning the insulation of outer walls.

Demonstration buildings were constructed using new concepts, products and technologies developed in the research programme. All demo-projects have been assessed and evaluated with the TQB-tool and are easy to be found with the “Buildings of Tomorrow” roadmap, which is available on the programme website. [12] TQB assessment results are available at www.oegnb.net.

In Austria, many of the buildings built between 1950 and 1980 are now being retrofitted or refurbished. If these refurbishments achieve a high level of energy performance, or even reach a plus-energy standard, they would represent a major step towards achievement of the European 2020 targets.

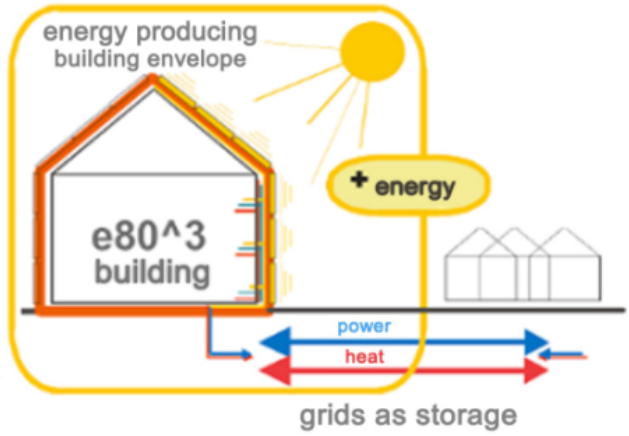


Fig. 1: Heat and electric power network

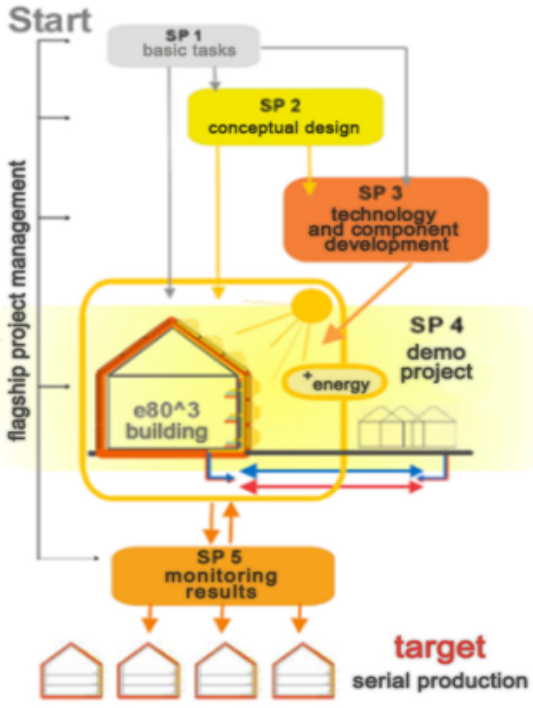


Fig. 2: Project stages

The concept contributes significantly to the achievements of three EC-objectives:

80% energy efficiency – reduction of energy demand
80% ratio of renewable energy sources of the total energy consumption
80% reduction of CO2 emissions

A change from buildings that consume energy to plus-energy buildings requires building functions and systems to be completely redesigned. High-performance refurbishments can only be achieved through an integrated design that includes advanced energy concepts. Specifically, this will require a high-quality thermal refurbishment of the building envelope with simultaneous integration of energy-producing active elements (solar thermal collectors and photovoltaic elements), as well as network integration for electricity and heat.

4.1 e80^3-Buildings - project

In the paper the successful refurbishment of the lead project “e80^3-Buildings” [13] - *reconstruction concepts towards energy plus house standard with prefabricated active roof and facade elements, integrated home automation and network integration* - of the research program “house of tomorrow – plus” will be described in detail. This project is realized as a case study – demonstration project – in Kapfenberg (Styria/Austria) by the property developer „Gem. Wohn- u. Siedlungsgenossenschaft ennstal“ in the years 2010 to 2013.

The aim of the project is to promote the high-efficient retrofit of existing buildings and estates built between 1950 and 1980 in urban areas. The retrofit concept is based on energy efficient measures, on a high ratio of renewable energy sources and on an intelligent integration of energy supply in heat and electric power networks (see *Fig. 1*). The project is divided into several subprojects, seen in *Fig. 2*.

5. Conceptual design

Within the first sub-project [14] a criteria catalogue was developed to select buildings with the highest energy potential within a building portfolio.

The decision whether to renovate or demolish a building is supported by assessment criteria grouped into four categories, applicable to all major building types.

- quality of the location and the building
- renovation potential
- potential towards a plus-energy standard
- potential for application of prefabricated modules

5.1 Conception of the thermal envelope

Through the regular facade structures, especially of buildings from the 60s and 70s, the project team decided on the development of a vertical facade module. Thus, large-format facade elements over the entire height of the building can be mounted between HVAC modules and other equipment. In the development process the transportation and installation on site plays a significant role. To allow an economic assembly, this must be possible without intermediate storage of the facade module by the use of one mobile crane. Another requirement for the facade module are the available sizes of components, such as windows and facade panels. An overview of the prototype can be seen in *Fig. 3*.

Fig. 3: The actual facade module

The thickness of the facade module (see *Fig. 4*) is defined by the functional and technical requirements, such as maximum heat transfer coefficient (U-value), static requirements and possibility to be compatible with existing tolerances of the existing buildings. Where as in the project the existing unevenness of the façade made it necessary to add an additional internal thermal insulation layer of about 4cm to compensate the tolerances.

To fulfill the requirements concerning moisture proofing, noise and fire protection as well as air tightness, special building materials such as oriented strand board (OSB) or mineral wool are used. To fulfill the moisture requirement vapor- and air-tight connection within the facade module for the windows as well as the connection between the modules are of particular importance.

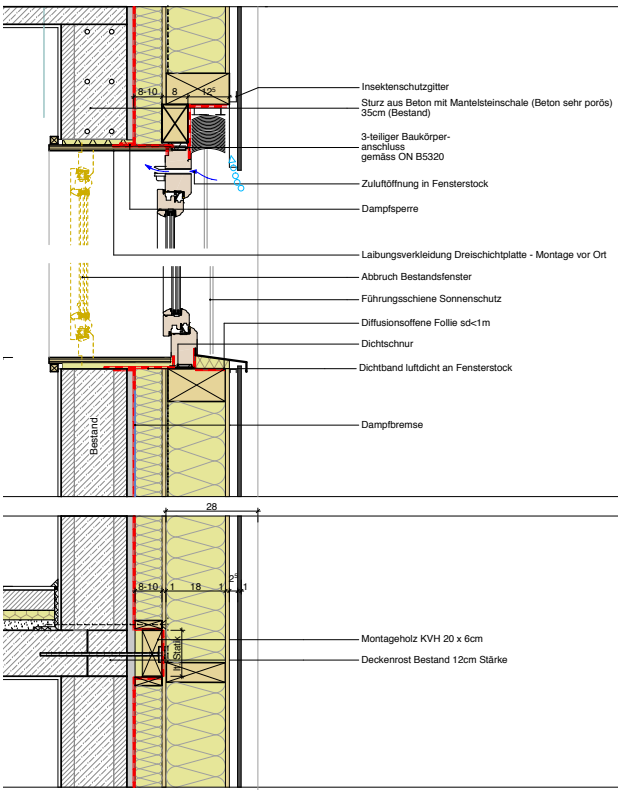


Fig. 4: Overview of the prototype (Nussmüller Architekten GmbH)

Another requirement for the facade module is the integration of active (energy producing) elements, such as photovoltaic, solar thermal panels or solar honeycomb elements. In *Fig. 5* a cross section of the integration of a solar thermal panel is shown.

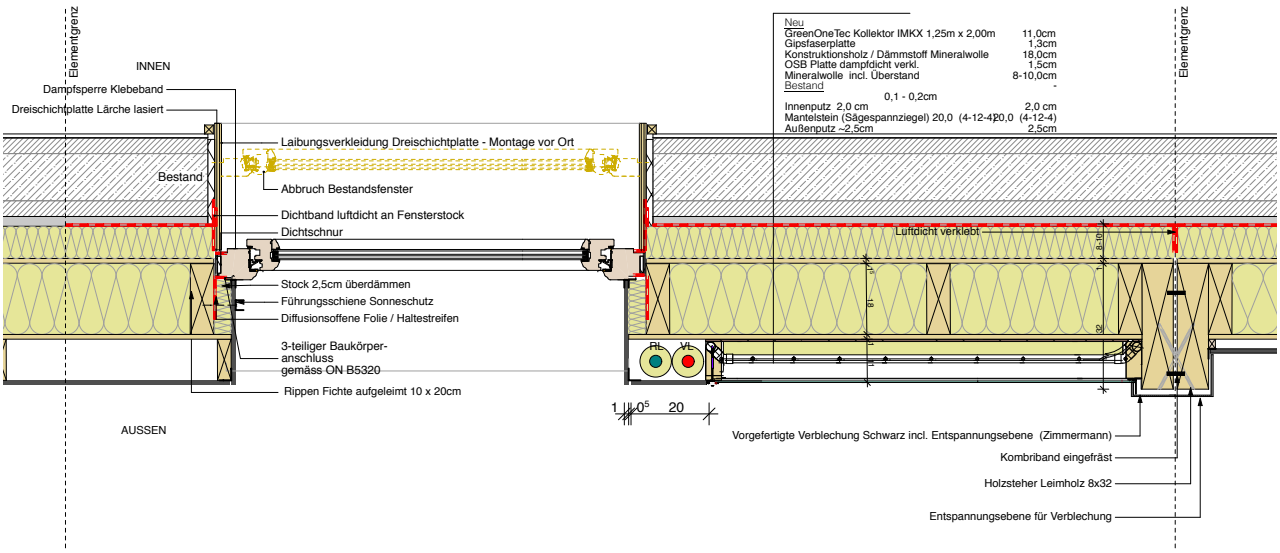


Fig. 5: Cross section of the facade module with integrated collector (Nussmüller Architekten GmbH)

5.2 HVAC modules

To achieve the goal of a plus-energy standard an innovative energy and building services concept needed to be developed. This means the design of technical building systems - HVAC (heating, ventilation and sanitary supply) and its integration into the façade (see *Fig. 6*, *Fig. 7*, *Fig. 8*).

In the project a façade integrated service module was designed to allow vertical and horizontal connections. The installation of the module and the technical building systems respectively has been integrated into the façade, which allows an easy way of inspection and fast replacement/adaptation of pipes and media.

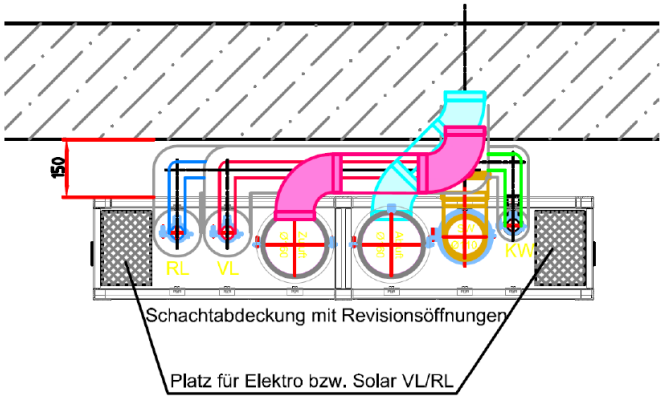


Fig. 6: Short description of building service modules (TB Hammer GmbH and Huter-Geberit)

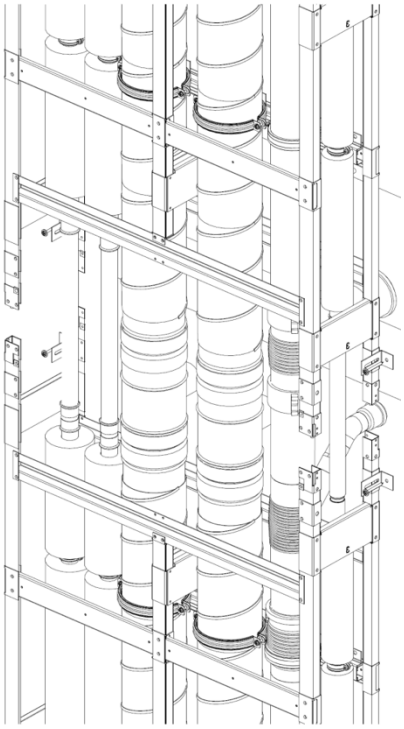


Fig. 7: Building service module (TB Hammer GmbH and Huter-Geberit)

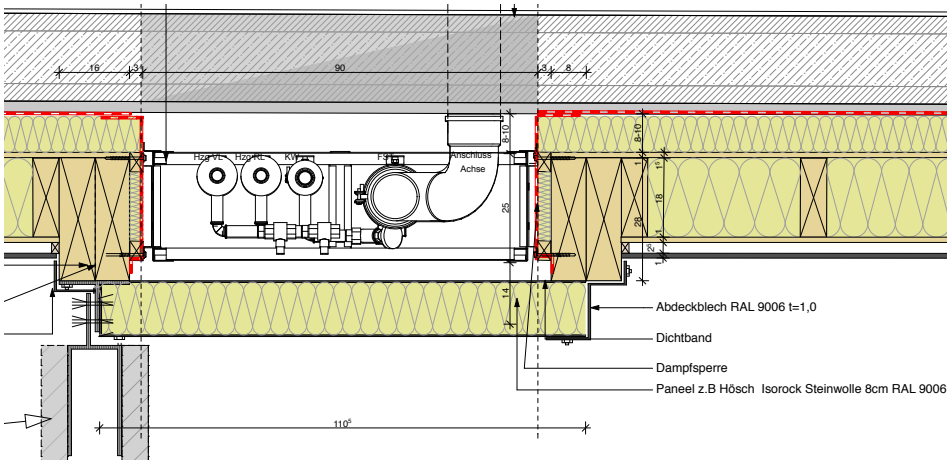


Fig. 8: Finished part of the building service module (Nussmüller Architekten GmbH)

6. Case study

The case study is located in the northern part of Styria, a City called Kapfenberg. The building owner is Gem. Wohn- u. Siedlungsgenossenschaft Ennstal reg. Gen.m.b.H. Liezen. The project consists of 32 residential units with a total gross floor area of 2.800 m^2 and total construction costs of approximately 3,5 Mio €. The case study is part of the research program “house of tomorrow – plus” as a so-called lead project e80^3-Buildings [13].

6.1 Architectural concept

One of the main issues of the architectural concept is to publicly display the installed innovative building elements in the facade and on the roof. With the integration of active elements like PV-modules and solar thermal collectors as well as passive components the transition towards energy generation of building becomes a visible element of the energy concept for the public (see *Fig. 9*).



Fig. 9: Rendering of the refurbished building (Nussmüller Architekten ZT GmbH)

6.2 Energy concept

The starting position for the refurbishment was a detailed site inspection and a calculation of the energy demand of the existing building. The heating energy demand was 101 kWh/m2*a. The main objective was to reduce this to approximately 15 kWh/m2*a.

To reach a plus-energy building the following key elements were integrated into the energy concept:

- high quality thermal refurbishment (opaque and transparent facade)
- controlled ventilation with heat recovery technology
- reduction of electric energy demand in households (e.g. smart meters and energy efficient equipment and lighting)
- use of solar (thermal) collectors for heating and hot water
- use of photovoltaic collectors ?

Main parameters (U-values) of the building envelope before and after the refurbishment are shown in *Table 1*.

Table 1: U-value comparison of existing building and restored building

Component	U-value of existing building in W/m^{2}K	U-value of refurbished building in W/m^{2}K
External wall	0,87	0,12
Window	2,50	1,00
Top floor ceiling	0,74	0,10
Basement floor ceiling	0,39	0,30

The energy concept of the refurbished building is pictured in *Fig. 10*.

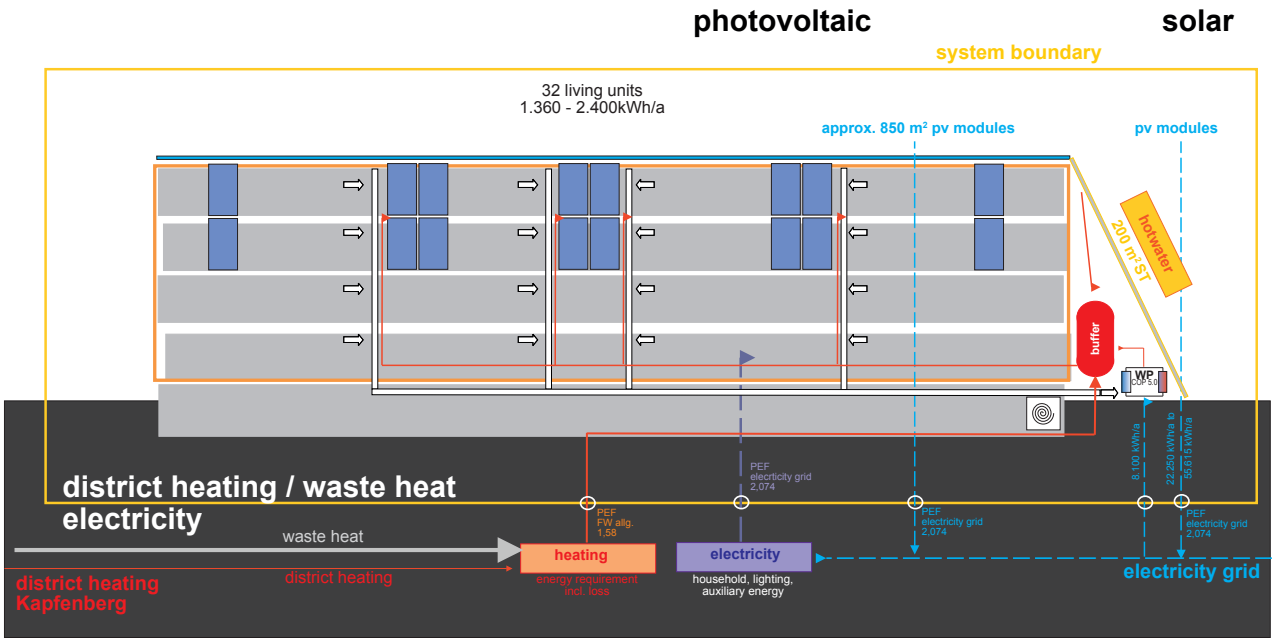


Fig. 10: Energy concept of the refurbished building (AEE INTEC, TU Graz)

6.3 Implementation on site

The various steps of the installation of the modules are pictured in Fig. 11 to 14.



Fig. 11: Manipulation on site with finished module (TU Graz)



Fig. 12: Fixing finished module (TU Graz)



Fig. 14: New finished building service module (TU Graz)



Fig. 13: Integrated PV-modules in facade (TU Graz)

7. Results of the sustainability performance

7.1 Building sustainability assessment

In the past few years, an increasing number of building certification systems have been placed on the market. In the current project a complete assessment by the use of TQB-assessment system [13,14,15,16,18,19] and monitoring [17] are part of the objectives for the research project.

The results for the first assessment in the planning phase are pictured in *Fig. 15*.

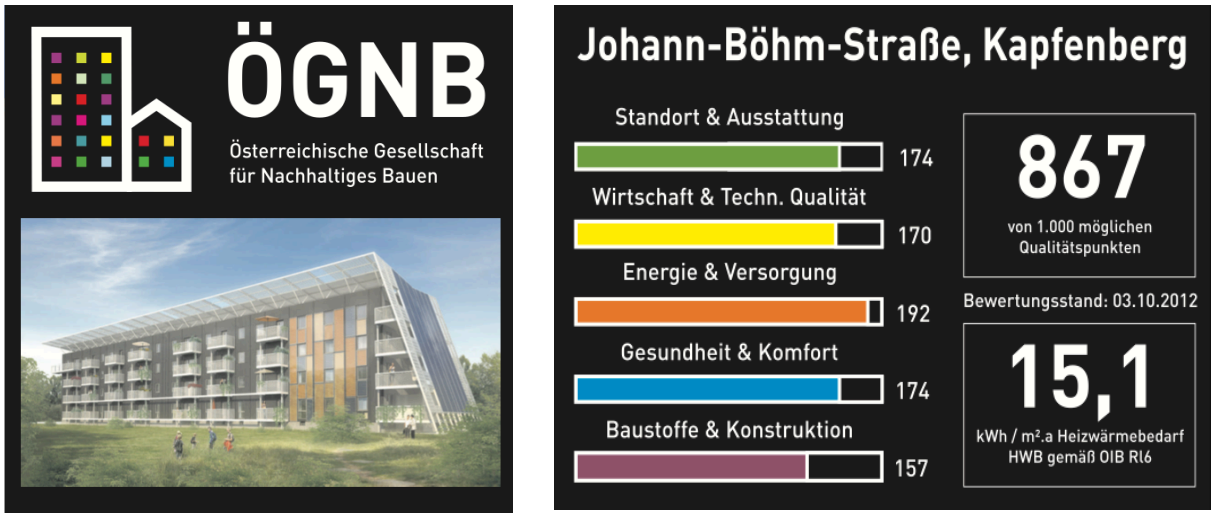


Fig. 15: Result of the TQB-certification

8. Conclusions and outlook

The demand on buildings, which allow the enhancement of the principles of a sustainable development, will gain more and more importance in the private as well as the public sector. This trend is based not only on marketing demands but also due to the need of better life cycle performance. One of the instruments in proving the performance is building certification, which includes aspects as e.g. LCA and LCCA as well as user comfort (as part of the functional performance) or technical aspects. The TQB building assessment scheme has an important role in the field of research and demonstration, and is very well accepted by innovators.

For the building sector this results in increased requirements primary focusing on new buildings. whereas the existing building stock offers the biggest potential to contribute to these targets.

In the current case study it is shown that a high-quality refurbishment towards plus-energy buildings is possible only through an integrated refurbishment approach including an energy concept. Thus requires a high-quality thermal refurbishment of the building envelope with simultaneous integration of energy-producing active elements (solar thermal collectors and photovoltaic elements), as well as network integration for electricity and heat.

By the use of prefabricated elements the goal of a more energy efficient and lower environmental building sector can be reached.

9. Acknowledgements

The research project *e80^3-Buildings* [13] - *"reconstruction concepts towards energy plus house standard with prefabricated active roof and facade elements, integrated home automation and network integration"* is funded by the Federal State of Styria and the program “Building of Tomorrow” of the Austrian Federal Ministry of Transport Innovation and Technology (BMVIT) via the Austrian Research Promotion Agency (FFG).

10. References

[1] Statistik Austria, Gebäude- und Wohnungszählung 2001.
[2] Energy Economics Group, Vienna University of Technology (2009): Energieszenarien bis

2020: Wärmebedarf der Kleinverbraucher, im Auftrag des Umweltbundesamtes.
[3] Lang, G.; Lang, M. (2009): CO_2 und Energie im Wohnbau. Wien: IG Passivhaus Österreich.
[4] reclip:more project website, http://foresight.ait.ac.at/SE/projects/reclip/ (2013-07-23)
[5] Geissler, S.; Bruck, M. (2001): ECO-Building–Optimierung von Gebäuden. Entwicklung eines Systems für die integrierte Gebäudebewertung in Österreich. Wien: Berichte aus Energie- & Umweltforschung 29/2001, Bundesministerium für Verkehr, Innovation und Technologie
[6] Geissler, S.; Bruck, M.; Lechner, R. (2004): Total Quality (TQ) Planung und Bewertung von Gebäuden. Wien: Berichte aus Energie- & Umweltforschung 08/2004, Bundesministerium für Verkehr, Innovation und Technologie.
[7] Austrian climate protection programme, http://www.klimaaktiv.at/article/archive/11911/ (2013-07-23)
[8] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPBD). Official Journal of the European Communities, 4.1.2003.
[9] OIB Richtlinie 6 Energieeinsparung und Wärmeschutz, Ausgabe: April 2007. Wien: Österreichisches Institut für Bautechnik.
[10] TQ and TQB certified buildings, http://www.oegnb.net (2013-07-23)
[11] Description of the research programme and reports for download, http://www.hausderzukunft.at/english.htm (2013-07-23)
[12] Demonstration buildings (Building of Tomorrow), map for download, http://download.nachhaltigwirtschaften.at/hdz_pdf/oesterreich_demonstrationsgebaeude.pdf (2013-07-23)
[13] e80^3-Buildings - "reconstruction concepts towards energy plus house standard with prefabricated active roof and facade elements, integrated home automation and network integration", Federal Ministry of Transport, Innovation and Technology, Austria, Research Promotion Agency (FFG), http://www.hausderzukunft.at/results.html/id5836
[14] Höfler K., Geier S. et al.: e80^3-Gebäude SP1: Subprojekt 1 (SP1) "Grundlagenarbeiten" des Leitprojektes e80^3 Sanierungskonzepte zum Plus-Energiehaus mit vorgefertigten aktiven Dach- und Fassadenelementen, integrierter Haustechnik und Netzintegration, Bericht aus Energie- und Umweltforschung 32/2011, Haus der Zukunft, bmvit, 2010.
[15] Höfler K., Kunesch R. et al.: e80^3-Gebäude SP2: Subprojekt 2 (SP2) "Konzeptentwicklung" des Leitprojektes e80^3 Sanierungskonzepte zum Plus-Energiehaus mit vorgefertigten aktiven Dach- und Fassadenelementen, integrierter Haustechnik und Netzintegration, Bericht aus Energie- und Umweltforschung 20/2012, Haus der Zukunft, bmvit, 2011.
[16] Höfler K., et al.: e80^3-Gebäude SP3: Subprojekt 3 (SP3) "Technologie- und Komponentenentwicklung", Zwischenbericht für Forschungs- und Entwicklungsprojekte, Haus der Zukunft, bmvit, 2011
[17] Federal Ministry for Transport, Innovation and Technology (BMVIT), Austrian Research Promotion Agency (FFG), monitorPLUS, http://www.ecology.at/monitor_plus.htm
[18] Passer, A., Kreiner, H., Halder, T., & Höfler, K. (2013). E80 ^ 3 - A PLUS - ENERGY BUILDING CONCEPT FOR EXISTING. SB13-Munich.
[19] Passer, A., Kreiner, H., & Halder, T. (2013). PLUS ENERGY IN REFURBISHMENT – PROOF OF CONCEPT Case study. Central Europe towards Sustainable Buildings 2013, 1–4.

Certification System for Research and Laboratory Buildings – The Case Study MED CAMPUS Graz



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Summary

In the year 2004 the Medical University of Graz (MUG) was founded as an autonomous university and is currently split into several locations spread all over the city of Graz. A project called MED CAMPUS will provide an opportunity to merge the university with the existing university hospital in one unified location. Physical contiguity will do more than solving the difficulties of the current situation; it will enable teaching, research & development and patient care to reach an international level of excellence.
The project area consists of two construction sites where twelve institutes are combined in four centers. Facilities will include teaching facilities, administration offices, a library, a canteen an assembly hall, and space for start-up companies operating in related fields. The building as a modern university, research and communication center will have space for around 1700 employees and 4300 students.
From the project's inception, the rectorate managed its development as a sustainable and healthy property in the broadest sense, and this has resulted in sustainability quality targets having been included in the public competition requirements.
This case study presents the architectural concept of the project MED CAMPUS Graz. Further more the applied assessment method and the achieved level of building sustainability based on the assessment criteria of DGNB/ÖGNI certification of lab buildings [2] will be shown.

Keywords

Sustainability; DGNB/ÖGNI certification of lab buildings; building assessment case study

Acknowledgments

This described work in the paper was carried out in the project MED CAMPUS Graz by Medical University of Graz and Bundesimmobiliengesellschaft m.b.H. with the generalplaner Riegler-Riewe Architects ZT GmbH (architects, commissioned by BIG) and Team TU Graz (Prof. Maydl, commissioned by Med Uni Graz). We would like to thank all partners for their support and their inputs.

References

[1] Project MED CAMPUS Graz, https://www.medunigraz.at/8214
[2] DGNB Certification of Lab Buildings, http://www.ogni.at/de/zertifizierung/

B2

Evaluation of Embodied Energy and Carbon Dioxide Emissions for Building Construction (Annex 57)

Chair: Isabella Zwerger
Federal Ministry for Transport, Innovation and Technology, Austria

IEA ECBCS, ANNEX 57
-EVALUATION OF EMBODIED ENERGY AND CARBON DIOXIDE EMISSIONS FOR BUILDING CONSTRUCTION-



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Short Summary

The total energy consumed by a building during its whole life cycle includes both embodied and operational energy. Embodied energy is 'embedded' in construction materials during all production processes, on site construction and demolition and final disposal, while operating energy is consumed in operating and maintaining the internal environment of a building. The accuracy of operational energy use and related carbon dioxide (CO_2) emissions prediction methodologies has been improved in recent years, resulting in more energy efficient building designs. As operational energy use is so reduced, the embodied energy and CO_2 emissions become proportionally more significant.

The project (IEA ECBCS, Annex 57, 2012-2015) is investigating methods for evaluating embodied energy and CO_2 emissions of buildings, to develop guidelines that contribute to practitioners' further understanding, and to find better design and construction solutions for buildings with less embodied energy and CO_2 emissions.

Keywords: IEA ECBCS, Embodied energy, Embodied CO_2 emission, Data base, Case study

1. Introduction

The evaluation of energy consumption and related carbon dioxide (CO_2) emissions due to the use of buildings is becoming increasingly accurate and is being applied in the design of more energy efficient building envelopes and systems. As such, the importance of energy consumption and CO_2 emissions due to stages other than the use of buildings is increasing, and, consequently, the methods used to estimate energy consumption and CO_2 emissions will become increasingly important. Therefore, the scientific basis of the embodied energy and CO_2 emissions for building construction should have been investigated by organizing the new Annex and an international team for the IEA ECBCS program.

The Annex 57 deals with methods for evaluating embodied energy/CO_2 of buildings in order to develop guidelines that contribute to improved understanding of evaluation methods and help developers to find better design and construction solutions for buildings with reduced embodied energy/CO_2.

2. Research areas of Annex 57

2.1 Basics

[1] Actual trends and activities related to embodied energy/CO_2 in the world
[2] Demands related to embodied energy/CO_2 by various groups of actors (survey)
[3] Integration of embodied energy/CO_2 into decision making process (survey)

2.2 Literature Survey

[1] Definition of key concepts and technical terms of embodied energy/ CO_2
[2] Characteristics of existing databases of embodied energy/CO_2 intensities and tools to quantify building materials and components
[3] Current trends and future perspective

2.3 Evaluation methods for embodied energy and CO_2 emissions

[1] Methodology for databases of the embodied energy/CO_2 intensities and quantifying volumes of building materials, components, equipment, and other elements
[2] Recommendations on how the databases and methods should be used

2.4 Design and construction methods for buildings with low embodied energy and CO_2 emissions

[1] Options for design and construction to reduce embodied energy and CO_2 emissions
[2] Use of recycled or reused materials and components
[3] Life of building and its prolongation
[4] Retrofit with low embodied energy and CO_2 emissions
[5] Consideration of GHGs other than CO_2
[6] Case studies and best practices

2.5 Deliverables

[1] The state of the art for embodied energy/CO_2 due to building construction.
[2] Guidelines of evaluation methods for embodied energy /CO_2 due to building construction.
[3] Guidelines of design and construction methods for buildings with low embodied energy and CO_2 emissions.
[4] Project summary report summarizing the technical outputs from Annex 57

3. Embodied energy/CO2 related to building construction in Japan

3.1 Input-Output (IO) analysis

IO table of Japan consists of 520x407 matrix, from which 401 symmetry matrix is derived. The inversion, GDP and final demand are expressed by the following formula.

$$\mathbf{X}=\{\mathbf{I}-(\mathbf{I}-\mathbf{M})\mathbf{A}\}^{-1}\{(\mathbf{I}-\mathbf{M})\mathbf{F}_{(D)}+\mathbf{F}_{(E)}\} \quad (1)$$

X:GDP(Yen/year) $\{\mathbf{I}-(\mathbf{I}-\mathbf{M})\mathbf{A}\}^{-1}$:Leontief inversion **I**:Unit matrix
M:Import matrix mi=**M**i/**C**i mi:Import parameter(-) **M**i:Import of industrial sector i (Yen/year)
Ci:GDP of industrial sector i (Yen/year)
A:Activity(-) $\mathbf{F}_{(D)}$:Final demand(Yen/year) $\mathbf{F}_{(E)}$:Export(Yen/year)

3.2 Energy/CO_2 intensities of industrial products in Japan

Final GDP shown by **X** can be derived by inputting final demand $\mathbf{F}_{(D)}$ in Equation (1). The value of **X** involves whole economic influences caused by $\mathbf{F}_{(D)}$. *Table 1* shows major energy consumption and CO_2 emission factors regading building construction. Assuming that 0.44kg-CO_2/kg-cement is

released in the cement resolving process, this value is added to CO_2 emission due to fuel consumptions. CO_2 emission due to residential construction (wooden) can be estimated 270 kg-CO_2/m^2 (=1,707/6.318) and non-residential (non-wooden), 395 kg-CO_2/m^2 (=2,704/6,844).

The intensities of equipment are similar between 1,727 and 2,408 kg-CO_2/Mln.Yen, which means the values are within ∓ 17%. It may be possible to estimate the embodied CO_2 of equipment by the average intensity and the total price of the equipments within the error of 17%. This estimation method is simpler for early building design stage.

Table 1: Energy/CO_2 intensities of industrial products in Japan by 2005 IO analysis (Rate: 1 Euro=137 Yen, 1US$=111 Yen)

No.	Industrual Sector	Energy (MJ)			CO2(kg-CO2)			Unit/Mil Yen
		Per Producer Price of Mln Yen		Per Consumer price of Mln Yen	Per Producer Price of Mln Yen		Per Consumer price of Mln Yen	Quantity of Matrial for Consumer Price of Mln Yen
		Energy in Product Process	Energy for Transportation and Trade		CO2 in Product Process	CO2 for Transportation and Trade		
1	Logs	10,264	3,477	11,739	713	242	816	62.36 m3
2	Gravel and quarrying	61,887	18,056	52,153	4,301	1,256	3,626	287.5 t
3	Timber	10,974	5,119	13,621	769	356	952	22.68 m3
4	Plywood	22,527	5,378	22,697	1,594	374	1,599	7.0 m3
5	Plastic products	68,239	3,165	56,893	4,763	221	3,971	
6	Sheet glass and safety glass	41,841	4,864	36,902	2,999	340	2,636	
7	Glass Fiber and g1ass Fiber products	85,036	3,949	71,691	5,732	276	4,842	
8	Cement	441,709	13,136	315,036	117,145	925	80,992	124.4 t
9	Ready mixed concrete	107,411	4,903	81,093	23,126	341	16,745	62.60 m3
10	Cement products	53,674	5,462	43,193	7,985	381	5,994	
11	Crude steel(converters)	410,207	454	394,408	41,509	32	39,897	21.45 t
12	Crude steel(electric furnaces)	103,517	432	100,059	8,651	30	8,356	19.47 t
13	Hot rolled steel	228,848	3,147	189,779	22,135	220	18,271	13.47 t
14	Steel pipes and tubes	142,490	3,212	119,963	13,374	224	11,182	6.158 t
15	Copper	22,898	1,640	22,906	1,756	115	1,745	2.072 t
16	Aluminum(inc. regenerated aluminum)	17,835	3,270	18,187	1,308	229	1,323	4.308 t
17	Metal products for construction	68,881	6,136	63,388	6,199	425	5,577	
18	Metal products for architecture	39,211	3,803	35,353	3,249	264	2,878	
19	Boilers	25,388	2,647	22,980	2,057	185	1,832	
20	Engines	35,119	3,106	29,550	2,910	217	2,408	
21	Refrigerators and air conditioning apparatus	25,350	2,288	23,502	1,970	160	1,808	
22	Pumps and compressors	31,573	3,134	27,127	2,657	219	2,238	
23	Electric transformer	22,871	1,898	21,509	1,860	132	1,727	
24	**Residential construction(wooden)**	**19,921**	**0**	**19,921**	**1,707**	**0**	**1,707**	**6.318 m2**
25	**Residential construction(non-wooden)**	**29,055**	**0**	**29,055**	**2,704**	**0**	**2,704**	**5.527 m2**
26	**Non residential construction(wooden)**	**21,103**	**0**	**21,103**	**1,835**	**0**	**1,835**	**7.749 m2**
27	**Non residential construction(non-wooden)**	**29,644**	**0**	**29,644**	**2,704**	**0**	**2,704**	**6.844 m2**
28	Public constructiono for roads	34,533	0	34,533	3,451	0	3,451	
29	Electricity supply	361,436	0	361,436	26,737	0	26,737	61.91 MWH
30	Gas supply	60,992	0	60,992	3,864	0	3,864	10910 m3
31	Railway transport (freight)	52,388	0	52,388	3,922	0	3,922	
32	Road freight transport service	45,328	0	690,696	3,132	0	47,728	

3.3 Profile of CO_2 emission

Fig. 1 shows the profile of CO_2 emission in Japan. Embodied CO_2 due to building construction and civil engineering is 19.2% and operation of buildings, 23.2%.

3.4 Fraction of embodied CO_2 in the world

Since Input-Output tables of 60 industrial sectors for OECD countries are provided at web site (http://epp.eurostat.ec.europa.eu), CO_2 emissions due to construction in major coutries can be calculated roughly with data of energy consumption in the countries. *Fig. 2* shows an estimation of the total CO_2 emissions in various countries and the corresponding fractions of embodied CO_2 due to building construction and civil engineering. The gray areas indicate the total embodied CO_2 in the world. In particular, fractions of embodied energy are higher in developing countries and often exceed the building operation energy.

As shown in *Fig. 2*, the embodied energy/CO_2 differs among countries depending on the building design, the energy intensity of materials, and the quantity of materials used in the building.

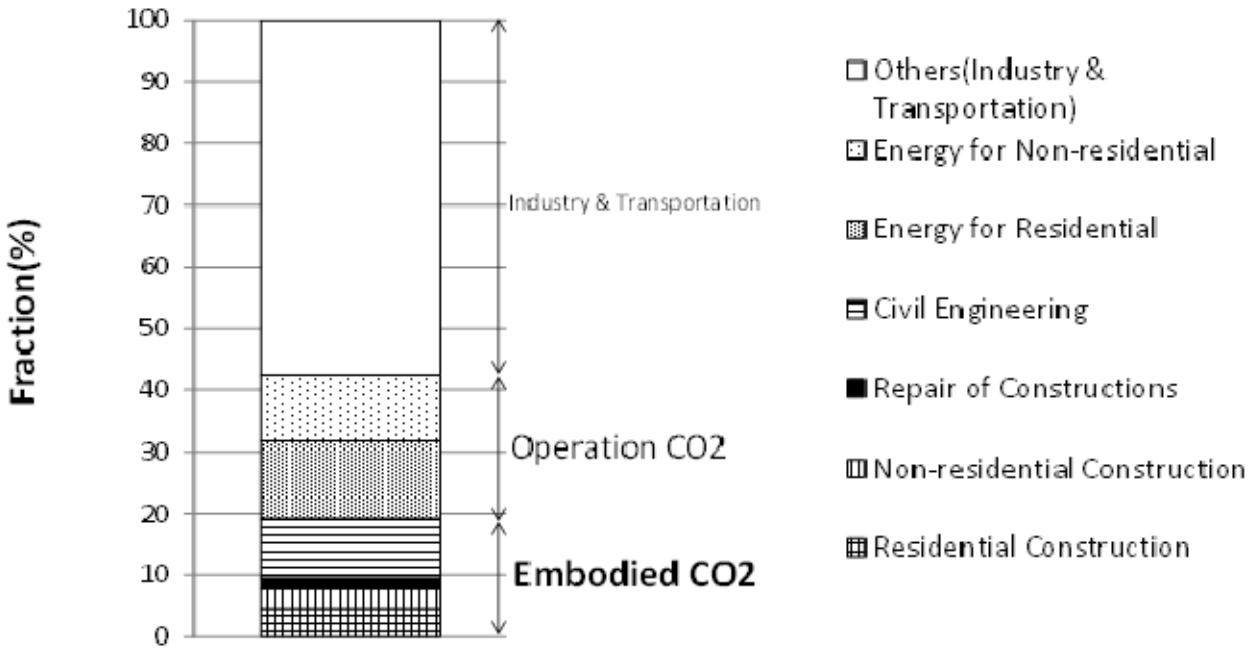


Fig. 1: Profile of CO_2 emission in Japan by Input-Output analysis (2005)

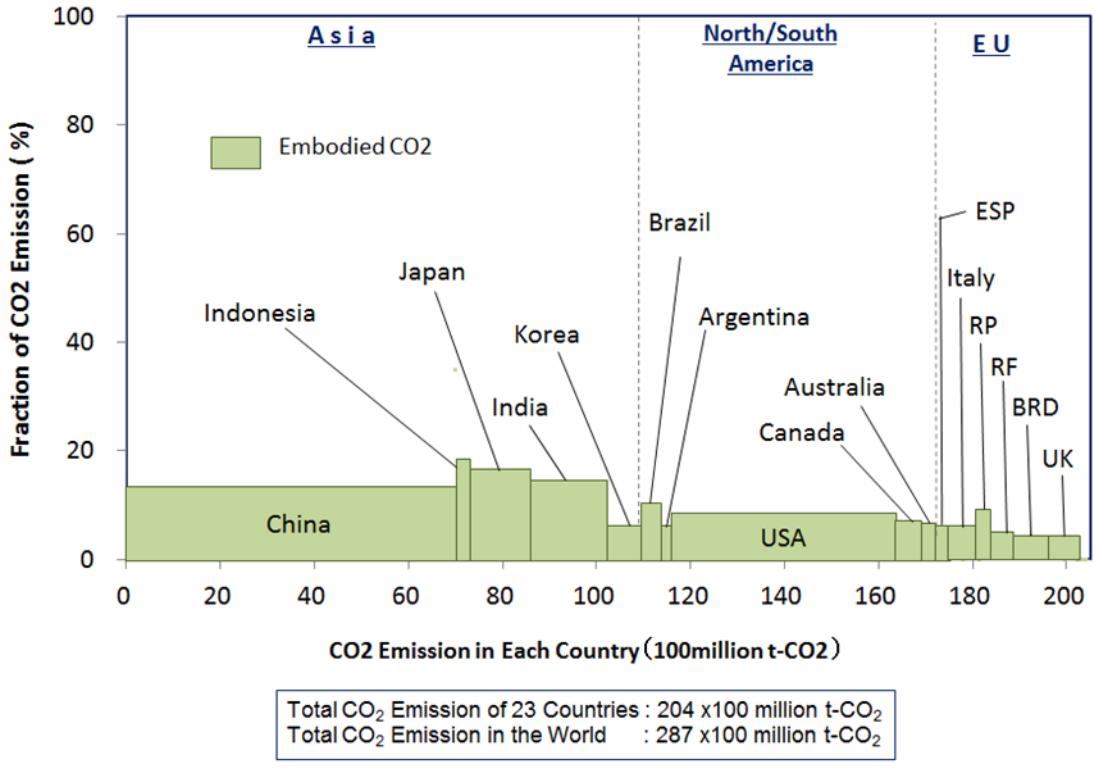


Fig. 2: The CO_2 emission of each chosen country (horizontal axis) and the fraction of embodied CO_2 (vertical axis) RP: Poland RF: France BRD: Germany

4. Some remarks regarding database and embodied energy/CO_2

4.1 Fraction of CO_2 emission in gate factory

The data of embodied energy/CO_2 for building materials complied with the International Organization for Standardization (ISO) or IO analysis are widely provided as tables for energy consumption and CO_2 emission factors. ISO tends to show the factory efficiency more than the embodied energy/CO_2 due to building construction. Although databases complied with IO analysis seem to be more relevant, the number of building component is much less than that of the ISO based database from a practical standpoint.
Table 1 shows the fraction of embodied CO_2 of building components in the gate factory, which is the final factory of the supply chain. These values can be calculated by IO analysis with Equation (1). CO_2 emission due to cement products is mainly in the process to produce cement. However CO_2 emission due to production of hot rolled steel is mainly in the process to produce pig iron and the CO_2 emission in the gate factory is very small. Generally the energy consumption and CO_2 emission in the gate factory is small compared with the whole embodied energy/CO_2, and therefore shows that the embodied energy/CO_2 of input materials into the gate factories should be estimated accurately.

Table 2: Fraction of CO_2 emission in gate factory

No.	Industrial Sector	CO2 emission in industrial sectors (%)					
		Cement products	Hot rolled steel	Air condit-ioning	Pump, refrige-rator	Wooden house	Non wooden building
1	**Cement**	**64.88**	0.04	0.29	0.18	17.61	18.00
2	Cement products	9.29	0.00	0.01	0.00	0.37	0.29
3	Pigiron	7.94	84.30	28.72	48.67	18.08	31.03
4	Crude steel(converters)	0.24	2.53	0.75	1.32	0.54	0.93
5	**Hot rolled steel**	0.33	**3.51**	0.89	1.78	0.74	1.27
6	**Refrigerators and air conditioning apparatus**	0.00	0.00	**4.32**	0.00	0.00	0.02
7	**Pumps and compressors**	0.00	0.00	0.06	**3.06**	0.01	0.01
8	**Residential construction(wooden)**	0.00	0.00	0.00	0.00	**2.70**	0.00
9	**Non residential construction(non-wooden)**	0.00	0.00	0.00	0.00	0.00	**4.59**
10	Electricity supply	7.63	4.77	32.15	21.38	16.00	12.94
11	Road freight transport service	0.98	0.25	2.07	1.65	4.80	2.99
Total		96.00	96.89	84.15	89.98	83.06	88.27

CO2 emission in Gate Factory

4.2 Approximate estimation of embodied CO_2 of buildings

Design and construction methods for buildings with low embodied energy and CO_2 are being improved by the use of recycled materials, prolongation of building life, retrofitting, and also reduction of non-CO_2 greenhouse gas emissions. Since approximately 90% of the building performance is determined in the initial design stages, it is effective to show designers the results of case studies to reduce the embodied energy/CO_2. An approximate estimation was made to find the significant factors to reduce embodied energy/CO_2.

4.2.1 Prolongation of building life

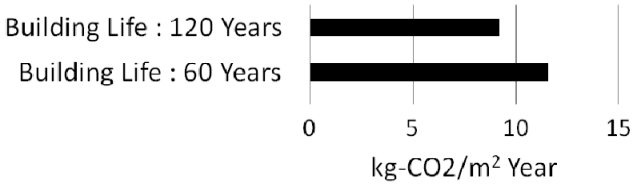
Table 3 shows the reduction of embodied CO_2 by the prolongation of building life in Japan. Although the quantity of steel is necessary more than 30% to prolong the building life, 21% of the whole embodied CO_2 can be saved per year.
In the case that the quantity of steel for the building structure is 30% more than the requirement by the regulation, the structure is predicted to respond within the range of elastic behaviour at the time

of the estimated maximum quake. This measure realizes the prolongation of the building life in Japan.

Table 3: Reduction of embodied CO_2 due to prolongation of building life

(a) Calculation process

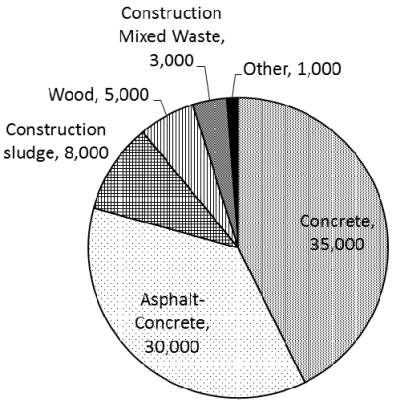
Durability	Unit	Concrete	Steel	Other	Total	kg-CO2/Year
60 Years	Material/m^2	0.50m^3	180kg	320	697	11.6
	kg-CO2/m^2	134	243			
120 Years	Material/m^2	0.55m^3	234kg	640	1103	9.2
	kg-CO2/m^2	147	316			
Remark	-	Deeper covering between steel and concrete surface	Stronger structure against earthquake	-	-	Reduction of Embodied CO2 by 21%



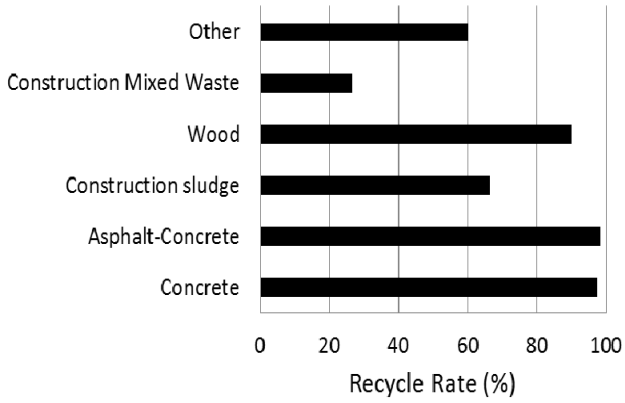
(b) Reduced embodied CO_2 by prolongation of building life

4.2.2 Recycle rate of building materials in Japan

Fig. 3 shows the waste of building and construction materials in Japan. Most materials such as concrete are recycled by reusing in different industrial sectors. Metal products such as steel and aluminum are 100% recycled. Since a lot of kind of glass is provided for building construction, glass is difficult material to recycle completely.



(a) Quantity of waste (Unit: 1000t)



(b) Recycle rate of waste

Fig.3: Recycle rate of building materials in Japan

4.2.3 Greenhouse effect by Freon gases

(1) Insulation material foamed by Freon Gases

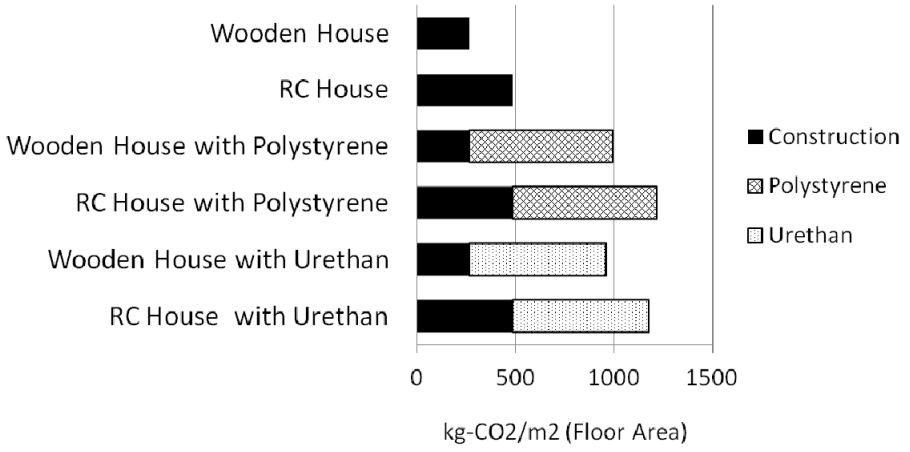
For global warming, 60% is due to CO_2 and 14% is due to Freon gases, which are used in insulation boards in some countries and in electric refrigerators. *Fig. 4* shows the impact due to insulation materials using Freon gases. This figure shows that the $CO_{2\ equivalent}$ by Freon gases is enormous.
Embodied CO_2 of wooden house can be derived from Table 1 (Embodied CO_2/m^2: 1707kg-CO_2/6.318m^2=270kg-CO2/m^2). Embodied $CO_{2\ equivalent}$ due to polystyrene insulation foamed by HFC_{134a} can be calculated by: 0.2m^3/m^2x20kg/m^3x0.07kg/kgx1300=364kg-CO_2, where since the durability of insulation is 30 years, life cycle $CO_{2\ equivalent}$ is 364x2=728kg-CO2/m^2 in 60 years. Embodied CO_2 of non-wooden house can also be derived with similar calculation.

(a) Premises of calculation

Floor area of model house	128 m^2	Durability: 60 years
Insulation (Thickness≒0.1m)	0.2m^3(Insulation)/m^2(Floor area)	Durability: 30 years
Polystyrene insulation	Density=20 kg/m^3	Durability: 30 years
Urethan insulation foamed at site	Density=30 kg/m^3	Durability: 30 years

(b) Premises of insulation materials

Polystyrene insulation	HFC134a : GWP=1300	0.07kg-HFC134a/kg-Polystyrene insulation
Urethan insulation foamed at site	HFC245fa : GWP=820	0.07kg-HF245fa-/kg-Urethan insulation



(c) Greenhouse effect

Fig. 4 Greenhouse effect by Freon gases in the insulation materials

(2) Freon gases in refrigerator

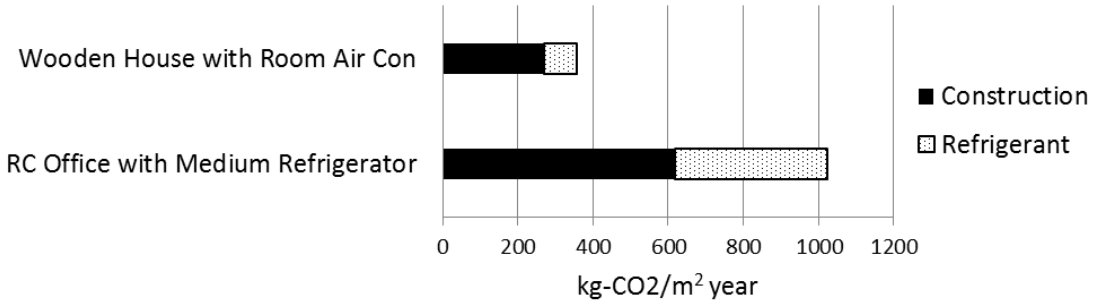
Fig. 5 shows the $CO_{2\ equivalent}$ of refrigerator and air-conditioner in the case that Freon gases are not recovered. The figure verifies that recovery and leak prevention measures are absolutely necessary to reduce embodied CO_2.
Embodied CO_2 of RC office is derived from value in *Table 3*. $CO_{2\ equivalent}$ of refrigerant can be calculated by: 0.045kg/m2x0.06x1300x60 years=211 kg-$CO_{2\ equivalent}$. To design the building which cooling/heating load is as small as possible or to use refrigerator with smaller GWP refrigerant is

effective to reduce embodied CO_2 of the building from the view point of $CO_{2\ equivalent}$ due to leakage of the refrigerant.

Type of building and refrigerator	Embodied CO2 due to construction (kg-CO2)	Refrigerant (kg)	Annual loss of refrigerant (%/year)	Refrigerant released (kg/year)	CO2equivalent of regrigerant in 60 years
Wooden House with Room Air Con	270	0.045	2.5	0.001125	88
RC Office with Medium Refrigerator	619	0.045	6-17	0.0027-0.00765	211-597 (404)

Refrigerant: HFC134a : GWP=1300 0.045kg(HFC134a)/m2

(a) Prerequisition for calculation



(b) Greenhouse effect by Freon gases in refrigerator and air-conditioner

Fig. 5 Greenhouse effect by Freon gases in refrigerators

5. Conclusion

1) The outline of Annex 57 text is described, in which the contents of literature survey, methodologies to calculate embodied energy/CO_2, the measures to reduce embodied energy/CO_2 are also shown.
2) Profile of CO_2 emission in Japan is shown with embodied CO_2 due to building construction and civil engineering as well as CO_2 emission due to building operation. Embodied CO_2 in the countries in the world are also shown as rough calculation result.
3) Energy consumption factors and CO_2 emission factors of the industrial sectors are shown as intensities. The rate of CO_2 emission in the gate factory in the supply chain is investigated.
4) Some measures and the effects to reduce embodied energy/CO_2 are investigated, in which the prolongation of building life, the use of recycled materials and the influences of Freon gases involved in insulation materials and refrigerators are described.
5) Simple prediction method is required to reduce embodied energy/CO_2 since it is the most effective way to use the guideline of embodied energy/CO_2 in the early design stage.

6. Acknowledgment

The authors express our thanks to the participants of Annex 57 and the ExCo members.

7. References

[1] Management and Coordination Agency, Government of Japan, *2005 Input-Output Tables in Japan* (http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001019588&cycode=0)
[2] National Institute for Environmental studies, http://rikanet2.jst.go.jp/contents/cp0220a/contents/f_02_05.html http://www-gio.nies.go.jp/aboutghg/nir/nir-j.html
[3] New Energy and Industrial Technology *Development Organization (NEDO), Investigation of insulation materials influenced on global warming*, 1998.3, NEDO GET 9709

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Summary

Identification of key materials which effectively define a building's impact profile have important implications not only on research time and investment, but also on understanding by designers and successful implementation of such concepts in their daily specification practice. Ranking building materials based on embodied energy and CO_{2e} and its disclosure to designers empower the material selection process, enabling more efficient, impact-driven specifications and materials balance. Disclosure of impact profiles to the general public can also provide the grounds for societal pressure for mitigation and technological improvement of the related industries, as well as advise public and sectorial policy-making. However, definition and calculation methodology of these metrics reflect current conceptual vagueness or even divergence, challenging replication, results aggregation and benchmarking. Life cycle assessment (LCA), though still embryonic in Brazil, can scientifically support such calculations. In this paper, cradle to gate LCAs were performed using SimaPro 7.3 software and followed ISO 14040:2006 methodological guidelines. Materials/components production cycle modeling used secondary data collected from national literature or adapted from international literature or from ELCD v.2.0, Ecoinvent v.2.2 and Industry Data v.2.0 databases. Inventory outputs were related to total material quantities (mass or volume) to calculate cradle-to-handover embodied energy and embodied CO_{2e}, normalized per unit of gross floor area (m^2_{GFA}) of four Brazilian case study buildings. For the studied typology, computed embodied energy and embodied CO_{2e} were around, respectively, 1.030 MJ/m^2_{GFA} and 128 kg CO_{2e}/m^2_{GFA}. Top six contributers (Portland cement CP III-32, ceramic brick, steel rebar, sawn timber planks, plywood and PVC tube) respond for over 80% of the total embodied energy computed. Analogously, over 80% of the accounted embodied CO_{2e} was related to cement, steel rebar, ceramic brick and PVC tube and conduit. Also, a core database encompassing twelve building materials and components provides a very accurate (over 97%-coverage) description of the accounted embodied energy and CO_{2e} profiles altogether, which can possibly streamline indicators monitoring scope.

Keywords: embodied energy; embodied CO_{2e}; LCA; building material; indicators; eco-efficiency

1. Introduction

The building sector is responsible for important impacts on the environment. On a global scale, building material manufacture and transportation as well as installation and construction of buildings consume great quantities of energy and emits large amounts of greenhouse gases [1].

The carbon footprint and embodied energy are indicators that, referring to buildings, measure, respectively, the CO_{2e} emitted and the energy used during the manufacture of building materials and components, in transporting these to the site, and during the construction process itself. Given

their life cycle perspective, they further include the measurements of energy and CO_{2e} emission incurred during renovations and replacement of components, as well as those resulting from demolition, waste and reprocessing at the end of the building service life.

Variability within within indicators' definition is observed worldwide, and calculations involved sometimes show clear conceptual conflicts. [2] affirm that in the building industry context, development of embodied carbon and energy accounting methods have been limited and inconsistent. Authors such as [3], for instance, defend that the carbon footprint should measure direct and indirect carbon dioxide emissions accumulated throughout a product's life cycle. Others ([2]; [4]) consider the carbon footprint as the total amount of greenhouse gases emitted – therefore referring to CO_{2e} – during a product or process's life cycle.

Calculation of both indicators can be aided by LCA platforms or, when appropriate, published databases such as [5] and [6]. In Brazil, studies performed by [7] and [8] emphasize the necessity of developing life cycle inventories for the local industry and/or carefuly validating international data before their application in national studies.

This paper presents calculations of life cycle embodied energy and embodied CO_{2e} normalized per unit of gross floor area (m^2_{GFA}) and provides preliminary Brazilian benchmarks based upon four case study buildings.

2. Methodology

The performed cradle-to-gate LCAs followed ISO 14040:2006 methodological guidelines and were supported by SimaPro 7.3 software. Data for modeling the production cycle of materials and components were mostly taken from national literature or adapted from ELCD v.2.0, Ecoinvent v.2.2 and Industry Data v.2.0 databases by switching into the Brazilian energy mix, and other appropriate adjustments. Table 1 indicates the functional unit adopted for each material/component, and the data inputs and sources used for modeling the respective production processes. The exception was the ceramic brick. Given the lack of information on that specific component in both national and international LCI databases, its production cycle modeling used embodied energy figures from [8], who explicitly detailed a methodological approach reasonably close to the one herein proposed; and embodied CO_{2e} data obtained from the University of Bath's Inventory of Carbon and Energy [5]. Even though the difference between the inventory and the Brazilian electricity mixes can impact accuracy, at the time of writing the ICE's methodological thoroughness suggested its use as a proxy.

Embodied CO_{2e} calculations was assisted by *CML 2001 v.2.05* environmental impact analysis, which presents equivalency factors for all greenhouse gases in the global warming impact category, and expresses results in kg of CO_{2e} per functional unit.

The typology investigated here is basically composed by low-rise (up to 3 floors), low window-to-wall ratio, reinforced concrete-framed, masonry façade and partitions, and ceramic or metallic roofing buildings. The four cases comprise one integrated service center (4.975,55 m²); one police-training center (1.511,74 m²); and two school buildings (4.869,23 m² and 2963,08 m²). Total usage of material/components was quantified for all case studies according to the functional unit previously defined, then divided by the total gross floor area and corrected by national estimates for construction waste [9], to configure a cradle-to-handover system boundary.

All case studies used cement type CPIII-32. For reference purposes, Portland cement and ready-mixed concrete are herein expressed considering three amounts of ground granulated blast furnace slag (ggbs) as clinker replacement: 5% in CPI-32, 30% in CPII-E-32, and 66% in CPIII-32, consistent with Brazilian standards [10], [11] and [12].

Table 1: Functional unit and inventory data source for each material and component considered.

Building materials and components	*Data input*	*Functional Unit*	*Data source*
Ready-mixed Concrete (fck 30)	Sand, gravel, water and cement (CP I-S-32, CP II-E-32 or CP III-32[1])	1 m³	[13] (cement) and Ecoinvent, version 2.2 (aggregates and water)
Portland Cement (CP I-S-32, CPII-E-32 and CPIII-32)	Calcium sulfate, clinker and crushed blast furnace slag	1ton	[13]
Steel rebar, Roofing steel structure, Copper wire	ELCD processes, adapted with Brazilian energy mix	1ton	ELCD, version 2.0 and Ecoinvent, version 2.2 (Brazilian energy mix)
PVC (conduit, tube)	Industry Data process, adapted with Brazilian energy mix	1ton	Industry Data, version 2.0 and and Ecoinvent, version 2.2 (Brazilian energy mix)
Wood (plywood; dry plank; dry roundwood)	Ecoinvent processes, adapted with Brazilian energy mix	1 m³	Ecoinvent, version 2.2
Sand, Gravel, Acrylic paint, Hydrated lime, Adhesive mortar, Ceramic tile	Ecoinvent processes, adapted with Brazilian energy mix	1ton	Ecoinvent, version 2.2

In all cases, the studied building had no basement. Ready-mixed concrete, steel rebar and formwork were considered only for the superstructure to isolate the effects of the soil's carrying capacity on the sizing - and consequently on material consumption - of foundation elements. External and urbanization elements were also disregarded. To account for typical reusability cycles, consumption of plywood, sawn planks and raw timber was divided by a factor of three. Consumption of each material/component per unit of gross floor area was then multiplied by its embodied energy/CO_{2e} per functional unit, in order to express these metrics per unit of gross floor area (m^2_{GFA}).

3. Results and Discussion

Figure 1 presents the top ten contributions to embodied energy of building materials and components per m² of gross floor area (median values of the cases studied). In this scenario, Portland cement was used in the production of other cement-based elements, as concrete was delivered ready mixed. As explained, embodied energy and CO_{2e} of Portland cement and concrete are expressed in terms of three clinker replacement possibiities practiced in accordance with Brazilian standards. International studies usually investigate the performance of ordinary Portland cement, which is composed primarily by clinker, with little or no mineral admixtures and would be equivalent to Brazilian CP I-S-32. In Brazil, however, CP II-E-32 (30% ggbs) is the cement type with the broadest commercial coverage, while CP III-32 (66% ggbs) is the top selling cement type in the region of study.

[14] speculated that 30 MPa ready-mixed concrete, steel rebar, cement, ceramic brick and timber are the materials with most embodied energy per square meter of gross floor area. [15] added glass and aluminum to this list. [7] and [16] also highlighted the relevance of concrete, Portland cement and reinforcement steel on the overall energy embodied in building materials.

Results achieved corroborate literature data and also show Portland cement and ready-mixed concrete (site-delivered as a composite) as the main contributors to the building's embodied energy profile.

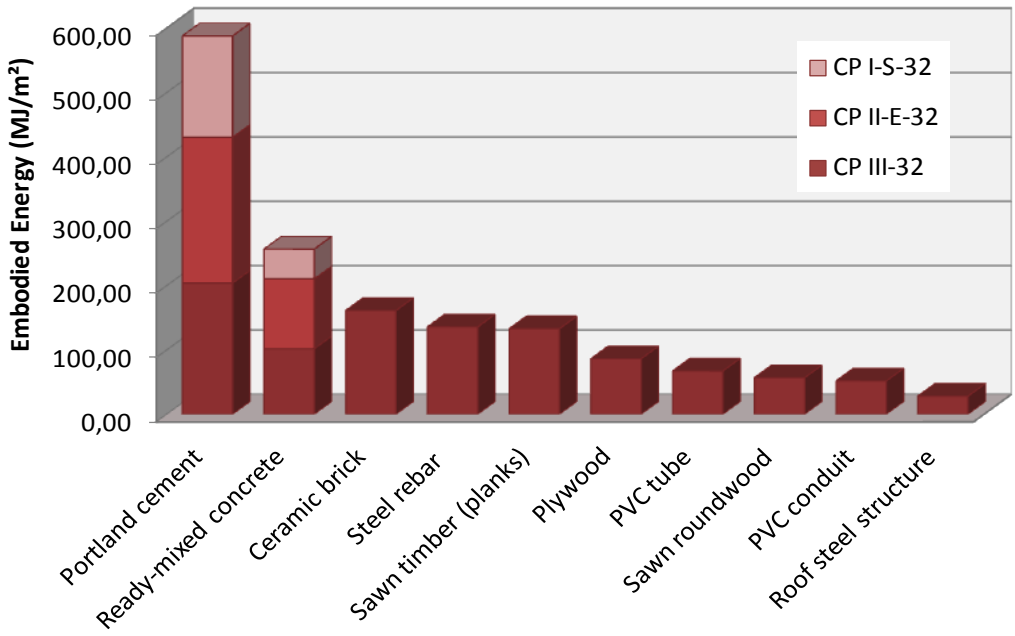


Fig. 1: Embodied energy of materials and components per built m² (median, MJ/m²)

In the scenario shown in Figure 2, concrete was broken down into its constituent elements. Corresponding cement, sand and gravel were added to those used in other construction applications.

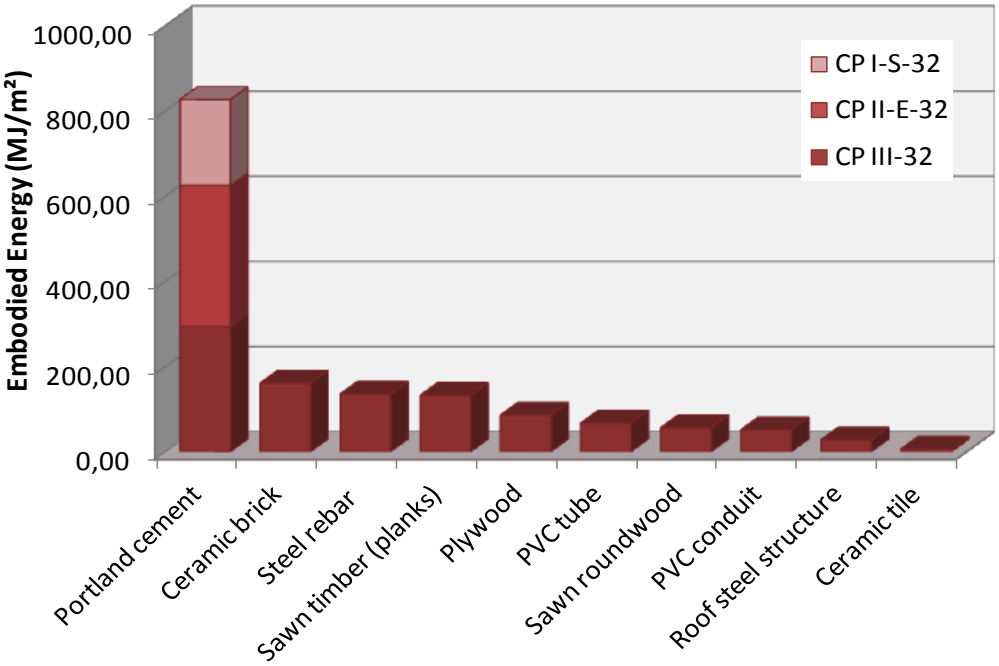


Fig. 2: Embodied energy of materials and components per built m², with concrete broken down into basic elements, which were added to cement, sand and gravel used in other applications (median, MJ/m²)

Table 2 presents embodied CO_{2e} and embodied energy values for the three types of cement with ggbs as clinker replacement, as well as for the corresponding concrete mixes. Both indicators for

cement (and, therefore, for concrete) diminished considerably as the ggbs content increased. Nevertheless, the highest embodied CO_{2e} was still that of cement CP III-E-32 (30% ggbs), followed by steel rebar and ceramic brick. [17] and [18] also reported large contributions from ready-mixed concrete and steel rebar.

Table 2: Embodied CO_{2e} and energy per built m² for different types of cement with ggbs and respective concrete mixes

Materials/components		*Embodied CO_{2e} (kg CO_{2e}/m²)*	*Embodied Energy (MJ/m²)*
Portland cement	CP I-S-32	*125,80*	*827,12*
	CP II-E-32	*94,95*	*625,79*
	CP III-32	44,17	294,13
Ready-mixed concrete (fck30)[1]	CP I-S-32	*39,49*	*256,68*
	CP II-E-32	*32,38*	*210,55*
	CP III-32	15,75	101,86

[1]Indicators for concrete mixes containing CP I-S-32 (5% ggbs, concrete mix 1:2,5:2,9:0,5) and CP II-E-32 (30% ggbs, concrete mix 1:2,2:2,4:0,5) were calculated for reference purposes. All case studies used cement type CP III-32 (66% ggbs, concrete mix 1:2,3:2,5:0,5).

Figure 3 presents the top ten contributions to embodied CO_{2eq} in building materials and components per m² of gross floor area (median values of the cases studied), while Figure 4 shows the same ranking, but with concrete broken down into basic elements, which were added to cement, sand and gravel used in other construction applications.

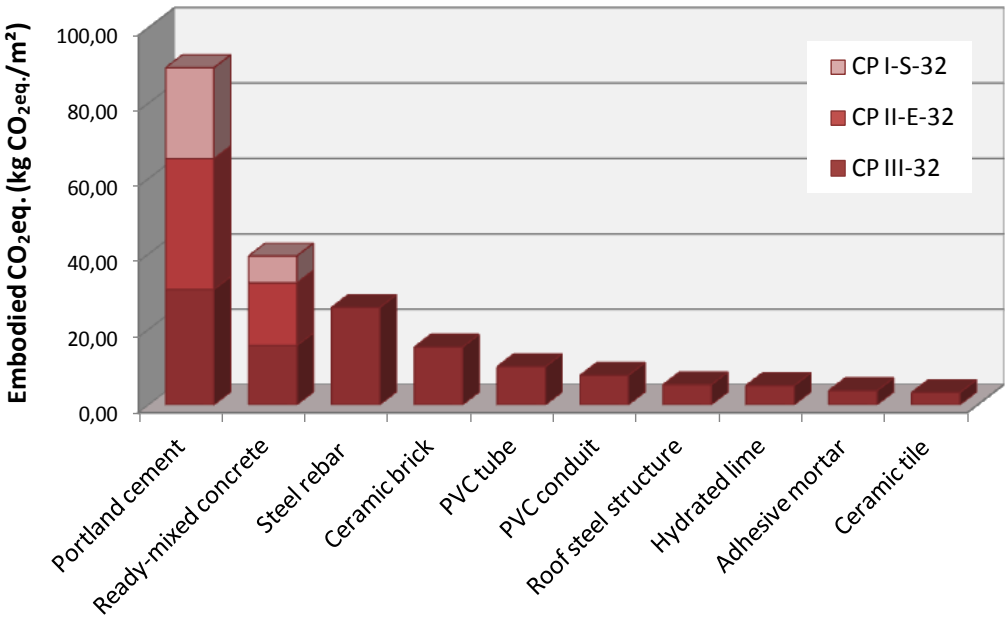


Fig. 3: Embodied CO_{2e} in materials and components per built m² (median, kg CO_{2e}/m²)

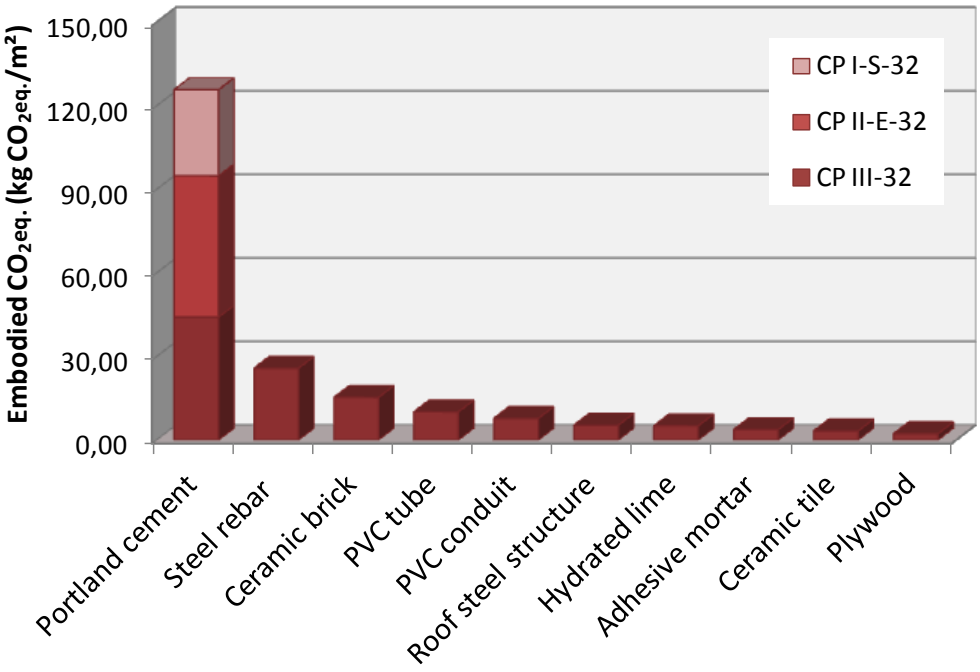


Fig. 4: Embodied CO_{2e} in materials and components per built m², with concrete broken down into basic elements, which were added to cement, sand and gravel used in other applications (median, kg CO_{2e}/m²)

Table 3 gathers data of the building materials/components actually applied in the case studies. Values for ready-mixed concrete were kept for reference purposes. Straightforward Pareto ranking suggests that, for the studied building typology, the top six contributions (Portland cement CP III-32, ceramic brick, steel rebar, sawn timber planks, plywood and PVC tube) respond for 85,2% of the total embodied energy computed. Analogously, 80,9% of the accounted embodied CO_{2e} was related to cement, steel rebar, ceramic brick and PVC tube and conduit. Enlarging this core database to encompass twelve materials and components would therefore provide a very reasonable (over 97%-coverage) description of the embodied energy and CO_{2e} profiles altogether, which can possibly streamline indicators monitoring scope.

For the studied typology, results for embodied energy and embodied CO_{2e} were, respectively, 1.029,58 MJ/m^2_{GFA} and 127,66 kg CO_{2e}/m^2_{GFA}. These figures are much lower than typical data found in literature, which is actually highly variable. Reasons for discrepancies are basically methodology-related and context-related. *Methodology-related variations* are connected to temporal (cradle-to-gate, cradle-to-site; cradle-to-construction…) and functional (whole-building; materials-only; materials and building services; superstructure-only; building typology) system limits as well as in accounting procedures (inference from I-O tables, process LCA, hybrid methods). *Context-related variations* are related to aspects such as energy mix (dependency on fossil fuels); climate (dependency on insulation); construction quality standard and susceptibility to natural disasters, which result in more robust structures. To help standardize evaluation and accounting procedures for estimating embodied energy and carbon dioxide (CO_2) emissions of buildings, the International Energy Agency Energy (IEA) Conservation in Buildings and Community Systems (ECBCS) Programme has created Annex 57 - Evaluation of Embodied Energy & Carbon Dioxide Emissions for Building Construction.

Table 3: Embodied CO_{2e} and energy per built m² for the main building materials/components analyzed in the case studies

Materials/components		*Embodied CO_{2e} (kg CO_{2e}/m²)*	*Embodied Energy (MJ/m²)*
Ready-mixed concrete	CP III-32	15,75	101,86
Portland cement	CP III-32	44,17	294,13
Steel rebar		25,82	135,78
Roof steel structure		5,34	28,08
Ceramic brick		15,33	161,24
Sawn timber (planks)		1,03	132,91
Sawn roundwood		0,32	56,76
Plywood		2,30	86,25
PVC tube		10,15	67,23
PVC Conduit		7,82	51,80
Adhesive mortar		3,78	3,13
Hydrated lime		5,11	1,58
Ceramic tile		3,28	6,85
Copper wire		0,10	1,15
Acrylic paint		1,02	1,12
PVA paint		0,41	0,45
Glass		1,64	1,07
Gravel		0,01	0,03
Sand		0,00	0,01
Ceramic roof tile		0,00	0,01

4. Final remarks

Ranking building materials based on embodied energy and CO_{2e} and the disclosure to designers can empower the material selection process, enabling more efficient, impact-driven specifications and materials balance. Disclosure of impact profiles to the general public can also provide the grounds for societal pressure for mitigation and technological improvement of the related industries, as well as advise public and sectorial policy-making.

For the studied building typology, a core database comprising twelve materials and components - *cement, ceramic brick, steel rebar, sawn timber planks, plywood, PVC tube and conduit, sawn roundwood, roof steel structure, ceramic tile, hydrated lime and adhesive mortar* - provides a very reasonable description of the embodied energy and CO_{2e} profiles altogether, which can possibly streamline indicators monitoring scope. Identification of key materials which effectively define a building's impact profile has important implications not only on research time and investment, but also on understanding by designers and successful implementation of such concepts in their daily specification practice. Results shown in this paper are specific to the construction typology considered, basically low-rise, low window-to-wall ratio, reinforced concrete-framed, masonry façade and partitions, and ceramic or metallic roofing. The case studies represent typical local building construction practices, not only for low-rise buildings but also for most multi-storey apartment buildings. Analysis of other construction typologies (e.g. steel or wood-framed, different wall systems and window-to-wall ratio), standards and cultures may result in other rankings and contributions per material/component.

Next research steps include investigation of additional building materials, components and systems, and of their performance as measured by other indicators; database expansion to include

other building typologies; and comparison of embodied and operational energy in Brazilian buildings, given the differences in industry technology and energy mix in relation to international data. It is also expected that, following a coordinated methodological outline, future works evolve to gradually constitute an LCI database of the most relevant building materials and components, to enable the use of the proposed metrics, as well as of LCA as a whole, as robust decision-making tools.

5. Acknowledgements

Authors thank CAPES, CNPq and CPFL Energia/ANEEL R&D funding line for the financial support to this research project.

6. References

[1] DIMOUDI A., TOMPA C., “Energy and environmental indicators related to construction of office buildings”, *Resources, Conservation and Recycling*, Vol. 53(1–2), 2008, pp. 86–95. doi:10.1016/j.resconrec.2008.09.008.

[2] ABANDA, F. H.; TAH, J. H. M.; CHEUNG, F. K. T. “Mathematical modelling of embodied energy, greenhouse gases, waste, time-cost parameters of building projects: A review”. *Building and Environment*, v. 59, p. 23-37, 2013. doi: 10.1016/j.buildenv.2012.07.014.

[3] WIEDMANN T., MINX J., “A Definition of Carbon Footprint”, *In: Pertsova, C.C. (ed.), Ecological Economics Research Trends,* Hauppauge NY, USA, 2008, pp. 1-11.

[4] ROSSI, B.; MARIQUE, A-F.; REITER, S. “Life-cycle assessment of residential buildings in three different European locations, case study”. *Building and Environment*, v. 51, p. 402-407, 2012. doi: 10.1016/j.buildenv.2011.11.002.

[5] HAMMOND G., JONES C., *Inventory of Carbon and Energy (ICE), Carbon Vision Buildings Program*, University of Bath, United Kingdom, 2011.

[6] ALCORN, A., “Embodied energy and CO_2 coefficients for New Zealand building materials”, 2003 <www.victoria.ac.nz > Accessed 12 april 2012

[7] SAADE M. R. M., SILVA M. G., GOMES V., FRANCO H. G., SCHWAMBACK D., LAVOR B., “Proposition and preliminary analysis of a core set of indicators to describe material eco-efficiency of Brazilian buildings”, *In: Smart and Sustainable Built Environment 2012*, São Paulo, Proceedings, 2012, pp. 525-532

[8] MANFREDINI C., SATTLER M., “Estimativa da energia incorporada a materiais de cerâmica vermelha no Rio Grande do Sul”, *Ambiente Construído,* Vol. 5, 2005, pp. 23-37.

[9] AGOPYAN, V., et al, “Alternativas para a redução do desperdício de materiais nos canteiros de obras”, São Paulo, 1998.

[10] Associação Brasileira de Normas Técnicas NBR 5732 (1991) Cimento Portland Comum, 1991.

[11] _____ NBR 11578 (1991) Cimento Portland Composto, 1991.

[12] _____ NBR 5735 (1991) Cimento Portland de Alto Forno, 1991.

[13] SILVA, M. G. (Coord). “Concreto de alto desempenho com elevados teores de escória de alto-forno: estratégia para consolidar e ampliar o mercado da escória de alto-forno”. Federal University of Espírito Santo, Research project report. Vitória, 2006.

[14] FAY R., TRELOAR G., IYER-RANIGA U., “Life-cycle energy analysis of buildings: a case study”. *Building Research & Information*, Vol. 28, 2000, pp. 31–41.

[15] ASIF M., MUNEER T., KELLEY R., “Life cycle assessment: A case study of a dwelling home in Scotland”. *Building and Environment*, Vol. 42, 2007, pp. 1391-1394. doi: 10.1016/j.buildenv.2005.11.023

[16] GHEEWALA H., KOFOWOROLA F., “Life cycle energy assessment of a typical office building in Thailand”, *Building and Environment,* Vol. 41, pp. 1076–1083. doi:10.1016/j.enbuild.2009.06.002

[17] POWELL J., MONAHAN J., (2011) “An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework”, *Energy and Building*, Vol. 43, 2011, pp. 179-188. doi:10.1016/j.enbuild.2010.09.005

[18] YAN H., SHEN Q., FAN L. C. H., WANG Y., ZHANG L., “Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong”, *Building And Environment* Vol. 45, 2010, pp. 949-955. doi:10.1016/j.buildenv.2009.09.014.

Embodied energy and CO2 emission associated with building construction by using I/O based data and process based data in Japan



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Summary

This study quantifies the embodied energy and embodied CO2 associated with building construction by using energy intensities and CO2 intensities obtained by process analysis and I/O analysis, and compare with each others in Japan.

The energy intensity and CO2 intensity table is calculated, which is based on 2005 I/O tables in Japan. In the intensity table, intensities of energy consumption and CO2 emission are shown as values of MJ and kg-CO2/million Yen, and each values are shown as based on producer's and purchaser's prices. It can be possible to calculate embodied energy and CO2 emissions due to constructions of various buildings.

The process-based data were referred to existing databases in Japan.

In this study, following comparisons are implemented;

・Comparison on energy intensity and CO2 intensity of building materials of the different databases: Cement, concrete, steel, glass, glass wool and lumber.

・Comparison on embodied energy and embodied CO2 of building by using different databases: a reinforced concrete office building and a steel frame structure office building.

The energy and CO2 emissions associated construction buildings were calculated by using energy intensity and CO2 intensity obtained by the I/O based analysis and the process based analysis. The results showed that many of intensities by obtained I/O analysis are larger than the intensities by obtained process analysis. The embodied energy and CO2 of office buildings by using I/O analysis are approximately 13% larger as the results of process based analysis.

Keywords: Embodied energy; Process based database; I/O based database

1. Introduction

Environmental and energy saving initiatives are becoming important strategies in the building sector today. Most of cases focus on operating stage of buildings. Building sector consume a lot of materials and components. When we look at energy and CO2 emission associated with building construction, embodied energy and CO2 occupy about 11% roughly in Japan, and it suggest that we should consider embodied energy and CO2.

If the energy saving strategies effect and reduce operating energy in near future, importance of embodied energy and embodied CO2 will increase.

Life cycle assessment is the one of the popular tools to assess building environmental loadings.

There are several issues among the life cycle assessment, different data collection measures, various or unclear data boundary condition settings and so on.

This study tries to make clear how different inventory databases influence on embodied energy

and CO2 emissions of buildings by comparing exiting databases.

This study selected three databases, JLCA-LCA Database, EE/EC database based on 2005 IO Table in Japan and Ecoinvent, and compared energy intensities and CO2 intensities of building materials and components. Furthermore, the study conduct analysis of embodied energy and embodied CO2 of a reinforced concrete building and the steel framed building.

2. LCI databases

2.1 Trend of databases

This study reviews LCA tools and LCI databases around the world. Fig.1 shows that LCI databases around the world and clarifies based on the methods of process-based analysis, I/O based analysis or hybrid analysis. This study could find 42 databases and most of the databases are created based on the process based methods.

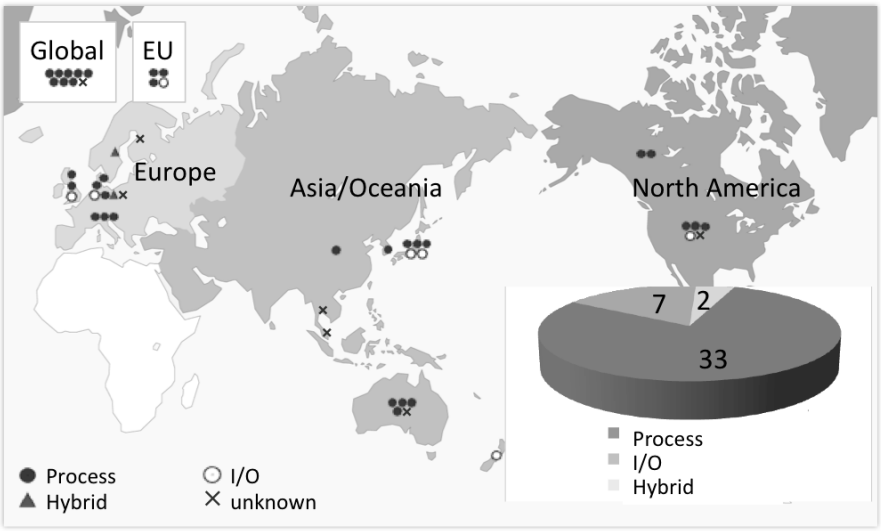


Fig.1 LCI databases in the world

3. Analysis of energy intensity and CO2 intensity of building materials and buildings

3.1 Summary and methods

This study selected three databases, JLCA database, IO database in Japan and Ecoinvent v2.2 compared these databases each other, and the energy intensities and the CO2 intensities of main building materials and components. Furthermore, the study conduct analysis of the embodied energy and the embodied CO2 associated with building construction.

This study conducted two case studies;

- Comparison on energy intensity and CO2 intensity of building materials
- Comparison on embodied energy and embodied CO2 of a steel frame building and a reinforced concrete building.

3.2 Selected databases for the case study

There are several databases in Japan and three database were selected considering characteristics of the process based database and the I/O based database, and the difference by the region.

- JLCA database in Japan
- Ecoinvent in Swiss
- EE/EC Database based on 2005 I/O Table in Japan

Table 1 Selected databases

		Total number of data	Number of data relating buildings	Data creation method
DB-1	JLCA	550	71	Process
DB-2	Ecoinvent	4000	39	Process
DB-3	EE/EC database 2005 I/O	401	57	I/O

3.3 Analysis

JLCA-LCA Database and Ecoinvent v2.2 provide energy and other environmental loading data for each items with explanation boundary conditions and the remarks by the data providers. JLCA-LCA 's energy data provide as consumption of electricity, crude oil, kerosene, coal and so on. It needs to convert these data into primary energy by using the primary energy factor.

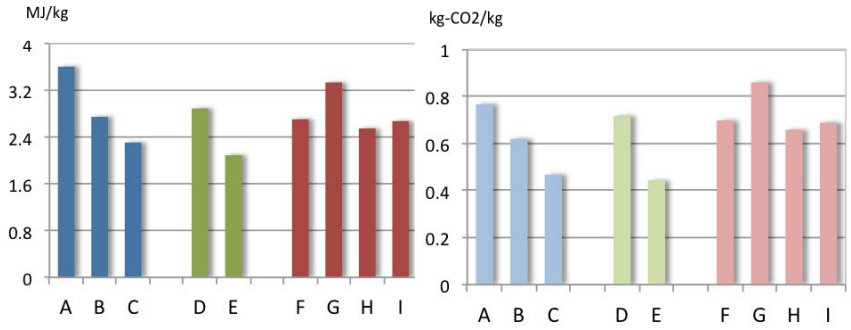
EE/EC database based on 2005 IO Table provides the energy intensity and CO2 intensity data. The unit of energy intensity and CO2 intensity of the I/O based database express MJ per 1million Yen and kg-CO2 per 1million Yen. This study converted these intensities into the unit uses MJ per kg or MJ per m3 and kg-CO2 per kg or kg-CO2 per m3 by using purchasers' price and quantity data of cost estimation information.

4. Results

4.1 Comparison on the energy intensity and the CO2 intensity of building materials

Fig.2, Fig.3 and Fig.4 show that the energy intensity and the CO2 intensity of cement, reinforced steel bar and sheet glass.

(1) Cement

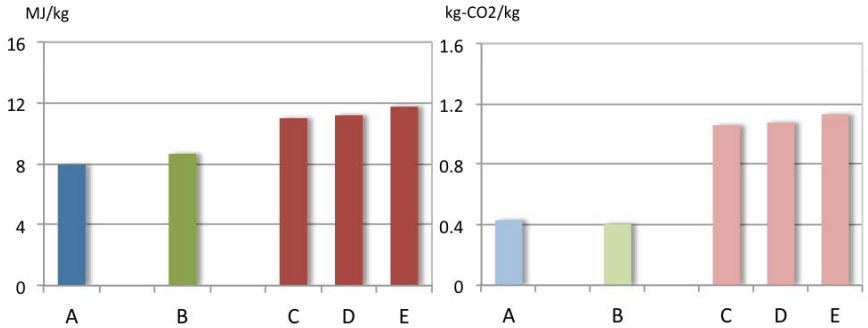


Legend of Fig.2

DB		Items
DB-1	A	Portland cement
	B	Fly ash cement Class B
	C	Portland blast-furnace cement Class B
DB-2	D	Portland cement
	E	Fly ash cement
DB-3	F	Portland cement
	G	High early strength portland cement
	H	Portland blast-furnace cement Class B
	I	Fly ash cement Class B

Fig. 2 Energy intensity and CO2 intensity of cement

(2) Reinforced steel bar

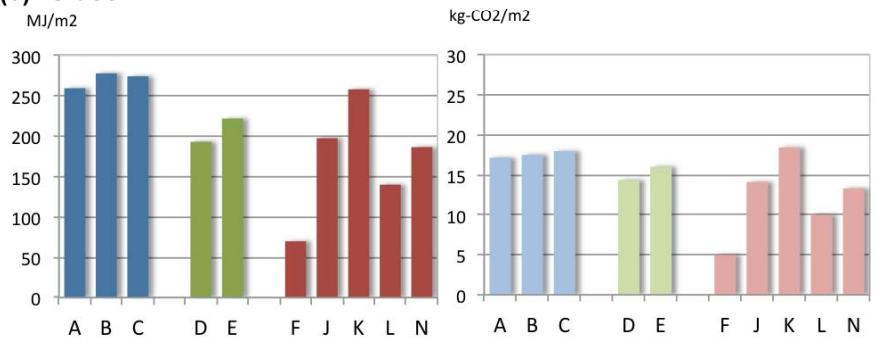


Legend of Fig.3

DB		Items
DB-1	A	Steel bar
DB-2	B	Electric furnace, non-low alloy
DB-3	C	Cold rolled & drawn profiled bars 1
	D	Cold rolled & drawn profiled bars 2
	E	Cold rolled & drawn profiled bars 3

Fig. 3 Energy intensity and CO2 intensity of reinforced steel bar

(3) Glass



Legend of Fig.4

DB		Items
DB-1	A	Flat glass
	B	Tempered glass
	C	Multiple glass
DB-2	D	Sheet glass
	E	Sheet glass coated
DB-3	F	Float plate glass
	G	Heat-reflective glass
	H	High performance heat-reflective glass
	I	Multiple glass
	J	Tempered glass

Fig. 4 Energy intensity and CO2 intensity of glass

4.2 Comparison on embodied energy and embodied CO2 of buildings

(1) Summary of buildings

A reinforced concrete building and a steel framed building are compared. Table 2 shows summary of these buildings, and Table 3 shows material quantities of the buildings. This study covers only seven building materials, concrete, reinforced bar, steel frame, timber, plaster board, glass wool and sheet glass.

Table2 Summary of case study buildings

	Bldg.A	Bldg.B
Structure	RC	S
Total floor area	9,097m2	9,097m2
Number of floors	10F, 1BF	10F, 1BF
Building type	Office	Office

Table 3 Material quantity of case study buildings

Main materials	(unit)	Structure	
		RC	S
Concrete	m3	0.919	0.426
Reinforced bar	t	0.122	0.036
Steel frame	t	0.009	0.103
Timber	m3	0.016	0.006
Plaster board t12.5	m2	0.777	1.012
Glass wool t50	m2	0.202	0.154
Sheet glass t12	m2	0.186	0.400

(2) Reinforced Concrete structure Building

Fig.5 shows the embodied energy and the embodied CO2 of the reinforced concrete building by using DB-1, DB2 and DB3. The result of embodied energy of DB-3 is 6.3 % larger as the result of DB-1, and the results of embodied CO2 of DB-3 is about 18% larger as the result of DB-1. Concrete and the reinforced bar occupy about 80% of embodied energy and embodied CO2.

(3) Steel structure buildings

Fig.6 shows the embodied energy and the embodied CO2 of the steel frame building by using DB-1, DB2 and DB3. The result of embodied energy of DB-3 is about 16 % larger as the result

of DB-1, and the results of embodied CO2 of DB-3 is about 28% larger as the result of DB-1. Steel frame occupies about 60% of embodied energy and embodied CO2.

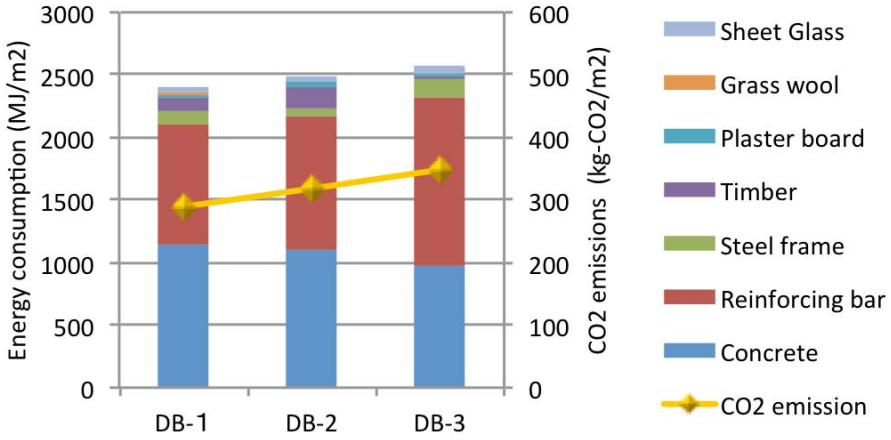


Fig. 5 Embodied energy and Embodied CO2 of Reinforced Concrete Building

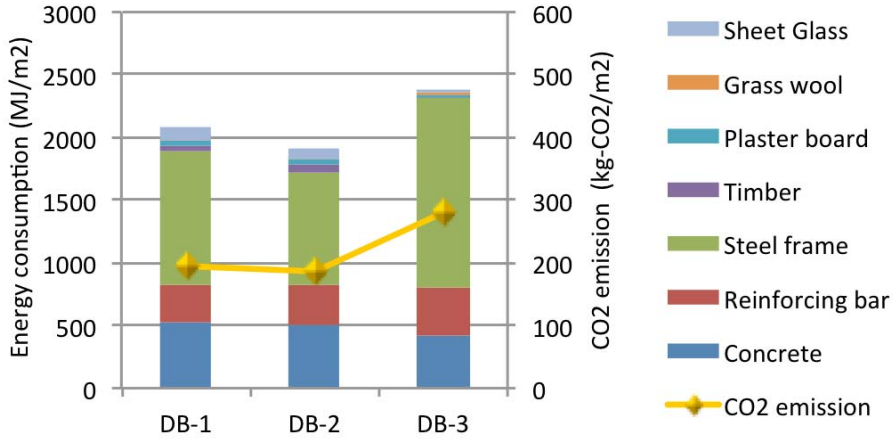


Fig. 6 Embodied energy and Embodied CO2 of Steel frame Building

5. Conclusions

This study conducted reviewing existing LCI databases and comparative case study on energy intensity and CO2 intensity by using different databases. The results show that different databases bring different results of embodied energy and embodied CO2 of buildings, and suggest that it is needed to prepare more accurate databases. This study compared only three databases and the number of building materials was limited to use as comparative study.

References

[1] Manish Kumar Dixit, José L. Fernández-Solís, Sarel Lavy, Charles H. Culp, Identification of parameters for embodied energy measurement: A literature review, Energy and Buildings, 42 (2010) 1238–1247
[2] JLCA- LCA Database, Life cycle Assessment Society of Japan, 2004
[3] SimaPro 7, Pre Consultants
[4] Ecoinventv2.2, Swiss Center for LCI
[5] Tatsuo Oka, CO2 intensities due to construction in various industrial sectors based on 2005 Input/Output Table, Journal of Environmental Engineering (Transactions of AIJ), Architectural Institute of Japan, Vol.653, 2010.7
[6] Noriyoshi Yokoo, Tatsuo Oka, Hiromi Numata, Keizo Yokoyama, Tatsuo Oka, Embodied energy and embodied CO2 associated with Building Industry in Japan, Proceedings of SB13 Conference in Munich, April, 2013
[7] Shunsuke Kaido, Noriyoshi Yokoo, Yukihiro Kawazu, Tatsuo Oka, Assessing trends in Embodied Energy and CO2 emissions Associated with Building Construction in Japan, Proceeding s of SASBE International conference in Delft, May, 2009

B3

Facade

Chair: Daniel Kellenberger
Intep – Integrale Planung GmbH, Switzerland

Leichtbau 3.0: Material, Structure, Energy



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Lightweight constructions basically mean the striving to design structures with a minimal weight compared with a full use of the material properties. In future this has to be complemented by a maximum reduction of the cumulative energy demand (amount of energy consumed over the whole lifetime) for structures.
The example of the development of a hybrid building envelope will demonstrate that evolution.



Fig 1. a) Spatial envelope: Zlote Tarasy, Warszaw [Waagner Biro], b) Façade: 1 Angel Square, Manchester [Daniel Hopkinson].

Each component of the structure has to act as a load-bearing member and has to fulfil the functional requirements of a building envelope at the same time. In this respect, the use of the glass elements as surface structures, the load transmission and the boundary conditions become particularly important.
The concepts of lightweight construction are the basic principles of a holistic development and design in building construction. The example shows that facades and building envelopes as part of our infrastructure are offering new development opportunities and innovations in structural engineering and design.

Keywords: Lightweight Structures, Facade, Surface Structures, Hybrid, Glass, Energy

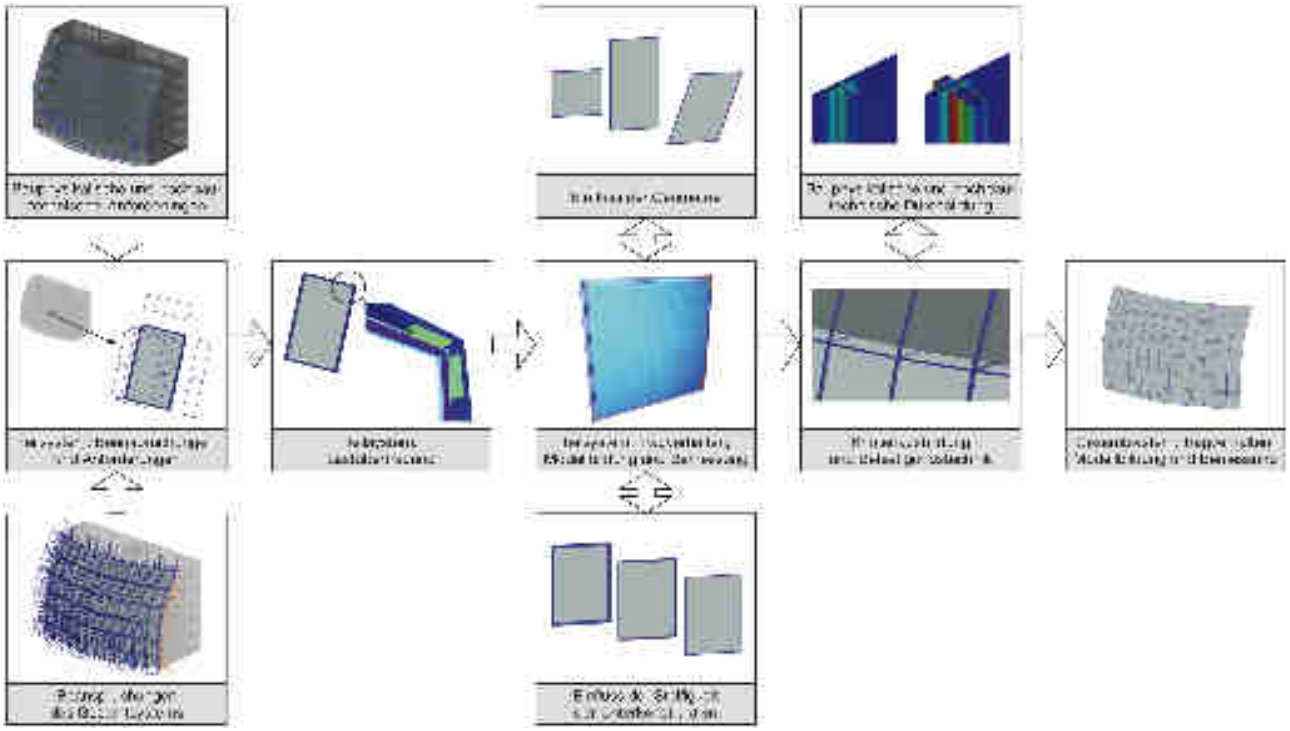


Fig 2. Hybrid Glass-Steel-Elements: impacts and relations for the use in building envelopes.

Energy performance of windows in various building types



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Short Summary

The paper presents an analysis of the influence of various building energy characteristic on the window energy balance in Polish conditions. The analysis is based on the building energy balance with hourly time step calculation in accordance with the methodology described in the ISO 13790 : Energy performance of buildings - Calculation of energy use for space heating and cooling. While the method of windows energy balance calculation is based on ISO 18292 : Energy performance of fenestration systems for residential buildings - Calculation procedure.
In the analysis two different public building types and several energy characteristics have been considered. The results indicate that the building energy characteristic significantly affect the energy balance of windows and thus should be taken into account in the process of setting of the reference data used for widows energy performance calculation.

Keywords:Windows; Fenestration; Certification; Labelling; Energy performance;

1. Introduction

New regulations such as the European Directive 31/2010 Recast impose new demands on the construction industry and investors. New low-energy buildings should be built using advanced technology and design techniques.
Complicated process of more efficient buildings construction can be facilitated by the introduction of energy classes for building elements. If a building is made of high-grade components, it should receive the same high energy class. For this reason, different countries bring in not only energy classes for buildings, but also energy classes for building components.
Windows play an important role in ensuring the comfort of indoor climate conditions. On one hand, they influence to a large extent the heating/cooling demand of buildings, on the other hand they are an irreplaceable source of daylight. This dual role of the windows makes assessment of the

overall energy efficiency of windows very difficult. However, even the assessment of the thermal balance of windows is quite complicated. Commonly used factor for windows thermal efficiency is the heat transfer coefficient U. This factor, however, does not describe the full balance of the window. In fact, windows are also a source of solar heat gains and allow air infiltration. That means that the lowest U-factor does not guarantee the best thermal performance. On the other hand precise calculation of an energy balance of each window would require much data and would be very time consuming. That calls for a simple window rating system that would take into account the most important factors that influence an actual thermal performance of windows.
Existing windows certification systems are based on more or less complex energy balance of windows based on some reference data such as heating/cooling degree hours and utilized solar irradiation. These parameters depend, however, on both climatic conditions and the general building energy characteristic. Therefore two windows with identical properties can have different thermal balance depending on the operating conditions.
In [1] a proposal for a windows certification system has been presented. The system was developed on a basis of an analysis conducted for a representative single family house in Poland. The question is whether the system could be used for certification of windows in different building types (with energy characteristic that differs significantly from residential buildings) .

2. Methodology

2.1 Assumptions

In order to analyse the influence of building energy performance on the energy balance of windows two different building types under various operating conditions have been examined. The analysis includes:

- two reference building types (office building and hospital) with different energy standards (current and from 1970s) with two different thermal masses (light and heavy),
- three climatic zones,
- separate energy balance calculation for both heating and cooling seasons,
- combined heating/cooling energy balance.

The method takes into account that the increase of solar gains (including solar energy utilization factor) during the heating season reduces energy demand for heating while in case of the cooling season, it causes an increase of the energy demand for cooling.

2.2 Calculation method

The general concept of the calculation procedure is presented in fig. 1.

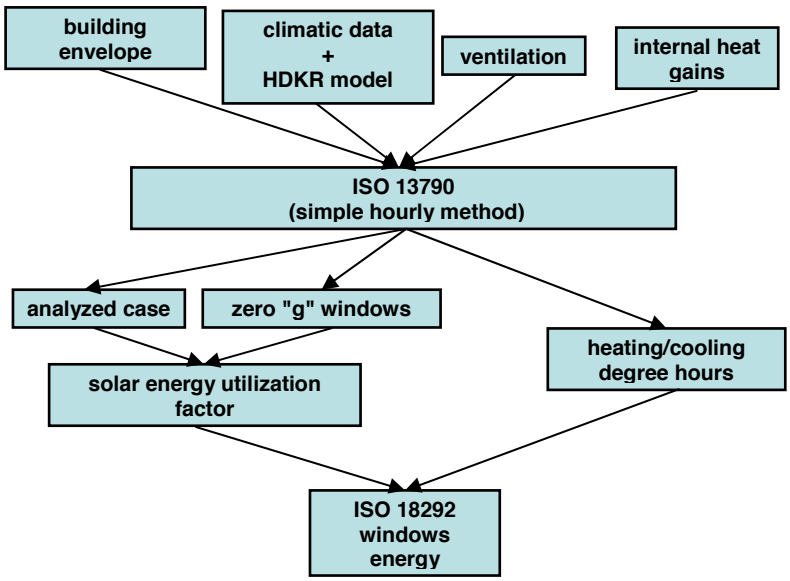


Fig. 1 Calculation algorithm

The assessment procedure in ISO 18292 requires data on both solar heat gains and heat loss through windows. Since both of these parameters depend largely on the climate and the energy characteristic of a building, detailed calculations for each reference building located in the three climate zones in accordance with the procedure proposed in ISO 13790 have been conducted. As not all of the available solar energy can be utilized for heat demand reduction, utilized fraction of the available solar energy is calculated on an hourly basis for the reference house. Solar energy utilization factor is calculated as a ratio of the effective reduction of the heating demand (calculated as a difference of the heating demand of the reference building and the building with windows for which solar energy transmittance equals 0) to the total solar irradiation through windows. Finally the energy performance of windows is calculated as a difference between the utilized transmitted solar energy and the thermal heat losses during the heating and cooling seasons.

$$E_{ref,heating} = I_{heating} \cdot g - D_{heating} \cdot U \quad (1)$$

$$E_{ref,cooling} = I_{cooling} \cdot g - D_{cooling} \cdot U \quad (2)$$

where:

$E_{ref,heating}$ - window energy balance for the heating season [kWh/m^2]
$E_{ref,cooling}$ - window energy balance for the cooling season [kWh/m^2]
$I_{heating}$ - utilizable solar irradiation during the heating season [kWh/m^2]
$I_{cooling}$ - utilizable solar irradiation during the cooling season [kWh/m^2]
g - solar energy transmittance of the window [-]
U - heat transfer coefficient of the window [W/(m^2•K)]
$D_{heating}$ - heating degreehours [kKh]
$D_{cooling}$ - cooling degreehours [kKh]

2.3 The reference buildings

The selection of reference building types is not random, the energy characteristic of office buildings differs significantly from that of hospitals, mostly due to differences in the internal heat gains to heat losses ratio and the windows area to floor area ratio. In order to investigate the influence of the building type on the energy performance of windows, the general building construction for both reference building types was the same:

- heated/cooled space - 4466.17 m^2,
- building volume - 14960 m^3,
- number of floors - 4,
- ground floor/roof area - 1298.30 m^2,
- roof pitch - 0^o.

The windows distribution for the reference building types is presented in table 1.

Table 1: Windows distribution an facades

	Window fraction on a facade [%]	
Orientation	**Office building**	**Hospital**
N	31,3%	17.8%
E	9,2%	7.8%
S	31,3%	17.8%
W	9,2%	7.8%

To investigate the influence for various energy standards of buildings two energy standards have been chosen:

- building WT2008 – building envelope coefficients are taken from present Ordinance of Minister of Infrastructure on the technical requirements for buildings and their location building design. This is an actual standard in Poland used for construction of new buildings.

- building from 70s – building envelope coefficients are taken from Ordinance of Minister of Infrastructure on the technical requirements for buildings and their location building design PN-64/B-03404 and PN-74/B-03404. This is a standard representative for most of existing buildings.

As currently buildings may be constructed in various technologies that may result in various thermal capacities, for new buildings two possible capacities have been considered. As a result three different construction types for both reference buildings have been considered (Table 2).

Table 2: Selected construction types

Construction type	*C [J/(K·m²)]*	*Walls U [W/m²K]*	*Roof U [W/m²K]*	*Ground floor U [W/m²K]*
WT2008 (light)	110 000	0.3	0.25	0.45
WT2008 (heavy)	260 000	0.3	0.25	0.45
70s standard	260 000	1.16	0.5	0.7

The most significant difference in energy characteristic between the reference building types is the ventilation airflow. In case of Office buildings the airflow is set at a level of 4288 m^3/h, while high hygienic demands of the hospital requires an airflow at a level of 50021 m^3/h (over 10 times higher). One of the other differences is the distribution of internal heat gains (Table 3) as different availability of internal heat gains may result in various number of heating/cooling hours and various utilization factor of solar heat gains in winter.

Table 3: Internal heat gains distribution

	Average heat gains [W/m²]	
Hours	**Office bulding**	**Hospital**
workday		
17-23	**15,2**	**9.2**
7-17	**1,6**	**9.4**
17-23	**1,6**	**2.2**
weekend		
17-23	**1,6**	**6.4**
7-17	**1,6**	**9.4**
17-23	**1,6**	**2.2**
average (week)	**5.6**	**6.6**

2.4 The climate data

In Poland, for the purpose of calculating the energy use for heating and cooling, data for 61 cities is given. To select locations that represent warmest and coldest climate a simplified energy balance for all 61 locations has been calculated. The balance has been calculated assuming the same heating and cooling season lengths for all locations. The locations have been arranged from lowest to highest energy balance for both heating and cooling (Fig. 2 and 3).

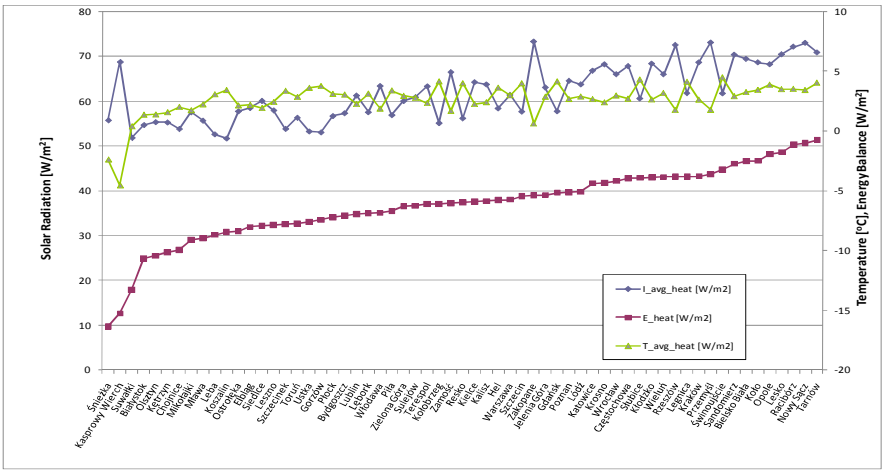


Fig. 2 Main climate data and simplified window energy balance for heating

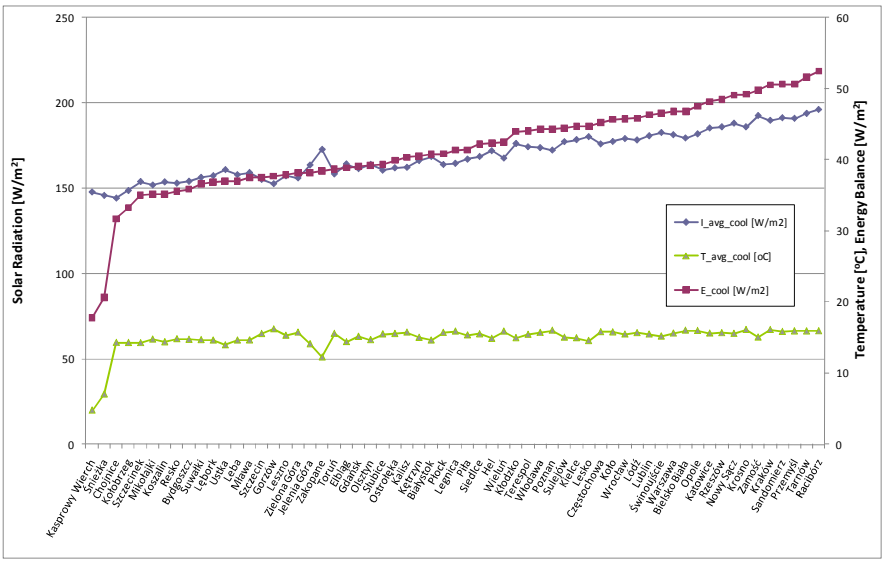


Fig. 3 Main climate data and simplified window energy balance for cooling

The meteorological stations Śnieżka and Kasprowy Wierch have been excluded from analysis as they are located in uninhabited mountain regions. Therefore for further calculations three locations have been selected - Tarnów – the warmest; Suwałki – the coldest and Warszawa as a moderate climate.

2.5 The heating and cooling hours

In order to determine the net energy gain, heating and cooling hours must be known for the specific reference house in an actual location. According to ISO 13790 standard the length of heating and cooling seasons are determined by averaging the cooling or heating demand over the previous 4 weeks. The start and end of the heating and cooling seasons is determined with a threshold value of 1 W/m^2 (related to the floor area). The length of heating and cooling season is needed to know the number of hours of operation of certain systems with auxiliary energy use (e.g. pumps, fans). In case of the energy balance calculations it is important to determine heating and cooling hours rather than seasons as it provides more accurate results. In the used hourly method heating and cooling hours have been determined basing on the calculated specific heat and cold demand with a threshold value of 1 W/m^2.

3. Results

3.1 Degreehours and irradiation

The heating and cooling degreehours and utilizable irradiation have been calculated for both of the reference building types and three construction standards for the three climate zones. The calculations have been made for two different reference building orientations in order to evaluate the influence of orientation on the energy performance. The results of calculations are shown in Tables 3-5. The results indicated a significant difference in the number of degreehours and irradiation for the analysed building types. These differences were mostly a result of lower relation of heat gains to heat losses due to a lower window area and a much higher ventilation heat loss in case of the hospital. As a result for the hospital the heating season was longer and there was almost no need for active cooling as most of heat gains were removed with ventilation air.

Table 4: Calculated number of degreehours and irradiation value for Suwałki

Building type	Orientation	Construction Type	Degreehours		Irradiation	
			D_h	D_c	I_h	I_c
			kDh	kDh	kWh/m^2	kWh/m^2
Office building	N	70s standard	109,4	1,8	218,0	43,8
		WT2008 (heavy)	100,1	16,6	166,9	197,4
		WT2008 (light)	101,2	15,9	165,1	196,5
	E	70s standard	109,6	1,6	217,2	40,8
		WT2008 (heavy)	100,5	16,1	167,5	194,8
		WT2008 (light)	101,6	15,4	166,9	195,1
Hospital	S	70s standard	120,2	-0,1	361,0	7,9
		WT2008 (heavy)	120,0	-0,1	371,5	7,3
		WT2008 (light)	120,0	-0,1	344,1	12,0
	W	70s standard	120,2	-0,1	301,9	7,4
		WT2008 (heavy)	120,0	-0,1	315,9	6,7
		WT2008 (light)	120,0	-0,1	286,6	12,2

Table 5: Calculated number of degreehours and irradiation value for Warsaw

Building type	Orientation	Construction Type	Degreehours		Irradiation	
			D_h	D_c	I_h	I_c
			kDh	kDh	kWh/m^2	kWh/m^2
Office building	N	70s standard	95,6	4,5	263,5	110,6
		WT2008 (heavy)	84,5	18,3	193,9	244,9
		WT2008 (light)	84,7	17,2	189,2	243,7
	E	70s standard	95,9	4,4	266,7	110,6
		WT2008 (heavy)	84,8	18,2	195,1	243,6
		WT2008 (light)	85,1	17,0	191,1	241,7
Hospital	S	70s standard	104,0	-0,1	380,6	0,0
		WT2008 (heavy)	103,7	-0,1	390,2	0,0
		WT2008 (light)	104,0	-0,1	367,2	0,0
	W	70s standard	104,0	-0,1	323,3	23,4
		WT2008 (heavy)	103,7	-0,1	333,6	19,9
		WT2008 (light)	104,0	-0,1	310,8	29,4

Table 6: Calculated number of degreehours and irradiation value for Tarnów

Building type	Orientation	Construction Type	Degreehours		Irradiation	
			D_h	D_c	I_h	I_c
			kDh	kDh	kWh/m^2	kWh/m^2
Office building	N	70s standard	87,1	3,7	273,1	96,6
		WT2008 (heavy)	72,5	22,6	172,3	277,3
		WT2008 (light)	73,5	19,3	168,0	260,0
	E	70s standard	87,4	3,9	276,2	100,5
		WT2008 (heavy)	73,1	22,8	176,9	280,1
		WT2008 (light)	74,1	19,5	171,6	260,7
Hospital	S	70s standard	97,5	-0,1	406,8	17,4
		WT2008 (heavy)	97,3	-0,1	421,3	14,8
		WT2008 (light)	97,4	-0,1	393,7	26,6
	W	70s standard	97,5	-0,1	334,6	20,7
		WT2008 (heavy)	97,3	-0,1	349,2	16,0
		WT2008 (light)	97,4	-0,1	323,2	33,3

3.2 Windows classification

Windows classification scheme requires an assumption that the net energy ranking for specific windows will be similar for various locations, meaning that a good window in Tarnów will also be a good window in Suwałki or Warszawa. Moreover as the rating may be different for heating and cooling in order to compare windows for both heating and cooling purposes a primary energy consumption factor may be used. Usage of this factor allows estimation of a total environmental impact of windows (3).

$$PE_{ref,total} = -E_{ref,heating} \cdot PRF_{heating} + E_{ref,heating} \cdot PRF_{cooling} \quad (3)$$

where

$PRF_{heating}$ primary resources consumption factor for heating [-]

$PRF_{cooling}$ primary resources consumption factor for cooling [-]

$$PRF_{heating} = \frac{w_{heating}}{\eta_{heating}} \quad (4)$$

$$PRF_{cooling} = \frac{w_{cooling}}{\eta_{cooling}} \quad (5)$$

where

$w_{heating}$ primary energy consumption for the representative fuel used for heating (assumed heat source for Poland – gas boiler; w_{gas}=1.1)

$w_{cooling}$ primary energy consumption for the representative fuel used for cooling (assumed cold source for Poland – electric compressor; w_{el}=3.0)

$\eta_{heating}$ total heating system efficiency (assumed heat source for Poland – central heating system with an atmospheric gas boiler; $\eta_{heating}$=0.78)

$\eta_{cooling}$ total cooling system efficiency (assumed cold source for Poland – split compressor system; $\eta_{cooling}$=2.7)

In the study a set of 12 different windows has been analyzed on the basis of the obtained degreehours and irradiation values (Tables 7-8). Results of calculations indicated that the rating for various locations is similar, which means that the assumption is correct and it is possible to develop a single rating system for all locations in Poland.

Table 7: Windows ratings in the office building for various locations

Window type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
U_w	0.80	0.80	1.0	1.0	1.2	1.2	1.2	1.3	1.4	1.4	1.6	1.6
g_w	0.21	0.28	0.28	0.35	0.32	0.35	0.42	0.44	0.35	0.42	0.35	0.42
Heating season balance [kWh/m^2]												
Tarnów	5	1	6	2	9	7	3	4	10	8	12	11
Warszawa	5	1	6	2	9	7	3	4	10	8	12	11
Suwałki	3	1	5	2	8	7	4	6	10	9	12	11
Cooling season balance [kWh/m^2]												
Tarnów	1	3	2	8	5	7	11	12	6	10	4	9
Warszawa	1	3	2	8	4	7	11	12	6	10	5	9
Suwałki	1	3	2	8	5	7	11	12	6	10	4	9
Primary energy balance [kWh/m^2]												
Tarnów	1	2	3	4	5	6	7	8	9	10	11	12
Warszawa	2	1	4	3	7	6	5	8	10	9	12	11
Suwałki	2	1	4	3	7	6	5	8	10	9	12	11

Table 8: Windows ratings in the hospital for various locations

Window type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
U_w	0.80	0.80	1.0	1.0	1.2	1.2	1.2	1.3	1.4	1.4	1.6	1.6
g_w	0.21	0.28	0.28	0.35	0.32	0.35	0.42	0.44	0.35	0.42	0.35	0.42
Heating season balance [kWh/m^2]												
Tarnów	10	4	7	3	8	6	1	2	11	5	12	9
Warszawa	8	4	7	3	9	6	1	2	11	5	12	10
Suwałki	5	1	6	2	9	7	3	4	10	8	12	11
Cooling season balance [kWh/m^2]												
Tarnów	1	2	3	5	4	6	9	12	7	10	8	11
Warszawa	1	2	3	5	4	6	9	12	7	10	8	11
Suwałki	1	2	3	5	4	6	9	12	7	10	8	11
Primary energy balance [kWh/m^2]												
Tarnów	8	4	7	3	9	6	1	2	11	5	12	10
Warszawa	8	4	7	2	9	6	1	3	11	5	12	10
Suwałki	5	1	6	2	9	7	3	4	10	8	12	11

Note that windows with a lower U-value are not necessarily the best performing windows as they significantly reduce the amount of obtained solar energy in the heating season, moreover the rating is quite different for the hospital and the office building. As an example, in case of the hospital the energy balance of a low energy triple glazed window (window types 1-2) do not perform as good as a low energy double glazed windows (window types 7-8). In case of the office building the U-value appears to be the most important factor, however in many cases the g-value decides on the rating of a window.

4. Conclusions

U-value of windows cannot be used to compare energy performance of windows. Therefore in order to provide decision makers information on the actual performance of windows it is necessary to develop a windows rating scheme based on an overall energy performance during both heating and cooling seasons. The development of a such system is possible as the performance of windows does not differ significantly for various locations, building envelope standard and orientation. However, different building types are used in a different way, therefore there is a need of a proper set of data depending on the building function, that would allow calculation of the energy balance of windows in buildings with various energy characteristics.
Thermal performance of windows is not the only aspect that should be taken into account, windows are an important source of natural daylight that allows for reduction of electricity consumption for lighting, therefore a method of daylight potential implementation into the windows rating system should be developed. Windows are also providers of natural ventilation, thus improving the indoor thermal climate and reducing cost/energy consumptions for mechanical ventilation. These effects should be considered in future studies

5. References

[1] Panek A., Rucińska R., Trząski A. ”Energy certification of windows”, International Sustainable Building Conference 2011, Helsinki, 2011
[2] Maccari A., Zinzi M. “Simplified algorithms for the Italian energy rating scheme for fenestration in residential buildings”. Solar Energy Vol. 69 (Suppl.), Nos. 1–6, pp. 75–92, 2000, ISSN: 0038-092X
[3] Duer K. et al. “Energy labelling of glazings and windows in Denmark: calculated and measured values” Solar Energy Vol. 73, No. 1, pp. 23–31, 2002, ISSN: 0038-092X
[4] Karlsson J. , Roos A. “Evaluation of window energy rating models for different houses and European climates” Solar Energy 76 pp. 71–77, 2004, ISSN: 0038-092X
[5] Karlsson J., Karlsson B., Roos A. “A simple model for assessing the energy performance of windows” Energy and Buildings 33, pp. 641-651, 2001, ISSN: 0378-7788

The pitfalls of building integrated photovoltaic.



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Short Summary

BIPV the short version for building integrated photovoltaic is one of the possibilities to turn a low or zero energy house into an active energy generating house.
There was a big development in products as well as in projects the last years. Market reports predicted tremendous growth rates which turned out to be wrong [1].
So there was no great breakthrough in the real market. Only few installations were realized in so called lighthouse projects.

Keywords:building integration; photovoltaic; architectural design

1. Introduction

Building codes and rating systems like Leed (US), Breeam (UK), DGNB (Germany) or ÖGNI and ÖGNB (Austria) plead for a direct installation of a PV system into a building.



Fig. 1: "The Peak Building", London with a 35 kW PV installation

In Fig. 1 for example is shown a Breeam rated Office Building in London. The full area also the triangles were covered with PV cells to obtain a maximum output. With this electric output the CO^2 saving is at a level to reach the highest rating according to the Breeam guideline.

From the experience of the author, there is a big demand on the market for similar buildings and projects which is reflected in high number of offers in the recent years. On the other hand the conversation rate is terrifying low. It depends to the project size and location, but averaged its between 1 and 3%. So that means a lot of projects are developed and will not be realized.
The purpose of this paper is to clarify the pitfalls of this lack of breakthrough. It goes into detailed

consideration about the product development and product range. It will consider the question if there is a sufficient range of possibilities to meet the demands of designers and architects. Who is involved in the planning process, are the interfaces clarified between façade-, glass-, electric- and photovoltaic design? Is there an opportunity to standardize the process and the products? Are the highly costs the main impact of the slight market growth?

2. Stages of BIPV projects

2.1 Planning process

At a very early stage all the players in a BIPV project like investors, architects, facade engineers and so on, like to know the exact details about the following topics.

2.1.1 Technical issues

The critical matter at a BIPV project is to solve all the interfaces between facade and glass engineering on the one hand and electric and PV engineering on the other hand. If it´s start whit a simple PV module which is usually standardised by the individual companies, it´s relatively easy to develop a PV plant. The only thing to consider is that every company has its individual design, which is given by the cell dimensions. In the past it was 5 inch (125 x 125 mm) and at the moment 6 inch (156 x 156 mm) which is shown in Fig. 2.

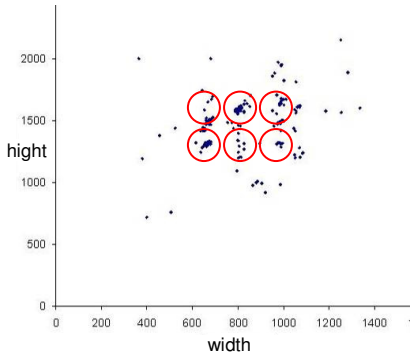


Fig. 2: typical measurement of different “Standard” PV modules

In the construction business especially in the glass facade business it’s unusual to work with fixed dimensions. The flexibility in size, shape and glass thickness is an absolute necessity to fulfil the wishes of the architects.
Therefore the engineering process starts at a very early beginning, at the design of an individual panel restricted by the existing cell technologies.
But this is a big investment in engineering for the BIPV industry, considering the conversation rate which is mentioned above, it´s much too high a risk.

It´s also important from the beginning, that the interfaces between all the four mentioned disciplines (facade, glass, electric, PV) are solved. There is a relationship between phases of error and fault costs, the rule says that the cost will multiplied by 10 at the certain stage if there is an error (planning, development, construction, ...). Therefore it´s indispensable to solve all the questions in the planning process and not at the construction site, which will understandable cost much more then at the end.
Again, from the experience of the Author, a lot of projects are developed too late; problems will be solved in some worst cases at least before delivering the panels on site.

Another lack is the missing information at the tender stage. There are no standardised texts on the market to allow each engineer or architect to prepare the tender documents. So every project has to be planed individual.
Typical for a BIPV tender is a separation in an electrically part and glazing part. This leads in some cases to misunderstanding and misinterpretation of the whole project. The needs of a facade company (weather proofed building) are sometimes contraire to the needs of an electrician (a lot of holes for the cables).
A better solution would be a holistic approach of a BIPV project.

2.1.2 Financial issues

There are two ways to debate this issue. One is about the monetary benefit; the other one is the extreme high cost compared to other standard PV or also building materials.

When we talk about photovoltaic, everybody is asking for a payback time. Therefore the author calls it satirical “The Pavlov Reflex”, because it´s not common for standard building products. That conditioning reflex is caused from the high feed in tariffs for standard photovoltaic installations which intend that individuals can earn money with a PV installation.
For a BIPV installation other benefits are at the foreground. These are the so called multifunctional issues, like weather protection, fall preventing (as a balcony), over head glazing, sun protection and very often the positive marketing effect.

The author has monitored two diploma thesis reg. a theoretically sun protection calculation for individual glazing systems. In the first diploma thesis the technical and theoretical background was figured out for a hypothetically office box with 2,5 x 3,0 x 5,0 m. The simulation was done for four different glazing types, a standard insulate glass, a solar coated glass, a BIPV glass and a brise soleil [2]. In the second diploma thesis an economic calculation where set up on the results from the first study [3]. One of the interesting results was that the supposed very cheap solution with insulated glass turned at the end (after a 20 years cycle) to a more expensive solution compared to the initially very expensive PV installation. This is regarding the high energy cost for cooling down the office with standard insulated glazing. That means if BIPV is considered only from the installing cost, it´s very expensive. If you compare it with other materials including the running cost (in case of PV also savings and earnings) it turns more positive. But projects whit considerations about total cost of ownership are very seldom at the moment.

The second debate is about the general high investment cost for a BIPV installation.
One reason is the above mentioned planning process. A lot of projects will be developed by the industry for free, if they will not be realized the other projects have to carry the load.
Compared to standard PV panels two main issues should be mentioned reg. the gap between the costs.
In a BIPV panel the thickness of the glass is always given by the loads and the clear span of a pane. Due to the fact that the dimensions for glass facades and roofs are getting bigger and bigger the glass is getting thicker. The price increase should not be underestimated.

Another reason is that every project will be calculated, planned and manufactured individual. So there is no serial production which makes the product on and on expensive.

2.1.3 Legal issues

There are a lot of issues to consider which is not possible to explain everything in this paper. In place of all the other topics the necessity of laminated safety glass and fire protection will be shown in detail.

The first topic laminated safety glass is very common in the glass industry, but not in the PV industry. We are talking about horizontal glazing if the facade or installation is declined more than 15° from the vertical. In such cases a laminated safety glass is required, no other products are allowed. Laminated safety glass guarantee, that no splinter fall down and that the entire glass pane

will stay in the construction in case of a breakage. The installation in Fig. 3 is not a typical horizontal (or overhead glazing) but it shows what will happen if a none laminated safety glass in this case a standard PV panel will be integrated into a facade combined with a illegal mounting system.
Because of the thermally toughened glass and its typical breakage structure the glass will collapse because the very slim backsheet which is only a foil is not strong enough to hold the glass pane stable in the structure.



Fig. 3: broken "Standard" PV module in a facade at a shopping mall in Carinthia

The second very important question is about the fire protection. Is there a danger if somebody installs a PV panel for example in a ventilated facade?
With the "Önorm B 3800 Teil 5" a test is established to figure out exact this question. This should be considered in every individual case. That means which type of PV panel will combined with which facade system. In Mai 2013 the Author monitored a fire test at the BVS in Linz Upper Austria. Several PV panels from ertex solar were integrated into a Schüco SCC 60 facade. The engineers found out that no pieces felt down bigger then 0,4 m² and heavier than 5 kg within the 30 minutes of the test procedure. So the system passed the test, but as mentioned above, every combination should be considered individual.



Fig. 4: fire protection test according to Önorm B 3800 Teil 5

2.2 Realization on site

The big critical question is always if the installation of a PV panel is a job for the electrician or for the glazier or facade builder. The answer is, it depends to the situation and to the type of installation. But for special dimensions it is recommended to take an experienced glazing company, if they are not afraid to connect also prefabricated plugs. There are several installation situations shown in Fig. 5 where it´s obvious that no electrician can mount such big panels.



Fig. 5: mounting situations for BIPV panels

A pitfall in BIPV application is, if a none or less experienced company tries to install the very fragile glass product.

2.3 monitoring of existing installations

In some projects monitoring systems are applied to see if the inital output calculation goes conform with the real production. In the best case the PV system is integrated into the building automatisation to see if production and consuption is cungruent. In Fig. 6 an example is shown for the winning project “Canopea” of the Team Rhone-Alpes at the student competition solar decathlon 2012.

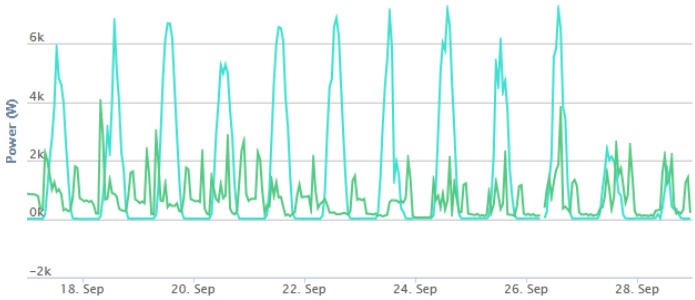


Fig. 6: monitoring between PV production and electricity consumption at the Solar Decathlon Europe 2012, winning project “Canopea” Team Rhone-Alpes www.sdeurope.org

Sad to say but in some projects years past the installation it comes out that no inverter was installed, and nobody take care about the electrically output, this is rare but happens however.

3. Additional considerations

If we are talking about the pitfalls of the BIPV business, there is always a question into two directions.
One direction is to make it more standardized and less flexible for the designers, or is a demand for more flexibilisation.
It seems that the first attempt should go conform to a cost reduction and the second attempt will stay in a niche market with high priced solutions.

3.1 Standardisation

Standardisation in a BIPV context could consider the process itself, for example standardizes the tender phase or electric output or shading calculation. But it could consider also the PV panel as a building material. A possibility could be a standardized PV panel not concerning the electrically standardisation which is more or less a panel with 72 cells easy to handle, it should be more a building product. This building product should be fire resistant, easy to mount and combinable with other processable, cutable, custom tailored materials like fibre cement, melamine board etc.

But is it really possible to create some standards bring it to the designer and finally on the market and hope that the architects will build a building around that existing measurement? It could be possible for some installations, like ventilated facade or very simple facade but not in high sophisticated glass projects.

3.2 Flexibilisation

On the other end of the market some new products are required concerning different colours of the materials, more transparent see through solutions or higher efficiencies. The development cost for such solutions or installations are tremendous high and the generated turn over by such projects will maybe very less. To be an early adopter in such a fragile sector it´s always a risk for the entire industry.

4. Conclusion

In this paper the Author tried to figure out the Pitfalls of individual BIPV projects. In summary it can be said that there is not just one reason.
At a first view it seems that the costs are the main reasons, but if we go into detail we found out, that several “stumbling block” will hinder the participants to use BIPV solutions frequently.

The engineering itself or respectively the establishment of reliable engineering offices is the first to foster BIPV solutions.

Another topic will be the development of PV building products which will follow the building codes, norms and guidelines.

If the BIPV production turns generally into a mass production the prices will getting lower and lower.

[1] DRACHMANN P, “Building Integrated Photovoltaics Markets: 2008-2015”. NanoMarkets, LC | PO Box 3840 | Glen Allen, VA 23058 | TEL: 804-270-7010 | FAX: 804-270-7017
[2] WERNER KREJCI *“Energetischer Variantenvergleich verschiedener Glasfassadensysteme ohne und mit Photovoltaik Anteil”*. MASTER THESIS zur Erlangung des akademischen Grades "Master of Science in Engineering", 2011
[3] WALTER LASERER “*Ökonomische Untersuchung verschiedener Glasfassadensystemen ohne und mit Photovoltaikanteil unter Einbezug der Lichtqualität”* MASTER THESIS zur Erlangung des akademischen Grades „Master of Science in Engineering“ im Studiengang MEE, 2012

Novel type of façade-window solar thermal collector



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Summary

The use of renewable energies in everyday life become more attractive from day to day. Even their use in buildings offer great benefits in terms of fossil fuel reduction as well as green label of those material goods. Particularly, the use of solar thermal systems in architectural integration has a big potential.

Façade solar thermal collectors show double benefits in new architectural goods: integrated functional elements that do not disturb the architectural appearance and there is a high fraction of solar energy as a part of total energy needs of the building. These are the main characteristics of facade solar thermal collectors.

The new model of the window façade collector is described in this work. Namely, it is an ideal way to build-it in the south façade of the building that can be residential / office building or manufacturing plant. With these type of façade collectors/modules, the architectural appearance of the buildings will not be destroyed and at the same time those build-in elements are functional: participate to a great portion of total energy needs of the building. This is a sustainable way of use of solar energy and consequently decrease the CO2 impact to the environment.

Keywords: facade solar thermal collectors, energy-efficiency, solar architecture, building integration, long term stability of collector

1. Architectural integration of new façade window collectors in buildings

Concept of energy efficient buildings does not only mean use of insulating materials to build them and consequently save the energy of the building facility, but also use the energy from renewable source, so they are at the same time declared as eco-friendly objects.

At the moment it is very important that architects and designers should accept a new way of thinking for building designs where beside the architectural appearance, the energy efficiency of building will be also important and valuable component of further decision. Usually, architects are mainly focussed on a good appearance of the building but not on free and renewable energy options that can contribute to eco-friendly aspects of the building. The most ecological and sustainable energy source in this case could be the usage of solar energy. The solar energy could

be used for heating the sanitary water as well as for space heating of buildings that are the main portions of total energy usage.

Solar thermal collectors usually were installed on roofs only but not on facades; nowadays the philosophy is changed. The ratio of available roof space related to the required solar collector area is usually too small, and it is difficult to supply energy from those collectors for the whole building. In this context, if there is enough space on the south facade wall then the solar collectors could be installed there [1-4]. The south facade of the building could be more attractive and better place to accommodate ,,functional,, building elements such as windows solar thermal modules instead their installation on the roofs of buildings.

Another benefit for solar facade collectors is the fact that their appearance could be very similar to the windows glass surfaces. It means that facade windows-like collectors should be free of welding lines, waves and folds and present good replace to a classic windows. They could be mounted on the same windows frames as the window glasses. There is no additional cost because the facade collectors will be integrated in the existing frames.

One of the most important characteristic of these collectors is the fact that water vapour condensation is overcome, otherwise it can destruct the facade appearance and architectural design will be unacceptable if even small amounts of humid exist inside of the collector.
Due to the fact that facade collectors will be mounted under angle of 90 deg. on the façade wall -it means collectors' efficiency will be decreased annually (particularly, more in summer time than in winter due to the fact that Sun has lower position in winter period)- (Figure 1). One way to compensate this decrease in collector's efficiency could be the use of collectors with very high efficiency as much as possible.

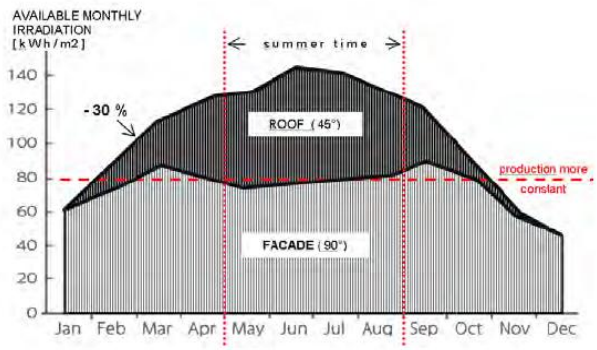


Fig.1. Roof versus facade collector annual yield pattern. [3]

Although, vertical placement of collectors on a building will not maximise the peak yield possible during summer, it makes it easier to scale a system for specific average requirements. As can be seen in figure 1- the yield is much more constant in case of façade placement. Hence, overheating or overproduction can be minimised. In addition, with the right design the shortcomings due to the façade placement can be compensated for by reduced thermal losses. In this context, the use of appropriate insulators options and designs of the facade collectors could help in decrease of thermal losses.

Usually, the insulating options come from the way of mounting of: window module (Fig.2) in the (existing) windows frames or mounting directly to the facade (Fig.3). If the window module is

mounted in the window frames (Fig. 2), then behind the module is insulation that can be also sliding/demounting wall in order to allow in winter time to replace it and the solar module at the same time not only to heat the water in the absorber but also to heat up the space behind the collector module. This is especially important if the back side of collector is made from Al plate that once warms up then by convection will heat up the room space as well.

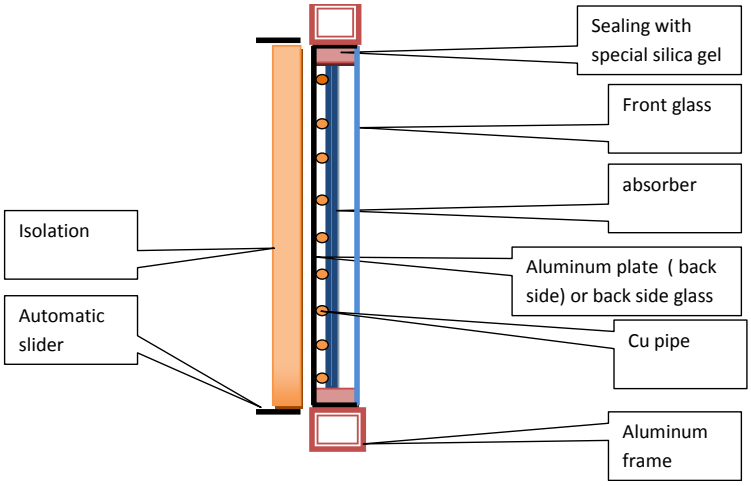


Fig. 2. Window module assembled in window frame. Insulation behind the window module.

If there is a case of mounting of collectors on the space between windows directly on the wall of the facade, then modules are framed in profiles (Fig. 3). Again, behind it is insulation material and they are almost the same as the windows ones. In this case insulation could be thicker than in the standard thermal collectors and the efficiency of the solar thermal collector goes up.

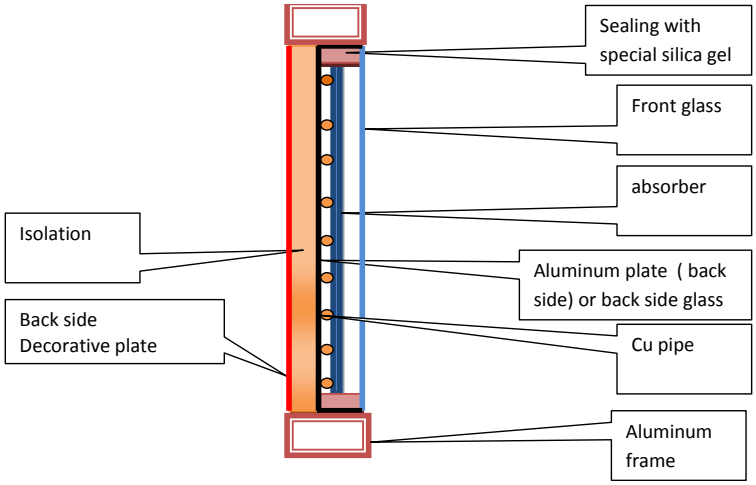


Fig. 3. Window module assembled on the facade wall. Behind is insulation.

2. Long term stability of facade window collector

The long term stability/durability of solar facade collectors is very important. It can be achieved if: the coefficient of efficiency of collector is stable and constant over a long period of time; have a stable colour of the absorber over a longer period of time in order to have optimal and constant optical properties; have a high transmission of the cover glass as much as possible due to the fact that should keep a good facade appearance and consequently have higher values of collector's

efficiency for a long period of time, and of course last but not less important is to overcome the humidity problems.

To solve these issues, it is necessary:

a) ***the selective coating*** of the absorber should be continuous and not damaged. The welding types that exist by now are:
   - ultrasound welding - it removes a part of the selective coating that later becomes a place for initializing of corrosion, water diffusion, oxygen and pollutant penetration and over the time period it causes decrease of optical characteristics of the coating. The emittance value increases that consequently decrease the collector's efficiency.
   - laser welding is the other type of welding that causes point melting of the selective coating that are initial spots of corrosion, water, oxygen penetration and decrease of important optical properties of the absorber.
   - These methods of welding are overcome with the new CS (Camel Solar) type of welding. Namely, the novel type of absorber is named as CS (Fig. 4a) and it is manufactured by the new technology for back-side welding (Fig. 4b).

b) ***humidity issues*** between glass cover and absorber should be solved: no water or vapours are allowed in this space of the collector, that could be achieved with vacuum in this area or with special hygroscopic substances that absorb all initial humidity.

c) the glass should have ***low-soiling or self cleaning coating*** that can stop corrosion as well as soiling or dust collection over the cover surface (glass or polymeric).



a) b)

Fig 4. New CS type of absorber: a) front side, b) back side.

3. Novel type of window facade collectors (modules) – CS type

Solar façade collectors are an elegant and aesthetically units of integrating solar thermal technology in buildings. However, integration currently requires full building refurbishment or in the case of a new building - then at beggining during the designing stage for the building the action for collectors' integration is taken.

During installation of the window modules (Fig. 5) in the existing or the same new window frames of the buildings, there is no need of elevators, protection equipment etc...for their integration. The installation is from the inner side of the building like mounting the windows. If there is a case of their installation during the stage of building, then the same equipment is used for installation of the windows module as well.

The main characteristics of novel CS collector (module) are summarised below:

- the surface area of contact between Cu tubes of the absorber and flat plate (that is Al or Cu) is three times bigger than that one of the standard collector, that means it is a better heat transfer;
- there are no waves on Al or Cu absorber due to the novel welding;
- no melting on the selective coating in spots as it is in laser welding case or ultrasound welding, and no any damage on the selective coating;
- the selective coating is totally undisturbed and there is no diffusion processes of oxygen, water or penetration of other substances that will cause corrosion of absorbers' plate.
- the contact between Cu tubes and Al plate is stable and it is not changed during lifetime of collector's existence and function.
- The module is made of two glasses and between them is the absorber. Behind the absorber is material that absorbs the humidity in the inner space found during the assembling of the collector. (After assembling there is no way to have new quantity of air/humidity, the inner area is totally without any humidity issues). The fact that there is no condensation inside the collector means that there is no any fraction of the collector's energy to be used for evaporation of the water.
- There is a good appearance of these modules on the buildings (Fig. 5) that can be made in different colours to fit the facade colour (Fig 6).
- The efficiency is greater than other flat plate collectors as it is shown in Fig.7.



a) b)

Fig. 5. Window –façade module made with CS absorber: a) single module, b) set of 4 modules.

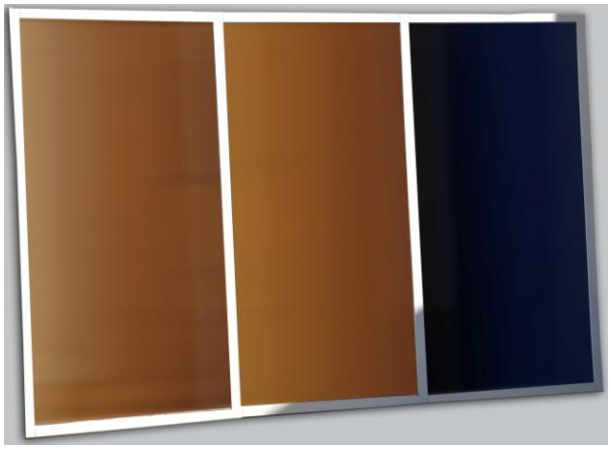


Fig.6. Different colours of window facade collectors.

4. Results and discussion

The Absorber of CS collector consists of 10 copper pipes ultrasonically welded with the aluminium full plate absorber with PVD selective coating with high efficiency. The new type of welding (Fig. 4b) of these absorbers contributes to:

- high coefficient of heat transfer and better performance compared to other types of absorbers.
- Fig 7. show comparison of the efficiency curves of absorbers that are laser welded (blue line) and new type of CS welding technology (red line). (Measurements are performed in independent German laboratory). The novel CS type of welded absorbers are more efficient than other ones.
- there is one of the best appearance of these facade collectors because absorbers are without welding lines and waves; the outer surface of the collector is very similar to window glass surface and therefore is the good choice for implementing in facades as well as to roofs.
- Additionally, the other advantages of these collectors are: smaller stagnation temperature during the summer time due to the fact of angle of installation.

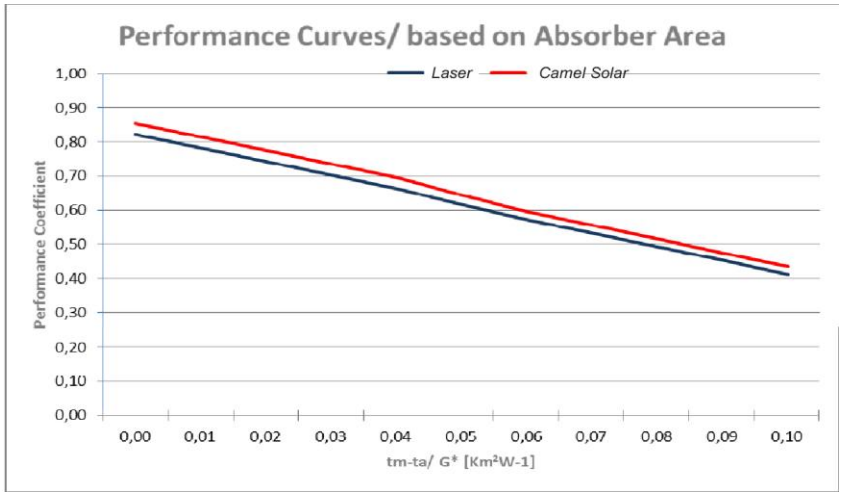


Fig. 7 . Efficiency curves compared for laser welded absorber and new type of CS absorber.

Fig. 8 presents the first demo building where novel CS collectors are installed (in middle vertical column in the existing window frames).



Figure 8. Facade –window collectors installed in south façade in existing Al frames as normal windows. In the middle column of the building are installed the façade window collectors (left and right are normal windows).

5. Conclusion

Novel type of window façade solar thermal collectors are multi-benefitial and functional novel elements integrated in the architecture. The new window module is already installed in several buildings in the last two years and the first results from in-field testing are very satisfying. These field tests are in progress and there will be a continuation of this work.

The main characteristics of window façade collector are summarised as:

a) good architectural appearance that can match the colour of the building façade (Fig. 6 and 8),
b) very high efficiency of these collectors (Fig. 7),
c) long term stability is extended and stable efficiency of the collector over long period of time during their function is shown and expected,
d) no corrosion issues due to the lack of humidity inside the collector (two years experience from installed modules and internal testing's confirmed this statement),
e) no destruction of the selective coating of the absorber is achieved due to the new type of welding of CS absorbers; therefore optical characteristics are kept constant for a longer period of time and no corrosion attacks are envisioned.

The experience with the novel façade-window collectors in demonstration building showed good and acceptable results during the test period, especially in winter time. There are benefits of them in summer time as well, lower stagnation temperature are measured due to the angle of installation on the vertical facades.

Acknowledgment

Data presented in this paper are collected and measured in CS facilities (Macedonia). The work is sponsored by the manufacturing company for window facade collectors- Camel Solar, and by team of collaborators of the authors.

6. Literature

[1] KUHN T. E., HERKEL S, HENNING H-M, *Active Solar Facades (PV and solar thermal),* http://www.cost-effective-renewables.eu/
[2] STADLER I., ,,*Facade Integrated Solar Thermal Collectors,,* a study by AEE INTEC, Gleisdorf, Austria (www.aee.at)
[3] PROBST M. C. M., Architectural integration and design of solar thermal systems, PhD Theses, LESO-PB, EPFL Station 18, 1015 Lausanne, 2008.
[4] MATUŠKA T., ŠOUREK B., *Façade solar collectors*, Solar Energy, 2006, vol. 80/11, pp. 1443-1452.

Development of innovative building skins in the context of sustainability assessment



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1. Short Summary

The construction sector plays a key role in sustainable development. It is therefore necessary to begin thinking about efficient ways to reduce harmful environmental effects. In this regard the focus should not only be on saving energy during the buildings operation, but also on the environmental performance of construction materials.

In this paper the consequences of sustainable development and sustainability will be discussed with respect to recent standardization activities and building certification systems. The development of innovative building skins in the context of sustainability assessment is presented for the case of a multifunctional plug & play facade (MPPF). Special solutions for energy-efficient operation, active and passive facade components for the use of solar energy will also be presented and evaluated, comparing the MPPF and a standard Façade.

Keywords: Facade; use of natural resources; end of life scenario; energy efficiency

2. Introduction

This paper gives an overview about the standardization activities of CEN and current building certification systems with a special focus on building skins. In the first part of the article there will be explained the latest developments of the standardization work on “Sustainability of Construction Works“[1]. As well as a preview of the future construction regulations, which include the new basic requirement No.7 “Sustainable Use of Natural Resources“ [2].

In the second part of the paper, the consequences of sustainable development in the construction sector will be discussed and the role of building certification systems will also be explained. Using the example of the multifunctional plug & play facade (MPPF) [3], the main measures of the sustainable assessment criteria will be explained. Special solutions for energy-efficient operation, active and passive facade components for the use of solar energy will be presented. Interior comfort and structural issues in production phase, as also for the maintenance works or any changes in use of the façade, will also be considered.

As a result of analyses based on several certification systems the impact of the ecological influence for different certification schemes will be shown. The importance of environmental assessment is one of the optimization tasks for future constructions.

2.1 Green and sustainable building

The construction sector has a great influence on sustainable development since it plays a key role in the consumption of energy and resources as well as in solid waste accumulation [4, 5]. It is therefore importanct to quantify the environmental performance of buildings in order to communicate their potential environmental impacts. [6, 7, 8]

Assessment methods for sustainability have been developed since the early 1990s. The International Standardization Organization (ISO), for example, prepared the first standards to address specific issues and aspects of sustainability relevant to buildings and civil engineering works (e.g. ISO 21930[9]). Already these standards were based on the Life Cycle Assessment methodology (LCA) in ISO 14040 [10].

On the basis of the ISO work, the European Committee for Standardization is working on a set of standards to harmonize the methodology for a sustainability assessment of buildings using the life cycle approach. According to the upcoming European Standards [11, 12, 13, 14, 15] the assessment of the environmental performance of buildings is based on LCA expressed with quantitative categories and Life Cycle Cost Assessment (LCCA).

In the past few years a growing number of building certification systems for green and/or sustainable buildings has been emerging in the market [16, 17, 18] parallel to standardization work to endorse green and sustainable buildings. As several building certification systems involve the assessment of the environmental and/or economic performance, these methodologies are definitely worthwhile looking at more closely [19, 20, 21].

A first evaluation of national and international building certification systems used in Austria shows that most of them do not include the assessment of the environmental performance with the use of LCA and the economic performance with the use of Life Cycle Cost Assessment (LCCA) is currently not fully in line with the upcoming European framework of CEN/TC 350.

2.2 Goal and scope

The aim of the present work is to give an overview about the standardization activities of CEN and current building certification systems with a special focus on building skins. Furthermore, an environmental LCA–based comparison between the Multifunctional Plug and Play Façade (MPPF) and a standard façade will be carried out.

In the conclusion and outlook we show how this might be integrated in the planning process to guarantee a better predictability of sustainability in the development of façades.

3. Standardization and Certification systems

3.1 Integrated performance of buildings according to CEN/TC 350

In the last few years many regulations for the environmental sector have been developed. The Technical Committee 350 is responsible for the development of new standards in the field of sustainability. In this context the two most important standards for the Austrian market, are the ÖNORM EN 15804 [10] and the ÖNORM EN 15978 [12]. These two standards form the basis for sustainable development in the material, building and construction sector.

Another important document of CEN/TC350 is EN 15643-1:2011[8]. Its goal is defined by supplying a common framework methodology that includes the principles, requirements and guidelines for a holistic assessment of the sustainability of buildings concerning their environmental, economic and social performance over the whole life cycle. The item to be assessed is the building including the site on the basis of user requirements in terms of a so-called "functional equivalents". The standardization documents will not include regulations regarding evaluation, quality-levels, or classes (benchmarks).

It is generally assumed that most of the CEN/TC 350-sustainability-standards will be available during 2013. Figure 1 shows the concept of the integrated building performance that incorporates environmental, social and economic performance as well the technical and functional performance that are intrinsically related to each other.

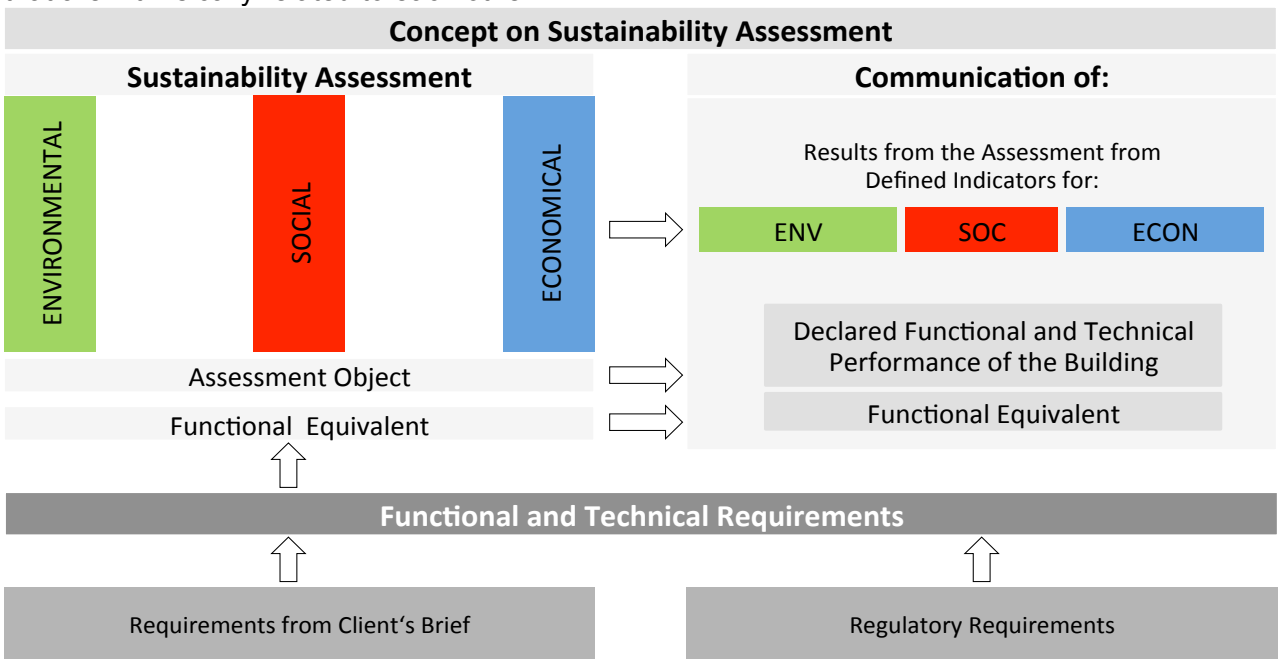


Figure 1: Concept of sustainability assessment of buildings [11]

3.2 The Construction Products Regulation

The Construction Products Regulation (305/2011/EU - CPR[1]) – replacing the Construction Products Directive (89/106/EEC - CPD[2]) is laying down harmonized conditions for the marketing of construction products. The European Parliament and the Council of the European Union adopted the CPR on March 9th 2011. The main parts of its substantial articles have been applied since the 1st of July 2013, at which time it replaced the CPD. The already applicable parts of the CPR focus on the notification and designation processes of the Notified Bodies (NB) and the Technical Assessment Bodies (TAB). The CPR is to ensure reliable information on construction products in relation to their performances, which is achieved by providing a *common technical language*, offering uniform assessment methods of the performance of construction products. These methods have been compiled in harmonized European standards (hEN) and European Assessment Documents (EAD). This common technical language is to be applied by:

- manufacturers when declaring the performance of their products, but also by
- authorities of Member States when specifying requirements for them, and by
- industry users (architects, engineers, constructors…) when choosing the products most suitable for their intended use in construction works.

One the major revisions concerns the basic requirement *hygiene, health and environment* and the addition of a new basic requirement (No. 7) *sustainable use of natural resources*.
This means that construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

a) reuse or recyclability of the construction works, their materials and parts after demolition;
b) durability of the construction works;
c) use of environmentally compatible raw and secondary materials in the construction works.

[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:088:0005:0043:EN:PDF
[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1989:040:0012:0026:EN:PDF

3.3 Building Certification Systems

In addition to the standards and regulations, building certification systems play an important role as voluntary instruments. In these certification systems a set of criteria is defined assessing the individual performance categories of buildings, allowing a comparison of different buildings.
At the international level, there already exist a large number of certification – systems, like BREEAM (BRE Environmental Assessment Method), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) or LEED (Leadership in Energy and Environmental Design). In Austria there are currently three systems, to be mentioned. First the ÖGNI (Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft) – system, which relies on the DGNB - system from Germany. Second the TQB (Total Quality Building) – system of the ÖGNB (Österreichische Gesellschaft für Nachhaltiges Bauen) with its related Klima:aktiv system.

4. Assessment methodologies

In order to identify the main influences of the different types of façade constructions on their environmental performance, a comprehensive analysis of the MPPF in order to an standard facade was carried out over their life cycle using the LCA method. The influence of the construction products is being compared over individual life cycle stages in relation to the building operation. Only this integrated approach allows for correctly quantifying the effective contribution of the façade construction and the different technical modules, which are integrated in the facades.

4.1 Methods for assessment of environmental performance of facades

This work was undertaken according to the European Standards [11] written by CEN/TC 350 that provide a system for the sustainability assessment of buildings using a life cycle approach. In this concept, the sustainability performance incorporates the environmental, social and economic performances as well as the technical and functional ones, and they are all intrinsically related to each other. The assessment quantifies impacts and aspects using quantitative and qualitative indicators. The purpose of this series of standards is to enable comparability of results of assessments without value judgments or setting benchmarks or levels of performance. The assessment of the environmental performance of buildings is based on the methodology of LCA [22] expressed using quantitative assessment categories [12, 15].
In contrast to the above-mentioned approach, this work only focuses on the quantification of the assessment of the environmental performance from two different types of facades. Thus, trying to quantify only parts of the sustainability performance in general does not seem to be sufficient, and a more integrated LCA approach was adopted.

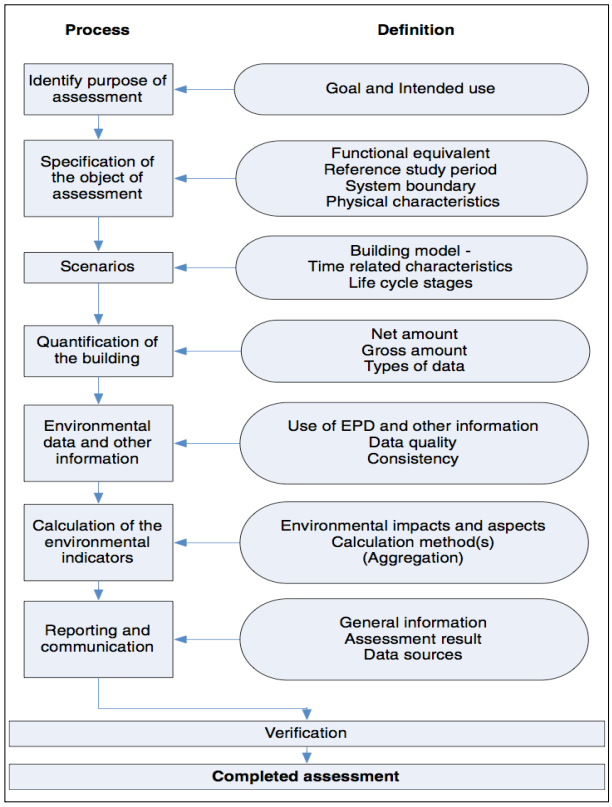


Fig. 2 Main steps within the environmental assessment–workflow according to FprEN 15978 [12]

Figure 2 displays the main steps in the process of assessing the environmental performance according to the FprEN 15978 [15] and gives some examples for required definitions. The scope of the various assessment steps needs to be adjusted to the goal of the assessment. In the various steps. Step number 4 - “quantification of the building” - similar to the LCI in ISO 14040 [10], plays a major role, since the quantification of the environmental performance can be accomplished on this basis.

4.2 Key parameters

For the assessment, the following key parameters, shown in Table 1, were defined. For the reference study period, 50 years was assumed. The functional unit used is an office block, which has been designed by a project partner.

Goal	Complete LCA
Scope	Two different facades life cycle entire facade products
Reference study period (T_{ref})	50 years
Quantification of the operational energy	According to ÖNORM H 5055
Functional unit	Office building (fictitious)
Environmental data	ecoinvent 2.2
Methods	CML 2001, cumulative energy demand
Indicators	AP, EP, GWP, ODP, POCP, CEDr, CEDnr

Table 1 Key assessment parameters

4.3 Inventory analysis

For the LCI based on the bill of quantities for each facade, *ecoinvent*[3] database v2.2 [23, 24] was chosen. This database contains industrial life cycle inventory data for, e.g. energy supply, resource extraction, material supply, metals, waste management services, and transport services.

The life cycle inventory was organized in a matrix. This allowed us to analyze the results for different life cycle stages of the façade constructions as well as for the environmental indicators specific to the construction products and specific to the building operation (use stage). Figure 3 shows the organization of the life cycle inventory and inventoried classes. The building life cycle is therefore divided into the before use, the use, and the end-of-life stage as well as into impacts and aspects specific to the facades and specific to operation.

The boundary conditions of the system determine the processes that are taken into account and are divided into time-related and space-related system boundaries. The time-related boundary covers the before-use stage, the use stage, and the end–of-life stage. The space-related system boundary concerns the whole façade constructions of the fictional office building. This includes all upstream and downstream processes needed to establish and to maintain the functions of the facade, ranging from the acquisition of raw materials to the end-of-life stage.

[3] The ecoinvent Centre, a competence center of ETHZ, EPFL, PSI, Empa, and ART, Switzerland

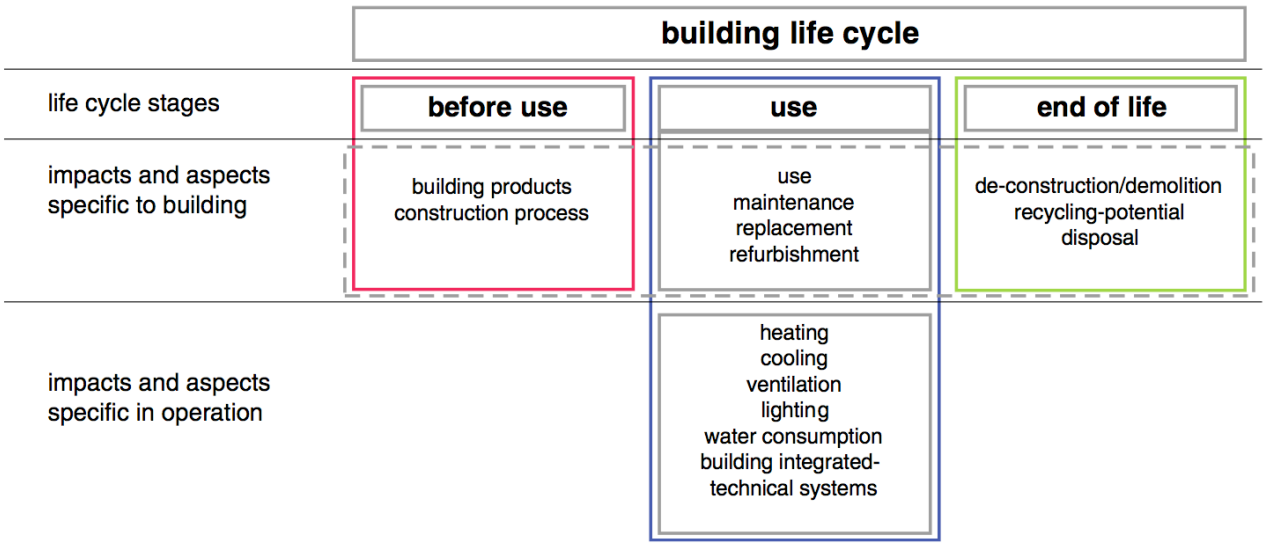


Fig. 3 Organization of the life cycle inventory in accordance with the life cycle stages [25]

4.4 Before-use stage

The before-use stage covers cradle-to-gate processes for construction products (materials/components) and services used for the construction of the facades. The LCI matrix is based on the different construction and support components of the different facades.

In a second step, the items were analyzed for their LCA relevance, which means that construction work without an influence on LCA, e.g., additional charge for special products or work, was ignored. For the LCI of the technical facade equipment, the materials for solar heating systems and PV – installation were taken into account. All technical facade equipment materials were analyzed in detail.

4.5 Use stage

The use stage spans the period from the completion of the construction works to the point when the facade reaches its end of life. The system boundary in the use stage includes the use of construction products (maintenance/replacement) and services for operating the building skin (see Fig. 3). For all construction products (components/materials) that may be replaced, the estimated service life (ESL) was defined in accordance with ISO 15686 parts 1 and 8 [26, 27]. The number of replacement rates for all specific construction products used in the buildings was calculated according FprEN 15978 [15]. Their estimated service life was taken assuming the values by the ESL-Catalogue in Austria [28]. The values given within the ESL are estimates obtained by expert opinions and experience. These values correlate with values in Blom [29] in the case of the technical building equipment.
The Institute of Thermal Engineering has calculated all energetic inputs and outputs for the different types of facades, according to ÖNORM H 5055.

4.6 End-of-life stage

The end-of-life stage of a building begins after the use stage, when the building is decommissioned and is not intended to have any further use. In the presented study, we assumed that the facade would be deconstructed at the end of its life stage and would provide a source of materials to be reused, recycled, recovered, or landfilled, depending on the type of construction product.

4.7 Quantification of the environmental performance

The calculation of the environmental performance is based on indicators according to FprEN15978 [15]. The underlying method is the LCIA according to ISO 14040 [10]. The indicators represent the quantifiable environmental impacts and aspects during the building life cycle. Environmental impacts are expressed with the impact category indicators of LCIA (e.g., global warming potential (GWP)) using characterization factors according to prEN 15804 [13], whereas environmental aspects are based on input flows of the LCI and describe, e.g., the use of renewable and non-renewable primary energy resources (cumulative energy demand (CED)). Out of the 22 indicators listed in the FprEN 15978 [15], [4] seven environmental indicators were selected which are given in Table 2. These seven indicators have been chosen because they are commonly used in practice, e.g., also in building certification systems, and widely accepted calculation methods.

For the calculation of the indicators describing environmental impacts, the characterization methods for the impact assessment according to CML 2001[5] [30, 31] were chosen (see Table 2, “Indicators describing environmental impacts”). For calculation of the indicators describing resource use, the cumulative energy demand (see Table 2, “Indicators describing resource use”), which has been implemented in ecoinvent v2.2, was selected [32].

The environmental indicator values for each indicator were calculated for each product in the different life cycle stages based on a matrix calculation routine (FprEN15978 [15]). This routine consists in multiplying each product and service quantified in the different life cycle stages of the building with its respective value for any environmental indicator. The same calculation routine was applied to all indicators listed in Table 2.

Indicators describing environmental impacts	Code	Unit
Acidification potential of land and water	AP	kg SO2 equiv
Eutrophication potential	EP	kg PO4 equiv
Global warming potential	GWP	kg CO2 equiv
Depletion potential of the stratospheric ozone layer	ODP	kg CFC 11 equiv
Formation potential of tropospheric ozone photochemical oxidants	POCP	kg ethylene equiv
Use of non-renewable primary energy (energy resources)	CEDnr	MJ-equiv
Use of renewable primary energy (energy resources)	CEDr	MJ-equiv

Table 2 Indicators for characterizing environmental impacts and describing resource use

[4] The environmental indicators proposed in the FprEN 15978 (FprEN15978) at the moment consist of seven indicators describing environmental impacts, eight indicators describing resource use, three Indicators describing waste categories, and four indicators describing the output flows leaving the system.

[5] CML, Centre of Environmental Science, Den Haag and Leiden, The Netherlands

5. Multifunctional Plug & Play Façade (MPPF)

5.1 Goal and Scope of the research project

In the last decades industrial prefabrication has been used mainly for building products and to some extend for building elements. The lack of technical knowledge and the lack of possibilities for individualization of components often led therefore to a monotonous design of elements and buildings, and created a poor image of prefabrication technology.

Recently some things have changed for the better. The rapid growth and availability of computer capacity to perform calculations and newest prefabrication technologies allow for the first time a combination of highly efficient prefabrication technologies with design tools simultaneously allowing a high individualization of products i.e. façades. In practice, this leads to enormous time- and cost savings as well as following possibilities:

- Comprehensive high quality transdisciplinary integral planning
- Efficient high quality prefabrication
- Minimization of installation times with lower error rate
- Mass production of basic elements due to prefabrication
- Expanding design options due to a modular approach
- High potential for enhancement of sustainability performance

Due to this initial position the K-Project, “Multifunctional Plug & Play Façade” (acronym: MPPF), launched in 2008. The research project MPPF aims the development of a multifunctional façade system to be used in modular construction methods with the highest possible level of prefabrication. The approach lies in “the expansion of the functionality of these prefabricated façade elements with building engineering functions (like e.g. heat, cold input, air input, lighting, water, power and IT supply) as well as by solar energy technologies (solar thermal, PV)”[33].

5.2 MPPF design principles

Within the MPPF project a criteria list for requirements for a Multifunctional Plug & Play Façade was developed [34]. These requirements are based on following design principles [acc. to 35]:

1. Adjustment of lifetime of structural components to estimated service life of the façade
2. Promoting of recyclability due to
   a. Simple disassembly
   b. Ease of dismantling and
3. Recyclability of materials. Components shall be
   a. Accessible,
   b. Verifiable,
   c. Repairable and
   d. Replaceable.
4. Reduced cleaning effort due to
   a. Accessibility of the surfaces and
   b. Material surfaces itself.
5. Reduction of transport related environmental impacts due to
   a. Optimization of transport routes (components to prefabrication site and building site),
   b. Optimization of truck capacity utilization (volume and mass goods) and
   c. Fuel-efficient and low-emission vehicles.

6. Requirement of documentation of the façade construction
   a. Materials and components,
   b. Maintenance and inspection schedule.
7. Development of a maintenance strategy
   a. Service schedule,
   b. Inspection plan,
   c. Replacement and improvement strategies
8. Use of components which guarantee following:
   a. Reduced primary energy and low impacts and
   b. Recycling materials or materials with high recycling content.
9. Reduction of the energy demand in the use phase due to
   a. Excellent thermal insulation properties of the façade and
   b. Special attention to technical connection details,
   c. Heat protection during the summer.

In addition to these *MPPF design principles* it could also be shown [36] that the MPPF guarantees best possibilities in terms of dismantling und recyclability. More than 84% of the used materials can be directly used for recycling, if a carefully planned recycling concept is implemented.

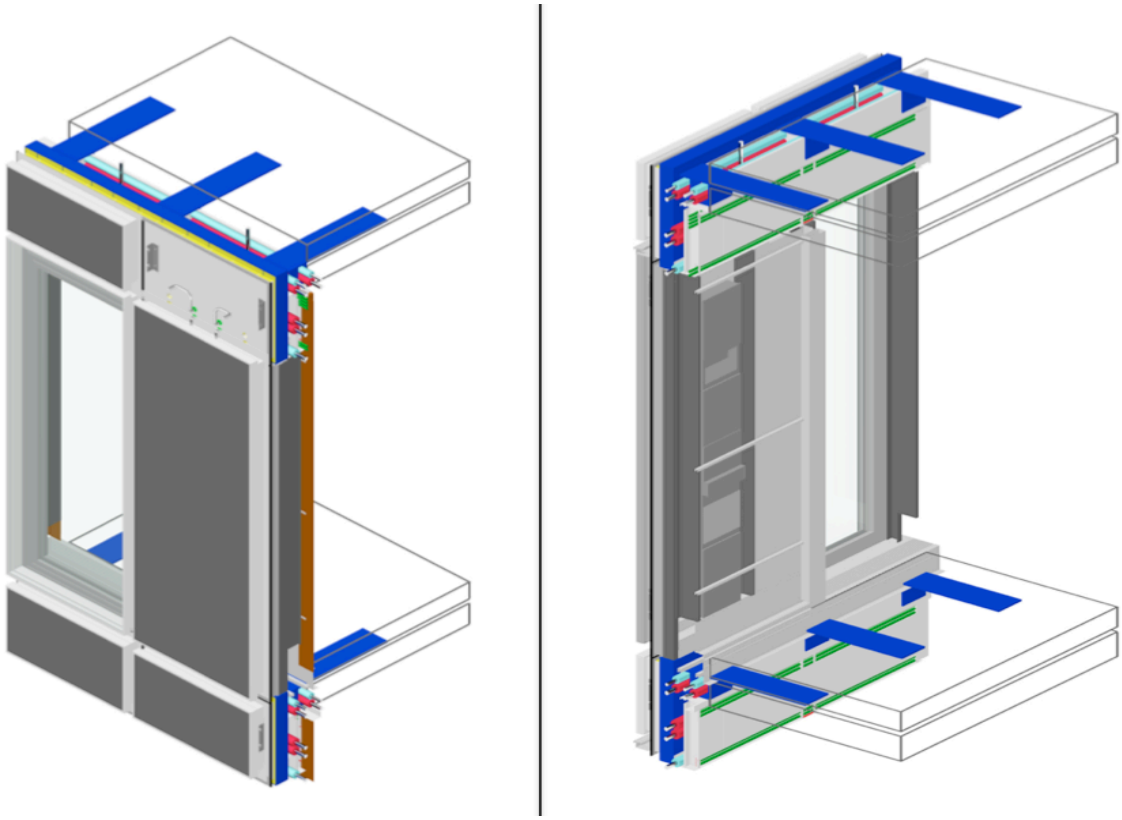


Fig. 4 System sketch of the MPPF [39]

6. Standard Façade

To create a reference to the MPPF it was necessary to design a standard façade, which is based on nearly the same requirements.

The rationale behind the MPPF is a high degree of prefabrication. For that reason it was decided to use an element façade as a basis for the comparison.

6.1 Design principles

An element façade consist, just like the MPPF, of prefabricated modular elements. The individual elements of the unitised façade system are produced in a factory. This means, that all components of the façade, even sun protection and photovoltaic panels get installed in plant.
On site, the finished modules only have to be attached on the building with adjustable anchors.

1. Rational planning of recurring façade elements
2. Specific solutions for different types of buildings
3. Integration of system components like sun protection and photovoltaic panels
4. High performance levels and process safety because of prefabrication
5. Saving time and money by using a prefabricated façade elements

In response to these demands it can be concluded, that an element façade system shows a basis for comparing the MPPF.

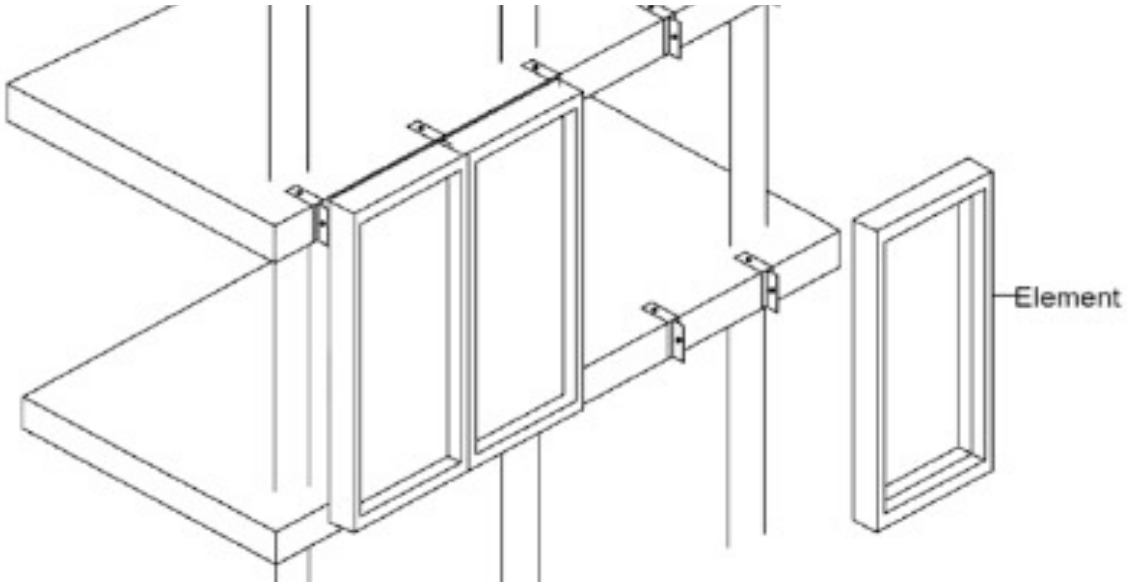


Fig. 5 System sketch of the element façade [40]

7. Comparative results of the different types of facades

The challenge was to show the environmental impacts of the MPPF in order to a conventional facade. Out of that reason the first step was to find a façade, which is constructed by nearly the same basic requirements as the MPPF. This was done by a research and compilation of the characteristics of different types of facades. Investigations revealed that it makes sense, to use an element façade for the comparison.

The next step to realise an LCA for the two different building skins was to obtain certain basic information about the MPPF as well of the element façade too (e.g. power demand, material input,…). In order to this information's it was also necessary to impose the masses of the materials, which were used in the façade constructions.

After collecting all the important basic information's about the materials and characteristics of the two facades the LCA could be done. The results out of the LCA of the different building skins as also the comparison is shown in the following subchapters.

7.1 First comparison, basic structure with passive covering

This first contrasting juxtaposition shows the MPPF basic structure in order to the element façade without any implementation of an active element into the skin of the building.
Figure 6 shows the impacts in order to the different parts of the standard façade. The diagrams of the several indicators clearly show, that the main environmental consequences came out of the finishing elements. For this diagram there also must be mentioned, that active elements like solar thermal panels or photovoltaic panels hasn't been considered in the first step of the investigation. The results for the active building skin will be shown in the next subchapters.

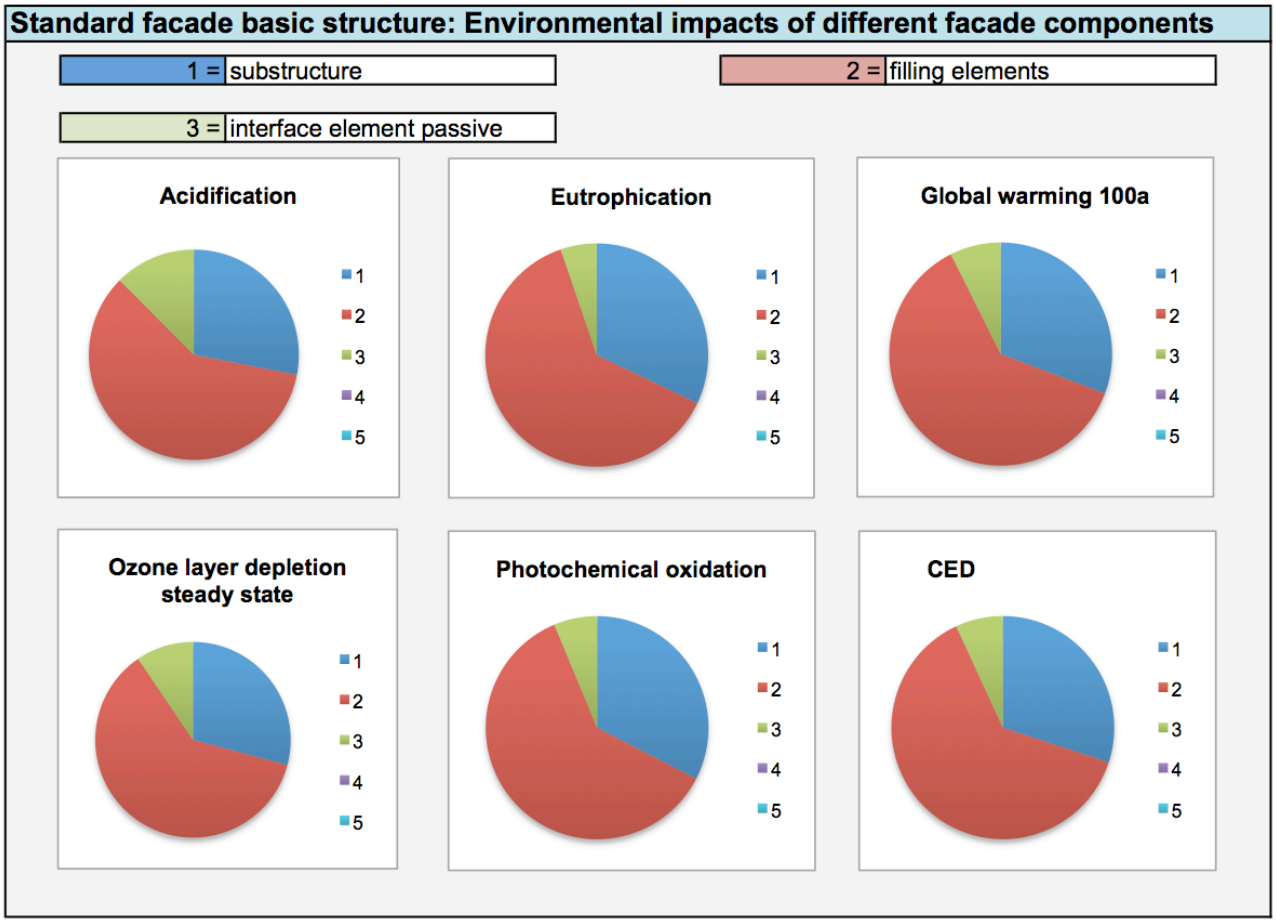


Fig. 6 Environmental impacts of different facade components on the example of the standard façade basic structure

In Figure 7 the issues of the LCA for the MPPF without any active building skin are presented. Out of the pie charts the most environmental relevant components of the MPPF basic structure are shown. Compared with the results of the standard façade (Fig. 6) it is easy to detect, that the majority of the environmental impacts move from the finishing element (standard façade) to the substructure (MPPF basic structure).

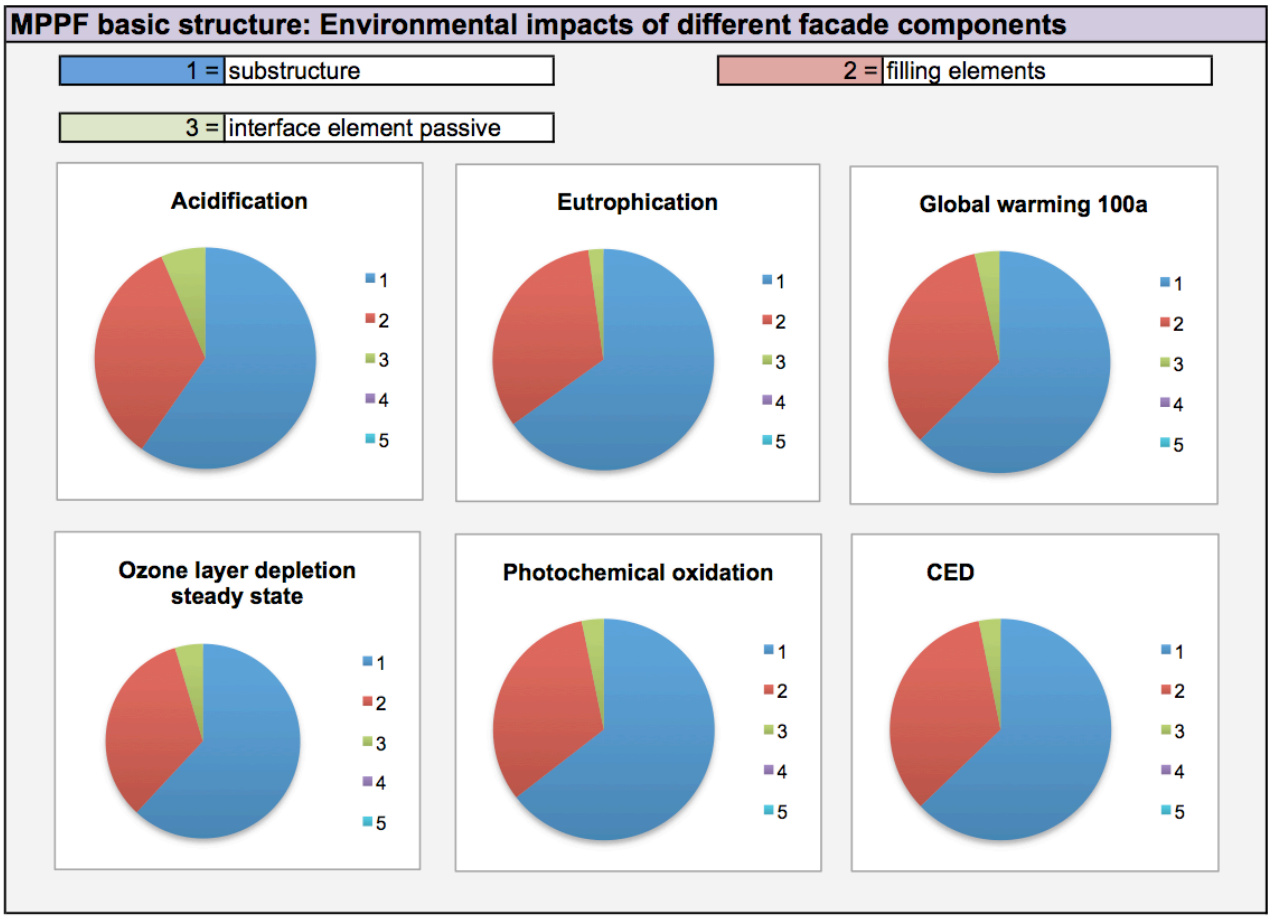


Fig. 7 environmental impacts of different facade components on the example of the MPPF basic structure

The line graph in Figure 8 represent an comparison of the energy demand over a observation period of 50 years. Out of this image (Fig. 8) it is easy to ascertain that a great store of embodied energy is necessary for the production of the facades, especially for the MPPF basic structure because of its substructure, which is necessary because of the requirements described in chapter 5.2. The illustration shows also, that the energy consumption of the building with the MPPF needs less energy over 50 years than the standard façade but the sum of the cumulated energy (embodied and operations energy) of the MPPF is still higher after 50 years of use.
One should bear in mind that in LCA functional and technical performance levels of different Façade systems could not be pictured. This means that the major advantages of MPPF like space for building technical equipment, plug & play capability, dismantling possibilities are not included in the results of Figure 8.

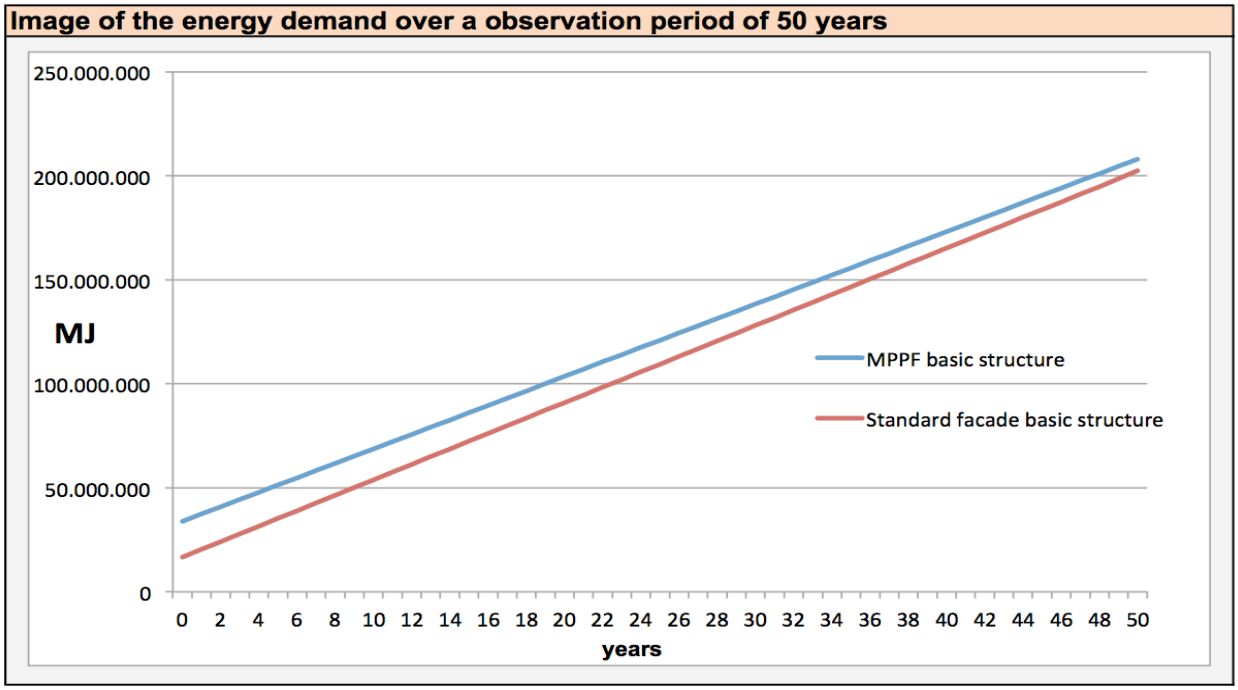


Fig. 8 Image of the energy demand over a observation period of 50 years (basic structure)

7.2 Second comparison, MPPF basic structure and MPPF with active covering (PV)

The second comparison shows the MPPF basic structure in order to an MPPF with implementation of active elements into the building envelope. For this arrangement, photovoltaic panels replaced all the passive items of the facade.
Picture 9 shows the results of the MPPF with an active building skin by the use of PV-Panels (polycrystalline PV - modules). Even though the environmental impacts from the PV-modules are very high, the substructure of the MPPF causes still the most ecological effects.

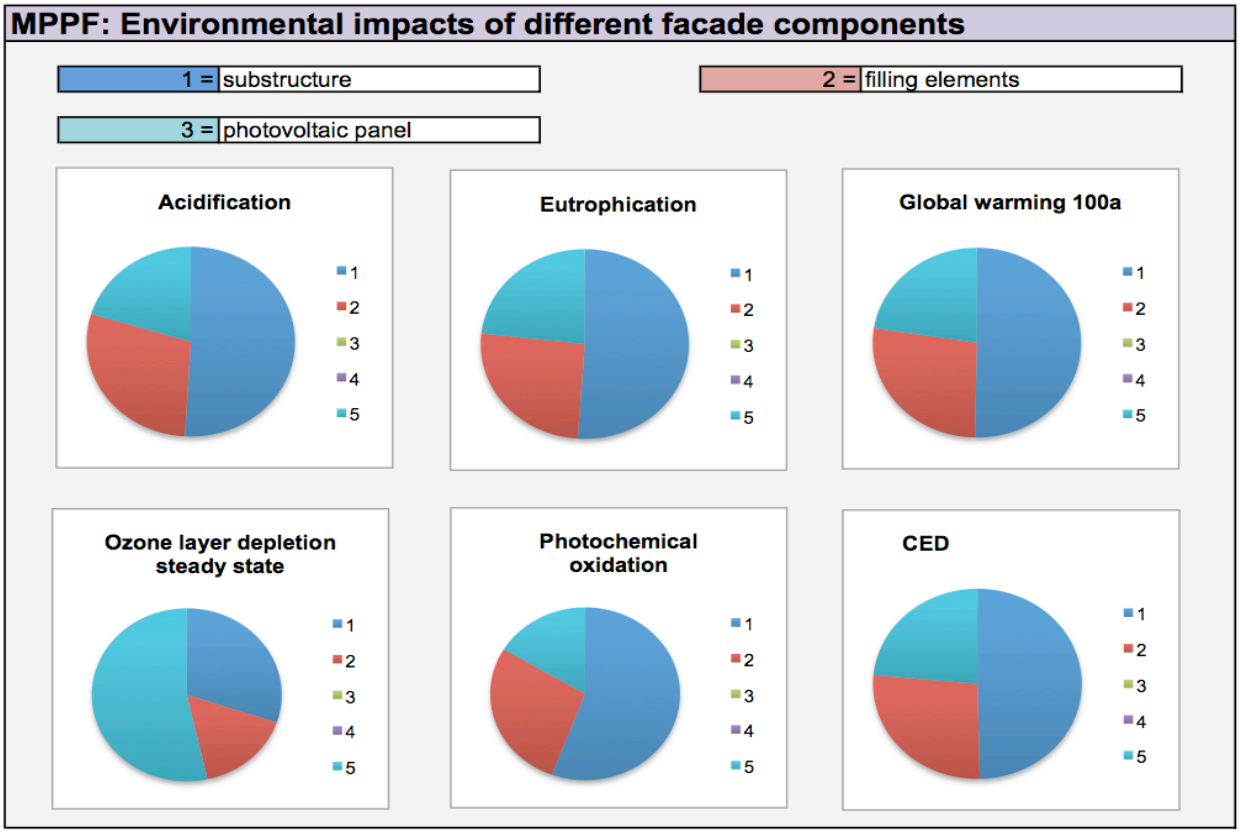


Fig. 9 Environmental impacts of different façade components on the example of the MPPF

Out of the line graphs of figure 10 it can be seen that the MPPF – active needs less energy than the MPPF-passive after a report period of around 4 years. Due to this it can be concluded, that an integration of active modules in the façade is indispensable for an optimization of the energetic building performance.

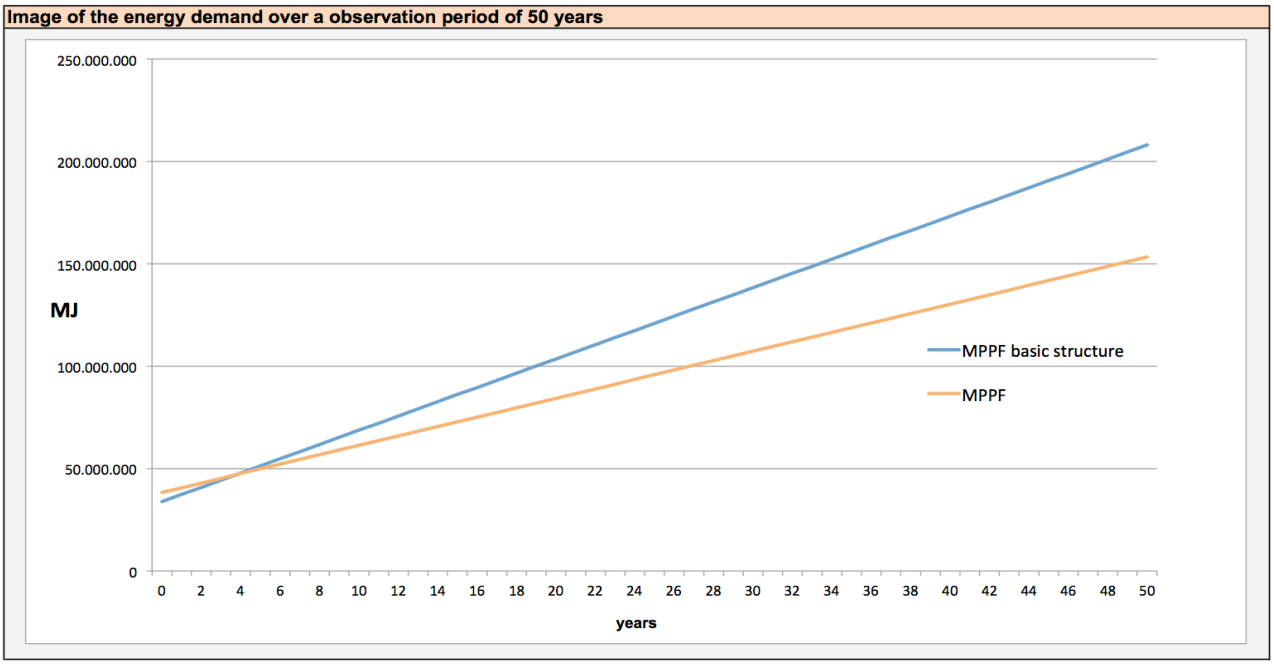


Fig. 10 Image of the energy demand over a observation period of 50 years (MPPF basic structure versus MPPF)

8. Conclusions & Outlook

The demand on buildings, which allow the enhancement of the principles of a sustainable development, will gain more and more importance in the private as well as the public sector. This trend is based not only on marketing demands but also due to the need of better life cycle performance. One of the instruments in proving the performance is building certification, which includes aspects as e.g. LCA and LCCA as well as user comfort (as part of the functional performance) or technical aspects.

For the design of façades this results in increased requirements. This means not only the development of “innovative” building products or elements but also in the “active” provision of adequate product information i.e. EPDs (Environmental Products Declarations) as well as the optimization of processes through out the value chain. A major trend is the assessment of the whole building where every part / component must ensure its contribution to the overall building performance.

For the MPPF project it can be shown that the design of the Façade has a big influence on building LCA results. Additionally the upcoming requirements i.e. sustainable use of natural resources by the new CPR or the assessment criterion “ease of dismantling and recycling” can only be fulfilled by a design process, which considers all these aspects and by façade systems, which integrate building engineering functions as well as solar energy technologies. Prefabrication technology makes it feasible to predict the performance of the façade.

The optimization of the energy performance as well as the optimization of the material choice in the construction (e.g. in terms of LCA or risks to the local environment), functional or technical assessment criteria is one of the most important criteria in the construction sector. It could also be shown that the functionalization of Facades is not only a trend but also environmentally reasonable. As the MPPF allows a broad range on functionalization (e.g. solar thermal, PV and HVAC system) an LCA should be performed on the building level comparing the integration of building functions into the Façade vs. conventional Facades and conventional technical systems.

One should bear in mind that the improvement of building performance is a non-linear approach as different assessment criteria influence each other (i.e. an interdependency of criteria) [37, 38]. Only by ensuring that already the design options are based on a holistic life cycle performance assessment, the demanding challenge of a holistic improvement of building performance can be reached in future [38]. Using a systematic approach could be one way in coping with the complexity of different requirements.

9. Acknowledgements

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Special thanks to the Institute of Thermal Engineering for the calculation of the energy demand for the different types of facades.

10. References

[1] Austrian Standards Institute, “Sustainability of construction works — Assessment of buildings — Part 2: Framework for the assessment of environmental performance”. Vienna, 2011

[2] The European Parliament and the Council of the European Union, “Regulation (EU) No 305/2011 of the European Parliament and of the Council – Basic Requirements for Construction Works”, Brussels, 2011

[3] A. Passer; T. Mach; H. Kreiner; P. Maydl, Predictable Sustainability? The role of building certification in the design of innovative façades. - in: Advanced Building Skins. (2012), ISBN 978-3-85125-213-2

[4] Wallbaum H and Meins E (2009): No sustainable planning, constructing and operating – (still) common praxis in the building industry for a good reason?, Bauingenieur, Band 84, Juli / August 2009: 291-303

[5] Maydl P, Structural Sustaillability - the Fourth Dimension? Structural Engineering International 3/2006: 268-269

[6] Mateus R. and Bragançaa L., Sustainability assessment and rating of buildings: Developing the methodology SBToolPT-H, Building and Environment, Volume 46, Issue 10, October 2011, Pages 1962-1971, ISSN 0360-1323, DOI: 10.1016/j.buildenv.2011.04.023.

[7] Bribian I. Z., Uson A. A., Scarpellini S., Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification, Building and Environment, Volume 44, Issue 12, December 2009, Pages 2510-2520, ISSN 0360-1323, DOI: 10.1016/j.buildenv.2009.05.001.

[8] Passer A, Assessment of the environmental performance of buildings, PhD-Thesis, TU Graz, 2010;
https://online.tugraz.at/tug_online/wbAbs.showThesis?pThesisNr=22305&pOrgNr=2265&pAutorNr=22702&pFassungNr=2&pPersNr=

[9] International Organization for Standardization (ISO), Sustainability in building construction — Environmental declaration of building products; ISO 21930:2007

[10] International Organization for Standardization (ISO), Environmental management - Life cycle assessment - Principles and framework, Umweltmanagement – Ökobilanz, Grundsätze und Rahmenbedingungen, ÖNORM EN ISO 14040:2006

[11] European Committee for Standardization (CEN), Sustainability of construction works — Assessment of buildings — Part 1 General Framework for assessment of buildings, EN 15643-1:2011

[12] European Committee for Standardization (CEN), Sustainability of construction works — Assessment of buildings — Part 2 Framework for the assessment of the environmental performance, EN 15643-2:2011

[13] European Committee for Standardization (CEN), Sustainability of construction works - Environmental product declarations — Core rules for the product category of construction products,), EN 15804:2012

[14] European Committee for Standardization (CEN), Sustainability of construction works – Environmental product declarations - Communication formats: business to business, FprEN 15942:2010

[15] European Committee for Standardization (CEN), Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method, FprEN 15978:2011

[16] Gertis K, Hauser G, Sedlbauer K, Sobek W (2008): Was bedeutet „Platin“? Zur Entwicklung von Nachhaltigkeitsbewertungsverfahren, Bauphysik 30 (2008), Heft 4: 244-256, DOI: 10.1002/bapi.200810032

[17] Graubner C-A and Lützkendorf T (2007): Studie zur Nachhaltigkeitszertifizierung von Gebäuden, Bundesamt für Bauwesen und Raumordnung -BBR-, Forschungsinitiative "Zukunft Bau"

[18] Fuerst, F.and McAllister, P. (2009): An Investigation of the Effect of Eco-Labeling on Office Occupancy Rates. Journal of Sustainable Real Estate, 1/1, 49-64.

[19] Humbert S, Abeck H, Bali N, Horvath A (2007): Leadership in Energy and Environmental Design (LEED). A critical evaluation by LCA and recommendations for improvement. Int J LCA 12 (Special Issue 1) 46–57, DOI: 10.1065/lca2006.12.291

[20] Wallhagen M and Glaumann M (2011): Design consequences of differences in building assessment tools: a case study, Building Research & Information (2011) 39(1): 16-33, DOI: 10.1080/09613218.2010.513210
[21] Optis M and Wild P (2010): Inadequate documentation in published life cycle energy reports on buildings, Int J LCA (2010) 15:644–651; DOI 10.1007/s11367-010-0203-4
[22] Cresnik, G., Maydl, P.: Multifunctional Plug & Play Façade, Annexbericht: Integration von kreislaufwirtschaftlichen Gesichtspunkten in die Entwicklung von MPPF – Bewertung der Fassade des FIBAG- Gebäudes (2010).
[23] Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Heck T, Hellweg S, Hischier R, Nemecek T, Rebitzer G, Spielmann M, Wernet G Overview and methodology, ecoinvent report No. 1, Swiss Centre for Life Cycle Inventories, Dübendorf
[24] Althaus HJ, Kellenberger D, Doka G, Künninger T Manufacturing and disposal of building materials and inventorying infrastructure in ecoinvent. Int J Life Cycle Assess 10(1):35–42
[25] Passer A (2010) Assessment of the environmental performance of buildings, PhD-Thesis, TU Graz
[26] International Organization for Standardization (ISO) Building and constructed assets—service life planning—general principles. ISO 15686–1:2000
[27] International Organization for Standardization (ISO) Building and constructed assets—service life planning—reference service life. ISO 15686–8:2008
[28] Hauptverband der allgemein beeideten und gerichtlich zertifizierten Sachverstaendigen Österreichs - Landesverband Steiermark und Kärnten: Nutzungsdauerkatalog baulicher Anlagen und Anlagenteile. ISBN-10: 3-200-00690-0, ISBN-13: 978-3-200-00690-4
[29] Blom I, Itard L, Meijer A (2010) LCA-based environmental assessment of the use and maintenance of heating and ventilation systems in Dutch dwellings. Build Environ 45:2362–2372
[30] Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ, Lindeijer E, Roorda AAH, Weidema BP Life cycle assessment; an operational guide to the ISO standards; parts 1 and 2 Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environ- mental Science (CML), Den Haag and Leiden, The Netherlands, retrieved from: http://www.leidenuniv.nl/cml/ssp/projects/lca2/ lca2.html
[31] Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Bruijn H, van Duin R, Huijbregts MAJ, Lindeijer E, Roorda AAH, Weidema BP Life cycle assessment; an operational guide to the ISO standards; part 3: scientific background, Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML). Den Haag and Leiden, The Netherlands
[32] Hischier R, Weidema B, Althaus H-J, Bauer C, Doka G, Dones R, Frischknecht R, Hellweg S, Humbert S, Jungbluth N, Köllner T, Loerincik Y, Margni M, Nemecek T (2009) Implementation of life cycle impact assessment methods. ecoinvent report no. 3, v2.1. Swiss Centre for Life Cycle Inventories, Dübendorf
[33] Wallbaum H. and Hardziewski R.: Minergie und die Anderen– Vergleich von Vier Labels, TEC21 (2011), 47:32—39.
[34] Ebert, T., Essig, N., Hauser, G.: Zertifizierungssysteme für Gebäude: Nachhaltigkeit bewerten, Internationaler Systemvergleich, Zertifizierung und Ökonomie. Institut für internationale Architektur-Dokumentation, München 2010.
[35] Müller M.: Multifunctional Plug & Play Façade, K-Project Review Core Document, FFG, 2010
[36] Cresnik, G., Maydl, P.: Multifunctional Plug & Play Façade, Annexbericht: MPPF Standard ökologische Nachhaltigkeit, (2009).
[37] Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft (ÖGNI), Austrian Sustainable Building Council, http://www.ogni.at/
[38] Passer, A.; Kreiner, H.; Cresnik, G.; Maydl, P.: Genormte Nachhaltigkeit?. - in: Nachhaltige Gebäude - Planung, Betrieb und Bewertung (2010), S. 25 – 33, Internationaler Kongress enova ; 2010.
[39] Grobbauer, M.; et. al.: Why design a façade? – MULTI FUNCTIONAL PLUG AND PLAY FAÇADE; 2012
[40] Universität Siegen: http://www.baunetzwissen.de/standardartikel/Fassade_Montagetechnik_154495.html?img=5&layout=galerie

B4

Best Practice

Chair: Peter Maydl
Graz University of Technology, Austria

Environmental performance of energy efficient residential building – a case study of Lithuania



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Short Summary

The paper presents life cycle analysis (LCA) results of the passive house in Lithuania. For the first approach three the most common and relevant impact categories of the life cycle were chosen – energy consumption, global warming potential and ozone layer depletion. Results of the LCA together with simulations of operational energy demand assert that embodied energy (construction & maintenance) constitutes 1/3 of the whole LCA energy, 1/5 embodied ozone layer depletion, and 2/3 of global warming potential. The environmental impact of various life cycle phases is presented. It is concluded that for different climates, during the life cycle of the energy efficient house, embodied energy is higher than in conventional buildings. Therefore sustainability of the construction materials and different occupation profiles has to be considered very carefully. In addition, influence of the occupants on LCA of the building is illustrated. Results show that it is not always purposeful, when performing dynamic LCA to take into account changes in occupation of the house.

Keywords: LCA; energy efficient house; embodied, occupants, environmental impact, simulation.

1. Introduction

Increase of energy efficiency in buildings sector is a key objective of the European Union's (EU) energy policy. With the adoption of recast Directive 2012/31/EU [1] - the main legislative measure in buildings energy efficiency sector, Member States were obliged by 2020 to move towards new and retrofitted nearly-zero energy buildings. Directive on energy efficiency 2012/27/EU [2] also aims to increase energy efficiency in buildings. But in frames of both directives, energy efficiency is understood as decrease of operational energy consumption of the building. Multiple researches came to the conclusion that the demand for operating energy reduction appears to be the most important aspect for the design of energy efficient buildings [3-7]. But this is correct just for inefficient or standard buildings. With the recent requirements of the above mentioned directives, buildings energy consumption during the operational phase started and will continue decreasing. Improvements made seeking to design more energy efficient building, as a rule, require more materials and as a consequence environmental impact of the building in its construction and demolition phases may significantly increase. The increasing energy demand to build an energy efficient building is already illustrated by some authors. For example, study performed by Blom et al. [8] has shown that improvement of the building equipping it with a heat pump causes the highest environmental burden of all the assessed climate systems. Blengini and Di Carlo [9] conducted a detailed LCA on a low energy family house and found that shell-embedded materials represented the highest relative contribution, but maintenance operations also played a major role. Citherlet and Defaux [10] study has shown that for a family house, it is important to be concerned about the indirect (construction and elimination phases) impact when the final (total) energy demand is lower than about 50 MJ/m^2/y for UCTE electricity mix.

Passer et al. [11] claim that despite many LCA studies were performed, the influence of the construction products used for the technical building equipment of buildings has hardly been described in literature and authors strongly recommend including the technical building equipment for assessments of the environmental performance of buildings. Some authors already have proposed to incorporate LCA approach to building's energy efficiency policy implementation measures. Some authors have already proposed to consider life cycle process in building's energy certification or energy auditing process [12-13]. Hence, an overall judgment on building sustainability should encompass all the life phases and this is emphasized by findings of above mentioned authors [8-10] and a holistic approach is needed, as single improvements might not be effective in a life cycle perspective. There is also a need for solutions adapted to particular climate conditions.

The presented study aims: 1) to assess environmental impact of the energy efficient single-family house, using LCA methodology, involving building's constructions and all engineering systems of the building (energy production, heating, ventilation, water supply, sewage and electrical installation); 2) to identify phases of the life cycle and elements of the building with the highest environmental impact; 3) to apply and evaluate measures to reduce environmental impact of the building during its life cycle; 4) to assess influence of occupants' characteristics (household size and age) and on life cycle of the building.

2. Methodology

Life Cycle Assessment (LCA) is a well-known and internationally identifiable method, properly described and determined by standards. Principles of LCA are also generally applied to environmental assessment of buildings and their constructions. Many studies on the environmental impacts during the operation phase of a building were performed as well as the analysis of life cycle costs, but there are still many questions and uncertainties regarding long-term and combined effects [14]. LCA is usually based on a static life cycle models. However, there are dynamic conditions in every phase of a building's life that could influence the balance of environmental burdens [6]. Dynamics could be expressed by changes in future resources, changes in equipment performance, future occupant behaviours. In some cases, changes during a building's lifetime can influence the LCA results to a greater degree than the material and construction phases. Adapting LCA to a more dynamic approach may increase the usefulness of the method in assessing the performance of buildings and other complex systems in the built environment [15].

Life Cycle Assessment (LCA) is currently used to a very limited extent in the building sector [16]. The recent studies proved that LCA should not be limited to building materials or building components only [17]. Therefore, making an LCA evaluation of a building requires a specific tool to process the large amount of data. The problem of LCA complexity was also analysed by Kellenberger and Althaus [18]. Study authors state that more building components should be studied. Some other examples of LCA studies and new techniques are presented in Table 1.

Despite existing standards, the depth of the methodology is not strictly regulated, therefore, as it was shown above, researchers are still free to choose models, tools and boundaries of the investigation. Main peculiarities and assumptions of the applied LCA method are presented below.

2.1 Life cycle assessment software and functional units

The LCA was undertaken using the computer tool SimaPro 7.2, with the functional unit 1 m^2 of the useful floor area. The single-family house in Lithuania and its subsequent use were calculated over a 100-year period. The key data for inventory analysis were identified by the simulation of the building and the data for impact assessment derived from IMPACT 2002+ V2.10 method SimaPro libraries. For the energy assessment of environmental performance during the operational stage of the building, also dynamic building energy simulation with DesignBuilder was performed.

Table 1: The examples of resent studies on LCA methodologies and applications

Reference	Main topic
Rogoza et al. (2006) [19]	3E factor for optimizations of energy systems
Zheng et al. (2009) [20]	Building energy conservation assessment model combining LCA and the extenics theory
Malmqvist et al. (2011) [16]	The ENSLIC simplified method
Heijungs et al. (2012) [21]	Life cycle sustainability analysis, combining LCA, LCC, and social LCA
Collinge et al. (2012) [15]	Dynamic process modelling (DLCA)
Veerbeeck and Hens (2012) [17]	Life cycle inventory model for life cycle optimisation of extremely low energy dwellings
Guo and Murphy (2012) [22]	Statistical methods integrated into LCA models
Tingley and Davison (2012) [23]	Methodology for LCA studies investigating reused materials or products/buildings
Audenaert et al. (2012) [24]	LCA of a low-energy building using the Eco-indicator 99 method

2.2 System boundaries

The life cycle phases included in the study are: 1) production/construction, 2) operation & maintenance, 3) dismantling and recycling, 4) transportation in all phases. The production and the construction phase include a production of materials for initial constructions and transportation of the materials to their plant. The operation and the maintenance correspond accordingly to a demand of energy for the building usage (heating, ventilation, domestic hot water and lightning) and a renewal of the constructions/systems (a periodic replacement of their elements). The dismantling and the recycling mean a preparation of the embodied materials for their final disposal or recycling. It covers the initial construction materials and the materials replaced during the maintenance. A benefit of the recycling was not counted in the boundaries of the life cycle. The transportation phase amounts all transport facilities throughout the building life cycle (transport of the constructions, elements, materials and fuel). It belongs to the phases mentioned before,but it was separated from.

The elements of the building existence were assorted into two groups – embodied and operational. The first group consists of: walls, windows, doors, roof, foundations, floor, plumbing and sewage, heating system, ventilation equipment, and electrical installation. The second one comprises of heat for space heating (wood pellets), heat for domestic hot water (DHW) (wood pellets) and electricity. All the embodied elements were examined throughout all life cycle phases and the operational elements were evaluated only during the operation & maintenance, and transportation phases (except electricity).

2.3 Indicators

For the first approach the most common and relevant life cycle impact categories were chosen. The focus of this study was on three impact categories: non-renewable energy, global warming and ozone layer depletion. The indicators of the categories are presented in Table 1.

Table 2: Environmental impact categories

Environmental impact category	Indicator	Unit of measurement
Primary energy demand	Non-renewable energy	MJ
Global warming	CO2 eq	kg
Ozone layer depletion	CFC-11 eq	kg

All indicators were assigned for functional unit (the amounts per 1 m^2 of the useful floor area).

2.4 Inventory

Inventory analysis was performed itemizing the building structure. The main components were expressed as volumes of the constitutive materials. Thereby the 35 leading materials were analysed using SimaPro software.

Assumptions:

- The building will be used for over 100 years.
- Calculating the transportation phase, distances were chosen only approximately.
- Examining the materials of which separate elements were produced; a very minor items were not included.
- Domestic electric appliances, their energy demand and furniture were not included in the calculations.
- The operational life span of separate elements (replacement periodicity) was estimated according the national recommendations.

3. Description of the building

To analyse building's energy performance during its operational phase of life cycle, model, described below, was created and simulated in DesignBuilder.

Geometry. One-storey, square-shaped house was selected as an object for the analysis. The total area of the analysed building - 81 m^2. Building is designed for standard family of 4 persons. Other characteristics of the envelope are supplied in Table 3.

Table 3: Characteristics of the building envelope

Building system	Description
Exterior wall	U=0.11 W/m^2K. Materials: Cement plaster, silicate blocks, polystyrene foam, cement mortar.
Foundation wall	U=0.57 W/m^2K. Materials: concrete block, EPS expanded polystyrene, cement mortar.
Internal partitions	U=1.49 W/m^2K. Materials: gypsum plasterboard, air gap, gypsum plasterboard.
Roof	U=0.10 W/m^2K. Materials: bitumen, MW stone wool, EPS expanded polystyrene, aerated concrete roofing slab, cement mortar.
Floor on the ground	U=0.15 W/m^2K. Materials: gravel, EPS expanded polystyrene, concrete, plywood flooring.
Windows	Triple glazed windows: 4-16Ar-4-16Ar-4. U_{glass}=0.72 W/m^2K; U_{frame}=0.94W/m^2K. Materials: Argon, glass, PVC
Doors	Internal door – U=2.5 W/m^2K. Materials: plywood, air gap;
	External door – U=0.75 W/m^2K. Materials: painted stainless steel and foam polyurethane

Lighting and electrical installations. LED lighting with a specific lamp power of 3 W/m^2/100 lx is assumed to be installed. Lighting levels correspond to the requirements of national regulations.

Domestic hot water (DHW). Heat for DHW is produced using solar collectors and biomass boiler. Domestic cold water and wastewater systems were also analysed.

Ventilation. Mechanical constant air flow ventilation system with heat recovery unit was designed in the building. Air flows were selected according to the requirements of national standards. Fresh air was supplied during the hours when building was occupied and one hour before the occupants came back home. During the unoccupied hours the system operated in recirculation mode. The total air change rate in the building of 0.6 h^{-1} was assumed including the infiltration and mechanical

ventilation.

Heating. Energy for heating is produced by wool pellets boiler and floor heating is assumed to be installed. The comfort temperature was maintained just during the occupancy hours. For unoccupied periods heating set back temperature was set 3°C lower than comfort temperatures.

4. Results

4.1 Environmental impact of the whole life cycle of the building

Simulations of the operational energy consumption together with the analysis of the embodied energy (construction and maintenance) have shown that for the building built according to the national passive house requirements (simulated annual heating energy demand - 17.7 kWh/m^2), embodied energy constitutes 31 % of the whole LCA energy and embodied ozone layer depletion – 21 %. Situation is different with the global warming – the highest impact (63 %) is made in construction and maintenance phases.

The environmental impact of various life cycle phases is presented in Fig. 1. As we can see, the phase of operation & maintenance dominates in all impact categories. This phase covers the operational group as well as it includes a part of the embodied group – a renewal of the building elements.

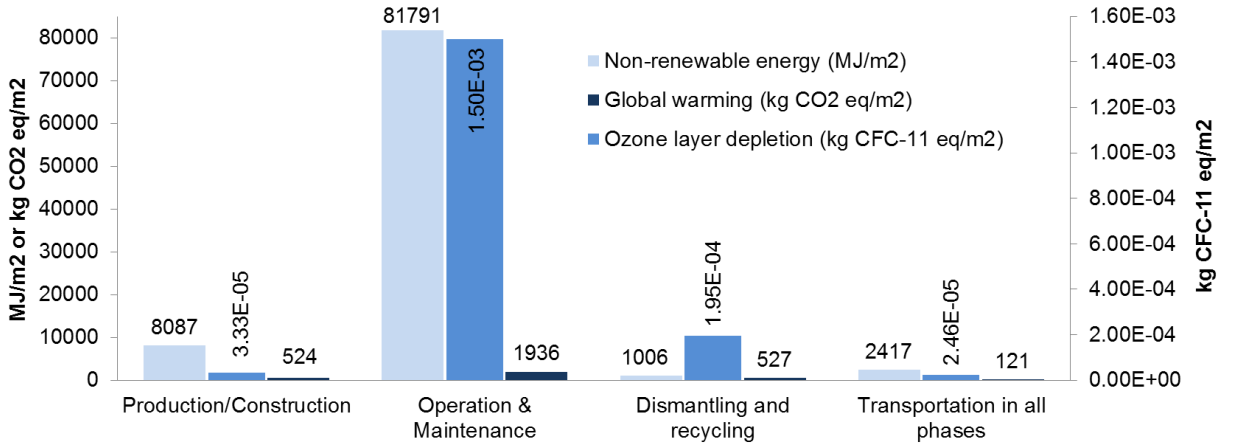


Fig. 1: The environmental impact of various life cycle phases

Results of the study confirm findings of Blengini and Di Carlo [9] for the low energy house in Italy and are very similar to the above mentioned statement of Citherlet and Defaux [10] (house in Switzerland).

4.2 Embodied energy and emissions

Analysis of the embodied energy and emissions of the building has shown that major impact is made by materials used to create building envelope, especially walls, roof and floor. Meanwhile technical installations of the building all together need just 15 % of embodied energy and their embodied CO2 and CFC-11 emissions accordingly are 15 % and 14 %. This might be explained by relatively smaller demand of materials. Seeking to decrease environmental impact of materials used to build and maintain the building; more sustainable solutions for walls, roof and floor should be found. Especially, attention to insulating materials and covering of the floor has to be paid, because of their high impact. Therefore, three embodied alternative improvements were evaluated: 1) new log walls with rock wool insulation; 2) the first alternative plus new steel sheet roof with rock wool insulation; 3) the second alternative plus new ceramic tile floor.

The calculations have shown (Fig. 2) that it is possible to save up to 25 % of embodied energy and

to reduce up to 23 % of embodied CO2 emissions by applying the second alternative. However the greatest reduction of embodied CFC-11 emissions (42 %) could be achieved by applying the third alternative. It is related with disuse of floor lacquer.

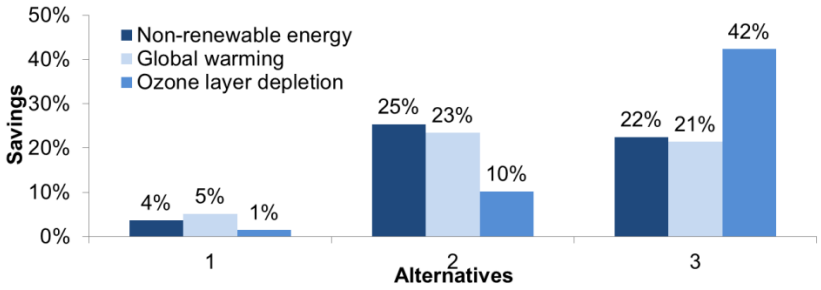


Fig. 2: Savings of embodied energy and reduction of the emissions

Taking into account all environmental impact categories, alternative 3 is considered to be the most efficient one.

Findings of this study together with findings of other studies enable to conclude that for different climates, during the life cycle of the energy efficient house, embodied energy is higher than in conventional buildings. Therefore, not just operational energy is important, but also sustainability of the construction materials has to be considered very carefully.

4.3 Operational energy and emissions - influence of the occupants characteristics

There are many studies proving that operational energy consumption of the building might be significantly influenced by characteristics of occupants (age, size of the household, inhabits etc.). It was also previously assed for the analysed house by Motuziene and Vilutiene [25]. The above mentioned Collinge et al. [13] also have stated that environmental performance of the building is a dynamic process and may change during building's life cycle and one of the reasons of that are changes in occupation. To illustrate how occupants may influence life cycle performance of the building, different occupation alternatives were simulated (Table 3). National specialities of the lifestyle for these different households were taken into account when simulating energy demand of the building.

Table 3: Characteristics of the building envelope

Household type	Description
4 - with children	Household size is 4 people (statistical Lithuanian family is 3.5 people), parent actively working in the city and 2 children stay during the working hours at school or kindergarten; children come back home together with parents.
2 - working couple	Household size is 2 – couple actively working in the city, no children.
2 - retired couple	Household size is 2 – two adult retired people.

Influence of the occupation of the building was assessed for the best alternative 3 (see Fig. 3).

Results show that occupants characteristic, such as family size and age has influence on all environmental impact categories. Compared to the base case (4 family members), total non-renewable energy demand, global warming potential and ozone layer depletion for a 2 working persons household might be accordingly 14 %, 10 and 15 % lower. Meanwhile retired couple, despite that there are twice less occupants, makes the same environmental impact as 4 people's family. Differences in operational energy consumption for analysed households occur because of DHW consumption, which depends mainly on size of household, as well as energy consumed for heating, since different occupation profiles enable to apply different heating system management and electricity for lighting, which depends both on household size and occupation hours.

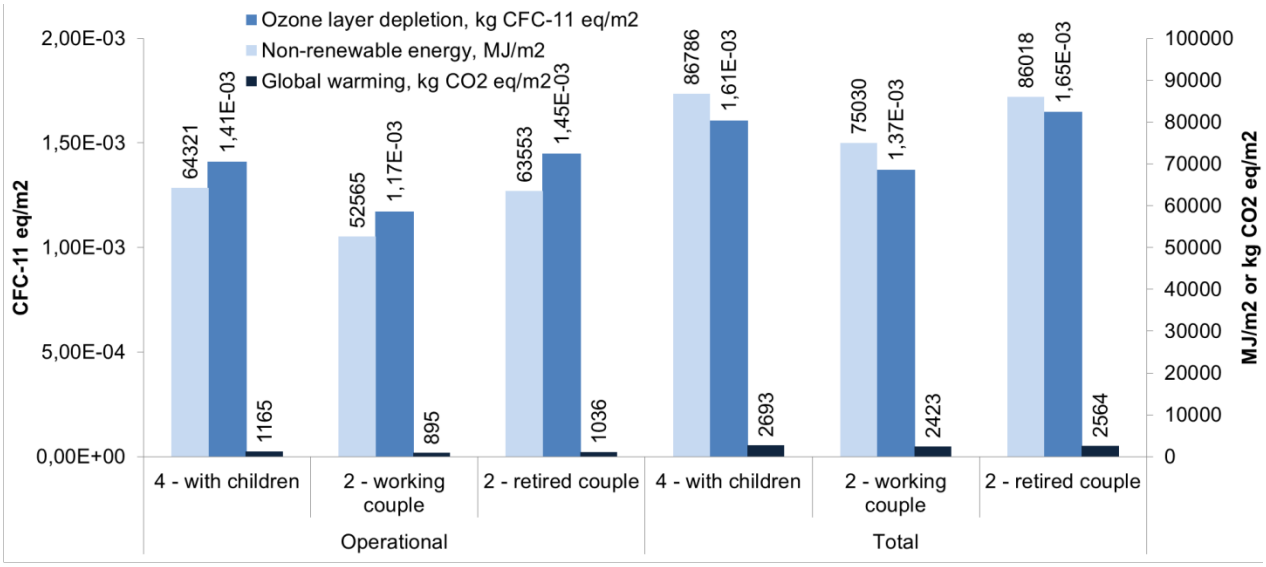


Fig. 3: Influence of different occupation on environmental impact categories

5. Discussion and conclusions

It is defined that for energy efficient houses environmental impact of the operational phase is decreasing, therefore consideration of envelope construction materials becomes a key issue for the design of sustainable building. Technical systems have relatively minor embodied environmental impact and improvement potential. Nevertheless, just complex detailed optimisation of the embodied and operational energy and emissions enables to get the best result.

Household size and age influences environmental impact categories, but it might be considered as insignificant if the size of household and age of occupants is changing during life cycle of the building. Therefore, when performing dynamic LCA, analysis of these factors might be inexpedient. There are still cases, when it might be important to take into account occupant's characteristics, e. g. students' hostels cannot be calculated as standard family houses, because such specific buildings have always the same occupants.

6. Aknowledgement

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7. References

[1] DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings.

[2] DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency.

[3] ZHANG Z, WU X, YANG X, ZHU Y. *"BEPAS—a life cycle building environmental performance assessment model."* Building and Environment, DOI: 10.1016/j.buildenv.2005.02.028; 2006, Volume 41/5, pp. 669–675.

[4] ROSSELLÓ-BATLE B, MOIÀ A, CLADERA A, MARTÍNEZ V. *"Energy use, CO2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands."* Energy and Buildings, DOI: 10.1016/j.enbuild.2009.10.024; 2012, Volume 42/4, pp. 547–558.

[5] KOFOWOROLA O F, GHEEWALA S H. *"Life cycle energy assessment of a typical office building in Thailand"*. Energy and Buildings, 2009, Volume 41/10, pp. 1076–1083.

[6] SCHEUER C, KEOLEIAN G A, REPPE P. "Life cycle energy and environmental performance of a new university building: modeling challenges and design implications." Energy and Buildings, DOI: 10.1016/S0378-7788(03)00066-5; 2003, Volume 35/10, pp. 1049–1064.

[7] SARTORI I, HESTNES A G. *"Energy use in the life cycle of conventional and low-energy buildings: A review article."* Energy and Buildings, 2007; Volume 39/3, pp. 249–257.
[8] BLOM I, ITARD L, MEIJER A. "*LCA-based environmental assessment of the use and maintenance of heating and ventilation systems in Dutch dwellings.*" Building and Environment, Elsevier Ltd, 2010, Volume 45/11, pp. 2362–2372.
[9] BLENGINI G A, DI CARLO T. *"The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings."* Energy and Buildings, Elsevier B.V., DOI: 0.1016/j.enbuild.2009.12.009; 2010, Volume 42/6, pp. 869–880.
[10] CITHERLET S, DEFAUX T. *"Energy and environmental comparison of three variants of a family house during its whole life span."* Building and Environment, DOI: 10.1016/j.buildenv.2005.09.025; 2007, Volume 42/2, pp. 591–598.
[11] PASSER A, KREINER H, MAYDL P. *"Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings."* The International Journal of Life Cycle Assessment, DOI: 10.1007/s11367-012-0435-6; 2012, Volume 17/9, pp. 1116–1130.
[12] ZABALZA B I, ARANDA USÓN A, SCARPELLINI S. "*Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification*." Building and Environment, 2009, Volume 44/12, pp. 2510–2520.
[13] UŽŠILAITYTĖ L, MARTINAITIS V. "*Search for optimal solution of public building renovation in terms of life cycle.*" Journal of Environmental Engineering and Landscape Management, DOI: 10.3846/jeelm.2010.12; 2010, Volume 18/2, pp. 102–110.
[14] JOHANSSON D. *"The life cycle costs of indoor climate systems in dwellings and offices taking into account system choice, airflow rate, health and productivity."* Building and Environment, DOI: 10.1016/j.buildenv.2008.03.011; 2009, Volume 44/2, pp. 368–376.
[15] COLLINGE W O, LANDIS A E, JONES A K, SCHAEFER L A, BILEC M M. "*Dynamic life cycle assessment: framework and application to an institutional building*." The International Journal of Life Cycle Assessment, DOI: 10.1007/s11367-012-0528-2; 2012, published online: 24 November 2012.
[16] MALMQVIST T, GLAUMANN M, SCARPELLINI S, ZABALZA I, ARANDA A, LLERA E, DÍAZ S. "*Life cycle assessment in buildings: The ENSLIC simplified method and guidelines*." Energy, Elsevier Ltd, DOI: 10.1016/j.energy.2010.03.026; 2011, Volume 36/4, pp. 1900–1907.
[17] VERBEECK G, HENS H. "*Life cycle inventory of buildings: A calculation method.*" Building and Environment, Elsevier Ltd, DOI: 10.1016/j.buildenv.2009.10.012; 2012, Volume 45/ 4, pp. 1037–1041.
[18] KELLENBERGER D. ALTHAUS H-J. "*Relevance of simplifications in LCA of building components*." Building and Environment, DOI: 10.1016/j.buildenv.2008.06.002; 2009, Volume. 44/4, pp. 818–825.
[19] ROGOŽA A, ČIUPRINSKAS K, ŠIUPŠINSKAS G. "*The optimizations of energy systems by using 3E factor: the case studies*". Journal Of Civil Engineering and Management; 2012, Volume XII/1, pp. 63–68.
[20] ZHENG G, JING Y, HUANG H, ZHANG X, GAO Y. "*Application of Life Cycle Assessment (LCA) and extenics theory for building energy conservation assessment*". Energy, Elsevier Ltd, DOI: 10.1016/j.energy.2009.07.035; 2009, Volume 34/11, pp. 1870–1879.
[21] HEIJUNGS R, SETTANNI E, GUINÉE J. "*Toward a computational structure for life cycle sustainability analysis: unifying LCA and LCC.*" The International Journal of Life Cycle Assessment, DOI: 10.1007/s11367-012-0461-4; 2012, published online: 07 July 2012.
[22] GUO M, MURPHY R J. *"LCA data quality: sensitivity and uncertainty analysis"*. The Science of the total environment, Volume 435–436, pp. 230–43.
[23] DENSLEY T D, DAVISON B. *"Developing an LCA methodology to account for the environmental benefits of design for deconstruction*". Building and Environment, DOI: 10.1016/j.scitotenv.2012.07.006; 2012, Volume 57, pp. 387–395.
[24] AUDENAERT A, DE CLEYN S H, BUYLE M. *"LCA of low-energy flats using the Eco-indicator 99 method: Impact of insulation materials."* Energy and Buildings, DOI: 10.1016/j.enbuild.2011.11.028; 2012, Volume 47, pp. 68–73.
[25] MOTUZIENE V, VILUTIENE T. "*Modelling the Effect of the Domestic Occupancy Profiles on Predicted Energy Demand of the Energy Efficient House*". DOI: 10.1016/j.proeng.2013.04.101; 2013, Procedia Engineering Volume 57 pp. 798–807.

REALITY CHECK OF A BRICK MADE PLUS ENERGY DWELLING



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Summary

Within the Austrian research project 'Solares Plus Haus' a plus energy building concept for a brick constructed dwelling is developed, planned and put into operation. The energy performance of the operated building is previously assessed by theoretical analysis of AIT and research partners. Since autumn 2012 a scientific monitoring is operated. This paper documents on the energy performance of the building based on measurement data acquired from January 1st till April 30th 2013. Monthly energy balances were calculated and selected detailed monitoring data of the energy performance of the heat delivering and distribution system are documented and assessed. Key findings are drawn and an outlook about the future research activities is given.

Keywords: Plus annual energy balanced building, energy efficient bricks, solar combisystem, photovoltaics, thermally activated brick wall, monitoring

1. Introduction

According the recast of the EU-Directive [1], future buildings are 'Nearly Zero Energy Buildings' and technically a bright variety of future building concepts exists. Two essential measures lead to such high energy performing buildings: high energy efficiency for both building envelopes and energy systems and use of renewable energy sources on site. Within the Austrian research project 'Solares Plus Haus' a plus energy building concept for a brick constructed dwelling is developed. The energy performance of the operated building is already and will be assessed by the Austrian Institute of Technology (AIT) by means of a scientific monitoring from autumn 2012 to the end of 2014. In particular high solar fractions above 50% for covering the demand for heating and domestic hot water (DHW) preparation contribute significantly to a negative annual primary energy balance (non-renewable part). The research activity focuses intensively on the feasibility of improved use of solar heat by applying the 'Sonnenhaus-Konzept' [2] in combination with thermally activated brick walls. The research project approves the energy performance of the building and thermal indoor comfort with the analysis of measured monitoring data of the operated building and creates advices how to design and control the solar heat activated brick walls.

Preliminary calculation performed by AIT, i.e. energy modelling and building simulation, result into a negative annual primary energy balance (non-renewable part), which could be so far interpreted as a 'plus energy balanced building' [3]. Since December 2012 the brick constructed dwelling is operated and is occupied by the building owner; a four person family. AIT has developed an energy monitoring concept and the required technical equipment of the scientific monitoring over two years is installed and put into operation. This paper essentially documents on first monitoring results related to the energy performance of the building and its subsystems from January 1st till April 30th 2013. Main objectives of the monitoring campaign are:

- Demonstration of the functionality and feasibility of the ‘building concept under real system operation and with the impact of user behaviour
- Quantification of the annual primary energy balance based on measured data
- Quantification of achieved solar fractions beyond 60% in practice
- Identifying measures to optimize the annual energy performance

2. Energy system

The future building as well called ‘e4Ziegelhaus2020’ [4] located in Zwettl, Austria provides 277 m² heated gross floor area and is mainly constructed by using a new generation of energy efficient bricks. The architectural and energy concept of the residential building focuses on a high energy efficiency standard of the building envelope (external walls and windows) and the usage of especially solar energy in order to cover significantly the demand for heat and electricity. The solar thermal system is designed as a solar combisystem, i.e. the solar heat covers the demand for heating and for hot water preparation. Around 50 m² flat-plate collectors south-oriented and titled with 60° provide solar heat to a 9,580 litre hot water tank which is placed centrally within the building. A 40 $kW_{thermal}$ biomass fired boiler serves as thermal back-up system in case of sunless winter days. Figure 1 shows schematically the heat delivering system. Besides a commercially available under floor heating system applied for the living room, the hot water stored in the tank is mechanically circulated also to thermally activated brick walls. Additional 35 photovoltaic modules with a peak power of 6.5 kW_{peak} are mounted on the roof of the garage; the PV system is designed to balance the total electricity consumption by the delivered solar electricity on site.

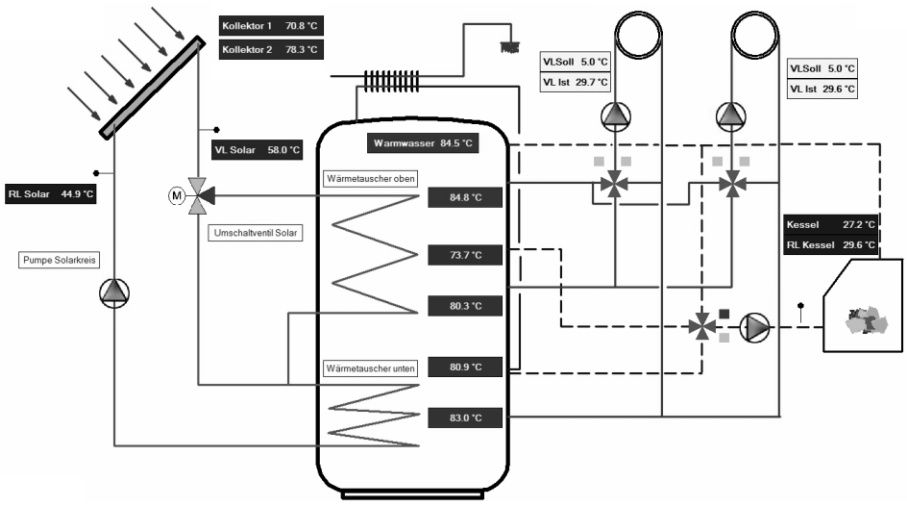


Fig. 1: Scheme of the heat delivering system

3. Monitoring results

All monitoring data presented in this paper are acquired in the period from January 1st till April 30th. In advance AIT did necessary data processing and checks of plausibility. According to statements of experts from ‘Zentralanstalt für Meteorologie und Geodynamik’ in Austria the available sun hours in January and February 2013 were less than 37% in comparison to the multiyear average in Austria [5]. Consequently with such low solar radiation values the applied solar technologies achieved only low solar fraction of both heat and electricity. Within this paper selected monitoring data sets are presented. The following documentation of the measured, post processed and assessed monitoring data addresses a) the total heat and electricity balance of the measurement period, b) energy performance of the heat delivering system and c) energy performance of one selected thermally activated inner brick wall.

3.1 Heat and electricity balance of monitoring period

In 2012 AIT and the research project partners calculated the annual energy balance with regard to heat and electricity demand of the brick made residential building. The specific values of the demand for heat and electricity were taken from Austrian standards except the values for heating demand which is a result of transient building simulation [6]. Table 1 lists the specific and total energy demand values for heat and electricity and additionally contains expected heat delivered by both the solar thermal system and biomass fired boiler. The expected delivered heat has been quantified by applying coupled transient system and building simulation [7]. As well the expected generated solar electricity on site is inserted.

Tab.1: Calculated annual energy balance
*(*Austrian Standard, **transient simulation, ***own calculation)*

	[kWh/m² gross per year]	**[kWh/a]**
Heating demand	39.10**	10,830.7
Demand for hot water preparation	13.00*	3,601.0
Heat losses of heating system	3.40*	936.5
Total heating demand	**55.50**	**15,368.2**
Electricity demand of household	13.00*	3,601.0
Electricity of heating system	2.90***	803.3
Total electricity demand	**15.90**	**4,404.3**
Annual delivered energy on site		
Biomass fired boiler (heat)	22.20**	9,220.9
Solar system (heat)	33.30**	6,147.3
Photovoltaic system (electricity)	18.30***	5,070.0

Figure 2 illustrates monthly heat balances from January till April 2013. For each month the heat delivered to the hot water tank from the solar system or from the biomass boiler is shown and also the heat which was pumped to the brick walls and as well to the under floor heating system. Furthermore the monthly amount of heat is numbered which prepared the hot water for domestic purposes. The thermal balance isn't equalised monthly because there is a water volume of 9.650 litres buffering the hot water provided by both delivering systems the solar and the biomass one. Approximately 630 kWh thermal can be stored potentially in the hot water tank.

Assessing the energy performance of the solar system the solar fraction is one key indicator. Here the monthly solar fraction is calculated by Equation 1.

$$SF_{thermal} = 1 - \frac{Q_{biomass}}{Q_{heating} + Q_{DHW}} \qquad \text{Equ. (1)}$$

with:

$SF_{thermal}$ solar fraction [-]
$Q_{biomass}$ heat delivered by biomass fired boiler [kWh]
$Q_{heating}$ heat delivered to the under floor and thermally activated brick walls [kWh]
Q_{DHW} heat delivered for domestic hot water preparation [kWh]

Equation 2 addresses the amount of electricity used to circulate all hot water of the heat delivering system.

$$EER_{HDS,el} = \frac{Q_{heating} + Q_{DHW}}{E_{HDS,pumps}} \qquad \text{Equ. (2)}$$

with:

$EER_{HDS,el}$ Electrical Energy Efficiency Ratio of the heat delivering system [-]
$E_{HDS,\ pumps}$ Electric consumption of all pumps as part of the heat delivering system [kWh]
$Q_{heating}$ heat delivered to the under floor system and thermally activated brick walls [kWh]
Q_{DHW} heat demand for domestic hot water preparation [kWh]

Figure 3 indicates monthly amounts of consumed electricity and delivered PV electricity from of January, February, March and April 2013. In January 2013 the building user applied an electrical machine for heating and drying the garage what resulted into an extraordinary amount of consumed electricity. The electrical consumption for the monitoring system and pumps of the heat delivering system do have more or less constant monthly values.

One indicator for preliminary assessment of the PV system performance is the ratio of the electricity delivered by PV and the total electrical consumption of the operated building. Additionally the amount of directly used PV electricity on site is from high economic interest in particular when feed in tariffs are below market prices. The monitoring system itself consumes as well electricity and it is necessary to indicate the share of the consumed electricity in contrast to the total amount of consumed electricity. Based on the allocated measurement data the average permanent electrical power of the overall monitoring system is 68 Watt. All monthly values of the introduced key performance indicators are quantified in Table 2.

Tab. 2: Calculated key performance indicators

		January	**February**	**March**	**April**
Electricity consumed, total	[kWh]	602.4	418.5	420.4	350.8
Heat transfered to heating systems and DHW, total	[kWh]	2,911.0	2,633.0	2,627.4	1,557.2
Solar heat system					
$EER_{HDS,elec}$	[-]	39.8	35.1	35.8	23.8
Solar fraction, $SF_{Thermal}$	[%]	9.0%	14.1%	47.0%	68.8%
Photovoltaics					
Solar fraction SF_{elec}	[%]	12.3%	41.2%	106.4%	176.2%
Directly used solar electricity	[%]	44.1%	49.4%	33.0%	29.2%
Monitoring system					
Share of electricty	[%]	8.5%	10.7%	11.7%	14.3%

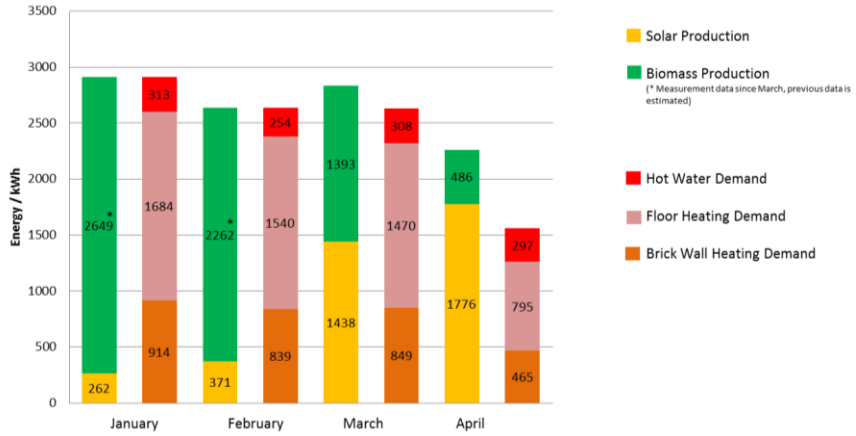


Fig. 2: Monthly energy balances from Jan 1st till April 30th (heat)

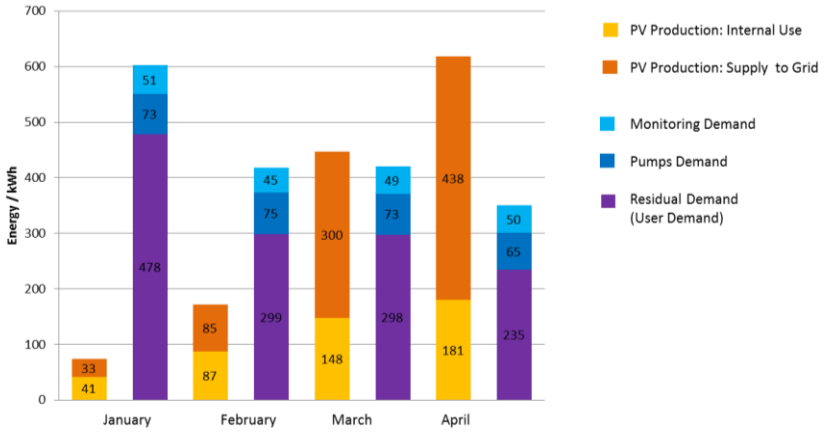


Fig. 3: Monthly energy balances from Jan 1st till April 30th (electricity)

3.2 Performance of the heat delivering system

A crucial part of the reality check is the performance of the heat delivering system – see Figure 1. In the previous section monthly energy balances were introduced and illustrated. For more detailed analysis daily performance data of the heat delivering system in terms of heat capacity and temperature profiles are addressed. Based on the acquired monitoring data of March 2nd 2013 the system performance is documented and evaluated. Figure 4 - right placed - illustrates profiles of thermal power from the solar collector system, the biomass fired boiler, the heat delivered to the under floor heating system and thermal activated brick walls and the heat taken from the tank for hot water purposes. The ambient temperature of that day was approximately in between 0 and 5 degree Celsius. In the evening of March 1st the biomass fired boiler is manually loaded with wooden split logs. The heat delivered to the hot water tank achieved a capacity of around 35 $kW_{thermal}$ (nominal 40 $kW_{thermal}$). Due the high level supply temperature (approx.. 70 to 75 degree Celsius) of the biomass boiler and the designed fixed inlet positions of the hot water just the upper one-third of the tank (95%, 88% and 74% of total highness of 5.5 m) is thermally effected. At around 6 a.m. the control unit operates the heating pumps, i.e. the under floor system and the brick walls are immediately provided with hot water. In the initial operation phase of both heat distribution systems were thermally loaded with high power values which decreased slowly to zero. The under floor heating system was thermally activated more powerful. Figure 4 left display the temperature profiles of the heat delivering system of March 2nd. The flat-plate collector system lifts the outlet collector temperature by approx. 20 Kelvin up to around 50 degree Celsius and generates a maximal heating power of around 27 $kW_{thermal}$. The temperature stratification of the 9.650 litre hot water tank functioned properly with regard to the creation and the continuance of low temperatures in the lower tank section, what allows generally an increased use of solar heat.

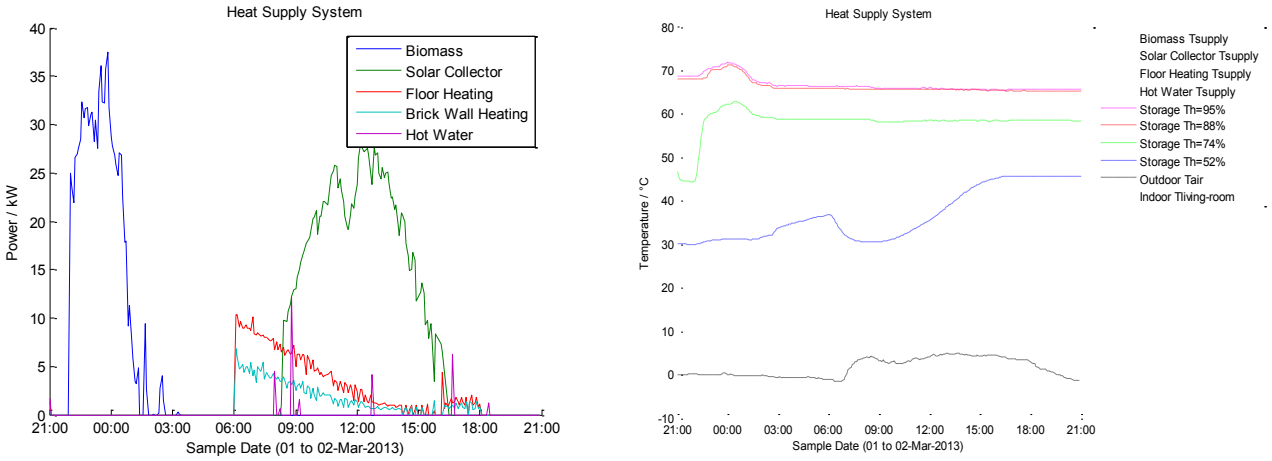


Fig. 4: Energy performance of the heat delivering system on March 2nd '13

Left:
Biomass – thermal power of the delivered hot water from the biomass fired boiler
Solar collector – thermal power of solar collector in the primary solar circuit
Floor heating – thermal power of the hot water which is delivered to the under floor system
Brick wall heat - thermal power of the hot water which is delivered to all activated brick walls
Hot water – thermal power which is delivered to the domestic hot water system

Right:
Biomass Tsupply – outlet water temperature of the biomass fired boiler
Solar Collector – outlet water/glycol temperature of the solar collector field
Hot water – outlet water temperature of the heat exchanger to prepare domestic hot water
Storage Th=95% - hot water tank temperature (level 95% of the total highness, i.e. 5.23 m)
Storage Th=88% - hot water tank temperature (level 88% of the total highness, i.e. 4.84 m)
Storage Th=74% - hot water tank temperature (level 74% of the total highness, i.e. 4.07 m)
Storage Th=52% - hot water tank temperature (level 52% of the total highness, i.e. 2,86 m)
Outdoor Tair – Ambient air temperature
Indoor Tliving-room – Indoor air temperature of the living room

3.3 Performance of the thermally activated brick walls

In the earlier project phase the research partners did theoretical calculation and analysis of the energy performance of the novel thermally activated brick wall. Herewith a 1D-model was developed in order to predict the thermal system performance by using coupled transient building and system simulation [7]. This paper addresses a reality check by presenting selected daily system performance of the thermally activated building element based on measured data of March 2nd 2013. Figure 5 illustrates the profiles of measured temperatures and thermal power provided to one specific brick wall, which is positioned close to the staircase facing the living room. Additionally Figure 5 displays a sketch illustrating the positions of the applied temperature sensors and the volume flow meter. On March 2nd the thermally activated part of the considered brick wall was supplied by water temperatures in the range of approx. 29.2 and 33.6 degree Celsius. In the initial operation phase the heat transferred from the circulated water to the colder thermal mass of brick wall achieves a peak power of approx. 0.4 $kW_{thermal}$ and ends with approx. 0.1 $kW_{thermal}$ at 6 p.m. Figure 5 plots as well selected surface temperature profiles, which represent the temperatures of the gypsum layer put on the thermally activated brick wall. There is an average temperature lift of all five displayed surface temperatures of 1.9 Kelvin. With regard to the monitored temperatures following findings are detected; a) the indoor air temperature is quite high (between 23.3 till 25.3 degree Celsius) in comparison to the standard set temperatures of 20 degree Celsius and b) manually opened windows provided fresh air for the living room and caused a temperature decrease for both indoor air temperature and surface temperature of the thermally activated brick wall.

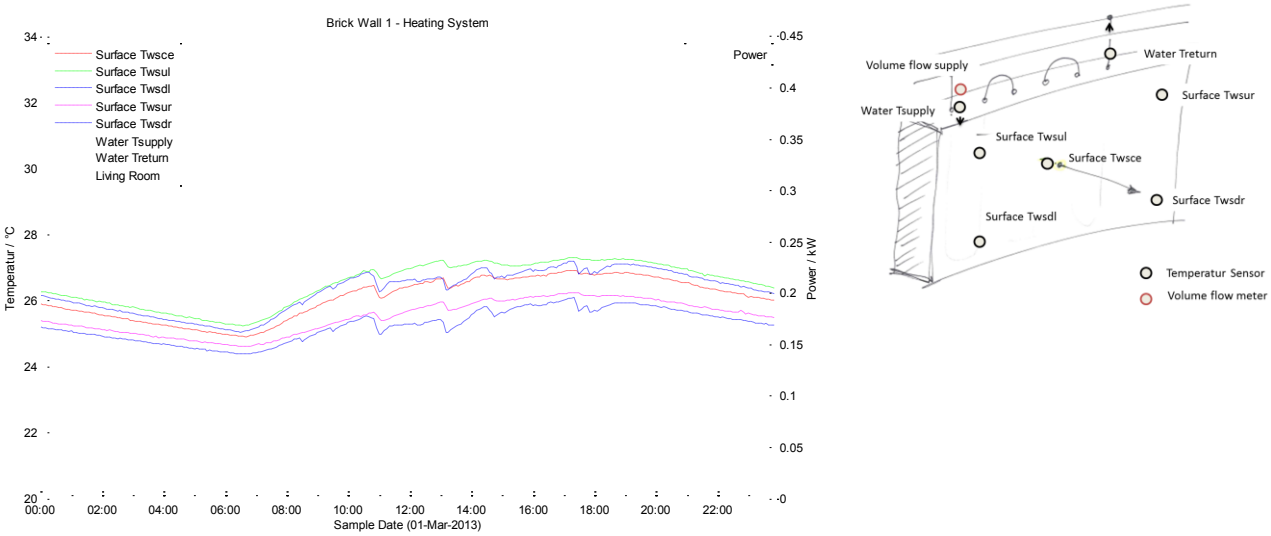


Fig. 5: Energy performance of the thermally activated brick wall on March 2nd '13

4. Findings and outlook

Based on measurement data acquired from January 1st till April 30th 2013 a first documentation and assessment of the energy building and system performance of the 'e4Ziegelhaus2020' is submitted. Monthly energy balances were calculated and the daily energy performance of the heat delivering and heat distribution system were analysed based on monitoring data of March 2nd. With the analysis of the selected monitoring data some conclusions are drawn. Key findings are:

- In comparison to preliminary theoretically generated annual energy balances it is most probable that the building operation will exceed the expected heating demand. During the first four month of 2013 the heat delivered to the under floor system and the thermally activated brick walls already cover 72% of the preliminary predicted 11,770 kWh heating demand including heating system losses. It is obvious that higher indoor temperatures of around and above 24 degree Celsius lead to higher amounts of delivered heat.
- Especially due to marginal sun hours in January and February the amount of heat delivered by the flat-plate collector system wasn't significant. In January the solar fraction was only SF_{Jan} = 9% and in February SF_{Feb} = 14.1%.
- The hot water tank operated with reasonable and stable stratification.
- The thermally activated brick wall operated with low supply temperatures, but the major heat was delivered via the under floor heating system – see Figure 4 right.
- The solar electricity delivered on site by the photovoltaic modules in March already equalises the total electrical consumption – see Figure 2. The percentage of directly used solar electricity in the building was between 29.2% and 49.4% - see Table 2.
- The scientific monitoring system operated with an average permanent electrical power of 68 Watt and that implies means a share of 8.5% up to 14.3% of the total electricity consumption – see Table 2.

Future research work will focus on:

- Continuation of the scientific monitoring till the end of 2014
- Acquisition of one complete monitoring data set from January 1st till December 31st in order to provide the annual energy balance based on measured data
- Comparison of theoretical models with measurement data (especially heat delivering system)
- Analysis of both the thermal building performance and the heat delivering system in summer (e.g. risk of overheating, risk of stagnation of the collector field)

5. Acknowledgements

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6. References

[1] EU-Directive 2010/31: The Energy Performance of Buildings Directive (2010/31/EU) recast October 2010

[2] www.sonnenhaus.co.at

[3] SELKE T. STIFT F. LEHMDEN A. „Plus Energy Building Concept for Dwellings based on high solar fraction and solar heat activated bricks“. EUROSUN2012. Sep 18th to 20th 2012. Rijeka. Croatia. Paper n° 62; ISBN/ISSN-N°: 978-953-6886-20-3

[4] http://www.wienerberger.at/energieeffizientes-bauen/das-e4-ziegelhaus-2020

[5] http://derstandard.at/1361241162057/Wenig-Sonne-und-viel-Schnee-Das-war-der-Winter-201213 last access May 18th 2013

[6] University of Wisconsin-Madison (2010): TRNSYS17: A TRaNsient System Simulation program . Solar Energy Laboratory. University of Wisconsin-Madison.

[7] SELKE T.. KREC K.. STIFT; „Plusenergie - Ziegelwohngebäude mit solarer Wandtemperierung“; Posterpräsentation auf GleisdorfSolar2012; 12. bis 14. September 2012. Gleisdorf/ Austria; Paper n° 60. Seiten 272 - 278

LCA of a Net Zero Energy Office Building - The New Technology Park of Bolzano



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Short Summary

We have performed a life cycle assessment of an office building of the planned Technology Park in Bolzano, Italy. The analysis takes into account embodied, operational and transport energy, carbon emissions and other environmental impact factors. Further, we have created two virtual scenarios that show how green choices during building design and operation can potentially reduce total life cycle energy and carbon emissions by 60%. Assessments of this kind are still missing in most design and tendering procedures, and even if they are done, they usually focus only on one single aspect at a time. Such an approach may result in a considerable waste of resources and increase in environmental impact. We have estimated that for Net Zero Energy Buildings embodied energy and transport energy may account for more than 90% of the total life cycle energy. Therefore, we strongly recommend integrating these factors in building design.

Keywords: office building; embodied energy; operational energy; transport energy; green insulation; emissions reduction; sustainable mobility; Net Zero Energy Building

1. Introduction

It is reported that conventional office buildings consume in the range of 250-550 kWh/m^2 per year and that Operational Energy (OE) for these buildings amounts to 80-90% [1]. Therefore, it seems natural to focus on OE. However, in highly efficient buildings such as Net Zero Energy Buildings (NZEB), OE is expected to be low. Therefore, Transport Energy (TE) and Embodied Energy (EE) of such buildings grow in importance. EE is even more important in office buildings that contain large amounts of steel, reinforced concrete and glass. TE can be reduced designing an efficient transport system that connects the building with the surroundings. Also, the building location affects the commuters' habits and therefore the TE.
A comprehensive Life Cycle Assessment (LCA) that includes EE, OE and TE is still rare in procurement, design and tendering procedures for new buildings. A study on residential buildings in line with such an approach has shown that EE and TE together can amount to almost 50% of the total life cycle energy demand in passive houses [2]. Office buildings are a much more complicated system from a construction and technological point of view. In this work we would like to analyse how the impact of different building life stages is transforming in a vision of very low energy demand office buildings.
Our case study is a new office building in the industrial zone of Bolzano, northern Italy. The building has been designed by Claudio Lucchin & Architetti Associati and Chapman Taylor and

denominated “Black Monolith”. Building owner and design teams aspire to reach the targets of total primary energy (PE) consumption less than 60 kWh per square meter per year and net zero energy balance. To reach these targets, a set of energy efficiency solutions has been selected during the integrated design process with the aid of dynamic simulation results. To reduce environmental impact, passive solutions, in particular natural ventilation and daylighting, have been preferred over active solutions. Apart from PV and solar-thermal renewable energy integration, otherwise wasted energy such as heated-up ground water in series with an industrial cooling process has been exploited. The building has been selected as a pilot for the European FP7 project DIRECTION dedicated to the demonstration of innovative, cost-effective and replicable energy efficiency solutions for low energy new buildings [3]. The results obtained in this study are useful to the project and to the building owners to a) better assess the sustainability of the DIRECTION pilots, b) identify the most impacting parts of them, and c) eventually unleash the potential of green alternatives.

2. Methodology

We have taken into account Operational Energy, Embodied Energy and Transport Energy in order to develop three main scenarios of the expected total life cycle energy (LCE) and emissions of the building. The method is replicable in other designs of office buildings.
The LCE is the life cycle energy demand of a building and its users and is therefore the sum of the requirements at building scale (embodied and operational) and at city scale (infrastructure and transport) [2].

2.1 Embodied Energy

We have evaluated the EE of the construction materials with the online tool “SBS Building Sustainability” (SBS) developed at the Fraunhofer Institute for Building Physics [4]. The tool integrates the European Sustainable Construction Database (ESUCO) and GaBi data [5] for less common materials.
As reported by the SBS online tool, the life cycle inventory is based on data collections from industry and on a literature research. A deviation margin of 10% is added to the results since they have not undergone independent review. The environmental profile contains the expenditures from "cradle to gate".
We have inserted the following constructive elements into SBS:

- Building envelope: major contributory elements and materials of façade and roof
- Load-bearing structure: concrete beams, pilasters, main walls, stairs and ramps
- Main party walls for services and technical rooms
- Floor slabs

For each material, the Life Cycle Inventory (LCI) of SBS takes into account the following impact factors: Primary Energy (PE), Global Warming Potential (GWP), Abiotic Depletion Potential (ADP), Acidification Potential (AP), Photochemical Ozone Creation Potential (POCP), Eutrophication Potential (EP) and Ozone Depletion Potential (ODP).
The load-bearing structure has an important impact on environment due to the considerable bulk of material. The subdivision of the indoor spaces of the Black Monolith has been kept flexible by request of building owner and future tenants. Nevertheless, main party walls have been considered as they are a common part of office buildings.
At the time of writing, bids have not been reviewed completely. Only the tendering documents with minimum equipment performance requirements have been available to us, but no information on specific brands or products. As the materials and their production chain may vary completely from one product to another, we have decided to exclude HVAC&R, lighting and renewable energy production systems from the analysis.
We have considered the following life cycle phases: production, operation, reuse/replacement and recycling/disposal taking into account a suitable lifespan for each material and a 50 years lifespan for the whole building. We haven’t considered a longer lifespan as construction materials and building system technologies change rapidly. However, the emissions distribution in the atmos-

phere changes considerably over much longer time periods [6,7]. Therefore, we have chosen a lifespan of 100 years for the emissions estimation.
SBS computes the maintenance and replacement cycles automatically according to the lifetime of the building.
First, we have performed a LCA of the actual building design as specified in the tendering documents. The building structure is of reinforced concrete. The EPS- and XPS-insulated envelope is a combination of glazed curtain walls and aluminium panels.
Next, we have chosen five claimed as greener insulation materials in order to reduce the EE and environmental impact of the façade: cotton fleece, expanded cork, hemp fibre fleece, natural rubber foam and mineral wool. We have varied the insulation thickness in order to keep the thermal transmittance of the building envelope constant. Finally, we have substituted the aluminium envelope with a wooden construction.
Based on the results, we have chosen the following three envelope variants:

- XPS- and EPS-insulated aluminium envelope
- XPS- and EPS-insulated wooden envelope
- Hemp fibre-insulated wooden envelope

2.2 Operational Energy

In SBS, the user can choose from generic equipment such as different kinds of heat pumps, boilers, chillers, etc. As the equipment and energy efficiency measures for the Black Monolith cannot be mapped in sufficient detail to the types available in SBS, we have computed the OE with a dynamic simulation model developed in TRNSYS. In the OE calculation, the PV field energy production has been subtracted from the thermal and electrical loads for HVAC&R and lighting.
We have calculated the OE for two cases. In the first case we have considered only the PV field on the roof of the Black Monolith (estimated MWh/year: 264). In the second case we have considered also the planned PV field on the roof of an adjacent historical industrial building (estimated MWh/year: 450) located on the same lot.

2.3 Transport Energy

Life cycle transport energy of a building is the energy demand associated with commuting and is mainly determined by the annual travel distances and energy intensities (energy consumed per unit of distance) of the transport modes used by the commuters [2,8].
We have compared three transport configurations: the as it is case, a case based on expected changes in Bolzano in the 20 years and a case going beyond.
The first strategy corresponds to the actual transport situation. We have combined the commuting behaviour of the roughly 40 employees at the Institute for Renewable Energy of EURAC research, Bolzano, Italy in 2013 with statistical data on transport modalities in the municipality of Bolzano shown in Table 1 [9]. We expect the near-future commuting behaviour of the roughly 300 employees working at the Black Monolith to be very similar as our offices are only 1 km away from the construction site and the future tenants will be involved mainly in RTD activities.

Table 1: Current commuting modality in Bolzano

Commuting type	Average commuting distance	Means of transport	Use percentage
Urban 65%	8 km/day	Bike Car Train Bus Motorcycle Foot	37% 29% 13% 10% 7% 4%
Extra urban 20%	50 km/day	Train Car Bus	75% 23% 2%
Extra provincial 15%	120 km/day	Train Car	75% 25%

The second strategy follows the Urban Mobility Plan 2020 for the municipality of Bolzano [10]. Compared to the previous as is solution, the bus transfers and 14% of the car transfers are substituted with tram transfers.
The third strategy envisages a transport based purely on electric vehicles: 71% train, 25% shared electric cars and 4% tram.
We have computed the TE for all three strategies using the following formula:

$$LCTE = \sum_{tm=1}^{TM} TD_{tm} \cdot DEI_{tm} \quad (1)$$

In Equation 1, LCTE denotes the life cycle transport energy demand of the building tenants. TD_{tm} denotes the total yearly travel distance of all users that use the transport mode tm and DEI_{tm} denotes the yearly direct energy intensity (energy dedicated only to propulsion per unit of distance) of the travel mode tm. We have taken the DEI_{tm} values from the literature [11].
Finally, we have calculated carbon emissions for all three strategies with the same formula where we have substituted energy intensity with carbon intensity (CO_2-equivalent emissions per unit of distance) [12].

2.4 Comprehensive scenarios

From the EE, OE and TE reduction strategies detailed above, we have developed three comprehensive scenarios listed in Table 2 that consist of meaningful combinations of the considered design factors: a) envelope construction, b) integration of RE production into the calculation of OE, and c) transport strategy. We have compared these scenarios with respect to total life cycle energy demand (LCE).

Table 2: Comprehensive scenarios for the LCE analysis

Scenario	EE	OE	TE
1 (as it is)	XPS- and EPS-insulated aluminium envelope	PV field on the roof of the Black Monolith only	As it is
2	XPS- and EPS-insulated wooden envelope	PV field on the roofs of the Black Monolith and the adjacent historical industrial building	Urban Mobility Plan for Bolzano (PUM 2020)
3	Hemp fibre-insulated wooden envelope	PV field on the roofs of the Black Monolith and the adjacent historical industrial building	Only electric vehicles

3. Results

In order to be able to compare the impact of OE, EE and TE, we have normalized the energy figures to kWh per year and the CO_2-equivalent emissions to kg/tons per year. Tables 3 and 4 report the overall energy and carbon demands for the three scenarios.

Table 3: Shares of OE, EE and TE in the total LCE for the three scenarios

Scenario no.	EE [kWh/year]	OE [kWh/year]	TE [kWh/year]	Total PE [kWh/year]
1	303,000	482,000	330,000	1,110,000
2	275,000	41,300	332,000	649,000
3	245,000	41,300	208,000	495,000

Scenario 1 is the as it is situation. The OE amounts to 38.5 kWh/(m^2 year). The PV field on the roof of the Black Monolith is estimated to produce 49.7 kWh/(m^2 year). Therefore, without renewable energy production, the OE would amount to 88.2 kWh/(m^2 year). OE, EE and TE share 43%, 27% and 30% of the total LCE, respectively. If TE is not considered, OE amounts to 61% and EE to 39% of the total LCE. 50% of the CO_2-eq. emissions are due to transport ("transport carbon"), 36% are due to building operation and 14% are due to "embodied carbon", that is, CO_2-eq. emissions caused by raw materials extraction, production processes and recycling.

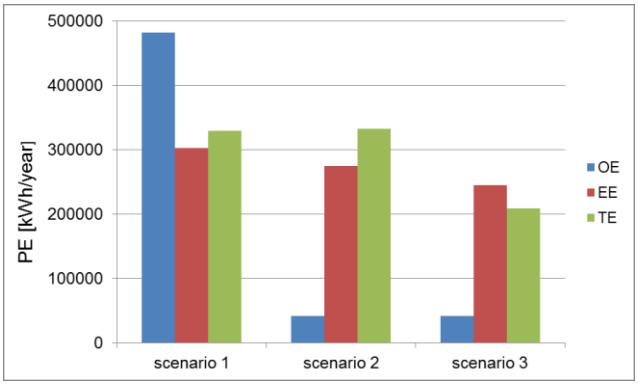


Fig. 1: OE, EE and TE shares in LCE for the three scenarios listed in Table 2

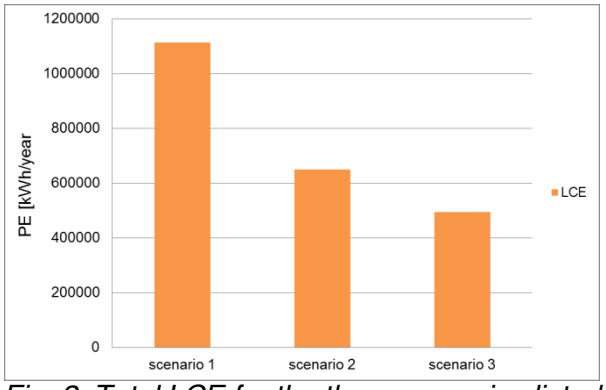


Fig. 2: Total LCE for the three scenarios listed in Table 2

Scenario 2 represents an intermediate solution. OE, EE and TE share 6%, 43% and 51% of the total LCE, respectively. The high shares of TE and EE are due to the use of cars and EPS and XPS as envelope insulation materials. If TE is not considered, EE amounts to 87% and OE to 13% of the total LCE.
Although the PE consumption due to transport is different from that in Scenario 1 by less than 1%, the CO_2-eq. emissions are reduced by 38% thanks to the Urban Mobility Plan for Bolzano. Transport is mainly responsible for carbon emissions (72% of the total carbon emissions), while embodied carbon amounts to 28%. The carbon emissions during the operational phase are lower than 1% as the electricity produced by the PV field enters the OE calculation as avoided carbon emissions. In practice, the electricity produced will be auto-consumed or fed to the grid.
The very low figures for OE in scenarios 2 and 3 are due to the applied conversion factors that profusely rewards the avoided emissions. That is, it is more a calculation effect than an actual zero emission phase.

Table 4: Shares of embodied, operational and transport emissions in tons CO_2-eq. for the scenarios listed in Table 2

Scenario no.	Embodied carbon	Operational carbon	Transport carbon	Tot.CO_2-eq
1	48,000	126,000	177,000	351,000
2	42,000	Less than 1, see text	109,000	152,000
3	38,000	Less than 1, see text	104,000	142,000

In Scenario 3, EE amounts to 50%, OE to 8% and TE to 42% of the total LCE. If TE is not considered, EE amounts to 86% and OE to 14% of the total LCE.
The CO_2-eq. emissions are 73% caused by transport ("transport carbon"). "Embodied carbon" amounts to 27%. For the same reason as in Scenario 2, the CO_2-eq. emissions during the operational phase are lower than 1%.

All other environmental impact factors assessed are listed in Table 5.

Table 5: Values of the other environmental impact factors on EE assessed for the scenarios listed in Table 2

Scenario no.	PE [kWh/m^2 year]	GWP [kg CO_2-eq]	ADP [kg Sb-eq]	AP [kg SO_2-eq]	POCP [kg ethene-eq]	EP [kg phosphate -eq]	ODP [kg R11-eq]
1	24.0	3.87	0.0286	0.0258	0.00255	0.00153	2.27 E-7
2	22.0	3.39	0.0262	0.0241	0.00243	0.00144	1.80 E-7
3	19.6	3.04	0.0225	0.0230	0.00192	0.00134	1.71 E-7
DGNB benchmark values	41.9	9.40		0.037	0.0042	0.0047	5.30 E-7

The results listed in Table 5 show that substituting the aluminium envelope with a wooden envelope reduces environmental impact by 5-12% in almost all impact categories except for the ODP which decreases by 21%.
In changing synthetic polymer insulation (XPS and EPS) with hemp fibre insulation, the highest decrease is in POCP (21%) followed by ADP (14%), whereas the other impact categories decrease by 5-10%.
The values relative to the main impact categories listed in Table 5 are all lower than the benchmark values reported by the Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council, DGNB) [13]. The values – reported in Table 6 for the convenience of the reader – are taken from a German national research project [14] in which "typical" buildings in Germany have been evaluated in order to derive benchmarks on the basis of mean values and develop an understanding of the relations between a building and its environmental impacts. The values are referred to educational, office, hotel and residential buildings in a reference study period of 50 years.

3.1 Conclusions and discussion

We have performed a LCA of a planned office building located in the industrial zone of Bolzano, Italy. In addition, we have created two virtual scenarios that show how primary energy and emissions could be reduced by 60%. We have put emphasis on a holistic approach that takes into account the primary energy consumed and produced during each life cycle phase of the building, from extraction of raw materials to deconstruction and recycling. We have also estimated the transport energy and shown that it may account for 50% of the total LCE. By substituting the current transport network with a network based on electric vehicles (shared cars, buses, trams and trains) supplied by renewable energy sources such as PV, PE savings due to transport of up to 60% may be achieved.
The shares of EE and OE reported for Scenario 1 are typical for efficient new office buildings. Good Net Zero Energy Buildings are able to reduce OE to a minimum and may have EE and OE shares similar to those reported for Scenario 2 or 3.
We conclude that, once a complete and accurate building materials, components and systems inventory will be available, a comprehensive LCA that takes into account OE, EE, TE, carbon emissions and environmental impact factors such as GWP, AP, ADP, etc. should be part of every integrated design and tendering procedure for highly energy efficient and sustainable new office buildings. It may even make sense to request a report of the LCA from bidders and to review it carefully during the bids evaluation process. Scenarios 2 and 3 demonstrate the potential and the importance of mobility plans tailored to the commuters' needs. In Bolzano, a number of cycling

lanes cross the industrial zone. A comprehensive cycling network connecting the building with other hot spots of the city promotes sustainable mobility and improves the quality of life of the workers.

3.2 Limits of the analysis

We have considered only the main building components. Fasteners, screws, cables, etc. have not been included in the assessment. We have had to leave out lighting and building equipment of the EE assessment due to lack of detailed information on the production chains, types and amounts of materials, but we have considered the thermal and electrical loads of these systems in the TRNSYS model and hence in the calculation of OE and carbon emissions. However, we do think that the active building systems play a role in EE assessment. We are awaiting the start of the construction works to be able to integrate reliable information on these systems in the EE evaluation.
We have selected all materials from the ESUCO database without editing their predefined impact factors. Therefore, production, maintenance and recycling processes are in line with the European average. We have made this design choice not only due to lack of information on how materials will be procured during construction, but also to ensure comparability with the LCAs of the other building demonstrators chosen for the DIRECTION project.
The SBS tool does not include transportation in the process cycles assessment. Transportation of materials may lead to a 10% increase in emissions [13] [15]. The tool hasn't any option to recycle the glazing. It is supposed that the glass is simply crushed and thrown into a landfill.
We have focused ourselves on the optimization of insulation and envelope only, without working on the building structure. We have made this choice mainly because the design of the Black Monolith was already at an advanced stage when we started with the LCA, and an analysis of more substantial interventions would have been of no practical use. However, although it may be a good idea to choose green insulation materials in most cases, the insulation is probably not the main element to focus on. The LCA optimization potential of the insulation may be marginal against an optimization of the building structure and the fenestration-wall ratio.
The assessment is based exclusively on an environmental point of view. For example, from an economic point of view, green insulation may be discouraged or prohibitive.
In the assessment of the TE, we haven't considered indirect transport energy intensities. Direct transport energy denotes only the energy used for the propulsion of a vehicle. Indirect energy includes: construction, operation, maintenance and demolition of infrastructure for transport; manufacturing, service and scrapping of vehicles; fuel production for the transport sector. Indirect transport energy may amount to 10-30% of total transport energy [11].

3.3 Acknowledgement

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4. References

[1] T. Ramesh, R. Prakash and K. K. Shukla, *"Life cycle energy analysis of buildings: an overview,"* Energy and Buildings, vol. 42, issue 10, 2010, pp. 1592-1600.

[2] A. Stephan, R. H. Crawford and K. de Myttenaere, *"Towards a comprehensive life cycle energy analysis framework for residential buildings,"* Energy and Buildings, vol. 55, 2012, pp. 592-600.

[3] EU FP7 Project DIRECTION, *"Demonstration at European level of innovative and replicable effective solutions for very low energy new buildings."* URL: http://www.direction-fp7.eu/

[4] Fraunhofer Institute for Building Physics, *"SBS building sustainability."* URL: https://www.sbs-onlinetool.com/

[5] PE International, *"GaBi software - a product sustainability performance solution."* URL:

www.gabi-software.com

[6] ENSLIC BUILDING, *"Energy saving through promotion of life cycle assessment in buildings,"* Intelligent Energy for Europe Programme, 2007-2010.

[7] IPCC *"Third assessment report – climate change 2001: the scientific basis,"* Cambridge University Press, Cambridge, UK, 2001.

[8] A. Ajanovic, C. Dahl and L. Schipper, *"Modelling transport (energy) demand and policies — an introduction,"* Energy Policy, vol. 41, 2012, pp. iii-xiv

[9] Province of Bolzano, Italy, *"Annuario statistico della Provincia di Bolzano (Yearly statistics of the Province of Bolzano),"* Provincial statistics institute ASTAT, 2013.

[10] Province of Bolzano, Italy, *"PUM – Piano urbano della mobilità 2020 (Urban mobility plan)."* URL: http://www.comune.bolzano.it/UploadDocs/7494_PUM2020.pdf

[11] GEA Writing Team, *"Global energy assessment - towards a sustainable future,"* Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, AT, 2012.

[12] Department for Environment, Food and Rural Affairs (DEFRA), *"2008 Guidelines to Defra's GHG conversion factors: methodology paper for transport emission factors,"* Queen's Printer and Controller of HMSO, UK, 2008.

[13] EU FP7 Project EeBGuide, *"EeBGuide guidance document part B: buildings,"* 2012. URL: http://www.eebguide.eu/eebblog/wp-content/uploads/2012/10/EeBGuide-B-FINAL-PR_2012-10-29.pdf

[14] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development, BMVBS), "Orientierungswerte für die ökologische Bewertung (Reference values for the ecological evaluation)," Research project no. 20088034379, Berlin, DE, 2008.

[15] J. C. Refsgaard, J. P. van der Sluijs, A. L. Højberg and P. A. Vanrolleghem, *"Uncertainty in the environmental modelling process – a framework and guidance,"* Journal Environmental Modelling & Software, vol. 22, issue 11, 2007, pp. 1543-1556.

Integration of sustainability targets into the planning process and their effects on project results – case study of the MED CAMPUS Graz



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Extended Abstract

In the year 2004 the Medical University of Graz (Med Uni Graz) was founded as an autonomous university and currently operates from several locations scattered across the city of Graz. The MED CAMPUS will combine the university with the existing university hospital in one unified location[1]. Physical contiguity will do more than solve the difficulties of the current situation; it will enable teaching, research & development and patient care to reach an international level of excellence.

The project area consists of two construction sites where twelve institutes are combined in four centres. These will include teaching facilities, administration offices, a library, a canteen, an assembly hall, and space for start-up companies operating in related fields. The building complex as a modern university, research and communication centre will have space for around 1700 employees and 4300 students.

From the project's inception, the office of the university's rector managed its development as a sustainable and healthy property in the broadest sense, and this resulted in sustainability quality targets being included in the public competition requirements. The project is currently being certified with a DGNB/ÖGNI Certification of Lab Buildings [2].

The present contribution describes the approach chosen by the university as customer and user, and key milestones for implementing sustainability targets in the planning of the campus. The effects of this strategy on the results of the project are presented.

In summary, it can be said that as far as can be judged at present, the very ambitious goals of the Med Uni Graz for the sustainability of the buildings will be reached. The extra effort of the design process is therefore worthwhile from the point of view of the Med Uni Graz.
The future will reveal how far this extra design and organizational effort can be reduced by developing standardized instruments and procedures. However, it does appear that the best solutions will always be highly specific to the location and the planned uses of the buildings. If we consider that diversity often seems to be one of the best survival plans, then this finding can be seen in a positive light.

Acknowledgments

This described work in the paper was carried out in the project MED CAMPUS Graz by Medical University of Graz and Bundesimmobiliengesellschaft m.b.H. with the generalplaner Riegler-Riewe Architects ZT GmbH (architects, commissioned by BIG) and Team TU Graz (Prof. Maydl, commissioned by Med Uni Graz). We would like to thank all partners for their support and their inputs.

References
[1] Project MED CAMPUS Graz, https://www.medunigraz.at/8214
[2] DGNB Certification of Lab Buildings, http://www.ogni.at/de/zertifizierung/

Keywords
Sustainability; DGNB/ÖGNI Certification of lab building; planning process; design consequences;

1. Introduction:

1.1 What is the MED CAMPUS?

In the year 2004 the Medical University of Graz (Med Uni Graz) was founded as an autonomous university and currently operates from several locations scattered across the city of Graz (Fig. 1).
The realization of the MED CAMPUS will gather the entire operation of the medical university onto one site immediately adjoining the LKH University Hospital (Fig. 2). This is intended to improve the levels of communication and interaction between the clinical and nonclinical sections of the university; to simplify the organisation and improve the quality of research and teaching activities; and to simplify the organisation of the administrative activities. Thus the new campus is meant to provide:

- a location that will encourage teaching and research to cross existing structural boundaries, forming new areas of excellence and a stronger overall profile
- space for communication between teachers, researchers, students and employees of the Med Uni Graz.

The move to the new campus will be accompanied by a reorganization of teaching and research. The overall goal of the project is to achieve a large step forward in the quality of the core activities of teaching and research.
To reach the defined goals, the Med Uni Graz, with the support of the Bundesimmobiliengesellschaft (BIG, Austrian holding & management company for federally-owned buildings), conducted a competition for the overall design, beginning in 2010, which was won by the office of Riegler-Riewe Architects in Graz (Fig. 3,4).
In the summer of 2013, construction work on the main building Module 1 of the MED CAMPUS will begin



Fig. 1: Departments being gathered to the MEC CAMPUS (MUG)

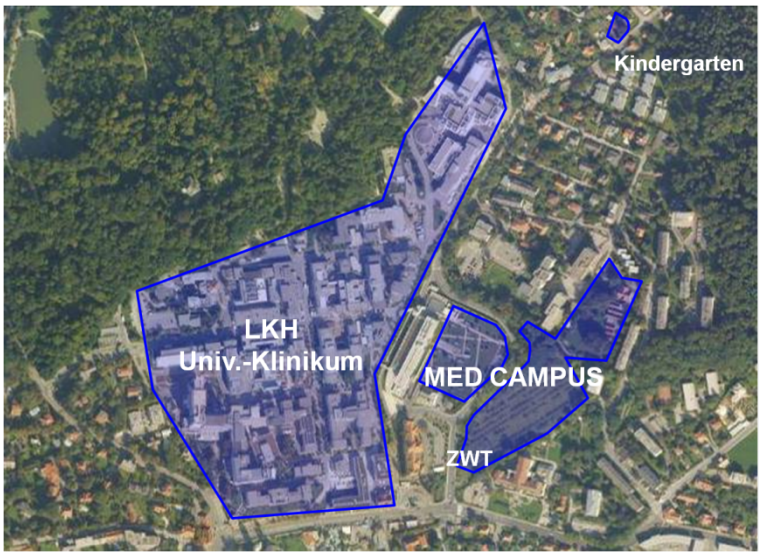


Fig. 2: Site plan of LKH University Hospital and MED CAMPUS (MUG)

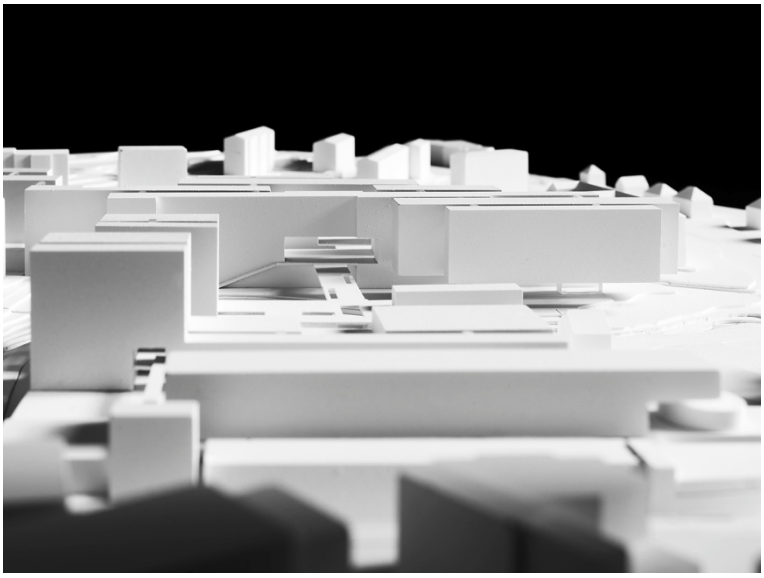


Fig. 3: Architectural model view MUG)

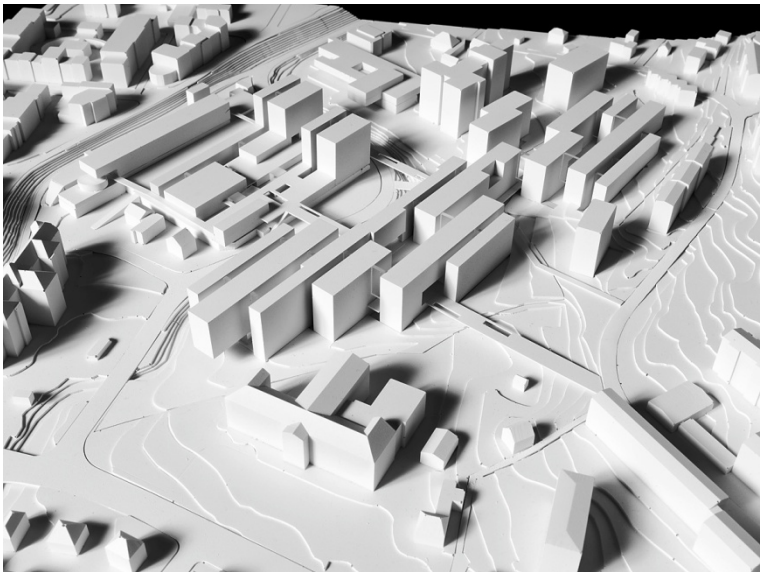


Fig. 4: Architectural model view (MUG)

1.2 MED CAMPUS key facts:

The MED CAMPUS will include space for research, teaching, administrative and for generell infrastructure.

Usable spaces to be created in main building modules 1 and 2 (Fig. 5):

- Research spaces for researchers and students
- Teaching spaces for 1200 students (medicine, dentistry and nursing science)
- General infrastructure for 4300 students (canteen, event spaces, open space)
- Administrative space for all together 840 employees of the Med Uni Graz

Total areas to be realized in main building module:

- Useful area MED CAMPUS Module 1: approx. 20,000 m² (total useful area 38,000 m²)
- Gross floor area MED CAMPUS: approx. 44,000 m² (total gross floor area 74,000 m²)
- Site area 43,000 m²

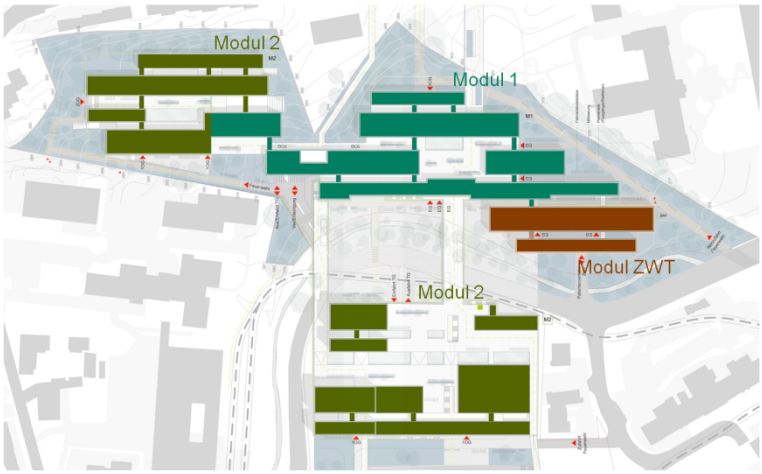


Fig. 5: Construction phases (RRA)

Current Status of the Project:

The project is now at the stage of tendering for the main building trades. Construction work began at the end of July 2013 (Fig. 6). At the same time, the preparatory work for the certification of the buildings by ÖGNI were completed.

2005	2006	2007	2008	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Use concept		Spatial programm		Prepare of comepition	Competition		Draft copy	Draft	Start of construkt. work	Construction work			Inspection	Operation

Fig.6: Time schedule of MED CAMPUS main buildings, Module 1 (MUG)

1.3 Motivation of the Med Uni Graz for building a sustainable MED CAMPUS:

The Med Uni Graz has a strong interest in creating sustainable campus buildings for the following reasons:

- A fundamental commitment of the Medical University of Graz to sustainability in research and teaching
- The improvement of the usage of the buildings that can be achieved by creating a high-quality built environment
- The wish for an innovative building
- Flexibility and adaptability of the built spaces for changing uses
- The need to keep future operating costs low, particulary in view of foreseeable rises in energy prices

1.4 Sustainability goals for the MED CAMPUS project:

The purpose of the MED CAMPUS is not just to create new buildings for existing organizational entities, but to accompany the reorganization of the non-clinical research and teaching activities and the administrative departments of the Med Uni Graz. Thus the MED CAMPUS is not a pure building project but the implementation of a new organizational concept.
As well as this overall project aim, the MED CAMPUS project has been designed to be sustainable in a broad sense of the term.

Extract from the competition text: the combination of the measures in the MED CAMPUS (buildings and organization) should serve the goal of achieving a quantum leap in the quality of the core activities of teaching and research. Besides this, networking of the MED CAMPUS with the clinical institutes of the LKH University Hospital Graz is expeczed to have beneficial effects on patient care.

In this context, the usual meaning of sustainability of buildings was deliberately expanded to include the sustainability of the functionality and of the added value of use of the buildings. This decision was taken in view of the complexity and scope of the requirements placed on the project and to ensure their integration into a holistic overall concept.

In the preparation of the call for the architectural design competition, two groups of sustainability goals were defined. In the contract negotiations with the chosen architecture firm, these were further developed, culminating in an agreed list of sustainability objectives.

1. General sustainability goals (hard and soft factors)
2. Sustainability goals based on ÖGNI criteria

Economics	Functionality	Added value of use	Ecology
Affordability	Open use conzept	Identity foundation	Human health
Life cycle costs	Use synergies	Image formation	Commodities, climate protection
Energy efficiency	Flexibility, adaptability, change of use	Integration of the urban space	Renewable energy
Maintenance costs	Operation optimization of the building	Quality of stay	Urban Ecology
Other operating expenses	Accessibility	Communicative qualities	Microclimate
Safety		Comfort of use	
Lifespan		Building Culture	
		Art and construction	

Fig. 7: Dimensions of sustainability in the MED CAMPUS project (MUG)

2. Main Challenges in the Design Process, and their Solutions:

Incorporating sustainability considerations into building design is not completely new. In fact, the long-term optimization of buildings, at least in some respects, has always been part of the building-design and construction processes.

What is new is the approach of creating a comprehensive evaluation and optimization of the buildings over a long time period, covering the dimensions of functional, economic, and environmental sustainability and also the added value of use (as an expansion of the concept of sustainability).

These requirements gave rise to the following challenges in the design process:

2.1 Implementing of Sustainability-targets makes the design process more complex, because it cuts across specialties

The sustainability perspective, and especially the evaluation according to ÖGNI, is one that cuts across all the usual design specialties.

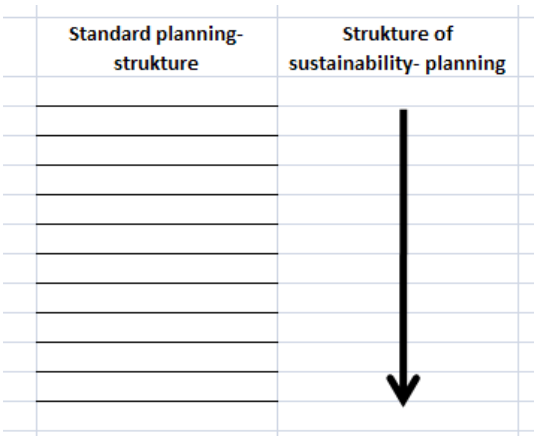


Fig 8: Structure of sustainability concept compared to conventional design process (MUG)

Furthermore an on going estination of the various aspects of sustainability is necessary.

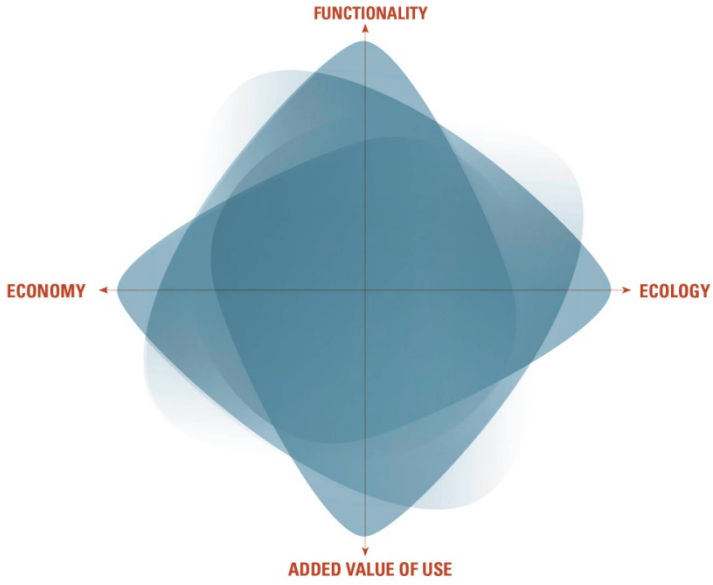


Fig. 9: Estination fo the various aspects of sustainability (MUG)

To keep the resulting complexity within practicable limits and to ensure a structured approach, the following measures were implemented:

- Kick-off workshops with all the specialist design/engineering staff
- Regular pre-checks to evaluate current status and track progress towards targets
- Interim reports on sustainability as a steering instrument
- Ongoing definition of thematic areas of focus
- Regular sustainability meetings
- Appointment of one sustainability coordinator in each of the organizations Med Uni Graz, BIG and Riegler-Riewe architects

2.2 Lack of standards for design of sustainable buildings

This challenge in the design process lay in the fact that in many areas, for the planned uses of the building, new standards had to be developed from scratch, for example:

- Definition of goals:
  The need to work out a consensus on the definition of sustainability

- Design activities:
  Structures and tools had to be developed to guide the implementation of sustainability in the design process

- Lack of task descriptions for the specialist designers:
  task descriptions had to be drawn up for various specialties and partly revised during the design process

- Certification procedures in accordance with ÖGNI:
  Process needed to be developed, especially for the laboratory areas, for which ÖGNI did not have any mandatory sets of targets at the beginning of the design process.

- Sustainable technical system solutions:
  Required the sustainability evaluation of all technical systems

- Choice of sustainable building materials and components:
  Required the sustainability evaluation of a large number of materials and components

2.3 Complexity of the building project itself

The building project is highly complex even before taking into account the sustainability goals (Fig. 10). The shape of the site, the large number of participating institutions, the spatial program the range of spaces needed and the functional requirements all contributed to this complexity. The floors at the base of the buildings will house different areas for teaching, the assembly hall, the large lecture theatres and the administrative infrastructure. The floor above these will contain highly-equipped laboratories and their dedicated office areas. Spaces for the university administration are planned in separate towers.
The MED CAMPUS will host the following functions:

- 39 organizational units
- 14 instituts
- 4 centers
- 9 core facilities
- 10 lecture halls
- 46 seminar rooms
- 345 laboratories
- 532 offices

- IT- rooms
- workshops
- communication space, Social rooms, meetings points, cafes, canteen, assembly hall
- supply rooms
- storage rooms

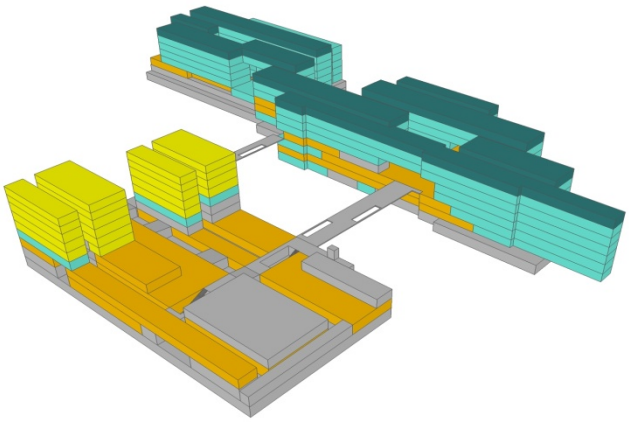


Fig. 10: Map of functions (RRA)

3. Methods and Tools used to reach the substainability goals

3.1 Definition of sustainability for the project MED CAMPUS:

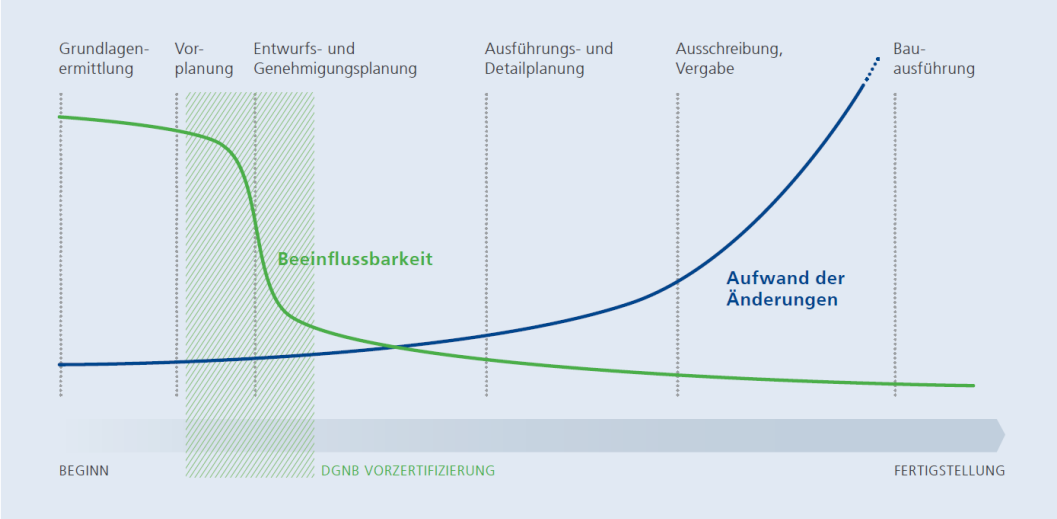
Sustainability is subject to a variety of different definitions. For the MED CAMPUS project, the following definition was adopted:

Sustainable development:
A development is sustainable if it "meets the needs of the present without compromising the ability of future generations to meet their own needs." Quoted from "Lexikon der Nachhaltigkeit", www.wirtschaftslexikon.gabler.de

3.2 Organizational *measures* to reach the sustainability goals:

Implementation of the defined tasks in a project of this size and complexity gave rise to the following organizational requirements:

- Integration of the sustainability topics in the early project development, in drawing up the usage concept, and in setting parameters for the architectural competition (Fig. 11). This to ensure the largest possible influenceability to reach the sustainability goals. To reach the sustainability targets numerous activities where set in the different planning phases – shown in Fig. 12.



Influenceability of the planning in the planning process
Outlay for modifications

Fig. 11: Influenceability of the planning in the planning process (aus: ÖGNI-systembroschüre 2013)

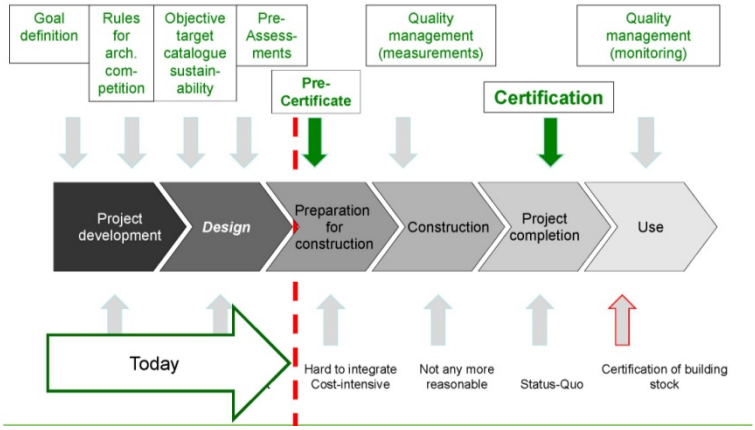


Fig.. 12: timing of integration of sustainability targets into the planning process (TTUG)

- Standardized definitions of targets, measures to ensure that the goals are understood and supported at all levels of decisions making and by all the people / organizations involded
- Selection of reference projects to support the definition of targets
- Establishment of an integrated planning team by BIG, integration of specialist design staff into the overall design team (energy design, LCC calculation etc.) as shown in Fig. 13.

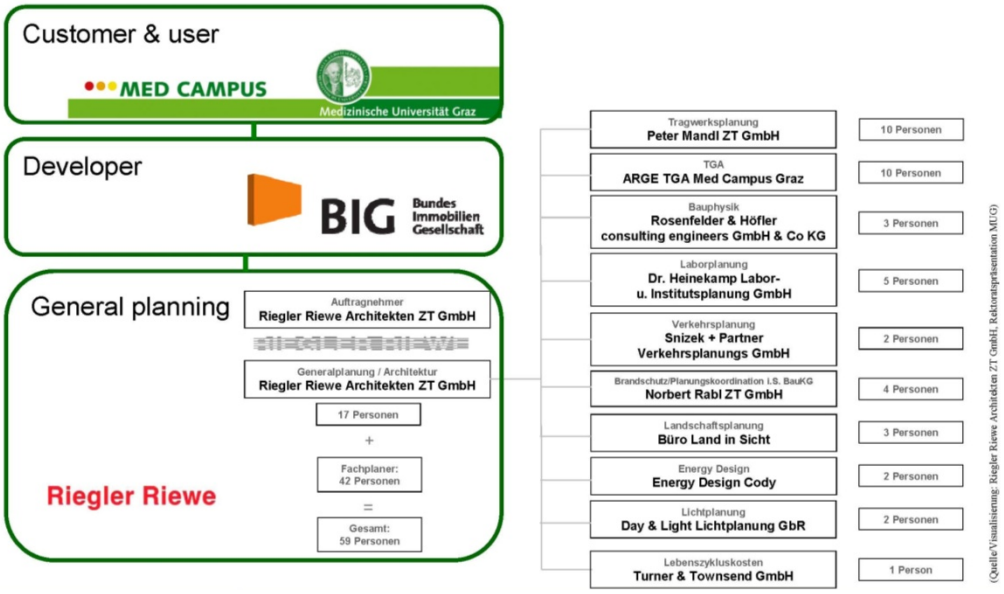


Fig. 13: Schematic representation of design organization (MUG)

- Ongoing dialogue between different areas of detailed design (continuous consideration of sustainability trade-offs in all decisions of specialist disciplines)
- Commitment and openness of all people involved to innovative practices
- Use of special control tools
- Operation of a separate sustainability budget to guide the project towards the goals

3.3 Planning and design tools used to reach the sustainability targets:

To reach the sustainability targets the following planning and design tools where applied in the project.

Evaluation of variants:
Variant studies were done for all the main components of the technical systems, beginning, in a simple form, with the earliest draft design.

Compilation and evaluation of detailed decision-making dossiers:
for decisions on individual system components, data were collected systematically on standardized forms, covering factors such as payback calculations, etc.

Design & development of an integrated energy concept, elaboration of comprehensive strategies & recommendations for energy optimization:
The buildings energy concept includes the areas of indoor climate, building shape, building envelope, building services and energy supply/distribution. It was drawn up in consultation with the relevant specialist design staff (building services, electrical engineering, facade) as a design task in its own right, and at the draft design stage it was passed to the specialist designers as a binding document.

In addition, the following design instruments were used:
Whole building simulations
Assessment of individual measures including economic feasibility calculations
Design and evaluation of energetic parameters & internal loads
Thermal building simulation
Daylight simulation
Life cycle costs analyses (LCCA)
Life cycle assessment (LCA)
Sustainability report

Use of the ÖGNI certification system as a tool to measure fulfilment of targets and thus as a control instrument on the client side (Med Uni Graz)

4. Planing Reasons

Generally there have been implemented sustainable solutions in each of the four dimensions of sustainability:

- Economy
- Functionality
- Added value of use
- Ecology

4.1 Specific sustainability measures to be implemented within the project (excerpt list):

The MED CAMPUS main building Module 1 will incorporate the following sustainability measures:

1. Usage Concept:

- The structure of the usage concept fosters flexibility and synergies during the operation (concept with centres, Medical Research Centre II (ZMF II), connections with ZWT (Fig. 14, 15).

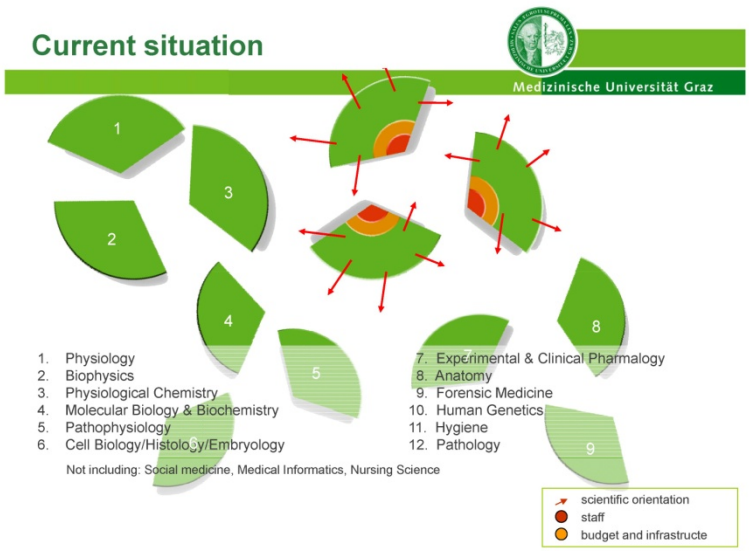


Fig. 14: Concept of centres (MUG)

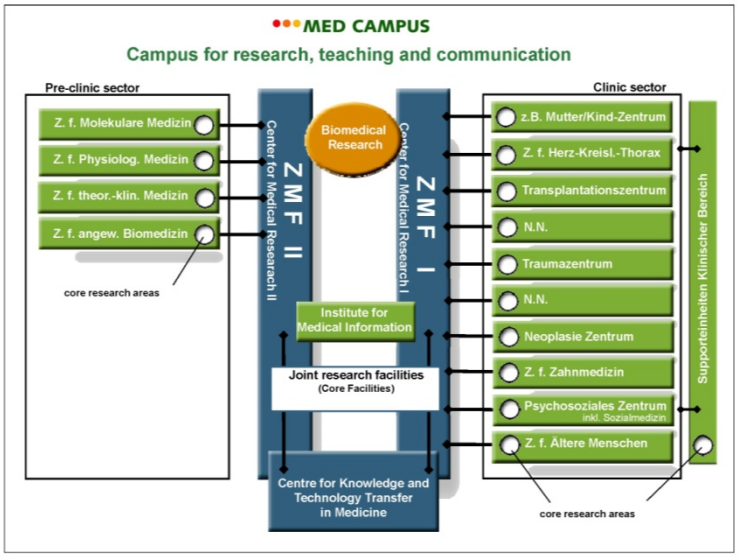


Fig. 15: Overall usage concept (MUG)

2. Sustainable traffic plan and implementation of a mobility plan: A mobility agreement with the city of Graz, the regional government of Styria and the hospitals corporation KAGEs, covers construction of new infrastructure and organizational measures. The plan includes measures on limiting the number of car

parking spaces, walking and cycling, public transport, motor traffic and mobility management.

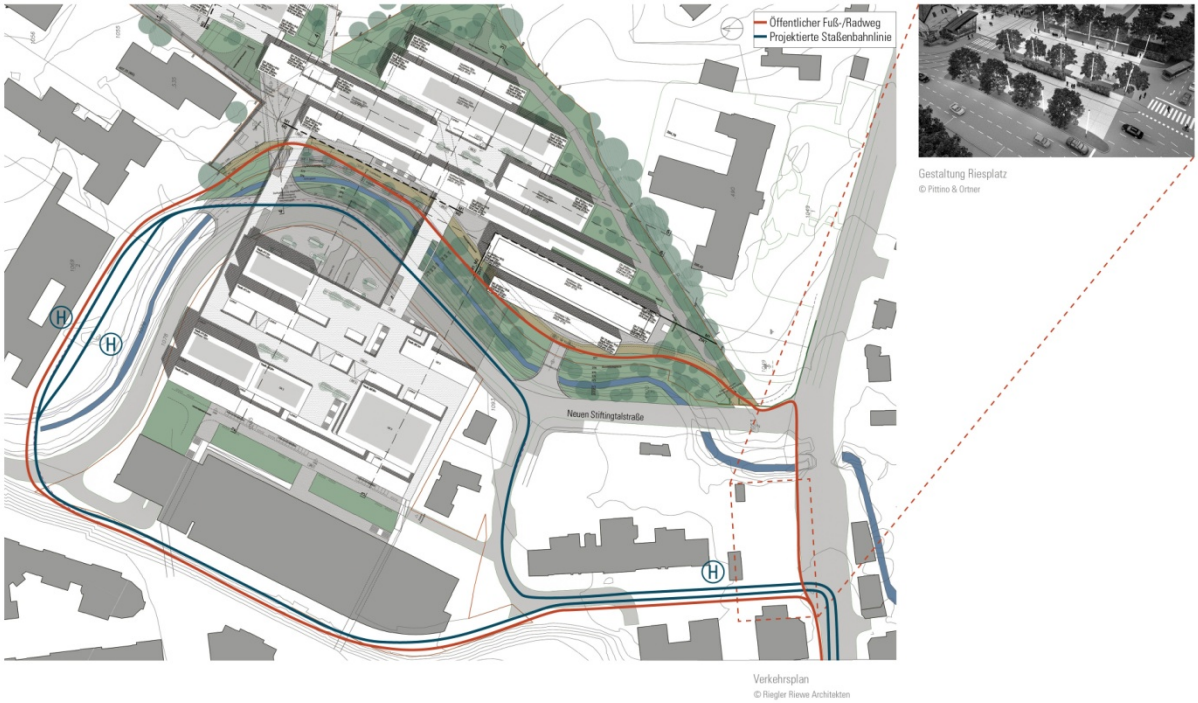


Fig. 16: Extension of tram line, reorganization of green spaces, rebuilding of Riesplatz (RRA)

3. Urban planning:

- High-density building:
- respecting the fresh air corridor for the city.
- The buildings are specially aligned and dimensioned so that they do not adversely affect the flow of fresh air from the Stiftingtal (river valley) into the city (Fig. 16)
- Integration of the MED CAMPUS into the urban space



Fig. 16: Fresh air corridor, orientation of buildings (RRA)

4. Design of floor plans:

- Interconnection of all building sections with bridges on all levels (Fig. 17)
- Standardized floor plans that are adaptable for different uses

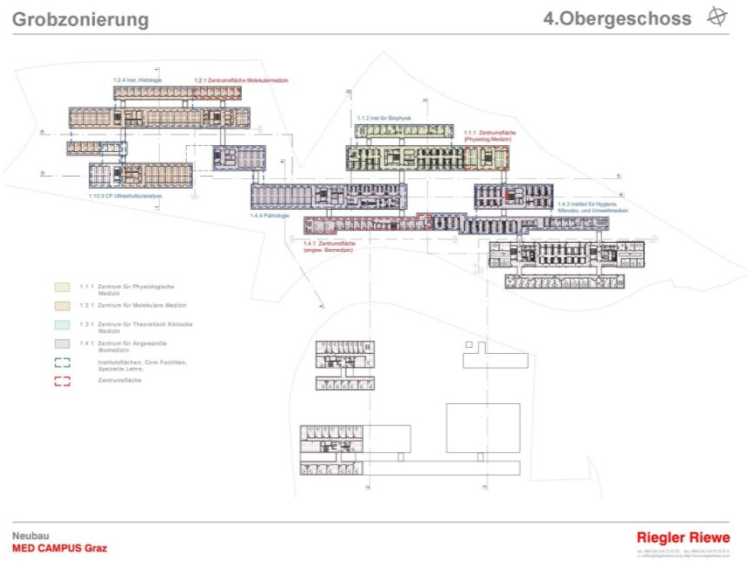


Fig. 17: Floor layout with bridges (RRA)

- Communicative qualities of the building and the outdoor spaces (Fig. 18)

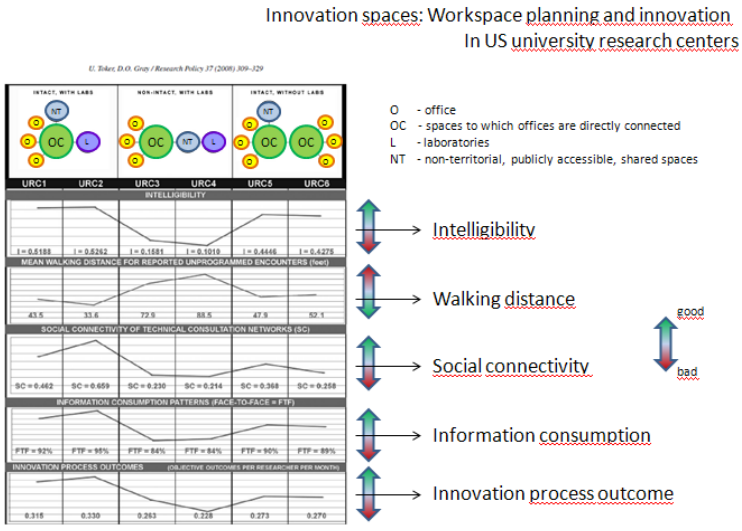


Fig. 18: Effect of communicative spaces on the research output (MUG)

5. Facade (Fig. 19)

- Automatic exterior shade elements
- Strategic use of different window sizes and positions according to functional requirements AWD lighting-situations

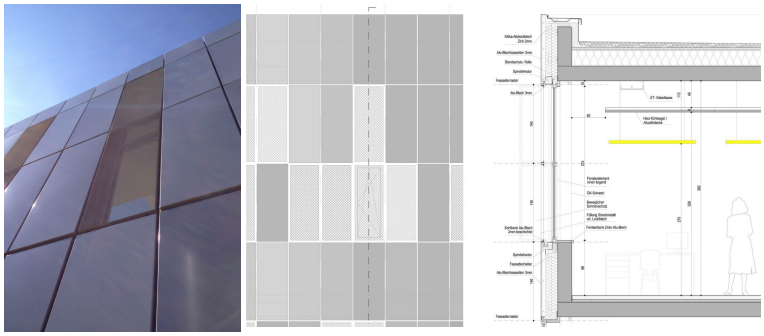


Fig. 19: Facade design (RRA)

6. Building technology:

- Thermal insulation of walls, roofs and floors to a higher level than in the reference buildings
- Triple glazing
- Use of ventilation systems with heat recovery systems in laboratory areas, including fume cupboards
- High-efficiency energy recovery systems in the lecture theatre areas (rotary heat exchangers instead of plate heat exchangers, η=0.8 instead of 0.65)
- High-efficiency energy recovery systems in the seminar room areas (rotary heat exchangers instead of plate heat exchangers)
- Control of ventilation in the lecture theatre areas using CO2 sensors.
- Utilization of waste heat from the cooling plant by means of water-based heat transfer to the central heating system
- Control of lighting in the office areas, corridors and laboratory office areas depending on natural light and occupancy
- Energy supply: use of energy piles (coupled to heat pumps) in the building foundations (approx. 300 structural piles needed).

7. Materials and surfaces:

- Use of environmentally friendly materials

5. Estimated fullfilment of goals – effects of the measures taken on the quality of the buildings and their future use

Thanks to the intensive collaboration of everyone involved, we succeeded in incorporating all of the defined sustainability goals into the design. The process of doing so placed extraordinary demands on the whole project staff, but the extra effort has paid off.

The result is a complex of buildings that fully meets the stringent requirements on:

- economy
- functionality
- added value of use
- and ecology

Concerning the costs there is:

- approx. 40 % saving of energy costs so that approx. 20% saving of operating costs, this with a amortization time of 7 to 17 years for those sustainability measurements, that have been examined concerning to amortization.
- added to this cost savings there is a cost saving that hardly can be measured, but that is in long terme probably even more important: the cost save resulting on the aspects of the factors of sustainability concerning functionality, added value of use (building quality) and ecology

In addition, the project was final awarded with a precertifcate in gold according to the ÖGNI system (Fig. 20). This would be the first gold award for a laboratory building in Austria. The single building qualities and the fulfilment of target values are shown in Fig. 21.

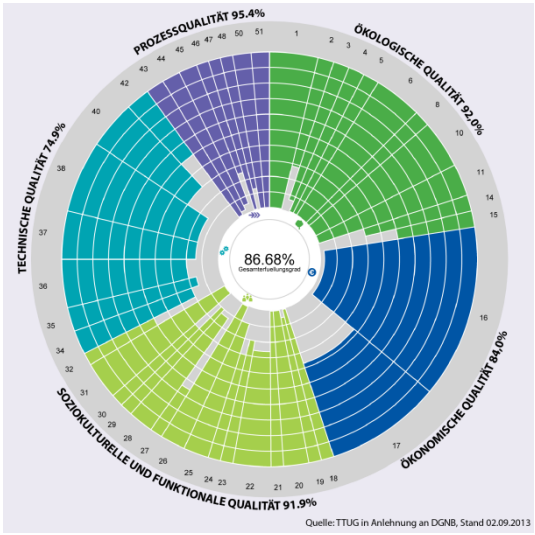


Fig. 20: Current status of evaluation according to ÖGNI criteria (TTUG)

Fig. 21: Precertificate of ÖGNI (ÖGNI)

6. Conclusion and Outlook

In summary, it can be said that as far as can be judged at present, the very ambitious goals of the Med Uni Graz for the sustainability of the buildings will be reached. The extra effort of the design process is therefore worthwhile from the point of view of the Med Uni Graz.
The future will reveal how far this extra design and organizational effort can be reduced by developing standardized instruments and procedures. However, it does appear that the best solutions will always be highly specific to the location and the planned uses of the buildings. If we consider that diversity often seems to be one of the best survival plans, then this finding can be seen in a positive light.

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8. References

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Plus Energy Building in Estonia

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Short Summery

The building uses the Passive House concept for a Nordic country and serves as a model for Passive and Plus Energy Buildings in northern latitudes. The building is housing a typical Estonian family with 5 members and demonstrates that a Passive House concept combined with active solar technologies can produce same amount energy than is needed over the year – even in northern countries.

Keywords: Plus Energy House, Passive House, Solar heat gains, Solar Active House

1. Climatic conditions

As a typical country bordering the Baltic Sea, Estonia is divided to two climatic zones – e.g. coastal area and inland area where conditions differ due to influence of nearby sea. The more detailed spatial division and climatic differences are given in [Kalamees and Vinha 2004]. The building described in this article is located in the town of Põlva at the South-East part of Estonia where more continental climatic conditions occur along with lower temperatures, deeper and longer lasting snow cover compared to coastal areas [Raik 1967 *cited in* Kalamees and Vinha 2004]. Compared to Central European climate where the use of passive and active solar techniques is more widely used the winters are cold in Estonia. Based on national Test Reference Year for energy calculations the long-term average dry bulb temperature for inland part of Estonia in December is -2,5°C, in January -3,0°C and in February -5,2°C [Kalamees and Kurnitski 2006], however long-term average daily minimum values for each month from November to March are below -10,0 °C reaching -14,3 °C for January [Kalamees 2006]. In more extreme years the air temperature falls below -30 °C occasionally, staying frequently below -15 °C for several days [Estonian Meteorological and Hydrological Institute 2002]. Despite the low temperatures there is also a lot of solar radiation available on Southern elevations on cold days (especially in February and March) due to lower solar altitudes and long lasting snow cover compared to Central European locations. Though the monthly sums of direct and indirect solar radiation on vertical surfaces strongly depend on the yearly variation of snow and cloud conditions [Estonian Meteorological and Hydrological Institute 2003], the nearly perpendicular sun-angles in heating period make the solar use strategy in this latitude (58°N, 27°E) interesting.

2. Project description

2.1 Architectural solution

The building site is a rectangular plot with two different levels. The new building is positioned within the given slope connecting those levels leaving the south and east façade of basement floor exposed to winter sun. The main glazed façade is oriented directly to south maximising the use of passive solar gain during the heating season. On southern façade terraces and balconies are partly reaching out over the slope to give shade and protect against the overheating during the summer period.



Figure 1 rendered view, cross sections, south fassade, winter and summer, etc.

The building has three stories, total net floor area of 305 m^2, external envelope surface area of 864 m^2 and enclosed volume of 1586 m^3, which corresponds to compactness factor A/V of 0,55 m^{-1} for the building. For the energy calculations a reduced “treated floor area” of 280,6 m^2 was used (40% of rooms with no windows and corridor in the basement was excluded).

The ground level consists of an entrance area, the big living room, the kitchen, the master bedroom and the corresponding auxiliary rooms. The living room is two stories high. In the upper floor you find a gallery, which is open to the living room and gives access to three children's bedrooms and a working area. In the basement there is a sauna and a steam bath (both very important in the daily day live of the inhabitants) connected with an area for shower and a big room for recreation (fully served with day light). There are also a technical room, a room for the kids and some storage rooms.

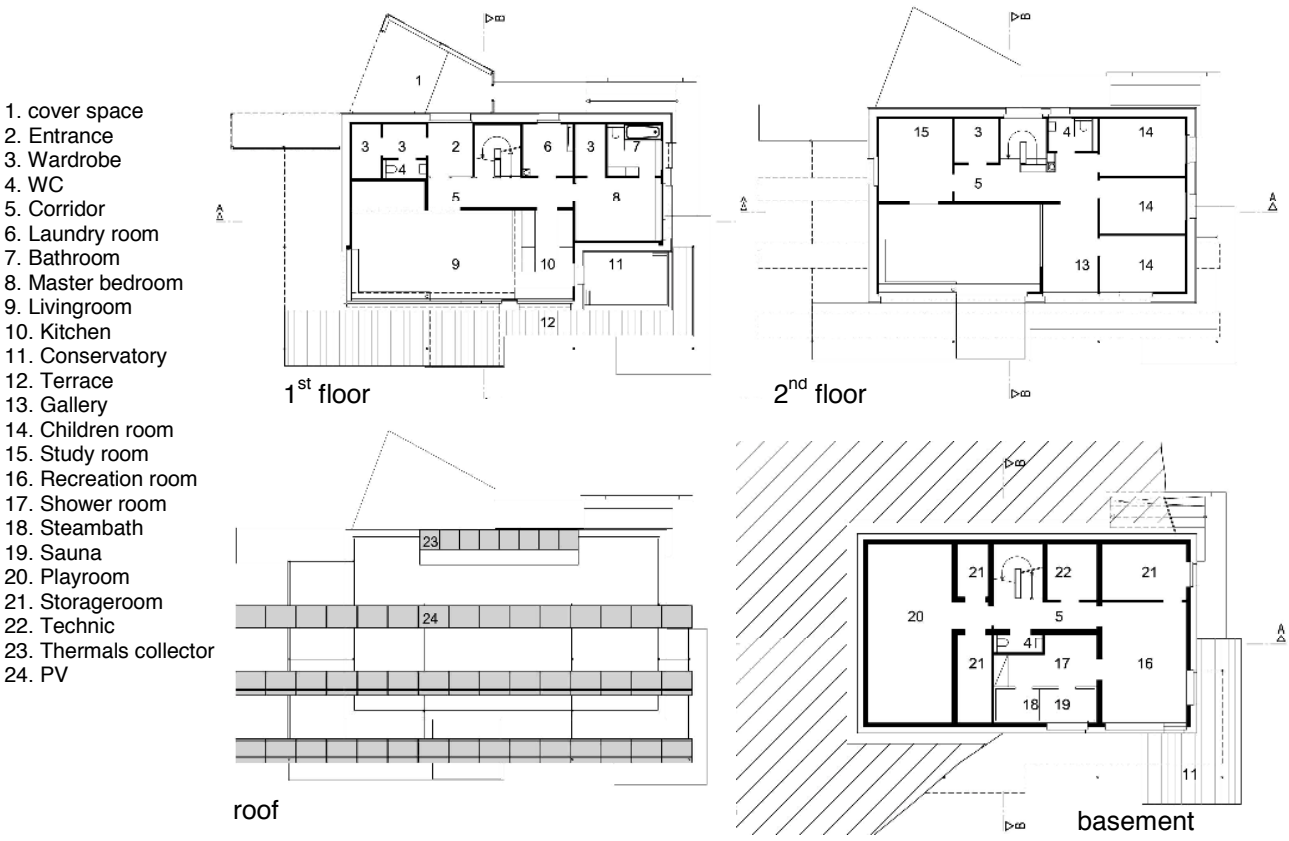


Figure 2 Floor plans and roof

Since the winter sun has to contribute a big part of the heating of the house, the south side of it is opened with big windows. This goes back to the fact that just in the south façade passive house quality windows can give a positive balance over the heating season (and not windows at other orientations).

Separate lightweight construction is built over the building to support the large array of photovoltaic panels (90 m^2), which provide a source for renewable energy and at the same time provide additional shading for the roof and southern façade.

Special slanted extension of the roof construction on the northern side is created to allow additional night cooling through natural ventilation. The extension also gives support and thermal resistance for roof integrated solar thermal collectors (11,6 m^2 active surface area). Those roof collectors are optimized for the summer sun (warm water production). Additionally, a separate array of solar thermal collectors (13,1 m^2 active surface area for

heating and warm water) are integrated to southern façade and optimized for the winter operation. Those vertical collectors gain special profit from the deep inclination of the winter sun and from the permanent snow reflection at this time.

2.2 Thermal envelope

The house is built with mixed construction system – the basement (partly in ground and partly open to the sloping hillside) is casted concrete construction with thick layer of XPS/EPS insulation depending on the wall/floor type. The aboveground perimeter walls have 300 mm of EPS insulation and belowground perimeter walls have 500 mm of EPS insulation. The floor slab configuration features 300 mm of XPS insulation and 100 mm of EPS insulation.

Ground floor and upper floor have a 94 mm thick cross-laminated timber block elements (KLH) as the static layer and 400 mm of cellulose insulation with custom made C-joists made out of timber and OSB sheets. The roof panel is insulated with wedge shaped EPS insulation (380 mm - 550 mm). The walls of the upper floors have façade solution with ventilated cavities mainly covered with rendering boards and partly covered by vertical solar collectors.

Special construction was applied to unheated (but inside building's rectangular form) conservatory floor, which needed 80 mm of vacuum insulation panels (Vacupor Vacuspeed) to achieve the needed thermal resistance and also lower the thermal bridges in surrounding junctions.

The glazed areas feature krypton filled triple glazing with different low-emissivity coatings depending on the orientation of the windows and glazed doors. The declared Ug values of the glazing units are 0,60 W/(m^2K) for the southern façade and 0,49 W/(m2K) for other orientations, the SHGC values for these glazing units are accordingly 0,59…0,62 for southern façade and 0,36…0,37 for other facades depending on the glazing thickness. The glazing properties are differentiated to maximize the solar gain during the heating season. The wooden window frames with thermal separation (SmartWin) have very low thermal conductivity (average Uf value for open able windows 0,75 W/(m^2K) and 0,59 W/(m^2K) for fixed windows) to minimize the heat losses.

Additionally all possible measures were taken to lower the heat losses including the optimization of thermal bridges. The thermal bridging in main junction types were avoided by the selection of construction type with uniform outside insulation. However, the bulk amount of different window connection details were calculated with LBNL Therm software to achieve as good as possible solutions for regular installation, but also for fixing the shading rolls on southern façade. Almost all possible junctions were assessed with 2D finite element calculation in order to gain all possible reductions in heat balance calculation. An overall reduction by 1,9 kWh/(m^2yr) to annual net heat demand was achieved compared to situation with no thermal bridge input using external dimensions.

In total the average thermal conductivity of the whole building envelope (including windows, doors and linear thermal bridges) is 0,146 W/(m^2K).

2.3 Ventilation system

The building has balanced mechanical ventilation system with PHI certified passive house ventilation unit (Paul Novus 300 with exhaust side heat recovery efficiency 93% according to PHI certification system) [Passivhaus Inst 2009]. Fresh air with no additional heating is supplied to living-room and bedrooms and then exhausted from kitchen, bathrooms. The airflows have been reduced to limit the risk of overly dry air during the winter season. The average airflow rate measured during the start-up of the ventilation system is 280 m^3/h, which corresponds to average air change rate of 0,4 h^{-1}. Preliminary measurements show that CO_2 levels are low enough to further lower the airflows if necessary.

The frost protection of the ventilation unit is solely by sub-soil brine heat-exchanger. The system features 226 m (with 40 mm diameter) of plastic pipe buried horizontally in the depth of approx. 1,0 to 1,2 m and connected to Paul Sole Defroster unit SD-550, which controls the fluid flow speed of the system according to air-temperature before the ventilation unit. Preliminary measurement results show stable air temperatures around 1°C after the defrosting unit for the first heating period.

The infiltration and exfiltration of the air through the building envelope is reduced radically through the use of special airtightness products and careful planning and execution. Measured average airtightness at the 50 Pa pressure difference (average air change rate n_{50} of the under- and over pressurization test) is 0,36 h^{-1}.

2.4 Heating system

The heating system is based on ground source heat pump combined with split solar thermal system. Wiessmann “Vitocal 300 G BWC” ground source (two 80 m deep vertical boreholes) heat pump unit with 5,9 kW heating power output and declared (EN 14511) COP of 4,51 (for B0W35 conditions at flow/return difference of 5K) is combined with Sonnenkraft roof-mounted (11,6 m^2 active area) and vertical wall-mounted (13,1 m^2 active area) solar thermal panels and 2 x 1000 l storage tanks (PSC1000E). The panels are oriented directly to south. The storage tanks are covered with 200 mm insulation to reduce the stand-by heat losses and lower the overheating of the rooms on the basement floor.

A very short DHW circulation system with connected distribution pipes as well as piping from storage tanks to wall- and floor-heating collectors are insulated with 40 mm mineral wool or 13 mm Armaflex technical insulation depending on the placement of the piping.

The heat is distributed through water based wall- and floor-heating system with supply and return temperatures of 39/33 °C. The wall-heating system was chosen to lower the fluid temperatures and provide more uniform temperature distribution for greater indoor comfort.

2.5 Grid-connected PV system

The system consists of 66 panels SolarWorld Sunmodule Plus SW 196 Vario poly with unit dimensions 1001 x 1357 mm. The total panel area is 89, 8 m^2. Maximum power P_{max} under standard test conditions (STC) is 196 Wp. The panels are located in 3 rows, 22 units in each row (figure 4). Tilt angle from horizontal is 38°.



Figure 3 Roof with mounted PVs. Solar thermal collectors on the left.

Inverter is Solutronic Solplus 100, 11 kW, 98% efficiency. The system has Solutronic Loger with LAN output. Maximum output AC is 11000 W. According to PVGIS calculation (Photovoltaic Geographical Information System for Europe) [ECJRC Institute for Environment and Sustainability 2013], the annual production of the system is 10120 kWh (setting 5% losses).

2.6 Heat balance of the building

The heat balance and subsequent net energy demand for space heating was calculated using PHPP2007 software (ISO 13790 monthly method). A detailed energy model was generated carefully describing all different envelope areas, lengths of the linear thermal bridges (calculated separately with finite element calculations) the shading situation etc.

Average climate data for Southern part of Estonia was selected from the default database in calculation software. The description of the usage (number of people, use of household appliances, energy demand for technical appliances etc) and internal gains was carefully estimated, which corresponded well with the conservative standard usage defined by Passivhaus Institute (average internal heat gains 2,1 W/m2) [Passivhaus Inst 2012]. Consumption of DHW (25 l/(d pers)) and heating setpoint temperature (20 °C) for Passive House certification were also defined according to standard usage.

Throughout the projecting phase and also in building process the heat balance of the house and its several configurations was iteratively calculated to optimize the room layout, insulation thicknesses, required efficiencies of the technical equipment and especially the

configuration of glazed areas regarding their size, fragmentation and thermal and solar transmittances in order to fulfil the passive house requirements defined internationally. The final (as built) heat balance of the building for the heating period is given in the figure 4. The estimated annual net space heat demand of the building is 4043,8 kWh/a, which corresponds to specific net space heat demand of 14,4 kWh/(m^2a).

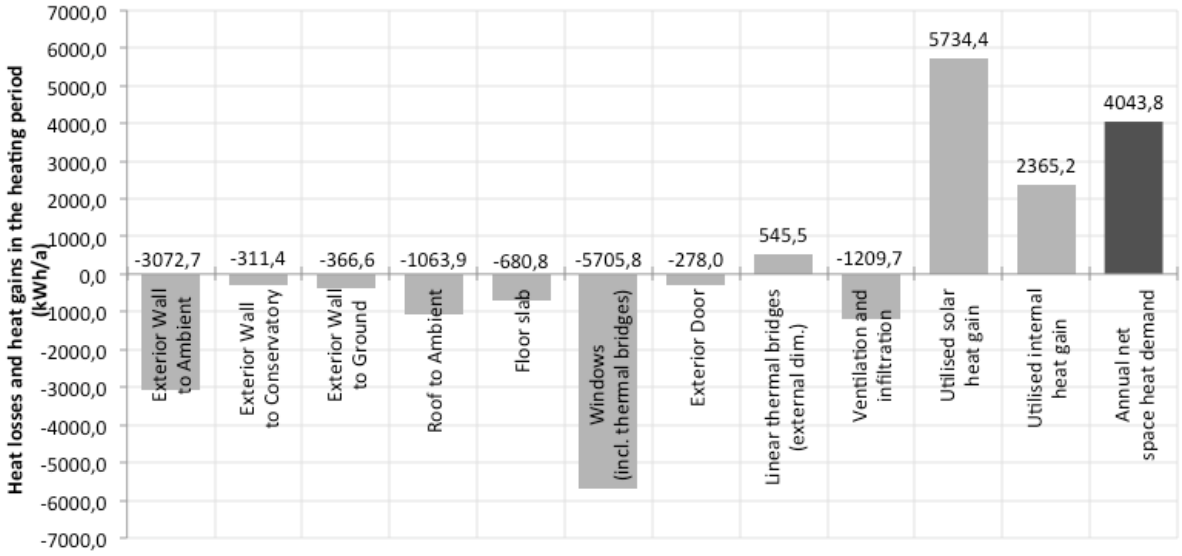


Figure 4 Heat balance of the building (as built) for the heating period.

From the Figure 4 it can be seen that heat loss through ventilation and air leakages is very small, which is achieved through the use of very efficient ventilation heat recovery system combined with ground-coupled brine preheating unit and good airtightness of the building envelope.

The heat loss through the highly insulated roof and floor construction is also quite small. The remaining heat loss through external wall (to ambient and also to unheated conservatory) has a lot more influence on heat balance. Although the thermal transmittance of the glazing units and also window frames are radically reduced, the windows are still the largest source of heat loss through the building envelope. The heat losses through windows and doors are more than all other sources of transmission heat losses altogether. This can be attributed to extensive glazing area on the south façade and also to few larger windows on eastern and western façade. Nevertheless, the large areas of glazing are a result of project optimization towards the energy efficiency. The losses through transparent envelope areas can be largely compensated by solar heat gains during the heating period even in the cold climate of Estonia. The separate heat balance of window areas for heating period (i.e. for the months that have calculated heat demand in this building) is given in the figure 5.

The calculations showed that using windows with high solar transmittance and very good thermal resistance resulted to overall heat gain in the heating period. The balance of heat gains and losses for the eastern and western windows showed that although a large part of combined heat losses can be compensated by the solar gains, the configuration still results

in total loss because of the high latitude and low sunshine duration during the heating period.

The monthly figures of total heat loss compared to utilize and non-utilized solar and internal heat gains are shown in the figure 5. It can be seen that for the deepest winter months (November, December and January) the solar gains are low in such high latitude and cold Estonian climate, but already in February the solar gains surpass the remaining heat demand. For all other months in a typical (average) year all heat losses are compensated by internal and solar heat gains so no remaining space heat demand occurs. The extensive part of non-utilised solar heat gains in spring and summer period reduced by using external shading blinds on southern façade and night cooling through automatically induced natural ventilation (the shading and night cooling effect is not included in calculation results shown in figure 5).

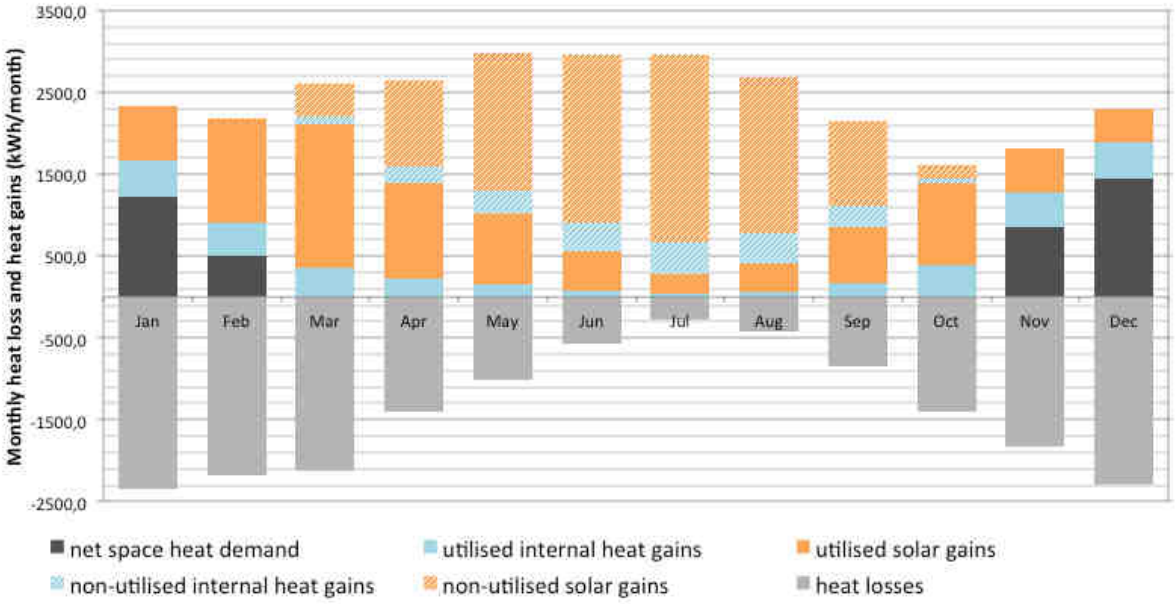


Figure 5 Estimated monthly heat losses and gains of the building (the effect of external movable shading elements are not taken into account for the summer months in this figure).

3. Final energy demand

Additionally to the heat balance and net space heat demand the heat losses of the heating system as well as domestic hot water system was calculated using PHPP2007 software package. Separately, the useful heat production of the solar thermal system was calculated using dynamic TSol calculation software by Sonnenkraft engineers. The useful heat demand for space heating and hot water production along with contributions of solar thermal as well as ground source heat pump system is given in figure 6. It can be seen that non-utilised heat losses from domestic hot water storage and distribution system have a big impact on total energy demand in the building when the energy demand of the building itself is radically reduced. This is mainly related to long pipe network, but also to 2000 l storage system of

solar thermal system, which has large surface area due to its size. The solar thermal system provides approximately 43% of useful energy for total heat demand in the building.

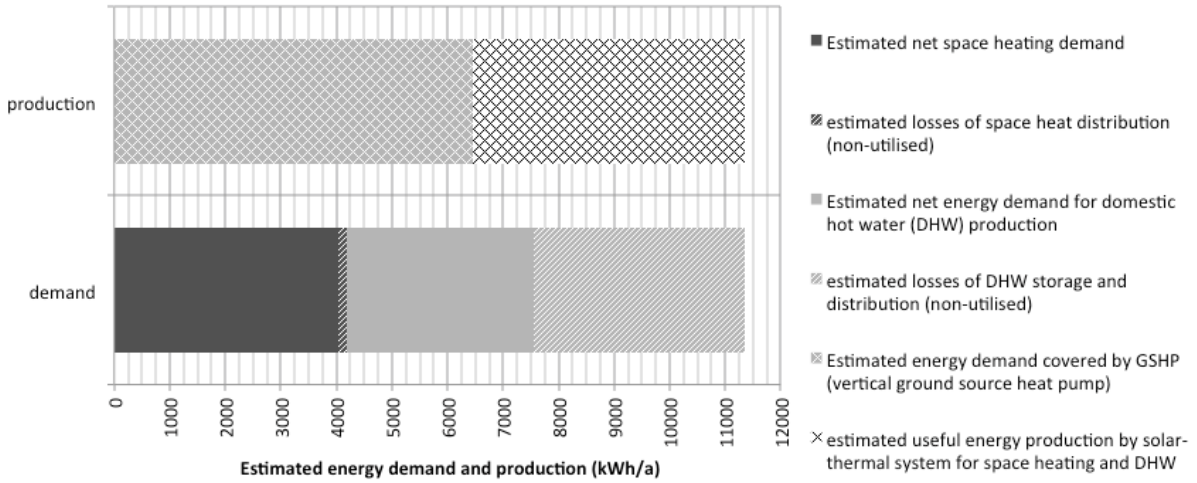


Figure 6 The useful heat energy demand of the building (including storage and distribution losses) and contribution of combined heating system.

In the end, the final energy consumption of the building was estimated for heating system, household appliances, lighting, technical appliance etc. based on standard usage. The necessary solar PV collector area was optimized to cover the final energy demand on a typical year. The electricity production of the PV system was estimated with PVGIS calculator using detailed configuration of the built system. As can be seen in table 1, the estimated final energy (electricity) demand of the building is approximately 10400 kWh/a, which corresponds to specific final energy demand of 37 kWh/(m^2a). The solar PV system produces approximately 10120 kWh/a, which nearly covers the total demand and shows that building a net-zero energy house is possible in Estonian climate.

Table 1 Estimated final energy (electricity) consumption and production of the building

	kWh/a
Estimated electricity production by solar PV (photovoltaic) system	**10120**
Total electricity demand of the building	**10356**
including electricity demand of GSHP (vertical ground source heat pump)	2149
including estimated electricity demand of technical installations (ventilators, pumps etc.)	2000
including estimated electricity demand of domestic appliances, lighting, sauna equipment etc.	6207

4. Monitoring

After completion in February 2013 the building has been equipped with extensive monitoring system to gather information about indoor climate and performance of building system as well as external wall construction. The air temperature, relative humidity and CO_2 levels are

monitored in several rooms, air temperature and relative humidity is monitored in ventilation system (air intake, preheated, supply, and extract airflows). Additionally energy consumption of heating system is measured along with solar thermal and solar PV system performance monitoring. Separately the external wall and massive clay partition wall layers are monitored.

5. Conclusion

The built project shows that through iterative calculation and design process a architectural solution is created, which allows extensive use of passive solar energy through the south facing glazed façade. The use of excellent building components along with favouring architectural solution radically reduces heat losses, which makes it possible to cover the entire energy demand of the building with renewable sources enabling to create net-zero energy building with the help of grid connected solar PV system. Maximizing the solar heat gain in the heating period, while keeping the transmission heat losses through the glazed areas is crucial when targeting the internationally defined passive house criteria in Nordic climate region.

6. Data and Project Participants

Object address: Metsa 5a, Põlva, Estonia. Owner: Kuldar Leis.
Architects: Martha Enriquez Reinberg and Georg W. Reinberg, Architekturbüro Reinberg ZT GmbH, Wien, Austria.
Treated floor area according to PHPP: 305 m²; Volume 1.586 m³
Construction time: October 2011 – May 2013

Consulters: Tõnu Mauring, Jaanus Hallik and Kristo Kalbe, University of Tartu (building physics, monitoring), Johannes Riebenbauer, Graz (static engineer), S&P Climadesign GmbH (technical systems), Margus Valge, Sense OÜ (project management and site supervision), PassiveHouse OÜ Estonia and Passive House Institute, Darmstadt (certification).

7. Pictures









8. References

[ECJRC Institute for Environment and Sustainability 2013] PVGIS: a web- based solar radiation database for the calculation of PV potential in Europe (available online: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=europe)

[Estonian Meteorological and Hydrological Institute. 2002] Raw measurement data at three-hour steps over the period from 1970 to 2001 in Tõravere weather station.

[Estonian Meteorological and Hydrological Institute. 2003] Handbook of Estonian solar radiation climate. 2003

[Kalamees, T. 2006] Hygrothermal criteria for design and simulation of buildings. Thesis, Tallinn University of Technology.

[Kalamees, T. and Kurnitski, J. 2006] Estonian test reference year for energy calculations. Proceedings of the Estonian Academy of Sciences. Engineering 12 (1): 40-58.

[Kalamees, T., Vinha, J. 2004] Estonian Climate Analysis for Selecting Moisture Reference Years for Hygrothermal Calculations. Journal of Thermal Envelope and Building Science 2004 27: 199 (2004)

[Passivhaus Inst 2009] Requirements and testing procedures for energetic and acoustical assessment of Passive House ventilation systems for Certification as “Passive House suitable component”, Passivhaus Institut (2009)

[Passivhaus Inst 2012] Certification criteria for residential Passive House buildings, Passivhaus Institut (2012)

[Raik, A. 1967]. Eesti klimaatilisest rajoneerimisest. Eesti Loodus, 2: 65–70.

B5

Database & Tools

Chair: Florian Gschösser
floGeco, Austria

Towards a new generation of building LCA tools adapted to the building design process and to the user needs?



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Short Summary

Life Cycle Assessment has been used for several years and has led to the development of different LCA tools worldwide.
Previous reviews have shown that each tool relies on its own data, methodological rules and environmental indicators, thus making comparison and interoperability difficult. To increase the harmonization and the widespread use of such tools in the construction sector, they need to be adapted to the different involved practitioners. For example, LCA can be used for early design but also for certification purposes (e.g. HQE, BREEAM, DGNB …). However, existing LCA tools do not entirely fulfil the user needs along the design process.

This paper presents general recommendations to move towards a new generation of building LCA tools. They are based on the findings from the recent European project EeBGuide. This project developed a comprehensive guidance document as an online InfoHub for building LCA practitioners and LCA tool developers [18]. The recommendations are breakdown according to the ISO 14040 standard and the ILCD Handbook steps (e.g. goal and scope definition, inventory analysis, impact assessment, interpretation) but also according to the conventional life cycle stages of a building (e.g. production, construction, use and end of life stages) defined in the new European standards EN 15978 and EN 15804. The scope of the guidance includes the different contributors of a building LCA: the building products and equipment, the construction site, the operational energy and water use, the transport of the users of the building.

The major outcomes are a proposal for adapting the data, calculation rules and methodology according to three different study types: screening, simplified and complete LCA. These study types let the possibility to conduct a LCA study in an early stage of a building by focusing e.g. on default values and adapted calculations rules while more detailed data can be chosen for specific assessment. Interests of the recommendations for the different stakeholders are discussed in this

paper. Then, the implementation of the recommendations on a case study of a detached house shows the feasibility to use adapted calculation rules within a building LCA tool.

Further works would now be needed, notably a validation works involving the comparison between a screening and a complete LCA. Another challenge is also the effort that needs to be done by building LCA tool developers to take into account the different study types within their own tools.

Keywords: LCA tools, buildings, products and equipment, water, energy consumption, screening, simplified, complete assessment.

1. Introduction

1.1 European context of Sustainable Construction

As new buildings now consume about the same amount of energy during an average 50 year lifespan as it is necessary to build them, new assessment methodologies encompassing the whole life cycle of building are required. Life Cycle Assessment (LCA) studies are being used more and more by leading practitioners as a means of demonstrating the ”whole life” energy efficiency of buildings. LCA studies analyse the impact of products, processes or services along the entire life cycle, which makes it a powerful tool to help companies optimise the ecological footprint of their products. For example, LCA enables to avoid problem shifting for the choice of energy systems of buildings as a whole by accounting of both direct and indirect impacts (e.g. upstream processes).
LCA has first been applied based on ISO 14040-44 [1][2] standards. However, these standards being too general, more specific guidance was recently released, e.g. the ILCD Handbook edited by the JRC of the European Commission [3].
In the construction sector, the recent European standards EN 15804 [4] and EN 15978 [5] are based on the LCA International standards ISO 14040-44. These standards define the general framework and general calculation methods for product LCAs and EPDs and building LCAs.
In the same time, in Europe, building LCAs are the foundation of many building certification schemes as well as of Environmental Product Declarations (EPD) for construction products. Yet the metrics and standards currently used in Europe can be interpreted and implemented in many different ways leading to inconsistencies and lack of comparability. Building certification schemes (like DGNB [6], HQE [7][8] or BREEAM [9]) use also individual sets of calculation rules for LCA in the construction sector.
Though previous papers on building LCA research perspectives recommend integrating the existing body of knowledge presented above (i.e. ISO 14040-44, ILCD, CEN standards) [10], it is unclear how a tool developer or a practitioner can currently do it due to current inconsistencies and diverging guidance [11]. As a consequence, the European landscape of LCA calculation rules is not dominated by harmonized methods, these inconsistencies being also found in available building LCA tools.

1.2 Review of existing building LCA tools

Several building LCA tools already exist in Europe and all over the world. They have been developed since the 1990’s along the development of the LCA methodology at the ISO (e.g. with the development of the ISO standards) or at SETAC level. Previous European projects funded by the seventh framework (e.g. PRESCO [12], ENSLIC-Building [13], LoRe-LCA [14]) have first reported and described the existing LCA tools in Europe. Generally speaking, these tools can be used depending on their goal e.g. for the comparison of design alternatives (ecodesign approach) or for the assessment of the environmental performance of a building (e.g. certification, labels). They can use different data and calculation rules. The environmental indicators are also different and not always comparable making difficult the comparison of studies between different tools.

Table 1 presents an updated review of some of the existing European building LCA tools. In total, 12 LCA software have been identified in Europe (including Switzerland). No general LCA software such as SimaPro or GaBi was considered in the state-of-the-art as we are mainly concerned on dedicated and user-friendly software for construction stakeholders. We also do not take into account other international building LCA tools such as the Impact Estimator [15] or the BEES [16] software developed in North America as the proposal of adapting the tools is first given under the European context for sustainable construction.
A template has been defined to report the main updated characteristics of existing building LCA tools. It includes: a short description of the tool, the country of development, the type of software [can it be used online or does the user need to install it on a personal computer?], the website, the purpose of the tool [are there different data or calculation rules within the tools e.g. for early design or more advanced assessment?], the modelling choices [what are the modelling choices e.g. situation A, B or C according to the ILCD Handbook?], the study type [are there different data or calculation rules within the tools e.g. for early design, complete LCA?], the data used [which LCA data are used in the tool e.g. generic data, EPD…], the life cycle stages assessed [which building stages are included in the tool?], the contributors assessed [which contributors of the building total impacts can be assessed with the tool?], the environmental indicators [which indicators are taken into account?] and the interpretation phase [e.g. is there any sensitivity analyses tool available to the user?]. The full review is freely available online in [17]. Table 1 only presents the main characteristics of available LCA tools for buildings.

Table 1: Main characteristics of available LCA tools for buildings based on [17]

N°	Building LCA tools	Country of development	Developer	Website
1	ECOSOFT	Austria	IBO	www.ibo.at/en/ecosoft.htm
2	BeCOST	Finland	VTT	http://virtual.vtt.fi/
3	ELODIE	France	CSTB	www.elodie-cstb.fr
4	EQUER	France	ARMINES-IZUBA	www.izuba.fr/logiciel/equer
5	GaBi Build IT	Germany	PE Int	www.pe-international.com
6	SBS	Germany	Fraunhofer IBP	www.sbs-onlinetool.com
7	LEGEP	Germany	WEKA	www.legep-software.de
8	ECOEFFECT	Sweden	KTH / Univ of Gävle	www.ecoeffect.se
9	ECO-BAU	Switzerland	HEIG VD / LESBAT	www.eco-bat.ch
10	ECO-QUANTUM	The Netherlands	IVAM	www.greencalc.com
11	GreenCalc+	The Netherlands	Dutch GBC	www.ivam.uva.nl/index.php?id=559&L=1#c4126
12	IMPACT*	UK	BRE	www.impactwba.com

* replacing the former LCA tool ENVEST II

The detailed characteristics of these tools show that each of them has been developed under a specific context and with a pre-defined goal in mind. Indeed, each building LCA tool currently lack in assessing the full “picture” of the building life cycle for the different user needs and objectives. For example, very few tools properly assess the impact related to the construction site, though construction companies are more and more interested in assessing this aspect. Not all of them propose different datasets (e.g. generic and specific data). Generally speaking, each tool has been developed to meet the need of some stakeholders but not all of them. In this paper, we present an approach for a new generation of building LCA tools based on a consistent framework (section 2) including different study types (section 3) with example of implementation (section 4).

2. Proposal for an improved framework for building LCA

2.1 Methodological approach and general framework

The existing documentations of LCA and buildings are rather not harmonized. Here, an approach is proposed to integrate existing knowledge in a structured way that could be further improved and updated. This is based on the findings of the European project EeBGuide [18]. The proposal consists in a list of important aspects to be taken into account for building LCA under different goal definitions e.g. assessment of a building stock, comparison of design alternatives within a design team, assessment of the environmental performance of a building, comparative assertions etc. The framework and the description of the aspects have been defined by a European LCA expert group including a panel of review experts as well as a public consultation process to get feedbacks from stakeholders on these recommendations.

Recommendations were structured according to the steps of the LCA methodology in ISO 14040 and in the ILCD Handbook (see Fig. 1): goal and scope definition (e.g. functional unit or equivalent of the building, cut-off rules, allocations, data quality, infrastructures treatment?), inventory and impact assessment (indicators to include?), interpretation (e.g. use of sensitivity analyses, uncertainty assessment?) and reporting (level of information?).
A first outcome is the proposal to adapt the building LCA tool to answer different goal definition (the “flexibility” perspective) next to a harmonization (set of commun rules). ILCD situations A and B referring to attributional and consequential modelling were thus analysed. Situation A refers to small changes in the background system while consequential LCA refers to bigger changes in the background system in response to a decision. As stated by [10], for the building sector, the electricity consumption may be subjected to situation B especially for large scale analysis in support to policies or regulations. In a simplified approach, consequential studies may also require light adjustments e.g. provide the users with different datasets (average and marginal consumption mix). In that case, the tool mainly relies upon attributional approach with marginal datasets for scenario analyses [21]. Such developments enable to improve the scope of the tools while keeping them as far as possible user-friendly for the construction stakeholders. The release of new generation of LCI databases may also help for this perspective.

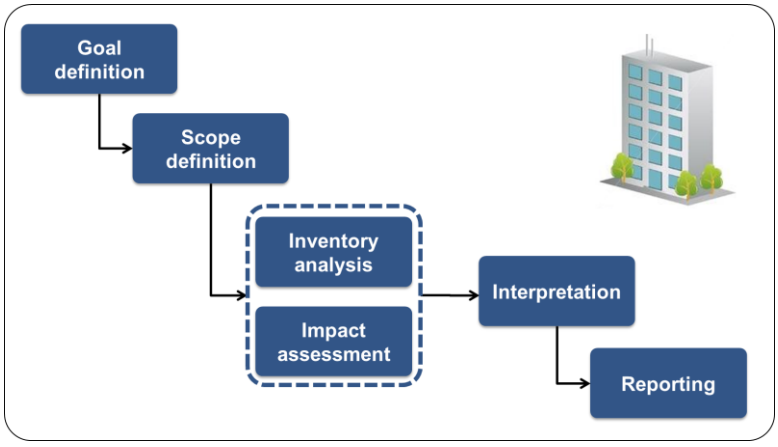


Fig. 1: Representation of the different steps of the LCA framework

With more than 100 important aspects identified and addressed, the EeBGuide Info Hub is a relevant source of information for building LCA tool developers willing to move towards a next generation of tools more adapted to the user needs and including the latest research (e.g. recent scientific results, previous EU projects results such as LORE-LCA) and standardization works on building LCA.

Beyond the content of each aspect (in terms of provisions, rules from both ILCD Handbook and CEN/ TC 350 standards, guidance), the recommendations provide a very systematic approach for carrying out building LCA studies.
Below are examples of important aspects mainly for attributional LCA that would need to be included in LCA tools according to the general framework:

- Development of filter functions in the tool to adapt or refine the goal and scope
- Develop and integrate different LCA datasets to match the users and project stages needs
- Inclusion of the different contributors of a building (see section 2.2)
- Implementation of different study types (see section 3)

Filter function and predefined rules may streamline the data and calculation rules for a specific goal definition. For example, this can be the case if we want to assess different refurbishment scenarios. To that purpose, a methodology to account for different refurbishment scenarios has been proposed in the guidance document [19]. When implemented in a tool, the different steps of the scope definition can be predefined for the final user by breaking down the different refurbishment stages for each scenario. Other goal and scope should follow a similar approach and are detailed in the online InfoHub [18].

Other specific aspects documented in the guidance document can be used as a basis by tool developers. Fig. 1 presents the steps of the LCA framework. The merging of both inventory analysis and impact assessment stages is due to the fact that most building LCA studies are done using already predefined data in terms of LCI or indicators (e.g. generic data or EPD of building products and processes). This is a simplification needed to keep building LCA tools (in opposite to general LCA software like SimaPro, GaBi, etc.) as user friendly as possible for the practitioners that are not and will not become LCA experts.

The full list of important general aspects to take into account in building LCA are reported in the online InfoHub for each step of the LCA framework. Other requirements are: the use of harmonized reporting templates as an output of the software [21], ability to perform sensitivity analysis and uncertainty analysis e.g. Monte Carlo, include the datasets complying with ILCD requirements, link the LCA assessment to CAD software and energy calculation software to optimize the workflow and to avoid user errors.

2.2 Towards conventional life cycle stages of a building and contributors

Most of the existing building LCA tools do not have the same system boundaries. They also do not present and separate the results in a harmonized way. One of the major outcomes of EeBGuide is to propose harmonization of the life cycle stages. Important aspects were classified per life cycle stage of a building as proposed in EN 15804 and EN 15978 (see Fig. 2): module A (production and construction processes), module B (use stage), module C (end of life) and benefits and loads beyond the system boundaries (notably recycling potentials). Fig. 2 presents the name of the modules and sub-modules according to the EN 15978 standard. The full list of important aspects to take into account in building LCA per life cycle step are reported in the online InfoHub for more information [18].
A building LCA can also be breakdown in different impact sources. Such a distinction with the contributors is essential as it enables the building practitioners to quickly identify the hotspots for both ecodesign and performance-based approaches. Building stakeholders are indeed more familiar with the notion of “contributor” than the life cycle stages as defined in EN 15978. The different contributors that should be included in an improved building LCA tools are: the building products and equipment, defined all along the life cycle of a building (modules A to C + D), the construction and deconstruction activities (modules A4-A5 and C1), the operational water consumption (module B7), and the operational energy use (module B6 in Fig. 2). Other contributors are the transport of the users of the building (within module B as additional information) and the waste produced by the users of the buildings (within module B as additional information).

Building Assessment Information			
Life cycle stage modules			**Name of the sub-module**
Building life cycle information	**PRODUCT stage**	A1	Raw material supply
		A2	Transport
		A3	Manufacturing
	CONSTRUCTION PROCESS stage	A4	Transport
		A5	Construction, installation processes
	USE stage	B1	Use
		B2	Maintenance
		B3	Repair
		B4	Replacement
		B5	Refurbishment
		B6	Operational energy use
		B7	Operational water use
	END OF LIFE stage	C1	De-construction, demolition
		C2	Transport
		C3	Waste processing
		C4	Disposal
Suppl. information beyond the life cycle	**Benefits and loads beyond the system boundary**	D	Reuse-, recovery- and/or, recycling potentials- potential

Fig. 2: Life cycle stages of a building according to EN 15978

3. Proposal for three building LCA study types

In this section, a proposal for three study types are described for three contributors of the environmental impacts of a building: the impact related to building products and equipment, the impact related to the energy consumption and the impact related to the water consumption. Most of the guidance for these study types relates to the situation A of the ILCD i.e. the attributional situation. This is in line with the CEN standards. Fig. 3 presents the adapted calculation rules (scope) and data (LCI and impact) referring to different goal definition. Conducting LCA may be very time consuming and is not very often matching the design team needs [22]. As a result, screening and simplified LCA are proposed here to help during the early design or for quick assessment where no detailed modelling is possible due to a lack of information. In opposite complete LCA provides a broader scope with more requirements in terms of cut-off rules or specific data.

The contributor “energy consumption” enables to assess the impacts related to the use phase (module B6 of the EN 15978). The main interest is to breakdown in different level of details the assessment. The expected performance target was chosen for screening LCA i.e. complying to current regulations when designing a building. If more detailed results are needed, the use of regulatory tool or dynamic simulation software is suggested for simplified and complete LCA. The scope should also be enlarged and data more specified from screening to complete LCA. For example, if the user wants to assess the exported renewable energy produced on site, the energy consumption values from the thermal analysis software need to be presented per hour and per end use e.g. heating, domestic hot water (complete LCA) [23].

A similar approach is proposed for the water consumption contributor. Starting from statistical data for the building type in a country (screening LCA), a top down approach (simplified LCA) and a bottom up (complete LCA) approach are proposed to refine the analysis once more characteristics are available for the water equipment devices.

Finally, the contributor “products and equipment” needs data from cradle-to-grave i.e. for the modules A, B and C of the European standard EN 15978. Based on these system boundaries, adapted data are proposed for screening and simplified LCA using ratio e.g. kWh/m² for the different building elements or generic LCA data describing components, products and materials. Equipment are included even in screening LCA as they are not negligible to the building impact [24] though default values may be used as well as for building products. More precisions on screening and simplified methods are proposed in [25]. A full description of the study types for each contributor is also available in the InfoHub of the EeBGuide project [18].

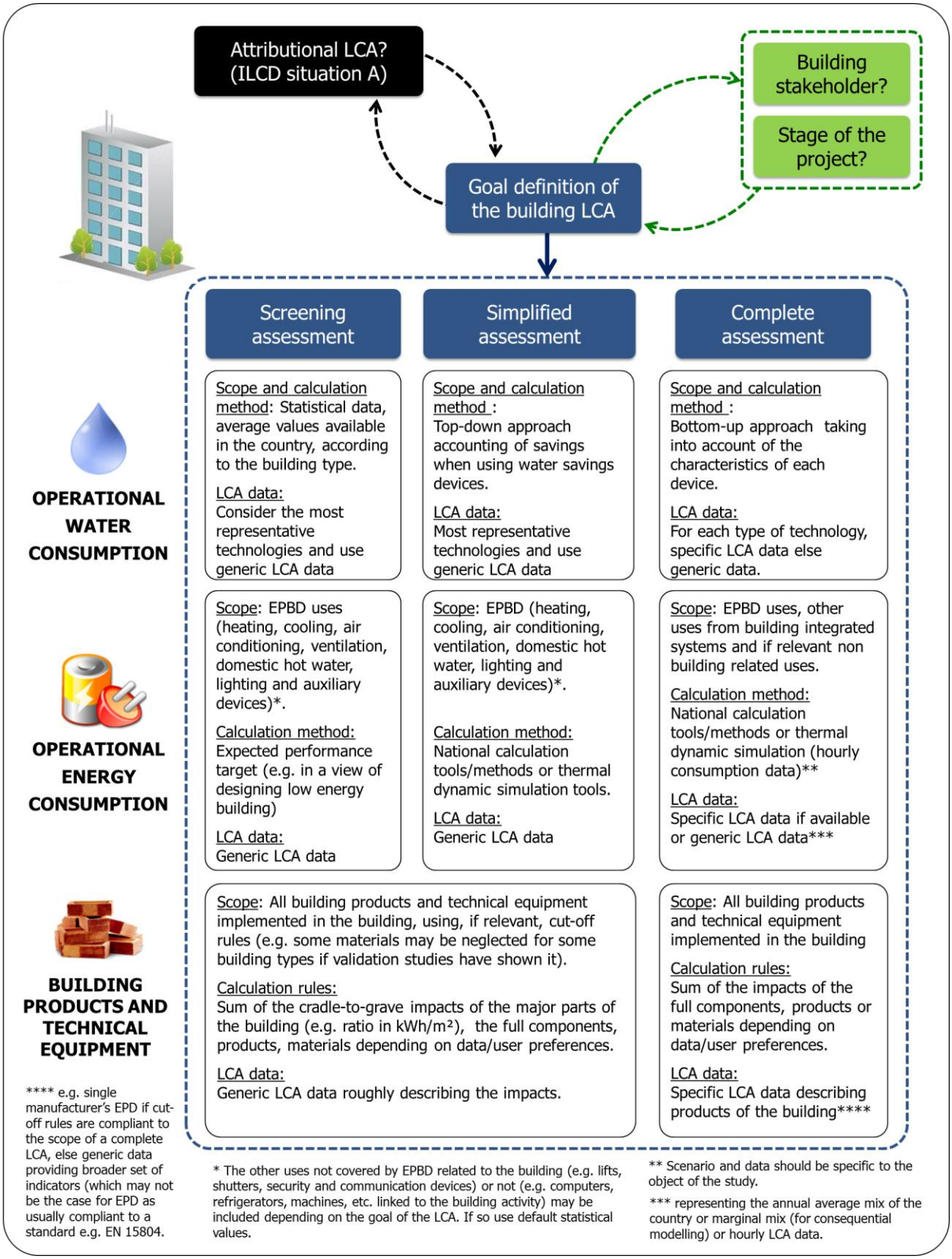


Fig. 3: Study types for the three contributors: operational water consumption, operational energy consumption, building products and technical equipment

4. Example of the use of the study types

4.1 Goal and scope

The aim of this study case is the calculation of the environmental performance of a single family house (stand-alone study, no comparative assertion).

4.2 Approach

The LCA analysis was undertaken in the context of the French pilot project HQE performance [26] concerning the assessment of the environmental performance of about 80 residential and non-residential low-energy buildings. This project allowed establishing first reference values indicator per indicator through a statistical analysis [27].The system boundaries are set from cradle to grave including the three contributors: water, energy and products and equipment. The reference study period is set at 100 years. To be in line with the requirements of HQE Performance project, a detailed assessment was chosen for these contributors. A detailed assessment corresponds to a complete LCA study type - see Fig. *3.* For example, the building products and technical equipment contributor was assessed using all the elements without cut-off rules in the description of the building. Moreover, specific data based on cradle-to-grave group or single manufacturer's EPD available in France [28] were used. 15 mid-point and Life Cycle Inventory (LCI) indicators were assessed based on the ones displayed in the French EPDs. All the case study assumptions are more detailed in [29].
In addition, the three study types (i.e. screening, simplified and complete LCA – see Figure 3) were performed for one contributor, i.e. the water consumption. The screening LCA was based on statistical data, considering a value of 48 m^3 / person / year. The simplified LCA was based on a top down approach, accounting for savings and extra consumptions compared to statistical data. Here, the example of two water saving devices: dual-flush toilet 3L/6L instead of single (traditional) flush toilet 6L and low-flow showerhead. The complete LCA was based on a bottom up approach, taken into account the specific data for all devices and users' behaviour.

4.3 Results and interpretation

Table 2 presents the global results for the three contributors for the complete LCA of the house. The contribution of products and equipment on total results is about 60% for the Global Warming Potential (GWP) indicator and 99% for the Non Hazardous and Inert (NHI) Waste. This is mainly due to the production of inert waste during the end of life of the building. It can also be noticed that the contribution of the operational energy use on total results is above 75% for the radioactive Waste (Rad W). This is explained to the use of the French grid mix having a 78% share of nuclear power plants (lower CO_2 emissions but higher radioactive waste). We finally noticed that the operational water use controlled the net fresh water indicator (about 95%). Further results for each contributor may be retrieved from [29]. The results obtained via the three study types for the water consumption contributor are given in Table 3.

Table 2: Results for the three contributors in complete LCA (reference study period of 100 years)

N°	Contributor *Unit per m²Net floor area*year*	GWP *[kg eq-CO2]*	Water *[L]*	NHI Waste *[kg]*	Rad W *[kg]*
1	Products and equipment	6.73	64.8	17.8	9.79E-04
2	Energy consumption	4.37	83.0	7.16E-02	4.40E-03
3	Water consumption	0.286	2600	3.32E-01	2.87E-04
	TOTAL	11.4	2747.8	18.2	5.67E-03

The results show that the study type does not mislead the assessment interpretation, since the same order of magnitude is found for the different indicators. The highest deviation is found for the net fresh water indicator with 30% of deviation between the complete and the simplified LCA and 7% between the complete and the screening approach. Such results were expected as this indicator is mostly driven by the operational water consumption contributor.

Table 3: Results for the three study types (complete, simplified, screening) for the Operational Water consumption contributor (reference study period of 100 years)

Study type *Unit per m²Net floor area*year*	GWP *[kg eq-CO2]*	Water *[L]*	NHI Waste *[kg]*	Rad W *[kg]*
Complete LCA	0.286	2600	2.85E-03	2.87E-04
Simplified LCA	0.200	1816	1.99E-03	2.01E-04
Screening LCA	0.267	2425	2.65E-03	2.68E-04

The deviation between the results is not linked to the complexity of the study type. With the data taken into account in this study, less deviation is noticed between the complete and screening than between complete and simplified. It can be concluded that each study type should be used according to the stakeholders' needs and data availability.

4.4 Interpretation and limitations

Other study types should be used and tested in another context e.g. in comparative assertions with a high emphasis on comparability purposes. In future works, it will also be useful to assess all the study types for all the contributors of a building.

5. Discussions

5.1 Relevance of study types for the building stakeholders and project stages

Designing a building is a complex process with different stakeholders. One possible option to ensure our proposal (section 2 and 3) is matching the user needs during their operational practice is to conduct surveys and interviews of these stakeholders involved at the different stages of a building project. So that, a tool developer can make sure his decision making tool and the related study types will be useful and used by designers, construction companies, labelling assessors etc. Such surveys are recently reported for the French context e.g. in [30].
In addition, depending on the stakeholders and on the stage of the design, the calculation method and the interface within the tool may be different even if general rules proposed in section 3 are the same. For example, to assess the impact related to products and equipment in screening and simplified LCA, architects, design offices or construction companies may want to use different level of data: more averaged or aggregated for the architect (willing to design elements and buildings as a whole) but more at the level of materials for the construction engineer (willing to quantify accurately kg of reinforcing steel and m3 of concrete). These preliminary works should be continued so that the tools and the proposed study types can be adapted accordingly.

5.2 Consistency, completeness and validation works between the study types

It is important to ensure consistency within the tool. The use of screening or simplified assessment only aims at easing the LCA in early design or for quick building LCA. Consistency should be ensured between the different study types by developing filter functions, default values for screening and simplified, use of a consistent LCA database within the tool providing generic and specific data [31], use of consistent Reference Service Life for products and equipment [32].

Different scope may also be defined within a study type. As the proposal does not want to be restrictive in further use and application, it may be possible to adapt the study type of the tool to the goal of the tool developer and to his user needs. For example, ideally, a complete LCA is based on specific datasets for a comprehensive set of impact categories. But very few data comply with these two requirements today. Indeed, specific data in the form of EPDs are usually limited in scope including a limited set of impact categories. If the tool developer has a special interest in assessing a broad set of impact categories, he may not use EPD according to EN 15804 that do not include e.g. toxicity and ecotoxicity indicators. In that sense, the current proposal is general

and should be refining according to the different use of LCA in the building sector.

Based on the proposal of this paper, validation works should also be conducted especially for screening and simplified assessment that may be subject to deviations with the complete LCA due to data gaps and differences (generic databases vs. EPD databases), limited scope (e.g. reduction of the system boundaries by neglecting life cycle stages or building elements) [33][34]. The proposal presented in section 2 and 3 is thus a first step towards harmonization of building LCA tools in Europe and then will be the basis of next generation of tools. Validation and inter-comparison should include the intra-validation between study types within a tool and then inter-comparison between the available tools. New validation exercises are needed in Europe to benchmarks the new kind of tools.

5.3 Challenges for European building LCA tool developers

The implementation of provisions and guidance briefly presented in sections 2 and 3 is a very challenging topic as we can see from the description of the main characteristics of existing LCA tools (section 1) that none of them include all the recommendations to date. These recommendations aim at increasing the use of the LCA in the building sector by proposing consistent guidelines according to different goal definitions and needs of the practitioners (that are not LCA experts). However, the implementation of the provisions and guidance can only be done in partnership with the European and national LCA networks (e.g. industry, research, tool developers, data providers) involved in LCA applied to the construction sector. For example, every national context does not have its own generic or EPD database today which can be a limit for the proper implementation of the proposed study types (e.g. for screening and complete LCA).
Concerning the study types proposed in this paper, the tool developer should carefully identify whether this proposal (mostly addressing an attributional situation) match his goal and scope. If not, other calculation rules should be defined e.g. for consequential modelling of buildings.

Collaborative work is also needed between the different software developers e.g. between thermal analysis software and building LCA software to make sure the output of one tool fulfils the needs of the other. Automatic link may be used but it depends on the user preferences e.g. a thermal analyst may be keen on having automatic link between thermal simulation software and LCA while a design office or a company willing to conduct an environmental assessment will only use the LCA tool. For some specific contributor of the environmental impacts of a building e.g. the construction site or the deconstruction activities, a closer cooperation with construction companies may be required for collecting statistics and on-site data as input for the building LCA tool.

The proper implementation of CEN/ TC 350 standards also requires feedback from the data providers to be sure the parameters used in the new European EN 15804 / EN 15978 standards are currently not easy to get from background data. For example, EN 15978 standard requests next to the LCIA indicators, “reminder flows” (according to the ILCD terminology) named as “indicators describing resources use” (according to CEN terminology e.g. “Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials” or “Use of renewable secondary fuels”) though current versions of background databases (e.g. Ecoinvent v2 or GaBi v5) do not automatically calculate them today due to current IT structures of LCI databases.

5.4 Relevance of the proposal for non-European building LCA tool developers

As recently stated by the Athena Institute in their webpage, it is likely that some European works e.g. the modularity principle of life cycle stages presented in the European standards EN 15804 and EN 15978 may be also used outside Europe e.g. in North America [36]. Such information let us think that the general framework derived from the EeBGuide InfoHub and the related study types presented in this paper can serve as a possible source of information for tool developers though accounting of regional particularities (e.g. non-EU datasets of the corresponding country).

6. Conclusions and perspectives

If the LCA approach is to be applied in ecodesign, research projects, but also in building labelling schemes and EPD schemes, LCA practitioners need on the one hand provision and guidance, and on the other hand should be supported by reliable and easy-to-use building LCA tools. The proposal presented in this paper aimed at integrating the important aspects identified for building LCA in the European EeBGuide project and the proposed study types (screening simplified and complete). Other outcomes include the structuring of the results according to the life cycle stages of EN 15804 and EN 15978 standards for increasing the comparability of European LCA studies, the breakdown the results and the calculation rules per contributor. Finally it is important to move towards a core and consistent set of data, rules and indicators for the new generation of LCA tools to have more comparable building LCA results. In that perspective, it seems relevant to have core rules at the European level and then more detailed guidance e.g. within each European country.

Acknowledgments

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References

[1] ISO 14040 *Environmental management – Life cycle assessment – Principles and framework*.
[2] ISO 14044 *Environmental management – Life cycle assessment – Requirements and guidelines*.
[3] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. *General guide for life cycle assessment: detailed guidance. First edition.* Luxembourg: Publications Office of the European Union 2010. ISBN: 978-92-79-19092-6.
[4] EN 15804: *Sustainability of construction works – Environmental product declarations – Core rules for the product category of building products.* CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2011.
[5] EN 15978: *Sustainability of construction works – Sustainability assessment of buildings – calculation method.* CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2010.
[6] DGNB, German Green Building Council, retrieved on 10/05/2013 from: www.dgnb.de
[7] HQE Association, retrieved on 10/05/2013 from: www.assohqe.org
[8] France GBC, French Green Building Council, retrieved on 10/05/2013 from: www.francegbc.fr
[9] BRE Group: BREEAM – BRE Environmental Assessment Method. Webseite. Watford: BRE Global Ltd 2011. Online: http://www.breeam.org/page.jsp?id=176, last checked: 7.3.2011.
[10] PEUPORTIER B, HERFRAY G, MALMQVIST T, ZABALZA I, STALLER H, TRITTHART W, WETZEL C, SZALAY Z. *"Life cycle assessment methodologies in the construction sector: the contribution of the European LORE-LCA project"*. SB11 Helsinki, 10 p.
[11] GANTNER J, LASVAUX S, LENTZ K, BÖTTGE J. *"Challenges of LCA in a European context – Findings from the research projects OPEN HOUSE and EeBGuide"*. Submitted to SB13 Graz, 25-28 September 2013.
[12] PRESCO: Practical Recommendations for Sustainable Construction, European project (FP7), 2011, deliverables available online: www.etn-presco.net/
[13] ENSLIC-Building: *Energy Saving through Promotion of Life Cycle Assessment in Buildings, European project (FP7),* 2011, deliverables available online: http://circe.cps.unizar.es/enslic/texto/wor.htm
[14] LoRe-LCA: *Low Resource consumption buildings and constructions by use of LCA in design and decision-making,* European project (FP7), 2011, deliverables available online: http://www.sintef.no/Projectweb/LoRe-LCA/Training/
[15] ATHENA Institute. *"Impact Estimator for Buildings"*, retrieved on 22/04/2013 from: http://calculatelca.com/software/impact-estimator/
[16] NIST. *"BEES (Building for Environmental and Economic Sustainability) Software"*. retrieved

on 22/04/2013 from: www.nist.gov/el/economics/BEESSoftware.cfm/
[17] LASVAUX S, GANTNER J, SAUNDERS T. *"Requirements for building LCA tool developers, Deliverable 4.3".* European Project EeBGuide, 2012, 46 p. available online: www.eebguide.eu/eebblog/wp-content/uploads/2012/12/D-4.3.-Requirements-for-Building-LCA-tool-designer.pdf
[18] EeBGuide Project *"Operational Guidance for Life Cycle Assessment Studies of Energy Efficient Buildings Initiative"* InfoHub available online: www.eebguide.eu
[19] EeBGuide project. *"Aspect G-11 – Definition of system boundaries for existing buildings".* European Project EeBGuide, 2012, available online: www.eebguide.eu/?page_id=1725
[20] EeBGuide project. *"Report Templates for Buildings".* European Project EeBGuide, 2012, available online: www.eebguide.eu/?page_id=659
[21] EeBGuide project. *"Aspect G-02 – Classifying the decision context as situation A, B, and C for building and product LCA".* European Project EeBGuide, 2012, available online: www.eebguide.eu/?page_id=1774
[22] MILLET D, BISTAGNINO L, LANZAVECCHIA C, CAMOU R, POLDMA T. *"Does the potential of the use of LCA match the design team needs"*. Journal of Cleaner Production 15 (2007) 335–346
[23] PASSER A, KREINER H, MAYDL P. *"Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings"*. The International Journal of Life Cycle Assessment, 2012, Volume 17/9, pp. 1116-1130.
[24] EeBGuide Part B BUILDINGS. *"Aspect B-23 – Operational energy calculation – Allocation of energy production for on-site systems connected to the grid".* Taken from the EeBGuide InfoHub available online: www.eebguide.eu/?p=2167
[25] SIBIUDE G, LASVAUX S, LEBERT A, BAZZANA M, RAVEL P, BONNET R. *"A modular LCA database adapted to different user needs during the building design process".* Submitted to SB13 Graz, 25-28 September 2013.
[26] ASSOCIATION HQE. "HQE Performance: Première tendance pour les bâtiments neufs / First Trends for new buildings". Report from the HQE Performance Test 2011. Available online: www.assohqe.org/hqe/IMG/pdf/HQE_Perf_-_BD_PPP.pdf
[27] LEBERT A, LASVAUX S, CHEVALIER J, HANS J. *"Environmental Performances of Buildings: identification of reference values through a statistical analysis"*. Proceedings of the International Symposium on Life Cycle Assessment and Construction – Civil Engineering and Buildings, 10–12 July 2012, Nantes, France, 9p.
[28] INIES, The French EPD database for building products, retrieved on 10/05/2013 from: www.inies.fr
[29] BOSDEVIGIE B, LEBERT A. *"EeBGuide Background Report for Buildings: building LCA of an individual house".* European Project EeBGuide, 2012, 63 p. available online: www.eebguide.eu/eebblog/wp-content/uploads/2012/07/LCA-report-new-buildings-simple-case-study.pdf
[30] LEROY Y, CLUZEL F, ZARAKET T, LASVAUX S, BENTOS M. *"An approach to integrate LCA-based models into the early design stages of an eco-design process for buildings".* Accepted for LCM2013, 25-28 August 2013, Gothenburg.
[31] LASVAUX S, SCHIOPU N, PEUPORTIER B, CHEVALIER J. *"Relevance of a French simplified Life Cycle Inventory database using building products industry data".* Proceedings of the International Symposium on Life Cycle Assessment and Construction – Civil Engineering and Buildings, 10–12 July 2012, Nantes, France, 9p.
[32] European Union: Legislation, 'Guidance Paper F – Durability and the Building products Directive', Revision December 2004
[33] KELLENBERGER D, ALTHAUS HJ. *"Relevance of simplifications in LCA of building components"*. Building and Environment 44 (2009) 818–825.
[34] BRIBIAN IZ, USON AA, SCARPELLINI S. *"Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification".* Building and Environment 44 (2009) 2510–2520.
[35] ATHENA Institute. Impact Estimator for Buildings version 4.2, press release available online: www.athenasmi.org/impact-estimator-for-buildings-version-4-2-build-02-press-release/

The use of Generic LCIA Databases in the Process of Building Sustainability Assessment – the case of SBTool$^{PT®}$



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Short Summary

The main constrain for the widespread use of LCA in the building sector is the lack of environmental data for most building materials, products and technologies. Based in the work of CEN TC 350 and in the work of iiSBE Portugal in the development of the Portuguese rating system SBTool$^{PT®}$, this paper aims at presenting and discussing the development of a method to simplify LCA for effective use during the design phase and in the processes of building sustainability assessment.

Keywords: Database, LCIA, LCA, Environmental performance, Sustainability

1. Introduction

It is widely recognised in the field of Building Sustainability Assessment (BSA) that LCA is a much more preferable method for evaluating the environmental pressure caused by materials, building assemblies and the whole life-cycle of a building. Life Cycle Assessment (LCA) is an effective and systematic tool to measuring the potential environmental burdens associated with a product, process, or activity by identifying, quantifying and assessing the impact of the used energy, and materials, and the wastes released to the environment [1]. The complete process of LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation. The process is naturally iterative as the quality and completeness of information and its plausibility is constantly being tested. LCA considers the potential environmental impacts throughout a product's life cycle (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. Although the LCA method was at first oriented to materials and products, its application in construction is generally accepted [1]. LCA is very important to compare several possible alternative solutions, which can bring about the same required performance but that differ in terms of environmental consequences. Life cycle impact assessment (LCIA) is the step of LCA in which the inventory (input and output flows of a certain system under analysis) is analysed for environmental impact. For instance, in the LCIA phase the volume of fossil fuel consumed during the transportation phase of a building material is converted in several impact categories, including global warming potential.

Although there are several recognized LCA tools, these tools are not extensively used in building design and most of building sustainability assessment and rating systems are not comprehensive or consistently LCA-based. Reasons for this failure are above all related to the complexity of the stages of a LCA. Besides of being complex, this approach is very time consuming and therefore normally used by experts at academic level. For these reasons most of the building sustainability

assessment methods are relied on singular material proprieties or attributes, such as recycled content, recycling potential or distances travelled after the point of manufacture [1].

The adoption of environmental LCA in buildings and other construction works is a complex and tedious task as a construction incorporates hundreds and thousands of individual products and in a construction project there might be tens of companies involved. Further, the expected life cycle of a building is exceptionally long, tens or hundreds of years. For that reason LCA tools that are currently available are not widely used by most stakeholders, including those designing, constructing, purchasing or occupying buildings. Due to its complexity most of them are used and developed only by experts, most times only at academic level.

In order to overcome this situation, most popular rating systems simplified LCIA for practical use. The simplified LCIA methods currently integrated in rating systems are not comprehensive or consistently LCA-based but they are playing an important role in turning the buildings more sustainable. Nevertheless, the LCA approach is not the same in the different sustainability assessment methods and therefore the results of the environmental performance assessment are not the same nor comparable. It is necessary to integrate more accurate environmental assessment methods in order to verify if the required performance has really been achieved, to accurate compare solutions and to compare the results from different rating systems [2].

In order to standardize, facilitate the interpretation of results and comparison between different building sustainability assessment methods developed within the European Countries, European Centre of Normalization (CEN) started on the Technical Committee 350 (CEN/TC 350 – Sustainability of construction works). The document EN 15643-2:2011 (Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance) is a part of the a suite of European standards, technical specifications and reports written by CEN TC 350 that will assist in evaluating the contribution of buildings to sustainable development through the assessment of the environmental performance of the building. In these standards the assessment methodology is based on a life cycle approach for the quantitative evaluation of the environmental performance of the building. For now these standards are specific for buildings but, with the necessary adaptation, their approach could be adopted to any type of constructions.

The two most important barriers for the quantification of the environmental indicators and therefore to the incorporation of LCIA in rating systems are [2]: a lack of LCI data for all building products and the inherent subjectivity of LCA. Environmental Product Declarations (EPDs) are a good source of quantified information of LCI environmental impact data. In order to potentiate their use, rating systems should be based in the same LCIA impact categories, as stated in the CEN standard. An environmental product declaration (EPD) is a communication tool that provides quantified information of the potential environmental impacts of a product or process, through a life cycle assessment. The information can regard aspects such as raw material acquisition, energy use and efficiency, content of materials and chemical substances, emissions to air, soil and water and waste generation. EPDs do not provide an evaluation of the environmental performance but are a comprehensive and transparent set of environmental information covering a predefined set of life cycle stages. An important advantage of using EPDs is the possibility to add LCIA-based information in the supply chain. This feature makes EPDs particularly valuable for the building sector where the final building is based on a large number of materials, construction products, semi-manufactured products and processes. According to ISO 14025, Environmental Product Declarations act as a basis of information for life cycle assessment. Therefore this is a fundamental source of information for building sustainability assessment and certification. Nevertheless, at the moment, there are important limitations on this approach, since there is only a small number of companies either having or making publicly the EPD of their products.

This paper proposes a solution to overcome the abovementioned problems that is based in the development and use of databases with the LCIA data of the most used building materials and

components. Therefore, based in the work of CEN TC 350 and in the work of iiSBE Portugal (in the development of the Portuguese rating system SBTool$^{PT®}$), this paper will present and discuss the development of an LCIA database with the environmental data for conventional and non-conventional Portuguese building solutions (macro-components). A macro-component is, according to our definition, a component of a building for which a technical specification can be given in relation to a set of essential structural characteristics and that is actually a combination of various materials. This database is continuously updated and covers common building technologies for each building macro-component (floors, external walls, partition walls, roofs, windows and doors), the most used building materials and the impacts of the transportation processes, according to the used type of transportation.

2. Structure of the LCIA database

2.1 Environmental impact categories

The number and type of environmental impact category indicators are different in the several sustainable assessment methods. There is a wide range of impact category indicators, normally categorized according to the endpoints or the midpoints. Endpoints are also known as damage categories and express the effect of the product in the Human Health, Ecosystems Quality, Climate Change and Resources. LCIA methods that use this type of impact categories are damage oriented and they try to model the cause-effect chain up to the endpoint, or damage, sometimes with high uncertainty. The midpoints, also referred as indicators, express the environmental effects between the emissions and resource extraction parameters, from life-cycle inventory (LCI), and the damage categories. These impact categories are used in the classic impact assessment methods to quantify the results in the early stage of the cause-effect chain to limit the uncertainties. Midpoints group LCI results in the so-called midpoint categories ac-cording to themes as “destruction of the stratospheric ozone layer”, “acidification of land and water resources” or “global warming”.

LCIA can be incorporated into rating systems for buildings to quantify environmental burdens associated with the manufacture of building products. Such burdens include the consumption of primary resources and the output of gaseous, liquid, and solid wastes. Most of the rating systems use midpoint impact categories but do not assess the Building and Construction’s environmental performance in a LCA consistent way, because they do not include LCIA-based indicators [2]. Three examples of rating tools that integrates LCIA-based Environmental Performance Criteria are: SBTool, Green Globes and Code for Sustainable Homes. Nevertheless, they use a simplified LCIA approach to promote its practical use [2].

The differences between the environmental impact assessment approach in the several rating methods – because some of them are not LCIA-based, not based in a reliable LCA method (be-cause do not integrate the most common impact categories) or do not share the same impact cat-egories – turns difficult the comparison of results from different rating systems.

The goal of the work undertaken by CEN/TC 350 standardization mandate is to overcome this problem at the European level, through the development of an approach to voluntary providing environmental information for supporting the sustainable works on construction. This technical committee set the environmental indicators that should be used in the European building sustaina-bility assessment methods. The aim of the list of the impact categories is to represent a quantified image of the environmental impacts and aspects caused by the object of assessment during its whole life cycle. The assessment approach of the CEN standards is applicable to new and existing buildings. It provides a calculation method that covers all stages of the building life cycle (assembly, operation and disassembly phases) and the list of environmental indicators is developed in such way that potentiates the use of the LCI data issued from Environmental Product Declarations (EPDs).

According to EN 15804:2012 [3], the environmental parameters to be declared in a EPD are organized in three types: i) parameters describing environmental impacts; ii) parameters describing resource use; iii) Other environmental information describing different waste categories and output flows. Table 1 presents the environmental parameters to be declared according to this standard. The Portuguese building sustainability assessment method (SBTool$^{PT®}$) it is already updated according to the requirements of this standard. Therefore the developed LCIA database covers the six parameters that describe environmental impacts: i) Global warming potential (GWP); ii) Depletion potential of the stratospheric ozone layer (ODP); iii) Acidification potential of soil and water sources (AP); iv) Eutrophication potential (EP); v) Formation potential of tropospheric ozone (POCP); vi) Abiotic depletion potential (ADP).

Table 1: Environmental parameters according to EN 15804:2012 [3]

Parameters describing environmental impacts
– Global warming potential (GWP)
– Depletion potential of the stratospheric ozone layer (ODP)
– Acidification potential of soil and water sources (AP)
– Eutrophication potential (EP)
– Formation potential of tropospheric ozone (POCP)
– Abiotic depletion potential (ADPelements) for non fossil resources
– Abiotic depletion potential (ADP-fossil fuels) for fossil resources
Parameters describing resource input
– Use of renewable primary energy excluding renewable primary energy resources used as raw materials
– Use of renewable primary energy resources used as raw materials
– Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)
– Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials
– Use of non renewable primary energy resources used as raw materials
– Total use of non renewable primary energy resources (primary energy and primary energy resources used as raw materials)
Parameters describing resource use, secondary materials and fuels, and use of water
– Use of secondary material
– Use of renewable secondary fuels
– Use of non renewable secondary fuels
– Use of net fresh water
Other environmental information describing waste categories
– Hazardous waste disposed
– Non hazardous waste disposed
– Radioactive waste disposed
– Use of net fresh water
Other environmental information describing output flows
– Components for re-use
– Materials for recycling
– Materials for energy recovery
– Exported energy

2.2 Boundaries of the LCA analysis

As presented in Figure 1, a typical life cycle of a building can be separated into three distinct phases, each consisting of one or several life cycle stages. The assembly phase refers to the collection

of raw materials through resource extraction or recycling, the manufacture of these raw materials into products, the assembly of products into a building, the replacement of building products and assemblies, and intermediate transportation. The operation phase refers to heating and electricity requirements, water services and other services excluding material replacement. The disassembly phase refers to the decommissioning and demolition of the building, the disposal/recycling/reuse of building products and assemblies, and intermediate transportation steps. Each life cycle stage can consist of many unit processes.

The LCIA database for building technologies covers the “cradle-to-gate” impacts, i.e. the environmental impacts from the raw material extraction to the manufacturing of building products and assemblies and the disassembly phase. Additionally, the database covers the environmental impacts derived from the transport of the demolition waste to the treatment units and with its treatment. The considered processes are highlighted in Figure 2.

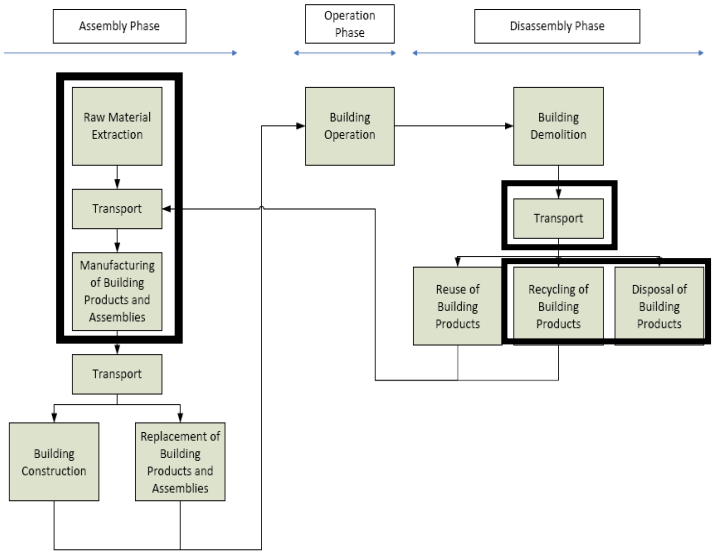


Fig. 1: Life cycle of a building [4]

2.3 Life-cycle inventory and waste scenario

The inventory analysis entails the quantification of the flows for and from a product system. In traditional life cycle environmental analysis, the inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. Taking into consideration the aims of this approach, the production and final destination of waste should also be included in the inventory. Therefore the database presents the quantified potential environmental impact categories for the embodied flows (cradle-to-gate) and the flows of the end-of-life scenarios, based in data from the companies that manufacture the materials and components.

Table 2 presents the considered end-of-life scenario, which is based in the Portuguese average context. In this context, the building materials that are normally recovered after demolition are the steel-based ones. The LCIA database also covers the potential environmental impacts of the transportation processes, according to the used type of transportation.

Whenever was not possible to found specific inventory data related to a process, average European databases (generic data) was used (e.g. EcoInvent [5]). Nevertheless the database is prepared to be updated whenever specific LCI data for a product is communicated from a manufacture.

Table 2: Considered waste scenarios

Material/waste	Waste scenario	Percentage
Reinforcing steel	Recycling	80%
Steel in profile	Recycling	95%
Other	Construction waste (inert) to landfill	100%

2.4 Life-cycle Environmental Impact Assessment (LCIA)

According to EN ISO 14044, Life Cycle Environmental Impact Assessment (LCIA) is a phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. Impact assessment should address ecological and human health effects together with resource depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts. Therefore, this tasks aims to convert the LCI data collected into potential environmental impacts using one or more normalized LCIA methods. As above mentioned, this database covers six environmental impact categories. The environmental impact categories and the used LCIA methods for their quantification are presented in Table 3.

Table 3: Environmental impact categories declared in LCIA database for building technologies and the used LCIA methods

Environmental impact categories	Unit/declared unit	LCIA methods
Depletion of abiotic resources	[kg Sb eq.]	CML 2 baseline 2000 [6]
Global warming potential (GWP)	[kg CO2 eq.]	CML 2 baseline 2000 [6]
Destruction of atmospheric ozone(ODP)	[kgCFC-11 eq.]	CML 2 baseline 2000 [6]
Acidification potential (AP)	[kg SO2 eq.]	CML 2 baseline 2000 [6]
Eutrophication potential (NP)	[kg PO4 eq.]	CML 2 baseline 2000 [6]
Photochemical Ozone Creation (POCP)	[kg C2H4 eq.]	CML 2 baseline 2000 [6]
Non-renewable primary energy	[MJ eq.]	Cum. Energy Demand [7]
Renewable primary energy	[MJ eq.]	Cum. Energy Demand [7]

In order to facilitated the quantification process, a life-cycle analysis software (SimaPro [8]) was been used to modulate the macro-components' life-cycles and to assess the mentioned life-cycle impact categories.

2.5 Communication format

Figure 2 presents how the information is organized in the LCIA database for a building macro-component and the list of environmental indicators and LCIA methods used. In the database of the building components the quantification is presented per each component's unit of area (m^2) and in the materials database, figures present the environmental impacts per each unit of mass (kg). Quantification is presented for two life-cycle stages: "cradle to gate" and "demolition/disposal". Using this database it is possible to estimate the overall impact of a building using a bottom-up up approach. The quantification begins at the level of the embodied environmental impacts in building materials and ends at the whole building scale. To evaluate the transportation impacts, the designer must know (for each building material or product) the distance from the factory to the construction site and the distance from the construction site to the recycling/management centre. By multiplying the distance (km) by the weight (ton) and by the unitary impacts associated to the used type of transportation it is possible to estimate the transportation impacts of the building technology. Adding the transportation impacts to the figures presented in Figure 2 it is possible to estimate the overall life-cycle impacts of a building technology. Table 5 illustrates the calculation principle of the total environmental of the building life cycle using the SBTool$^{PT®}$ LCIA database.

At this stage, the developed database covers more than 100 building's macro-components (16 floors, 28 external walls, 22 partition walls, 23 roofs and 18 types of windows), 47 construction materials and the potential environmental impacts associated to the use of 12 acclimatization and hot water production equipments [9].

Building technology	**Collaborating slab (with steel structure and lost steel formwork) for floors**							**Ref: Floor 10**
	Life-cycle stages	**Environmental impact categories**						**Embodied energy**	
		ADP[1]	GWP[2]	ODP[3]	AP[4]	POCP[5]	EP[6]	ENR[7]	ER[8]
	Cradle-to-gate	3,84E-01	5,79E+01	2,10E-06	1,69E-01	2,32E-02	3,31E-02	7,08E+02	1,55E+01
	End-of-life	1,02E-01	1,48E+01	2,39E-06	7,00E-02	2,70E-03	1,46E-02	2,35E+02	1,37E+00
	Total	4,86E-01	7,27E+01	4,49E-06	2,39E-01	2,59E-02	4,77E-02	9,42E+02	1,69E+01
	Comments:	**Considered materials:** Concrete and steel (including steel panels, profiles and reinforcing steel bars) **LCIA methods:** CML 2 baseline 2000 version 2.04 (to assess the environmental impact categories) and Cumulative Energy Demand version 1.04 (to assess the embodied energy) **LCI libraries:** Ecoinvent system process and ETH-ESU 96 system process							

Notes:
[1]Abiotic depletion potential in kg Sb equivalents;
[2]Global warming potential in kg CO_2 equivalents;
[3]Ozone depletion potential in kg CFC-11 equivalents;
[4]Acidification potential in kg SO_2 equivalents;
[5]Photochemical ozone creation potential kg C_2H_4 equivalents;
[6]Eutrophication potential in kg PO_4 equivalents;
[7]Non-renewable embodied energy in MJ equivalents;
[8]Renewable embodied energy in MJ equivalents.

Fig. 2: Part of the SBTool$^{PT®}$ LCIA database

Table 5: Method quantification of the whole building's life cycle environmental impacts

Building Component (C_i)	Area (m^2)		LCIA indicators							
C_1	A_1	x	ADP_1/m^2	GWP_1/m^2	ODP_1/m^2	AP_1/m^2	$POCP_1/m^2$	EP_1/m^2	ENR_1/m^2	ER_1/m^2
			+	+	+	+	+	+	+	+
(…)	(…)	x	(…)	(…)	(…)	(…)	(…)	(…)	(…)	(…)
			+	+	+	+	+	+	+	+
C_n	A_n	x	ADP_n/m^2	GWP_n/m^2	ODP_n/m^2	AP_n/m^2	$POCP_n/m^2$	EP_n/m^2	ENR_n/m^2	ER_n/m^2
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts			ADP'_e	GWP'_e	ODP'_e	AP'_e	$POCP'_e$	EP'_e	ENR'_e	ER'_e
			÷	÷	÷	÷	÷	÷	÷	÷
			Time boundary of the LCIA assessment							
			÷	÷	÷	÷	÷	÷	÷	÷
			Net floor area of the building							
			=	=	=	=	=	=	=	=
Whole building embodied environmental impacts /m^2.year			ADP_e	GWP_e	ODP_e	AP_e	$POCP_e$	EP_e	ENR_e	ER_e
			+	+	+	+	+	+	+	+
Environmental impacts of the maintenance scenario /m^2.year			ADP_m	GWP_m	ODP_m	AP_m	$POCP_m$	EP_m	ENR_m	ER_m
			+	+	+	+	+	+	+	+
Environmental impacts of the operational energy use for heating and cooling /m^2.year			ADP_o	GWP_o	ODP_o	AP_o	$POCP_o$	EP_o	ENR_o	ER_o
			=	=	=	=	=	=	=	=
Total life cycle impacts of the whole building /m^2.year			**ADP**	**GWP**	**ODP**	**AP**	**POCP**	**EP**	**ENR**	**ER**

3. Conclusions

Although LCA is considered the best method available to assess the environmental performance of a product, its application in construction is very complex. This is because the huge number of different materials, actors, processes and also the wide life cycle span of a construction product.

Based in the work of CEN TC 350 and in the development of the Portuguese sustainability rating system (SBTool$^{PT®}$), this paper presented some solutions to overcome the difficulties in the integration of more accurate LCA-based approaches is the assessment of the environ-mental performance in rating systems. The development by experts of databases with the LCIA data of the most used building technologies and materials is a good solution to integrate more accurate and LCIA-based approaches, without turning the rating systems too complex for practical use.

Compared to other existing databases, the one presented in this paper has two main differences that could promote the practical implementation of the LCIA approach during the design of a new construction or refurbishing operation. Consequently, it will promote the practical implementation of the sustainable construction concept.

The first difference is that this database covers a larger number of environmental parameters (those that are included in the EN 15804:2012). Therefore it could be directly used to support the environmental performance assessment of a building according to recent standardization work (EN 15643-2:2011).

The other advantage is that this database presents the environmental data for construction macro-elements normally used in the construction of buildings (e. g. slabs, walls, panels, etc.) and not for single materials and products (i.e. bricks or cement) as in other databases. The purpose of defining a set of macro-component typical for the construction and renovation of buildings is to establish a data bank that has information about the essential environmental characteristics, in order to support design teams in the processes of designing and rating sustainable buildings.

This database will decrease the time and cost for conducting an environmental life-cycle analysis of a building. Additionally, this advantage could indirectly promote the design and construction of more sustainable buildings.

4. References

[1] Passer, A., Kreiner, H., Maydl, P. 2012. Assessment of the environmental performance of buildings: A critical evaluation of the influence of technical building equipment on residential buildings. International Journal of Life Cycle Assessment. DOI 10.1007/s11367-012-0435-6.

[2] Mateus, R., Bragança, L. (2011). Sustainability Assessment and Rating of Buildings: Developing the methodology SBTool^{PT}. Building and Environment 46, p. 1962-1971

[3] CEN. EN 15804:2012, Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. CEN: Brussels.

[4] Anderson, J.; Howard, N. The Green Guide to Housing Specification: an environmental profiling system for building materials and components. Building Research Establishment Press (BRE Press): Watford. United Kingdom, 2006.

[5] Hischier, R., Weidema, B., Althaus, H.-J., Bauer, C., Doka, G., Dones, R., Frischknecht, R., Hellweg, S., Humbert, S., Jungbluth, N., Köllner, T., Loerincik, Y., Margni, M., and Nemecek, T. 2010. Implementation of Life Cycle Impact Assessment Methods. Final report ecoinvent v2.2 No. 3. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

[6] CML. CML 2 baseline 2000. Characterization factors of the Institute of Environmental Sciences (CML) – V2.04. Leiden University: Leiden, Netherlands.

[7] Frischknecht, R., Jungbluth ,N., et al. 2003. Implementation of Life-cycle Impact Assessment Methods, final report ecoinvent 2000, Swiss Centre for Life Cycle Inventories, Dübendorf, CH.

[8] Pré-consultants (2010). SimaPro 7. LCA software version 7.3.3. Product Ecology Consultants: Amersfoort, The Netherlands.

[9] Bragança, L., Mateus, R. 2012. Life-cycle assessment of buildings: Environmental impact of Building elements. iiSBE Portugal: Guimarães, Portugal [https://repositorium.sdum.uminho.pt/handle/1822/20481].

ADAPTING EXISTING LIFE CYCLE INVENTORY OF BUILDING PRODUCTS FOR THE BRAZILIAN CONTEXT

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Summary

The construction sector is responsible of several environmental impacts among which energy and water consumption, climate change and waste generation. For instance, the primary energy consumption for regulatory uses (heating, air-conditioning, ventilation and hot water) on a 50-year period for a French building is about the same as the embodied energy for its manufacturing and construction processes. In this context, new assessment tools are required to assess the global environmental performances. Thus, there is a growing need to assess the environmental performance of buildings by means of Life Cycle Assessment (LCA). Databases are also needed to make available Life Cycle Inventory data of building materials and processes for each national context. However, in Brazil, few data have been provided so far by the building industry e.g. by means of Environmental Product Declaration (EPD). Two solutions can be distinguished: development a new national LCI database or adaptation of existing LCI databases. If the first option is the most relevant, it requires time and resources, while the second solution is scientifically acceptable and practicable.

The aim of this paper is to present an approach to adapt existing LCI data of building products for the Brazilian context in order to propose a set of consistent and representative LCI datasets. The approach is based on literature researches, analyses of Brazilian and generic LCI data and on the adaptation of European LCI data for the Brazilian context for some key parameters e.g. the energy mixes, the types and distances of transportation. The feasibility of the methodology is then supported by case studies comparing the environmental indicators of concrete, considering the use of Brazilian, original and adapted LCI data.

The approach can be easily applied to other building products. The comparisons show the weaknesses of some Brazilian data e.g. in terms of completeness of the system boundaries. The results for primary energy and global warming potential indicators show that the adapted LCI data

is found to have less impact than the indicators calculated with the original LCI (differences between 5 and 10%). This is mainly explained by the efficiency of the Brazilian energy mix despite the large consumption of the non-renewable energy due to the type and distance of transportation. The adapted LCI must now be improved e.g. by working closely with Brazilian producers to get more accurate data on the foreground processes.

Key-words: performance, environmental requirements, Life Cycle Inventory – LCI, Life Cycle Impacts Assessment – LCIA.

1. Introduction

The construction sector is responsible of several environmental impacts and Life Cycle Assessment (LCA) databases are needed to assess the environmental performances of any construction product or process. The environmental impacts are closely related to the type of product, the suppliers and to the national characteristics of waste and energy processes.

Many countries, such as UK, France, Japan and Australia, have developed sectorial LCA databases to assess the environmental impacts of buildings over their life cycle. These databases are then used for building sustainability assessment using LCA-based indicators (global warming potential, energy use, waste generation, and other related impacts). However, sectorial databases often present cumulative LCI (Life Cycle Inventory) or selected indicators that cannot be adapted to other countries. These data often related to EPD describe the impacts of producers that sold their product in the given country. As a result, it is generally not recommended to directly reuse data for other contexts (e.g. South America).

In opposite, LCA data can also be made available by major background data providers. For example, the Swiss Ecoinvent database provides more than 4500 unit processes describing the impacts of materials products and processes mainly for the Swiss and European context. In this case, the data are breakdown into processes with raw data and LCI that can be adapted for a new context by means of LCA software (e.g. GaBi, SimaPro).

As the development of new LCI databases can be time and cost consuming, adapting existing background LCI databases to other national context can be seen as a consistent and more adapted way than having no data at all or non-adapted data.

The main benefits for the country (e.g. Brazil) is to take into account the completeness of these background databases (e.g. for the energy and transportation processes) but also to be able to change the foreground date based on the national practices (e.g. share of energy carriers or distance and truck load for the transportation of building materials).

Looking more specifically at the Brazilian context in South America (scope of this paper), few LCA data exist on the impacts of building materials (GOLDEMBERG; AGOPYAN, JOHN, 2011). When data are available, there are calculated using different rules and no central database has been developed to date.

Therefore the aim of this paper is to present an approach to adapt existing LCI data of building products for the Brazilian context in order to propose a set of consistent and representative LCI datasets which can be used to conduct an environmental assessment of buildings. This assessment will be, not to a specific product, but represent the building industry because it will be done based one generic database.

2. Research method and analysis

The approach is based on literature researches, analyses of Brazilian and generic LCI data, and on the adaptation of LCI data for the Brazilian context.

The Brazilian data of building materials used on this paper were taken from previous studies (Lima, 2010; Souza, 2012; Saade et. al., 2010; Campos, 2011 and Punhagui et. al.,2012). Some studies has also been conducted by producer associations such as the IABr (2010) that conduct a study related to the LCA of steel.

The existing Brazilian data is used only in order to compare them to adapted LCI data from the Ecoinvent database v2. The adaptation of LCI data for the Brazilian context considered aspects relating to energy mix, types and distances of transportation. Ecoinvent version 2.2 was the generic database selected, and the LCI adaptation was done using the software SIMAPRO Version 7.3.

The feasibility of the methodology is then supported by case studies comparing the environmental indicators of concrete, considering the use of Brazilian, original and adapted LCI data.

3. Approach to adapt existing life cycle inventory of building products for the Brazilian context

Ideally, country-specific data for the life cycle inventory analysis should be collected in the respective country and no 'transferability' approach would be necessary. Nevertheless, while this data collection process is in progress or still to be started, a systematic approach need to be defined in order to enable the performance of LCA studies in any country with reliable results (Colodel, 2008).

Colodel (2008) proposed an approach organized in four main steps:

- assumptions and conditions;
- overview the country indicators at branch level: 'top down' approach;
- overview of the influencing parameters at a process level: 'bottom-up' approach;
- transfer factor calculation/ 'adjusted' inventory.

Then, this paper show an approach organized from these four steps that detail the aspects that must be considered to Brazilian context. Table 1 presents the approach detailed. This approach has ten steps, organized in four groups: scope and database definitions (step 1 and 2); data collecting considering overview of the country technologies and manufacture process (step 3 and 4), calculated method (definition of LCA method and also uncertainties method e.g. steps 5, 6 and 7), and the results analyze (steps 8, 9 and 10).

The approach takes into account five impacts indicators: Consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation. Somme researchers suppose the consumption of primary energy, related to non-renewable resources, must adopted as an environment impact indicators, because most of the others impacts indicators have strict relation to the consumption of non-renewable energy (LASVAUX, 2010). In addition, the Brazilian building sector have already some macro indicators related to these indicators, so it was choose in this approach for permitting some analyses and comparisons.

Table 1- Steps to adapt existing LCI data for the Brazilian context (adaptation of Colodel, 2008; HODKOVA and LASVAUX, 2012)

1- Goal and scope definition
Set the building product functional unit and building process phase to analyze (cradle to gate or cradle to grave)
2- Selection of a Generic LCI data (the proposal is to adopt Ecoinvent database)
In the Ecoinvent there are specific documents that demonstrate the context and the parameters in which the building products were inventoried. These documents present the main technologies adopted, type and distances of transportation, standard deviations, etc. (KELLENBERGER , 2007 and Frischknecht, 2007). In addition, the inputs of Ecoinvent database can be modified using for example the software SIMAPRO. In this approach the SIMAPRO will be used in order to modify the Ecoinvent LCI to Brazilian context.
3- Identify the Brazilian context and indicators – Overview the differences related to energy mix, technologies/process, market size, etc – *Top down approach*
3.1- Identify the indicators considering the Brazilian context and building product – mostly energy mix and technologies/process; 3.2 – Identify if the Brazilian context serve for all country or it is restricted to certain parts; 3.3 - Verify the differences between the inputs considered in the Ecoinvent data base and the Brazilian context. KELLENBERGER (2007) detail the Ecoinvent information; 3.4- Compare the technologies and the process between Brazilian context and the onefrom Ecoinvent. Only process with similar technology can be compared. This means that the flows of each unit process must be the same for both countries, exception to type of transportation; 3.5- Make certain considerations and set transfer factors related to the analyze of countries inputs – making attention to functional unit to set the transfer factor.
4- Adapt the generic data base inputs related to the process - Overview the inputs of the inventories concerning the process - amount of raw materials, transport distance, etc – *Bottom up*
4.1- Compare the amount of raw materials from Ecoinvent and from Brazilian context; 4.1.1- Verify the amount of raw materials with the most important impacts and not consider that materials have less than 2% of influence; 4.1.2- In the SIMAPRO, modify the inputs/ flux until the forth level, or at least second level; 4.1.3 - Set correct transfer factor taking care to the functional unit; 4.2- Compare type and distance of transportation between the Ecoinvent LCI and the Brazilian context /data; 4.2.1 Consider an average distance of 100 km to Brazil (hypothesis adopted when it does not know the real mean data)- 100 km go and 100 km back, in the back tour the transport vehicle is without load, as a result only the vehicle weight will be considered; 4.2.2 – Make attention to functional unit to set the transfer factor, take care to relation among amount of raw materials, distance of transportation, and load transported.
5-Verify the data quality of the inputs data – identity the uncertain values adopted on Ecoinvent
5.1- For the changed inputs - identity the uncertainties of the inputs from Ecoinvent, calculate the uncertainties of the Brazilian context using the Pedigree Matrix method (Pedersen and Wesnaes, 1996) and compare the two uncertainties. Chose three of the most important inputs to verify the uncertainty, or select the inputs that influence more the impact. It is not suggested modifying the uncertainty adopted in LCI Ecoinvent, avoiding to rise the deviations. The analysis will serve to justify the use of the module adapted. 5.2 - For the non-changed inputs – adopting a process similar to 5.1
6- Set the impacts indicators to be considered and analyzed
The hypotheses considered take into account: Consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation
7- Selecting on SIMAPRO the method to calculate the impacts, also considering the standard deviation by Monte Carlo simulation

7.1 - It is proposed to select the French method that integrates the IPCC[1], CML[2] and CED [3]method. Adopting the French method will be possible to analyze the indicators related to consumption of primary energy; consumption of the non-renewable energy; climate change; water consumption and waste generation; 7.2 – Determining the Number of iterations for Monte Carlo Simulations – As the Monte Carlo method is time consuming we have consider 500 iterations. (The number of iterations change a little the results and their deviations, so it is an aspect to study in the future)
8- Results presentation- Set a worksheet model to be fulfilled for each LCI adapted, granting reliability and transparence
8.1 – Fulfilled one worksheet to each LCI adapted, making evident all hypotheses and considerations (methodology, adaptation, uncertainties, results, calculus demonstration). 8.2 – Present the impact indicators data in terms of mean value and of the minimum and maximum value, with standard deviation. 8.3 – The primary energy source must be the addition of non–renewable energy and renewable energy – considering the need of software that perform environmental assessment;
9- Data Analyses - Macro Comparisons among environmental indicators calculated by Brazilian LCI, original and adapted LCI
9.1 – Calculate the environmental indicators of building product using the LCI from Ecoinvent data without adaptation – impact indicators also calculated from SIMAPRO, considered 500 iterations in Monte Carlo simulations; 9.2 –Calculate the environmental indicators of building product using the LCI from Ecoinvent data adapted – impact indicators also calculated from SIMAPRO, considered 500 iterations in Monte Carlo simulations; 9.3 - Calculate the environmental indicators of building product using the LCI from Brazilian data, if existed, even if this data not fit the methodology proposed (weak data), the propose is only compare macro-values; 9.4 – Compare the results among these environmental indicators, analyzing the macro-values, deviations and tendency, trying validate the indicators with LCI adapted.
10- Others observations
10.1 Remove any type of transportation means input “0” at SIMAPRO; 10.2 Include other type of transportation need consider the uncertainty; 10.3 The LCI take into account in general cradle to gate – until end production - transportation of the raw material extracted and at the plant is considered – the transportation out of production plant is not considered.

4. Case studies on building materials

The table 2 shows the details considered to adapt LCI concrete data to the Brazilian context using the approach proposed at table 1.

Table 2- Methodology applied to adapt the module concrete normal at plant to Brazilian context

Step	Method	Considering
1	Goal and scope definition	1m^3 of normal concrete adapted to Brazilian context - module consider cradle to gate (production phase)
2	Identify the Generic EPD data base selected	module base: concrete normal, at plant/CHU - Ecoinvent
3	Identify the Brazilian context and indicators – overview the differences related to mostly energy matrix and	use the Brazilian energy matrix
		changing means of transportation-consider only dumpers for cement and bricks, and mixer truck to concrete

[1] IPCC 2001 is a method developed by the International Panel on Climate Change. Climate Change 2001. IPCC Third Assessment Report. The Scientific Basis. Available on http://www.grida.no/climate/ipcc_tar/

[2] CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterization methods for the impact assessment.

[3] Cumulative Energy Demand (CED). Details on the CED method may be found in Bösch *et al.* (2007)

	technologies/process, etc				
4	Adaptation of the generic data base inputs related to the process - Overview the inputs of the inventories concerning the process - amount of raw materials, transportation distance, etc	production phase -concrete production including transportation of raw materials to the concrete production site			
		change transport distances			
		remove transportation by boat and train			
		remove transportation by 20 and 28t			
		include 32T truck to transport cement, sand and gravel (100 km round-trip to sand/gravel and 200 km round trip to cement)- consider the same uncertainties of 20-28t			
		change amount of electric energy at plant - 2, 05KWh/m^3 (Brazil data, from Souza 2012)			
		remove natural gas			
		losses were not considered neither water losses			
5	Verify the data quality of the inputs data	inputs/flow	Uncertainties		
			from Ecoinvent	calculate for Brasilan context	
		cement	1,3	1,3	
		electricity	1,22	1,22	
		lorry 28t	2	2	
		lorry>32t	2	2	
6	Identify the impacts indicators to be considered and analyzed –	Consumption of primary energy (non-renewable)			
		climate change (kgCO2 equiv)			
		water consumption			
		waste generation			
7	Selecting on SIMAPRO the method to calculate the impacts with the uncertainty estimations calculated by Monte Carlo simulation	French Method (because its included CML, IPCC and CED)			
		500 iterations to perform Monte Carlo simulation			
8	Results	Module adapted: Normal Concrete, at plant/CH U-module BR-Ecoinvent/SIMAPRO			
9	Validation and Macro Comparisons	Macro Comparisons among environmental indicators calculated by Brazilian LCI, original and adapted LCI			
10	Others points/observations	transportation of concrete is classified in construction site phase, as EN 15978 (2012)			

The table 3 shows the LCI original and the adapted LCI. The table 4 shows environmental indicator of concrete calculated with the adapted existing LCI data.

Table 3 - Adaptations of Life cycle inventory (LCI) data from Ecoinvent to Brazilian context – normal concrete, at plant

Original Ecoinvent Inputs				Changed Inputs	Ecoinvent adapted inputs			deviation comparisons	
No.	Parameters	initial amount	functional unit	Parameters Changed	new input	assumptions	demonstrative calculus	Ecoinvent	Brazilian context
1	concrete mixing plant CH U	4,57E-07	unit						
2	diesel, burned in building machine GLO U	22,7	MJ						
3	disposal, concrete, 5% water, to inert material landfill	16,9	kg						
4	disposal, municipal solid waste, 22.9% water, to municipal incineration	0,0951	kg						
5	electricity, medium voltage, at grid CH U	4,36	kwh	Brazilian energy matrix	2,0500	Brazil specific data (Souza, 2012)		1,21	1,21
6	gravel, round, at mine CH U	1890,00	kg						
7	heavy fuel oil, burned in industrial furnace 1MW, non-modulating CH U	3,09	MJ						
8	light fuel oil, burned in industrial furnace 1MW, non-modulating CH U	13,3	MJ						
9	lubricating oil, at plant RER U	0,0119	kg						
10	natural gas, burned in industrial furnace low-NOx >100kW RER U	1,16	MJ	remove	0,0000	not used to concrete production in Brazil (generic data)			
11	Portland cement, strength class Z 42.5, at plant CH U	300	kg	module cement BR	300kg			1,3	1,3
12	steel, low-alloyed, at plant RER U	0,0238	kg						
13	synthetic rubber, at plant RER U	0,00713	kg						
14	tap water, at user CH U	186,00	kg	Changed amount	170,00	Brazil specific data (Souza, 2012)			
15	transport, barge RER U	4,92E+01	tkm	remove	0,0000	changed by lorry			
16	transport, freight, rail CH U	6,82	tkm	remove	0,0000	changed by lorry			
17	transport, lorry 3.5-20t, fleet average CH U	0,998	tkm	remove	0,0000	transport of cement, sand, gravel to construction site by truck			
18	transport, lorry 20-28t, fleet average CH U	9,44	tkm	remove	0,0000		*	2	2
19	transport, lorry >32t	0	tkm	included	193,0900		*	2	
19	treatment, concrete production effluent, to wastewater treatment, class 3 CH U	0,0143	m3						
20	concrete, normal, at plant CH U	1	m3						
21	Heat, waste	15,7	MJ						

* calculus demonstration sheet is prepared but is not showed in this paper

Table 4- Environmental indicator of normal concrete at plant -module BR (adapted of Ecoinvent data based on Brazilian context)

The environmental parameter declaration		unit	Value adapted	SD (500 number of runs)	Min value (2, 5%)	Max value (97, 5%)
	Functional unit	flux/m^3				
1.	Primary energy sources		1280,00	230,000	926	1790
1.1	Renewable primary energy use		108,00	17,100	81,2	151
	hydraulic electricity	kwh				
	wood and vegetal coal	MJ				
	biomass	MJ				
	others	MJ				
1.2	Non-Renewable primary energy use		1170,00	222,00	836	1660
	petroleum and derivatives	MJ				
	natural gas	MJ				
	mineral coal	MJ				
	uranium	MJ				
	nuclear					
1.3	Water consumption	l	3510	376,00	2830	4370
2.	Parameters of environmental impacts					
2.1	Climate change	Kg CO2	232	38,70	164	317
3	Waste Generation					
3.1	Waste dangerous disposed	kg	6,89E-02	3,42E-02	2,78E-02	1,58E-01
3.2	Waste non-dangerous disposed	kg	1,10E+00	4,92E-01	4,28E-01	2,33E+00
3.3	Inert waste	kg	3,35E+01	1,17E+01	1,63E+01	6,07E+01
3.4	Radioactive waste	kg	2,66E-03	5,61E-04	1,79E-03	3,99E-03

5. Comparison among Brazilian, generic and adapted LCI data.

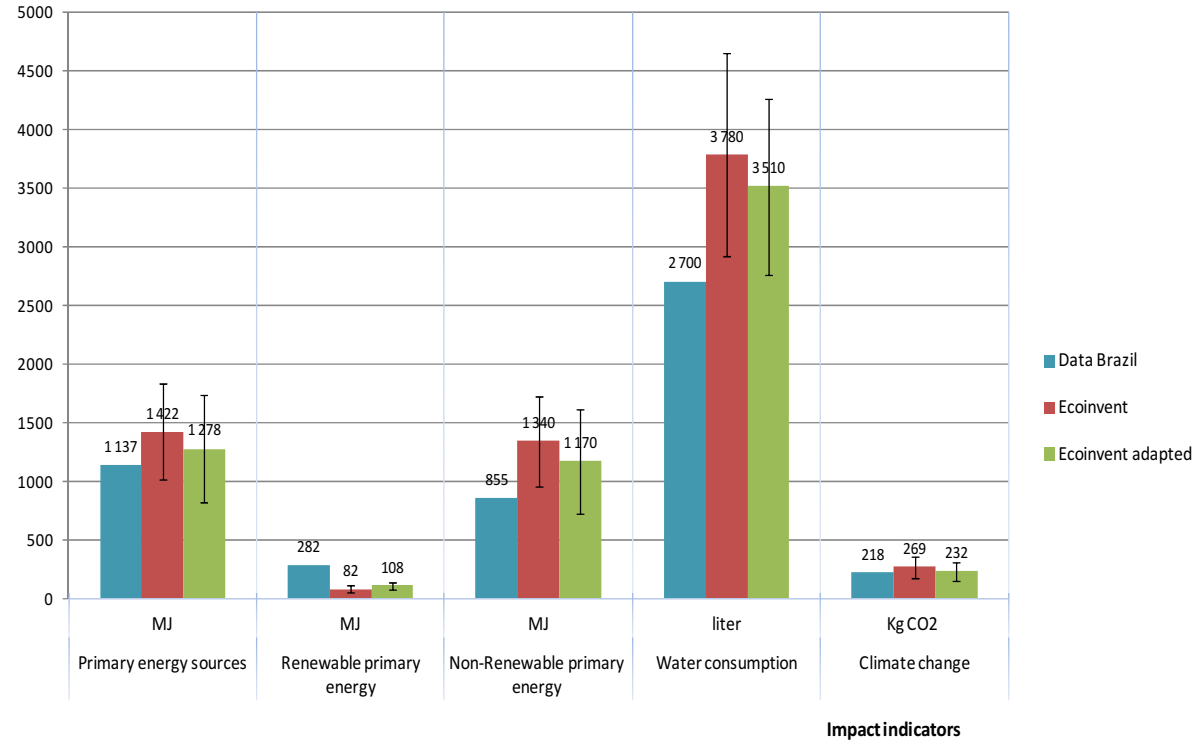
The approach set the phase 9 - Data Analyses – which aims the comparison among environmental indicator came from three types of LCI: Brazilian, original and adapted LCI:

1- Brazilian environmental indicators: it was organized the environmental impacts data of six building products, according to EN 15.804 (2012): cement, sand, brick, crude steel, concrete and concrete block. However, only data of normal concrete is show in this paper.

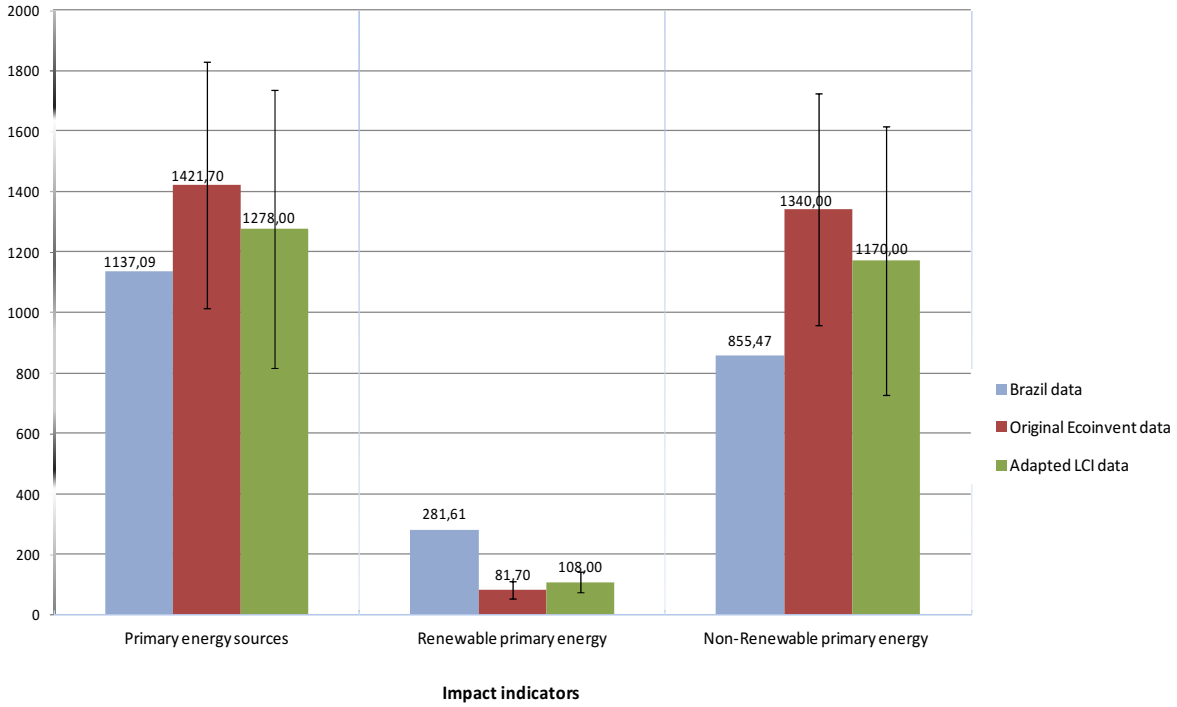
2- environmental indicators from original LCI (from Ecoinvent): seven building products had their impacts calculated by SIMAPRO using the LCI data from Ecoinvent without adaptations: cement, normal concrete, concrete block, mortar, reinforced steel, fiber cement board, gypsum plaster board. These LCIs consider only the production phase. However, only the data of normal concrete is show in this paper.

3- environmental indicators from adapted LCI: seven building products had an LCI adapted in order to fit the Brazilian conditions: cement, normal concrete, concrete block, mortar, reinforced steel, fiber cement board, gypsum plaster board. Only the indicators from adapted LCI of normal concrete is show in this paper. The table 2 and 3 show the adapted LCI concrete data. The table 4 shows the environmental indicator of the concrete calculated by SIMAPRO using the adapted LCI.

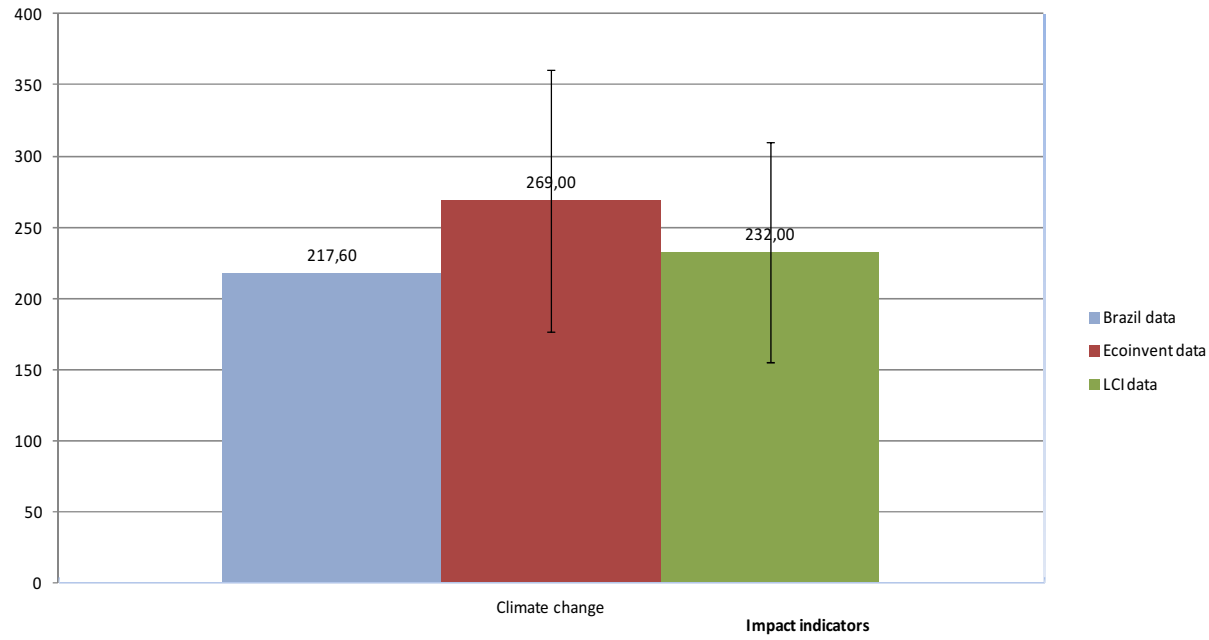
The graphics 1 to 3 show this comparison. The uncertainties was taken into account to data from original and adapted LCI, because the Brazilian LCI does not have this information; but this information is very important because the mean value is analyzed and not an specific producer.



Graphic 1 – Comparison among impact indicators (primary energy, water consumption and climate change) calculated from Brazilian, Ecoinvent and adapted LCI data



Graphic 2 – Comparison among primary energy, renewable energy and non-renewable energy indicators calculated from Brazilian, Ecoinvent and adapted LCI data



Graphic 3 – Comparison among climate change indicators calculated from Brazilian, Ecoinvent and adapted LCI data

6. Conclusions

As the Brazilian building sector does not have organized and centralized LCI or LCA database, adaptation of overseas data (from Europe) is suggested in this paper to facilitate the environmental assessment of buildings using consistent yet not fully representative datasets. Once producers are willing to get involved, original data can be modified and raw data from producers could replace the Ecoinvent data based on the Swiss context (i.e. adapted Ecoinvent data).

To date, our approach is a first step, as some parameters were adapted such as the transportation distances and the energy mixes. The methodology is based on previous research studies from Colodel (2008) and Hodkova et al (2012).

Case studies looking at the concrete building materials (considering Brazilian, original and adapted LCI) show the weaknesses of some Brazilian data e.g. in terms of completeness of the system boundaries. The results for primary energy and global warming potential indicators show that the adapted LCI data is found to have less impact than the indicators calculated with the original LCI (differences between 5 and 10%). This is mainly explained by the efficiency of the Brazilian energy mix despite the large consumption of the non-renewable energy due to the type and distance of transportation. The adapted LCI must now be improved e.g. by working closely with Brazilian producers to get either a more accurate generic data for Brazil or different specific data representing different concrete manufacturers producing concrete for the Brazilian construction sites.

BIBLIOGRAPHICAL REFERENCES

BÖSCH M.E., HELLWEG S., HUIJBREGTS M.A.J., AND FRISCHKNECHT R. *Applying Cumulative Energy Demand* (CExD) *Indicators to the Ecoinvent Database*. In: Int J LCA 12 (3), 2007, pp. 181–190.

CAMPOS, E. F.; P., K. R. G.; JOHN, V. M. *Emissão de CO2 do transporte da madeira nativa*

da Amazônia. Ambiente Construído (Online), v. 11, p. 157-172, 2011

COLODEL, C.M.T. *Systematic approach for the transferability of life cycle inventory data between countries*. Proceeding. In: 8th International Conference on EcoBalance 2008 : Tokyo (Japan), 10-12.12.2008.

COMITE EUROPEAN DE NORNALIZATION - EN15.978:2012 - Contribution des ouvrages de construction au développement durable - Évaluation de la performance environnementale des bâtiments - Méthode de calcul.

FRISCHKNECHT, R. et al. *Overview and Methodology. Ecoinvent report nº01*. Swiss Centre of Life Cycle Inventories, Dübendorf, 2007.

GOLDEMBERG, J.; AGOPYAN, V.; JOHN, V.M. *O Desafio da Sustentabilidade na Construção Civil* - Série Sustentabilidade. São Paulo, ed.Blucher, 2011

HODKOVA, J.; LASVAUX, S. *Guidelines for the Use Of Existing Life Cycle Assessment Data On Building Materials As Generic Data For A National Context*. In: International Symposium on Life Cycle Assessment And Construction, Nantes, France, 2012.

INSTITUTO AÇO BRASIL – IABr – *Relatorio de sustentabilidade*. Rio de Janeiro, 2010

KELLENBERGER D. et al. *Life Cycle Inventories of Building Product.* Final Report Ecoinvent Data v2.0 No.07. Swiss Centre of Life Cycle Inventories, EMPA Dübendorf, 2007

LASVAUX, S. *Étude d'un modèle simplifié pour l'analyse de cycle de vie des bâtiments*. These de doctorat. MINES Paris-Tech, 2010

LIMA, J. A. R. *Avaliação das consequências da produção de concreto no Brasil para as mudanças climáticas*. Tese (Doutorado) - Escola Politécnica, Universidade de São Paulo, São Paulo (2010).

PEDERSEN WEIDEMA, B. and M.S. WESNAES. 1996. *Data quality management for life cycle inventories- An example using data quality indicators*. (3–4) J. Cleaner Production 4:167–176.

PUNHAGUI, K. R.G.; CAMPOS, E.F.; GONZALEZ BARROSO, J. M.; JOHN, V. M. *Prospects for the Use of Wood in Residential Construction in Brazil - First Results*. Key Engineering Materials, v. 517, p. 247-260, 2012.

SAADE, M. R. M.; OLIVEIRA, B. M.; SILVA, M.G.; GOMES, V. *Aplicação da Análise do Ciclo de Vida na construção civil: discussão sobre alocação de impactos entre o aço e suas escórias*. Revista PARC [pesquisa em arquitetura e construção] da Unicamp, vol1, n6, 2010. Disponível em:<http://revistaparc.fec.unicamp.br>

SOUZA, M.P. R. *Avaliação das emissões de CO2 antrópico associadas ao processo de produção do concreto, durante a construção de um edifício comercial, na Região Metropolitana de São Paulo*. Dissertação (mestrado). Instituto de Pesquisas Tecnológicas do Estado de São Paulo – IPT, São Paulo, 2012.

LCC and LCA of dynamic construction in the context of social housing



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Short Summary

Continuously changing household needs and evolving building standards require a frequent upgrade and renovation of our existing residential building stock. A lack of adaptability of buildings, however, often leads to destructive interventions, resulting in financial and environmental impacts. The goal of this paper is to contribute to the search for new design concepts enabling easier and more cost-effective upgrade and renovation of buildings. It should moreover contribute in achieving a lower life cycle environmental impact. A more dynamic design is evaluated in the specific context of a social housing project in Mechelen (Belgium). In this context, building elements with reversible detailing techniques facilitating disassembly and component reuse are compared to more traditional static elements. The benefits and drawbacks are assessed at the building level using a life cycle approach of economic and environmental aspects, i.e. a Life Cycle Costing (LCC) and Life Cycle Assessment (LCA). Different renovation scenarios are simulated focussing on the internal restructuring of the housing units. Two alternatives were investigated: dynamic assemblies of all internal walls versus dynamic assemblies of only those internal walls which are expected to change more frequently. The analysis revealed that the building concept and layout are important for making more dynamic design beneficial or not. Building layouts which provide opportunities for change generally require limited constructive adaptations during the building life span. Application of dynamic assemblies to only those walls which are assumed to be changed in future is then preferred over an application to all internal walls. This could be called a ‘selective’ approach. Such a ‘selective’ approach can result in life cycle environmental benefits while the additional financial costs remain limited.

Keywords: adaptability; building level, life cycle assessment; life cycle costing; renovation.

1. Introduction and objectives

Continuously changing household needs (e.g. due to demographic changes and fluctuations in household composition), evolving building standards (e.g. comfort standards and energy performance regulations) and changing performance desires (e.g. improved acoustical performance or fire resistance) require a frequent upgrade and renovation of our existing residential building stock. A lack of adaptability of buildings, however, often leads to destructive interventions (i.e. demolition works), resulting in financial and environmental impacts. To avoid these, a more dynamic design approach can be proposed, using concepts like disassembly,

adaptability, transformability and multi-functionality. The basic principle is the integration of time as design parameter in order to enable buildings to deal with changing needs over their building life cycle [1].

The goal of this paper is to apply and evaluate a dynamic design approach in the specific context of the upgrade of the social housing neighbourhood “Mahatma Gandhi” in Mechelen (Belgium). The paper is based on a research project commissioned by the Public Flemish Waste Agency (OVAM), looking at adaptable design in buildings [2]. The focus is set on the evaluation of a number of representative renovation scenarios at the building level, considering dynamic alternatives for internal wall systems (i.e. assemblies using reversible detailing techniques, in order to facilitate disassembly and component reuse) [1]. Based on a life cycle approach, the financial and environmental benefits and drawbacks of these dynamic alternatives are compared with traditional solutions.

In the subsequent section the assessment method is briefly summarised, including Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) and the dynamic design scenarios. Section three focusses on the case study, describing the results of both a qualitative and quantitative assessment. Some conclusions are drawn in the final section.

2. Methodology

2.1 General

The financial and environmental assessment method used for the evaluation of the dynamic building solutions is based on the methodology developed in the SuFiQuaD (“Sustainability, Financial and Quality Evaluation of Dwelling Types”) research project which proposes an integrated method combining economic and environmental impact calculations during the whole building life cycle, i.e. Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) (Fig. 1) [3],[4]. This means that not only the initial construction stage is taken into account but also the use and maintenance, and the end-of-life (EOL) stage of buildings and subparts. With such approach the long term advantages and/or drawbacks of dynamic design solutions of buildings can be analysed over the total building life cycle.

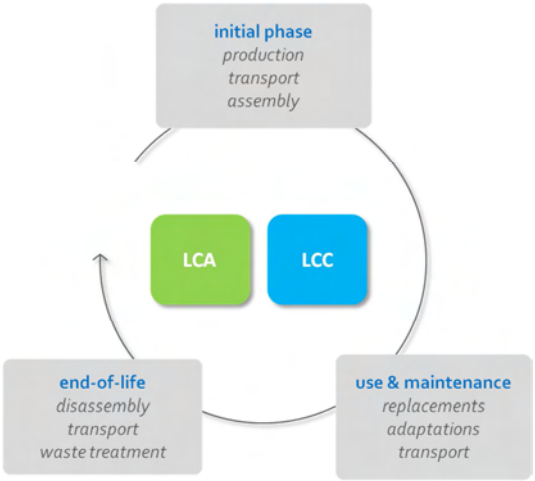


Fig. 1: Integrated life cycle approach in buildings [1]

Another important feature of the SuFiQuaD methodology is the evaluation structure based on the element method for cost control [5]. The basic principle is the hierarchical subdivision of the building in functional elements (e.g. walls, floors, technical installations) for which financial and/or environmental data can easily be calculated. A distinction can be made between five scale levels: building materials (e.g. brick, mortar, plaster), work sections (e.g. brickwork, plasterwork), building elements (e.g. internal wall including finishes), buildings and neighbourhoods (Fig. 2). This hierarchical structure allows using easily the results from the lower scale level for analysis at the

higher scale levels. In the context of the research presented, the dynamic design approach was analysed at three scale levels: the building element level, the building level and the neighbourhood level. This paper focuses on the results at the building level.

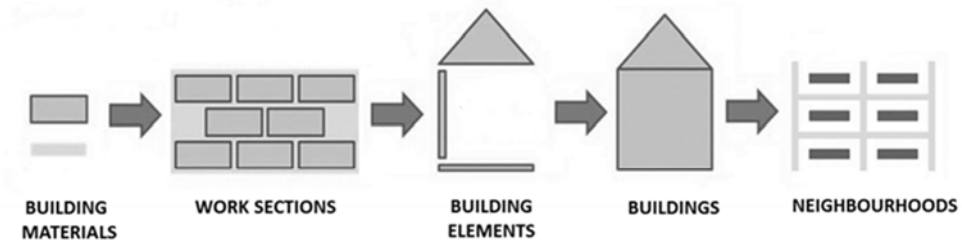


Fig. 2: Element method for cost control and scale levels [2]

In the subsequent paragraphs the applied LCC and LCA method and the scenarios used for the life cycle analysis are explained in more detail.

2.2 Life Cycle Costing (LCC)

The financial costs which occur during the different life cycle stages are assessed via an LCC. These include the costs for material acquisition, the labour and indirect cost, costs for transport and EOL treatment. The financial data are based on Belgian cost databases and product specific data from catalogues and tenders (for the cost estimation of dynamic assemblies) [1]. Future costs are integrated with initial costs by calculating their present value. The following is assumed – based on Belgian statistical data - regarding the economic parameters [1]:

- Inflation rate: 2%
- Real discount rate (above the inflation): 2%
- Real growth rate labour costs (above the inflation): 1%
- Real growth rate material costs (above the inflation): 0%

2.3 Life Cycle Assessment (LCA)

The environmental impact assessment is based on the LCA method developed in the MMG ("Milieugerelateerde Materiaalprestatie van Gebouwelementen") research project, commissioned by the Public Waste Agency of Flanders (OVAM) [6]. This project focuses on the elaboration of an evaluation method for the environmental performance of building elements, adapted to the Belgian context. Besides individual impact indicators, the MMG assessment method allows to assess the environmental impact based on an aggregated indicator, expressed in environmental costs (external costs caused by environmental impacts). In this paper, this monetary indicator is used to evaluate the environmental impact of the proposed dynamic assemblies for internal walls. The environmental impact simulations are made with the Simapro software using the Ecoinvent database (version 2.2) [7][5],[8], which was adapted to the Belgian context (replacing the Swiss electricity mix and transport processes by European corresponding processes).

2.4 Service life scenarios

Scenarios must be defined regarding the life span of buildings and the replacement of building elements and subcomponents in order to evaluate the benefits and/or drawbacks of using dynamic construction. Based on the methodology used in the PhD research of Paduart [1], service life scenarios are defined at three levels: building, building element and subcomponent (Fig. 3). For the *building*, an average life span of 60 year is determined as representative for residential buildings in Belgium [3]. At the *building element* level, a functional service life is used to take into account the changing needs of residents and building standards. Based on a survey among social housing companies [1], the following scenarios are defined:

- Scenario without periodic intervention
  The building element undergoes no major renovation interventions during the building life span (i.e. functional service life equals 60 years), except for the replacement and maintenance of subcomponents at the end of their technical service life.

- Scenario with periodic intervention
  The building element position is altered due to major renovation during the building life span. For internal walls a periodic turnover of 15 year is defined. When the functional service life is exceeded, building elements are replaced by identical new components, except for dynamic assemblies (Design for Disassembly – DfD) where disassembly and reuse of subcomponents can take place (Fig. 3).

Finally, a technical service life is attributed to the analysed *subcomponents* based on reference values from literature for the building sector [9]. For this study average values are used for the simulations. When the technical service life of subcomponents is exceeded, the subcomponent is replaced, eventually together with adjacent subcomponents if those are connected with irreversible connections [1].

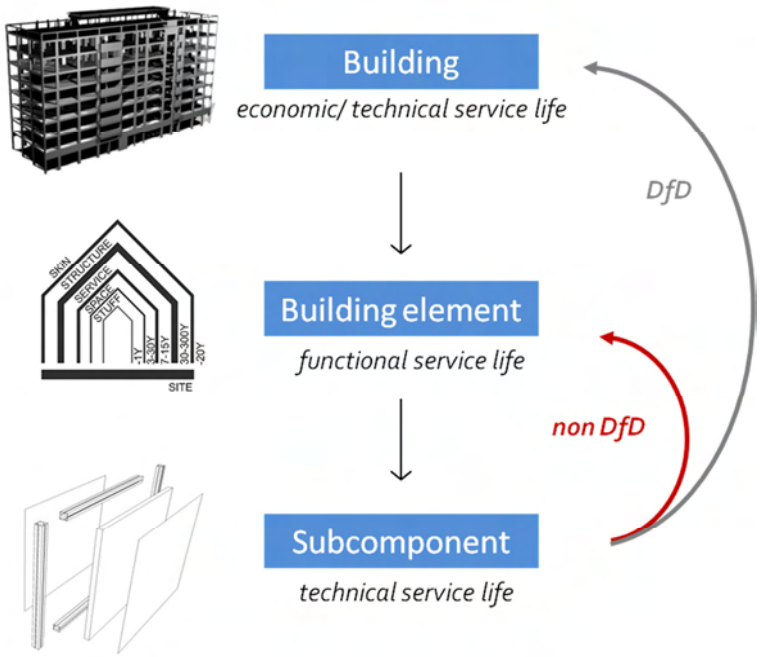


Fig. 3: Service lives on three levels: building – building element – subcomponent [1]

3. Evaluation of case study at the building level

The dynamic design approach is applied and evaluated in the specific context of the upgrade of the social housing neighbourhood “Mahatma Gandhi” in Mechelen (Belgium). Besides the renovation of existing buildings the project includes the demolition of a number of outdated apartment buildings that will be replaced by new collective building blocks (subdivided in 3 parcels).

The case study consists of the first building block (parcel 1) designed by KPW-architecten (Fig. 4). This building is composed of a mix of one-bedroom and two-bedroom apartments. A representative housing unit with two bedrooms is selected for the analysis at the building level (Fig. 4). Before starting the quantitative life cycle analysis of this building block - as described in the previous section - the original building renovation design was analysed (qualitatively) to investigate to what extent dynamic concepts were already integrated. This qualitative analysis was done for three aspects: the construction method, the characteristics of the building layers (*structure*, *circulation*, and *service)* [11], and the plan layout of the housing units. Based on this analysis renovation scenarios, including dynamic assemblies for internal walls, were proposed for the quantitative assessment.

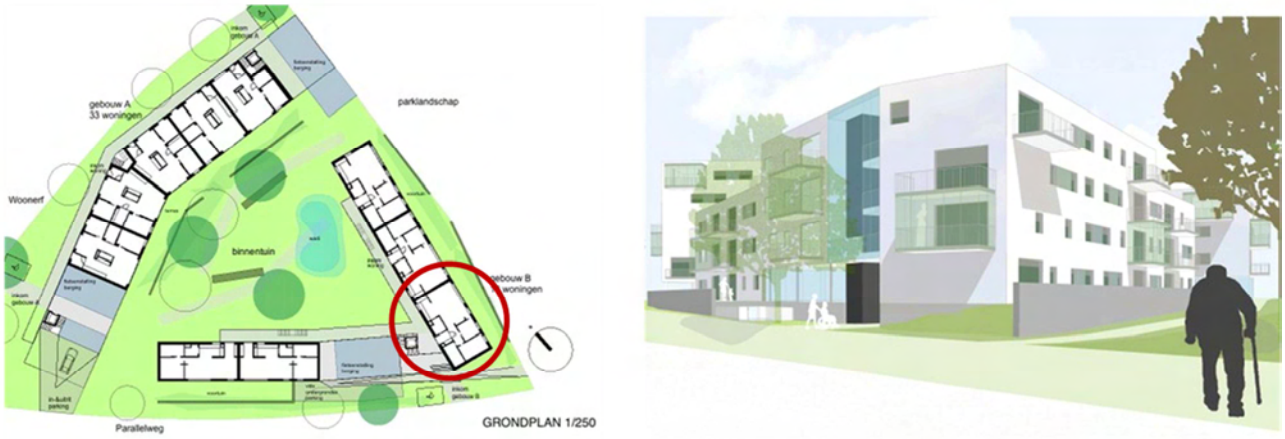


Fig. 4: Ground floor plan (left) and perspective view (right) of the building block (Parcel 1 – neighbourhood Mahatma Gandhi) [10]. The red circle indicates the analysed housing unit.

3.1. Qualitative assessment of the building

3.1.1 Construction method

The buildings of parcel 1 are constituted of masonry walls and concrete floors. This traditional construction method is characterized by irreversible connections (i.e. use of cement mortar) making disassembly and reuse of subcomponents impossible (Fig. 5). In the quantitative assessment (§ 3.2) dynamic alternatives for internal walls are simulated at the building level and compared with the traditional masonry walls.

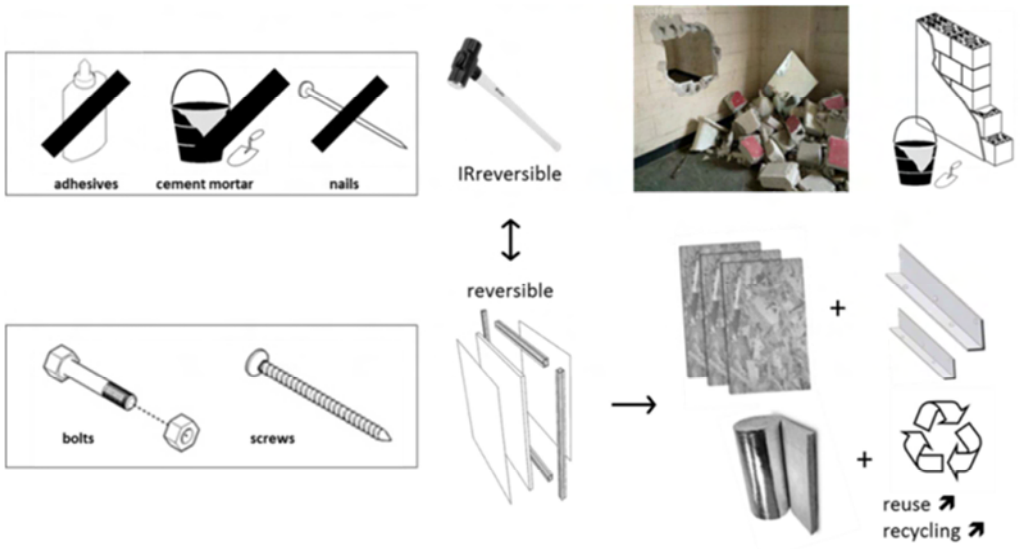


Fig. 5: Static versus dynamic assemblies [1]

3.1.2 Building layers: Structure, Circulation, Services

An analysis of the building layer characteristics identified the opportunities and limitations for adaptability (Fig. 6). The facades, partitioning walls and some internal walls consist of a structure of loadbearing walls. Loadbearing walls can be an obstacle for future adaptations of the layout of housing units. Concerning the circulation, vertical circulation (staircases and elevators) is grouped and the apartments can be accessed via an external gallery. This organisation does not impede the internal subdivision in housing units. Finally, technical services are clustered in central technical ducts increasing the plan flexibility.

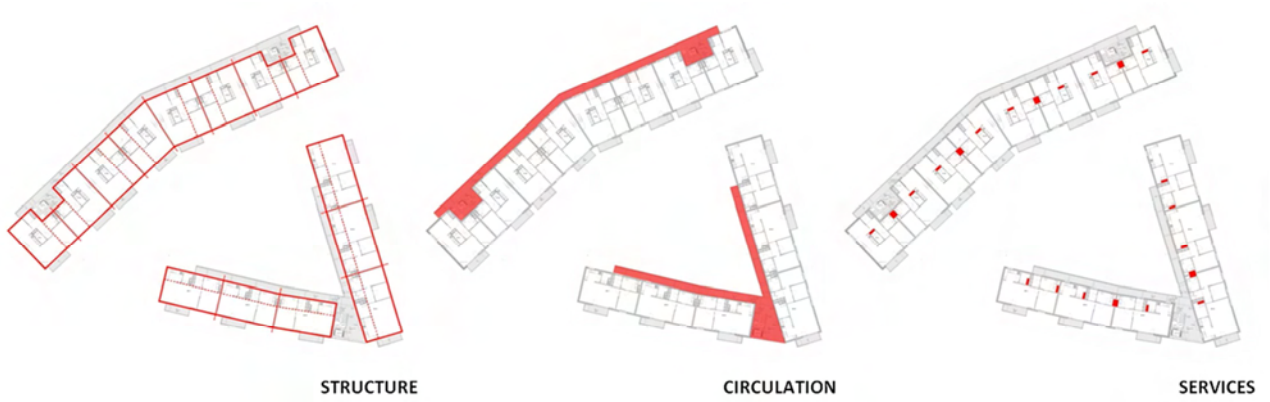


Fig. 6: Analysis of the building layer characteristics: structure, circulation and services (Parcel 1 - neighbourhood Mahatma Gandhi) [2]

3.1.3 Plan layout housing unit

The housing units are characterized by their flexible plan layout. Attention is paid to the grouping of rooms (distinction between living areas and technical and wet rooms) and the clustering of technical ducts, in order to increase the possibilities for future adaptations of the dwelling. Moreover the configuration of the plan lay-out is adapted to wheel chair users (dimensioning of space considering the wheelchair turning radius)



Fig. 7: Flexibility of the analysed housing unit [2]

3.2 Quantitative assessment of renovation scenarios for a housing unit

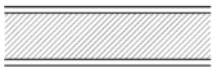
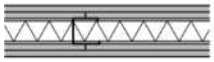
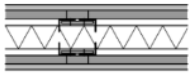
The quantitative analysis at the building level is carried out in three steps. In a first step, renovation scenarios for the internal restructuring of the dwelling are defined. In this paper two scenarios for the transformation of the housing unit from a two-bedroom to a one-bedroom apartment are discussed (Fig. 8 and Fig. 12). As is shown in the figures, the dwelling consists of fixed-positioned internal walls (i.e. walls undergoing no intervention during the building life cycle, except the periodic replacement of subcomponents) and variable-positioned internal walls (i.e. walls of which the position is altered in the course of the building life cycle).
In a second step, the two renovation scenarios at the building level are translated into scenarios for the internal walls. This is done by defining the use period (i.e. period within which the wall is used in the housing unit) and the periodic turnover of each internal wall. Based on these wall scenarios the life cycle environmental impact and financial cost can be calculated for each internal wall type (per m^2 of wall).

In a final step, the LCA and LCC results at the element level (i.e. of the internal walls) are translated to the building level by multiplying the results per m^2 wall by their respective ratio (i.e. m² wall/ m² floor area). The final results at the building level are then expressed in cost and impact per m^2 floor area.

For the simulations three categories of internal walls have been analysed (Table 1) going from traditional (static) wall systems (masonry walls and dry walls) to dynamic assemblies (Design for Disassembly (DfD) walls, using reversible connections and reusable subcomponents) [2].

Besides the evaluation of the different variants described in Table 1, two alternatives are compared per renovation scenario: the use of dynamic assemblies for all internal walls (simulations “1 wall type”) and a selective approach focussing on dynamic assemblies for the variable-positioned walls (simulations “2 wall types”).

Table 1: Composition of the analysed internal wall categories [2]

Category	Composition	Thickness
 Masonry wall	- brickwork:	
	a) perforated clay bricks (case study)	140 mm
	b) cellular concrete blocks	150 mm
	c) hollow concrete blocks	140 mm
	- plaster + painting	12 mm
 Dry wall	- metal studs	50 mm
	- mineral wool	40 mm
	- gypsum plasterboard	12.5 + 12.5 mm
	- painting	
 DfD wall	- metal framework	50 mm
	- glass wool	40 mm
	- OSB boarding+	15 mm
	a) MDF boarding	12.5 mm
	b) gypsum fibreboard	12.5 mm
	c) gypsum plasterboard	12.5 mm
	- painting	

3.2.1 Renovation scenario 1: Transformation from a two-bedroom to a one-bedroom apartment with an enlarged living room

In the first renovation scenario a two-bedroom apartment is transformed into a one-bedroom apartment by using the small bedroom as extension of the living room (Fig. 8). Moreover the wall between the kitchen and the living room is removed to create an open kitchen. This renovation scenario can be translated into wall scenarios (Fig. 9), looking at four consecutive periods of 15 years (year 0 until year 15, year 15 until year 30, year 30 until year 45 and year 45 until year 60) in which the apartment is switched from a two-bedroom to a one-bedroom apartment and vice-versa. A distinction can be made between fixed-positioned walls (red walls in Fig. 9) and variable-positioned walls (orange and yellow walls in Fig. 9). For the walls with an interruption of the analysis period (the yellow walls are not present in the housing unit in period “15-30 year” and “45-60 year”) the assumption is made that dynamic assemblies are stored (or eventually used in another dwelling) in order to be reused later in the housing unit.

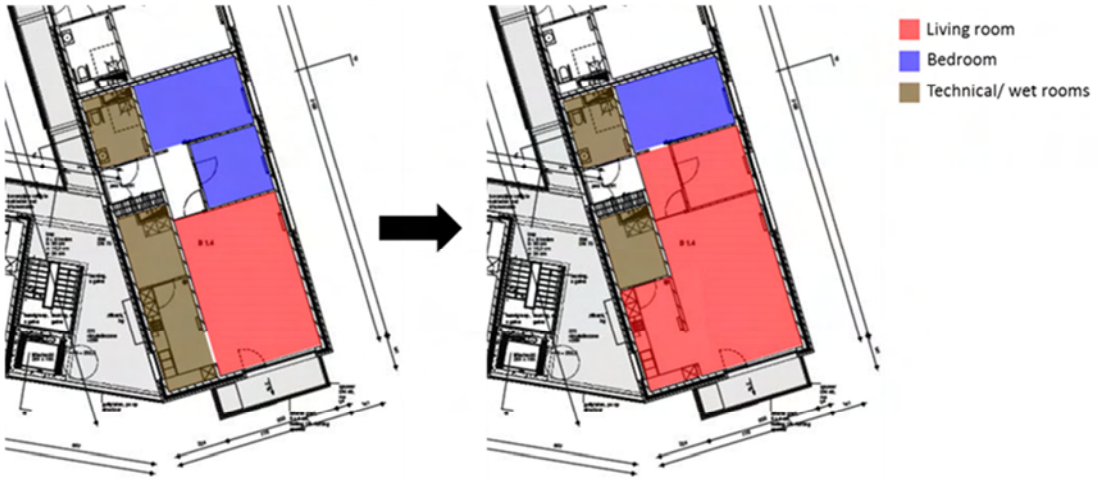


Fig. 8: Renovation scenario 1 (transformation from two-bedroom apartment to one-bedroom apartment) [2]

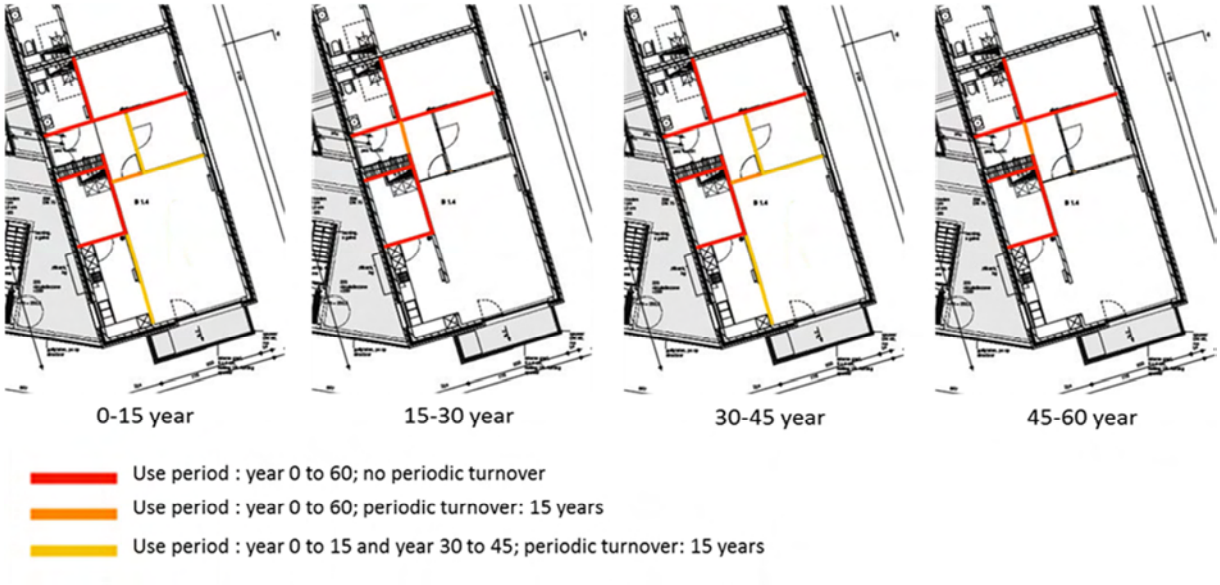


Fig. 9: Wall scenarios in renovation scenario 1 [2]

The LCA results (Fig. 10) show that dynamic assemblies for all internal walls (simulations “1 wall type”) are not beneficial compared to masonry walls. This is due to the design of the floor plan-layout which requires a low number of interventions in order to transform the housing unit from one typology to another. When a selective application of dynamic assemblies is chosen (simulations “2 wall types”), the life cycle environmental costs can be reduced. The reduction compared to the “1 wall type”-simulations is however limited because a large part of the internal walls (yellow walls in Fig. 9) are moved to another housing unit during the building life cycle, so that the benefits of component reuse are allocated to that unit.

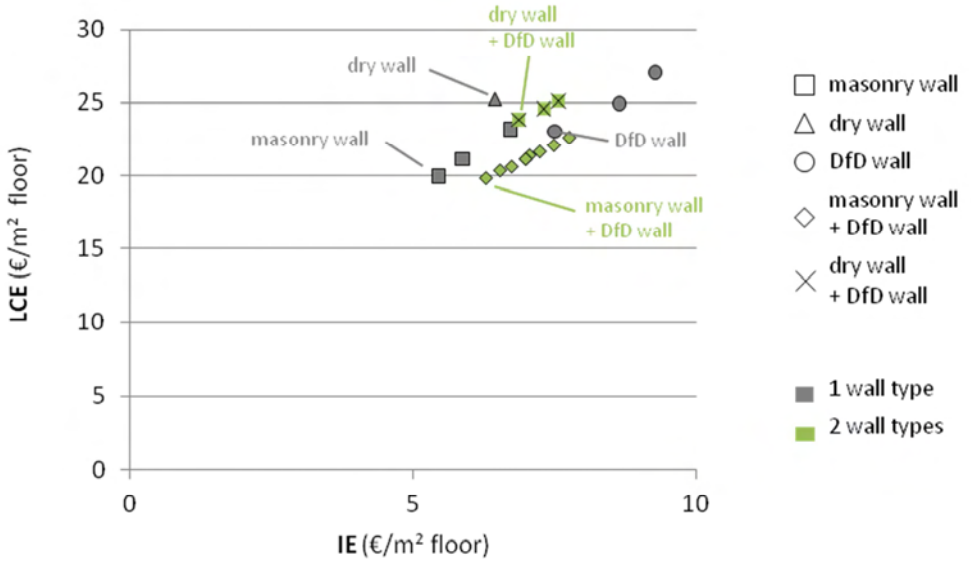


Fig. 10: Overview of the initial environmental costs (IE) and life cycle environmental costs (LCE) for renovation scenario 1 for simulations with 1 or 2 wall types [2]

Concerning the financial evaluation (Fig. 11), the "1 wall type"-simulations show that dynamic assemblies can compete with masonry walls (cost reduction resulting from the pre-assembly of dynamic variants [1]) but are more expensive than dry wall systems (the labour costs for disassembly and reassembly of dynamic variants are higher than the saved material cost resulting from component reuse [1]).

A selective approach for the use of dynamic assemblies (limited to variable-positioned walls) in combination with masonry walls can be interesting (decrease of the initial and life cycle financial costs compared to the use of masonry walls for all internal walls). On the other hand a combination with dry wall systems results in a limited additional cost compared to the generalized use of dry walls.

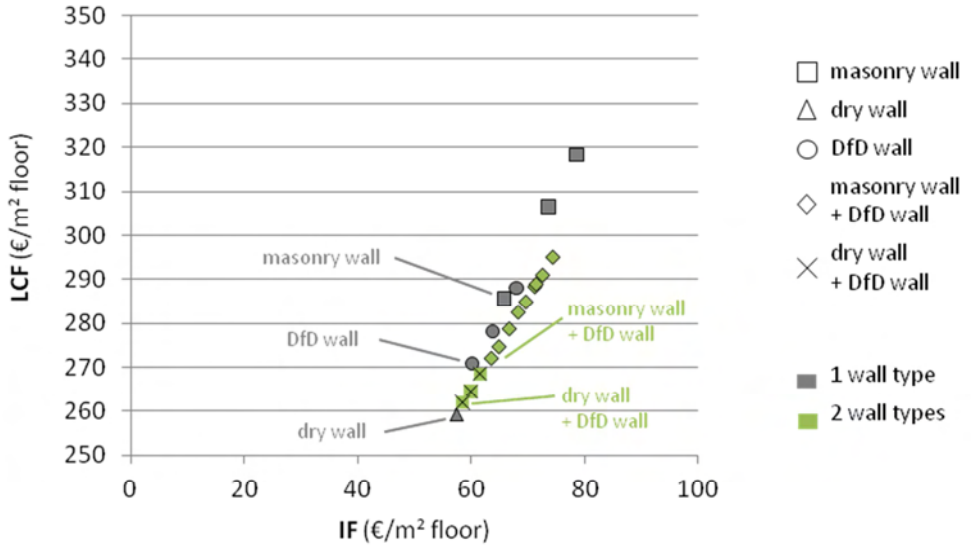


Fig. 11: Overview of the initial financial costs (IF) and life cycle financial costs (LCF) for renovation scenario 1 for simulations with 1 or 2 wall types [2]

3.2.2 Renovation scenario 2: Transformation from a two-bedroom to a one-bedroom apartment with a living room subdivided in a sitting and eating room

The second renovation scenario (Fig. 12) is similar to the previous scenario, except that a part of the internal walls can be reused to divide the living room in a sitting and eating room. This renovation scenario enables to evaluate the impact of higher reuse capacity of internal walls inside the housing unit and the possible environmental and economic benefits of dynamic assemblies. The wall scenarios are shown in Fig. 13.

The LCA and LCC results show the same trends as in renovation scenario 1. From an environmental point of view, a generalized use of dynamic assemblies is not beneficial while from an economic point of view, dynamic assemblies for all internal walls can compete economically with masonry walls but are still more expensive than dry wall systems. A selective approach of dynamic variants results in a higher reduction of environmental costs, compared to renovation scenario 1. This is the direct consequence of the higher reuse of internal walls inside the housing unit. From a financial perspective, a selective approach of dynamic assemblies is advantageous in combination with masonry but leads to additional costs in combination with dry wall systems. Compared to renovation scenario 1, the additional costs are even higher because of additional disassembly steps due to the higher reuse of internal walls inside the housing unit.



Fig. 12: Renovation scenario 2 (transformation from two-bedroom apartment to one-bedroom apartment) [2]

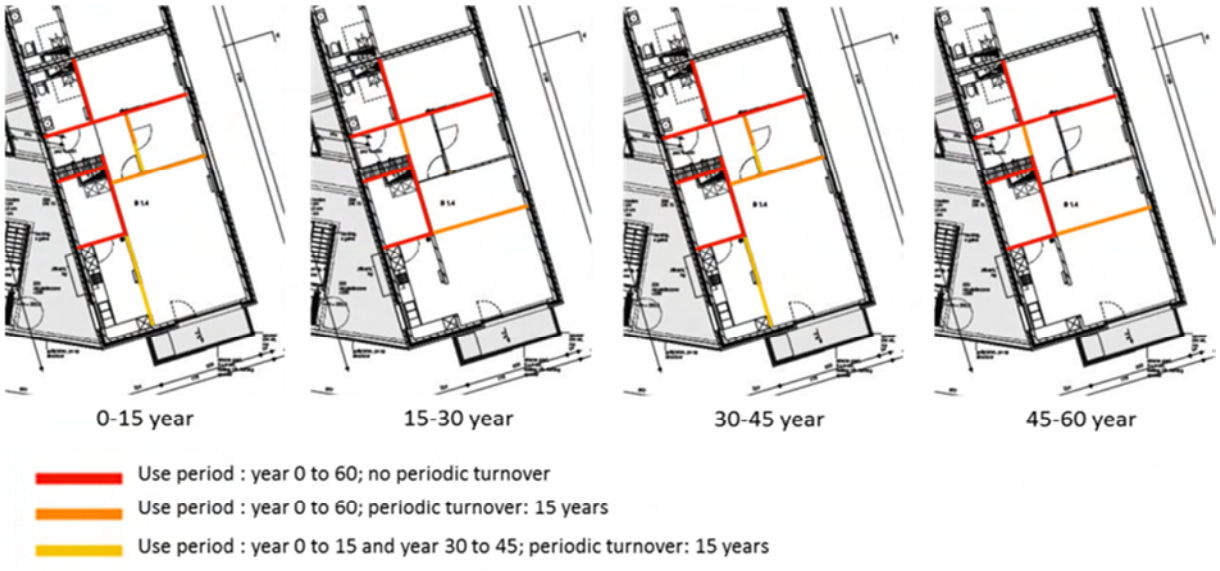


Fig. 13: Wall scenarios in renovation scenario 2 [2]

4. Conclusions

It can be concluded that the building concept and layout are important to make dynamic design beneficial or not. The qualitative assessment of the housing unit revealed that different aspects related to adaptability were integrated in the design proposal of the case study (flexible plan-layout, space and room clustering, adaptability for wheel chair users, external circulation). In consequence, renovation scenarios only required limited interventions and made a generalized use of dynamic assemblies not beneficial, neither from an environmental nor financial perspective. Instead, a more selective application of dynamic assemblies, i.e. to only those walls which are assumed to be changed in future, was proven to be preferred. This selective approach can result in life cycle environmental benefits while the additional financial costs remain limited.

As the conclusions drawn are only valid for the analysed case study with a flexible and polyvalent plan layout, it might be that the advantages of dynamic assemblies were not fully highlighted. It is therefore recommended to apply the same analysis to other case studies. This would allow a more representative picture of the benefits and drawbacks of dynamic assemblies at the building level. Furthermore research should be done about the impact of scenarios for the renovation frequency and service life span of subcomponents. Based on sensitivity analysis at the element level [1], it is expected that those parameters can have an important influence on the evaluation results.

5. Acknowledgements

The authors would like to thank the Flemish Public Waste Agency (OVAM) that commissioned this research and all members of the steering committee for their input and suggestions in the course of the project.

6. References

[1] PADUART A, *"Re-design for Change: A 4 dimensional renovation approach towards a dynamic and sustainable building stock"*. PhD Dissertation, VUBPRESS, Brussels, 2012, ISBN 978-90-5718-112-2

[2] PADUART A, TRIGAUX D, DEBACKER W, DANSCHUTTER S, DE TEMMERMAN N, DE TROYER F, *"Casestudy ontwerp van gebouwen in functie van aanpasbaarheid: Mahatma Gandhiwijk – eindrapport"* (translated title: Case study design of buildings in terms of adaptability: neighbourhood Mahatma Gandhi – final report), OVAM, not yet published

[3] ALLACKER K, "*Sustainable building, The development of an evaluation method"* PhD Dissertation, Leuven, Katholieke Universiteit Leuven, 2010, ISBN 978-94-6018-231-0

[4] ALLACKER K, DE TROYER F, GEERKEN T, DEBACKER W, SPIRINCKX C, VAN DESSEL J, JANSSEN A, DELEM L. *"Final Report: Sustainability, Financial and Quality Evaluation of Dwelling Types (SuFiQuaD)"*, Belgian Science Policy (BELSPO), 2011, www.belspo.be/belspo/SSD/science/Reports/SuFiQuaD_FinalReport_ML.pdf [accessed May 2013]

[5] DE TROYER F, *"Bouweconomie en systeembouw"* (translated title: Building economy and building systems), ACCO, Leuven, 2007.

[6] DEBACKER W, ALLACKER K, DE TROYER F, JANSSEN A, DELEM L, PEETERS K, DE NOCKER L, SPIRINCKX C, VAN DESSEL J, *"Milieugerelateerde Materiaalprestatie van Gebouwelementen - finaal rapport"* (translated title: Sustainable Material Management of building elements – final report), OVAM, 2012 , www.ovam.be/jahia/Jahia/pid/2594?lang=null [accessed MAY 2013]

[7] www.pre-sustainability.com/simapro-lca-software, [accessed MAY 2013]

[8] www.ecoinvent.ch, [accessed MAY 2013]

[9] HUFFMEIJER F.J.M, *"Levensduur van bouwproducten: praktijkwaarden"*, (translated title: Life span of building products: values from the practice), SBR, Rotterdam, 1998.

[10] www.kpw-architecten.be, [accessed MAY 201]

[11] BRAND S, "*How Buildings Learn: What Happens After They're Built*", Penguin Books, New York, 1995

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Chair: Oliver Englhardt
Graz University of Technology, Austria

Guidelines and Indicators for Sustainable Mega-Event-Buildings



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Short Summary

Over the past years organisation committees of mega-events, like Olympic Games or European or World Football Championships, have more and more been demanding for the evaluation of the sustainability performance of their venues. These assessments have been made with different instruments and a comparison of the sustainability is not yet possible at all. Therefore the abstract will show a common set of sustainability indicators for the whole life-cycle of mega-event venues that integrate ecological, social, and criteria, as well as aspects for sport events.

Keywords: Sustainable mega-event venues, sport facilities, planning instruments, assessment methods

Introduction

Mega-event venues are not only sport facilities, they stand for national and regional representation and shall show the competence of technology, engineering and architecture of the Olympic cities or European or World Football Championships countries. In the last years the organisation committees of sport events are demanding for environmental assessments for their temporary and long-lasting buildings (venues, multi-functional halls, exhibition centres etc.) and also tools for legacy and sustainability aspects have been implemented in the planning process of mega-event venues to guarantee ecological, economic and social infrastructures for sport events. Further on slogans, like „Green Games“ or „The Greenest Games in Modern Times“ have been shown during the recent Olympic Games, like Beijing 2008, Vancouver 2010 or London 2012. The Olympic cities seem to compete for the greenest Games. But are these slogans just a “Greenwashing” or will these „Green Games“ and „Green Venues“ concepts be reality?

1. Green and Sustainability Guidelines and Assessment Methods for Mega-Event Venues

It is clearly true, that mega-events have strong additional and long-lasting impacts on the surrounding environment of the host countries and cities and could never be announced as “sustainable”. Especially the mega-event buildings have the greatest visible and long-lasting effects [1]. The impacts of mega-events could be reflected by a variety of aspects, influencing the environment, the society or the countries’ economy as well in a negative, as in a positive way. For the construction sector the following positive successes could be announced [2]:

- Introduction and improvement of environmental laws and building standards in the field of energy efficiency, sustainability and protection of historic buildings and monuments

- Promotion of energy-efficient and environmental technologies for the building construction sector
- Development of planning tools for the evaluation of the sustainability performance of buildings

To implement sustainable concepts in Olympic Games or in Football World and European Championships, the IOC (International Olympic Committee) and also the FIFA/ UEFA (Federal International Football Association/ Union of European Football Associations) have started to demand for sustainability impact assessments for venues since a couple of years. Regarding to this demand different sustainable planning concepts and the use of sustainability assessment methods have been adopted by the host cities and organisation teams. Examples are the venues of the Vancouver 2010 Olympic Winter Games (LEED Canada certification), the London 2012 Olympic Games (BREEAM certification) or for the Stadia for the Football World Cup of Brasilia (LEED U.S. certification). But this process is just at the beginning and the implementation of sustainability aspects into mega-event venues is still on an early stage [2].

1.1 Environmental and Sustainable Guidelines of Non-Profit-Organisations (NON), Sport Federations and Organising Committees

To define and reduce the enormous additional impacts of mega-events, the national and international sports federations and organizers of sporting events have launched various sustainability initiatives in recent years. However, the intent of these guidelines and projects is focused more on the environmental friendly management of the events, rather than on the planning, construction and operation of sustainable venues. For mega-events in general the guideline "Green Champion - Guide for Large Sporting Events" has been developed by the German Olympic Sports Confederation (DOSB) together with the Federal Ministry of Environment (BMU) in 2009. For European and World Football Championships the project “Green Goal” has been advanced for the World Cup 2006 in Germany. The Green Goal concepts aim to reduce the impact on the environment and the climate. The main topics of this label are energy, water, waste, mobility and catering. The concept was overtaken for the Football World Cup 2010 in South Africa, as well for the Women World Cup 2011 in Germany [3].

While football associations, like FIFA or UEFA have launched the implementation of environmental topics just for a few years, the IOC has started to support the Host Cities since the early nineties. This circumstance promotes both the quality and the attractiveness of the Games, as well as the sustainability. Some of the important steps are shown in the following [2]:

- 1994: Announcement of the environment as the third dimension of the Olympism
- 1996: Implementation of an environmental chapter in the Olympic Charter
- 1996: Foundation of the Sports and Environment Commission.

In addition, numerous voluntary guidelines, such as the Olympic Movements Agenda 21, the Manual on Sport and Environment or the IOC Guide on Sport and Environment have been established. This development is supported by further mandatory IOC tools, the so-called “Five Pillars” of the Olympic Games Management [2]:

- the Applicant and Candidature Procedure and Questionnaire
- the Olympic Games Study
- the Transfer of Knowledge
- the Global Impact of the Olympic Games
- and the Audit and Masterplan.

To implement sustainable Olympic venues, the IOC demands in its Candidature Procedure and Questionnaire that sustainability impact assessments for all Olympic venues have to be carried out already in the candidature phase. Yet this demand is answered by the future host cities by employing different assessment methods: starting from sustainability reports of NGOs, like UNEP, Greenpeace or WWF to national assessment methods, like the American Label LEED or the British system BREEAM [2].

1.2 National and International Assessment Methods for Sustainable Venues of Large Sport Events

While FIFA and UEFA are claiming for an environmental assessment of the venues based on the American label LEED, the IOC is asking for national sustainability evaluations. This development goes back to the Olympic Games 2000 of Sydney, where benchmarks have been launched for the ecological assessment of venues the first time. The national Australian assessment methods Green Star (Green Building Council Australia – GBCA) and NABERS (National Australian Built Environment Rating System, Australian Government) have been developed on the basis of the Olympic indicators [2].

	Methods	Facilities	Assess-sess-ment	Development
Sydney 2000	**ESD** (Environmental Sustainable Development)	Olympic Village and Venues	*	**Green Star** **NABERS** (National Australian Built Environment Rating System)
Salt Lake City 2002	**LEED New Construction (U.S.)**	Venues	*	Existing assessment system
Turin 2006	**GBTool** (Green Building Tool)	Media Village	*	**Protocollo Itaca**
Beijing 2008	**GOBAS** (Green Olympic Building Assessment System)	Olympic Village and Venues	*	**GBAS** (Green Building Assessment System)
	LEED for Neighbouring Development	Olympic Village	Gold	Integration of LEED in China
Vancouver 2010	**LEED New Construction Canada** Types: LEED for Neighbouring Development Canada, LEED Interior Design	Olympic Village and Venues	Silver to Platin	Existing assessment system
London 2012	**BREEAM** Types: BREEAM Bespoke, EcoHomes, BREEAM Communities	Olympic Village and Venues	Code Level 4, Excellent	Existing assessment system: Development of **BREEAM for Olympic Park and Venues** (based on BREEAM Bespoke) Development of the pilot version BREEAM Communities
Sochi 2014	**EIA** (Environmental Impact Assessment)	*	*	*
	BREEAM Russia	Olympic Village and Venues	*	Integration of BREEAM in Russia
Rio de Janeiro 2016	**LEED New Construction (U.S.)**	Venue	*	Existing assessment system

* no information available

Fig. 1: Assessment methods for the evaluation of the sustainability performance of Olympic facilities [5].

The organising committees of the Olympic Winter Games of Vancouver 2010 (VANOC) and the London Summer Games of 2012 have certified their new and existing competition venues and non-competition facilities by applying existing national assessment schemes to build and operate Games facilities, that would ensure a minimal environmental footprint. Vancouver, for instance, has used the North-American system LEED Canada (Leadership in Energy and Environmental Design) to assess its Olympic sports facilities. For the London Games 2012 the label “BREEAM for Olympic Park and Venues” was developed by BRE (Building Research Establishment) within the national sustainability method BREEAM (BRE Environmental Assessment Method) to assure the ecological implementation of the Olympic venues [5]. Especially for the Olympic venues of the Beijing 2008 Games, the Chinese Ministry of Construction (MoC) and the Ministry of Science and Technology (MoST) developed the Green Olympic Building Assessment System (GOBAS), which is based on the Japanese assessment method CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) and the North-American LEED system. For the Olympic Winter Games of Turin 2006, the Turin media village was assessed by means of GBTool, which provided the basis for the current national assessment method PROTOCOLLO ITACA. The example of the Winter Olympic Games of Sochi 2014, however, shows that the use of assessment methods for Olympic venues has not yet been enforced at all. First approaches to assess the Olympic venues of Sochi, has been mentioned in the Bid Book (application form), but concrete implementations are not visible one year before the Games. At the moment the development of a BREEAM Russia version to assess the venues is under discussion [2].

Considering that the IOC is only demanding for assessing the sustainability performance of the facilities, but not giving out common mandatory indicators and benchmarks, the host cities have fulfilled this requirement with different assessment tools in the last year. Due to these diverse instruments, the evaluation results of the venues are not comparable at all, have different significances according to environmental, economic and social aspects and are not integrating the entire life cycle of sport venues (Olympic legacy).

2. Criteria and Indicators for the Sustainability Performance of Mega-Event Venues

At the moment a comparison of the sustainability performance of mega-event buildings is not yet possible at all. In most cases just ecological and energy efficiency aspects and the use of the buildings during the mega-event were analysed. Social, economic, technical, functional, process and site orientated criteria, as well as the re-use of the buildings after the event have not been addressed so far.

Therefore the abstract shows a new set of common criteria, indicators and benchmarks for the sustainability performance of mega-event sports architecture. This set of indicators is based on the results of the dissertation “Sustainability of Olympic Venues” that was published in 2010 [1], and on the outcomes of the research project “Guidelines for Sustainable Venues of Mega-Events” that was supported by the BMWi (Federal Ministry for Economics and Technics) from 2012 to 2013 [2]. The main goal of these projects was to develop a guideline for the assessment of buildings of mega-events in order to be able to compare the sustainability of mega-event buildings over the whole life-cycle (design, event, post-event and end-of-life). During these studies, analyses of the concepts and impact assessments for recent Olympic Games and Football Championships have been done. Also sustainability reports of NGOs, like UNEP, Greenpeace or WWF have been integrated into the analyses, as well as the sustainability guidelines and regulations of the IOC and the FIFA/ UEFA. The main objective of this research project was the derivation of criteria for sustainable mega-event venues.

2.1 Structure and Methodology for the Sustainability of Mega-Event Venues

The structure of the indicator catalogue is based on the results of the EU project "OPEN HOUSE". The main goal of the OPEN HOUSE, which was initiated in the seventh research framework

programme, was to develop a European methodology for assessing the sustainability performance of buildings (time period: February 2010 to August 2013). During this project all existing Europe assessment methods have been compared with each other and a catalogue of sustainability criteria for the construction of office buildings have been developed (www.openhouse-fp7.eu). The structure and the content of the OPEN HOUSE project is an international sustainability assessment method, that is based on environmental and energy aspects, social and economic issues and the latest international and European standardization (ISO TC 59 SC 17: Sustainability in Building Construction, CEN TC 350: Sustainability of construction works - Framework for assessment of buildings) [6].

Besides the OPEN HOUSE six pillars model
- Ecological Quality
- Social/ functional Quality
- Economic Quality
- Technical Quality
- Technical Characteristics
- Process Quality
- and the Site

special indicators for mega-events have to be considered as well. After analysing the voluntary and mandatory guidelines of the IOC and the FIFA/ UEFA and the sustainability reports of the NGOs, like UNEP, Greenpeace or WWF and discussions with mega-event experts, the new category
- Quality of Mega-Event Venues

was added [3].

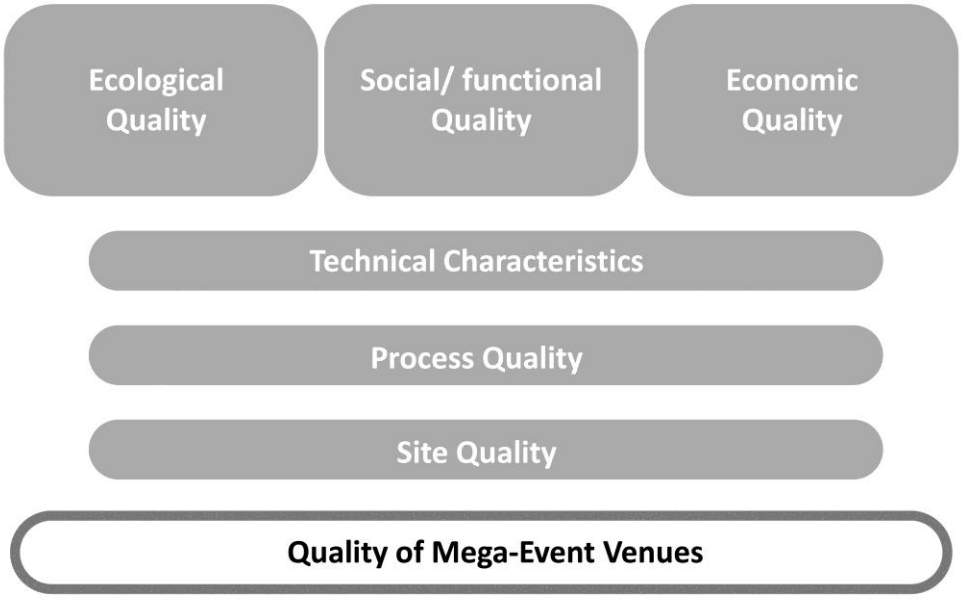


Fig. 2: Sustainability categories for mega-event buildings based on OPEN HOUSE [3].

2.2 Sustainable Indicators for Mega-Event Facilities

Based on the results of the research project the following catalogue with 63 indicators for sustainable mega-event buildings have been developed [2 and 3]:
- Ecological Quality:
  Resources, energy, life cycle assessment (LCA), water, waste, materials, land use, recycling, biodiversity etc.
- Socio-cultural and Functional Quality:
  Comfort, healthiness, user, barrier free accessibility, area efficiency, reuse, security, public

accessibility, service comfort, architecture and design, regional and cultural aspects, innovation etc.

- Economical Quality:
  Value stability, life cycle costs etc.
- Technical Quality:
  Fire protection, durability, cleaning and maintenance, resistance against hail, storm, high water and earthquake, technical building equipment, building shell, ease of deconstruction etc.
- Process Quality:
  Planning process, integral planning, tendering, construction site, operation etc.
- Site Quality:
  Risks at the site, options for transportation, circumstances at the site, bicycle comfort, image and conditions at the neighbourhood, vicinity of amenities etc.
- Quality of Mega-Event Buildings:
  Re-use and legacy, temporary and existing buildings, sport functional aspects etc.

In summary 25 core goals for sustainable venues could be derived from the main catalogue. These core indicators could be used as a simplified and transparent decision-support-tool for decision-makers of major events and should provide a first overview of the sustainability performance of mega-event facilities (see figure 3).

Environmental Quality	1. Life-Cycle Analyses (LCA: GWP, Primary Energy etc.)
	2. Biodiversity and Depletion of Habitats
	3. Water and Waste Water
	4. Land Use
	5. Waste Management
Social/ Functional Quality	6. Barrier-free Accessibility
	7. Security and Healthiness
	8. Comfort
	9. Public Accessibility
	10. Conversion Feasibility
	11. Responsible Material Sourcing
Economic Quality	12. Building-related Life Cycle Costs (LCC)
Technical Characteristics	13. Noise Protection
	14. Quality of the Building Shell
	15. Ease of Deconstruction, Recycling, and Dismantling
Process Quality	16. Quality of the Project's Preparation
	17. Integrated Planning
	18. Construction Site impact/ Construction Process
	19. Commissioning and Monitoring
The Site	20. Options for Transportation
Ouality of Mega-Event Buildings	21. Integration of the Olympic Buildings into the urban planning (Master Plan)
	22. Quality of the Legacy: concepts for re-use



23. Temporary and Existing Venues
24. Sport-functional Requirements of the Ifs (International Associations): Sportsmen and visitors
25. Enhancement of Sustainability in Education (Architects, Engineers, Construction worker etc.)

Fig. 3: Core indicators for sustainable mega-event buildings [3].

3. Criteria and Indicators for the Sustainability Performance of Mega-Event Venues

Based on the results of the named studies the following advantages for the use of assessment methods for the sustainable performance of venues could be noted [3]:

- Promotion of subsequent use and degree of capacity utilization of the Olympic sports arenas after the Olympic games through higher competitiveness and considerable increase of added value of the sports venues through their whole lifecycle (Olympic Games and thereafter) Securing the comparableness of the Olympic sports venues on an international level.
- Promotion of the Olympic values through an integral sustainability assessment of the Olympic sports facilities (ecological, economic, socio cultural and Olympic aspects).
- Improvement of the transparency of the Olympic planning process through characterization of sustainability quality of the Olympic sports venues and through the provision of information for operators and users of the sports facilities.
- Guarantee of the implementation of sustainable building quality of Olympic sports facilities through monitoring und promotion of the integrative planning process.
- Promotion of the quality standards of the international construction of sports venues by accelerating the introduction on the market of new and energy efficient technologies and ecological materials for the construction of sports arenas.
- Reduction of the negative effects of the mega event Olympic Games on the environment through improvement of the building quality, comfort for the user, the energy efficiency and the public effects of the Olympic sports facilities.
- Certification as marketing instrument for sustainable Olympic sports facilities.

References

[1] PREUSS, H. *"The Economic of Staging the Olympics: A Comparison of the Games 1972-2008"*, Cheltenham, 2004, 978-1845427221

[2] ESSIG, N. "*Nachhaltigkeit von Olympischen Sportbauten (Sustainability of Olympic Buildings)*", Stuttgart, 2010, ISBN 978-3-8396-0168-6

[3] ESSIG, N., HIEBEL, M., SCHNEIDER, S., JÄGER, M. *„Leitfaden zur Bewertung der Nachhaltigkeit von Bauten für Großveranstaltungen (Guidelines for the Assessment of the Sustainable Performance of Buildings of Mega-Events)*", 1st Interim Report, Munich, 2012, DOI:http://www.ins.din.de/cmd?level=tpl-artikel&menuid=52986&cmsareaid=52986&cmsrubid=159225&menurubricid=159225&cmstextid=145423&2&languageid=de

[4] ESSIG, N., GANTNER, J., MAGDOLEN, S. *„London 2012 - ein Ansatz für nachhaltigere Spiele? (London 2012 – An Approach for more sustainable Games)"*, Munich, 2012, DOI: http://www.detail.de/architektur/news/london-2012-ein-ansatz-fuer-nachhaltigere-spiele-019406.html

[5] ESSIG, N., HINIESTO MUNOZ DE LA TORRE, D. *"OPEN HOUSE – an European Approach to Assess the Sustainability of Buildings*", in Proceedings SB 11 Helsinki World Sustainable Buildings Conference, 18.-21. Oktober 2001, S. 462-464, Helsinki, 2011

A free building assessment tool facilitates change in the construction sector towards environmental, economic and social sustainability



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Short Summary

The ÖGNB offers a comprehensive sustainability criteria framework for residential and non-residential buildings which should be used from the very beginning of a building project, especially as a checklist for the meetings between the design team and the client which serve to shape the project and to define the design targets. ÖGNB members recognise ambitious building performance requirements to approach the goal of sustainability in the building sector. However, there are also concerns regarding the related costs, on the one hand for the building assessment procedure itself, and on the other hand regarding a potential increase in construction costs as a consequence of building performance requirements. In 2012, ÖGNB organised a series of workshops for the ÖGNB members to deal with these concerns and to elaborate the basis for revising the assessment criteria, scales and guidelines accordingly. These review workshops resulted in many small adjustments, based on the experience gained during the utilisation of the assessment tool. In addition, the workshop participants agreed on some major revisions, among others for the criteria *energy, building operation, accessibility without barriers,* and *fire safety*, which represent selected examples described in this paper. The revision of the building assessment framework contributed to the discussions among the ÖGNB members and initiated discussions in the respective associations and companies. It did not only improve the assessment framework but also contributed to awareness creation regarding the costs of the building assessment itself, the feasibility of the required building performance and the associated construction and life cycle costs, thus revealing the need and the potential for technological innovations.

Keywords:Green building; building assessment; integrated planning; building optimization

1. Introduction

The ÖGNB - Österreichische Gesellschaft für Nachhaltiges Bauen (English: Austrian Sustainable Building Council) builds on the experience gained from the participation of its founding members in the international *Green Building Challenge* starting from 1996. Austria joined 1998 and experts from different fields developed the first Austrian building assessment scheme with the support of three Austrian Federal Ministries. [1]

Today, ÖGNB still runs this building assessment scheme in the form of a further developed version and offers also building certification based on this system.

However, the organization’s focus is rather on providing a platform for further developing technical concepts, enabling product innovations and discussing new ideas and concepts than on promoting building certification.

Therefore, above all, the building assessment scheme is used as a communication and information tool as well as an instrument to facilitate change in the construction sector. In this regard, in 2012 a sequence of criteria-review workshops has been conducted with the members of the ÖGNB, to discuss the assessment criteria, the targets, allocation of scores and required supporting documents in the light of new technical developments, changing framework conditions, lessons learnt from previous building assessments, European research projects and experiences of other building assessment schemes offered in Europe.
This conference contribution presents selected results of the criteria-review workshops and their implication on the assessment scheme, resulting in an adjusted version. Like the previous one, the adjusted version is publicly accessible via the Internet, free of charge and available in English.
It is easy to understand and to operate and van be used in education, for quality control, risk assessment and product innovations, in order to facilitate the change in the construction sector towards environmental, economic, and social sustainability.

2. Background information: ÖGNB building assessment procedure

ÖGNB offers a comprehensive criteria framework for the sustainability assessment of residential and non-residential buildings which should be used from the very beginning of a building project, especially as a checklist for the meetings between the design team and the client which serve to shape the project and to define the design targets.
This criteria framework is available in the internet and corresponds with the web-based tool which is applied to collect building related information during the building assessment process to prove whether requirements are met or not. These are the so-called supporting documents which are specified for each criterion to ensure the comparability of assessment results.
In short, the ÖGNB building assessment procedure is carried out in five steps:

- Building documentation using online declaration tools; carried out by consultants who are appointed by the ÖGNB
- Handover of submitted project to the ÖGNB and application for building surveying
- Verification of proof by ÖGNB auditors, who are listed by the ÖGNB; if necessary revision of proof by ÖGNB consultants
- Approval of assessment results by ÖGNB after consulting with submitters
- Publication of assessment results in ÖGNB press, above all on ÖGNB website

3. ÖGNB building assessment – review workshops

ÖGNB members recognise ambitious building performance requirements to approach the goal of sustainability in the building sector. However, there are also concerns regarding the related costs, on the one hand for the assessment procedure itself, and on the other hand regarding a potential increase in construction costs as a consequence of building performance requirements. In 2012, ÖGNB organised review workshops to deal with these concerns and to elaborate the basis for revising the assessment criteria, scales and guidelines accordingly.
The main objectives of the review were the following ones:

- To compare assessment criteria and targets with the technical development and the development regarding the regulatory framework, and to agree on necessary adaptations
- To check whether the procedure to produce supporting documents can be simplified
- To analyse the relation between the efforts needed to meet a requirement and the scores allocated to this requirement, and to agree on necessary adaptations

The review workshops resulted in many small adjustments, based on the experience gained during the application of the criteria, scales and guidelines, and the utilisation of the assessment tool.

In addition, the workshop participants agreed on some major revisions such as for the following criteria representing selected examples which are described in the next chapters:

- Energy (adapt to change of regulation to save effort for preparing supporting documents)
- Building operation (in view of nearly zero energy buildings and plus-energy buildings: what to consider to ensure low energy consumption during building operation)
- Accessibility without barriers (take into account construction costs of building assessment requirement)

- Fire safety (relation between the efforts needed to meet a requirement and the scores allocated)

3.1 Energy

The ÖGNB building assessment builds on Austrian practice and framework conditions. It is the objective to use available documents as supporting documents during the assessment procedure, whenever possible. This limits additional costs caused by the building assessment itself. Therefore, energy-related criteria comply with the respective regulations. Due to the recast EPBD (Energy Performance of Buildings Directive, Directive 2010/31/EU) there was the need to adapt the ÖGNB assessment framework accordingly.
The main indicators to be assessed in terms of building energy performance correspond with the indicators displayed in the new Austrian energy performance certificate according to recast EPBD (Directive 2010/31/EU).
These indicators are the following ones:

- HWB - Heizwärmebedarf, heating energy demand: describes the energy related quality of the building envelope (refers to transmission losses);
- fGEE - Faktor Gesamtenergieeffizienz, total energy efficiency factor: describes the efficiency of building energy use (includes also energy conversion losses caused by the building services, such as the heating system);
- PEB - Primärenergiebedarf, primary energy demand: this indicator includes the amount of energy needed to provide the energy used in the building and thus refers to the ecological dimension;
- CO2 - Carbon dioxide emission: This indicator refers to CO2 emissions caused during building operation and thus refers to the amount of renewable energy used by the building, taking into account the amount of energy produced at the building site.

3.2 Building operation

This criterion refers to the fact the user behaviour is an important aspect regarding the actual energy consumption of the building. Therefore this criterion asks for the appropriate building equipment in terms of separate measuring the energy consumption by major consumers such as heating, ventilation, cooling, lighting, and pumps. In addition, appropriate user information is required, e.g. manuals which describe the equipment, addressing occupants but also facility managers. Only if the appropriate equipment is installed and information is available it will be possible to steer the users' behaviour during building operation and to ensure that the actual energy consumption does not exceed the predicted level.

In view of developments such as nearly zero energy buildings and plus-energy buildings user behaviour and actual energy consumption becomes even crucial.

In one of the workshops it was discussed that energy accounting and separate measuring of energy consumption by consumer is very important but needs to be complemented by occupancy data. During building operation it is necessary to verify energy accounting data against occupancy data, because only if it is known which part of the building is actually in use at what time, energy data will be interpreted correctly and measures to steer actual energy consumption will be effective. This aspect should be included in manuals especially addressing facility managers in large buildings.

3.3 Accessibility without barriers

Building requirements must be economically acceptable. While in new construction additional costs caused by sustainability requirements are modest or even not existing taking into account the entire life-cycle of a building, this might be completely different in building renovation. In general we believe that the same criteria should be applied to new and existing buildings, due to the fact, that the occupants are interested in the building performance as such, irrespectively whether the building is a new or an existing one. However, in some cases like to following one, exemptions are justified.

Access for all without discrimination is essential and must be taken into account when designing a new building. It is an important criterion in the ÖGNB assessment framework, but in building renovation there is a major trade off with costs, especially in residential buildings for social housing where affordability is the key issue.

Therefore, in terms of accessibility without barriers, the assessment of new and existing buildings will be different in future, and the scale of the criterion was adapted in the following way for the assessment of existing buildings and building renovations:

- It is the minimum requirement that in the course of a building renovation at least one apartment must be adapted to meet the requirements of accessibility without barriers.
- At the same time, at least those parts of the building leading to that apartment must be free of barriers, as well.

3.4 Fire safety

In Austria, structural fire protection is very much advanced and so is the mandatory level required by the building code (large buildings).

Increase in safety can be achieved by additional requirements in the area of organisational fire protection measures, e.g. additional fire alarm boxes, fire smoke boxes, fire hydrants on each floor and even smaller building units. This strengthens the occupants' perceived safety, actually helps in case of emergency, and additional costs are acceptable.

Therefore, the outcome of workshop discussions was to change the weightings of the sub-criteria *structural fire protection* and *organisational fire protection*, resulting in more scores for the organisational fire protection measures compared with the predominantly mandatory structural fire protection measures.

4. Conclusion

The revision of the building assessment framework contributed to discussion among the ÖGNB members and initiated discussions in the respective associations and companies. It did not only improve the assessment framework but also contributed to awareness creation regarding the costs of the building assessment itself, the feasibility of the required building performance and the associated construction and life cycle costs, thus revealing the need and the potential for technological innovations.

5. References

[1] GEISSLER S, BRUCK M, LECHNER R „*Total Quality (TQ) Planung und Bewertung von Gebäuden".* Wien: Berichte aus Energie- & Umweltforschung 08/2004, Bundesministerium für Verkehr, Innovation und Technologie

SCHOOLS GO GREEN - EXTENSION OF THE BNB-CERTIFICATION METHODOLOGY FOR EDUCATIONAL BUILDINGS



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Short Summary

The development and implementation of a sustainability certification methodology for buildings is considered to be a milestone of establishing principles for sustainable construction. In order to anchor this approach as widely as possible within the construction practice a continual extension of the certification methodology for different types of buildings is necessary. This paper outlines such a process on the basis of the system development and implementation for sustainable educational buildings.

Keywords: Sustainability; certification methodology; educational facilities; new system implementation

1. Introduction

Worldwide the sustainability approach is considered as a strategic response to global challenges of increasing scarcity of resources and climate change [1]. Germany committed to this approach by its national sustainable development strategy as well. Therein the construction and real estate industry plays a crucial role and is addressed by corresponding objectives and measures [2] since this key sector takes responsibility for enormous extractions out of and substance loads into our environment by constructing, operating and dismantling buildings. More than one third of all energy and material flows are, for instance, caused by the construction industry. In addition a comparable proportion of all CO2-emissions of the OECD-countries is induced only by residential and commercial real estate and furthermore construction industry waste represents approximately 60 % of the entire German waste production (fig. 1).

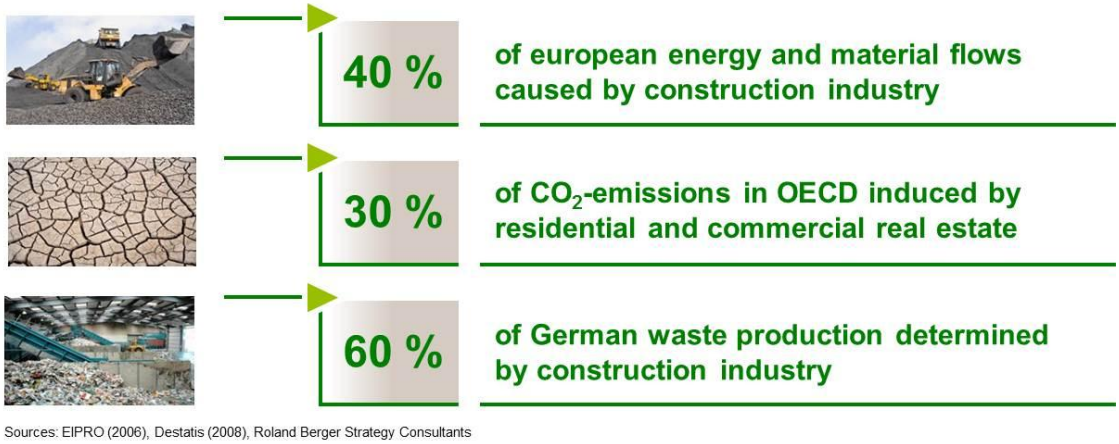


Fig. 1: Environmental impacts of the construction and real estate industry

An accelerated life-cycle approach to buildings by taking into account ecological, economical and socio-cultural aspects equally and completed by technical and functional concerns - that means in fact the establishment of principles for sustainable construction - is one of the key elements of the construction industry's sustainable development [3]. A logical consequence is that such a systematization of the sustainability approach requires making the sustainability quality of buildings measurable and transparent.

Therefore the development of the German sustainability assessment or certification system "Nachhaltiges Bauen für Bundesgebäude" (BNB) involving all relevant stakeholders created the basic prerequisite for public building projects. This system was initially launched as a basic system appropriate for the typology of office buildings. Fig. 2 shows the essential methodology of the described BNB-basic system.



Fig. 2: Assessment and certification methodology of BNB-basic system [3]

However the large variety of building typologies belongs to the main attributes of the construction and real estate industry. This means that a macroeconomic anchoring of strategy and principles for sustainable construction needs an enlarged portfolio of BNB-system versions beyond office buildings and for the entire range of market relevant types of buildings.

2. System draft "Nachhaltige Unterrichtsgebäude"

Educational buildings represent such a relevant type of buildings because the according real estate stands for a significant part of the total public building stock [4]. For this reason a working group formed of municipal and federal representatives as well as scientists and planners was engaged by the Federal Ministry for Transport, Building and Urban Development to develop a system draft for the assessment of sustainable educational buildings which is able to be embedded in the existing BNB-certification methodology. This further development of the BNB-basic system towards a system version for educational buildings is challenging because the different forms of use to be mapped (elementary schools, secondary schools, universities, training centres) vary considerably and the consequential heterogeneity of the user structure leads to an enormous range of requirements and quality respectively sustainability criteria to be integrated in a corresponding system draft.

Although several assessment criteria of the BNB-basic system could be adopted, a large number of criteria had to be adjusted to specific needs of educational buildings (i.e. criterion for the assessment of acoustic comfort). Furthermore additional criteria had to be developed for the aimed system version "*Nachhaltige Unterrichtsgebäude*" [5] (see fig. 3).

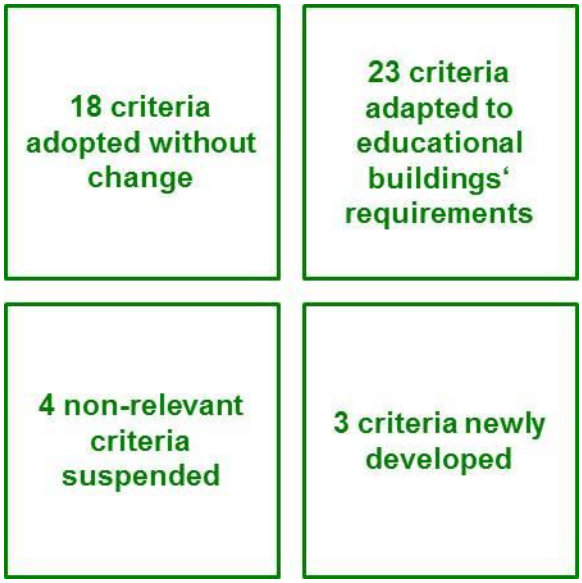


Fig. 3: Main results of system version development

One of these new criteria is for instance the quality of an educational building concerning the prevention of damages due to vandalism. This procedure was essential in order to ensure an adequate capacity of mapping specific sustainability aspects of educational buildings and furthermore a high acceptance of the assessment or certification system itself. Moreover especially the assessment methods and levels had to be configured without advantaging or discriminating one special form of use.

3. System implementation and initial application - Key findings

As part of the development and market implementation of sustainability assessment or certification systems it is common practice to check the application suitability of a system draft by realising a pilot study. During August 2011 to November 2012, the authors of this paper carried out a research project on behalf of the Federal Ministry for Transport, Building and Urban Development in order to test and check intensively the described first version of a system draft for sustainable educational buildings by implementing a phase of initial application. The group of participating pilot projects consisted of seven new built educational buildings of different usage forms from all over Germany which had to face a sustainability assessment by applying the system draft. Pilot projects and their basic characteristics are shown in table 1.

Table 1: Participating pilot projects

Fig.	Number	Name	Usage form	Floor area [m²]	Certification performance
	0001	Uckermark-Kaserne	Lecture hall building	1564	68 %
	0002	Technologiezentrum Holz	Vocational school centre	2976	59 %
	0003	Bildungszentrum Fischbeck	Educational/ cultural centre	6976	68 %
	0004	Fachhochschule Erfurt	Lecture hall/ laboratory	2246	*under examination*
	0005	Berufsbildende Schule Mainz	Vocational school centre	5521	70 %
	0006	Universität Regensburg	Lecture hall building	7649	71 %
	0007	Romaneum Neuss	Cultural centre	9400	65 %

First objective of the project was on the one hand the professional supervision and technical support of the sustainability coordinators of the participating pilot projects by preparing the certification and documentation data. Based on this data the pilot projects' conformity assessment was implemented regarding its compliance with the requirements of the system draft as far as the sustainability quality of sustainable educational buildings is concerned. The results of the conformity assessment led to the calculation of a certification performance and finally to the awarding of sustainability labels (see table 1).

On the other hand the operable completion of the system draft, this means the finalisation towards an operational market version, was the second basic element of the research project. Therefore the participating pilot projects' results and key findings of the conformity assessment had to be analysed concerning possible weaknesses and deficits of the system draft. Thereby especially the feedback of the pilot projects' sustainability coordinators played a highly important role. First of all one conclusion and key finding (see fig. 4) is that the system draft is basically suitable for a sustainability assessment of multiple forms of educational buildings.

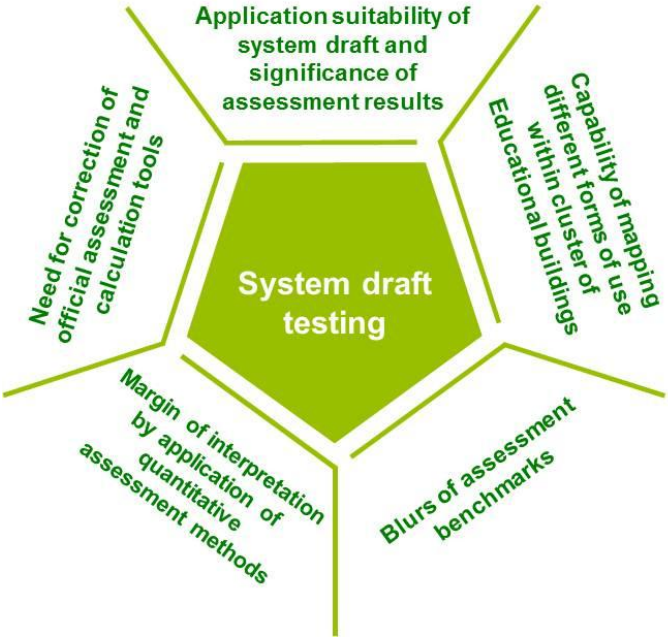


Fig. 4: Key findings of system draft testing

But secondly particular assessment criteria were not adequately specific to map different forms of use or showed selective blurs in assessment benchmarks. Lastly several assessment methods left inacceptable margins of interpretation by their application and particular assessment or calculation tools showed marginal need for correction [6].

4. System finalisation - Market version 2013

By a change of perception - from diagnostic inventory towards a means orientation - the identified conclusions could be transformed into a correlated strategic approach of finalising the system draft for a operational market version (see fig. 5).

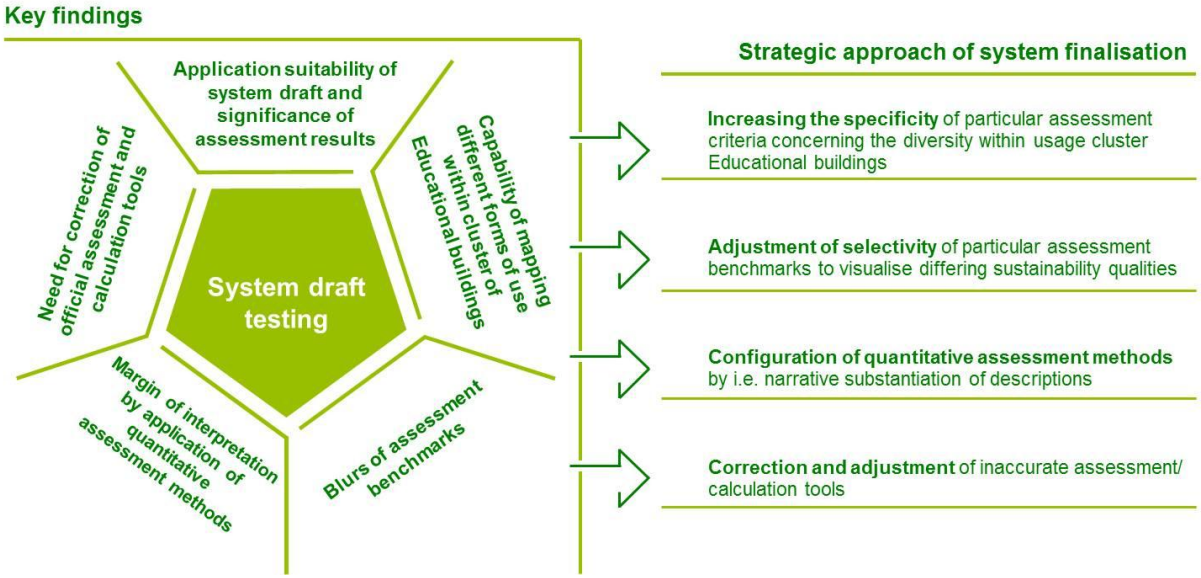


Fig. 5: Strategic approach of system finalisation

An increased specificity of particular assessment criteria concerning the diversity within the usage cluster of educational buildings was achieved i.e. by splitting and individualising their assessment methods with regard to the expected age of building users. The adjustment of selectivity was furthermore ensured by a more precise partition of the assessment benchmarks, whereas undesirable margins of interpretation as part of the application of quantitative assessment methods was repaired through a new configuration of these methods, i.e. by narrative substantiation of descriptions. Finally a correction and adjustment of inaccurate assessment or calculation tools was realised in cooperation and coordination with the Federal Ministry of Transport, Building and Urban Development.

On this basis the implementation of the market version is scheduled for the early year of 2013. But since sustainability assessment or certification systems always have to be adapted to the technical and scientific progress, the market version for sustainable educational buildings will also be part of a continuous development process of system updating.

References

[1] GRAUBNER C.-A., SCHNEIDER C., POHL S., WRONNA A., „Beyond Platin - Nachhaltigkeitstrends in der Bau- und Immobilienwirtschaft“, Mauerwerk, Vol. 16, No. 5, 2012, pp. 255-261

[2] THE FEDERAL GOVERNMENT (ed.), „Perspektiven für Deutschland. Unsere Strategie für eine nachhaltige Entwicklung“, www.bundesregierung.de, 2002

[3] FEDERAL MINISTRY OF TRANSPORT; BUILDING AND URBAN DEVELOPMENT (ed.), “Leitfaden Nachhaltiges Bauen”, www.nachhaltigesbauen.de, 2011

[4] FEDERAL MINISTRY OF TRANSPORT; BUILDING AND URBAN DEVELOPMENT (ed.), “Typologie und Bestand beheizter Nichtwohngebäude in Deutschland”, BMVBS-Online-Publikation 16/2011

[5] FEDERAL INSTITUTE FOR RESEARCH ON BUILDING; URBAN AFFAIRS AND SPATIAL DEVELOPMENT (ed.), “Begleitung der Arbeitsgruppe Nachhaltige Unterrichtsgebäude - Endbericht”, www.bbsr.bund.de, 2011

[6] FEDERAL INSTITUTE FOR RESEARCH ON BUILDING; URBAN AFFAIRS AND SPATIAL DEVELOPMENT (ed.), “Bewertungssystem Nachhaltiges Bauen - Erprobung des Systementwurfs Nachhaltige Unterrichtsgebäude - Endbericht”, www.bbsr.bund.de, 2012

Challenges of LCA in a European context – Findings from the research projects OPEN HOUSE and EeBGuide



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Summary

Since the first LCA study was conducted in the 70ies and 80ies [14], Life Cycle Assessment (LCA) had to face multiple challenges. Most of them were related to data availability and methodological questions like a consistent approach to conduct LCAs. Some of the challenges are still up-to-date (e.g. data availability), others were solved by the International standards ISO 14040 [12], ISO 14044 [13] or the more construction specific European standards EN 15804 [5] and EN 15978 [6]. Also the ILCD Handbook [7], [8], [9], [10], [11] helped to form a transparent and commonly discussed basis for LCA. Hence, there are still some LCA challenges to be solved today. Some are similar to the first which appeared, others elaborated over time. This paper states challenges of LCA today based on the outcomes of the European research projects OPEN HOUSE and EeBGuide and should be considered as a start for discussions and not as complete summary.

Keywords: LCA, challenges, OPEN HOUSE, EeBGuide

1 Introduction

After the oil crisis in the 70ies and due to the increasing energy prices for oil and natural gas, Europe took a path leading to energy reduction and independency. In the last decades energy efficiency not only was considered in legislation (Energy Performance of Buildings Directive (EPBD) [4]) but also as an aspect for planning and evolution of buildings. Hence, building types were developed that have a very little energy demand, e.g. “minergie [29]” buildings, “Passivhaus [30]” buildings or even “plus energy” buildings. Due to that the overall environmental impact of the operational phase of a building decreased tremendously. By the reduction of energy consumed during operation and therefor the decrease of environmental impacts dedicated to these, the production phase and the End-of-Life (EoL) of the building materials gain in importance. Figure 1 illustrates this tendency.

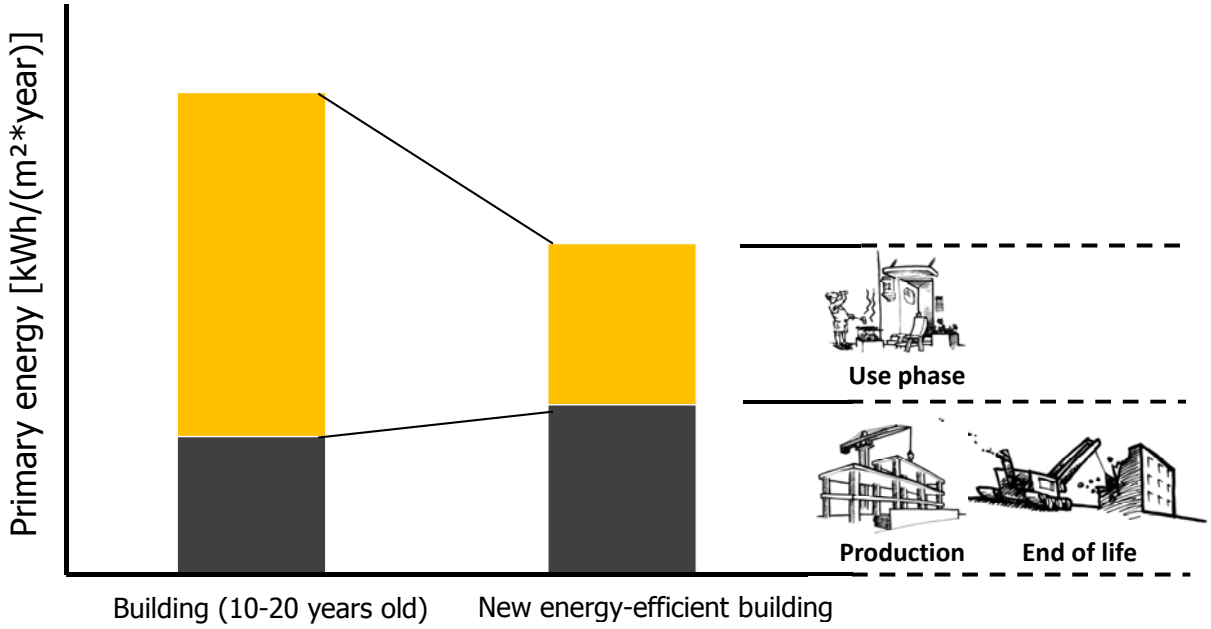


Figure 1: Ratio of use phase to production/EoL for a 10–20 year old building compared with a newly built “Passivhaus” [2]

The trend for more energy efficiency therefore created a need for a holistic view over the whole lifecycle of a building in order to avoid shifts of burden between different lifecycle stages. One important methodology to support planners and architects is Life Cycle assessment (LCA). In recent years LCA in the building sector has increasingly gained in importance. They are applied in the certification of sustainable construction (e.g. BREEAM, HQE, VERDE, DGNB), provide a base for environmental declaration of building products (EPD) and progressively serve as well for decision support. Nevertheless on a European level LCA still faces some challenges. For future progress in LCA it is important that these are transparently pointed out and discussed within LCA experts. Therefore the major challenges figured in the European research projects OPEN HOUSE [1] and EeBGuide [2] are addressed and set in the overall European context.

2 Challenges of LCA in the future:

In order to form a discussion basis, the following major challenges figured in the European research projects OPEN HOUSE [1] and EeBGuide [2] are addressed and set in the overall European context. Hereafter, some of these challenges are stated and explained in more detail. When relevant, potential solutions are pointed out.

2.1 Inconsistency of current guidance documents and standards on LCA

Inconsistency in LCA guidelines and LCA standards is problematic for the widespread use of LCA in general but more specifically in the construction sector. The different available legislative guidelines (e.g. ILCD handbook) and standards (e.g. ISO 14040 [12], ISO 14044 [13], EN 15804 [5], EN 15978 [6]) differ from each other regarding Life Cycle Impact Assessment (LCIA) and other LCA related methodological aspects. This fact can be explained due to the expert groups that differ between the ILCD Handbook (only LCA experts with no specific focus in the construction sector) and the CEN TC 350 standards (EN 15804 and EN 15978) where less LCA scientists attend the committee meeting but more construction stakeholders and building LCA experts. In the end, the goals of these two documents are diverging and many inconsistencies can be noticed based on EeBGuide results [2].

Following the ILCD may let the user adopt a consequential approach while the CEN TC 350 standards approach is only attributional. The first option can be relevant when analyzing large building stocks that can influence the background system (e.g. on national energy level) over their very long service life or decisions on a policy level.

Another example concerns the Life Cycle Assessment (LCIA) stage of the LCA framework.

Differences in completeness between ILCD and CEN TC 350

The ILCD handbook proposes recommended LCIA methods for the different impact categories including mid-point (e.g. global warming, acidification, human toxicity, ecotoxicity potentials) and end-point (e.g. damages on resources, ecosystem, human health) indicators. These methods were proposed at the end of several ILCD expert meetings gathering LCIA developers. The recommendations included all the impact categories though a level of maturity of each LCIA method was also added for information to the final user. Finally, highly uncertain impact categories like human toxicity are recommended to be included, using e.g. the latest developments (USETox), though, limitations were reported in the ILCD reports. In opposite, impact categories like GWP are judged not too uncertain and a recommended method is the one generally accepted (e.g. the IPCC method).

When the LCIA discussions moved within a sector-specific standardization committee (e.g. the CEN TC 350 for Sustainability of Construction Works), the approach may be slightly different. Robustness and agreement of the LCIA method may prevail on the latest scientific works. The share of the committee e.g. diversity of LCA experts, building stakeholders and industry trade unions can also play a role when deciding what should be or should not be included in the standard. It is crucial that in standardization work both visions on LCA – the academic one as well as the business perspective – shall be took into account in order to have the latest scientific results included in the standards but also in order to focus on applicability and relevance of these new developed methods. In addition, relevant indicators for sector specific committees may differ from the general practice. For example, the construction sector may prefer assessing MJ of primary energy and kg of waste.

In EN 15804 and EN 15978, no toxicity, ecotoxicity, ionizing radiations and land use LCIA indicators were taken into account as they were judged by the CEN TC 350 committee as not “mature enough“. Interestingly, the ILCD provision for the calculation of LCA results gives a background justification:

ILCD provisions for the calculation of LCIA results

> *ILCD Handbook – Part – Analysing of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment*
>
> *4 Requirements for specific impact categories*
>
> *“For some impact categories, many alternative methods have been selected. This can be seen as a sign that there is no clear consensus on how to model such a method. Clear examples are acidification, eutrophication, land use and resources.”*

As the standard reflects a consensus (in that sense, it is a different approach than doing research activities and working on guidance documents), it may be explained why in EN 15804 and EN 15978, no such indicators are included.

Surprisingly, additional LCI information is provided in the standards corresponding, according to the ILCD wording, to reminder flows (see the caption below) which are useful for the interpretation of results (i.e. useful for a reviewer but not corresponding to a proper parameter for impact assessment).

ILCD provisions for reminder flows (e.g. MJ of energy, secondary fuels, recycled waste…):

I)	*MAY – Use reminder flows to keep original information for specific purposes*
II)	*SHALL – Exclude reminder flows from impact assessment*
III)	*SHALL – Clearly identify reminder flows in the flow name*

In that case, the standards in a way go beyond ILCD recommendations by providing next to the 6 LCIA indicators more than 10 reminder flows corresponding to the breakdown of primary energy, water input, resource efficiency (material input, secondary fuel and material), waste (hazardous, non hazardous, radioactive) and recycled waste.

Finally, putting the two aspects together, we can question whether the ILCD recommended LCIA methods are fully applicable [18] due to lack of feedbacks and shortcomings still existing in the latest methods like USETox [11] and the choice of the construction sector standards to only use 6 LCIA indicator but around 10 reminder flows are not appropriate for impact assessment and thus for decision making.

Differences in LCIA hypotheses between ILCD and CEN TC 350

Another aspect are the differences in LCIA hypotheses between the ILCD Handbook [7] and the EN 15804 and EN 15978 standards. This is the case e.g. for the acidification and eutrophication potential. The reference units proposed in case of acidification (EN standards: kg SO_2- Equiv.; ILCD: moles H+ Equiv.) and eutrophication potential (EN standards: kg PO_4^{3-}- Equiv.; ILCD: mole N Equiv.) does not match. Indeed, the CEN TC350 standards are about to go towards a CML approach for calculating these two indicators while the cumulative exceedance method was chosen as the most appropriate by the ILCD Handbook.

Similarly, different LCIA methods exist in the case of abiotic depletion potential for non-fossil resources (ADP-elements). Historically, the CML approach (widely used in LCA) calculated the ADP by dividing the extraction rate of resources by the square of the ultimate reserves out of the same for the reference reserve (the antimony). The ILCD now recommends using the reserve base approach which only considers reserves that meet specified minimum

physical and chemical criteria related to current mining and production practices. Again, the CEN TC 350 standards are about to choose the CML approach.

The advantage of the standard choice is to stay with known methods but the issue is to increase the differences between ICLD and CEN requirements in a European context.

Furthermore LCA practitioners have to keep in mind, that some of the newly ILCD-recommended methods may not be implemented in commercial LCA. This can be the case because of newness but also due to the fact that these methodologies have not yet proven to be valid in practice in terms of giving meaningful results and applicability [18]. As a result, also regarding future developments in LCA (e.g. Product environmental footprint (PEF)) it is necessary to have a consistent approach in ILCD Handbook and the European standards.

2.2 Availability and inconsistency of LCA datasets and EPD

The amount of available LCA datasets increased steadily over the years, but compared to construction products available on the market, the number of existing construction LCA datasets in databases is still quite low. Even the increasing number of EPDs is hardly covering a certain range of construction products. Also in the ILCD database [19] just a small number of datasets are implemented that are sometimes outdated and not sufficiently documented to be used in LCA studies. So far, the majority of available datasets are not consistent regarding modelling principles and usually not sufficient concerning documentation. For example, the question how to handle carbon capture and storage are treated differently in various EPD schemes and countries. Therefore the use of EPD from different EPD schemes within the same environmental assessment is so far not possible.

To overcome all of these issues concerning data availability, the different EPD programmes, among others INIES [20], IBU [21] and BRE Profiles [Q], should come to an agreement with regard to system boundaries or used product construction regulation (PCR). The benefit would be using different EPD datasets from different EPD programmes in one LCA study and being able to use producer specific EPDs in different European countries. The ECO platform [Q], as European EPD umbrella organization, is already trying to solve some of these issues, but so far no major arrangement has been established.

Also the current ongoing developments in France could help to form a consistent LCA database. In the next few years every construction product in France should have an environmental product declaration based on EN 15804 if the company plans to communicate about the environmental performance of its product [28].

2.3 Inconsistency of current labelling schemes

Another challenge is the diverging LCA approach in the different labelling schemes for sustainability. Building labelling schemes use their own individual sets of calculation rules for building LCA. Even if referring to EN 15978, none of them are fully compliant with it to date. In some of the labelling schemes like LEED [22], LCA has been recently incorporated, whereas in other building labelling schemes like HQE Performance [16] and DGNB [17], LCA is already a fundamental part. But even if LCA is used to assess the environmental impacts, the system boundaries and cut-off rules are often not consistent between them and included life cycle stages and materials considered may vary. For example, in DGNB the transport of the materials to the construction site and the transport of the materials at the EoL are not considered. The selected LCIA indicators can also be different out of the usual GWP. For example, the HQE Performance scheme includes cradle-to-grave impacts of the building products and technical equipment (embodied impacts), the impact of water and energy consumption (operational impacts). These contributors are quantified for the primary

and non-renewable energy consumption, the water consumption and the different waste indicators. In contrast, DGNB is only assessing the water demand in the operational phase (but not the embodied water demand) and wastes are not considered from an LCA perspective. In order to transparently state all of these differences in the methodological approaches and try to overcome them, the SB Alliance project [23] has undertaken research activities and set up common metrics towards a first harmonization. Especially the choice of important environmental indicators and LCIA methodologies is one of the major outcomes of the SBA common metrics (see Figure 2).

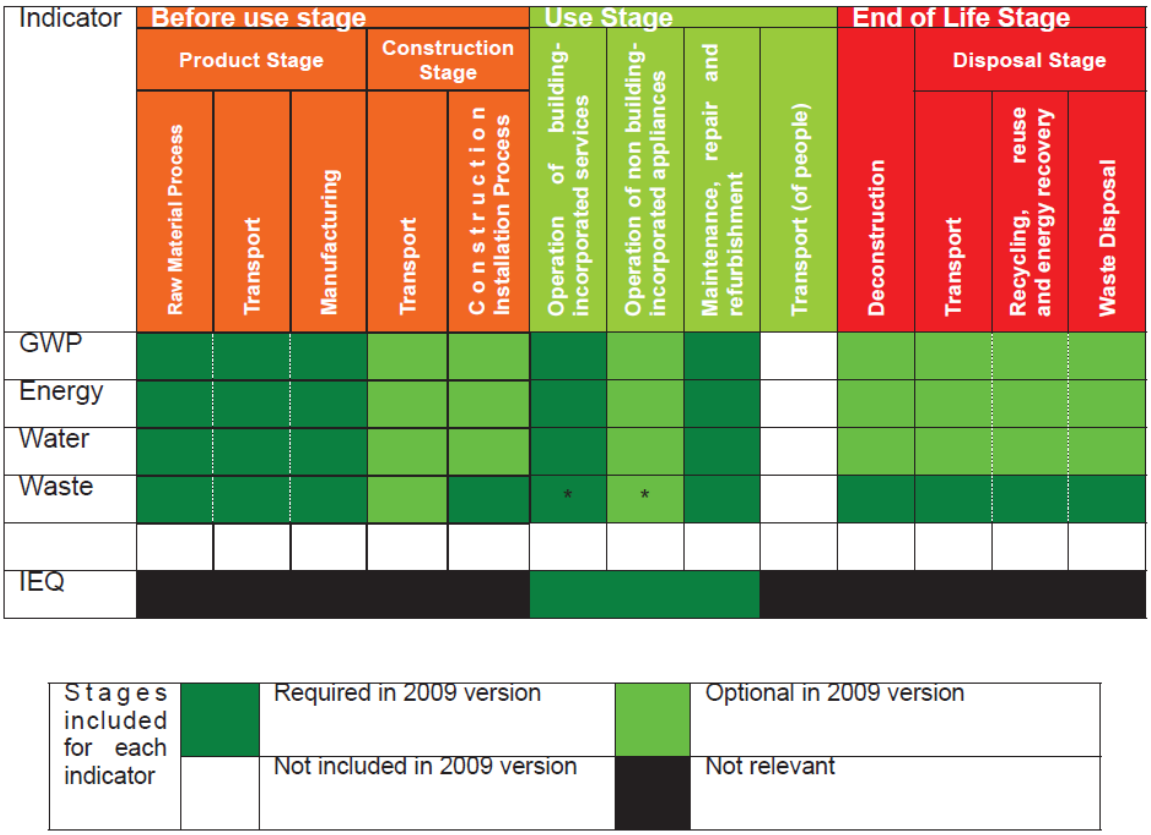


Figure 2: Lifecycle stage included in the framework for common metrics [23]

Also within the research project EeBGuide [2] different system boundaries for construction products as well as buildings were defined within a group of LCA experts all over Europe and verified in a public consultation process. EeBGuide also gives guidance on how to adapt these system boundaries regarding different levels of complexity (Screening, Simplified, Complete). Figure 3 shows a table presenting the framework for the production and construction regarding system boundaries, datasets and included materials.

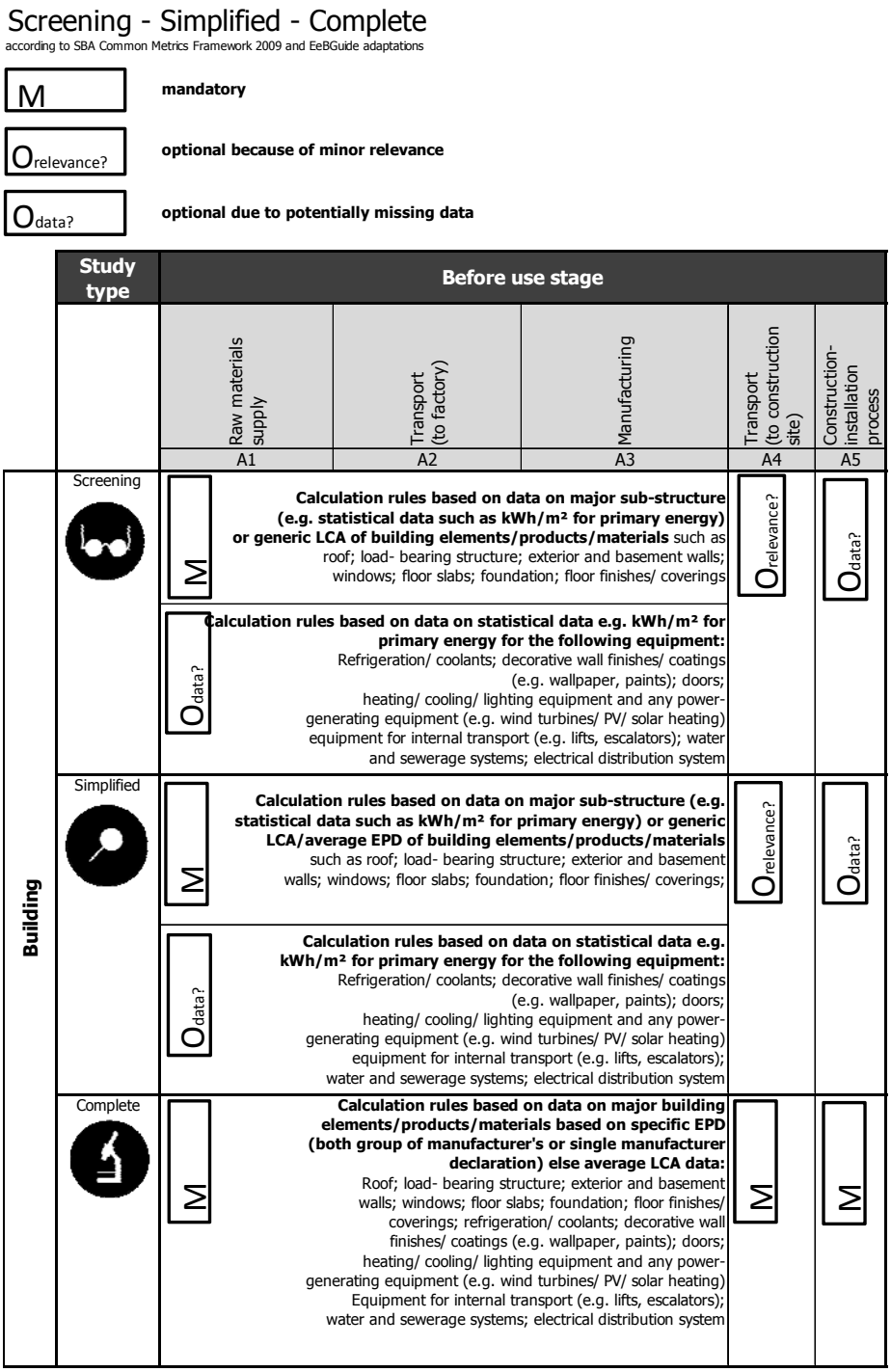


Figure 3: Caption of the definitions of the included materials and system boundaries [2]

2.4 Reference service life

LCA studies in the construction sector are often characterized by having very long reference service lives. Service lifespans of one or more decades are typically more difficult to oversee than service lifespans of consumer products, for example. Therefor the choice of reference service lifespans can have a major influence on the overall LCA results. Besides basic principles mentioned in ISO 15686 [24] and guidance paper F [25], data about average service lives and laboratory findings regarding repair, refurbishment and maintenance of construction products are so far very rare. Also there are still ongoing discussions if a theoretical reference service life should be applied or statistical collected real life data.

2.5 National and European reference buildings

Another important issue is that so far very little information about reference buildings in different countries is available. Not only for building labelling schemes, but also for European research projects reference buildings for different countries/ regions/ Europe would be highly valuable. It is hardly possible to interpret or even compare the results from different research projects. As an example, energy efficient measures and technologies are normally proven by means of a real building. But often this building is so special and extraordinary in terms of technical equipment, user behaviour, situation, etc. that it is not easily possible to transfer the results to another building. In order to compare and value the outcome of different research projects this would be necessary. Therefor, it would be highly beneficiary to have different reference buildings for different climatic regions and also for different regional existing construction types (e.g. heavy structured buildings, light structured buildings, etc.).

2.6 Surface calculation methodologies and national EPBD versions

Another challenge for building LCA on a European level is the difference in surface calculation methodologies and national EPBD versions. Both are crucial input data for building LCA, but differ by large numbers depending on the country. In the European research projects ASIEPI [3] and OPEN HOUSE [1] these differences were found to be tremendous (see Table 1).

Table 1: Results of LCA questionnaires of OPEN HOUSE [1]

Questionnaire topic	Answers by 76 case studies
Additional information about national practices	
Implementation of EU standards/directives/regulations Are such standards implemented / existing in your country?	Most European countries already have a national version of the EPBD and regulation on the calculation of the surfaces. During the project time the national EPBD version was just to be implemented in Turkey, but could not be considered anymore for this project. In the majority of cases national regulations on the service life time of construction products / components were not existing.
National standards and/or regulations Specifications regarding the national EPBD Specifications regarding the surface area calculation methodology	National EPBD versions: One outcome of the questions regarding some of the main assumptions of the different EPBD versions was that there is no common calculation methodology but a multitude of differences. Especially the system boundaries of the EPBD versions are not consistent (e.g. inclusion of electricity consumption of building equipment, lifts, etc.). Also the temperature levels and user behavior was not consistent. National regulation on the calculation of building surfaces: Similar results could be seen by the different national calculation methodologies. This methodologies are similar, but by a detailed look differences could be found regarding the boundaries (e.g. niches included in NFA) and the calculation methodology (e.g. surface calculation of the exterior walls from the outer edge/ mid of the wall, etc.).
National basic and best practices Are there any national basic and best practices (EPBD and LCA)?	In most of the countries national best practices/ regulations regarding the operational energy demand of buildings were available, but very few information is available regarding LCA related environmental impact categories. So far DGNB is providing information regarding best practice values for LCA. Additionally in UK values for GWP can be found.
Annex 1.1_7 Questionnaire Expansion of System Boundaries	In most of the European countries there is little information available regarding the lifecycle modules A4 (Transport to construction site), A5 (construction stage), B2 (Maintenance), C1 (Deconstruction) and C2 (Transport to EoL).

Especially the national EPBD versions vary quiet a lot regarding system boundaries (e.g. interior temperatures) and calculation methodology (fix reference value vs. reference

building). A major issue are the differences in included or excluded energy consumers. For example in some countries the electricity demand of the user equipment is included in the calculation of overall energy demand of a building, whereas some countries explicitly exclude it. As a result, EPBD versions can hardly be used for LCA studies on a European level, because the results can not be transparently compared. If the assessment of the overall energy demand of a building can not be stated by a thermal dynamic simulation, a consistent and common energy calculation approach, e.g. ASIEPI should be used. In order to overcome the huge differences in the surface calculation, a European measuring code should be implemented in a European standard. A starting point could be the already existing measuring code for buildings of the European commission [22].

4 Conclusion and outlook

All in all, LCA in construction already passed a long way and established the life cycle thinking idea in construction industry. But there is a huge need for standardization and harmonization on a European level in order to maximize the output of every LCA study and to be able to rely on these results. Furthermore some of the differences in national standards, like the measuring code for surfaces, can be a huge market barrier in and for Europe. A lot of activities are already undertaken towards a harmonization of standards and guidelines, but there are still different tendencies. Legislative Top Down approaches are competing with industry developed established standards. LCA approaches in different countries are competing with each other. All of this currently prevents LCA to gain its full potential.

5 References

[1] http://www.openhouse-fp7.eu/

[2] www.eebguide.eu

[3] ASsessment and Improvement of the EPBD Impact (ASIEPI), Comparison of Energy Performance Requirement Levels: Possibilities and Impossibilities, http://www.buildup.eu/publications/9099, 2010

[4] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010L0031:EN:NOT

[5] EN 15804: Sustainability of construction works – Environmental product declarations – Core rules for the product category of build-ing products. CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2011.

[6] EN 15978: Sustainability of construction works – Sustainability as-sessment of buildings – calculation method. CEN – European Com-mittee for Standardization. Brussels: CEN – CENELEC 2010.

[7] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. General guide for life cycle assessment: detailed guidance. First edition. Luxembourg: Publications Office of the European Union 2010. ISBN: 978-92-79-19092-6.

[8] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment. First edition. Luxembourg: Publications Office of the European Union 2010.

[9] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. Framework and requirements for Life Cycle Impact Assessment models and indicators. First edition. Luxembourg: Publications Office of the European Union 2010.

[10] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. Recommendations for Life Cycle Impact Assessment in the European context – based on existing environmental impact assessment models and factors. First edition. Luxembourg: Publications Office of the European Union 2011. ISBN: 978-92-79-17451-3.

[11] European Commission – Joint Research Centre – Institute for Environment and

Sustainability (Ed.): ILCD Handbook. Characterization Factors of the ILCD, Recommended Life Cycle Impact Assessment methods, database and supporting information. First edition. Luxembourg: Publications Office of the European Union 2012. ISBN: 978-92-79-22727-1.
[12] ISO 14040 Environmental management – Life cycle assessment – Principles and framework.
[13] ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines
[14] http://www.etseq.urv.es/aga/Investigacion/LCA.htm
[15] http://www.breeam.org/
[16] http://assohqe.org/
[17] http://www.dgnb.de/de/
[18] Baitz et. al., LCA's theory and practice: like ebony and ivory living in perfect harmony?, International Journal of Life cycle assessment, Volume 18, Issue 1, pp 5-13, Springer Verlag, 2013
[19] http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
[20] http://www.inies.fr/
[21] http://bau-umwelt.de/hp1/Startseite.htm
[22] http://www.usgbc.org/leed
[23] http://sballiance.org/
[24] ISO 15686 series: Buildings and construction assets – Service life planning Part 1 to 10. ISO – International Organization for Standardization. Geneva: ISO 2011
[25] European Union: Legislation, 'Guidance Paper F – Durability and the Building products Directive', Revision December 2004
[26] http://ec.europa.eu/oib/pdf/mesuring-code_en.pdf
[27] http://sballiance.org/wp-content/uploads/2013/01/A-Framework-for-common-metrics-2010.pdf
[28] ELALOUF Z. "Environmental declaration for construction, decoration, electrical equipment, electronics and climatic engineering used in buildings". Oral communication presented at the International Conference LCA Construction 2012 – Civil Engineering and Buildings, 10-12 July, Nantes, France.
[29] www.minergie.ch/
[30] http://www.passiv.de/

Practical Aids, Instruments and Tools of the Assessment System for Sustainable Building (BNB)



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Short Summary

In March 2011, the reworked Guideline for Sustainable Building was introduced by the German Federal Ministry of Transport, Building and Urban Development (BMVBS). Thus the Federal Building Authorities were obliged by edict to evaluate Office and Administration Buildings, using the Assessment System for Sustainable Building (BNB). Using the Assessment System is voluntary for other building authorities, such as Federal States, municipalities or the private sector.

Every assessment system requires the most diverse basic data and practical instruments to work efficiently. Parallel to the BNB-System several tools and instrument were developed, as WECOBIS (Web-based Ecological Building Material Information System) or Ökobau.dat (German building material database) and other Checklists and worksheets. They are supporting the user in the planning and building process as well as in evaluating the building with the BNB-System.

Keywords:Building; Guideline; Assessment; Tool; Instruments; WECOBIS; Ökobau.dat;

1. Introduction

According to the national Sustainability Strategy the German Federal Ministry of Transport, Building and Urban Development (BMVBS) published a Guideline for Sustainable Building in 2001 for the first time. It was made obligatory for the Federal Building Authorities and operate as a practical aid in the planning phase, the construction, the utilisation including the structural maintenance and the modernisation.

New scientific standards, technical developments and changing of requirements in regulations and norms made it necessary to review the guideline fundamentally. In March 2011, a reworked version of the Guideline for Sustainable Building was introduced by the German Federal Ministry of Transport, Building and Urban Development (BMVBS). Thus the Federal Building Authorities were obliged by edict to evaluate Office and Administration Buildings, using the Assessment System for Sustainable Building (BNB). Therefore the Guideline is orientated to the chronological progression of the planning phases according to the “Guidelines for the Realisation of Federal Building Measures - RBBau” or the performance phase of the “German Fee Scales for Architects and Engineers - HOAI”. Using the Assessment System is voluntary for other building authorities, such as Federal States, municipalities or the private sector.

The Guideline for Sustainable Building was revised once more and completed in 2012/13 [1] with the following structure:

- General Part
- Part A Basic Principles of Sustainable Building
- Part B New Buildings
- Part C Recommendations for Sustainable Operation and Maintenance
- Part D Building Stock / Complete Modernisation

The Guideline directly refers to the Assessment System for Sustainable Building (BNB) [2], based on several research project, financed by the BMVBS research initiative “Future Building”. The quality of sustainability, as requested in the Guideline with silver level, is to verify by using the BNB-System. This system based on a holistic assessment procedure which considers the life cycle of a building and a comprehensive quantification.

The Assessment System based on protective goods and goals of sustainability, which were extracted for the construction sector. They are allocated to the well-known dimensions of sustainability – Ecological Quality, Economical Quality and Socio-cultural/functional Quality. Those qualities are complemented with horizontal qualities, as Technical Quality and Process Quality. The Location Profile describes the local characteristics. They are separately evaluated from the objective qualities and shown as additional information.

These five main criteria groups are divided in criteria files and can be measured or evaluated according to quantifiable amounts.

2. Practical Aids and Tools

Every assessment system requires the most diverse basic data and practical instruments to work efficiently. Parallel to the BNB-System several tools and instrument were developed, involving the working groups of the Round Table of Sustainable Building. At present three important instruments are available:

- WECOBIS (Web-based Ecological Building Material Information System)
- Ökobau.dat (German building material database)
- Use life of Construction Parts
- Checklists and worksheets.

WECOBIS and Ökobau.dat will be described in the following chapters.

The German assessment methodology uses a holistic assessment procedure which considers the life cycle of a building and a comprehensive quantification. In this context the focus is not only on the construction of buildings but also on the operation and the maintenance.

The BMVBS therefore provides free available quantitative data for life cycle analysis, which ensure that sustainability criteria ca be included in planning and construction processes and comprehensively documented. The calculation is made for a period of 50 years. Therefore not only the demand of resources and the environmental impact but also the certain useful life of construction products is important and necessary. The Table of Use Life gives information about the average useful life of building material and constructions.

Furthermore several schemata and tableau are supporting the user in the planning and building process as well as in evaluating the building with the BNB-System, par example:

- Schedule for objective agreement
- Requirements for sustainability in architectural competitions
- Functional specification for energetic requirements
- Pre-Check report

- Evaluation reports

These tools are published on the Internet Portal Sustainable Building.

In the moment a research project is in progress, in which an EDP-aided assessment and documentary report (eBNB) is to work out. This report has to take into account the requirements of the criteria of the BNB-System, but also important framework conditions of the public building sector, as the “Guideline for the Realisation of Federal Building Measures (RBBau)”.

3. WECOBIS

WECOBIS as a “Web-based ecological building material information system” supports the planning team with qualitative information to sanitary and ecological aspects of building material. A substantiated choice and assessment of building products during the planning phase is one of the main challenges for sustainable planning, construction and management of buildings. WECOBIS serves as a practical aid, allows a qualitative assessment of main construction materials and products and should aid for tendering. Therefore WECOBIS offers basic information and important links to continuative sources and web portals.

The objectives of WECOBIS are:

- Neutral information to health, ecological, technical and functional aspects of construction products
- Raw material, production and manufacturing process, use and re-use of the products
- Online links with further sources of information and data.

The WECOBIS can be used by architects, planners, auditors et.al.:

- Simple selection of building products or materials by a simple navigation
- Acquire a basic knowledge to general and special information concerning technical and functional aspect, health and ecology
- Compare different products to each other by viewing at the sam time and choose the most suitable
- Manage your projects in MyWECOBIS by arranging the documents accordingly to the phases of the planning or the phases of the lifecycle.

The web page of WECOBIS, which has its origins already in 2000, is operated by the Federal Ministry of Transport, Building and Urban Development (BMVBS) in cooperation with the Bavarian Chamber of Architects (BayAK). The administrative office has been set up in the BBSR, Division II 6 Construction and Environment. The online presentation will allow continuous updating.

4. Ökobau.dat

The Ökobau.dat contained generic quantitative information on the ecological quality of building material. The Ökobau.dat is used in the Life cycle assessment (LCA) and other criteria.

The Ökobau.dat includes data for the assessment of environmental impact of building products:

- Global Warming Potential
- Ozone Depletion Potential
- Photochemical Ozone Creation Potential
- Acidification Potential
- Eutrophication Potential

It based on the Environmental Product Declarations (EPD) with proved manufacturer based information (environmental indicators). They are available for various building products and are undergoing an independent review. In Germany the examination is conducted by the Institute for Building and Environment (IBU). The systematic and standard data basis – currently available for national buildings – enables an ecological evaluation of a building in a building block system of declarations of individual constructions. Use of resources and emissions in the environment are included into the entire manufacturing process.

5. Conclusions

The Guideline for Sustainable Building will be implemented into the practical work of the Federal Building Authorities. The Assessment System BNB enables a transparent, objective and comprehendible evaluation or qualification of the sustainability of buildings. The tools would be able to support the building authorities to implement the assessment into practice. The publication is carried out with the Information Portal Sustainable Building “www.nachhaltigesbauen.de”.

6. References

[1] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Federal Ministry of Transport, Building and Urban Development): “*Leitfaden Nachhaltiges Bauen (Guideline for Sustainable Building)”*, introduced by decree on 03.03.2011; revised edition 2013

[2] KERZ, N.; MÜLLER, J.; RIETZ, A.: “*Sustainable Building Strategies - Methods - Practice*”; BBSR-Berichte KOMPAKT 8/2011; Federal Institute for Research on Building, Urban Affairs and Spatial development (BBSR); Berlin, 2011

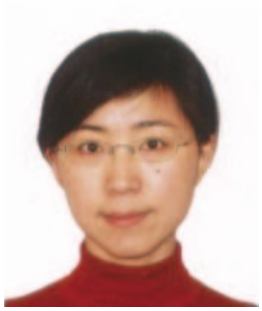
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Building Information Modelling

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An integrated BIM-LCA framework for building assessment:

Case study in Tianjin, China



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Short Summary

In order to develop a methodology for building ecological and economic assessment and optimization from the early design stage, a framework that facilitates the integration of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) with Building Information Modelling (BIM) is proposed. Buildings are described in the Revit model as assemblies with information of construction, material and cost, whereas in the LCA and LCC model, they are described as elements of different life spans, which are linked to the life cycle inventory (LCI) data of building materials. Energy load is calculated with Energyplus and related to inventory data of Chinese energy products. BIM provides a parametric database including cost, material, and elements. This framework is applied to a retrofit project in Tianjin. The geometric model combined with dynamic information of mass and energy flows, environmental impacts and costs helps to monitor and manage the construction, renovation, operation, refurbishment and demolition of buildings.

Keywords: BIM, LCA, LCC; building; assessment; China

1. Introduction

The development of building stock accounts for considerable part of energy consumption and environmental impact in the Chinese cities. The design of more performing new buildings, the renovation of existing buildings and the management of the end-of-life phases need new assessment tools. The life cycle impacts and costs must be estimated in a consistent way to avoid partial decisions. A common framework and calculation tools concerning new buildings and refurbishment will be the basis for design and management decisions as well as for advanced sustainability certificates.

In line with international standard (ISO TS 21929-1), life cycle oriented environmental and economic criteria have been introduced in several major building sustainability assessment systems in the recent years, such as the European LEnSE and the German BNB/DGNB system. Integrated Life cycle analysis (LCA) and life cycle costing (LCC) methods and tools are the basis for calculation and developing the benchmarks. Conventional LCA need detailed description of the building according to 2D CAD drawings and quantity survey data, which is time consuming. Moreover, the calculation and interpretation process needs specialized knowledge, which makes it difficult for designers to optimize the project in the early design stage. Building Information modeling (BIM) provides a platform integrating 3D geometrical model with various text and numerical data. The input data needed for LCA can be derived from BIM. It can largely reduce the effort for building description and enable the assessment results be feedback to the designing process.

In China, the inventory database for major building material and energy products is being developed in the recent years, although much has to be done in comparison to the European databases. Chen Y. & Zhu YY (2010) studied the LCA method for residential buildings. Zhang Z.H. (2010) presented the building life cycle carbon emission calculation method. However, there is so far no integrated LCA and LCC tools. Moreover, the calculation methods are mainly based on

quantity survey data, which cannot indicate some important information of building assemblies, such as construction, position, life span and physical performance. Hence the result is difficult for architects and decision makers to interpret and to feedback in the designing process. It is important to develop a method, which integrates the geometrical information, life cycle impacts and costs in the same framework, and allows the dynamic feedback between assessment results and the design scheme.
This contribution aims to develop an integrated BIM-LCA framework with supporting tools that can be easily applied to the designing and evaluating process of the Chinese buildings. The methodology could enhance the efficiency and accuracy of the assessment. It also helps evaluate and optimize the project from the early design stage.

2. Methodology

The integrated life cycle environmental and economical analysis features the 2nd generation of building sustainability assessment system, whereas the BIM-LCA methods will be the basis of the 3rd generation in the future (Koenig H., et al, 2009). The methodology was discussed in the EU FP7 project 'SuPerBuildings' report (2012).
The assembly database is the bridge that links BIM to LCA. The assembly category and material schedules derived from BIM can be imported in the integrated LCA model and be linked to LCI data and costs, so that the inventory analysis of building LCA can be largely simplified. Moreover, the information of life cycle impacts and costs of the assemblies can be reimported to the BIM database, which helps the designers to choose building elements with low environmental impacts in the early design stage.
The BIM model can also carry information for operational energy calculation, such as the U values of building elements, window to wall ratio and space information. The results from energy simulation tools are linked to the integrated LCA and LCC model, too.
Figure 1 demonstrates the structure and tools of a simplified BIM-LCA framework.

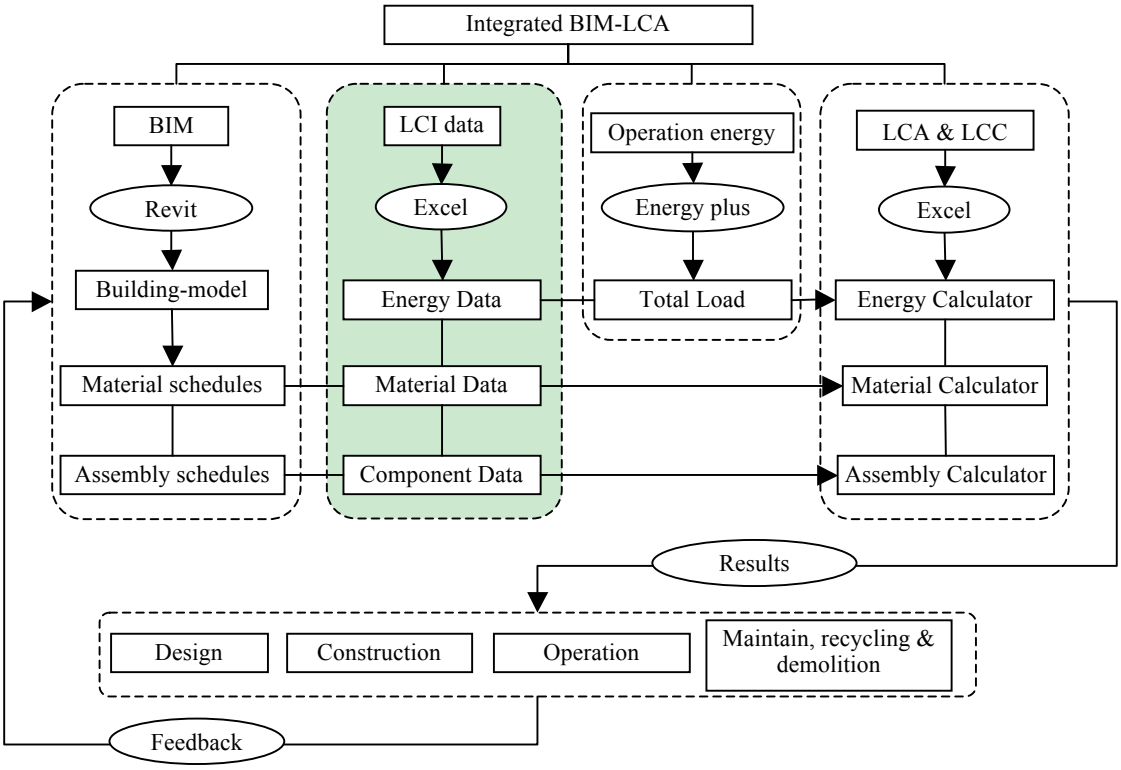


Fig. 1: Framework for integrated BIM-LCA methodology

2.1 Databases and indicators

Necessary databases for integrated LCA methods includes LCI and costs of building material and

assemblies, as well as national category of building assemblies and their life spans. Gong ZQ (2004) presented the LCI data for 6 major building materials in China (Table 1). The Chinese Core Life Cycle Database (CLCD) contains more extensive categories of building material, processes and energy products. Carbon emission for the Chinese electricity grid is reported each year (Table 2). Due to the incompleteness of the Chinese data, Ecoinvent database is referred for specific materials and End-of-life processes. Indicators for energy resource consumption and environmental impacts are selected as shown in Table 3.
China has published standard drawings of building assemblies for each climate zone as common reference of the building industry. The quantity survey of buildings is regulated by the National Cost Engineer qualification system. Local regulation of construction project cost provides the database for costs of all the building materials and assemblies.

Table 1: LCI of 6 major building materials in China

Building Materials	Primary energy Non renewable (MJ/t)	GWP ($kgCO_2eq/a$)	AP ($kgSO_2eq/a$)	NP ($kgNO^-eq/a$)	Solid waste (kg)	Dust (kg)
PVC tube	0.03	1.28	1.29	0.43	12.5	4.84
Glass	0.03	0.44	0.4	0.18	0.06	0.66
Common steel	0.6	2.05	1.86	0.72	268	6.92
P.I.52.5	0.038	0.18	0.039	0.04		0.125
P.O.42.5	0.033	0.159	0.035	0.03		0.112

Table 2: Electricity Carbon emission factor in China

2012 factor	EFgrid, OM, y (tCO_2/MWh)	EFgrid, BM, y (tCO_2/MWh)
North China District grid	1.0021	0.594

Table 2: Impact indicators considered in the paper

Impact indicators	Category	Unit
Primary energy /renewable	cumulative energy demand	MJ-Eq
Primary energy / non renewable	cumulative energy demand	MJ-Eq
Global warming potential (GWP100a)	IPCC 2001	kg CO2-Eq
Acidification (AP)	EDIP	kg SO2-Eq
Nutrient enrichment (NP)	EDIP	kg NO3-
Land filling (Solid waste)	EDIP	kg waste
Stratospheric ozone depletion (OPD100a)	EDIP	kg CFC-11-Eq
Photochemical ozone formation (POPC)	EDIP	kg ethylene-Eq

2.2 Integrated LCA and LCC tools

There had been several building LCA tools developed in the industrialized countries. The LEGEP software for German buildings is an effective tool of integrated LCA and LCC, which combines the calculation of costs, energy simulation and environmental impacts in the same physical framework. The Athena eco-calculator has a user-friendly interface and contains a practical building assembly database for North America, which makes it easy to describe the buildings and to calculate the impacts. However, their methods and databases are highly relevant to specific context, which makes them difficult to be adapted to Chinese buildings. Therefore, we try to build an integrated LCA and LCC model using Chinese data with Excel program, because it conveniently matches to the BIM take-off schedule. In the model, buildings are described as assemblies with the information

of construction details and material composition.

2.3 BIM tool and operation energy software

The application of BIM is developing rapidly in China. Many architectural design institutes have started to use BIM instead of 2D CAD drawings. However, the common standard for BIM database of building elements is not available so far. It will soon be published to regulate the current BIM market.
Autodesk Revit is the most popular BIM tool in the Chinese building industry. As the first step of the BIM-LCA model, major assemblies are chosen from the standard drawings and are described as families of different categories (e.g. walls, windows, doors, floors, roofs) in Revit, which contain the information of material, construction, costs and U values. On this basis, buildings can be described and information for energy calculation and the input data for LCA can be deduced.
The Revit model can be exported in energy simulation tools such as Ecotect, Vasari and Green Building Studio. However, we have chosen Design-builder based on Energyplus software to estimate operational energy demand in order to get more reliable results.

3. Case study in Tianjin, China

The BIM-LCA framework can support the assessment of new constructions as well as retrofit of existing buildings. Case study of a high-rise residential building built in 2010 was presented in Yang W. & Wang SS (2013).
For the renovation project, a teaching and office building in Tianjin University is analyzed. The old building was constructed in 1980. The building is 4 stories with a rectangular plan (72*19m). The gross floor area is 5380 m^2. The renovation aims to adapt to the need of the new faculty, as well as to improve the energy efficiency and the comfort level of the building (Tab.4).

Table 4: The renovation strategies of the building

Renovation strategy	Items
Conserved structure	Solid clay brick with reinforced concrete structure
Envelope & Space Retrofitting	Interior partition and finishing; insulation panels (XPS, stone wool) applied to the external walls supported by additional steel keels; Roof insulation and waterproof; Windows and doors
Designed lifespan	50 years
Solar heated area	4160 m^2
District heated area	1220 m^2
New heating system	Solar heating system with supplementary boiler
Cooling system	Central air conditioning

Information of the building and its elements is defined in the Revit model (Fig. 2), which can be derived for energy simulation and integrated LCA calculation.

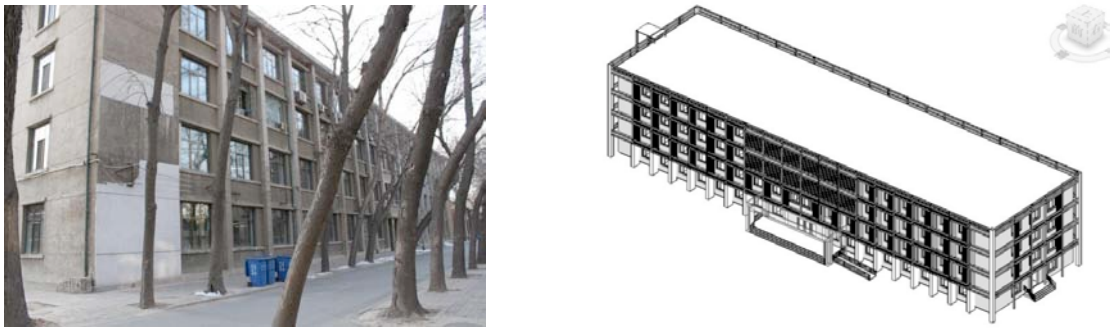


Figure 2: The image of the old building and the BIM model of the renovated building

3.1 Building information modelling with Revit

The Revit model of the retrofitting project consists of three parts: the conserved original structure made of clay brick and concrete, the demolished old elements and newly added elements. The assembly and material schedules are derived from the model. Steel frames are constructed surrounding the façade of the building to support the insulation panels, claddings and blinds. With the 'schedule/quantities' and 'materials take-off' tool in Revit, all the building assemblies are exported with the construction information and physical attributes such as dimensions, U values, and density. Table 5 gives an example of the wall assembly schedule, which can be linked to integrated LCA model.

Table 5: Examples of wall schedule and material take-off in Revit

Element category	Volume (m^3)	Area (m^2)	Width (mm)	Envelope material	Thickness(mm)
Interior wall clay brick	433.83	827.91	524	Emulsion painting	2
				cement lime mortar	20
				clay brick	480
				cement lime mortar	20
				emulsion painting	2
Interior wall, aerated concrete block	20.77	87.27	254	Quarry tile	8
				cement mortar	19
				aerated concrete block	200
				cement mortar	19
				quarry tile	8
Exterior wall, clay brick	675.01	1562.51	432	XPS panels	50
				clay brick	360
				cement lime mortar	20
				emulsion painting	2
Exterior finishing	7.04	251.26	28	Cement mortar	20
				Stone cladding	8

3.2 Operational energy simulation

The energy consumption before and after the energy efficient renovation is calculated with Design builder. The insulation and the heating system are major changes in the retrofit. The solar heating system supplies a use area of 4160 m^2. It consists of the solar collectors (Fig.3), energy storage device, heat pumps, supplementary boiler and radiators.

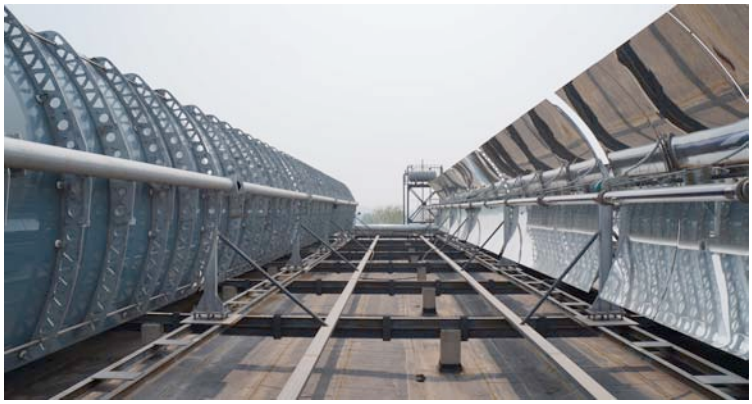


Fig. 3: The solar collectors on the roof

The solar thermal capacity is calculated with two different methods. One is with the energy simulation tool (Design builder). The other is to calculate directly with the heating time, solar radiation data (Tab. 6) and area of the solar collectors (216m^2). The simulation result of the solar

energy capacity in one winter season is 64681.51KWh, while the result from the latter method is 77203.8 KWh. The 10% deviation may be partly due to different estimation of heating time.

Table 6: Weather references in heating seasons in Tianjin

Heating Period	Nov. 15 to Mar. 15
Average temperature (℃)	0.5
Radiation intensity (W/m^2)	454.5
Daily average time (h)	6.5

Table 7 shows that heating energy consumption is reduced by 70% after retrofit. However, if the district heating system were not replaced by solar energy, the energy saving from better insulation would be 27%. The related primary energy, environmental impacts and costs are discussed in 3.3.

Table 7: Comparison of energy consumption before and after renovation (results from Designbuilder; Unit: KWh per year)

Heating system	After renovation (KWh)	Assumption for energy demand with better insulation but without solar heating system (KWh)	Before renovation (KWh)
Auxiliary devices for solar heating (electricity)	84223.5		
Solar (renewable)	64681.5		
District heating (coal)	55834.2	314982.1	432330.3

3.3 LCA and LCC

Through an integrated LCA, the long-term environmental and economical quality of the renovated building is evaluated and compared with its initial status. The system limits and data sources are listed in Table 8. Figure 5 to Figure 8 demonstrate the results of LCA and LCC. The results demonstrate that the energy efficient renovation, especially the solar heating system has a large contribution to improve the environmental performance of the building.

Table 8: General Conditions for integrated LCA of the case building

	LCC	LCA
Observation time span		50
Life cycle phases	Operational energy; Renovation	Dismantling of old components Renovation; Operational energy; Refurbishment; End of life
Discount rate (%)	8	
Annual increase of energy costs (%)	5	
Energy costs	Electricity =0.49 yuan/kWh, district heating=36yuan/m^2	
Service life of building components	Chinese data, Germany Sustainable Building Guideline (BMVBW, 2001a) and VDI (2000)	
Inventories	Construction and decoration project budget in Tianjin, DBD29-101-2008	Chinese LCI data, Ecoinvent
Function unit	1m^2 gross floor area	1m^2 gross floor area

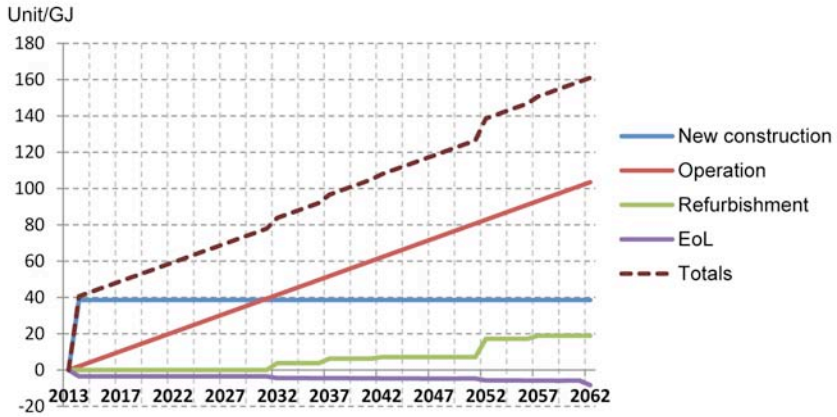


Fig. 5: The accumulative primary energy (non-renewable) consumption in each life cycle stages after renovation

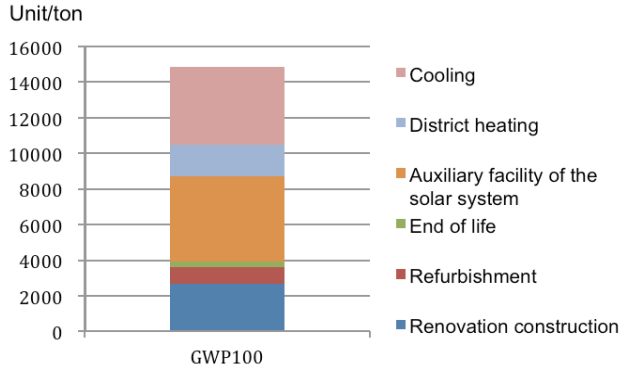


Fig. 6: GWP from each life cycle stages of the renovated building

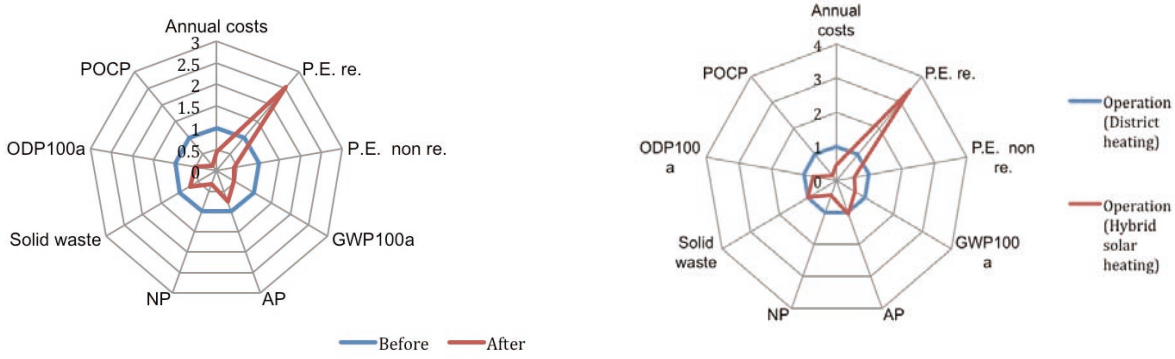


Fig. 7 Comparison of the life cycle environmental impacts between before and after the renovation, and with or without solar heating system

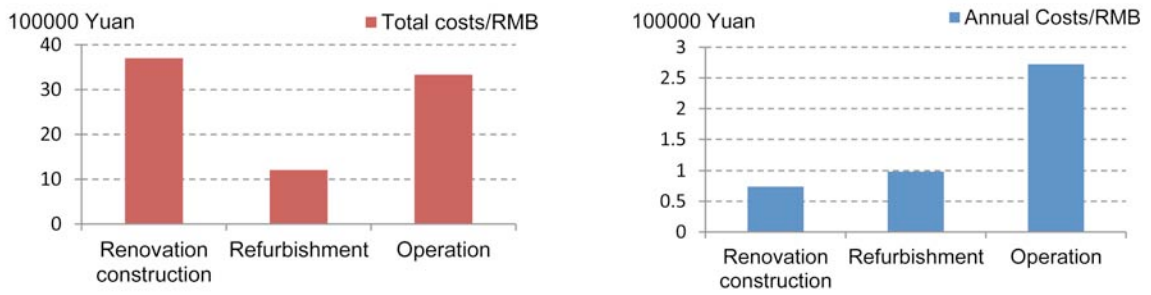


Fig. 8: Costs in each life cycle stages of the renovated building

4. Discussion and Conclusion

This paper introduced an integrated BIM-LCA methodology, which combines several conventional approaches in building design and assessment, including geometrical model, quantity survey, operational energy simulation, LCA and LCC. Through test of the methods and tools with a case study, the following issues can be addressed:
(1) The existing building LCA methods and tools in China are mostly based on quantity survey data and CAD drawings, which is either incomplete or time consuming. There is a need for a BIM-LCA framework to enable an interactive optimization process.
(2) The parametric information databases of building assemblies, LCI data for building materials and their costs are the foundation of Integrated BIM-LCA application in China.
(3) The first results from a case study of a renovation project shows that the BIM-LCA methodology based on Autodesk Revit, energy simulation tools and excel program for LCA and LCC can support the optimization and evaluation of the project.
(4) There exist limits in the interconnection of the Revit model and the energy simulation tool (Design builder for Energyplus). Moreover, the assembly description needs to be improved to include more detailed data of the material composition and construction.
(5) The BIM-LCA framework can be improved by developing the user-friendly interface, completing the building material and components databases, and setting benchmarks for different types of buildings according to national and local standards.

5. Acknowledgement

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6. References

[1] YANG W. *"Modelling building stocks- the developing strategies of the Chinese urban rural buildings in the next 50 years".* China/Nanking, Southeast University Press, 2010.
[2] CHEN Y, ZHU YY. *"Residential building life cycle energy consumption and emission model"*. Journal of Tsinghua University, China / Beijing, 2010, Volume 50/3, pp. 325-329.
[3] SHANG CJ, ZHANG ZH. *"Building life cycle carbon emission calculation".* Journal of project management, 2010, Volume 24/1, pp. 7-12.
[4] GONG ZQ. *"A Quantitative Method to the Assessment of the Life Cycle Embodied Environmental Profile of Building Materials".* Tsinghua University M.S. thesis paper, 2004.
[5] KÖNIG H, KOHLER N, KREISSIG J., LÜTZKENDORF T. "*A life cycle approach to buildings".* Munchen: Institut fur International Architektur-Dokumentation GmbH&Co. KG (DETAIL Green Books), 2010.
[6] The report of Climate change department of Chinese development and renovation board. *"2012 Baseline Emission Factors for Regional Power Grids in China"*. 2012.
[7] ZHOU ZH. *"Application study on solar heating system".* Tianjin University PhD thesis paper. 2010
[8] YANG W, KOHLER N. *"Simulation of the Evolution of the Chinese Building and Infrastructure Stock"*. Building Research and Information, 2008, Volume 36/1, pp. 1-19.
[9] YANG W, LÜTZKENDORF T. *"Methods for the sustainability assessment of housing in China: the next generation".* The 6th International Conference on Green & Energy-Efficient Building, China / Beijing: Urban Studies, 2010, pp. 144-153.
[10] YANG XQ. *"Research on design and technical strategies of zero-energy solar house prototype".* Tianjin University PhD thesis paper, 2011.
[11] YANG W., WANG S.S. "*A BIM-LCA Framework and Case Study of A Residential Building in Tianjin"*. The 3rd SREE Workshop on Applied Mechanics and Civil Engineering. Hongkong, 2013

Life Cycle Sustainable Assessment and BIM



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Short Summary

The task of assessing the contribution of individual buildings to sustainable development becomes more and more complex. Currently, there is a transition in the sustainability assessment from a previously predominantly qualitative to a predominantly quantitative evaluation. In addition, in the assessment the entire life cycle of a building is included, increasing the need to exchange and adapt data related not only to the technical and functional requirements of the building but also to the sustainability oriented requirements throughout the life cycle. As a result sustainability consultants among others have been added to the traditional building stakeholder groups, like designers and owners. Therefore, as communication, organization and management of information flow becomes of much greater importance, the integration of sustainable building assessment and benchmarking systems with the different stages of BIM is suggested. The BIM (Building Information Model) creates a single information node that simplifies updates and synchronisation mechanisms among the various actors involved in the same construction project. We will present in the paper how the current version of the IFC (the open language supporting the exchange with the BIM) suits the needs to compute and store the various indicators selected or developed in the frame of the SuperBuildings projects.

Keywords: Sustainable Assessment, Sustainable indicators, BIM, IFC, IFC4, Property Sets

1. Introduction to Sustainable Building Assessment

The assessment of the contribution of individual buildings to sustainable development is a complex task. This has to do both with the specifics of the object of assessment and the complexity of the assessment task.
The object of assessment is the building including its plot. In the assessment the entire life cycle of a building is included from the manufacture of building products to the construction of the building on its plot as well as from the stage of operation, management and maintenance to deconstruction and disposal.

To ensure the comparability of the assessment results, the building must be described through its functional equivalent. This task is usually carried out with reference to the functional and technical requirements of the owner of the building, which can be supplemented in accordance with EN 15643-1 [1] with additional demands on the economic, environmental and social performance of the building.
According to the ISO 21929-1:2011 [2] and EN 15643-1 the described requirements for a sustainability assessment of buildings are from an environmental, economic and social viewpoint.

Thus, the impact of manufacturing, construction, use, removal and disposal of the building on the environment, economy (including managerial interests of those involved) and society (including the interests of the community, the participants at the manufacturing and construction, the neighbourhood and the immediate users) is evaluated. Additionally, it needs to be checked and displayed whether and how the building meets all the technical and most importantly the functional requirements in an effective way.
Currently, in the sustainability assessment a shift is taking place. There is a transition from a previously predominantly qualitative (e.g., presence of green roofs) to a predominantly quantitative evaluation (e.g., calculation and evaluation of the GWP). For example, the Life Cycle Analysis is applied, which combines the Life Cycle Assessment (LCA) with the Life Cycle Costing (LCC), while this is often supplemented by a user satisfaction analysis, or a complaint management.
The results of a sustainability assessment can be used to improve the building performance only when they are successfully integrated into the process of planning, construction and management so that they are available at the time of a decision. This requires that the sustainability assessment can be adapted to the achieved state during the planning process and the lifecycle of the building. This state is a consequence of present at that time information about the building, its components and its former or foreseeable future life span as well as of the type of decisions reached at that time.
The impact of a building on the environment, economy and society during its life cycle must not only be described and evaluated, but also manipulated in a targeted way. This is done not only during the formulation of the brief, but as well as during the design, construction, management, deconstruction and disposal. The information on a building over its life cycle must not only be managed but also updated, supplemented and expanded.

2. The need for input data

It is clear that a prerequisite for the sustainability assessment and management in the life cycle of buildings is the identification, update and supplementation of information and data as well as their interpretation and assessment. Thus, the management of data both on the life cycle of buildings (perspective of object of assessment) and in the life cycle of buildings (perspective of a process of the life cycle of the building) becomes essential. For managing the information appropriately issues arise in relation to the identification and updating of data, including the representation of data source, data quality and data history. This includes information on:

- the location, including the forecast of future developments (e.g., climate and climate change, existing infrastructure and infrastructure development)
- the site (e.g. the ground, exposition to sun light)
- the user requirements (including requirements for the technical and functional quality, possibly supplemented by requirements for the economic, environmental and/or social performance of the building)
- the functional equivalent on the basis of user requirements including scenarios of for the nature, scale and intensity of use
- the geometry of the building and its components
- the physical composition of the building at the time of its construction – among others as a prerequisite for the application of the LCA (from cradle to handover) - including verifying the completeness of its description (possibly including the costs incurred during the construction of divergence and breakage losses of construction products in consequence of the construction activities)
- the cost of manufacture and construction of the building - possibly expressed as the construction price at the time of delivery, if calculated using the element method
- the actual or the forecast of the consumption of services (energy, water) and the occurrence of wastewater and waste, if necessary separately for the user related and the building related activities
- the actual or the forecast of the material consumption due to cleaning, repair and replacement investments on the basis of scenarios, including where necessary the possibility of checking of the coverage completeness of the data collection

The demand of data with a direct as well as indirect relationship with sustainability assessment needs to be specified. This is the subset of data that arise during the life cycle of buildings and has to be managed.
The determination of data for a sustainability assessment can be based on a documentation of requirements, a prediction (e.g., planning, calculation or evaluation), the representation of current conditions or facts and the acquisition of consumption data or survey results. On the one hand, the assessment has to be guided by the available data in relation to the various stages of planning and thereby the first generic or average data to be replaced gradually by manufacturer- and product-specific information. On the other hand, in the course of the construction process and the life cycle planned data have to be replaced by actual data. Possibly the actual values have also to be compared with the planned ones. In this case, the respective perspectives (geometrical, physical, functional, technical, environmental, economic, and social) are considered and managed. In particular, the ecological assessment requires further calculations. Both data from the area of physical composition of the building, including the scenarios for maintenance and replacement cycles as well as in the field of supply and disposal must be linked to data that allow the creation of an LCA. Usually, these are available on the basis of environmental product declarations (EPD's).

3. The need for harmonised indicators

In the frame of the SuperBuildings project, a number of European and international harmonisation and standardisation activities, i.e. CEN TC 350, ISO TC59 SC17, Sustainable Building Alliance (SBA), UNEP SBCI, LEnSE and Perfection, has been reviewed for the current availability and state of harmonisation of sustainability indicators and their assessment methods for buildings. Based on these analysis [3] and review [4], it can be conclude that both issues and indicators that are not (commonly) covered by the different tools and issues and indicators that are most occurring within the tools have been identified.
For all issues that are covered by more than one tool, the variation in assessment criteria and methods has been looked into in order to draw conclusions on their needs for further development and/or harmonisation.
Furthermore, both missing indicators and indicators that need (further) development and core indicators have been identified and compared to the indicators that are considered by the different tools.

4. Selected indicators

More than 20 key indicators have been either selected, or improved or developed, and documented through a structured format [5]. They cover the 3 pillars of sustainable development, but not all the related issues. Some are of particular interest and include added-value because they have been newly developed, as land use, cultural heritage, aesthetic quality, long term stability of economic value.
These indicators are listed in three tables below. Each table is presenting the indicators sorted by “subject of concerns” under the three “dimensions” of sustainability which are the environmental; societal and economic aspects.
Each of the selected indicators is documented on a textual basis according to the same structured methodology.
The next step is now to identify if and how the integration of these sustainable indicators with the BIM is feasible.

5. Relevance of a BIM based approach

5.1 Definition of BIM

There are several definitions for the notion of BIM. The Acronym BIM is sometimes turned into “Building Information Model” or “Building Information Modelling”, one representing more the concept and the other the approach.

On Wikipedia, the following definition is given to BIM:
"*Building information modelling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities. Dynamic information of the building, such as sensor measurements and control signals from the building systems, can also be incorporated within BIM to support analysis of building operation and maintenance.*"
This definition presents several facets of the notion of BIM, among others, the most important ones are:

- It covers the whole life cycle of a building project;
- It creates a single information node that simplifies updates and synchronisation mechanism among actors of the same construction project.
- It is a structured collection of building and construction objects including physical components, spaces, processes, actors involved, and relationships between these objects. All of these objects may be enriched by shared or specific properties. As a con-sequence, quantities or values stored in these proper-ties can be extracted and reused as the source of in-formation to perform calculations, analysis or simulations.
- It is a mean to enable heterogeneous actors to work together in an efficient way and for better results;

SD pillar	Subject of concern	Issue	Indicator
Environmental	Resources	Depletion of non-renewable energy resources	Consumption of non-renewable primary energy
		Non-renewable and scarce material resources	-
		Sustainable management of renewable resources	-
		Rational use of water	Embodied water use Operational water use Wastewater production
		Land use / Change of land use	Soil sealing Change of land use
	Biodiversity	Loss of biodiversity Respect of the local original species (planting) Preservation / improvement / restoration of local biodiversity	-
	Ecosystems	Protection of atmosphere (GHG)	Global warming potential
		Protection of atmosphere (other pollutants)	-
		Protection of water and soil quality (pollution and waste)	-
			Construction and demolition waste generation - Non-hazardous waste to disposal - Hazardous waste to disposal - Nuclear waste to disposal Solid waste separation
	Climatic systems	Climatic systems (risk of extreme climatic events) Adaptation to climate change	-

SD pillar	Subject of concern	Issue	Indicator
Societal	Health	Indoor air quality	Concentration of various pollutants
	Comfort	Thermal comfort	PMV (Predicted Mean Vote) PPD (Predicted Percentage Dissatisfied) Operative temperature Air temperature Relative Humidity Air velocity
		Visual comfort	Illuminance Daylight factor
		Acoustic comfort	-
	Safety / security		-
	Human interactions / relationships		-
	Culture and architecture	Architectural quality	Aesthetic quality
		Cultural heritage	Monument or monumental value / Historical value

SD pillar	Subject of concern	Issue	Indicator
Economic	Economic value	Economic value of 'goods' on the long term versus obsolescence	Life cycle costs - Capital cost - Costs in the operational phase *(Whole life costs)* *(External costs)*
	Economic risks	Prosperity versus risks	Long term stability of value *(Cost/value ratio at point of hand-over)*

Fig. 1: SuperBuildings key indicators

5.2 Advantages from a Sustainable Building Assessment point of view

From the user side, relying on a BIM centred approach presents several benefits from a sustainable assessment point of view. Among others, the following ones can be mentioned:

- BIM contains already most of the data listed above to perform a Sustainability assessment (building location, geometry, detailed composition) of a building that can be analysed from different environmental analysis point of views with different analysis tools (even if the data only was general geometries, quantities and qualities).

- BIM can include also data about the environmental properties of the building parts and building products (there are links with EPD's).
- BIM is the place where the results of the analyses could be stored back to ease comparison between different options or approaches.

The concept of BIM is easy to understand but hard to turn into a tangible reality in a current working environment as there is a strong need for an interoperable exchange format, rich enough to allow ALL users / stakeholders working simultaneously around the same digital model to enrich and retrieve data from the same single model.
BuildingSMART International (neutral, international and non for profit organisation coordinating technical and standardisation work around the BIM) is supporting the notion of OPEN BIM and thus promoting the use of a unique exchange language to dialogue with the BIM. This language is the IFC.

5.3 IFC4, the open language for an Open BIM

The building sector's Industry Foundation Classes IFC represent an open specification for Building Information Modeling BIM data that is exchanged and shared among the various participants in a building construction or facility management project. IFC's are the international openBIM standard.
The IFCs were originally developed to describe building components in an objectified way [6]. Based on STEP principles, the IFC data model is an object oriented model that separates the object identification and the associated properties, including potential different geometric representations and materials association. Since the beginning a lot of improvement has been made but the integration of sustainable/environmental notions is quite new as it has been done in the last release.
Now the IFC counts approximately 800 entities.

5.3.1 The "Property Sets" mechanisms

In the IFC4 documentation, a Property set is presented as "any specialization of object can be related to multiple property set occurrences. A property set contains multiple property occurrences. The data type of property occurrence are single value, enumerated value, bounded value, table value, reference value, list value, and combination of property occurrences. "
In the construction domain, for instance, IFC-based implementation of product libraries has a good prospect for meeting the industry requirements. Indeed, while IFC classes represent generic categories of elements (e.g. wall, beam, space) with very few attributes associated with a class to transfer information relevant to a manufacturer, IFCs incorporate a mechanism called Property Sets (PSets) which allow information publishers to dynamically allocate new properties to an object they wish to describe. Since there are numerous alphanumeric attribute definitions depending on discipline, life-cycle stage, building regulation and region, there will never be a complete set of internationally standardized attributes. Therefore, IFC defined property sets intent to standardize a basic set of properties, whereas other property sets can be regionally defined, or agreed upon in projects. The current drawback, however, is that there is no specification of the semantics of PSet information outside that published in the IFC distribution (PSD - Property Set Definition - Schema for the definition of property sets and properties).
It is important to stress the assets of such mechanism. IFC objects can have properties attached to them. The IFC model differentiates between attributes that are directly attached to the object as attribute of the entity, and properties, group in a property set and assigned to the object by a relationship. The latter is the more flexible way to extent applicable properties.
Furthermore these properties may be specific to particular regions, projects or process. The IFC schema supports storing and transmitting these properties in named sets (so called "IfcPropertySet"). Therefore, a property set is a collection of properties that can be declared outside of the IFC schema but that can be assigned to all objects defined within the IFC schema.

In the case of a BIM way of working and a process lead approach, it is worth defining well-suited property sets commonly agreed by parties as the right structure to convey the domain specific information between BIM and this specific activity.
In the current version IFC4, there are more than 400 property sets already defined.

5.3.2 Environmental Property sets and their connections with Building elements

In the scope of this paper it is worth mentioning two property sets that have just been introduced in this IFC4 version.
The first one is the property set “Pset_EnvironmentalImpactIndicators” which official definition is “Environmental impact indicators are related to a given “functional unit” (ISO 14040 concept). An Example of functional unit is a "Double glazing window with PVC frame" and the unit to consider is "one square meter of opening elements filled by this product”. Indicators values are valid for the whole life cycle or only a specific phase (see LifeCyclePhase property). Values of all the indicators are expressed per year according to the expected service life. The first five properties capture the characteristics of the functional unit. The following properties are related to environmental indicators. There is an international consensus agreement for the five one. Last ones are not yet fully and formally agreed at the international level”.
The second one is the property set “Pset_EnvironmentalImpactValues” which official definition is “the following properties capture environmental impact values of an element. They correspond to the indicators defined into Pset_EnvironmentalImpactIndicators. Environmental impact values are obtained multiplying indicator value per unit by the relevant quantity of the element”.
These two property sets are strongly interrelated as the first one is dedicated to the definition of the considered indicator(s) along with its unit(s) and validity domain(s).
They are commonly attached to the notion of IfcElement which is an abstract concept in the IFC ontology that can be further described as a generalization of all components that make up an Architecture, Engineering and Construction product. Those elements can be logically contained by a spatial structure element that constitutes a certain level within a project structure hierarchy (site, building, storey or space).

5.4 IFC elements addressed in a Sustainable Building Assessment

Actually, most of BIM/CAD tools propose export function to IFC. The resulting IFC exported files then contain IFC objects with their properties that can be used to perform Sustainable Building Assessment. A report for the Sustainable Building Alliance [7] shows a list of different devices and appliances that are concerned by different indicators and it makes the link from these devices to the corresponding IFC objects, expressing thus the ability of the IFC language to support the representation of various objects that are concerned by sustainable assessments. Of course, the inputs listed in the chapter “Need for Input Data” are present in the IFC model (building location, building structure and composition).
Sustainable analysis tools require the input of geometry to define the simulation model. This is mostly done by either importing the geometry or manually rebuilding it. Importing and exporting of building geometry is error-prone and tedious, especially as geometry models established in CAD-software are often not suitable as simulation models. The main asset of the BIM is to facilitate the reuse of existing data without retyping them. Even the environmental data produced by manufacturers (EPD’s on construction products) are now available via the BIM [8].

5.5 Sustainability indicators and corresponding IFC objects

In the frame of the SuperBuildings project a survey has been conducted in order to identify if the IFC model already contains the concepts able to support the 20 indicators listed previously.
This survey shows clearly that in its recent update (IFC4), the IFC have made a significant step forward in the integration of sustainable indicators into the BIM.
In the tables below, for each of these indicators, the corresponding IFC property set and element is indicated when existing.

Table 1 : List of SuperBuildings environmental indicators and corresponding IFC structures

Issue	Pset & Related property	Comment / definition attached to the property	IFC related element
Consumption of non-renewable primary energy	Pset_EnvironmentalImpactIndicators/NonRenewableEnergyConsumptionPerUnit	Quantity of non-renewable energy used as defined in ISO21930:2007	IfcEnergyMeasure
• **Embodied Water use** • **Operational water use** • **Wastewater production**	Pset_EnvironmentalImpactIndicators/ WaterConsumptionPerUnit	Quantity of water used	IfcVolumeMeasure
Soil sealing **Change of land use**	Pset_SiteCommon/SiteCoverageRatio	The ratio of the utilization, Total Area/Buildable Area, expressed as a maximal value	IfcAreaMeasure
Global warming potential	Pset_EnvironmentalImpactIndicators/ ClimateChangePerUnit	Quantity of greenhouse gases emitted calculated in equivalent CO2	IfcMassMeasure
Protection of atmosphere (other pollutants)	Pset_EnvironmentalImpactIndicators/ • PhotochemicalOzoneFormationPerUnit • StratosphericOzoneLayerDestructionPerUnit • AtmosphericAcidificationPerUnit	• Quantity of gases creating the photochemical ozone calculated in equivalent ethylene • Quantity of gases destroying the stratospheric ozone layer calculated in equivalent CFC-R11 • Quantity of gases responsible for the atmospheric acidification calculated in equivalent SO2	IfcMassMeasure
Construction and demolition waste generation • **Non-hazardous waste to disposal** • **Hazardous waste to diposal** • **Nuclear waste to disposal** • **Solid waste separation**	Pset_EnvironmentalImpactIndicators/ • NonHazardousWastePerUnit • HazardousWastePerUnit • RadioactiveWastePerUnit	• Quantity of non hazardous waste generated • Quantity of hazardous waste generated • Quantity of radioactive waste generated	IfcMassMeasure

Table 2 : List of SuperBuildings Societal indicators and corresponding IFC structures

Issue	Pset & Related property	Comment / definition attached to the property	IFC related element
Concentration of various pollutant			
Thermal comfort • **PMV** • **PPD** • **Operative temperature** • **Air Temperature** • **Relative humidity** • **Air velocity**	Pset_SpaceThermalRequirements • NaturalVentilation • NaturalVentilationRate • SpaceTemperature • MechanicalVentilationRate • SpaceHumidity	Properties related to the comfort requirements for thermal and other thermal related performance properties of spaces. This includes the required design temperature, humidity, ventilation, and air conditioning.	IfcThermodynamicTemperatureMeasure IfcRatioMeasure IfcCountMeasure
Illuminance **Daylight factor**	Pset_SpaceLightingRequirements Illuminance	Properties related to the lighting requirements that apply to the occurrences of IfcSpace or IfcZone. This includes the required artificial lighting, illuminance, etc.	IfcIlluminanceMeasure

Table 3 : List of SuperBuildings Economic indicators and corresponding IFC structures

Issue	Pset & Related property	Comment / definition attached to the property	IFC related element
Life cycle cost • **Capital cost** • **Cost in the operational phase**			IfcCostItem
LongTerm stability of value			

The property set mechanism demonstrates its ability to provide a semantic layer above the IFC elements. For instance, in the Table 1 above, the same IFC element “IfcMassMeasure” is used four times to store four different notions (Quantity of greenhouse gases emitted calculated in equivalent CO2, Quantity of gases creating the photochemical ozone calculated in equivalent ethylene, Quantity of gases destroying the stratospheric ozone layer calculated in equivalent CFC-R11, Quantity of gases responsible for the atmospheric acidification calculated in equivalent CO2). It is only because the property set has a well-defined and documented structure enabling the fact that the semantic attached to the four occurrences of this “IfcMassMeasure” element differs.

5.6 Gaps between the Indicators and their support in IFC

There is room for enhancement. Among others, one of the main assets of the BIM is to provide a unique repository of data along the whole life cycle of a construction project. In order to facilitate the understanding among the various actors, the exchange model and corresponding language (IFC) is structured and documented to ensure a semantic continuity about the information exchanged and stored at the various phases.
Three levels of trust for this semantic continuity can be defined:

- Level 0: There is not support from the IFC language and thus there is not guarantee at all that other actors or software platforms will be able to reuse it
- Level 1: There is a support from the IFC language. But there is no dedicated specific object or property to explicitly qualify the value of the indicator. The best example for that are the different notions of costs. There are few IFC entities dedicated to the cost and the notion of "cost per phase" can be determined and its value stored thanks to the "IfcCostItem" element but this specific meaning cannot be explicitly defined in current version. It relies for the moment on a possible agreement among concerned actors.
- Level2: There is a direct and explicit support from the IFC. In that case a common understanding in ensured.

The tables below recap for all indicators the semantic quality of its support in the IFC model.

Table 4 : List of SuperBuildings Environmental indicators and corresponding IFC structures

Issue	IFC related element	Quality of the IFC support	Comment
Consumption of non-renewable primary energy	IfcEnergyMeasure	**Level 2**	There is a direct support with the dedicated Property Set
Embodied Water use	IfcVolumeMeasure	**Level 1**	There is a support of the Water use via the WaterConsumptionPerUnit property. The notion of Embodied Water is not explicit.
Operational water use	IfcVolumeMeasure	**Level 2**	Direct support with the dedicated Property Set
Wastewater production	IfcVolumeMeasure	**Level 2**	There is a direct support with the dedicated Property Set
Soil sealing	IfcAreaMeasure	**Level 2**	Direct support with the dedicated Property Set
Change of land use		**Level 0**	No support
Global warming potential	IfcMassMeasure	**Level 2**	Direct support with the dedicated Property Set
Protection of atmosphere (other pollutants)	IfcMassMeasure	**Level 2**	Direct support with the dedicated Property Set Pset_EnvironmentalImpactIndicators/ • PhotochemicalOzoneFormationPerUnit • StratosphericOzoneLayerDestructionPerUnit AtmosphericAcidificationPerUnit
Construction and demolition waste generation • Non-hazardous waste to disposal • Hazardous waste to diposal • Nuclear waste to disposal Solid waste separation	IfcMassMeasure	**Level 2**	Direct support with the dedicated Property Set Pset_EnvironmentalImpactIndicators/ • NonHazardousWastePerUnit • HazardousWastePerUnit RadioactiveWastePerUnit

Table 5 : List of SuperBuildings Societal indicators and corresponding IFC structures

Issue	IFC related element	Quality of the IFC support	Comment
Concentration of various pollutant		**Level 0**	
Thermal comfort • PMV • PPD • Operative temperature • Air Temperature • Relative humidity Air velocity	IfcThermodynamicTemperatureMeasure IfcRatioMeasure IfcCountMeasure	**Level 2**	Direct support with the dedicated Property Set Pset_SpaceThermalRequirements • NaturalVentilation • NaturalVentilationRate • SpaceTemperature • MechanicalVentilationRate • SpaceHumidity
Illuminance	IfcIlluminanceMeasure	**Level 2**	Direct support with the dedicated Property Set Pset_SpaceLightingRequirements/ Illuminance
Daylight factor		**Level 0**	

Table 6 : List of SuperBuildings Economic indicators and corresponding IFC structures

Issue	IFC related element	Quality of the IFC support	Comment
Life cycle cost • Capital cost • Cost in the operational phase	IfcCostItem	**Level 1**	There is a support of the notion of Cost, via the IfcCost item and there possibilities to qualify this cost item via the “IfcCostValue” which is an enumeration of cost categories. But only the “whole life” category sounds related to the needs expressed here. The rest is not mentioned
LongTerm stability of value		**Level 0**	

It appears that:

- For the Environmental indicators 10 (among the12 studied) have a direct equivalent in IFC, one has an indirect support and one is not supported;
- For the Societal indicators 7 (among the 9 studied) have a direct equivalent in IFC and 2 are not supported;
- For the Economic indicators none (among 2) have a direct equivalent in IFC, one has an indirect support and one is not supported.

6. Conclusion

This paper presented part of the work performed in the frame of the SuperBuildings project.

Among the noticeable outcomes, the indicators developed represent the corner stone of a sustainable assessment process that becomes now more quantitative than qualitative. As environmental issues and sustainability increasingly have become hot topics in the building industry, there is a real need to perform sophisticated simulations and analysis based on detailed initial data and the analyses should be introduced as early as possible to allow for early collaboration between the design and assessment teams.

To perform such assessments it necessary to have an easy and quick access to input information such as the construction characteristics (dimensions of the building elements, composition and material used, physical and environmental characteristics, etc...). This is typically where the open BIM approach makes sense. The IFC model has proven its ability to convey necessary information to perform these assessments.

This paper has demonstrated also the ability of this language, especially in its latest version to support sustainable assessment results. Even if there are still some gaps most of the indicators developed or selected in the frame of the SuperBuildings project are already supported by the IFC4.

7. Acknowledgement

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8. References

[1] CEN – European Committee for Standardization, EN 15643-1 Sustainability of construction works – Sustainability assessment of buildings - Part 1: General framework, 2010

[2] ISO – International Organisation for Standardization, ISO 21929 -1:2011 - Sustainability in building construction -- Sustainability indicators -- Part 1: Framework for the development of indicators and a core set of indicators for buildings, 2011

[3] BBRI. ed. Deliverable D2.1 of Superbuildings “Conclusions about the needs for development of sustainability indicators and assessment methods”, 2010,

[4] Nibel S.,Chevalier J, Lebert A. ed. Deliverable D2.2 of SuperBuildings “Conclusions about the needs of development of performance levels and benchmarking criteria and weighting methods”, 2010,

[5] Nibel S, ed. Deliverable D4.2 of SuperBuildings “D4.2 Description and explanation of the selected indicators and related measurement and assessment methods with special focus on reliability, comparability and compatibility”, 2011,

[6] Liebich, T. "Unveiling IFC2x4 - the next generation of openBIM." CIB W78 2010: 27th International Conference. Cairo, Egypt, November 2010,

[7] Huovila P. Et Al, SBA report, “Linking SBA metrics to IFCs and BIM”, January 2012,

[8] Chevalier J. Et Al, SBA report, “ELODIE: a tool for the environmental assessment of building”, CIB 2010 Conference,

The sustainability effects of Product/Service-System design validated through Life Cycle Assessment



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Short Summary

Temporary buildings are generally considered to be unsustainable due to a short life span of the materials applied in the building. The construction materials typically have a longer use life than the required use life of the building, thus functioning building materials are often discarded after the demolition. In an attempt to improve the sustainability of temporary buildings, a Product/Service-System (PSS) strategy is here applied to a case project. The case project concerns a temporary building made of leased materials and building components such as shipping containers, scaffolding materials and lifts. The major research question for the case is how the supplier's continued ownership of the building materials influences the sustainability of such buildings.

By using a PSS design approach in the early design stages, the architects involved in the case project were able to make design decisions based on the whole life cycle of the building components, e.g. design-for-disassembly and design-for-reuse. The lease of materials will ensure that the building materials are re-used at the end-of-life stage. This is expected to prevent production of waste and improve the overall environmental sustainability of the temporary building.

The validation of the improved sustainability of the PSS-based building solution is achieved by comparing the PSS with a corresponding conventional approach for the temporary building through a comparative Life Cycle Assessment (LCA). The results show that over the entire life cycle, the aggregated environmental impact score for the PSS solution is 27% lower than the conventional solution when including operational energy and 37% lower when operational energy is excluded.

Keywords: Product/Service-Systems; temporary buildings; Life Cycle Assessment; closed loop systems; circular economy; life cycle design; waste prevention.

1. Introduction

The manifesto for a circular European Economy was published by the European Commission on the 17th of December 2012. It declares that:

"In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy. Our future jobs and competitiveness, as a major importer of resources, are dependent on our ability to get

more added value, and achieve overall decoupling, through a systemic change in the use and recovery of resources in the economy". [1]

The building sector creates one third of the total waste production in Denmark [2] and in Europe [3] and represents a challenge in terms of resource consumption and waste handling. At the same time, there is an increasing need for temporary and affordable buildings which can adapt to the changing needs and sizes of companies, municipalities, schools and universities. However, impermanent buildings are generally unsustainable, as the amount of material required is comparable to permanent buildings, though with a much shorter lifespan. As the European Commission declared above, this calls for systemic change in the use of resources. Product/Service-Systems offer such a systemic change, which has the potential to radically reduce the environmental impacts of traditional products. Several studies ([4], [5] and [6]) performing LCAs on various Product/Service-Systems have shown a 30-75% reduction of the environmental impact of Product/Service-Systems compared to the conventional solutions.

This paper presents the business potential for using Product/Service-Systems (PSS) in the building sector and explains how the suppliers extended ownership and responsibility in a PSS can facilitate multiple use cycles of building materials, thereby avoiding useful materials going to waste.

Thereafter, the sustainability effects of a Product/Service-System will be quantified using LCA. An LCA has been carried out on a case study in order to investigate how a PSS solution can alter the environmental profile of temporary buildings.

2. Product/Service-Systems in the building sector

2.1 Introduction to Product/Service-Systems

Product/Service-Systems (PSS) have already entered the building sector through lighting services (e.g. Philips), furniture services (e.g. Gispen, the Netherlands) and carpet leasing programmes (such as Interface Inc, USA) [7]. Here, the customer pays for the function, e.g. square meter carpet per year, rather than for the product which delivers the function, e.g. the carpet itself. The company installs, monitors, maintains and replaces the carpets whenever necessary, making it convenient for the customer.

Product/Service-Systems have similarities with circular economy, where resources are kept and restored in closed loops, belonging to either the technosphere or ecosphere. They also have parallels with approaches such as Service Economy and Functional Economy, where the object of sale is a performance, customer satisfaction or result, in contrast to industrial economy, where the object of sale is a product [8].

Here we will offer two general definitions of PSS, the first relating to what it is, and the second to how it can be achieved.

"A marketable set of products and services capable of jointly fulfilling a users/customers need in an economical and sustainable manner." [9]

"PSS strategy is to shift from business based on the value of the exchange of ownership and responsibility, to business based on the value of supporting and enhancing the utility of products throughout their entire life cycle." [10]

This paper will apply both definitions to construction materials and quantitatively as well as qualitatively assess the sustainability of Product/Service-Systems in the building industry.

2.2 PSS business case for construction materials

Currently, most construction material suppliers work with a simple point-of-sale model, where the ownership and responsibilities are transferred to the customer. A Product/Service-System extends the ownership and responsibility of the supplier to the entire life cycle [8], i.e. in our case to the entire life cycle of the temporary building. Thereby, the supplier sells the right to use the material, rather than the material itself, typically through a lease agreement. The PSS may also include servicing and repair of the construction components during use. After use, the manufacturer will take back the product and re-use or recycle it. The customer gets what he wants; the ability to use materials in the form of a building for a certain amount of time, and avoids the usual hassle of being in charge when something breaks down as well as having to cover the expenses for disposal of materials at the end-of-life.

Product/Service-Systems thus provide opportunities for entirely new business models in the construction industry. Lease agreements give economic benefits for both the supplier and the contractor; they give a sustained income for the supplier and improve the cash flow of the developer. The supplier keeps a 'material bank' at his customers, which later can be used as feedstock in the production, making him more resilient to fluctuating market prices and resource scarcity.

There are thus strong economic incentives on both the supply and demand side for Product/Service-Systems. However, it should be considered whether PSS solutions also are environmentally beneficial.

2.3 Product/Service-Systems and sustainability

Mark Goedkoop et. al. [9] found that although a shift from a product to a service is, on average, environmentally sound, there are exceptions with high variability. Therefore they recommend assessing the sustainability of Product/Service-Systems case by case.

Several studies on the sustainability effects of various Product/Service-Systems have previously been carried out. A study of a bicycle sharing system [4] found that the total environmental impacts could be reduced by 30% through improved robustness of the bicycles and that a 45% reduction could be achieved through improved maintenance service. A similar study [5] comparing a PSS self-service laundry system with household washing machines found that the carbon emissions could be reduced by more than 50% through optimised utility of the washing machines. Another study of the leasing of water filtration devices [6] concluded that a reduction of 75% of the total environmental impact over a 4 year lifespan could be obtained through maintenance, increased lifespan and improved end-of-life treatment.

In these studies, several features of Product/Service-Systems were identified as factors to improve sustainability:

- Longer lifetimes through robustness and maintenance
- Optimised utility of products through leasing and sharing
- Improved end-of-life treatment.

All of these features can be relevant in a Product/Service-System of construction materials. However, this case project has focused on optimised utility through leasing and improved end-of-life treatment. In order to achieve optimised utility and improved end-of-life treatment of construction materials, the Product/Service-System design may take its starting point in a cyclic material model, as first suggested by the Swiss architect Walter R. Stahel in 1982 [11]. His self-replenishing model recommends choosing reuse over repair, repair over reconditioning and reconditioning over recycling. Incineration and landfill are not at all included in his model, and should be excluded from PSS models since recycling is generally preferable to these options [12].

Whether a given PSS is sustainable is thus a question of its design. As PSSs focus on the value of use rather than the value of ownership, they render planned obsolescence obsolete and instead promote durable design. They extend the responsibilities of the producer and thereby align the producer interests with the interests of the consumer. Product/Service-Systems may thus be an important step in the transition from a 'buy-and-throw-away' consumption culture, to a system where the utility of products is optimised, equitably distributed and environmental resources carefully managed.

3. Case study and environmental impacts

3.1 Measuring the environmental effect of PSS through LCA

This paper seeks to go beyond conventional eco-design, and focus on the sustainability effects of the Product/Service-System. Thus, the focus is not so much put on choice of materials, but on the effect of making re-use an intrinsic part of the system surrounding the building.

LCA is suitable for assessing the environmental impacts of both products and services, as these can be compared on the basis of the same functional unit [13]. That allows us to compare leased and bought materials in this case. The LCA was carried out according to the ILCD recommendations and EN15978:2011 standards for environmental assessment of buildings.

3.2 Introduction to the case study

This study is based on a temporary building designed by Lendager Arkitekter, a Danish architect studio which is specialised within sustainable design. The building consists of components and materials that are either leased or bought on take-back contracts between the developer and suppliers. In these contracts, the suppliers guarantee taking back the materials after use, which ensures re-use of functional materials.

The building itself is designed for assembly, disassembly and re-use of the materials. The dimensions of the leased materials determine the dimensions of the construction, rather than fitting the materials to the design. Thereby construction waste is reduced significantly, and the materials can be re-used directly after the use phase. The materials chosen for the building are materials which are traditionally leased for other purposes. They include shipping containers, scaffolding materials, lifts and pre-fitted bathroom containers. The containers are used as building blocks to form the outer wall of the building. The resulting modular design makes it possible to modify the layout and size of the building during operation, according to the changing needs of the tenants.



Fig. 1: The case study building 'Eco-Box'

This building is seen as a pilot project for use of Product/Service-Systems in the building industry. The concept behind the building is to lease all construction materials, functions and furnishings, thereby avoiding the creation of waste. However, working within the current network of suppliers, it has not been possible to lease the insulation, wall lining, windows and doors. As the building is still in the design phase and planning stage, the PSS solution focuses on the overall leasing of construction materials, and not on functions such as lighting and furnishing.

3.3 Compared scenarios

The Product/Service-System scenario of re-used and re-usable materials is compared to the conventional scenario of applying first-use materials which receive conventional Danish end-of-life treatment, see table 1. In other words, the LCA compares a model with multiple use cycles of materials with a model with only one use cycle of the materials.

3.3.1 The European waste hierarchy

The European hierarchy prioritises five different waste options, see figure 2 [14]. Out of these five options, the preferred one is waste prevention. The waste prevention strategy has been followed in the design phase of the building under study by reducing the amount of materials per square meter office space and choosing environmentally friendly building materials over materials containing hazardous substances.



Fig. 2: European waste hierarchy [14]

The end-of-life of materials are on average placed higher in the waste hierarchy for the PSS solution compared to conventional Danish building waste treatment, as many materials are re-used rather than recycled. Table 1 shows the construction materials divided into the four waste scenarios; prepare for re-use, recycling, recovery and disposal.

Table 1: Comparison of end-of-life treatment for the two scenarios

Waste treatment	PSS	Conventional
Prepare for re-use	Containers Steel foundation Scaffolding HVAC elements Lift	-
Recycling	Plastics Gypsum Wood based materials Windows and doors Fibre cement Staircases and bridges Screws, bolts and nails	Containers Steel foundation Scaffolding Windows and doors Staircases and bridges HVAC elements Wood based materials Plastics Gypsum Screws, bolts and nails Lift
Recovery (energy recovery rate >60%)	Bitumen Cellulose insulation UPM flooring Roof cover	Bitumen Cellulose insulation UPM flooring Roof cover
Disposal (energy recovery rate <60%)	-	-

In 2009, 5 mio tonnes of building waste was produced in Denmark, this equalled more than one third of the total waste production. 96% of the total mass of building waste was recycled. However, most of this recycled material is dirt, stone, concrete and asphalt which is crunched and used as roadfill [1]. This can be considered 'downcycling' rather than 'recycling'. This means that there are still improvements to be made in the treatment and utility of building waste, improvements which are often intrinsic in Product/Service-Systems.

3.4 Goal and Scope

3.4.1 Goal

The goal of this LCA is to quantify the environmental improvement originating from Product/Service-Systems of building materials and components.

3.4.2 Functional unit, reference flow and key parameters

The PSS and conventional solutions are compared on the basis of the functional unit:

Providing 790 m^2 office space in Denmark for 8 years (2013-2021) including heating, ventilation and cooling according to Danish energy requirements for 2015.

The reference flow is one building and its energy consumption during use. The key parameters are the amount of materials per square meter office space and use life of construction materials.

3.4.3 Modelling framework and handling of re-use and recycling of materials

The modelling of the end-of-life is done by system expansion and subtraction using average data according to the ILCD handbook (situation A) [15] and the EN 15978:2011 standards [16].

The recovered energy resulting from incineration of the materials is assumed to substitute average

electricity in the Danish grid.

For recycling, the net impact of the building material is calculated as the impacts related to the recycling process minus the impacts from producing the substituted product. The substituted product is the average market mix, in accordance with the recommendations of the ILCD handbook [15].

The modelling of re-used materials is relevant in this case, as the use life of the materials is longer than the required use life of the building. Reused and reusable materials are however not environmentally 'free' due to wear during use. The total impacts related to the production stage and end-of-life of the component must therefore be allocated to the different use cycles. The allocation is done according to ILCD's recommendations for handling of re-used materials in attributional LCAs, and the chosen allocation factor is based on time.

The allocation factor is the ratio between the required use life of the building (RULB) and the expected use life of the materials (EULM), where RULB < EULM.

For leased materials, the economic and time-based allocation factors are equivalent, as the monthly payment does not depend on the former use period of the materials. In a Product/Service-System, the customer pays according to functionality of the solution, not according to the newness of the materials. At the end of the materials' use life, the entire production and end-of-life processing is accounted for by the sum of use cycles.

3.4.4 System boundaries

The LCA covers the whole life cycle of the building, from raw material extraction to end-of-life or 'end-of-cycle'. The included life cycle stages are shown in table 2.

Table 2: Life cycle stages in the LCA

Stage	Unit process
Production stage	Raw material supply
	Transport to manufacturer
	Manufacturing
Use stage	Replacement of components
	Operational energy use
End-of-life	Waste processing
	Disposal
Next product system	Reuse, recovery or recycling potential

The surrounding outdoor grounds and materials for plumbing, furnishing, electrical installations and lighting are outside the system boundaries.

3.5 Life cycle inventory

In the production stage, primary data from suppliers was used to set up the life cycle inventory of materials. The inventory was modelled in the LCA tool GaBi (version 4.4) with EcoInvent (version 2) datasets using fully parameterised modelling. The production stage of all construction materials were modelled and divided into six building elements to allow a better overview of the building:

1) Building base (including leased containers and point foundations)
2) External walls (no leased materials)
3) Internal walls (no leased materials)
4) Ceilings, floors, stairs and balcony (including leased scaffolding and lift)
5) Roofs (including leased scaffolding and cover)
6) Central energy, heating and cooling units (including leased HVAC elements)

For the replacement stage and for allocation of re-used materials, the expected lifetimes of materials and components were collected directly from suppliers. The operational energy was calculated as a function of floor area using the Danish 2015 energy requirements for office buildings. The import of electricity was modelled using average Danish grid mix. The waste processing and recycling was modelled manually with data from EcoInvent datasets and WRAP 2010 [12] data for plastics. The recycling processes are assumed to be 90% effective. BUWAL datasets were applied for the energy recovery of different materials.

3.6 Life cycle impact assessment methodology

ReCiPe version 1.0 was applied in this case, and all 18 midpoint categories and 3 endpoint categories were calculated using the Hierarchist characterisation and normalisation factors. The characterised impact categories are extracted at midpoint, translated to endpoint, then normalised and weighted at endpoint using average ReCiPe weighting factors [17]. The weighted endpoints are then aggregated to a single score on which the different alternatives are compared.

3.7 Life cycle impact assessment results

3.7.1 Production stage

Quantified in dimensionless weighted endpoint scores, the total impacts related to the production are 27% lower for the PSS solution than for the conventional solution due to the use of re-used materials. The leased materials currently make up 65% of the total mass of the building. Therefore, a greater reduction could potentially be achieved if an even higher ratio of the materials could be leased.

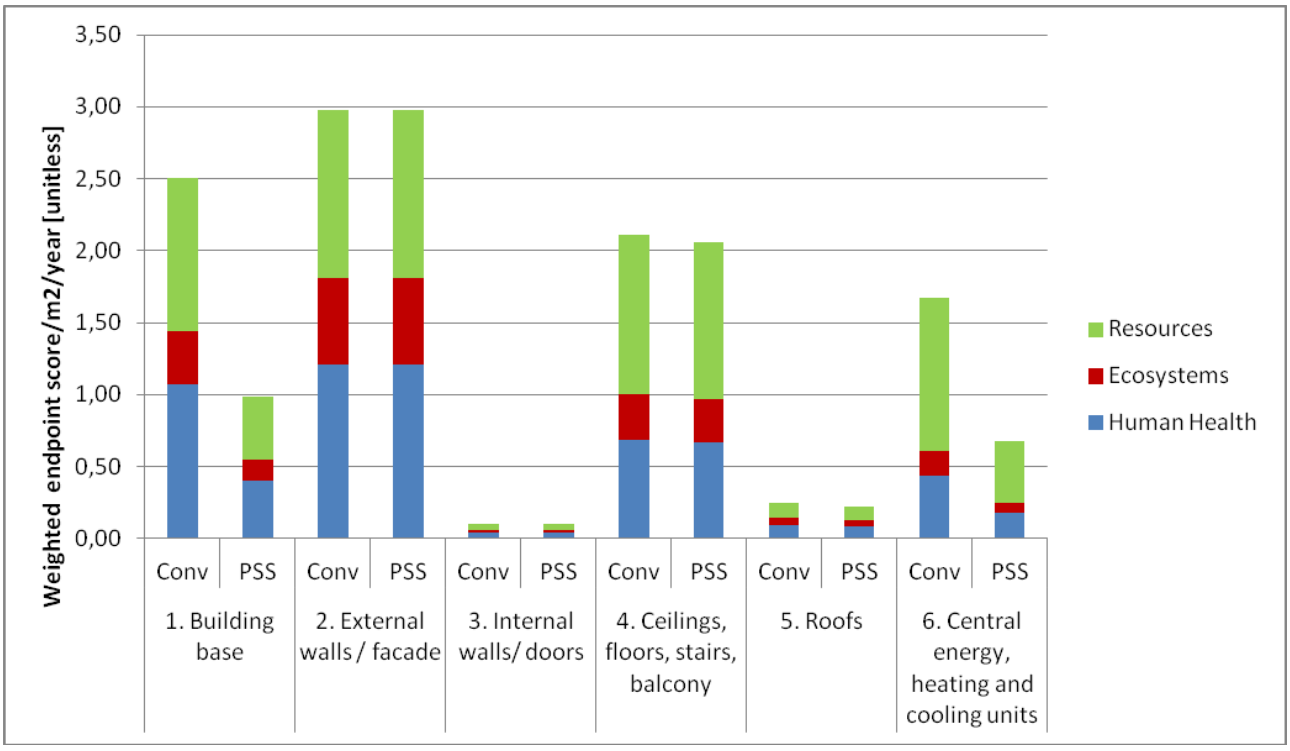


Fig. 2: Weighted endpoint scores for building materials of conventional and Product/Service-System solutions

Figure 2 compares the conventional solution with a Product/Service-System building using the same materials split into six building elements. The largest difference can be found in the building base, which consists of leased containers and leased point foundations. Here, the PSS components only amount to 39 % of the conventional solution quantified in dimensionless weighted endpoint scores - a reduction of 61%. The internal and external walls consist of wood,

plastic, windows and insulation, which are currently not offered by a Product/ Service-System. Therefore, the impact here is the same for the two solutions. Building elements 4, 5 and 6 specified in figure 2 consist of a mix of re-used and new materials; therefore the PSS solution's potential impact is slightly lower than the conventional solution.

3.7.2 Use stage

Figure 3 shows the potential life cycle impacts divided into five stages. The operational energy consumption is the same for the two solutions. This stage corresponds to 26% of the total life cycle impact for the conventional solution, and 36% for the PSS solution which has lower impacts in other stages. This is relatively low due to the short life span of the temporary building. There is however great uncertainty related to the amount of operational energy required, as no energy calculation has yet been performed on the building. The impacts here are also highly dependent on the composition of energy sources in the grid.
In the replacement stage only the roof cover is replaced due to the short life time of the building. Therefore, the replacement stage only contributes with 1% to the total life cycle impacts.

3.7.3 End-of-life

For the end-of-life processing, the environmental impact score of the PSS solution is 52% lower than the conventional solution. This is significantly more than the reduction at the production stage. This is caused by the energy demanding process of smelting steel and aluminium, which also contribute highly to the endpoint impact 'Resources'. The roof cover containing PVC and cellulose insulation containing boric acid are incinerated rather than re-used at end-of-life. These materials contribute highly to eco-toxicity. It can therefore be argued that improvement at end-of-life could be obtained by replacing these materials by non-toxic ones, in an eco-design approach.

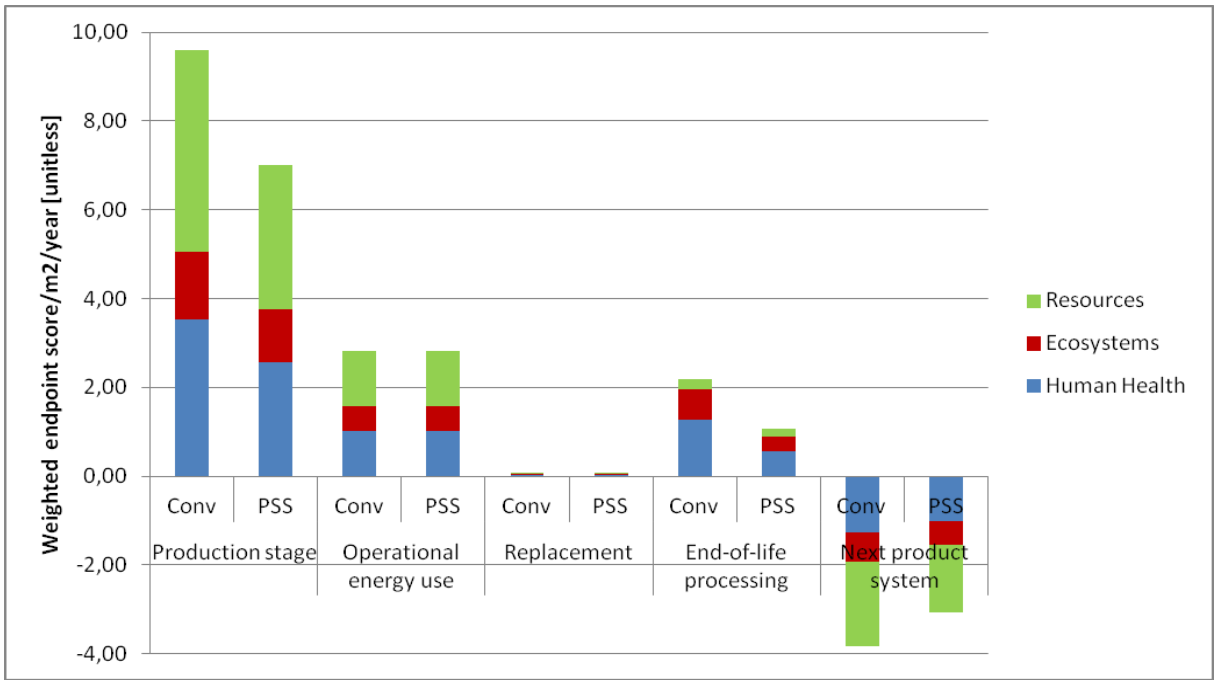


Fig. 3: Weighted endpoint scores for the full life cycle of the conventional solution and PSS

The fact that the end-of-life processing is significantly lower for re-use compared to recycling is another reason to extend the total use life of components through Product/Service-Systems, thereby postponing recycling of the material and lowering the impact per use.

3.7.4 Total life cycle

Over the entire life cycle, the aggregated environmental impact score for the PSS solution is 27% lower than the conventional solution when including operational energy and 37% lower when operational energy is excluded.

3.7.5 Sensitivity analysis

A sensitivity analysis was performed by varying the input parameters by 10% and calculating the corresponding change in total output. The sensitivity analysis showed that all of the input parameters has a sensitivity ratio (percentage change in input divided by percentage change in output) of below 0.01, and can therefore be characterised as having low sensitivity. This means that a change in individual parameters will not have a significant effect on the result.

4. Conclusions

4.1 Discussion

A barrier to using Product/Service-Systems in the building sector today is that the materials cannot be modified. Customisation of leased materials to meet many different needs and building designs represent a challenge for both architects and material suppliers. Also, the limited choice of materials which can be leased today may result in bulkier designs, which eventually use more resources despite re-use. In this case, the shipping containers may be much larger and heavier than alternative materials necessary to create the building structure. Thus, the total material consumption and type of material should be taken into consideration when designing buildings based on Product/Service-Systems.

Furthermore, the rebound effect should be avoided, so that the higher affordability of impermanent buildings through Product/Service-Systems does not lead to increased use of resources on the whole. Although the temporary building can be built and run with 27% less potential environmental impacts through Product/Service-Systems, permanent buildings may on average remain more sustainable than temporary buildings. This is due to the added impacts of transport, construction and deconstruction in temporary buildings. A PSS model may not be suitable for permanent buildings, as the lease period can be too long and therefore the risk too great. Only 65% of materials can be leased in this case example, as materials which are too fragile to be mounted and de-mounted several times cannot be leased. A Product/Service-System based on leasing entire module-based buildings would ensure re-use of all building materials.

4.2 Conclusion

Product/Service-Systems push the benchmark for lifetimes and end-of-life treatment of materials, and thereby reduce the total environmental impact. It was shown that Product/Service-Systems can potentially improve the environmental sustainability of single building components used in temporary buildings radically, in our case example up to 85%. The improvement rate depends on the lifetime of the component versus the lifetime of the building. In general, the shorter the lifespan of the building or the greater the uncertainty of the building's future, the more environmentally beneficial the PSS solution will be.

Since not all the building materials can be leased in this case, the leased materials must be supplemented to form a functioning building, and this affects the total environmental sustainability of the building negatively. Thus over the entire life cycle, the aggregated environmental score for the PSS solution is 27% lower than the conventional solution. The overall reduction of impacts in the production stage is 27% in this case study. The total environmental impact score related to the end-of-life processing is reduced by 52% in the PSS solution, due to avoided energy-heavy recycling of metals. The operational energy only amounts to 26% of the total impacts of the temporary building. This underlines the importance of improving the sustainability of materials used in temporary buildings, by e.g. leasing materials through Product/Service-Systems.

4.3 Further work

Further research on PSS in relation to this case was carried out in this project. A main goal was to compare the environmental life cycle assessment with a life cycle costing model on the same case, in order to find environmental and economic trade-offs and synergies of Product/Service-Systems. Also, further work can be done on how much a PSS and an Eco-design approach respectively can contribute to reducing the environmental impacts in the building sector.

4.4 Acknowledgements

We would like to thank Lendager Arkitekter and Design City Kolding for providing the case on which this paper is based.

5. References

[1] EUROPEAN COMMISSION, *"Manifesto for a circular European Economy",* http://europa.eu/rapid/press-release_MEMO-12-989_en.htm, 2012.
[2] MILJØMINISTERIET, *"Affaldsstatistik 2009 og Fremskrivning af affaldsmængder 2011-2050",* Danish Ministry of Environment, 2011, pp. 35-47.
[3] EUROPEAN COMMISSION, *"Waste statistics*". http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Waste_statistics, 2013.
[4] AMAYA J, LELAH A, ZWOLINSKI P, *"Environmental Benefits of PSS Strategies: A Bicycle Sharing System Case Study".* CIRP IPS2 Conference 2012, 2012, pp. 339-344.
[5] HU H A, LIN R W, HUANG C Y, WU C L, *"Carbon Reduction Assessment of a Product Service System: A Case Study of Washing Machines"* in *"Design for Innovative Value Towards a Sustainable Society".* Springer Science+Business Media Dordrecht, DOI: http://doi.org/10.1007/978-94-007-3010-6_205; 2012, pp. 998-1001.
[6] LIN S L, JUAN P H, CHEN C Y, *"The study of a product service system for the leasing of a water filtration device"* in *"Design for Innovative Value Towards a Sustainable Society".* Springer Science+Business Media Dordrecht, DOI: http://doi.org/10.1007/978-94-007-3010-6_205; 2012, pp. 982-985.
[7] MONT O, *"Product-Service Systems*". The International Institute of Industrial Environmental Economics, Lund University, 2000, pp. 66-70.
[8] TAN A R, *"Service-oriented product development strategies*". DTU Management Engineering. 2010, pp 1-221.
[9] GOEDKOOP M, VAN HALEN C, TE RIELE H, ROMMENS P, "*Product Service systems, Ecological and Economic Basics"*. Pré Consultants for Dutch Ministry of Environment (VROM) and Economic Affairs (EZ), 1999, pp. 1-105.
[10] TAN A R, MCALOONE T C, ANDREASEN M M *"What happens to integrated product development models with product/service-system approaches."* Proceedings of the 6th Integrated Product Development Workshop, IPD2006. 2006.
[11] STAHEL W R, *"The Product-Life Factor"* in "*An Inquiry Into the Nature of Sustainable Societies: The Role of the Private Sector"*. Houston Area Research Centre, Houston, 1982 pp 72-96.
[12] MICHAUD J C, FARRANT L, JAN O, KJÆR B, BAKAS I, *"Environmental benefits of recycling – 2010 update".* Waste and Resources Action Programme, Oxon. 2010.
[13] BEY N, MCALOONE T C, *"From LCA to PSS – Making leaps towards sustainability by applying product/service-system thinking in product development",* LCE conference paper, 2006.
[14] EUROPEAN COMMISSION, "*European waste hierarchy"* http://ec.europa.eu/environment/waste/framework/.
[15] EUROPEAN COMMISSION JRC INSTITUTE FOR ENVIRONMENT AND SUSTAINABILITY, *"International Reference Life Cycle Data System – General guide for Life Cycle Assessment – Detailed Guidance".* 2010, pp. 349-354.
[16] CEN TC/350. *"Sustainability of construction works – Assessment of environmental performance of buildings - Calculation method"*, 2012, 1st edition.
[17] GOEDKOOP M, *"ReCiPe 2008 - A life cycle impact assessment method which comprises*

harmonised category indicators at the midpoint and endpoint level". Ruimte en Milieu. Ministerie van Volkshuisvestin, Ruimtelijke Ordening en Milieubeheer, 2009, pp. 1-55.

An LCA Study on a Concrete Structure by Variations of Compressive Strength of Concrete to define the characteristics of GHGs emission



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Short Summary

This study aims to define the characteristics of Carbon Dioxide emissions from concrete structures when different compressive strength of concrete applied to structural systems having the same functional unit with different durability. A total of 24Mpa, 40Mpa and 60Mpa cases is analyzed to define the characteristic by Life Cycle Assessment including the stages of production, construction, maintenance and disposal. As results, the amount of cement appears to be a major factor for the emission from the production stage, the amount of concrete from construction and disposal, durability of concrete from use and maintenance. It is recommended to develop optimal mixture designs for sustainable concrete in the consideration of life cycle characteristics of concrete structures to be used.

Keywords: LCA, CO_2 emission, Concrete structure, Compressive strength, Reinforced concrete structural wall system

1. Introduction

As various carbon policies being implemented in order to address climate change and the need for the mitigation of greenhouse gases associated with industrial activities at the national and enterprise level being emerged, efforts are also being made in the construction sector to minimize greenhouse gas emissions. Buildings which are composed of various materials and components, induce enormous environmental pollution throughout the life cycle from construction to disposal and therefore, in order to control environmental impacts from the building, it is necessary to verify the environmental burdens caused by construction material. In particular, since concrete products using cement and aggregates, are the most popular construction material and the proportion of these materials used in a building, is over than 80% among all materials input by weight per unit floor area, it is important to identify the environmental impacts from concrete products[1].
This study is intended to evaluate quantitatively potential impacts of a concrete structure throughout its construction, use and disposal from the perspective of global warming that has been an issue in relation to climate change. It analyses the characteristics of greenhouse gas emissions for concrete structures as there can be the differences in the amount of inputs and durability by the compressive strength of concrete even in the same structure, serving as a basis for the prediction of environmental impacts for the construction of sustainable concrete structures in the future.

2. LCA Implementation

2.1 Overview

The environmental impact assessment which is mainly applied in the field of construction is in accordance with the LCA (Life Cycle Assessment) standards proposed by the International Organization for Standardization[2].
As an evaluation tool for environmental labelling standards, the LCA is intended to compare the full range of effects of products and services on the environment and society in order to provide a sound basis for informed decisions being able to reduce environmental burdens in various aspects of human activity[3]. An LCA is carried out by four main phases including goal and scope definition, life cycle inventory analysis, life cycle impact assessment, life cycle interpretation.

2.2 LCA plan for concrete compressive strength

2.2.1 Comparative assessment plan

Basically, the comparative assessment of environmental impacts for specific concrete compressive strength complies with the LCA techniques as specified in the ISO14040 series but only global warming potential is utilized from the characterization impact categories of the LCA to simplify evaluation processes. For the carbon dioxide emission factor of each material, the National Environmental Information[4] (LCI DB; Life Cycle Inventory Database) which is on the basis of the LCA standards was referenced.
A variety of concrete mixes are chosen with different use of cement. The amount of material inputs varies in each mix and the resulting durability and environmental burdens also can be different. In this assessment, the use and duration of concrete products remain the same, and by assessing them only with varying concrete compressive strength, the life cycle environmental burdens of concrete with general and high compressive strength are analysed. The assessment was carried out by varying the compressive strength of concrete from 24MPa, which is typically required in buildings, to high compressive strengths of 40MPa and 60MPa, and the applied casting area was limited to the walls of reinforced concrete wall structure. Besides, the assessment period of environmental impacts was determined to be a total of 120 years, and the use period of structures was assumed to be 60 years for a structure with 24MPa and 120 years for high compressive strength concrete with 40MPa and 60MPa.

2.2.2 Requirements for assessment

(1) Functions, functional units and reference flows

The comparative assessment in the LCA process must be based on the same function and functional unit. The functional units and reference flows for conducting an LCA on a concrete structure are presented in Table 1.

Table 1: Function, Functional Unit and Reference Flow

Classification	Definition
Function	To form structural wall of reinforced concrete apartment building
Functional Unit	Reinforced concrete walls of 25-story apartment building occupied during 120 years
Reference Flow	Materials and energy input for reinforced concrete walls of 25-story apartment building occupied during 120 years

(2) System boundaries

A system is a collection of series of activities to perform clearly defined functions. In a broad sense, it is associated with all the stages of a product's life from raw material extraction through materials processing, industrial or customer use, and disposal. In the ISO 21930, which embodies the principles and procedures of LCA in the field of construction products, the system boundary of the

life cycle of a construction product is subdivided into production stage, construction stage, use stage and disposal stage, and the environmental impacts due to the flows of material and energy for each stage are designed to be identified. The stage and scope definition of system boundaries associate with the concrete LCA are shown in Table 2.

Table 2: System Boundary for LCA of Concrete

Stage	Scope Definition
Production	all the processes of producing the materials to be inputted into a structure by consuming the resources and energy required for production, manufacture of products
Construction	the process of transporting materials from the production site to the construction site and the stage of completing the structure by inputting building materials, energy, etc
Use & Maintenance	the process wherein a user maintains a structure through additional repair and maintenance while the user resides in the building until the completed building is demolished
End of Life	the process of demolishing a structure using equipment, transporting for reclamation or incineration or recycling

(3) Scope of data collection

The amount of material inputs with respect to the mixture ratio for concrete compressive strength for this study is presented in the following Table 3, which is refered to an actual mixture table from a ready-mixed concrete company. Data on major constituent materials including Portland cement type 1, sand, coarse aggregates and mixing water are collected to perform an LCA.

Table 3: Amount of Input by Concrete Compressive Strength

Strength	Materials (kg/㎥)					
	Aggregate	Sand	Portland Cement Type 1	Water	Admixture	Total
24MPa	931 (40%)	863 (38%)	334 (15%)	170 (7%)	2.34 (0%)	2300.34 (100%)
40MPa	896 (39%)	748 (33%)	459 (20%)	163 (7%)	6.63 (0%)	2272.63 (100%)
60MPa	905 (41%)	705 (32%)	426 (19%)	165 (7%)	6.09 (0%)	2207.09 (100%)

(4) Life cycle assessment scenarios

According to the ISO 21930, all the stages of a product's life cycle (“Cradle to grave") should be subdivided into at least four life-cycle stages and served as basic information modules to present the environmental information on construction products.

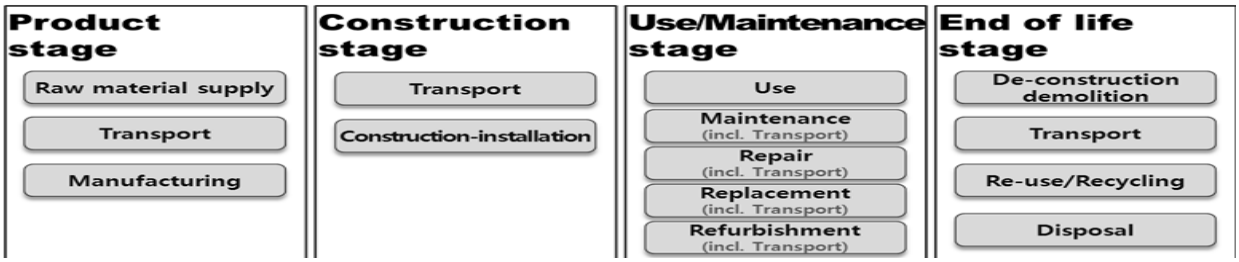


Fig. 1: System Boundary of Materials(ISO 21930 Sustainability in building construction - Environmental declaration of building products)

When the principles and procedures of the LCA are applied to this assessment, the scenarios on each stage of the life cycle for a concrete structure with 3 types of compressive strength and corresponding data collection methods are summarized as follows:

Table 4: Assessment Scenarios for LCA

Stage	Phase	Data Collection	Type of Data	GHG Emission Unit (Source)	Supposition
Production	Material Manufacturing	Aggregate	Field Data	6.65E-03 $kgCO_2$ e/kg (KLCI)	Materials within 95% of the cumulative weight contribution
		Sand		2.42E-03 $kgCO_2$ e/kg (KLCI)	
		OPC Type Ⅰ		9.48E-01 $kgCO_2$ e/kg (KLCI)	
		Water		1.14E-04 $kgCO_2$ e/kg (KLCI)	
	Transportation	Energy Consumption	Transportation Data	(KLCI, Carbon Labelling, IPCC)	Transport data between manufactories
Construction	Construction/ Installation	Oil consumption by Concrete Pump Car	Field Data	2.66E+00 $kgCO_2$ e/L (Carbon Labeling)	Activity data related with construction machinery
	Transportation	Energy Consumption	Transportation Data	(KLCI, Carbon Labelling, IPCC)	Transport data between manufactories and site
Use & Maintenance	Maintenance	Aggregate, Cement, Water Consumption	Field Data	(KLCI, Carbon Labelling, IPCC)	Activity data related with product maintenance
	Transportation	Energy Consumption	Transportation Data	(KLCI, Carbon Labelling, IPCC)	Transport data between manufactories and building
End of Life	Deconstruction	Energy Consumption	Field Data	(KLCI, Carbon Labelling, IPCC)	Activity data related with machinery
	Transportation	Energy Consumption	Transportation Data	(KLCI, Carbon Labelling, IPCC)	Transport data to disposal facility
	Disposal	Waste Concrete Reclamation	Disposal Scenario	(Carbon Labeling)	Activity data related with waste landfill
	Recycle	Waste Concrete Recycling	Recycling Scenario	(Carbon Labeling)	Activity data related with recycling

3. Global warming impacts from the life cycle of a concrete structure

3.1 Production stage

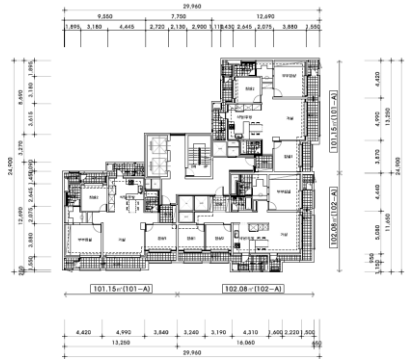
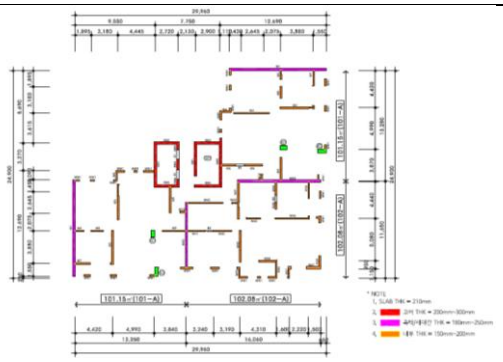
3.1.1 Calculation of the amount of concrete

First, when the concrete compressive strengths of 24, 40 and 60MPa to be assessed are applied to the buildings with the same structure, the following conditions are assumed in order to compare the changes in the amount of concrete inputs with increasing compressive strength.
The structural safety against the lateral load with different wall thickness for concrete compressive strength was examined on the basis of the conditions above, and the amount of concrete inputs in the area of walls was calculated. The results showed the concrete inputs of 3,032.2 ㎥, 2,490 ㎥, and 2,110.7 ㎥ were required to sustain the compressive strengths of 24MPa, 40MPa and 60MPa, respectively. In other words, as the compressive strength of concrete, that is applied to the same structure, increased, the amount of concrete decreased by about 18% at 40MPa, and about 30% at 60MPa, compared to the value at 24MPa.

Table 5: Building Condition for Quantity Survey by Compressive Strength

	Contents			
Building Summary	◦ Structure Type : Reinforced concrete structural wall system ◦ Building Size : 3 stories below and 25 above the ground (305 ㎡/level)			
Wind Load	◦ Basic Wind Velocity : Vo = 30m/sec (Incheon) / Various Roughness Ratios “B” ◦ Power Law Exponent(Kzr) : (Z≤Zb => 0.81) , (Z>Zb => 0.45zα) ◦ Topographic Wind Speed-up Factors(Kzt) : 1.0 ◦ Importance Factor of building use (Iw) : 1.0			
Seismic load	◦ A = 0.176(0.22x0.8), ◦ Ie = 1.2, ◦ R = 4.0, ◦ Ωo = 2.5, ◦ Cd = 4.0, ◦ Ground Type : SC ◦ Earthquake-resistant System : R.C. structural shear wall for X, Y ways ◦ T-value Calculation Formula : X way = 0.049(hn)(3/4) , Y way = 0.049(hn)(3/4)			
Wall Thickness		24MPa	40MPa	60MPa
	Core	300mm	250mm	200mm
	External Wall	250mm	200mm	180mm
	Internal Wall	200mm	180mm	150mm

Table 6: Architectural and Structure Plan of Assessment Target

Architectural Plan	Structure Plan
	

3.1.2 Characteristics of carbon emissions at the production stage

Carbon emissions at the production stage can be calculated by summing the amount of the raw material applied for the concrete structure and the multiplication of the material by its carbon dioxide emission factor. The amount of raw material was calculated using the mixture design used earlier for each concrete compressive strength and the carbon dioxide emission factor of each raw material inputs was based on the global warming potential of the environmental information database (LCI DB).

Table 7: Comparison of CO_2 Emission on Production stage

Strength	Concrete Quantity	CO_2 Emission($kgCO_2eq$)				
		Aggregate	Sand	Portland Cement Type 1	Water	Total
24MPa	3,032.2 ㎥	18,765 (1.90%)	6,329 (0.64%)	960,092 (97.45%)	59 (0.01%)	985.244 (324.93 $kgCO_2eq/㎥$)
40MPa	2,490.0 ㎥	14,830 (1.34%)	4,505 (0.41%)	1,083,479 (98.24%)	46 (0.00%)	1.102.860 (442.92 $kgCO_2eq/㎥$)
60MPa	2,110.7 ㎥	12,697 (1.46%)	3,599 (0.41%)	852,402 (98.12%)	40 (0.00%)	868.738 (411.59 $kgCO_2eq/㎥$)

In the case of concrete walls with a compressive strength of 24MPa, the carbon emissions appeared to be total 985,244 $kgCO_2eq$ in which the emission by cement, which was 960,092 $kgCO_2eq$, accounted for 97.45% of the total emissions. In the case of 40MPa, the carbon emissions were shown to have total 1,102,860 $kgCO_2eq$ accounted for 98.24% by cement of the total emissions. For 60MPa, the emissions appeared to be total 868,738 $kgCO_2eq$ accounted for 98.12% by cement of the total emissions.
The total amount of emissions was greater at the compressive strength of 40MPa compared to the compressive strength of 24MPa because the amount of cement inputs was considered to be large.

3.2 Construction stage

Carbon dioxide emissions at the construction stage mainly occur during the processes of transporting materials to the site and using construction equipments.
In this assessment, however, the carbon dioxide emissions generated during the transportation process are excluded, and the carbon dioxide emissions arising from the construction process are limited only to the emissions by the oil energy that is consumed in the casting process on site using a concrete pumping equipment.

Table 8: Comparison of CO_2 Emission on Construction stage

Strength	Concrete Quantity	Pump Car Capacity	Pump Car Working(hr)	Pump Car Diesel Consumption (L)	GHG Emission Unit of Diesel	CO_2 Emission ($kgCO_2eq$)
24MPa	3,032.2 ㎥	80 ㎥/hr	37.9	625.39	2.66E+00 $kgCO_2eq/L$	1,664
40MPa	2,490.0 ㎥	Diesel Consumption	31.13	513.56		1,366
60MPa	2,110.7 ㎥	16.5L/hr	26.38	435.33		1,158

In the calculation results, the carbon emissions by a concrete pumping equipment appeared to be 1,664 $kgCO_2eq$ for the case of concrete walls with a compressive strength of 24MPa, 1,366 $kgCO_2eq$ with 40MPa, and 1,158 $kgCO_2eq$ with 60MPa. Since the increase in the compressive strength of concrete induces the decrease in the total amount of concrete pumped into a structure, the carbon emissions arising in the construction process are also considered to be reduced.

3.3 Use Stage

In this assessment, the use period of structures was assumed to be 60 years for compressive strength concrete with 24MPa and 120 years for high compressive strength concrete with 40MPa and 60MPa. In order to compare the environmental burdens generated during the assessment period, it was assumed that the concrete structure with 24MPa has undergone demolition and reconstruction once during 120 years of the total use period of the structure, and maintenance or demolition has not occurred in the case of the compressive strengths of 40MPa and 60MPa. However, as in the construction stage, scenarios for transportation were excluded.
The comparison results of the environmental burdens of a concrete structure by compressive strength at the use stage are shown in Table 9. Only in the concrete walls with a compressive strength of 24MPa, the carbon emissions due to the reconstruction process was generated additionally by total 986,907 $kgCO_2eq$ during the use period.

Table 9: Comparison of CO_2 Emission on Use & Maintenance stage

Strength	Concrete Quantity	Assessment Period	Rebuilding	CO_2 Emission($kgCO_2eq$)		
				Materials for Rebuilding	Reconstruction	Total
24MPa	3,032.2 ㎥	120 year	1	985,244	1,664	986,907
40MPa	0		N/A	0	0	0
60MPa	0		N/A	0	0	0

3.4 Disposal stage

In principle, the environmental burdens associated with the use of equipments in the deconstruction, and the burdens in the transportation and disposal process of construction wastes, should be considered together. However, for this assessment, only the carbon dioxide emissions occurred during the disposal processes after deconstruction are taken into account.
In the case of recycling or landfilling concrete waste occurred after 120 years of use period, the carbon emissions due to the disposal of walls with 24MPa were 2,776 tonCO_2eq, 1,090 tonCO_2eq with 40MPa, and 897 tonCO_2eq with 60MPa. The carbon emissions arising in the disposal stage appeared to be more than three times higher in general compressive strength concrete with 24MPa, as compared to 60MPa concrete, because the amount of wastes increased due to the reconstruction in the use period.

Table 10: Comparison of CO_2 Emission on End of Life stage

Strength	Concrete Quantity	Assessment Period	Waste Concrete(ton)		CO_2 Emission(kgCO_2eq)		
			Recycling	Reclamation	Recycling	Reclamation	Total
24MPa	6.064.4m^3	120 year	13,490	460	2,684,475	91,611	2,776,086
40MPa	2,490.0m^3		5,472	187	1,088,949	1,307	1,090,256
60MPa	2,110.7m^3		4,505	154	896,450	1,076	897,526

4. Results of the LCA

So far, the life cycle environmental burdens with varying compressive strength of concrete were analyzed from the perspective of carbon emissions. From the assessment results, it was found that in the walls built with a concrete compressive strength of 24MPa, total 6,064.4 m^3 concrete was consumed over 120 years of assessment period and the total amount of carbon emissions was estimated to be 4,749,901 kgCO_2eq. In the case of 40MPa, total 2,490 m^3 concrete was consumed and the total emissions was estimated to be 2,194,482 kgCO_2eq. In the case of 60MPa, total 2,110.7 m^3 concrete was consumed for 120 years and the emissions estimated 1,767,422 kgCO_2eq. Due to the difference of durability by compressive strength, about 54% of carbon reduction over the life cycle of 120 years was shown in the walls with high compressive strength of 40MPa, compared to the walls with general compressive strength of 24MPa, and about 63% carbon reduction appeared in the 60MPa walls.

Table 11: Comparison of Life Cycle CO_2 Emission by Concrete Compressive Strength

Strength	Concrete Quantity	Assessment Period	CO_2 Emission(kgCO_2eq)				
			Production	Construction	Use & Maintenance	End of Life	Total
24MPa	6.064.4m^3	120 year	985,244	1,664	986,907	2,776,086	4,749,901
40MPa	2,490.0m^3		1,102,860	1,366	0	1,090,256	2,194,482
60MPa	2,110.7m^3		868,738	1,158	0	897,526	1,767,422

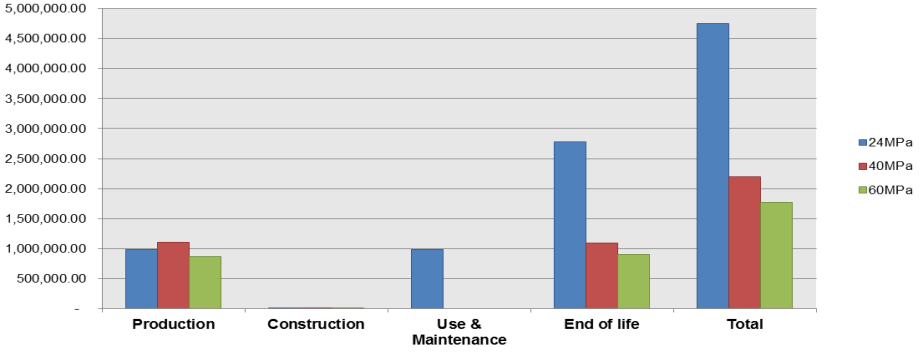


Fig. 2: Comparison of CO_2 emission by Compressive Strength

5. Conclusions and Further Studies

The following procedures and assumptions were applied for analyzing the characteristics of carbon dioxide emissions of concrete structures with varying compressive strength of concrete.

(1) Performance requirements including size, wind load and seismic load were set to maintain the same structural performance in a 25-story apartment housing.
(2) After setting the compressive strength of concrete with three types of 24Mpa, 40Mpa and 60Mpa, and calculating the amount of wall for specific compressive strength required for the same structure performance, the emission factors for each material were applied. At this time, the use period of structures was set to 120 years.

As a result of analyzing the global warming effects of concrete structures for specific compressive strength calculated by the procedures above, the following conclusions were obtained.

(1) At the production stage, the carbon emissions appeared to be higher in the concrete structure with 40MPa, compared to the structures with 24Mpa and 60Mpa, implying that large cement inputs influenced the emissions.
(2) At the construction stage, the carbon emissions appeared to be 1,664 kgCO2eq for the case of concrete walls with a compressive strength of 24MPa, 1,366 kgCO2eq with 40MPa, and 1,158 kgCO2eq with 60MPa. The results indicate the increase in the amount of concrete also increases the carbon emissions.
(3) The concrete structure with 24MPa was assumed to undergo one time reconstruction during the service life of 120 years at the use stage, resulting in increased emissions as in the production stage.
(4) At the disposal stage, the carbon emissions increased with increasing concrete inputs, implying the concrete structure with 24MPa made high environmental impact.
(5) For the carbon dioxide emissions during the life cycle, due to the difference of durability by compressive strength, about 54% of carbon reduction over the life cycle of 120 years was shown in the walls with high compressive strength of 40MPa, compared to the walls with general compressive strength of 24MPa, and about 63% carbon reduction appeared in the 60MPa walls.

As results of analyzing major environmental impact factors at each stage of the life cycle, it is found that the amount of cement input appears to be a major factor for the emission at the production stage, and the total amount of concrete at the construction stage, durability of concrete at the use stage and the amount of concrete waste at the disposal stage.
Based on these results, further studies are needed to present optimum mix designs of concrete structures considering the durability and environmental impacts of concrete.

6. Acknowledgement

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7. Reference

[1] CHANG-U CHAE, *“Results of environmental impact assessment for the LCA of aggregates and the type of fine aggregates*”, Korean Concrete Institute Special Contribution, Seoul, 2010
[2] SUNGHEE KIM, *“An assessment technique of LCCO2 for the development of low-carbon construction materials”,* Green Technology Information Portal, Seoul, 2010
[3] HEO TAK et al, *“The basic principle of LCA”*, The Korean Employers Federation, Seoul, 1995
[4] CHANG-U CHAE et al, *“Construction materials environmental information national DB establishment - final report”*, Korea Institute of Construction Technology, Ministry of Land, Transport and Maritime Affairs, Seoul, 2008
[5] KOREA ENVIRIONMENTAL INDUSTRY & TECHNOLOGY INSTITUTE, *“Carbon declaration of products guidelines”*, Ministry of Environment, Seoul, 2009

C2

Smart Cities

Chair: Holger Wallbaum
Chalmers University of Technology, Sweden

Environmental sustainability assessment of urban systems applying coupled urban metabolism and life cycle assessment



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Short summary

The necessity of assessing and addressing the environmental sustainability of urban systems is becoming increasingly relevant due to growing urbanization across the globe, higher consumption in urban systems and related competition for finite resource stocks. In this study we present how fused urban metabolism (UM) and life cycle assessment (LCA) can be applied to assess the sustainability of urban system, taking into account up- and downstream activities directly or indirectly linked to the metabolism of urban systems. Further we apply the fused UM-LCA approach to assess the absolute environmental sustainability of large urban systems by relating the environmental sustainability performance of urban systems with global environmental burden boundaries quantifying pollution thresholds beyond which performance of global ecosystems services may be detrimentally affected.

Keywords: Urban metabolism, life cycle assessment, UM-LCA, planetary boundaries

1. Introduction

Urban metabolism (UM) has over the last 4 decades served as a credible means to assess the environmental performance of urban systems, however its purest form, 1st generation UM, only provides the magnitudes of non-standardized material and energy flows making it difficult to provide meaningful comparative analysis of the environmental performance of different cities. Independently over the last 3 decades emergy has been implemented as a 2nd generation UM analysis model by systems ecologists. However, due to its complex thermodynamic origin, the emergy based UM models are opaque and are at a disadvantage to communicate results to the public and policy makers alike. In the present study we introduce 3rd generation UM, relying on the coupling of UM and full-scale (i.e. complete indicator set) life cycle assessment (LCA), the UM-LCA fusion approach.

The UM-LCA coupling was tested out on existing UM studies covering 5 major urban areas [1]. The results of this UM-LCA application study clearly underline that the UM-LCA coupling facilitates comparison across cities, mainly due to the ISO standardized LCA framework. Further the study by [1] reveals that the major sustainability burdens of cities are not related to the impacts within the cities but occur up- and downstream of the cities showing that the major impacts are embedded within the provision of energy and goods for consumption in the cities and the waste and goods excreted by the cities. Furthermore, the representation of an urban environmental loading with common indicators (e.g. global warming potential, particulate matter formation, etc)[1] appeared to improve communication of UM-LCA results over earlier UM methods.

Application of LCA for relation of product system impacts and planetary boundaries as suggested by [2] is still in its infancy [3] but the available data suggests that LCA can serve as a means to address the absolute sustainability of product systems and hence urban systems that consume those products. In this presentation we therefore propose a UM-LCA framework to assess the

absolute sustainability of urban systems, relating the climate burdens of the 5 urban systems assessed in [1] to the planetary climate boundaries suggested by [2] as a cursory example.

Cities as they currently function are simply not sustainable into the future. They are heavily reliant on other cities and beyond to provide material and energy resources, and dispose of waste [4]. In the process of this material and energy metabolism, cities interrupt the cyclical material flows of the biosphere and transfer them to the predominantly linear material flows in the technosphere (taking resources from the biosphere and returning them as waste to incompatible receiving areas) [5]. Cities take useful materials and largely relegate them to the landfill or the incinerator, which would not pose an issue if not for the fact that many of the planet's resources are finite, and that humanity is consuming them at an ever increasing rate as both the global economy and population grow [6]. Additionally, cities being the centres of economic growth [7] play an important role in the scale and direction of material flows [8]. Concurrently with their resource consumption cities are also disproportionately large producers of many forms of pollution [9]. Pollution problems in cities vary from the local to the global in their impacts. For instance the industrialization of Manchester 200 years ago has left contaminated soil and waterways that the city is still grappling with today [10]. In a global sense, cities are estimated to contribute upwards of 70% of greenhouse gas (GHG) emissions to the atmosphere [11]. Compounding these issues is the increasingly globalized economy, whereby the consumption of goods in a city in one part of the world can lead to negative local environmental implications across the planet at the point of extraction and processing [12], while at the other end of the consumption train, the exportation of waste to emerging economies, such as electronic waste, has become increasingly common in recent decades [13].

Urban areas are overwhelmingly absorbing population growth around the world through both domestic and international migrations [14]. Urban environmental pressures will increase parallel to the growth of the planet's urban population if current environmental trends continue, with an approximated 70% of the humanity expected to reside in urban environments by 2050, up from roughly 50% in 2008 [15]. The bulk of this rural to urban migration is going to occur in the transition economies, which will place increased pressures on an already stressed planetary ecosystem as new urbanites attempt to attain the same standards of living (and consumption) in line with the developed world [6]. Cities, the hyper-concentrated centres of human activity [16] represent both the problem and solution to global sustainability. Cities not only pose a looming environmental challenge, but they also represent areas where technological innovation and behavioural shifts can be implemented on large populations. In essence, an economy of scale with regards to the effects of sustainable policy can theoretically be achieved, as these policies can target large populations in condensed spaces. The predicted growth in urban population has additional benefits in that it will allow for sustainable urban development (SUD) policy to be implemented from the ground up, as the city grows. This provides the opportunity for planners in the developing world to avoid the difficulties of "technological lock-in" – whereby the socio-techno-economic systems support the use of an unsustainable technology to the point that it is difficult to displace [17]. Because of all of these reasons, SUD is not only important, but imperative, particularly in a world where estimated planetary boundaries for pollution and resource extraction are quickly being met [3]. Cities represent the battleground for the future sustainability of society.

2. Methodology

In this study we, based on the results presented by [1], illustrate how fusion of the Life Cycle Assessment (LCA) framework and the UM methodology can provide a more complete description of the environmental impact profiles of 5 major case cities and how the fused UM-LCA methodology addresses some of the existing issues in UM practices. Further, we illustrate how the results obtained applying the fused UM-LCA methodology can be used to relate the environmental sustainability performance of cities to the planetary boundaries as those presented by [2].

2.1 Case cities

For the application of the fused UM-LCA methodology presented here, 5 case cities were chosen. The case cities are all major capitals and presented in table 1.

Table 1: Characteristics of the 5 case cities to which the fused UM-LCA methodology is applied during the years modelled.

City	Population (millions)	Population Density (inhabitants/km2)	GDP (billions Year 2000 USD)
Beijing (2006)	17.1	1016	85.2
Cape Town (1997)	3.0	1239	18.9
Hong Kong (1997)	6.6	6480	169
London (2000)	7.4	4978	211
Toronto (1999)	5.07	858	160

2.2 Urban metabolism

Urban Metabolism (UM) is becoming an increasingly popular framework, due to its novel aim of providing a complete measure the environmental loading incurred by the total sum of city's activities. Though UM has only come into vogue in the past decade, it is one of the oldest tools for quantifying the environmental impacts of urban areas [18]. UM is gaining greater traction with policy makers around the world and is being considered a serious methodology for municipalities to track their sustainability. UM was developed in the 1960s, whereby a city was viewed as analogous to an organism in that it requires flows of material and energy inputs to sustain functions and grow, while at the same time generating waste as a by-product [19]. Much like an organism, this process of consuming matter and energy to sustain life functions in a city, is termed the city's metabolism. The concept is very much akin to material flow accounting (MFA), but performed on the scale of the urban agglomeration. Astonishingly, the principles of the UM method in the original paper have seen little advancement in the convening 45 years. An enlargement in the number of flows included have been made, and the accounting methods have been updated to reflect agreed upon standard methods [20] but essentially, the method has remained primarily focused accounting the annual direct mass and energy flows through a city. The field of UM has not remained completely static since its development. A second school of UM studies which integrates Odum's thermodynamic concept of emergy (a method that accounts for the embedded solar energy in material and energy flows) emerged in the 1970s [21]. The UM method has waxed and waned in popularity since its introduction, but it has seen a resurgence in popularity, mainly from a school of researchers based in China who primarily use it as a tool for assessing the SUD of Chinese cities. Another indirect development of the UM method has been the birth of the Ecological Footprint (EF) framework. This framework is very similar to UM in that it quantifies the flows of material into a city over a year, however it differs from the MFA method in that it converts these flows from mass to the global hectare [22]. Though originally intended for use on national accounts, it has been routinely applied to cities, and can be considered an unofficial extension of the UM method. Because the core of UM studies are firmly rooted in the concept of capturing only direct mass flows, they remain unable to fully assess SUD.

One failure is that by only accounting for masses directly consumed by the city, current UM studies neglect those masses utilized in processes upstream necessary to provide the direct mass flows consumed [8]. Secondarily, mass flows are incommensurate with environmental loading, and therefore do not form a proper basis for assessing the environmental sustainability of a city [23]. Shortcomings in the current UM framework highlight the need for methodological advancements that can both, capture the upstream flows not being quantified now, and transform the quantified masses into indicators that better represent their environmental loading. Capturing upstream flows has been addressed to an extent by the emergy and EF assessment methods. However, this success remains limited in the amount of upstream flows these methods can account for and the limited number of downstream pollutants they model [22, 24]. Additionally, the esoteric concept of emergy is difficult to convey to both policy makers and the public, limiting its practical application to SUD. Thus, major methodological gaps remain in the UM tool, and complimentary improvements are necessitated to bring it to the level that it can be applied to properly quantify SUD. Moreover, if

the goal of UM is to provide indicators to properly inform SUD policy decisions, then current deficiencies must be addressed, otherwise by providing incomplete or erroneous results UM risks being of little utility to policy makers, or worse, counteractive to SUD. Given the importance of SUD and its potential contribution to overall global sustainable development, it is necessary to quantify the environmental loading of cities [14]. UM can contribute to this end, but as outlined above, the method is currently immature.

Urban metabolism has been described as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy and elimination of waste” [25]. In essence, urban metabolism uses analogies from biology to liken a city to an organism. Thus, cities are perceived as entities requiring resources in the form of metabolic fluxes that are required to maintain human activities and provide for growth [26]. Accordingly, urban metabolism is focused on quantifying flows of materials and energy into cities, and the resulting wastes out of cities. The flows of materials through societies have been an interest of economists and philosophers (eg. Marx and Malthus) since the 19th century [27], the concept was not crystallized to the scale of the city until 1965 by Wolman as outlined in his seminal work that studied a hypothetical American city of 1 million inhabitants [19]. Though crude in its formulation, this study provided the framework of all future urban metabolic studies. In the three decades following the publication of Wolman’s study, only a dozen or so urban metabolism projects were completed, however since the mid-1990s the field has seen a renaissance as a topic of renewed research by a number of engineers, systems ecologists and environmental scientists [8].

2.3 Life Cycle Assessment

‘LCA is a methodology for assessment of the environmental effects of a product or service throughout all stages of its life. Potential impacts are gauged quantitatively, and the perspective can be holistic – from ‘cradle to grave’ – depending on the assessor’s goals [28]. LCA developed over a two-decade period due in part to the economic interest of large corporations to realize greater material efficiencies in production processes [29] or to assist decision making of clearly defined product end goals [28]. It was not until the publication of the Centrum Milieukunde Lieden (CML) LCA handbook in 1992 that a worldwide standardization of the science began to take shape.

By providing quantification of the resource use and release of pollutants to the environment LCA can be applied to [30]:

- Finding where material and energy optimizations can be made along a life cycle
- Identifying phases in a life cycle that are environmentally problematic
- Comparing and choosing between existing and new product/service designs
- Benchmarking the environmental impacts of a product or servces

As the science has become increasingly regimented, it has also proliferated in the scope of its application. LCA is now a popular choice of environmental assessment tool for a wide range of decision makers including academics, private firms, NGOs and policy makers [31]. The framework of LCA remains a work in progress as the field continues to harmonize. A major step in this direction was the establishment of an international standard [32]. Guidelines for the practice of LCA have also been released to compliment the ISO standard, most recently the International Reference Life Cycle Data Reference System [33] or the earlier work of others [30]. Additionally on the international level, projects by the United Nations Environmental Program (UNEP) and the Society of Toxicology and Chemistry (SETAC) aim to further build consensus in the field [31]. LCA consists of four separate phases intended to track the impacts of a product or process from raw material extraction to disposal: Goal and Scope Definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation [33]. LCA is an iterative process that relies on communication between the phases and updating of information in accordance with the goals and data requirements set out for the process.

The LCA based comparison of products and services, works by assessing the flows associated with a functional unit. This is the process or service that must be fulfilled (eg. hold 500 mL of liquid, or transport a person 1000 km in a day, etc.). Thus, all calculations are related to the impacts

required to fulfil the functional unit.

2.4 Life Cycle Impact Assessment (LCIA)

Contrary to the UM methodology, the LCA methodology does not stop at the mass, direct material and energy exchanges with the environment. The flow results obtained in the LCI step can via an impact assessment methodology and accompanying characterization models be converted in to potential environmental impacts or damages. Results from a full LCA including the LCIA step are typically provided as predicted/potential environmental impacts resulting from the flows needed to fulfil the functional unit. These flows can be communicated as midpoint impacts which characterize predicted impacts in terms of specific environmental indicators (eg. global warming potential, terrestrial ecotoxicity, etc.). A second option is the use of endpoint indicators that are aggregations of midpoint impacts. Endpoint impacts communicate predicted effects of the system in of more general environmental and health issues (eg. ecosystem quality, damage to human health, etc.) [28].

The conversion of the flows, quantified in the LCI, to potential impacts is impact assessment methodology specific. In present study we apply one of the most recent and widely acknowledged methodologies, the ReCiPe methodology, see fig. 1 and [34]. LCA is a malleable framework in that optional steps can, as presented in fig. 1, be applied. These include converting predicted midpoint impacts to endpoints, normalizing predicted impacts to a reference quantity, or weighting and aggregating impacts to create a single score. As such, LCA can be tailored by practitioners to suit their needs, including providing information to support SUD policy development.

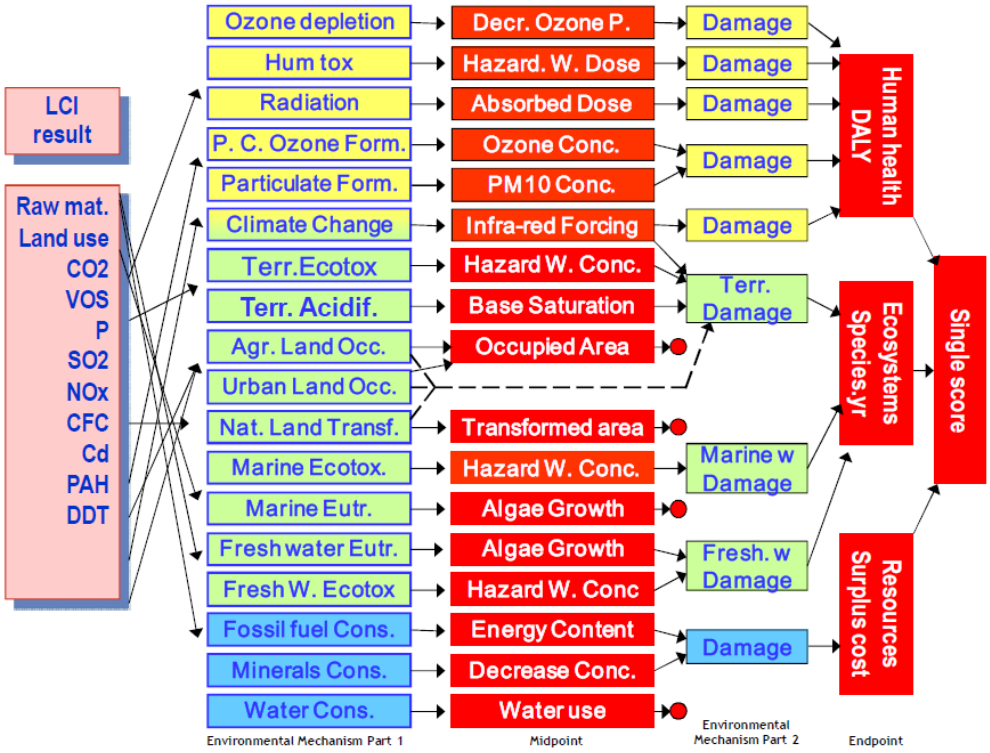


Fig. 1: The ReCiPe framework. From [34].

2.5 Fused urban metabolism and life cycle assessment (UM-LCA)

LCA is a widely applied QSA tool and the coupling of UM and LCA to most LCA practitioners seems obvious, thus, an LCA literature review was done to judge the novelty of the fused UM-LCA approach. Ensuring that LCA practitioners have not already covered this project in another form provides confidence that this study will not only be novel, but also provide an improvement to the field of UM. From reviews of previous LCA literature there appear to be only two papers which

attempted to assess the built environment with a full LCA. A study [36] of high and low density housing in Toronto using an economic input-output LCA, this case was limited in the sense that it only performed a carbon accounting of building materials, transport energy and operational energy inputs. The other study of study interest is the aforementioned 3rd Generation UM by [36] on Finnish cities. Both previous studies depart from the current one at hand in a number of key dimensions. Firstly, in both cases the LCA was was focused on carbon and energy accounting, not applying all of the potential LCIA (i.e. multiple impact categories), as will be done here. Moreover, the Toronto study only looked at hypothetical “built forms”, thus primarily serving as a conceptual model as opposed to an assessment of an existing urban system. Hence the coupling of UM and LCA presented here applying a full set of LCIA impact indicators is new and has never been performed before on existing urban environments.

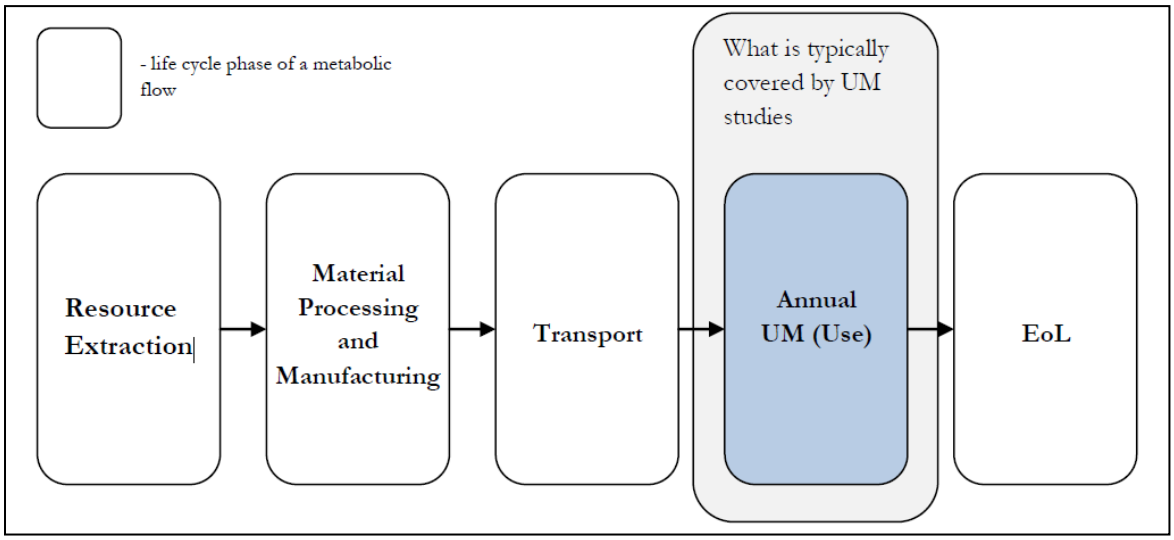


Fig. 2: Comparison of the UM and the UM-LCA coverage. From [1].

2.6 Planetary boundaries

The planetary boundaries as defined by [2] quantifies for a range of earth-system processes/impact categories, thresholds or rather planetary boundaries below which ecosystem services as we know them can be maintained, the boundaries quantified by [2] are listed in table 2. Since many subsystems of the earth react non-linearly or even abruptly, exceeding the planetary boundaries can according to [2] lead to bifurcations of some earth sub-systems such as e.g. the monsoon system shifts permanently into a new state with deleterious or even disastrous consequences for humanity. In the study at hand we solely try to relate the results obtained on the 5 case cities to the planetary boundary for climate change. The planetary boundaries for climate are presented in table 2.
keys are listed in table. 3

Table 2: Planetary boundary for climate change in atmospheric CO_2 concentration and radiative forcing change. From [2].

Earth-system process	Comment	Proposed boundary	2009 status
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5

The planetary climate change boundary as presented in table 2 provides an absolute measure for sustainable life on planet earth in terms of global warming. Hence if humanity according to [2] can

maintain atmospheric carbon dioxide concentration below 350 ppm, the Earth should not experience abrupt changes in its sub-systems and hence avoid potential environmental disasters. The issue is that humanity already has transgressed the 350 ppm CO_2-eq. boundary and the question is hence how to get below this boundary again and avoid potential disaster. According to [37], there should be a 75 % chance to get below the climate change boundary again if the predicted 2050 global greenhouse gas (GHG) emissions are cut by 60 % compared to the global 1990 GHG emissions implying an atmospheric peak concentration of GHG gasses in the atmosphere of 470 ppm CO2-eq between 2010 and 2020. According to [37] should the global 2050 GHG emissions amount to app. 4 GtC-eq/year (equalling 14,4 GtCO2-eq/year).

Combining the data from [2] and [37] hence provides us with absolute sustainability measures in the form of global CO_2 "boundary quotas" for sustainable life in 2050. The boundary quotas can be calculated according to various allocation keys and thereby provide political angle specific SUD measure for climate change. In this study we apply two CO_2 quota allocation keys; an egalitarian (E) key allocating the CO_2 quota equally based on population number (i.e. each person receives same share) and an individualist (I) allocation key allocating the CO_2 according to GDP (i.e. the higher the GDP the higher the city quota). For a more thorough introduction to political perspective specific sustainability analysis, please see *[34].* The CO_2 sub-quotas allocated according to the two

Table 3: Planetary boundary based and city specific 2050 CO_2 quotas, allocated according to an egalitarian (E) and individualist (I) allocation key. Allocation keys based on data from table 1, a global population in 2000 of 6.188 billion people [38] and a world GDP in 2000 of 32,334 billion US $ [38].

City	CO_2 quota (E) $MtCO_2$-eq/year	CO_2 quota (I) $MtCO_2$-eq/year
Beijing	40.2	37.9
Cape Town	7.2	8.4
Hong Kong	15.6	75.3
London	17.4	94.0
Toronto	11.9	71.3

3. Results

Applying the fused UM-LCA the impact potentials normalized per capita were initially calculated in order to compare the city performances across a variety of impact categories, thereby facilitating the comparison of the environmental burdens related with the metabolisms (i.e. consumptions and excretions) of each of the cities covered by our study.

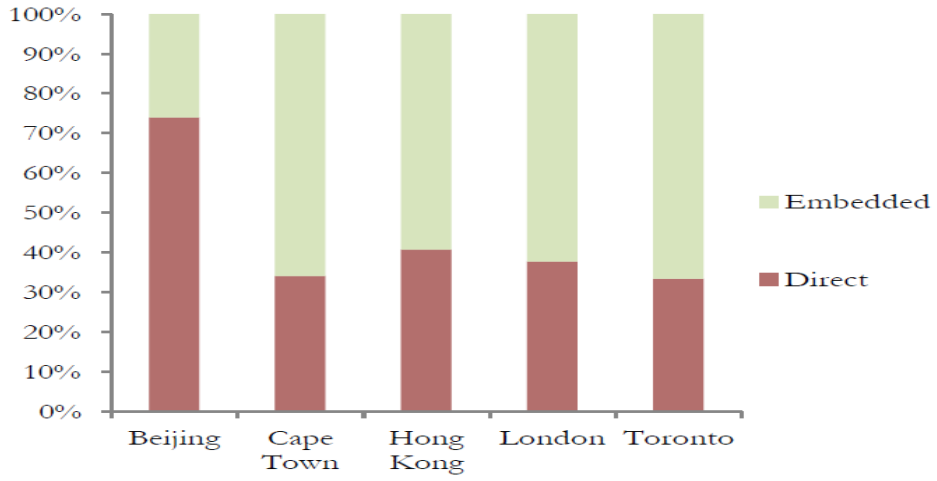


Fig. 3: Proportions of the mass flows covered by conventional UM (direct) as well as the fused UM-

LCA approach and mass flows solely covered by the fused UM-LCA approach (embedded).

The fraction of potential impacts covered by the conventional UM approach compared to the fused approach (please see fig. 2) can by visualized by the fraction of mass flow occurring within the urban area (direct) and up- or downstream of the urban area (embedded) as presented in fig. 3.

Applying the fused UM-LCA methodology allows, due its process based nature, for quite detailed analysis of the origin of potential impacts, fig. 4 illustrates this point by highlight the activities contributing the most to impact profile of the city.

Table 4: Midpoint impacts for the 5 case cities. PMF = Particular Matter Formation, POF = Photochemical Oxidant Formation and pr. = per resident. Highest value within each midpoint impact is marked in bold

Midpoint Impact	Beijing	Cape Town	Hong Kong	London	Toronto
Agricultural land occupation [m2a/pr.]	1700	1500	2200	**3300**	2700
Contribution to GWP [t CO2-eq/pr.]	17.1	11.2	10.2	12.2	**18.0**
Fossil depletion [t oil eq/pr.]	4.8	2.3	3.1	3.6	**4.9**
Freshwater ecotoxicity [kg 1,4-DB eq/pr.]	**170**	62	31	36	43
Freshwater eutrophication [kg P eq/pr.]	**0.88**	0.33	0.35	0.29	0.51
Human toxicity [t 1,4-DB eq/pr.]	**1.9**	1.0	0.8	0.4	0.6
Marine ecotoxicity [kg 1,4-DB eq/pr.]	134	42	**672**	19	22
Marine eutrophication [kg N-Equiv./pr.]	**26**	13	20	12	18
Metal depletion [t Fe eq/pr.]	**8.2**	0.4	0.7	0.7	0.8
Natural land transformation [m2/pr.]	2.33	1.42	2.83	2.02	**2.86**
Ozone depletion [g CFC-11 eq/pr.]	0.83	0.36	0.42	**2.78**	1.39
PMF [kg PM10 eq/pr.]	**42**	18	18	11	16
POF [kg NMVOC/pr.]	**60**	29	42	25	34
Terrestrial acidification [kg SO2 eq/pr.]	**106**	56	54	34	54
Terrestrial ecotoxicity [kg 1,4-DB eq/pr.]	**5.2**	5.0	5.3	2.3	4.5
Urban land occupation [m2a/pr.]	355	206	349	217	**408**
Water depletion [m3/pr.]	22900	9400	8400	10600	**114900**

Based on the annual GHG emissions from the 5 cities and the planetary boundary determined CO2 quotas presented in table 3, the GHG emission reductions needed by 2050 can be calculated.

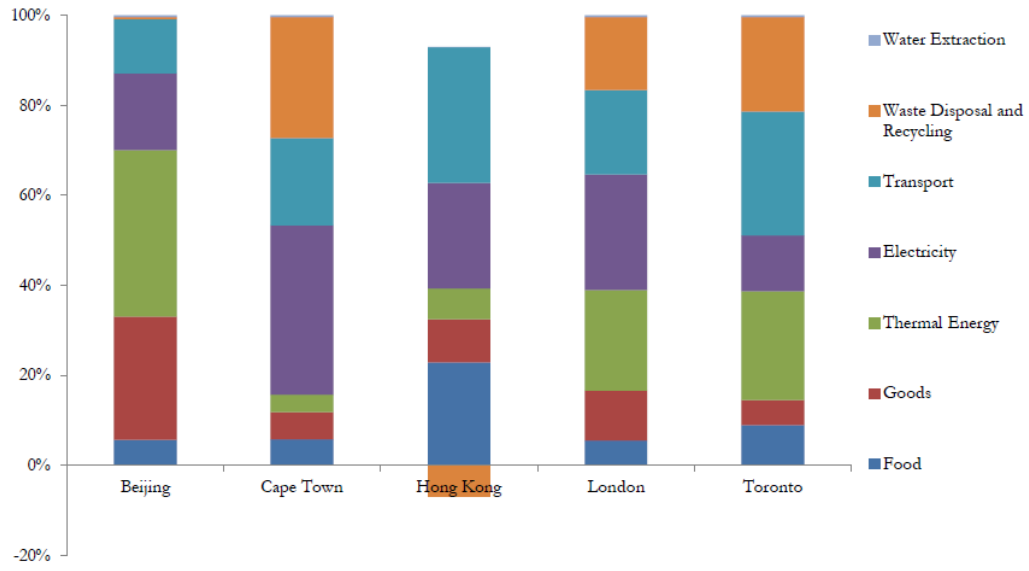


Fig. 4: GHG emission hot spot analysis of the 5 case cities.
The annual GHG emissions and needed emission reduction for the 5 case cities are presented in table 5.

Table 5: GHG emissions reductions quantified by the planetary boundary for climate change quantified by [2] applying the fused UM-LCA approach and two sets of political perspective determined CO_2 emission quotas allocation.

	Beijing	Cape Town	Hong Kong	London	Toronto
Contribution to GWP [Mt CO2-eq/year]	291.9	34.1	67.5	90.3	91.3
Emission reduction needed by 2050 - egalitarian allocation of CO2 boudary quotas (%)	86.2	79.0	76.9	80.7	86.9
Emission reduction needed by 2050 - individualist allocation of CO2 boudary quotas (%)	87.0	75.3	-11.5	-4.1	21.9

4. Discussion

The application of UM and LCA in combination to assess and quantify the environmental burdens of urban systems appears, as presented above, promising. One major issue relating to the comparison of urban environments is the question of whether the comparison is following the basic LCA requirements and hence if the assessment is based on comparison of the same functional unit. The services provided by the 5 cities compared in this study are basically seen as the same since the essential services the cities delivers to the citizens are the same (i.e. provision of an urban system), the quality of this service however differs tremendously across the compared the cities, which cannot be accounted for by the UM nor the UM-LCA approach.

Comparing UM studies is difficult due to the non-standardized manner in which UM studies are performed. The lack of an “UM standard” clearly introduces a considerable source of comparison error, since the UM assessors are given a large “artistic freedom” to e.g. include and exclude flows contributing to an urban metabolism. A similar problem has been encountered in LCA. In order to ensure that LCA studies are comparable an ISO standard on the general LCA framework was published in 1996 [39], thereby laying the basic validation criteria for the any LCA, and thereby providing standardized guidance on e.g. goal and scope definition, inventory analysis (i.e. analysis of exchanges between technosphere and ecosphere), impact assessment and interpretation of assessment results.

Fusing the UM and the LCA methodology may seem as a further complication of the assessment of urban systems. The midpoint results presented in table 4 on the other hand reveals that by combining the two methodologies, midpoint impact indicators facilitate comparison of assessment results across the cities. Since one of the major deficiencies of the MFA based UM approach is the problems relating to the comparison of various forms of mass flows (e.g. comparison of steel and concrete flows). At the same time we find that the midpoint impact indicators presented in table 4, are generally easier to communicate than emergy based UM results since it is possible for people, with some guidance to relate to the individual impact categories. Hence fusing UM and LCA facilitates inter-city and inter-study comparisons of results and further enhances the communication of the assessment results compared to emergy based UM results.

Applying the fused UM-LCA approach ensures a holistic approach, by taking into account the up- and downstream exchanges between the urban system and the ecosphere, and hence facilitates the coverage of the complete system. This approach decreases the likelihood of burden shifting by shifting, whereby environmental burdens from direct to embedded flows (i.e. moving environmental burdensome processes up- or downstream as illustrated in fig. 2, by e.g. moving concrete production upstream and hence out of the urban system). As presented in fig. 3 are the majority of ecosphere-technosphere exchanges related to cities metabolisms located up or downstream of the urban system and hence outside the scope the conventional UM framework.

The process nature of the LCA part of the fused approach facilitates, as presented in fig. 4, easy in-depth analysis of the assessment results and streamlined identification of the activities contributing most to the pallet of impact categories included in any given study applying a LCIA methodology. As presented in fig. 4 can the varying importance of problematic processes such as e.g. energy provision be tracked across the impact profiles of the cities.

Accounting for the environmental burdens of large complex socio-technical systems such as nations, cities or large companies may in some instances require discounting/cut-off of impacts being passed on up- or downstream to the final consumers who may reside in geographically disparate regions. The problem relating to the standardization of accounting for “trading of environmental burdens” has, primarily based on the carbon accounting trends, is not new and has been dealt with in LCA, most recently by the European Commission [40]. Hence standardized approaches for allocating environmental burden trading are already implementable in LCA context and hence these standard approaches could easily be applied to the fused UM-LCA approach, thereby providing guidance with how to deal with this difficulty.

In the present study it was chosen to assess the cities applying mid-point indicators. Comparing cities across the 17 impact indicators is as is evident from table 4 a complex task. Absolute ranking of cities based on the 17 impact categories included in present study is impossible, without weighing the individual impact categories. The ReCiPe methodology includes, as presented in fig. 2, two additional impact assessment steps, endpoint assessment (i.e. quantifying the damage caused by the exchanges between the technosphere and ecosphere) and single score assessment (i.e. aggregating the mid-point impacts via the end-points to single scores), see fig. 1 and [34]. Despite the fact that single scores are related to some subjective interpretation of impact category prioritisation (and related uncertainty), it does allow for comparative ranking of cities in terms of environmental sustainability.

On the other hand, single-score based assessments allow for comparison of the impact assessment result with absolute sustainability measures such as the planetary boundaries presented by [2]. Comparison of the UM-LCA results of the cities with absolute sustainability indicators provides an initial quantification of the sustainability of the case cities relative to environmental tipping points, and hence, the limits of the environmental loads that these urban areas can place on the ecosystem before they become incommensurate with the populations or economic activity they support. However, as presented in table 5, it remains to be seen whether the allocation of absolute sustainability measures allow for various more or less true/objective depictions of the environmental sustainability performance of urban systems. Judging from the egalitarian perspective, the data in table 5 indicates that, for the case cites, avoiding crossing the planetary boundary is related with considerable effort (77-87 % reduction of GHG emissions) however also that this goal in term of CO2 emission reduction seems plausible for all cities. Moreover, the need for some cities (Beijing, Cape Town and Toronto) to reduce GHG emissions based on the Individualist approach, shows that their economies are sub-optimized for environmental performance.

5. Conclusions and comments

The UM methodology has a number of research needs that until now have been largely discussed but not addressed; a narrow scope not addressing up- and downstream impacts of a cities metabolism and inter-city and inter-study incomparability of different mass and energy flows. Combining UM and LCA seems to attenuate these weaknesses by introducing a holistic scope and ensuring inter-city and inter-study via standardized sets of impact indicators.

The fused UM-LCA approach further allows for comparison with planetary boundaries and evaluation of cities performance relative to the earth carrying capacity in terms of environmental deterioration/pollution.

Present study had to be based on more or less fragmented data sets and the fused UM-LCA approach hence needs further validation.

6. References

[1] GOLDSTEIN B, BIRKVED M, QUITZAU M-B, HAUSCHILD MZ. *Quantification in urban metabolism through coupling with the life cycle assessment framework: concept development and case study.* Accepted for publication in Environmental Research Letters: 2013

[2] ROCKSTRÖM J, STEFFEN W, NOONE K, PERSSON Å, CHAPIN III FS, LAMBIN E, LENTON TM, SCHEFFER M, FOLKE C, SCHELLNHUBER H, NYKVIST B, DE WIT CA, HUGHES T, VAN DER LEEUW S, RODHE H, SÖRLIN S, SNYDER PK, COSTANZA R, SVEDIN U, FALKENMARK M, KARLBERG L, CORELL RW, FABRY VJ, HANSEN J, WALKER BH, LIVERMAN D, RICHARDSON K, CRUTZEN C, FOLEY, J. *A safe operating space for humanity*. Nature, Nature Publishing Group, DOI 10.1038/461472a, 2009, Volume 461: pp 472-475etc.

[3] BJØRN A, HAUSCHILD MZ, BIRKVED M, DIAMOND M. *Exploring the feasibility of addressing ecological boundaries through chemical footprint assessment – The case of eco-toxicological impacts on surface freshwater bodies from pesticide use in Denmark*. Submitted for publication in Environmental Science and Technology, ACS Publications.

[4] AGUDELA-VERA, C, MELS, A. KEESMAN, K, RIJNAARTS, H. *Resource management as a key factor for sustainable urban living*. Journal of Environmental Management, 2011: pp 2295-2303.

[5] BARLES, S. *Urban Metabolism of Paris and Its Region*. Journal of Industrial Ecology 13, nr. 6, 2009,: pp. 898-913.

[6] KRAUSMAN F, GINGRICH S, EISENMENGER N, ERB K-H, HABERL H, FISCHER-KOWALSKI M. *Growth in global materials use, GDP and population during the 20th century.* Ecological Economics (Elsevier) Volume 68, 2009: 2696-2705.

[7] JACOBS, J. Cities and the Wealth of Nations. New York: Random House, 1984

[8] KENNEDY C, PINCETL, S, BUNJE, P. *The study of urban metabolism and its application to urban planning and design*. Environmental Pollution, 2011: pp. 1965-1973.

[9] BAI X. *Industrial Ecology and the Global Impacts of Cities*. Journal of Industrial Ecology, 2007: pp. 1-6.

[10] IAN D, HODGSON R, LAWSON, N. *Industry, environment and health through 200 years in Manchester*. Ecological Economics, 2002: pp. 235-255.

[11] UN-HABITAT. *State of the World's Cities* 2010/2011. UN-HABITAT, 2011.

[12] REES, W. *The ecological crisis and self delusion: implications for the building sector*. Building Research and Information, 2009: pp. 300-311.

[13] BASEL ACTION NETWORK. *The Digital Dump - Exporting Re-Use and Abuse in Africa*. Media release, Seattle, 2005.

[14] NEWTON, P, BAI, X. *Transitioning to Sustainable Urban Development. In Transitions - Pathways Towards Sustainable Urban Development in Australia*, by Peter Newton, pp. 1-20. Collingwood: Springer, 2008.

[15] UN-ESA. *World Urbanization Prospects, the 2011 Revision. 2011*. http://esa.un.org/unup (accessed August 14, 2012).

[16] BETTENCOURT L, LOBO J, STRUMSKY D, WEST G. *Urban Scaling and Its Deviations: Revealing Structure of Wealth, Innovation and Crime across Cities*. PLoS ONE 5, no. 11 (2010).

[17] ALLENBY B. *Climate change after the Durban conference: The dangers of cultural lock-in. Environmental Quality Management*, 2012: pp. 19-23.

[18] SAHELY H, DUDDING S, KENNEDY K. *Estimating the urban metabolism of Canadian cities: Greater Toronto Area Case study*. Canadian Journal of Civil Engineering, 2003: pp. 468-483.

[19] WOLMAN A. *The metabolism of cities*." Scientific American, 1965: pp. 179-190.

[20] EUROSTAT. *Economy-wide material flow accounts and derived indicators: A methodological guide*. Luxembourg: Office for Official Publications for the European Communities, 2001.

[21] ZUCCHETTO J. *Energy-economic Theory and Mathematical Models For Combining Systems of Man and Nature, Case Study: The Urban Region of Miami Florida.* Ecological Modelling, 1975: pp. 241-268.

[22] GLOBAL FOOTPRINT NETWORK. *Accounting for demand and supply of the Biosphere's regenerative capacity: the National Footprint Accounting underlying methodology and framework*. Draft Methodology, Global Footprint Network, 2011.

[23] BARLES S. Society, energy and materials: the contribution of urban metabolism studies to sustainable urban development issues. Journal of Environmental Planning and Management, 2010: 439-455.
[24] LI D, WANG R. *Hybrid Emergy-LCA (HEML) based metabolic evaluation of urbban residential areas: The case of Beijing, China*. Ecological Complexity, 2009: pp. 484-493.
[25] KENNED C, CUDDIHY J, ENGEL-YAN J. *The Changing Metabolism of Cities*." Journal of Industrial Ecology (MIT Press) 11, nr. 2, 2007: pp. 43-59.
[26] BACCINI P. *A city's metabolism: toward the sustainable development of urban systems*." Journal of Urban Technology 4, 1997: pp. 213-221
[27] RAPOPORT E. *Interdisciplinary Perspectives on Urban Metabolism*. Literature Review, London: University College London, 2011.
[28] RUIMTE EN MILIEU. ReCiPe 2008 - *A life cycle impact assessment method that comprises harmonized categrory indicators at the midpoint and endpoint level*. Ministeri van Volkshuistvesting, 2009.
[29] LIU J, MATSUMOTO T, XUE Y. *Applicability of Emergy analysis method to indicators for sustainable development by comparison with Exergy*, LCA and footprint methods. 2011.
[30] GUINEE J.B. *Handbook on Life Cycle Assessment: Operational Guide to ISO Standards*. Dordrecht: Kluwer Academic Publishers, 2002.
[31] FINNVEDEN G, HAUSCHILD M, EKVALL T, GUINÉ J, HEIJUNG R, HELLWE S, KOEHLER A, PENNINGTON D, SUH S. *Recent developments in Life Cycle Assessment*. Journal of Environmental Management. Volume 91, 2009. pp. 1-21.
[32] ISO. ISO 14040 - *Environmental Management - Life cycle assessment - Principles and framework*. International Standards Organization, ISO, 2006.
[33] EUROPEAN COMMISSION. *ILCD handbook - International Reference Life Cycle Data System. Standards and Guidelines*, Luxembourg: European Commission, 2011.
[34] GOEDKOOP MJ, HEIJUNGS R, HUIJBREGTS M, DE SCHRYVER A,STRUIJS J., VAN ZELM R. *ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation. 2009*
[35] NORMAN J, MACLEAN H, KENNEDY C. *Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions. Journal of Urban Planning and Development*, 2006: pp. 10-21.
[36] HEINONEN J, JUNNILA, S. *Implications of urban structure on carbon consumption in metropolitan areas*. Environmental Research Letters, 2011.
[37] Meinshausen M, Hare B, Wigley TML., van Vuuren D, den Elzen MGJ, Swart R. *Multi-gas emission pathways to meet climate targets*. Climatic Change, 2006. Volume 75(1): pp. 151-194.
[38] WORLD BANK (2002). *World Development Indicators database*, World Bank, May 2013.
[39] ISO (1996). International Standard ISO 14040. *Environmental management - Life cycle assessment - Principles and framework*. First edition. Geneve: International Organization for Standardization.
[40] JRC (2012). *Life cycle indicators for resources, products and waste – Framework*. Report EUR 25466 EN. Institute for Environment and Sustainability, Joint Research Centre, European Commission

Modelling the transformation of heat supply and demand – a case study for the residential building stock of the city of St. Gall



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Short Summary

In Northern European countries, the transformation of prevailing systems to supply and use energy for heating residential buildings is considered a major challenge in urban development. Ongoing renewal and growth in the residential building stock allows increasing energy efficiency by introducing new buildings standards. By additionally encouraging alternative sources for heat supply such as geothermal and solar energy, a significant reduction of greenhouse gas emissions seems feasible. To evaluate options and conditions favourable for such a development, we developed a spatial explicit, dynamic model for the transformation of the residential building stock. This model was used to assess energy demand and greenhouse gas emissions for heating the residential buildings in the City of St. Gall and analyse alternative scenarios for future development. The model incorporates the communal energy plan as well as empirical data of 50 refurbishment projects (estimates for construction costs and gains in energy efficiency). Model-based scenario calculations show that the City of St. Gall can reach its ambitious goals in energy policy within the next 50 years. However, the municipality and private property owners have to provide substantial funding and make a great effort in refurbishing their old building stock.

1. Introduction

In Switzerland, the operation of buildings built between 1950 and 1980 is of growing importance in the overall urban energy demand. While new constructions become more and more efficient in heat demand and supply – encouraged by regulations as well as technological development – refurbishment of older buildings is often limited to minor improvements in energy standards (see [1], [2] and [3]).

In recent years, however, many municipalities have set themselves ambitious goals in energy policy. One example is the «2000-Watt-Society» which has become a guiding principle for a number of cities in Switzerland such as Zurich, Bale, Geneva, Winterthur or St. Gall aiming at a reduction of individual energy demand to approximately one third of today's demand. The Swiss Association of Engineers and Architects (SIA) has introduced guidelines and tools for planning in the so called «Energy Efficiency path» [4].

[5] and [6] accentuate the need for urban renewal determined to significantly increase energy efficiency in heat consumption if such ambitious goals are to be reached. In addition, [7] claims the necessity to increase the use of renewable energies. He introduces a concept called «Zero-

Emission Low-Ex Architecture» combining the use of stationary available heat (e.g. ground heat) with optimizing energy efficiency in heat transport, storage and use ([8]). Stationary available heat, thus, becomes an important parameter for planning processes in urban renewal. It can be defined in energy plans on communal level as described in [9] and combined with common instruments in spatial planning.
The challenge in urban renewal oriented towards a «2000-Watt-Society» lies in a pragmatic and goal-oriented combination of such tools and concepts. The development and application of empirically based, numerical models can help to encourage this development. To this aim, models have been developed in Germany (see [10] and [11]) and have also been applied in Switzerland (see [12]). Yet, they are not sufficiently adapted to data available on communal level in Switzerland and to common planning tools. A spatial explicit analysis of heat demand of residential buildings, for example, can be derived by combing data from official statistics with standard estimates from literature (see [13]). Information from communal energy plans can be used in modeling and results from model calculations can be fed into Geographic Information Systems (GIS) to generate spatially explicit representations of scenarios in future development.

In this paper, we introduce a model combing heat demand for residential buildings and the use of stationary heat in a settlement area that is adapted to data available on communal level in Switzerland and common planning tools. The model is applied for the city of St. Gall and used for a scenario analysis for urban renewal combing refurbishment and structural modification of residential buildings with the introduction of renewal energies for heat supply.

2. Method

The development of the built environment can be described in stock-flow-models (see e.g. [14]). The building stock is captured in floor area, built volume or settlement area. Its development causes costs and revenues as well as demand for energy, materials and waste management services. Such variables determined by the building stock development are described as flows of money, energy or material (in monetary or physical units). Their development depends on activities in construction, refurbishment, structural modification and demolition, comprised in the overall model of the buildings stock dynamics.

Stock-flow-models have been used to analyze a wide range of different questions ranging from development in real estate markets ([15], [16] and [17]), modelling heat demand for residential buildings ([18], [19], [20] and [21]) to modelling future demand for construction minerals ([22], [23], and [24]) and services for construction waste management [25], [26] and [27]).

In this paper, we introduce a stock-flow model for cumulative energy demand for non-renewable energies ($CED_{non\text{-}renewable}$) and greenhouse gas emissions (GWP) related to the heat demand of residential buildings. The cumulative energy demand of building materials, however, is not taken into account as recent studies revealed its minor importance in the overall energy demand of the building stocks current development (e.g. [6], [28] and [29]).

We assume that future heat demand of residential buildings depends on the development of heated area in buildings stock of specific construction and refurbishment periods and their energy standards given by the heat demand coefficient for each period. For spatial explicit representation of the model, each square meter of heated area is allocated to square cells of a 100 x 100 meter (hectare) creating a grid covering the entire study regions.

$$\mathrm{HWV}_t^j = \sum_{i=1}^{n} \mathrm{HA}_t^{ij} * \mathrm{HDC}^{ij} \quad (1)$$

HWV_t^j: Total heat energy at point t in cell j

HDC^{ij}: Heat demand coefficient for construction and refurbishment period i in cell j

HA_t^{ij} Heated area for the construction and refurbishment period i in cell j at point t

n Number of construction and refurbishment periods

To calculate $CED_{non\text{-}renewable}$, the heat demand of each cell j is multiplied with the weighted average of specific $CED_{non\text{-}renewable}$-coefficients for each energy carrier s used to provide heat in buildings allocated to cell j.

$$\mathrm{CED}_t^j = \mathrm{HWV}_t^j * \sum_{s=1}^{m} \mathrm{AN}_s^{jt} * \mathrm{CED_CE}_s \quad (2)$$

$\mathrm{CED_CE}_s$: $CED_{non\text{-}renewable}$-coefficients for each energy carrier s

AN_s^{jt}: Percentage of the energy carrier s to provide heat in cell j at point t

m Number of the energy carriers

GWP is calculated the same way, both using coefficients from [30].

[31] differentiate between two types of models. The first type assesses the development of the building stock – mostly based on either assumptions about the service life of buildings or building components ([34], [3] and [6]) or empirical evidence for construction and demolition activities ([31] and [33]). The second type describes the development of construction, refurbishment and demolition rates ([23] and [11]).

In our model, we use the first type of model to describe the development of heated area. We distinguish between periods of construction and refurbishment and assume that the building stock in this period is given by two inputs - new construction in this period as well as refurbishment activities transferring heated area from older buildings into this period – minus one output – heated area transferred from this period to an even more recent period by refurbishment activities.

$$\mathrm{HA}_t^{ij} = \mathrm{HA}_{t-1}^{ij} + \mathrm{NHA}_t^{ij} + \mathrm{CRA}_t^{ij} - \mathrm{HACR}_t^{ij} \quad (3)$$

HA_{t-1}^{ij} Heated area for construction and refurbishment period i in cell j at point t-1

NHA_t^{ij}: New built heated area for construction and refurbishment period i in cell j at point t

CRA_t^{ij}: In construction and refurbishment period i refurbished heated area of older construction periods in cell j at point t

HACR_t^{ij}: Heated area for the construction and refurbishment period i which are refurbished at point t in cell j

Refurbishment activities in each period are a function of the amount of heat area in the specific period, the average persistence time of heated area in this period and the time needed for transferring the building to more recent periods (by refurbishment).

$$\mathrm{HACR}_t^{ij} = f\left(\mathrm{HA}_{max}^{ij}, \tau_i, \kappa_i\right) \quad (4)$$

HA_{max}^{ij}: Maximum of total heated area in the construction and refurbishment period i in cell j

κ_i: Time period of the construction and refurbishment period i, within the buildings of the construction and refurbishment period are not refurbished

τ_i: Time period after the time period κ_i, within the buildings of the construction and refurbishment period are refurbished

A high degree of uncertainty is a common feature in all building stock models ([35]) because there is yet little empirical evidence of processes of urban renewal on a higher level of aggregation. Some models address this problem incorporating stochastic models for the distribution of key parameters (see e.g.[24] and [25]). Most models, however, use deterministic model approaches and discuss uncertainties in the interpretation results derived from model applications (e.g. [3]).

In our model, we use a deterministic model approach. It is shown in *Fig. 1* taking one period of construction and refurbishment as an example. In this example, the heated area is built up between 1940 and 1960 and remains untouched by refurbishment activities relevant of heat demand until 1990 (persistence time (κ_i): 30 years). Starting 1990, buildings containing this heated area improve their energy standards due to refurbishment activities. Step by step their heated area is transferred to more recent periods of construction and refurbishment characterized by energy standards corresponding to technological standard of the period in which the refurbishment takes place. In these periods, the building stock grows accordingly. By 2030 almost the entire building stock is transferred from the period 1920-30 to more recent periods of construction and refurbishment (transformation time (τ_i): 40 years).

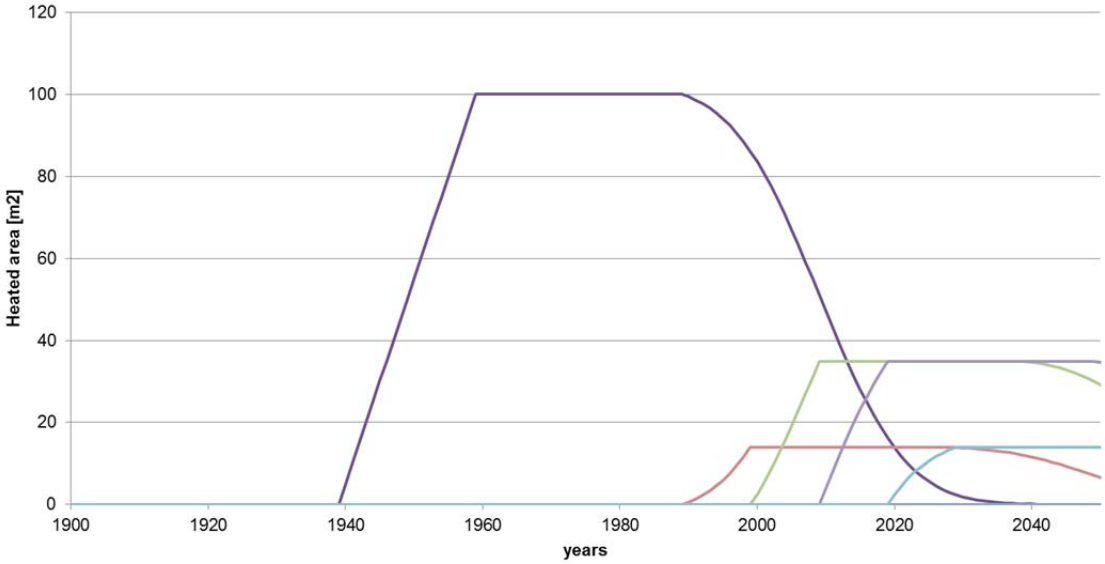


Fig. 1: Demonstration of the model on an example of a building with 100 m2 heated area (Source: own analyses)

One major challenge is the assessment of future technological development in heat supply. Technological development in general can be described with assumption about the diffusion process of innovations (see e.g. [5], [36] and [31]).
We use a similar approach describing the diffusion process with an s-curve presenting the substitution of one system to provide heat for residential buildings (e.g. combustion of fossil fuels) with an alternative system (e.g. geothermal energy). This s-curve is defined by a starting point of the substitution process α_{sj} and the time needed until 50% of the substitution has been completed (half-life period β_{sj}).

$$AN_s^{jt} = f(\alpha_{sj}, \beta_{sj}) \quad (5)$$

with

$$\sum_{s=1}^{m} AN_s^{jt} = 1 \quad (6)$$

α_{sj}: Time from t=0 to the beginning of spreading the energy carrier s in cell j

β_{sj}: Half-life period for the energy carrier s in cell j

In addition, we calculate the expected costs for refurbishment activities in each period by multiplying our results for heated area refurbished in this period with estimates for the related construction costs.

$$SK^l = SNF^l * Ssk \quad (7)$$

SNF^l: In time period l refurbished heated area

Ssk: Specific costs for refurbishment per m^2 heated area

3. Case study: city of St. Gall

The city of St. Gall is located in the east of Switzerland south of the Lake Constance. With a population of around 73'000 it is Switzerland's eighth largest city. The city's population density is comparatively low: St.Gall covers 40 km², of which around 50 percent is green space. 6 km2 of buildings and infrastructures are located in a valley. The valley bottom, situated 700 meters above sea level, is densely populated with the city's oldest buildings originating from medieval times as well as the 19th century when the city prospered due to texile manufacturing. Today, commerce and industry are mostly located at both entry points of the valley providing work for around 66'000 people, many of them commuting into the city from suburban areas. Municipal utilities provide for electricity and gas. District heating is supplied by the local waste incineration plant. Most buildings are heated by decentralized combustion of either gas or oil.

Yet, the city has set itself ambitious goals in energy policy: By 2050 authorities aim at reducing the demand of fossil fuels for heating by two-third of today's demand. They developed an energy plan to better coordinate activities in construction and the transformation of energy supply systems. The most important project is a geothermal power station providing heat for almost 40% of all buildings in St. Gall as well as electricity. In addition, the municipality encourages construction activities aiming at a significant increase of efficiency in production and use of heat in residential buildings by public consulting as well as public funding.

In our paper, we choose this case study to analyze how the introduction of new energy systems focusing of stationary available heat can be combined with promotion of construction activities to increase energy efficiency.
The city of St. Gall also provides an excellent data base to apply the model introduced in the previous section. The most important data base for model application is data on floor area or volume of buildings described in the model. Most models require a data set differentiating between important building characteristics such as construction period, building size or type of use. In Switzerland, the National Register of Buildings and Dwellings provides an appropriate set of geo-referenced data that is frequently used to assess heat demand for residential buildings (see [13], [5] and [37]). The following table shows how this data is incorporated in our model.

Table 1: Overview of the used data (Source: own analyses). GWR : german abbreviation for the National Register of Buildings and Dwellings.

Source	Data	Explanations	Use in the model
GWR	Swiss building identity (EGID)	For the explicit identity of the buildings in switzerland.	Key for correlation of the building's specifications
GWR	X- Coordinate (GKODX)		Cell structure
GWR	Y- Coordinate (GKODX)		Cell structure
GWR	Construction period (GBAUP)	Time period given in the registry given time period i.e. 1971- 1980	Parameter value for number of new buildings per period of construction and refurbishing
GWR	Building category (GKAT)	single detached family houses, apartment buildings or buildings with/without secondary use	Attribution of the heat demand coefficient
GWR	Energy carrier used for heating (GENHZ)	i.e. oil, gas, electricity	Share of energy carrier in each cell needed to calculate the weighted average
GWR	Floor area used for living (WAERA)	In m^2	Parameter value for heated area
ERP	Energy system used to provide heat for residential buildungs in future	Setting is given by the municipal energy plan	Parameter values for assessing the diffusion processes for new energy systems
ERP	Time until the intended substitution of energy systems	Refers to the develpment of the planned distribution network for long distant heating	Parameter values for assessing the diffusion processes for new energy systems

Data for heat demand coefficients and refurbishment costs are taken from a survey of the the effecs of refurbishment acitvities in the city of St. Gall in 2012 ([39]). It analysed planing documents attached to applications for public funding by the municiplity for 52 buildings (21 single detached family houses and 31 apartment buildings) and data on heat demand from the energy data base of the city of St. Gall.
The following table shows the heat demand coefficients derived from this study differentiated in single detached family houses (german abbreviation: EFH) and apartment buildings (german abbreviation: MFH). These values are between 10 and 50% below coefficients presented in [37] and [5] indicating that most older buildings in our survey have already been refurbished in an earlier period.

Table 2: Heat demand coefficients for the construction and refurbishment periods HDC^{ij} (The heat demand coeffiencients from 1980 to 2010 derived and interpolated on the heat demand coeffienct decrease of 20% from 1960 to 1979)

Construction and refurbishment period i	HDC_{EFH}	HDC_{MFH}	HDC^{ij}
	MJ heat per m^2 heated area		
1900-1919	701	512	Weighted average from HDC_{MFH} and HDC_{EFH} calculated with the percentage of the heated area in cell i, obtained for each building category (GWR)
1920-1939	624	455	
1940-1959	547	480	
1960-1969	566	468	
1970-1979	525	456	
1980-1989	499	431	
1990-1999	473	406	
2000- 2010	448	380	

For modelling the development of the building stock we need data on future refurbishment activities. Yet, according to [38] there is no empirical evidence for typical refurbishment cycles in Switzerland. The Swiss building stock is still rather young and up to now only moderate refurbishments can be observed in large numbers whereas complete refurbisment or reconstruction is still an exception in urban renewals. Therefore, our estimation of parameter values for the persistence time (κ_i) and transformation time (τ_i) can not be based on emiprical evidence. We decided to use best estimates in accordance to [3] and [5]. [3] estimates the time until a building is refurbished with moderate improvements in heat efficiency as 25 year in average. A complete refurbishment, however, is to be expected in between 50 and 70 years. As our model does not differentiate between different types of refurbishment, we assume that an average building is not refurbished with improvements in energy efficiency until 30 years after it was built (persistence time κ_i = 30). After these 30 years, however, it takes further 40 years to refurbish all buildings built at that time (transformation time $\tau_i = 40$).

Parameters for improvements in energy efficiency obtained by refurbishment and the related costs are taken from the before mentoined survey [39]. We differentiate between refurbishment with moderate improvements in heat efficiency and complete refurbishment aiming at a significant increase of energy efficiency.

Table 3: Heat demand coefficient for scenario calculation for the years 2011 to 2050

Construction and refurbishing period i	HDC_{EFH}		HDC_{MFH}	
	MJ heat demand per m^2 heated area			
	Complete refurbishment	Moderate refurbishment	Complete refurbishment	Moderate refurbishment
2011- 2050	234	358	217	351

Estimates of refurbishment costs are also taken from [39]. For model calculations we use an average values covering all periods of construction and refurbishment and types of buildings. For complete refurbishment we assume building costs of 537 Swiss Francs per square meter of floor area (CHF per m^2), for refurbishment with moderate improvements in heat efficiency building costs

amount to 211 CHF per m^2.

In addition, we use the communal energy plan – german abbreviation: ERP - for information about planned transformation of energy supply. In contains information on the intended system to provide heat in future differentiated between different areas within the settlement. This information can, thus, be georeferenced easily and matched with the GWR building stock data. For future community heating the ERP also indicates the intended time frame for phasing out the prevailing systems of heat supply. This information is used to estimate parameters for the diffusion processes described in equation (5). As the municipality strongly encourages the use of long-distance heat from the planned geothermal power plant, we assume that phasing out the existing heat supply systems in areas to be connected to the distribution system will be completed within 20 years. For district heating or other more decentralized future heat supply systems parameter values have been defined in expert interviews with the municipality. We assume that the diffusion processes begin in 2010 and it will take sixty years until all prevailing systems have been substituted.

4. Results

In 2010, the city of St. Gall need 1.8 PJ or 500 GWh of non-renewable energies to provide heat for operating all residential buildings in the settlement area (including all processes to produce and transport of energy carriers for final use). An average building in St. Gall needs 492.42 MJ of energy per year for each square meter floor area. Apartment buildings are major consumers with 70% of total consumption. Efficiency in heat supply increases significantly in more recent construction periods. Energy coefficients don't vary much for buildings constructed before 1980. Since then, their values decline continuously due to improved building standards and the increasing use of renewable energies in heat supply. Yet, the majority of all buildings in the city of St. Gall were built before 1980. Older buildings are mostly located in the densely populated valley bottom in the city centre whereas recent construction is located at the periphery.

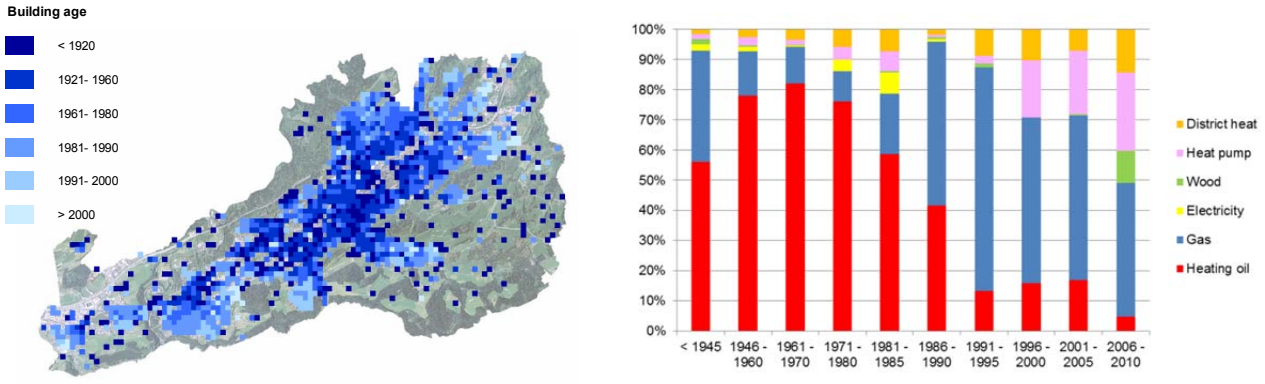


Fig. 2: Left: Age distribution of building of the city of St.Gall presented in the hectare grid used; Right: Share of different energy system providing heat for residential buildings per construction period (Source: own analyses)

Therefore, the density of heat demand is highest in the historic city center at the valley bottom and the surounding areas. In these areas refurbishment and structural modifications are most challenging because of conflicting interests the with protection of sites of historic interest. Density of heat demand is significantly lower on the slopes of the valley where a lot of single detached family houses are located. In the periphery, the density of the settlement decreases and so does heat demand per area unit. Even in areas where older buildings are located, density of heat demand remains low.

Most buildings constructed before 1985 are heated with oil. In 1986, the municipalities starts building a gas supply network and gas becomes an important energy carrier for heat supply in buildings constructed since then. Geothermal heat is increasingly used for new buildings since 1996. District heating is has been used for many years, but it only covers a minor share of heat demand focusing of the settlement area near the municipal waste incineration plant. In 2006-2010

50% of all heated floor area in newly constructed buildings is heated with renewable energies.
Fig. *3* presents the spatial distribution of heat supply in St. Gall today. Is shows the location of distribution networks for heat and gas. The majority of all residential buildings, however, are still heated with oil.

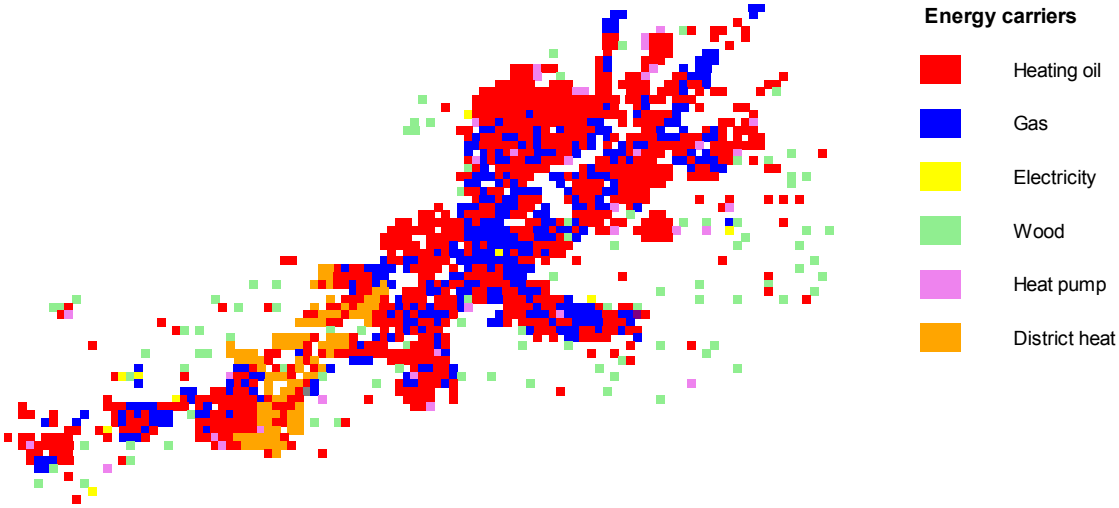


Fig. 3: Distribution of heat supply per hectare in the city of St. Gall today (Source: own analyses)

To analyze the future development of demand and supply of heat for operating residential builds in St. Gall, we use our model for scenario calculations. Four different scenarios for future development are calculated (parameter values for these scenarios are presented in section 3 of this paper):

- Scenario 1 «complete refurbishment with transformation of heat supply systems»: In this scenario, every residential building is completly refurbished until 2050 and its heat demand per square meter heated floor area has been significantly reduced. In addition, a new system of long-distant heat supply has been installed using heat from a geothermal power plant.

- Scenario 2 «complete refurbishment without transformation of heat supply systems»: This scenario is defined as scenario 1 except for its assumptions on provision of heat for operating residential buildings. In scenario 2 we assume, that current heat supply systems are still in place and no substitution has taken place.

- Scenario 3 «moderate refurbishment with transformation of heat supply systems»: This scenario is defined as scenario 1 except for its assumptions on refurbishment activities. In scenario 3 we assume, that buildings are only moderately refurbished and their heat efficiency is not significantly reduced.

- Scenario 4 «moderate refurbishment without transformation of heat supply systems»: This scenario combines assumptions on refurbishment activities from scenario 3 with assumptions on provision of heat for operating residential buildings from scenario 2.

In all scenarios, we assume that building stock will not grow between 2010 and 2050.

The following figures show the results of the scenario calculations for the developments of cumulative energy demand from non-renewable resources ($CED_{non\text{-}renewable}$), greenhouse gas emissions (GWP) (see *Fig. 4*) and construction costs related to refurbishment activities (see *Fig. 5*).

$CED_{non\text{-}renewable}$ declines in all four scenarios. This reduction is caused by two effects: (a) refurbishment activities leading to increased energy efficiency and (b) the on-going substitution of

heat supply systems replacing non-renewable by renewable energies. Scenario 1 combines both effects and assumes a maximal impact from both. It results in a reduction of $CED_{non\text{-}renewable}$ by almost 80% until 2050. A comparison between the results of all scenarios reveals that assumptions on provision of heat for operating residential buildings have significantly higher impact compared to assumptions on refurbishment activities. The introduction of long-distance heating supplied by a geothermal power plant leads to a reduction of $CED_{non\text{-}renewable\ by}$ 70% even if we assume only moderate gains in energy efficiency due to refurbishment activities. Without changes in heat supply systems only 41% reduction can be obtained by complete refurbishment until 2050.

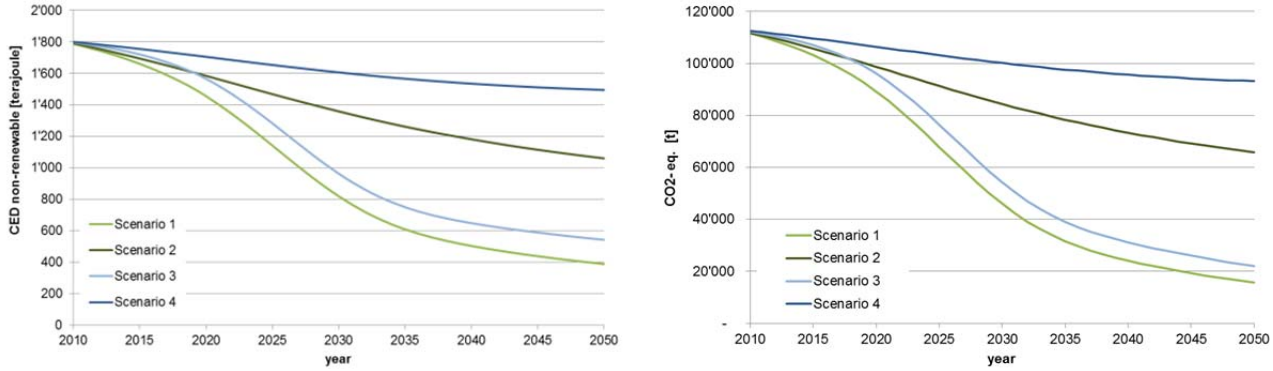


Fig. 4: Left: $CED_{non\text{-}renewable}$ development for all four scenarios; Right: GWP development for all four scenarios (Source: own analyses)

We get very similar results for greenhouse gas emissions. The potential to reduce GWP by combining complete refurbishment with heat supply by a geothermal power station amounts to 86%. Even if refurbishment activities remain moderate, 80% of today's GWP can be reduced with heat supply from a geothermal power station until 2050.

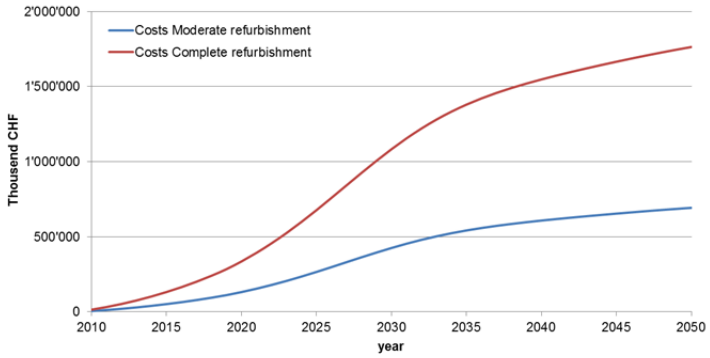


Fig. 5: Cumulated costs for complete and moderate refurbishment of the buildings in the city of St.Gall (Source: own analyses)

Fig. 5 shows a comparison of cumulative construction costs for scenario 1 and 3 (complete refurbishment) and scenario 2 and 4 (moderate refurbishment). It reveals that the costs of complete refurbishment are significantly higher. Real estate owners have to spend approximately 700 million Swiss Francs (CHF) until 2050 if we go for moderate refurbishment and around 1'700 million CHF if we choose complete refurbishment.

5. Discussion

In combination with increasing refurbishment activities, the city of St. Gall has defined a very promising strategy to reduce energy demand for heating residential buildings in the settlement area by two-third of today's demand – according to the target proclaimed in the city's energy policies. Scenario calculations show a reduction of more than 70% if all measures described in the communal energy plan are implemented.

This reduction represents the gross energy savings not taking into account the energy invested in the refurbishment or structural modifications. This additional energy consumption can be represented by the estimates for the $CED_{non\text{-}renewable}$ of building materials used in these building processes. A rough estimate based on benchmarks from [4] shows that approximately 250'000 terrajoule $CED_{non\text{-}renewable}$ per year will be invested on average between 2010 and 2050. It confirms results from recent studies that showed the minor importance of the cumulative energy demand from building materials in the overall energy demand (e.g. [6], [28] and [29]). $CED_{non\text{-}renewable}$ of building materials will, however, become more and more important in the transformation of the building stock with major increases in energy efficiency – as represented in scenario 1 in our study. In this scenario the average cumulative energy demand for building material amounts to over 50% in the overall energy demand in 2050.

Our results emphasize the importance of the geothermal power station currently planned in the city of St. Gall. As shown in *Fig. 4*, it will supply a major part of the settlement area with heat from renewable sources without producing significant amounts of greenhouse gases. The historic city center where heat density is highest will be entirely supplied with long distance heat. This is favorable for the efficiency of the planned community heating. It also helps solving conflicts with goals of protecting historically sites because a complete refurbishment of buildings in the historic city center is no longer necessary to reach the city's ambitious targets in energy policy.



Fig. 6: Distribution of heat supply per hectare in year 2050 (Source: own analyses)

Yet, this strategy requires substantial funds from real estate owners as well as the municipality itself. If the city encourages complete refurbishment of residential buildings aiming at a significant efficiency increase in heat supply, real estate owners will invest a total amount of 1.7 billion Swiss Francs until 2050 – an average of 40 million per year. A part of this huge amount of money can be accounted to the on-going process of urban renewal independent from energy policies. Yet, the financial burden for real estate owners remains significant and increased energy efficiency of residential buildings will have minor effects on future revenues in real estate. In addition, the municipality plans to invest around 160 million Swiss Francs to build the geothermal power station. With this infrastructure, the city will reduce its dependency on future prices for fossil fuels. Thus, the economic and environmental benefits from increased heat efficiency of buildings supplied with long distance heat seem small.
Expected costs for real estate owners could be reduced significantly with a more differentiated approach for increasing energy efficiency in the building stock. In areas connected to the distribution system for long-distance heat moderate refurbishment should be encouraged with significantly lower construction costs. Public funding to encourage extensive refurbishment activities, however, should focus on areas not connected to the distribution system.

The results of model calculations, however, should be interpreted carefully. Some parameters

values could not be based in empirical evidence (e.g. parameters for the building stock dynamics) and for others the dispersion of values is significant (e.g. heat demand coefficients). Yet, our results for the four scenarios differ considerably (by more than factor 2 between scenario 1 and 4) indicating that our findings are robust in spite of data and model uncertainties.

6. Conclusions

Based on our case study results we conclude that buildings supplied by long distance heating can refrain from extensive refurbishment aiming at significant efficiency gains in heating if three conditions are fulfilled:

- Long distance heating is provided by low emission processes based on renewable resources,
- Renewable resources used for heat production are available abundantly at all times,
- Renewable resources used for heat production cannot be used for other purposes relevant in sustainable urban renewal (e.g. to produce electricity).

The geothermal power station planned in the city of St. Gall seems a promising option. Yet, at the current planning state we cannot be certain that these three conditions will be met in future. The municipality, therefore, is well advised to keep its current strategy in promoting both energy efficiency and the transformation of energy systems. Yet, it should carefully keep track on the ongoing development and be ready to adapt its strategy.

The application of the model introduced in this paper, could help to monitor the ongoing development and evaluate alternative strategies if necessary. It supports prioritization of measures and adaption of existing concepts in energy policies. By using data from official statistics as well as commonly used planning instruments, it can be easily updated. It provides a consistent data pool of expert knowledge which can be improved continuously within the learning process on sustainable urban renewal.

7. Abbreviations

CED Cumulative Energy Demand
CHF Swiss Francs
ERP Communal energy plan
GIS Geographic Information System
GWh gigawatt hour
GWP Global Warming Potential
GWR National Register of Buildings and Dwellings
EFH Single detached family houses
MFH Apartment buildings
MJ Mega-Joule
PJ Peta-Joule

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9. References

[1] BUNDESAMT FÜR ENERGIE. *„Der Energieverbrauch der Privaten Haushalte 1990 – 2035. Ergebnisse der Szenarien I a Trend und I b Trend und der Sensitivitäten Preise hoch, BIP*

hoch und Klima wärmer“. Bern August 2005.
[2] BUNDESAMT FÜR ENERGIE. „*Neubauen statt Sanieren?“.* Bern, März 2002.
[3] BUNDESAMT FÜR ENERGIE. „Grenzkosten bei forcierten Energie-Effizienzmassnahmen in Wohngebäuden“. Bern September 2002.
[4] SCHWEIZERISCHER INGENIEUR UND ARCHITEKTENVEREIN. „*SIA Effizienzpfad Energie“*. Merkblatt 2040; Zürich 2011.
[5] KOST M. *„Langfristige Energieverbrauchs- und CO2-Reduktionspotenziale im Wohngebäudesektor der Schweiz*“. Diss. ETH Nr. 16421, Zürich 2006.
[6] BUNDESAMT FÜR ENERGIE. *„Gebäudeparkmodell SIA Effizienzpfad Energie Dienstleistungs- und Wohngebäude*“. Vorstudie zum Gebäudeparkmodell Schweiz – Grundlagen zur Überarbeitung des SIA Effizienzpfades Energie; Schlussbericht 1. Oktober 2009. Bern.
[7] LEIBUNDGUT H. *„Unsinnige Normen und Vorschriften“*. TEC21, Volume 5-6, 2010, P. 16.
[8] LEIBUNDGUT H. *„LowExBuilding Design für eine Zero Emission Architecture“*. Zürich 2011.
[9] KNÜSEL P. *„Räumliche Energieplanung“*. Raum & Umwelt, Schweizerische Vereinigung für Landesplanung (VLP), Volume 3 2011.
[10] BLESL M, KEMPE S, OHL M, FAHL U, KÖNIG A, JENSSEN T, ELTROP L. „*Wärmeatlas Baden-Württemberg. Erstellung eines Leitfadens und Umsetzung für Modellregionen*“. Forschungsbericht FZKA-BWPLUS. Stuttgart Februar 2008.
[11] BUNDESMINISTERIUM FÜR VERKEHR, BAU UND STADTENTWICKLUNG. *„Nutzung städtischer Freiflächen für erneuerbare Energien“.* Bonn 2009.
[12] AMT FÜR ENERGIE UND UMWELT DER STADT BASEL. *„Basel auf dem Weg zur 2000-Watt-Gesellschaft. Eine Studie zu den energetischen Potentialen des Kantons Basel-Stadt“.* Departement für Wirtschaft, Soziales und Umwelt des Kantons Basel-Stadt. Basel 2011.
[13] SCHLEGEL M, TRUTNEVYTE E, SCHOLZ R.W. *“Patterns of residential heat demand in rural Switzerland”.* Building research and information. 40 (2), pp 140-153.
[14] DIPASQUALE D, WHEATON W.C. *“Urban Economics and Real Estate Markets”*. New Jersey 1996.
[15] GABATHULER C. *„Bevölkerungsentwicklung und Wohnungswesen. Möglichkeiten und Grenzen einer Lagebeurteilung am Beispiel der Stadt Zürich“.* Berichte zur Orts-, Regional- und Landesplanung. Zürich 1988.
[16] BANSE J, EFFENBERGER K-H. *„Deutschland 2050 – Auswirkungen des demographischen Wandels auf den Wohnungsbestand“*. IÖR-Texte Nr. 152. Dresden 2006.
[17] DEILMANN C, EFFENBERGER K-H, BANSE J. *„Housing stock shrinkage: vacancy and demolition trends in Germany”.* Building Research & Information 37 (2009) 5-6, pp.660-668
[18] BUNDESAMT FÜR ENERGIE. (1994), Basisdaten und Perspektiven zur Entwicklung des Gebäudeparks 1990-2030. Arbeitsbericht Bern 1994.
[19] ROLFSMANN B. *“CO_2 emission consequences of energy measures in buildings”.* Building and Environment 37 (2002), pp. 1421 – 1430.
[20] ANSTALEDEN R.W, KOST M, NATHANI C, IMBODEN D. *”Economic potential of energy-efficient retrofitting in the Swiss residential building sector: The effects of policy instruments and energy price expectations”*. Energy Policy 35 (2007), pp. 1819–1829.
[21] SANDBERG N.H, BERGSDAHL H, BRATTEBO H., *“Historical energy analysis of the Norwegian dwelling stock”.* Building Research and information 39 (1), pp.1-15.
[22] BUNDESAMT FÜR BAUWESEN UND RAUMORDNUNG. *„Prognose der mittel- und langfristigen Nachfrage nach mineralischen Baurohstoffen“.* Forschungsbericht des Bundesamtes für Bauwesen und Raumordnung. Heft 85. Bonn 1998.
[23] REDLE M. *„Kies- und Energiehaushalt urbaner Regionen.“* Diss ETH, Zürich 1999.
[24] MÜLLER D.B. *“Stock dynamics for forecasting material flows – Case study housing in The Netherlands”.* Ecological Economics 59(1), pp. 142-159.
[25] RUBLI S, SCHNEIDER M. „*Ressourcenmodell mineralischer Baustoffe auf der Ebene Stadt Zürich“*, Studie im Auftrag des Hochbauamts der Stadt Zürich. Zürich 2007.
[26] ARIOLI M, HAAG M. *„Bauabfälle Schweiz-Mengen, Perspektiven und Entsorgungswege“.* Band 1 und 2. Umwelt-Materialien Nr. 131 Bundesamts für Umwelt, Bern 2001.
[27] BERGSDAL H, BOHNE R.A, BRATTEBO H, *“Projection of Construction and Demolition Waste in Norway”*. Journal of Industrial Ecology, 11(3), pp. 27-39.
[28] OTT W et al. *„Energieaspekte städtischer Quartiere und ländlicher Siedlungen“.* Bundesamt für Energie 2008.

[29] SANDBERG N.H, BERGSDAHL H, BRATTEBO H, *“Historical energy analysis of the Norwegian dwelling stock”*. Building Research and information 39 (1), PP. 1-15.
[30] KBOB/ECO-BAU/IPB, *„Ökobilanzdaten im Baubereich 2009/1“*, Bern Dezember 2008.
[31] STREICHER-PORTE M, WIDMER R, JAIN A, BADER H.-P, SCHEIDEGGER R, KYTZIA S. *„Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Dehli“.* Environmental Impact Assessment Review 25 (2005), pp. 472-491.
[32] BOHNE R.A, BERGSDAL H, BRATTEBO H. *”Dynamic eco-efficiency projections for C&D waste recycling strategies at city level”.* Journal of Industrial Ecology 12(1), pp.52-68.
[33] BRADLEY P.E, KOHLER N. *„Methodology for Survival Analysis of Urban Building Stocks”.* Buildung Research & Information No. 5, pp. 529-542.
[34] MEYET P, CHRISTEN K. *„Optimierung von Instandsetzungszyklen und deren Finanzierung bei Wohnbauten“.* Zürich 1999.
[35] KOHLER N, HASSLER U. *“The Building Stock as a Research Object”.* Building Research and Information 30 (4), pp. 226-236.
[36] WITTMER D. *„Kupfer im regionalen Stoffhaushalt. Ein methodischer Beitrag zur Exploration urbaner Lagerstätten“.* Diss. ETH Nr. 16325.
[37] BUNDESAMT FÜR ENERGIE. *„Erarbeitung einer dem vorliegenden Bundesergebnis vergleichbaren Darstellung der kantonalen Heizwärmebedarfe nach Gebäudetypen und Baualtersklassen“.* Bern 2007.
[38] BUNDESAMT FÜR ENERGIE. *„Mobilisierung der energetischen Erneuerungspotenziale im Wohnbaubestand“.* Bern 2005.
[39] MOSIMANN C. *„Ökologische und ökonomische Bewertung von Massnahmen der Gebäudesanierung“.* Projektarbeit im Masterstudium der Hochschule Rapperswil. FS 2012.

Norwegian Smart Cities - Towards cross-scale indicators



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Short Summary

The parallel commissioning process in the Brøset project made it clear that physical measures can only reduce GHG emissions to 5-7 tonnes per person per year [1]. This paper assesses the potential of Smart Cities methods and solutions to reduce emissions further towards 3 tonnes per person per year (which is the overall goal of the Brøset neighbourhood), based on the progress made in the EERA Joint Programme Smart Cities within the European Smart Cities and Communities Initiative. The main aspects of Smart Cities discussed in this paper are cross-scale energy-efficient networks integrating people, buildings, urban planning, energy infrastructure and supply, and the ICT-based tools and solutions needed to model and manage these cross-cutting networks.

In order to really achieve integrated energy planning at neighbourhood scale and avoid sub optimisation, the paper recommends key indicators and assessment methods that can be included in Brøset regulations and quality programme. These are related to: urban structure with optimal orientation related to solar access, wind and precipitation; optimisation of energy efficiency at neighbourhood scale based on diversity, proximity, distribution, accessibility and density; energy-efficient interactive buildings with integrated RES; robust bioclimatic solutions resilient to climate change impact.

Keywords: Smart cities, Sustainable neighbourhoods, urban planning, CO2

1. Introduction

“Cities of the Future” is collaboration between the Norwegian Government and the 13 largest cities in Norway to reduce greenhouse gas emissions and make the cities better places to live. The new suburb of Trondheim, Brøset, will be carbon neutral. Built from healthy materials and using little energy, Brøset will make an integrated and future-oriented suburb. The work in Brøset will be given full priority in Cities of the Future and should become a model for future urban development.

The results of the Brøset parallel commissioning process showed that through planning and design of traditional technological issues such as building standards, energy supply and motorised transport, it is possible to directly reduce carbon footprint with 3 to 5 ton of CO_{2eq} per capita from 12 to 7-9 tons CO_{2eq} (Norwegian conditions) [1]. This indicates that careful design of buildings and infrastructure alone will not lead to carbon-neutral, resilient neighbourhoods, although such neighbourhoods are an absolute necessity in order to facilitate transition to a more sustainable future. Staying below 550 ppm CO_2 in the atmosphere (IPCCs 2-degree limit) requires far-reaching changes in built environment, energy systems, and people’s lifestyles, and particularly in the interfaces between them.

Design solutions in urban strategic planning, infrastructure and buildings, and the interfaces

between them, will have a direct impact on the stationary energy performance of the Brøset neighbourhood, and it is therefore important to create a set of energy indicators able to incorporate these distinct physical scales and their interfaces. Successful planning and implementation of the Brøset neighbourhood and its long-term integration in Trondheim municipality's political priorities, legislation and planning practice require several steps:

- Creating a holistic vision for integrated energy design of the Brøset neighbourhood;
- Establishing well-defined Key Performance Indicators (KPI) and benchmarks that allow the city to plan Brøset neighbourhood design and monitor its performance;
- Ensuring support by measurements, simulations and qualitative methods, in co-operation with knowledge institutions;
- Devising an implementation plan for translating the design into practice;
- Exploring synergy effects with other municipal priorities such as climate change adaptation (resilience, capacity to respond to crises), health, mobility and commercial development;
- Setting up governance structures to support planning, implementation, monitoring and transferring of experiences to other projects, both within the municipality and to others [2]

The development of the Brøset neighbourhood offers a unique innovation potential in terms of integrated energy design of urban environment, buildings, infrastructure networks and supply systems, combined with high quality of life. In order to achieve this, a common vision was developed early on in the project, which resulted in a holistic planning programme for the neighbourhood, and a parallel commissioning process in which four interdisciplinary teams developed a master plan for the site.

2. Strategic energy planning: interfaces between urban form, infrastructure, and buildings

Energy efficiency is a core issue in the global effort towards tackling climate change and resource scarcity [3], and its effect is even increased when combined with other resource efficiency measures [3]. Simultaneously, however, one of the main challenges to be addressed is managing potential synergies and conflicts between strategic urban planning topics as diverse as energy-efficiency, carbon-neutrality, climate change adaptation, aesthetics, functionality, socio-economic benefits, health, well-being, comfort, productivity, culture and heritage [4].

In addition, resilience of energy system design and management has become of increasing concern for cities during the past years. While originally used to express resistance against natural disasters such as earthquakes, resiliency has come to be linked to the robustness of a neighborhood, city or country to withstand climate and climate change and the ability to cope with the consequences of their impact, including local adaptation of the built environment, social well-being, ecosystem services, accessibility and safety [5]. For Trondheim, for example, potential climate change scenarios include amongst others more intensive extreme weather conditions, less snow, a higher yearly average temperature, sea level rise, more and more intensive rain, and increased danger of erosion and landslides, stressing amongst others the importance of integrating green and blue infrastructures into urban zones for storm water management [6]. As a consequence, principles for climate change adaptation of energy systems need to be integrated at various scales including urban form, infrastructure, and buildings.

Integrated urban energy planning and transformation processes require thorough understanding of how aspects such as urban morphologies and typologies influence the neighbourhood's overall energy performance characteristics. However, few methods currently analyze what happens in between the building and urban level (i.e., building clusters, neighborhoods). Most simulations are centered on buildings, users or grids, and experts are educated and trained correspondingly. It is therefore difficult to model and optimise synergy effects for energy efficient buildings that interact with the grid, their users and the environment in real-time, and to integrate flexible, general and elastic solutions that can adapt over time [7, 8 and 9].

Furthermore, energy efficiency can be promoted by fully integrating individual buildings as active hubs in the neighbourhood energy grid, using information and communication technology (ICT) to gather and exchange relevant information, and to facilitate robust, yet flexible design and demand

side management:

- Building design for optimised interactivity with surrounding site, microclimate, people and cultural heritage, in order to optimise energy efficiency, enable generation of renewable energy, and support energy efficient lifestyles;
- Building envelope materials and technologies that can optimise the interface between buildings and their surroundings;
- Energy interface between buildings and the grid;
- Interface between buildings and users: how to include users and user behaviour in designing and monitoring energy measures;
- Buildings as disseminators, which can create awareness and a multiplier effect [10].

In order to promote integrated energy design in urban form, infrastructure, buildings and supply systems, it is important that this type of design is being perceived as relevant and attractive for all residents and stakeholders in general – not only those with a particular interest in the subject. This type of challenge is the topic of a branch of behavioural science called choice architecture, extensively explored amongst others by [11], arguing that the manner in which people make decisions depends a lot on the manner in which the problem is framed. The authors claim that people, when given a choice, in most cases just choose the default option, unless they are especially engaged in the subject. This phenomenon, called the Status Quo Bias, is often used in Tversky and Kahneman [11 and 12] and is implemented amongst others in product placement in supermarkets: putting groceries at eye level increases their sale in a predictable, easy and cheap manner, regardless of the type of product placed in this position. What would be the equivalent for environmental issues in architecture? In order to answer this question, several rules of thumb for the factors on which people base their decisions can be applied [12]. Particularly highlighted are the concepts of anchoring, availability and representativeness:

- Anchoring relates to the fact that, when making a decision, people start from something they know, and adjust this “anchor” in a direction they think is appropriate in the given context.
- A second factor that guides people’s choices is representativeness: is the situation and context representative of what one oneself has experienced or thinks is relevant?
- The third factor, availability, is related to the ease with which people come up with relevant examples. The more readily available relevant examples are, the more likely it is that these will influence people’s decision making – for better or worse.

These three issues can be applied to increase the probability that people will make more energy-efficient choices. For example, when a household is given information on the energy consumption of their neighbours, they will in most cases adjust their own consumption correspondingly [11]. Such connections or patterns have also been explored extensively in the past [13, 14 and 15], and particularly in contemporary eco-villages and the traditional garden city principles on which they are based: “an attractive and green neighbourhood which is safe, pollution-free and uncongested; a sense of local community and excellent access to friends and facilities both locally and regionally. People hope through telecommunications to participate in wide flung networks and activities while (in many cases) living a less frenetic and more locally-based life” [16]. In fact, we found suggestions related to anchoring, representativeness and availability in the parallel commissioning teams’ master plan proposals for Brøset, which will be one of the topics discussed in the next section

3. Cross-scale energy measures and indicators for Brøset

There are several assessment and certification standards for buildings and urban areas which include relevant measures and indicators for integrated energy design. Common for these are that they are mostly using indirect and qualitative indicators for the assessment, rather than quantitative and measurable indicators. They are also mainly dealing with improving and optimizing existing characteristics, rather than seeking synergies and new solutions.

The Brøset project took a different approach by seeking new solutions and synergies between technologies and consumption patterns (lifestyle) and scales. The tender for the parallel

commissioning process called for “new technological and social perspectives on energy and resource consumption are to be tested and to show a more climate benign manner in which to live” [17], and, correspondingly, a wide range of measures was proposed by the four parallel commissioning teams to support a holistic master plan for the Brøset area. The measures could generally be divided into two main categories: urban design strategies creating the architectural and technical framework for the Brøset area, and facilitation of an attractive social network spurring citizens to a more environment-friendly lifestyle [18]. Regarding energy in buildings, the tender asked for proposals that can contribute to:

- Show various types of settlement structures that facilitate development of energy efficient buildings during a later, more detailed stage of the process;
- Low greenhouse gas emissions related to energy in buildings; this requires extensive use of renewable energy sources such as solar energy, biomass, and heat pumps. Shared energy solutions can be considered for building clusters;
- Explore housing typologies that reduce land use per person;
- Illustrate new buildings in the area with at least passive house standard or better, or other solutions that result in minimal greenhouse gas emissions;
- Assess flexibility and adaptability of the proposed urban structure and building typologies;
- Assess collective versus individual heating system solutions;
- Draft potential choice of materials (…)
- Use of green infrastructure to reduce heating need in buildings [17]

In the next stage, these proposed measures will have to be transformed into a detailed quality programme for the planning, construction and management of the neighbourhood. The challenge lies in describing and validating these potential synergies, translating the measures to an assessment scheme with measurable indicators, and weighting of indicators in order to enable comparison of various scenarios, benchmarking, and monitoring.

This section summarises and discusses the measures proposed by the tender for the parallel commissioning process, the proposals from the four participating teams, and the evaluation report [19]. Where relevant, additional measures and indicators are suggested by the authors of this paper is based on state of the art development within the European Energy Research Alliance Joint Programme on Smart Cities (EERA JP Smart Cities), and the European Environmental Agency’s report on urban adaptation to climate change in European cities [20]. The EEA report provides an excellent state of the art summary of climate change adaptation challenges and measures in European cities, including those related to energy infrastructure. EERA JP Smart Cities was chosen for comparison because it is the largest research programme looking dealing with innovative energy efficiency measures in cities across urban, infrastructure and building scale.

Table 1 Overview of the steps in BREEAM Communities 2012 and the scales approach in the Brøset project

	Scale 1: Integrated urban energy planning and transformation processes	**Scale 2: Infrastructure networks**	**Scale 4: Energy-efficient buildings as interactive elements of the urban energy system**
Step 1: Establishing the principle of development			
Step 2: Determining the layout of the development			
Step 3: Designing the details			
Innovation			

The analysis is of course influenced by the fact that different levels of detail are of importance for various design and development phases; a parallel commissioning process to procure a master plan for the Brøset site will thus not go into detail on the specific building details needed to obtain good energy efficiency. However, it is important to remember that the development of the Brøset site and its energy system in any case requires high levels of investment regardless of whether the design optimised complementarities between urban form, infrastructure, buildings and supply. Planning for integrated energy design from the very start, using a range of 'no regret', flexible options, is therefore an appropriate scenario, in order to avoid the neighbourhood's energy consumption and corresponding emissions from being locked for decades.

3.1 Scale 1: Integrated urban energy planning and transformation processes

Make best possible use of local climate and site conditions to optimise energy efficiency and create an attractive outdoor space

During the parallel commissioning process, teams suggested that working with local climate in terms of urban morphology, infrastructure and vegetation, and thorough understanding of the nature of the site and its connection to the surrounding environment builds a solid foundation for good comfort conditions combined with resource conservation; this includes microclimatic conditions such as wind, sun and humidity, remote and local view, and shelter from noise and dust from the neighbouring road. A high ratio of solar-oriented buildings provides good access to daylight and sun for human well-being as well as for energy production; these conditions are optimised by careful planning of neighbourhood densities, building heights and depths, and roofscapes.

The evaluation committee remarked that while solar and daylight access seem to be met in a fair manner by the four teams' proposals (though not always for ground floor housing units), it is questionable whether the form and location of the built structures on the Brøset site will provide a comfortable outdoor microclimate [21], an issue that is also extremely important in terms of climate change adaptation [20].

3.1.1 Robust energy solutions that can tackle impact by climate change

The teams propose green infrastructure on site, including green roofs and facades, to mitigate the urban heat island effect; even distribution across the neighbourhood is to be preferred above a few large parks. In addition, it is specified that outdoor surfaces on buildings and public spaces should have high albedo to mitigate the heat island effect and reduce need for mechanical ventilation indoors. Development of infrastructure and buildings at the Brøset site will require a large investment and the opportunity needs to be used to make them resilient to future climate change. In the upcoming detailed design stage, high albedo and green roofs and facades as measures to cope with heat in buildings and public spaces will need to be extended to better insulation in buildings, solar control measures such as shading, orientation and building morphology, and passive cooling measures to reduce need for air conditioning in housing but particularly workplaces and public buildings on the Brøset site [22]. These are typically no or low regret measures that either are reversible or provide a range of co-benefits such as storm water management, increased contact with nature, and, possibly the largest driver for climate change adaptation, more attractive living environments [20].

3.1.2 Making energy efficient solutions the most accessible and attractive alternative

Within ambitious energy standards for the whole neighbourhood, the teams propose a variety of housing types with different energy, technology and cost profiles to cater to a broad potential target group, ensure accessibility for various user groups. In addition, they are aiming to create a built environment that facilitates a new, low-carbon way of living, hopefully influencing the manner in which people think and act, and to create a reinforcing cycle by making low-carbon alternatives more available, and high-carbon alternatives less available, in the entire Brøset neighbourhood.

An Environmental Centre is proposed established on-site that can serve as innovation hub and showroom for residents and visitors, providing stakeholder support during planning, construction

and monitoring of the neighbourhood's performance; helping residents when needed; showcasing methods and solutions that support the vision of the area; and facilitate selling and renting housing units and commercial units on the Brøset site.

3.1.3 Reducing embodied energy and transport by providing local products, services and service agreements

The teams propose cradle to cradle [23] design of goods and services, including support for small businesses and facilities for recycling, re-use, re-design and sharing, such as an object library, second-hand stores, garage sale facilities, and shared workshops with high quality equipment with long lifetime.

Environment-friendly service agreements, including the best available technology at all times, are to be preferred above ownership agreements. A range of these services combine individual comfort and time-saving with potentially commercially viable activities. For example, local-food delivery, cleaning services, repair-services for household appliances, furniture and other items can be provided to residents or even located on-site. Brøset can provide a framework for quality control, start-up facilities for businesses for trading, organizing and scaling this practice for Brøset, Trondheim and the entire region. Stores located at the Brøset site should be encouraged to review their packaging and storage routines to reduce the amount of waste.

In order to increase the chance that people want to spend more time in the area, the municipality should facilitate local shops and market places, cafés and restaurants, sports and leisure, schools, workplaces, library, organic food and allotment gardens with energy efficient greenhouses; slow food restaurants on attractive street corners, a high-end, luxurious yet environment-friendly spa, concert hall and cultural centre, engaging Brøset inhabitants as well as neighbours and visitors – "a place so sublime (and expensive) it becomes addictive" [24]. In order to secure these facilities from the start, lower rent and/or other incentives are advised.

3.1.4 Finding synergies between integrated urban energy planning and other municipal priorities

The teams state that an integrated, long-term land use plan for activities, functions and urban structure is needed to support the overall vision of the Brøset area. The plan should be adaptable over time, according to changing use, users, and available technology and knowledge. Active use of existing built environment should be encouraged when developing the new Brøset identity. Historic buildings, landscape and built environment can be used as story-tellers to give the neighbourhood an identity and a soul, using them as anchors for the new neighbourhood.
Qualified density should be provided to ensure well-functioning, cost-efficient infrastructure and services, but with high-quality living environment. Reduced area for motorised transport, combined with mixed use in different parts of the neighbourhood, can support this policy. Mixed use is proposed by the teams to support good accessibility of shared and/or public facilities. In fact, this type of structure could be extended to become a smart energy district [2] or synergy zone [8], allowing for smart coupling of different buildings with complementary energy requirement, such as schools, industry, shopping centres, homes, and workplaces.

3.2 Scale 2: Infrastructure networks

3.2.1 Smart coupling of energy generation, consumption and storage

Several teams propose a smart grid for the neighbourhood, with plug-and-play system and central smart management. The evaluation committee comments that while some teams propose smart grid solutions, it is not specified how this can be solved on the Brøset site or how this will contribute to lower energy consumption and corresponding greenhouse gas emissions. This is particularly important since smart grid solutions are not yet "best practice" and may appear to be somewhat uncertain [19]; within a few years' time, however, when the Brøset area will be constructed, these conditions will most likely have changed, with experience from demonstration projects in other areas.

3.2.2 Promoting renewable supply technologies integrated into urban infrastructure

Shared low-carbon energy supply for the area is suggested by most teams, ready when the first residents move in, with diversity and flexibility for future development. A mixture of renewable energy sources is proposed, for example district heating based on biomass or waste incineration, combined with on-site generation of local renewables (mainly solar thermal and PV, but also wind turbines, geothermal, biomass CHP, potentially combined with seasonal storage). These should be integrated in large-surface buildings and structures such as the Brøset energy hub, the environmental centre, schools and noise-reduction screens towards highly-trafficked roads. The system should be able to adapt to more energy-efficient, carbon-neutral energy sources should these arise in the future. In addition, solar thermal and photovoltaic systems can be installed in individual housing units when economically viable; buildings should at least be designed to allow this option in the future. The system can be coupled to electric cars gathered in a central underground garage in the future.

In order to make this development economically viable, the teams recommend that a stepwise development and investment plan is provided for local renewable energy supply in co-operation with a private energy company, in return for temporary monopoly on energy supply to the area.
According to the evaluation committee, however, with low energy demand by Brøset buildings, it will not be cost efficient to develop a multitude of renewable energy systems in parallel. In addition, cost efficiency and usability of a district heating system on-site have to be evaluated against large-scale local renewable energy system development [21].

3.2.3 Increased energy efficiency through synergies with water and waste management systems

The teams didn't deal with energy efficiency of infrastructure systems; blue-green infrastructures are mainly mentioned in the context of climate change adaptation for the purpose of storm water management, urban heat island mitigation and so forth.

However, several co-benefits of coupling energy efficiency and infrastructures could be highlighted, amongst others using water systems for pumping and storage to balance the energy system; using waste water systems in the energy system, e.g., for cooling water, or as heat source for local heat pumps; using waste incineration plants for power and district heat production in connection with cities; and using organic waste for biogas used either for heat and power or in transport [25].

3.3 Scale 3: Energy-efficient buildings as interactive elements of the urban energy system

3.3.1 Set minimum standards for individual building energy performance

All teams propose that Brøset buildings should have at least passive house standard or better, and, at any time the buildings should perform better than national regulations. New as well as existing buildings need to comply with these rules, though with lower ambitions for the historic, protected buildings on-site.

The evaluation committee remarks that while almost all proposals include passive house or similar standards, this does not necessarily indicate low energy consumption during the buildings' lifetime, only low operational energy consumption per square meter. Total lifetime energy demand can only be reduced if the built area is restricted as well, and embodied energy of materials and technologies is taken into account. In some cases for example steel and concrete are used while advocating use of materials with low embodied emissions [21].

3.3.2 Robust bioclimatic design

According to the teams, passive design strategies should be used extensively, such as compact building, orientation and adaptation to local climate and site, passive solar heating and use of solar rooms and basements for insulation, thermal mass, good airtightness and insulation of building envelope including windows. Ample potential for public-private interface should be provided, for example in the form of balconies and roof terraces.

The teams recommend that buildings be designed for future integration of solar thermal and photovoltaic panels when economically viable; this requires design able to combine current passive energy saving strategies with potential future integration of renewable energy systems. It is, however, not sure how this measure will be combined with the extensive use of green roofs and facades described in the teams' proposals.

In the upcoming detailed design stage, the proposed urban textures need to be optimised according to their bioclimatic potential, by means of urban shape factors such as volume to surface ratio (the enclosed built volume to envelope surface area ratio), passive volume (the building's potential for use of passive systems such as natural light and ventilation, and passive solar gains), the degree of occlusion of the sky (variation with the height of the surfaces and perimeters of horizontal sections), vertical sections and directionality (influencing incident solar radiation and wind direction) [9].

3.3.3 Diversity, flexibility, generality, elasticity

The teams recommend that buildings be designed with innate flexibility to adapt to changes in use and users when required, on a daily, seasonal or long-term basis. Housing units should have potential for expanding and shrinking, also in terms of room height. It is also suggested that design regulations should open for a diversity of plot sizes and shapes, ownership structures, contractors, developers, and design teams. Housing should have in-built potential for lifelong living, preferably combined with contact with outdoors and ground floor, to create housing units with the feeling of single housing with own entrances and access to private or semi-private outdoor space. The evaluation committee remarks, however, that the teams' claims as to these solutions leading to a lower-emission lifestyle are not supported by state of the art references. In addition, the evaluation committee remarked that while diversity has definitely been taken into account, the teams offer few assessments of how the diverse housing types will perform energetically [21].

Several teams suggest it is desirable to allow for do-it-yourself (DIY) building practices while maintaining high energy efficiency standards. Therefore it is necessary to establish professional consulting on-site or connected to the Brøset neighbourhood to assist DIY builders in their practices. In addition, a catalogue can be provided containing prefabricated, mass-customised options, using energy-efficient, low-carbon design, materials and equipment.

3.3.4 Reduce energy needs per person through reduction of built area per person

The teams suggest that individual core facilities should be included in each housing unit, while rooms that are not essential for daily use can be moved to shared facilities, for example laundry rooms, storage sheds and workshops, boats and cabins. In order for shared facilities to be attractive, they have to be located close to the private residence – therefore clustering of housing units that share facilities are preferably located around a courtyard, or similar types of clustering. Well-designed, space-efficient floor plans with attractive facilities in the neighbourhood should further support reducing individual housing units.

The evaluation committee remarks that this is a vital issue for reducing energy consumption and corresponding greenhouse gas emissions. kWh/m^2 only relates to energy efficiency, but if the built area is not restricted, this will have no effect on total energy consumption [21].

3.3.5 Creating awareness about energy efficiency and renewable energy systems

Diverse solutions are proposed to make the residents more aware of their energy consumption, amongst others in the form of competition among residents, or with other low-carbon neighbourhoods. Visible and smart metering allow for user-controlled demand side management of operation of electrical household appliances and heat pumps, and recharging of electric cars and car batteries. Visibility of energy efficiency measures and renewable energy systems (RES) can also be used to support dissemination purposes.

4. Discussion

In order to transform the vision for Brøset as low-carbon neighbourhood and potential lighthouse

project for Smart City Trondheim into reality, it has to be firmly anchored and detailed in co-operation among Trondheim politicians and policy-makers, commercial actors, knowledge institutions, media and citizens. Scenario analysis and testing of alternative transition pathways should be performed, and potential synergies and conflicts with other municipal goals investigated to ensure that the development, implementation and monitoring of the Brøset vision does not happen 'on top of' conventional urban practice in Trondheim municipality, but rather is embedded in Trondheim's transition towards a more energy-efficient and low-carbon city.

The Brøset projects is different from other assessment methods in that the project tries to limit the overall emissions from the development at by 3tons CO_{2eq}/capita*year, including embodied energy and end of life. Thus the Brøset projects are the first project worldwide that tries to limit the overall emissions from an area. This in turn influences the choice of indicators, and how they are used.

In assessment schemes, stationary energy is measured as kwh/m^2 or kg CO_{2eg}/m2, giving points to how much better the proposed building is when compared to current building code. The embodied energy is also rated a similar way, but there is no limit to the "allowed" total energy used or emissions from a project over its lifespan.

At Brøset, a different approach is chosen. First of all, all buildings should comply with the passive house standard or better (15 to 25 kwh/m^2) in terms of in-use energy consumption (or emissions). Second, the total emissions from the development should not exceed by 3tons CO_{2eq}/capita*year. This in return leads to an optimization of material consumption (embodied energy/emissions) and area per capita. Area efficiency is crucial in order to achieve the goals set for Brøset.

Also, on-site energy productions, energy storage, smart integrated grids and the areas albedo is taken into account in the design and development of the area. The idea here is to create excess energy that can be exported back to the grid, or be used for other purposes such as transport etc. Also the change in the albedo from the area will create a net "reduction" of CO_{2eq} from the area.
So where other assessment schemes look at stationary energy consumption, embodied energy and transport systems in relation to each other, but independent of each other, the Brøset projects limits the whole development with a final emission cap. This will in turn force an integrated design and search for synergies and energy design across different scales and disciplines.

5. Conclusions

The measures proposed by the parallel commissioning teams provide a plethora of robust, diverse and adaptable solutions and methods for integrated energy design at Brøset that can avoid lock-ins, provide adaptability to uncertain challenges, and create an attractive built environment.

The next phase will be the creation of an environmental programme, including development of standardized and clear criteria by which project proposals can be judged in a uniform manner. This environmental programme will provide a basis for monitoring all stages of development of the Brøset project, including design and selection of proposals, construction phase, and long-term management of the area. The parallel commissioning process clearly showed the importance of being able to describe correct and measurable goals, and exposed the lack of science-based, planning-friendly decision-making tools for the early design phases of a neighbourhood project.

In particular, there was a lack of design, assessment and management tools to examine synergies and conflicts between building and energy network performance. In the parallel commissioning process relatively few solutions were proposed for interaction between buildings and networks, including any smart or ICT systems, responsive building facades, or seasonal bioclimatic solutions. This type of interaction should be further developed to create energy efficient, integrated energy planning (building-grid-user) for the entire neighbourhood, and avoid potential redundancy or incompatibility among the various systems.

6. References

[1] Bohne, R A, Solli, C, 2011, How to measure environmental impact in the planning phase of a settlement. The case of Brøset, Trondheim (Norway), Proceedings of the SB11 Helsinki World Sustainable Building Conference, Volume 2, pp.438-439.

[2] Bach, B, Schütz, R (eds), 2013, EERA Joint Programme on Smart Cities, Description of Work.

[3] EC, 2012, Smart Cities and Communities website, hosted by the European Commission, http://ec.europa.eu/energy/technology/initiatives/smart_cities_en.htm (last accessed 29 April 2012).

[4] Leipzig Charter on Sustainable European Cities, 2007, adopted by the European Council of Ministers on 24 May 2007. http://www.eukn.org/E_library/Urban_Policy/Leipzig_Charter_on_Sustainable_European_Cities (last accessed 29 April 2012).

[5] Otto-Zimmermann, K, 2011, Cities and Adaptation to Climate Change - Proceedings of the Global Forum 2010, Springer.

[6] Trondheim kommune, 2008, Trondheim kommune handlingsplan 2008 – 2014 i Framtidens byer (Trondheim municipality's action plan 2008 – 2014 in Cities of the Future, in Norwegian), pdf available at <http://www.regjeringen.no/upload/MD/Kampanje/klimatilpasning/Bilder/Framtidens%20byer/Tr.heim_handlingsprogram.pdf> (last accessed 8 April 2013).

[7] Conte, E, Monno, V, 2012, Beyond the buildingcentric approach: A vision for an integrated evaluation of sustainable buildings, Environmental Impact Assessment Review, 34, pp.31-40.

[8] Larsson, N, Hovorka, F, Salat, S, Bourdic, L, 2011, From Smart Grids to Synergy Grids, Proceedings of the SB11 Helsinki World Sustainable Building Conference, Volume 1, pp.46-47.Alexander, C, Ishikawa, S, Silverstein, M, Jacobson, M, Fiksdahl-King, I, Angel, S, 1977, A pattern language. Towns, buildings, construction, Oxford University Press, New York.

[9] Salat, S, 2012, Cities and forms: on sustainable urbanism, Editions Hermann.

[10] Sartori, I, Wyckmans, A (eds), 2013, EERA Joint Programme Smart Cities, Subprogramme 3 Energy Efficient Interactive Buildings, Description of Work.

[11] Thaler, R H, Sunstein, C R, 2009, Nudge, improving decisions about health, wealth, and happiness, Yale University Press, New Haven.

[12] Tversky, A, Kahneman, D, 1974, Judgment under uncertainty: heuristics and biases, Science, 185, pp.1124-1131.

[13] Alexander, C, Ishikawa, S, Silverstein, M, Jacobson, M, Fiksdahl-King, I, Angel, S, 1977, A pattern language. Towns, buildings, construction, Oxford University Press, New York

[14] Gehl, J, 2010, Cities for people, Island Press, Washington DC.

[15] Walton, D, (ed), 2007, Urban Design Compendium, London, English Partnerships. 2nd Edition (1st Edition in 2000), http://www.urbandesigncompendium.co.uk (last accessed 29 April 2012).

[16] Barton, H, (ed), 2000, Sustainable Communities. The potential for eco-neighbourhoods, Earthscan, London.

[17] NAL I Ecobox, 2010, Oppgaveprogram for parallelloppdrag for utvikling av ny klimanøytral bydel på Brøset (Tender for parallel commissioning process for the development of a carbon-neutral neighbourhood at Brøset, in Norwegian), available at <www.trondheim.kommune.no/gronnbybroset> (last accessed 8 April 2013).

[18] Team SLA, 2012, Brøset Håndbok. Det enestående hverdagslivet. (Brøset Manual. Unique every-day life), contribution of Team SLA to the Brøset parallel commissioning process, in Norwegian, http://www.arkitektur.no/?nid=216632&lcid=1044&waf_ispreview=true (last accessed 29 April 2012).

[19] Trondheim kommune, 2013, Trondheim municipality's website on the Brøset project, <www.trondheim.kommune.no/gronnbybroset> (last accessed 8 April 2013).

[20] EEA, 2012, Urban adaptation to climate change in Europe. Challenges and opportunities for cities together with supportive national and European policies, EEA Report 2, Copenhagen.

[21] Trondheim kommune, 2012, Brøset x 4, available on <www.trondheim.kommune.no/gronnbybroset> (last accessed 8 April 2013).

Efficiency Optimization of a Real Settlement



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Summary

The topic of “Smart City” gradually becomes more important, especially because of the growing world's population. Considering this situation, experts recognize the potential values of cities with long-term sustainability. For buildings, the establishment of an energy certificate is mandatory, with considerations of the building environment, locality, infrastructure provision and other issues that have not been taken into account.
In this study, using a real community in Vorarlberg, Austria, various factors were investigated and their impacts were analyzed. The “Energy Certification of Communities” software, co-developed and provided by the Lower Austrian Land Government, Department of Spatial Planning and Regional Policy, was used for the calculations and analyses. The focus of this program is not only on the quality of the location but is more on the utilizations of various areas. Essentially, concerns of this development were mainly costs in Euro per living unit and year; it means the more built in an area the less the cost. The last part concerns the effects of developments on the CO_2 emission, which is affected by traffic emission. First, the present situation was calculated, including the following factors:

- Indicators;
- Partial areas;
- Development;
- Quality of open spaces;
- Connectivity and transportation;
- Locations and buildings.

Considering these factors, different variants could be worked out. Initially, the existing green spaces would be partially removed to reduce the developmental costs. Another factor is to build a central school or shopping center. In this case, the individual transportation routes would be shorter and the CO_2 emissions would decrease. Other variants were also investigated and evaluated. Results show that we can achieve a lot, but more than two efficiency levels cannot be reached. An energy-efficient use of resources can be achieved in all cases.

Keywords: Smart city; Development costs; Building environment; Locality; Infrastructure provision

1. Introduction

One of the key instruments of the EU for accelerating the development of large scale use of low carbon technologies is the European Strategic Energy Technology Plan (SET Plan) [1]. It proposes systemic approaches and organizational innovation about the energy efficiency, low carbon technologies and the smart management of energy supply and demand (SEC 1295, 2009) [2]. Technology roadmaps serve as a basis for strategic planning and decision making applying a collective approach in research, development and demonstration planning and implementation with a clear focus on large scale programs, such as the European Industrial Initiatives (EII) [3]. Together with other industrial initiatives, the “Smart Cities” initiative highlights the importance of intelligent energy management systems in cities in order to achieve a 40% reduction of greenhouse gas emissions by 2020. For the design and planning of smart energy systems, the detailed

understanding of the energy performance characteristics in urban areas is of crucial importance. The future energy management of “Smart Cities” is a very complex interdisciplinary problem that requires a new research approach, as the research aims of individual fields concentrated on progress in the technological issues of those fields, sometimes even at the cost of the whole system.

A “Smart City” can generally be defined as a sustainable urban community, with importance of mobility, environment, economy, life and people. The sustainable development of cities has long been in prospect, but there are many concepts currently discussed: Sustainable Cities, Green Cities, ecocities, climate neutral cities and also cities of the future [4]. However, clear distinctions between these concepts are rather difficult [5].

Due to the thematic diversity in the field of “Smart Cities”, it is more difficult to define future research strategies in this area. But there are some substantial core themes that characterize a Smart City.

Typically, a “Smart City” meets specific quality features that are composed of various factors or axes. On the one hand, every cities infrastructure is taken into account, but also the existence of innovative ecological/environmental concepts. A smart city as well is a city with a high quality of living [6].

In this study, using a real community of Dornbirn in Vorarlberg, Austria, various factors were investigated and their effects were analyzed. The “Energy Certification of Communities” software [7], co-developed and provided by Lower Austrian Land Government, Department of Spatial Planning and Regional Policy, was used for the calculations and analyses.

Following aspects were taken into account:

- Key figures
- Subareas
- Development
- Quality of open space
- Accessibility and traffic
- Location and development

The key figures included on the one hand building land areas and on the other hand living units (LU). The building areas were divided into subareas. It was important that those areas to have the same topography and not separated by streets, paths, rivers or greenways, so the alignment, the art of development as well as the types of buildings are always the same. Those subareas are then filled with residential units.

The factor “improvement” is concerned with developmental costs. There are interior and exterior developmental costs. Interior costs only include the length of the pipeline for supply and disposal, whereas the exterior costs include traffic development, water supply, wastewater and rain water management, street lighting, gas pipeline and also local and district heating system. So, generally speaking, we can assume that the longer the required pipelines bring the larger costs.

The subareas, already explained, carry great weight in consideration of the factor “quality of open space”. They provide information about existing sources of disturbance and if there are recreational areas nearby. This means that every subarea receives its own evaluation.

The aspect of “Accessibility and Traffic” considers every subarea separately and focuses on the distance to certain facilities and authorities, for instance, the subarea located in close vicinity of the town center, local amenities and kindergarten and primary schools, the evaluation increases towards energy efficiency. Almost all kinds of distances are taken into account, excluding the trip to work, since it differs too much from resident to resident.

Under the point “Location and development” we found data regarding topography and buildings types in every single subarea. It should also state the subarea’s alignment, where the alignment’s direction is heading away from the street.

The evaluation was conducted in three sections:

a) Development costs in □ per living unit and year;
b) CO_2-Emission affected by the traffic of the art of development per living unit and year;
c) Quality of location and development.

There is an individual outlay between the classes “A” and “G” that follows those points in which “A” is for the most energy efficient use and “G” is the weakest rating. Before this final classification, each of those 3 parts has to be weighed differently while part a) weighs 0.40, part b) weighs 0.25 and part c) weighs 0.35.

2. Energy pass of the actual state

The study area is located in Austria, Vorarlberg province, as one of the largest cities in the state. For this study, all of Dornbirn is too large of an area so the survey was narrowed down to only one part of the city. This part is located in the west of Dornbirn and is bounded by Josef Ganahl Straße, Lustenauer Straße, by the Dornbirner Ach and the railroad tracks. The region has a total area of 828,630.18 m² and an auxiliary of housing construction of 100,000 m² (left part in Figure 1).
After defining the area, we divide it into subareas. Here, it is important that the topography and the alignment characters of the majority of the buildings are the same. The subareas should not be divided by streets but the area was too large to avoid that. Hence there were 25 arrangements with different areas and living units (right part in Figure 1). The existing transport routes have a total length of approximately 9,045.24 m with an average width of 6 m. The arrangements and related information are presented in Table 1.



Fig. 1. Left: blue line denotes the investigated area; green line denotes the green area. Right: red line denotes the subareas with numeration.

Table 1. Subareas: number, area and the living units.

Number	area [m²]	LU	number	area [m²]	LU
1	13,558.53	5	14	38,754.16	32
2	12,286.44	4	15	19,711.56	19
3	14,385.85	12	16	24,115.90	35
4	13,385.73	8	17	16,174.01	30
5	8,614.08	7	18	23,471.45	22
6	11,672.08	2	19	26,665.13	25
7	28,001.01	14	20	20,926.58	16
8	15,859.10	35	21	15,655.63	15
9	27,376.71	27	22	57,638.62	61
10	14,918.31	16	23	28,490.56	36
11	23,707.36	20	24	25,471.53	28
12	18,226.37	15	25	7,564.69	18
13	34,625.68	37			

The exterior and interior developments include the length of the supplying pipelines, traffic development, water supply, electricity supply and gas pipelines. In this housing estate, the rating of the energy efficiency class regarding to development is “G”, which is the lowest level in the rating system. Regarding to the quality of open space, this estate is rated “C” due to the existence of private green spaces and a low source of noise within 150 m. Even though this rating is not taken into account for the classification of this housing estate, it gives a roughly evaluation of the area on the comfort of the residents.

The next section of b) includes an exact description of each of the subareas and how far they are apart from various reference points. Then, it calculates a sum of CO_2 emission of traffic/LU/year of 0.26 t /LU/year, which is a satisfying rating of “D” level.

The last section of c), which weighs 0.35 in the overall calculation, is the quality of location and development. As the definition already tells us, the topographic location of every single subarea provides an influence. Those are all on one level. The type of building is also important, dividing into 4 different varieties: single family house attached or detached, row house and apartment complex. The last part for the overall evaluation is the alignment of the subareas. To define those houses closer, the direction was considered averted to the side of the street. In our housing estate this section is rated “B” and therefore the best rating in the weighting of classification. With those 3 calculated points of evaluation we have a total classification of the actual state in class “E”, meaning that it is in the lower level of the classification system.

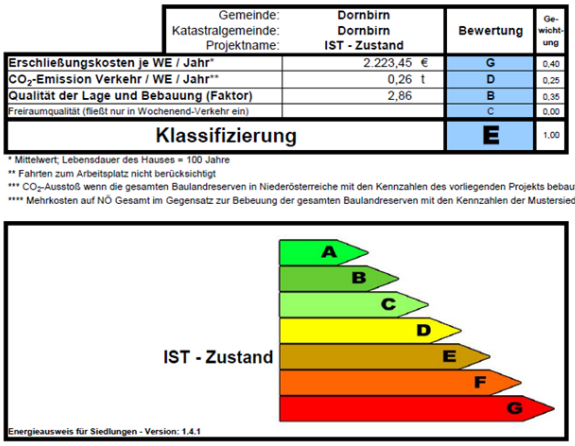


Fig. 2. Energy passes of the actual state.

3. Research of alternatives

After the evaluation of the energy pass in the actual state, we attempted to increase the energy usage efficiency. In this process, it was important to avoid a big alteration of the area; a total resituating of houses or a modification already existed in the street courses. Two different alternatives were elaborated, as explained below.

3.1 Alternative 1

Firstly, various parts of classification were closely considered and was found that the development costs per year are the largest in weight. Considering the energy pass of this housing estate, the factor has a relatively bad rating. To change this, the interior and exterior developments should be reviewed and edited or more building land has to be added.
The first point includes length of pipelines, traffic development, water and electricity supply, street lighting and length of gas pipelines. The problem is that the alteration of the area is not desirable. This means that in order to change those developments, the lengths have to be shortened. But, that is possible only if the whole streets are altered or houses are relocated. Because that is not the best option, maybe more lands for buildings could be added.

The investigated area has a total of 100,000 m² of auxiliary housing constructions, so this section will be extended. Two new subareas, one with 17,886.89 m² and 16 living units and the other with 27,969.23 m² and 28 living units are added, reducing the auxiliary to approximately 57,000 m². The new building areas certainly need accessibility to the transport system leading to the construction of a new street. This street causes an increase in the length of transportation routes of 567 m. Consequently, there is still a green area and an ideal expansion of the housing estate that causes almost no modification in the cityscape and the small increase of living units has no influence on the improvement of the energy level of the development.
Our chosen area in Dornbirn-Schoren has approximately 539 living units, with the expansion the number increases to 583. But, as there is a constant growth of population, the area is calculated with a triple expansion. This decreases the development costs per living unit from 88,376 to 25,000 euro per year and the energy efficiency increases by three levels and is now at the level of “D”.
The remaining calculations did not reveal any increase so the end classification for a) is class “D”, factor b) is also at level “D” and the last factor c) reaches the level “B”. As a result of the increase the number of living units, a better classification arises and is now at level “C”, which is an acceptable result.

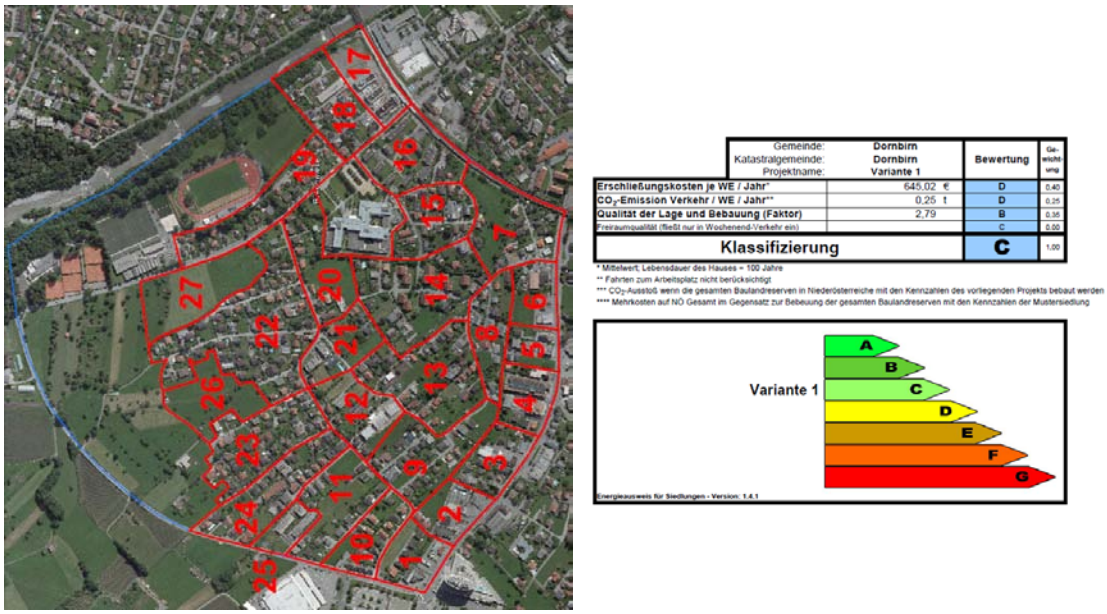


Fig. 3. Left: blue line denotes the investigated area, red line denotes the subareas with numerations right: energy passes alternative 1.

3.2 Alternative 2

Another alternative to improve the energy usage efficiency is to change the CO_2 emission and the quality of location and development. The latter is quite difficult to readapt, because it would be difficult to relocate the estate from a flat topography into a mountain range. Equally impossible would be to consider a new development since the area already exists and is not newly constructed. For building the future estates, those factors should be taken into consideration in advance because it might be impossible or really difficult and costly to change it afterwards. That means, for the second alternative, the CO_2 emission is going to be influenced to get to a higher level of classification. Currently, the rating is at the level of “D”. To change this, the following factors can be changed, involving a length specification of different subareas.
Weekday

- To town center
- To closest local amenity
- To playground/green area
- To kindergarten
- To primary school

- To closest public transport station

Saturday, Sunday and holiday

- To green area > 1500 m²
- To recreational or cultural facility
- To sports area or playground > 500 m²

In this housing estate almost every subarea is at least 1500 m away from the town center, thus a reduction of 500 m is assumed. This could be realized through assuming that the existing peripheral area with the same development is close to the city area. Using this method, an improvement of every subarea of 1 to 2 levels can be induced.

The other factor of improvement is the distance to the closest local amenity. The investigated area is part of a larger city and the local amenities are usually 1500 m away. Another increase of the outcome could be achieved through making sure they are only 1000 m apart.

With those two improvements in the performance of Dornbirn, Area Schoren, can be improved from level “D” to “B”. That means, two levels of enhancement, meaning improvement from a satisfying efficient energy usage level to an almost very good level. So, with a certain consideration of the structure of a housing estate, a significantly good usage can be gained.

The remaining calculations did not bring any increase, so the end classification can be calculated with the respective weighting.

- Development costs per LU/year: level “G”
- CO_2 emission of traffic per LU/year: level “B”
- Quality of location and development: level “B”

With the improvement of CO_2 emission of traffic the area increases to level “D” which means that there is a satisfying energy efficient usage of resources.

Gemeinde: / Katastralgemeinde: / Projektname:	Dornbirn / Dornbirn / Variante 2	Bewertung	Gewichtung
Erschließungskosten je WE / Jahr*	2.223,45 €	G	0,40
CO_2-Emission Verkehr / WE / Jahr**	0,08 t	B	0,25
Qualität der Lage und Bebauung (Faktor)	2,86	B	0,35
Freiraumqualität (fließt nur in Wochenend-Verkehr ein)		C	0,00
Klassifizierung		**D**	1,00

* Mittelwert; Lebensdauer des Hauses = 100 Jahre
** Fahrten zum Arbeitsplatz nicht berücksichtigt
*** CO_2-Ausstoß wenn die gesamten Baulandreserven in Niederösterreiche mit den Kennzahlen des vorliegenden Projekts bebaut werden
**** Mehrkosten auf NÖ Gesamt im Gegensatz zur Bebeuung der gesamten Baulandreserven mit den Kennzahlen der Mustersiedlung

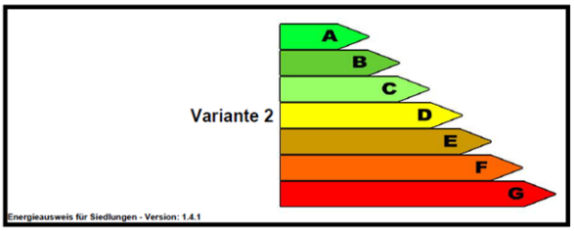


Fig. 4. Energy passes of alternative 2.

4. References

[1] European Strategic Energy Technology Plan (SET Plan) http://ec.europa.eu/energy/res/setplan/.
[2] A Technology Roadmap. SEC (2009) 1295. Brussels, 7.10.2009.
[3] European Industrial Initiatives (EII), 2008.
[4] Finalreport „Smart City: Terms, Characteristics’ und Examples”. Wien 2011/ Wiener Stadtwerke.
[5] Projectreport “Smart City fit for Set”. http://www.smartcities.at/netzwerke-2/das-smartcitiesnet-projekt/.
[6] http://www.stadtbekannt.at/de/wien/leben/wien-als-smart-city_.html.
[7] “Energy Certification of Communities”. Lower Austrian Land Government, Department of Spatial Planning and Regional Policy, http://www.energieausweis-siedlungen.at/.

SMART ENERGY DEMOnstration: First research results of an Austrian SMART CITY



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Short Summary

The small city of Hartberg wants to demonstrate a smart city within the Austrian promotion program “smart energy Demo”. By establishing a zero emission district at downtown of Hartberg with outstanding showcases of “green” technologies Hartberg turns the conditions of a small city into advantages to support an expansion to the surrounding. Based on a comprehensive bottom-up approach and a scientific / technical monitoring a balanced bundle of demonstrations are being implemented, that are linked to each other interdisciplinary (smart… buildings, municipal disposal, energy, communication, mobility, business-models). „SMART CITY Hartberg“ has already overcome several challenges to establish a small city of the future. Thus small cities show a significant potential for realizing a climate-protecting and sustainable environment.

Keywords: Smart city; demonstration; zero emission district; sustainability; energy.

1. Introduction

Cities cause currently 80% of the global greenhouse gas emissions, even though they account for only 2% of the global surface. In addition, the current world population development shows an increasing urbanization [1]. This fact is also true for Austria, whose cities will grow significantly until 2030 [2]. In the interdisciplinary and complex field of tension between quality of life, competitiveness and environmental protection therefore new, holistic approaches to the CITY OF THE FUTURE are required.
The small city of Hartberg (inhabitants: 11,000; area: 10 km²) faces the challenges as one of 6 Austrian SMART CITIES within the promotion program “smart energy Demo – fit for set”. [3] The district capital is a small sized town and by the the use of "green" technologies it wants to become CO_2 neutral. The urban area of and around Hartberg accumulates a mature, cohesive and compact area. Its characteristics are comparable with thousands of cities across Europe. By a comprehensive package of measures tailored and adapted to a small town a reproducible model region (small Smart City) should be established with a national impact. In particular, Hartbergers buildings provide innovative, meaningful demonstration possibilities of future urban development.
In opposition to major cities Hartberg has significantly different conditions to demonstrate a Smart City. There are differences in terms of sustainable transport solutions, energy policy for decentralized generation, the scale and complexity of demonstration opportunities, available resources (human, energy, financial, time, building, infrastructure, resources etc.), the process of participation of residents and stakeholders, the economic structures and the philosophy etc.. Additionally the vision of the city of Hartberg is is inspired and influenced by the cultural trend "Città Slow". This motion wants to improve the urban quality of life, while globalization and homogenization, which exist especially in larger cities, should be avoided. Thus other actions are necessary to encourage demonstrations and investments.

2. Objectives to establish a SMART CITY on small-town scale

The main objective of the project is the development and demonstration of a zero emission district at downtown of Hartberg (historic core zone) as highly frequented "heart" of small towns by outstanding showcases of “green” technologies. Thus Hartberg turns the conditions of a small city into advantages to support an expansion to the surrounding. Following demonstrations should be implemented:

- Smart Buildings / Smart Municipal Disposal:
  - (A) Establishment of an ideal new smart building complex for commercial & residential issues in a historical downtown area: highest efficiency, PV-integration (landmarked area), electricity storage, energy management, (re)utilisation of gray & rain water, e-mobility-infrastructure, city information system & carpooling.
  - (B) Renovation of the landmarked town-hall of Hartberg: Building automation, e-mobility-infrastructure to an ideal historical smart city building.
- Smart Energy(grids) - Establishment of a smart biomass-based district heating network in the project core zone:
  - (A) Load management / optimization / shifting to avoid grid enforcements.
  - (B) Providing of a smart monitoring for consumers.
  - (C) Optimization of consumption at the consumers (based on the monitoring data).
- Smart Communication and Information: Several information outdoor & indoor-terminals in the project core zone: Touch-screen-function, real-time-information (e. g. traffic & city news), integrated feedback-possibility, free WLAN, additional public utilization via internet & mobile phones, routing and communication, traffic guide to provide real-time information (e. g. congestions or news).
- Smart Mobility:
  - (A) Establishment of car sharing: At the new basement garage of project “Alleegasse”.
  - (B) Providing of an e-mobility infrastructure for bikes, scooters and cars: At the new basement garage and at the main square.
  - (C) Establishment of 3 Shared Spaces: Main-square, Alleegasse & pedestrian zone-end.
  - (D) Real-time-traffic information & optimization of carless transport chain from/to Hartberg.
  - (F) Demonstration of an ideal e-mobility-package for single-buildings (typical characteristic of small towns): e-mobility-garage with PV-roof, charging unit, electricity storage, energy management tool.
- Smart business-models for consumption & supply as well as a package for carpooling together with flat-sale.

3. Approach to establish a SMART CITY on small-town scale

(1) Technical feasibility study (incl. roadmaps and action plans) according to Hartberg’s vision have been established on a comprehensive bottom-up- & interdisciplinary approach with focus on all smart city topics (interdivisional: energy, building, mobility, communication, society):

- Basis for the project is a comprehensive participatory process to link local stakeholders, experts, the population, companies (more than 50) and organizations with the initative.
- By a holistic approach (> 200 exploratory and coordination meetings) numerous demonstration opportunities and activities in the areas of buildings, energy networks, mobility, and communication and information were identified.
- From more than 200 demonstration facilities a priority with regard to feasibility, ecological relevance, financing possibilities and relevance of the vision of the city have been evaluated. The highest ranked measures, that have a chance of being implemented within the next 3 years, were included in the Smart City project. By a multidisciplinary integrative orientation with respect to ALL Smart City themes (across divisions: energy, buildings,

mobility, economy, society, ...) a coordinated and balanced package of measures have been worked out. The projects intents to implement integrated demonstration (no individual solutions), which are particularly suitable for the small town of Hartberg.

(2) Implementation of more than 10 smart city relevant and connected demonstrations (incl. business models), that are very suitable / reproducible for small / comparable cities by addressing an integrated, balanced and adjusted bundle of realizable measurements (no single solutions);

On the basis of experience of the project team [4, 5, 6] an appropriate approach to the development / demonstration a Smart City project was developed (see figure 1):

- A revision loop was built, which consists of 5 steps, so that a steady but consistent optimization of the entire urban system can be guaranteed.
- All 5 steps, which are interrelated, are with a diverse and inclusive stakeholder process crossed (complete involvement / participation of residents and stakeholders).
- Steady monitoring, evaluation and improving measures (incl. repeating loop, steady optimization measures and heterogeneous & integrated stakeholder-process): With the aim to provide reproducible results for small towns a monitoring and evaluation are accompanying the demonstration project.
- Accompanying research activities (technical, social and economic orientated);
- A comprehensive communication / dissemination of multipliable results / findings is performed.
- Finally, also preparations are made for the continuation of the Smart City activities after the project end. The goal of a CO_2-neutral Smart City will be followed after the project period.

The approach of Smart City Hartberg does not aim to develop components and individual solutions, but the high degree of innovation is given by the intelligent, holistic and complex linkage of almost mature technologies and systems.

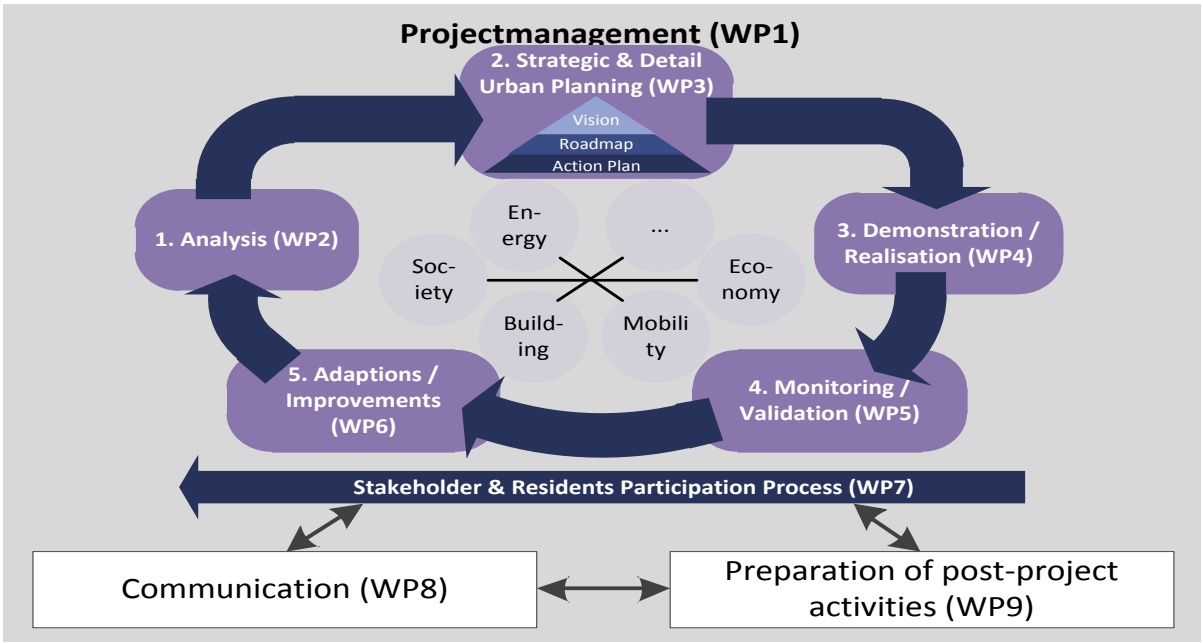


Fig. 1: Methodological approach for demonstrating the SMART CITY Hartberg

4. Factors of success to establish a SMART CITY on small-town scale

4.1 Project development: Creating Hartberg`s vision

Starting point for all Smart City activities was the "Città Slow" vision of Hartberg, which was developed through a comprehensive participation process with the full integration of the population, experts and politicians to build Hartberg`s vision of 2050 (see figure 2). [7]



Fig. 2: Vision of SMART CITY Hartberg 2050

The vision building process of Hartberg can be identified as one of the key factors of success, because it supported the comprehensive "Smart City" project (public, politicians, decision makers, stakeholders, associations, government agencies, business, and especially by a unanimous vote of the Municipal Council for the vision), and it was the basis for a successful Living Lab approach.

4.2 The Living Lab approach of SMART CITY HARTBERG

Behind the concept of Living Lab SMART CITY HARTBERG there is an innovative approach that shifts the development of innovative products from the laboratory to the real world. In particular, the (potential) users can express their opinions on new ideas as early as possible or try out first test applications in their everyday life. But also representatives of other groups (energy suppliers, component suppliers, planners, municipality / agencies, R&D facilities etc.) play a role. They are involved actively in the development process and give a feedback about the product quality, equipment and conditions. In this way, costly mistakes could be prevented and the user friendliness of products is increased. The innovativeness of the project Smart City Hartberg need not only be provided from the consortium, but the innovation aspect is generated through the creation of a diverse and inclusive environment from the interaction of people with different interests, perspectives and knowledge. These conditions are guaranteed by the Living Lab SMART CITY HARTBERG and thus increase the probability of the emergence of new, application-oriented solutions. Living Lab SMART CITY HARTBERG therefore promotes an intensive participation (especially for ongoing feedback), which can be used in addition to the participation in workshops and the new ICT media (internet, apps, Facebook etc.) to allow the inclusion of different actors and to bundle the communication (through e-participation).

4.3 Convert small-town features / challenge into advantages

As mentioned in section 1, in small towns exist differences for sustainable urban policy as in bigger cities. Small-town characteristics should therefore be transformed into a success factor:

- The close to the people provide an intensive participation process, leading to a broad support and project-related volunteer work. The available human resources have to be activated in other ways.
- The combination of ALL Smart City topics due to lower complexity and less effort is easier possible. A holistic view of the urban and (energy) system is supported.
- Project management is more efficient and flexible.
- In relation to the city size a large / wide consortia is possible through personal contacts. Optimally coordinated expertise and project partners can be implemented more easily.
- A decentralized energy supply policy is easier to implement, because there are more "open spaces" for solar use available in relation to the energy demand. Further a close relationship with the surrounding region for the biomass supply can be provided.
- Through the buttom-up approach appropriate targets for the region and measures can be defined. Mistakes can be avoided. This also affects the awareness positive.
- The economic structures have a significant impact on urban development and must be optimally integrated into a smart city theme. Therefore Smart City Hartberg binds several regional local companies in the project. At the same time a regional value is achieved.
- Small towns are financially weaker than bigger cities. In order for a secure financing partnerships are necessary. This was realized in Hartberg for the capital-intensive investment (EUR> 14 million), in particular through a public-private partnership (PPP) model.
- In small towns customized business models need to be implemented that address the specifics (e.g.: How the return of investment can be achieved with fewer inhabitants?). Therefore, different business models are developed and implemented within Smart City Hartberg, which are ideally suited for this city sizes.
- Pre-commercial Procurement: The project does not address the entire city area of Hartberg. Thus it is intended that the sustainable urban development goals are carried out in the downtown area through selected demonstrations (see Figure 3). This should support the spread to the surrounding region. This is achieved through pre-commercial procurement by the public sector that operates in the downtown area as a climate-and energy-conscious seller / investor of green / innovative technologies.

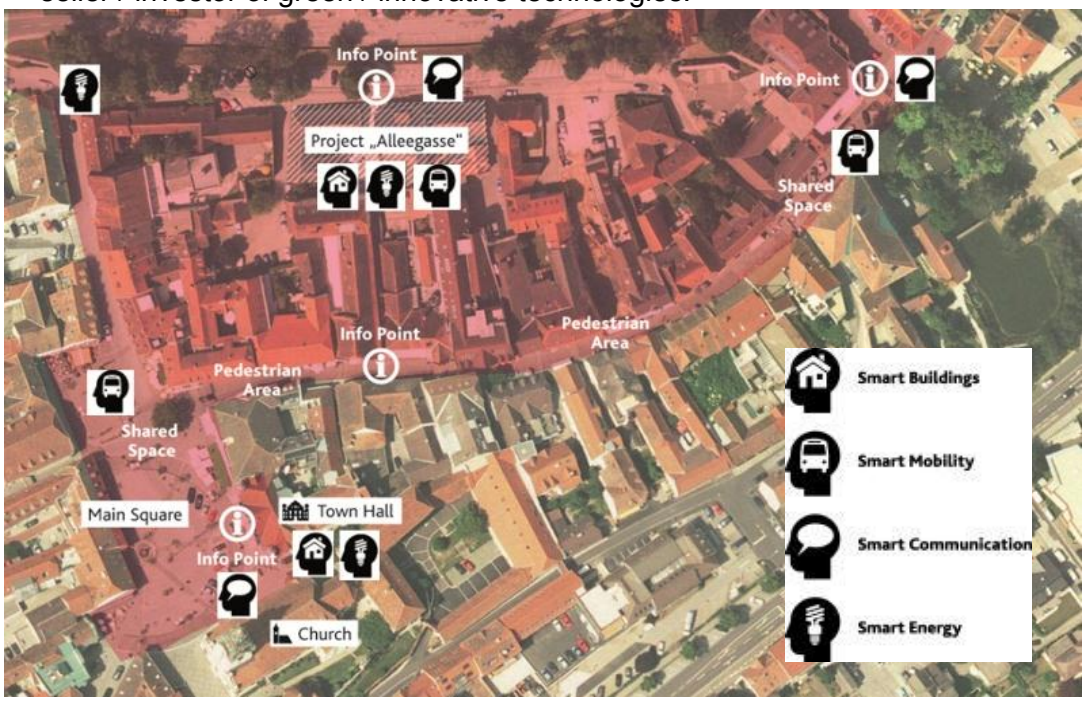


Fig. 3: Planned SMART CITY-demonstrations in downtown of Hartberg

Summing up a small town has many (other) degrees of freedom for sustainable urban policy. However, nodes must be found, which makes the complex Smart City-topic detectable for all. In Hartberg, this was done on the building sector, with an optimal interleaving of all other Smart City-topics.

4.4 Buildings as central “Smart City”-hub

In the building sector Smart City Hartberg has an energy-related orientation: About highest energy efficiency, renewable distributed generation from photovoltaics and a building-wide energy management for electricity, heating and cooling (central management, building automation, storage technologies, load shifting etc.). However, the buildings are also hubs of the Smart City-philosophy by linking all topics to each other. Thus demonstrations are integrative and visible:

- Implementation of an electric vehicle infrastructure in selected buildings;
- Implementation of a smart city-interactive information system (e.g. at the entrance to authorities, shops, offices or houses);
- Real-time information on energy consumption, CO_2-emissions, awareness raising, public transport (e.g. via the City Bus), car sharing points, e-vehicles-rental stations etc. in selected objects;
- Integration of a user feedback over the building infrastructure;
- Implementation of a flagship building, that is optimally integrated into the historic city area (on a PPP model);
- Demonstration of an intelligent and efficient landmarked building (City Hall);
- Implementation of business models in real estate (such as a sale of an apartment together with a car-sharing-utilisation).

With the term "Smart City" Hartberg therefore understands the coordinated linking of sustainable mobility technologies and flexible forms of suitable business models, which will lead over the nodal points of the building to a high quality of life.

5. Conclusions

Small towns have a great potential for implementing a climate protective and sustainable environment. However, this activation requires overcoming many challenges. The first results of the small smart city of Hartberg have shown, that it was worth to identify the city`s characteristics and to turn them into an advantage.

The earlier project development stage (establishment of the feasibility study) was much more time-consuming as proposed, because the comprehensive bottom-up approach involved more than 200 meetings. This has been resulting in a very high motivation of the stakeholders.

The close contact to the citizens and stakeholders in all project stages supports an ideal living lab approach (“user in the loop” & e-participation), whereas a balanced bundle of demonstrations could have been worked out for the demonstration stage.

The users and the quality of life have always been in the focus by a Living Lab approach. In this context an intensive preparation and coordination is necessary. The comprehensive bottom-up participatory process has been one of the key factors of success of this project phase.

Also a strong commitment of the city (government) is necessary, because the goal of a CO_2-neutral smart city must also be followed after the project period.

For the realization of sustainable urban development, it is advantageous if visible nodes are created via flagship projects. These has happened in the building sector, where all issues of sustainable urban development have been linked to each other (energy, buildings, mobility, economy, society, ...).

It has been advantageable for Smart City Hartberg not to pursue the development of new components and individual solutions. Thus Hartberg does not follow the implementation of single, but linked solutions. Hence compared to major cities several more topics and integrated demonstrations could have been addressed. But the project focuses on a smart and holistic

combination of almost mature technologies and systems. This approach is very complex / innovative and would otherwise be very risky.
For several investments the city of Hartberg acts as pre-commercial procurer. By these public pre-investments several private investors could have been encouraged to spend their money in smart city relevant projects. Thus a strong (financial) commitment of the city government enables leverage effects for private investments even in smaller cities (despite fewer economic growth potential than in bigger cities).
SMART CITY Hartberg enables smart demonstrations of sustainable urban development based on a Living Lab in a small urban area. It will create references for Austrian companies, provides experiences and recommendations for actions in the field of sustainable town development and provided extensive dissemination activities for multiplying the results.
Small cities show a significant potential for realizing a climate-protecting / sustainable environment. The activation needs to overcome several challenges that are different to major cities. „SMART CITY Hartberg“ has already overcome these challenges to establish a small city of the future.

6. Project key data

Table 1: Project key data of “Smart City Hartberg

Start, Duration	01/09/2012, 36 months
Projectvolume	Ca. 1.3 Mio EUR
Projectmanagement	4ward Energy Research GmbH, Alois Kraussler
Applicant	City of Hartberg
Consortium	Stadtwerke Hartberg Verwaltungs GmbH
	Eaton Industries (Austria) GmbH
	KELAG Wärme GmbH
	Forschungsgesellschaft Mobilität GmbH
	Inter-University Research Centre for Technology, Work and Culture (IFZ)
	DICUBE MEDIA GmbH
	HSI Hartberg Standortentwicklung und Immobilien GmbH
	B.I.M. – Beratung und Informationsverarbeitung im Mobilitätsbereich
Website	www.smartcities.at

7. Acknowledgement

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8. References

[1] WUPPERTAL INSTITUTE FOR CLIMATE, ENVIRONMENT, ENERGY. *Sustainable Urban Infrastructure, London Edition – a view to 2025*. Research work for Siemens AG Corporate Communications, Wuppertal, Germany, 2008.

[2] UNITED NATIONS. *World Urbanization Prospects - The 2007 Revision*. Department of Economic and Social Affairs - Population Division. New York / USA , 2008.

[3] AUSTRIAN CLIMATE AND ENERGY FUND. *Smart Energy Demo*. Funding Promotion Programme. http://www.smartcities.at/foerderung-2/. Vienna, 2013

[4] NINAUS J, HEIDENREICH M, KRAUSSLER A, PINTER C, POSCH G, THEISSING M, THEISSING-BRAUHART I, TRAGNER M. *“Energiekonzept Ökoregion Kaindorf”.* Final project report within the scope of the Austrian research programme „Energy of tomorrow “ of the Austrian Federal Ministry for Transport, Innovation and Technology. Kapfenberg / Austria 2010

[5] TAUSZ K, KRAUSSLER A, SCHLOFFER M, THEIßING M, TRAGNER M, ZAWICHOWSKI M. *”Regionale Energiebereitstellung und effizienter zwischenbetrieblicher Energieaustausch in der Region Krems - Optimierte Energiestrukturen ausgewählter Industriebetriebe, Vernetzung industrieller und regionaler Energiestruktur im Raum Krems”*. Final project report

within the scope of the Austrian research programme „Energy of tomorrow “ of the Austrian Federal Ministry for Transport, Innovation and Technology, Kapfenberg / Austria 2010

[6] TRAGNER M, KRAUSSLER A, SCHLOFFER M, SCHUSTER D, THEISSING M, THEISSING-BRAUHART I. *“Regenerative Energieversorgung einer Industrieregion: Chancen – Potenziale – Grenzen“*. Final project report within the scope of the Austrian research programme „Energiesysteme der Zukunft“, Kapfenberg / Austria 2007

[7] KRAUSSLER A, SCHULLER A. *„Città Slow Hartberg meets Smart City“*. Final project report within the scope of the Austrian research programme „Smart Energy Demo – FIT for SET 1. call“ of the Austrian Federal Ministry for Transport, Innovation and Technology, Hartberg / Austria 2012.

C3

Smart Cities

Chair: Annette Aumann
City of Zurich, Switzerland

KomMod as a tool to support municipalities on their way to becoming Smart Energy Cities



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Short Summary

For the upcoming transition of the energy system towards higher shares of renewable energies, the municipalities should be provided with a sound basis of information, scientifically supporting their decisions and aiming at overall optimal solutions. KomMod as a holistic high-resolution municipal energy system model offers such an analysis and the resulting strategic recommendations for a detailed and cost-effective future energy system of a municipality, thus helping to pave the way for future “Smart Cities”.

Keywords: Smart Energy Cities; KomMod; energy system model; municipality; mathematical optimisation

1. Introduction

Worldwide climate change mitigation is meanwhile seen as one of the most urgent and important challenges to humanity. This is most evident in cities in which as of approximately 2007 an ever increasing proportion of the world's population now resides and where correspondently most of the world's greenhouse gas emissions and energy consumption is concentrated. As this development is predicted to continue, the term “Smart City” has to have a special focus on energy if we want to tackle climate change [1].
Additionally, from a German perspective, cities also play a major role in the so-called Energiewende, or energy transition, that is, the transformation of the energy system from fossil and nuclear to renewable energy sources. While some of the required adaptions have to take place on a national level, many measures have to be implemented locally, for example, the energetic refurbishment of buildings, the installation of renewable energy based supply technologies as well as of new infrastructure for district heating and cooling.
Accordingly, many municipalities in Europe have recognised the resulting need for a significant reduction of their green house gas emissions as well as their energy consumption and have already taken on responsibility by setting themselves the relevant goals, for instance by joining initiatives like ICLEI or the Covenant of Mayors [2, 3]. These municipalities, willing to actively steer the transformation process of their energy systems, typically follow a pathway of three steps. First, an analysis of key indicators of their energy systems is carried out, and the municipalities commit themselves to climate goals. Secondly, the identification of possible measures for green house gas reduction and energy saving is done by studies on their building stock, on the reduction potentials of their energy consumption and the renewable energy potentials on their territory. And third, based on the first two steps, a refined specification of the municipal climate goals, together with a

roadmap of concrete measures to be taken to reach this target energy system, has to be developed. Besides social and political aspects which have to be taken into account, the roadmap is often developed under the premise of being cost-effective. The time horizon of such a roadmap involves decades and therefore has to be seen as an evolutionary process where the individual steps have to be evaluated and changed if and when necessary.
For the first two steps of the pathway shown, an annual analysis of energy flows, regarding demand and supply, local renewable energy potentials and so on, is usually sufficient. This means that the relevant studies are mostly based on annual cumulated amounts of energy instead of time series of demand and supply. Interdependencies between technologies as well as between the different energy sectors, electricity, heat/cold, gas, and transport, therefore are not yet taken into consideration. In contrast, at the latest for the third step, an in-depth analysis of the municipal energy system is needed, regarding time series and taking these interdependencies into account.
The energy system model, KomMod, described in the following and currently developed at the Fraunhofer ISE, delivers such an analysis and the resulting strategic recommendation for a detailed and cost-effective future energy system of a municipality, thus helping to pave the way for future “Smart Cities”.

2. Methodological Approach – The municipal energy system model KomMod

The development of KomMod is structured into three main tasks: analysis of the requirements of a municipal energy system model, comparison of the requirements with existing models, and creation of an energy system model, either based on an existing solution or by starting from scratch, that fulfils all needs.

2.1 Identified requirements

The future development of a municipal energy system is influenced by many parties forming a municipal community, among them, the municipal governance, (local) utilities, local industry, trade and commerce, citizens and other stakeholders.
The energy system model, KomMod, in the first place aims to address the needs of and find optimal solutions for this community as a whole and therefore takes a macroeconomic perspective. Accordingly the resulting solutions and recommendations are expected to differ from optimal solutions found for individual companies or groups of interest. The key questions from this perspective are what the future energy system should look like in detail and which measures ought to be taken to support the municipal goals best. To answer these questions, several fundamental aspects have to be taken into account.

As it is well-recognised that future energy systems will contain a high share of fluctuating renewable energies, an in depth-analysis has to be done in a high temporal resolution to make sure the energy supply is guaranteed at all times. A simplified calculation based on annual cumulated amounts of energy could, in contrast, lead to undetected temporal surpluses and shortfalls.
The same applies to spatial resolution. An aggregation of all data to a single spot would miscalculate the real conditions in certain situations. A solar thermal system on a building, for example, may provide excess heat during summer. Neglecting a spatial resolution, this heat could cover the neighbour's need for hot water too, even if there isn't any physical connection (piping) between the two buildings.

Another major aspect to be considered are interdependencies. This relates to cross-sectoral interdependencies between all four demand sectors, namely electricity, heat/cold, natural gas, and (local) transport, as well as to different technologies within a sector. Examples for cross-sectoral dependencies are combined heat and power plants (CHP), heat pumps (driven by gas or electrically), electric cars, and rooftop areas used for either photovoltaics or solar thermal installations. Intra-sectoral dependencies occur when for instance the specific CO2 emissions of a building could be reduced by insulation, by connection to a district heating network or by use of solar thermal energy.

Other kinds of dependencies, which also have to be considered, occur between structure (design) and operation of the components of an energy system. Below is a simple example of this.
Within a system consisting of a small thermal power plant run on biomass, a wind turbine and an electrical storage, times of little wind could be covered either by extended operation of the thermal power plant, an enlarged storage or additional wind turbine capacity. In each case, both structure and operation of the components would be affected by the decision, for example, that an enlarged storage may lead to a better utilisation of the wind conditions and therefore reduce the full load hours of the thermal power plant. For this reason it is necessary or at least useful to optimise structure (design) and operation simultaneously when dealing with strategic decisions.
Even in the above-mentioned very simple example, several solutions exist which might be equivalent or similar regarding technical criteria. It is very likely though, that they differ in cost as wind turbines and storages have higher specific investment costs than a thermal power plant, while the latter is much more costly during operation. Thus it is obvious that interdependencies between technical and economical aspects should be integrated into the calculations.

Against this background and regarding the complexity of the overall municipal energy system, a holistic energy system tool is needed which enables municipalities and other stakeholders to make decisions on a sound basis of information. The resulting future energy system and the roadmap to get there have to be specific to the municipality, offering an effective solution to reach their climate goals in a cost-effective way and taking the specific local circumstances into account, like building stock or local renewable energy potential.
An overview of a possible future municipal energy system including all of the above-mentioned demand sectors, interdependencies and a fundamental spatial structure is given by figure Fig. 1. As shown in the scheme, it can be useful to extend the system borders to the surroundings of a municipality to integrate agricultural areas as well as sites for wind turbines or large photovoltaic systems.

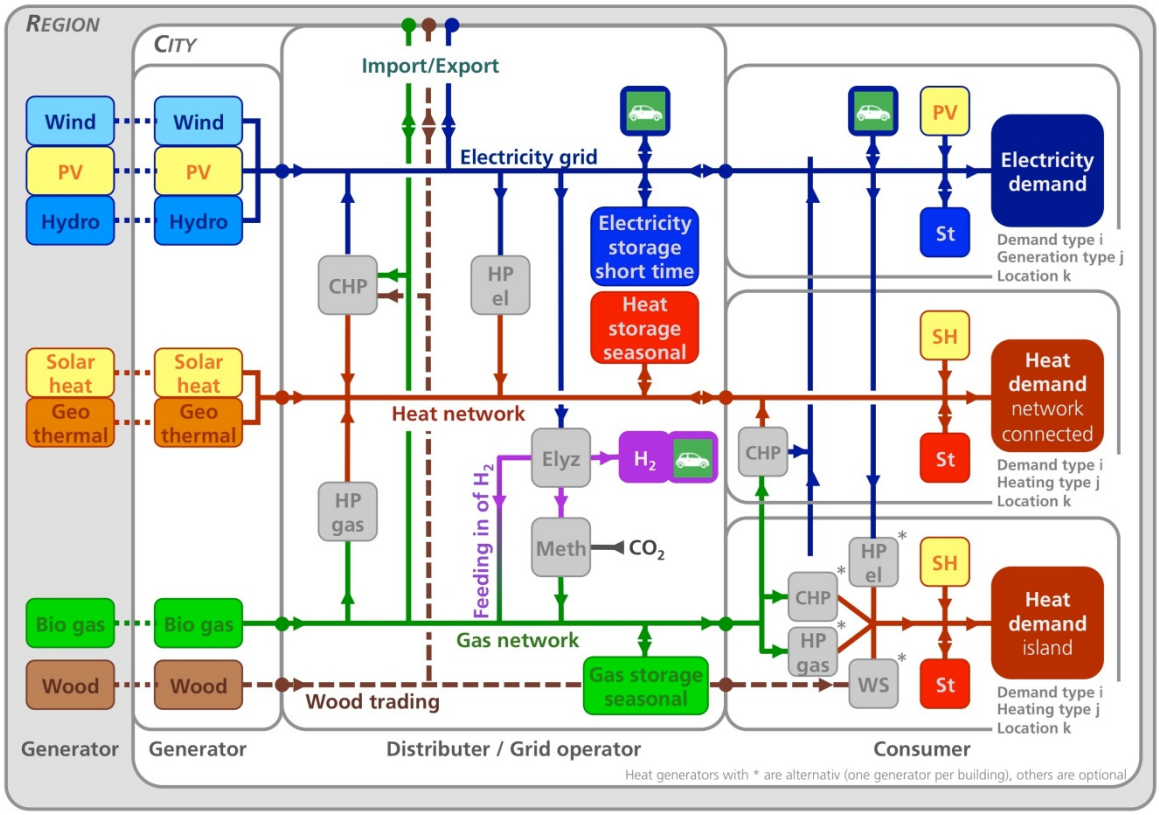


Fig. 1: Scheme of a municipal energy system based on renewable energies HP el/Gas = Heat pump electric / Gas driven, CHP = Combined Heat and Power, WS = Wood Stove, St = Storage, SH = Solar Heat, Elyz = Elektrolyzer, Meth = Methanation [4]

2.2 Analysis of existing energy system models

Over time many different energy system models have already been developed [5, 6, 7, 8]. Hence, it seemed reasonable to first take a look at existing models before starting from scratch. Complementary to the requirements described above with regards to content, the model has to fulfil several criteria with respect to flexibility and access, convenience, and stability. Crucial to the Fraunhofer ISE as a scientific institute is the ability to have almost complete access to every detail of the model, for example, to be able to adapt the model to future developments. This refers to the structure, the components included in the libraries, temporal and spatial resolution, and more. For the sake of convenience, the existence of component libraries (buildings, power plants, heaters) and a graphical user interface are desirable. More important though, is the computational power and robustness of the included mathematical solvers. A high developmental stage and the widespread use of the software therefore are wishful. Last but not least, licensing terms, including the right to change and distribute the model, and fees are of particular importance.

A comparison of the design specifications with existing models showed that none of them covers all of the identified needs. There are three main reasons for this discrepancy. The first reason is a deviation in scope. Many models are designed to deal with national or even the European energy system, hence the technical, temporal, and spatial resolution is, due to computational limitations, cruder than needed for a municipal dimension. The second reason is a restriction to only one or two of the above-mentioned four demand sectors, again often due to computational limitations. The third reason involves licencing issues and the resulting lack of publicly available documentation of models. As a result, it is hard to evaluate if any existing model does indeed cover the needs of or could be adapted to specific municipal requirements, and it is precisely for this reason that the Fraunhofer ISE initiated the development of an energy system model tailored specifically for the needs of a municipality.

3. KomMod – Design specifications

3.1 Holistic approach

KomMod is designed as a holistic and comprehensive energy system model to specifically fulfil the needs of municipal energy system analysis and optimisation. It is meant to serve as a tool for structural analysis and optimisation enabling strategic decisions from a holistic municipal community perspective. Technical as well as economical constraints are taken into account, covering the demand sectors, electricity, gas, and heat and in the near future also transport. The goal is to integrate most interdependencies between these sectors as well as between system design and operation into the model. KomMod therefore is built with a homogeneous modelling approach, implementing all components with the same modelling environment and including the optimisation of system design and operation into one simultaneously solved equation system. As a modelling environment, AMPL is used in combination with the mathematical solvers Gurobi and Conopt [9, 10].
Operation optimisation in this context relates to the derivation of general operation strategies for every component to best serve the needs of the whole system. The result for a certain component therefore may change if the rest of the system changes. This perspective is different from the optimisation that utilities do for their daily power plant operation, looking at only their own power plant portfolio. It also has to be distinguished from short term optimisation of forecasting and control where uncertainty, for example, of the prospected demand, weather conditions or market behaviour, plays a major role.

3.2 Perfect foresight and dynamic optimisation

Due to the strategic objective, the model is provided with perfect foresight over the whole time horizon of the optimisation. All input data therefore has to be available to the model at the beginning of an optimisation run, enabling the model to dynamically optimise over the whole time horizon simultaneously. Dynamic here refers to the fact that the requirements of future time steps are already taken into account for decisions regarding the current time step. This method is also commonly used for optimisation in real life environments, but with a much shorter time horizon due

to uncertainty. Dynamic in this context is different from the meaning within control theory – a field which KomMod doesn't aim for.
As the short term dynamics of the system components are not in the scope of KomMod either, every time step is seen as a point of steady-state operation. Limitations on a macroscopic scale, resulting from system dynamics, have to be taken into account, of course. Accordingly the component models include part-load efficiencies, load acceptance rates, minimal charging levels (reducing the net capacity of a storage) and self-discharge of storages for example. Some important properties, like minimal downtime, minimal run-time, and ramp-up time are still to be included in the model. Technologies are grouped into components of similar physical behaviour which can be described with identical equations. The equations within the component for combined heat and power (CHP) plants, for example, describe a CHP plant on a household level as well as a 800 MW hard coal power plant. The differences between the elements of a technology are expressed by a change in the parameter sets. As KomMod is built modular, any component model could be easily replaced by a more precise one if a specific technology should be examined in the system context in more detail later on.

3.3 Temporal and spatial resolution

The temporal resolution is set to an averaging period of one hour, intended to be reduced to 15 minutes. The range of 60 to 15 minute time steps provides a reasonable balance between the availability of data and the computational performance on the one hand, and the ability to cover times of shading due to passing cloud fields or times of wind calm on the other. Gusts of wind and single clouds won't be captured on a 15 minutes time interval though. While these have a huge impact on mechanical and electrical loads respectively, as well as on control engineering, their influence is negligible from an energetic point of view. The time interval chosen enables KomMod to provide answers to questions with respect to the amount and operation of short term storage.

Spatially the model is divided into zones, sub-zones, and building types. The size and the shape of the zones and sub-zones are adjustable to the specific needs of every municipality. A building type represents the smallest energy subsystem within the model. It is derived by grouping several different buildings with similar properties, such as the type of building (single family house, high-rise building), its age and heating demand, to one category thus allowing for a balance between detail and the amount of data [11]. With this concept of different levels of spatial aggregation it is possible to define interfaces at several levels which are of practical importance, as explained below.

On every level, from zones to building types, the energy balance for all three sectors (electricity, heat, and gas) currently included, has to be fulfilled for each time step. Except for the heating demand of buildings, KomMod expects the demand side to be given as input data, which therefore is fixed. The energy balance on every level has to be fulfilled accordingly on the supply side by either internal production or by import and export. KomMod allows import and export between the different spatial levels as well as an exchange within a level. To keep transfer routes short the direct exchange within a level is preferred.
The boundary of a building type is also interesting from a legal aspect as it is the interface between the house owner and the utility company. As KomMod calculates the time series at this boundary for every sector, it can provide utilities or grid operators with information about structural changes in the demand patterns if, for example, the share of photovoltaics or micro-CHP plants would increase in the future.
Sub-zones can be used to distinguish an area that differs in at least one property from the rest of the zone but still for some reason belongs to that zone. This could be the case when the sub-zone is a potential extension area for a district heating network which already exists in the rest of the zone. Here again, KomMod calculates load patterns and annual energy demand, also at the interface between the existing network and the potential extension, thus delivering key indicators for a utility provider or grid operator to decide pro or contra the extension.

3.4 Dealing with stochastic effects and uncertainty

KomMod is designed as a deterministic mathematical model. The underlying equations, transferring input into output data, don't contain any stochastic elements, and identical input parameters therefore will lead to the same results (there might be a deviation if several equal optima exist or if equations become non-linear and the model gets stuck in different local optima). The known and fixed relations between input and output facilitates troubleshooting of the model if necessary. It offers the possibility to reproduce calculations and, compared to a model containing stochastic elements, makes it easier to understand the overall relations between input parameters and the resulting output. In an optimal case this would lead to a better general understanding of the whole system as underlying general principles could be recognised.
KomMod aims at real world problems and even if it is a deterministic model, it cannot be ignored that uncertainty occurs in real life all the time and in different ways, and this must therefore be incorporated into the model where possible. Examples are stochastic effects like prediction uncertainties in terms of both demand and supply, in user behaviour, wind speed, and solar irradiance. Other sources of uncertainty derive from measurement errors, such as a lack of knowledge, insufficient or missing diagnostic options, and social aspects. While some measures dealing with uncertainty can be integrated within the pre-processing of KomMod or handled by scenario calculations and parameter variation, others are out of scope. According to the strategic focus of KomMod it is provided with real data but not online data.

3.5 Input data

Several input data for both the demand and supply side of each sector is required to enable the model to start with calculations. Above all, the technologies and resources which are available at a specific location have to be defined. Thus far, solar thermal systems and photovoltaics, wind turbines, combined heat and power plants run on fossil and renewable fuels, electrical and thermal storages, and different boilers are implemented in the model. Heat pumps and water power, inter alia, will follow.
For every supply technology to be included in the calculations limitations on fuel resources, for renewable energies mainly due to limited available surface areas, have to be given. Often this is coupled with administrative decisions regarding land use planning and other regulations. This applies to rural areas and agricultural ground as well as to development areas where it could be determined that for new buildings a certain amount of solar thermal systems or photovoltaics installed on the roof is mandatory. Information about the existing infrastructure, like power plants, district heating networks and the building stock, also has to be entered into the model.
Furthermore time series for weather data, solar irradiation, wind speed, and ambient temperature has to be known on the supply side. On the demand side the current demand for electricity and process heat has to be given, while the heating demand of every building type is calculated based on the ambient temperature and the irradiation at every time step.
In addition to the technical and energy-related limitations described above, economical values also have to be set. This includes interest rates, an average inflation rate, several specific costs for all technology included, existing and possible extensions of district heating networks, power plants and other infrastructures, as well as the refurbishment of every building type.

3.6 Output data

As KomMod optimises design and operation of every technology included simultaneously, it delivers recommendations for the capacity and number of facilities to be installed, as well as the relevant time series for these operations. Each facility is displayed with its location, its land requirements, its investment and operation costs. For all building types the best supply option for heat and the optimal refurbishment rate is calculated, leading to conclusions about extensions of district heating networks, if available. In combination with the expertise of the user, strategic recommendations for municipal stakeholders are a major outcome.

4. KomMod – First results, discussion and conclusions

Within this section first results will be presented serving as examples to show the practical relevance of the criteria catalogue and the soundness of the course of development described above. The underlying data is drawn from real measurements and technical specifications, but it is not consistent and doesn't belong to one single real site. Accordingly the results shall only be used to check the relevance of the formulated requirements and the compliance of these requirements with the model, but not to draw additional conclusions especially with regard to decisions in a real life environment. For this reason only a graphical analysis without underlying data will be presented. It should be emphasised that different and consistent data might lead to severe changes, for example, concerning the relevance of different technologies or their operation.

4.1 Temporal and spatial resolution

The figures Fig. 2 to Fig. 5 with an hourly resolution show clearly the well known diurnal variations particularly of electric demand and insolation. Besides the huge difference in the absolute values of the heating demand between winter and spring, these curves clearly show at a glance that temporal resolutions of one year and even down to a daily basis are too rough to analyse demand, fluctuating energies, and storages in depth, leading to a severe underestimation of the needed installed capacity and the negligence of interdependencies.

While it might be sufficient to represent the electric grid with a single node in many cases it is obvious that the results fail for the heat sector as figure Fig. 3 demonstrates. The different heating technologies and fuels are used in the order of their specific cost. Under the given circumstances this means that the CHP plant and the gas boilers are run constantly at full load and the solar thermal installations provide as much heat as possible. Only the load of the oil boilers is actively varied to cover the residual load. As already explained earlier this would only be possible if all suppliers and consumers were connected to a single district heating network. Hence the next step in model development is the integration of spatial disaggregation together with building types and district heating networks.

4.2 Interdependencies

Comparing the figures for electricity and heat in spring (Fig. 4, Fig. 5), the necessity to integrate inter-sectoral interdependencies becomes obvious. For the CHP plant it shows that the shape of electricity and heat supply curves is identical, implying that a certain amount of the one comes with a fixed amount of the other simultaneously. While for larger plants this ratio can be influenced and production can be shifted towards one side or the other within certain limits, the operating hours are strictly coupled. This can be seen around the 3120th and 3240th hour, when the CHP plant is switched off despite a need for heat supply which then is covered by the gas boiler. Looking only at the heat figure this doesn't seem plausible as, in the model, heat from the gas boiler is more expensive than that from the CHP plant. In combination with the electricity figure it can be seen that the model chose to operate the CHP plant electricity-led during that particular period and hence it can be concluded that electricity taken from the storage must be cheaper than that from the CHP plant and that the overall savings in cost on the electric side outweigh the additional expenses on the heat side. Accordingly, the operation of the different technologies changes if the fuel costs of the CHP plant are set to lower values. In this case, which is not shown in the figures, the CHP plant would be preferable also at the electric side at least at times around the 3120th hour and the operation of the CHP plant would swap from electricity-led to heat-led. It should be underlined that it is not predetermined in the model whether the operation of the CHP plant is electricity-led or heat-led, it could even change from time step to time step within one optimisation run. These reflections also show that technical and economical aspects have to be examined concurrently.
Similar changes in operation, as when changing the specific costs, also occur when changing the restrictions on the resource potentials. This means that changing the restrictions doesn't only affect the installed capacity of the technologies as is obvious when reaching the limits but also might change their operation widely at the same time. For this reason it is important to simultaneously optimise both aspects, structure and control.

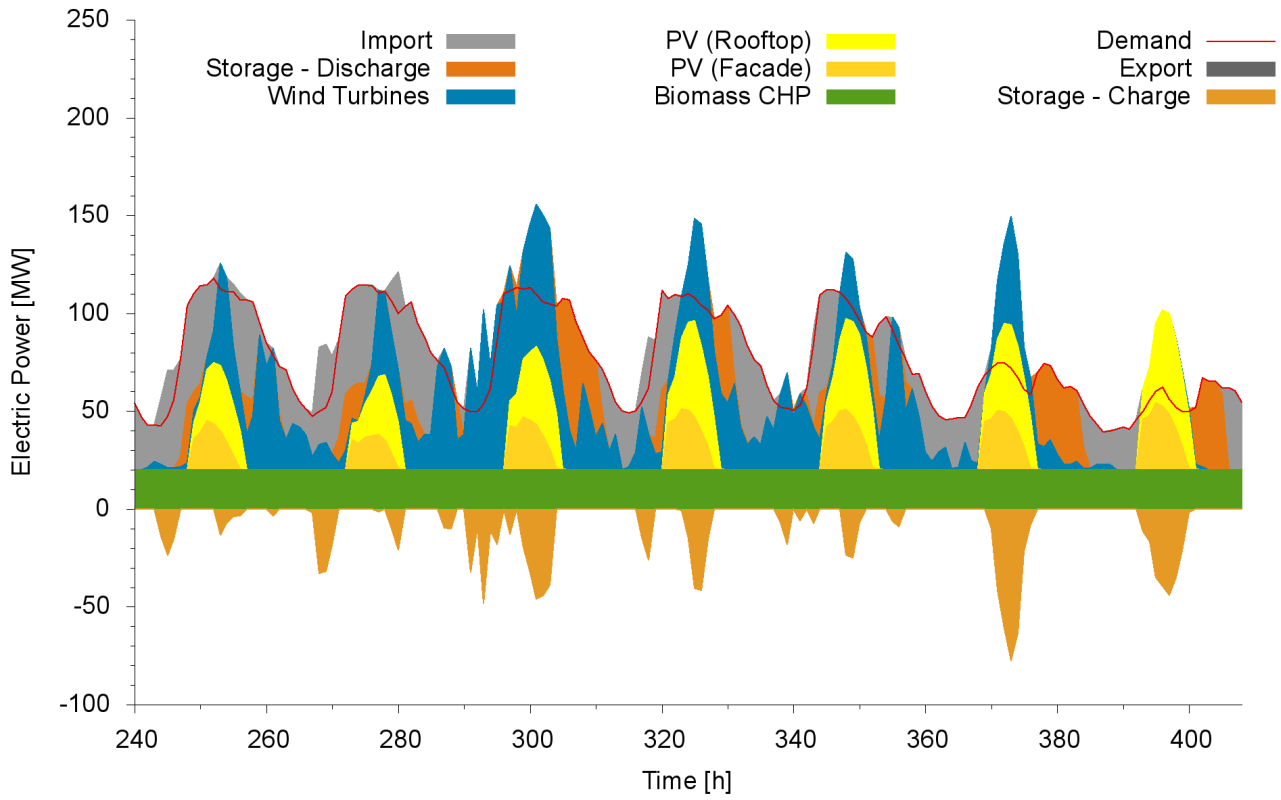


Fig. 2: Electricity demand and supply for one week in winter

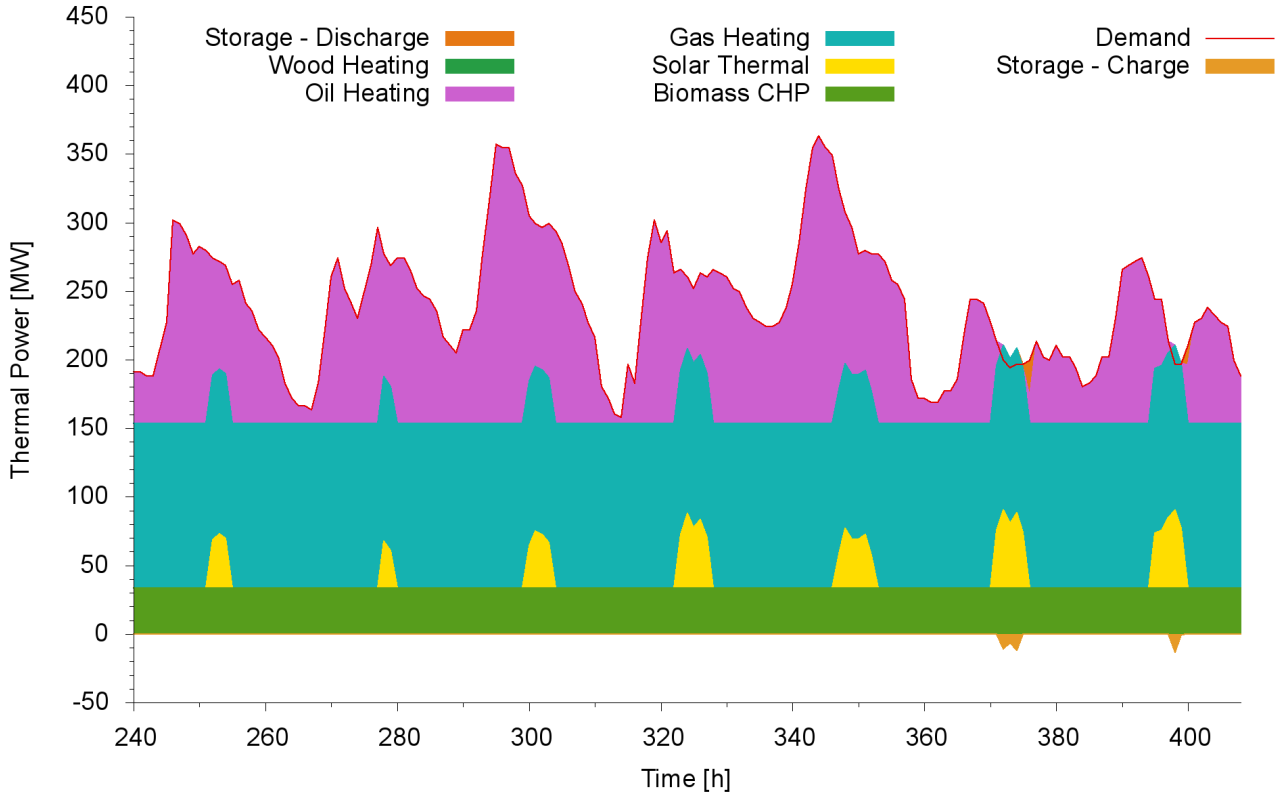


Fig. 3: Heat demand and supply for one week in winter

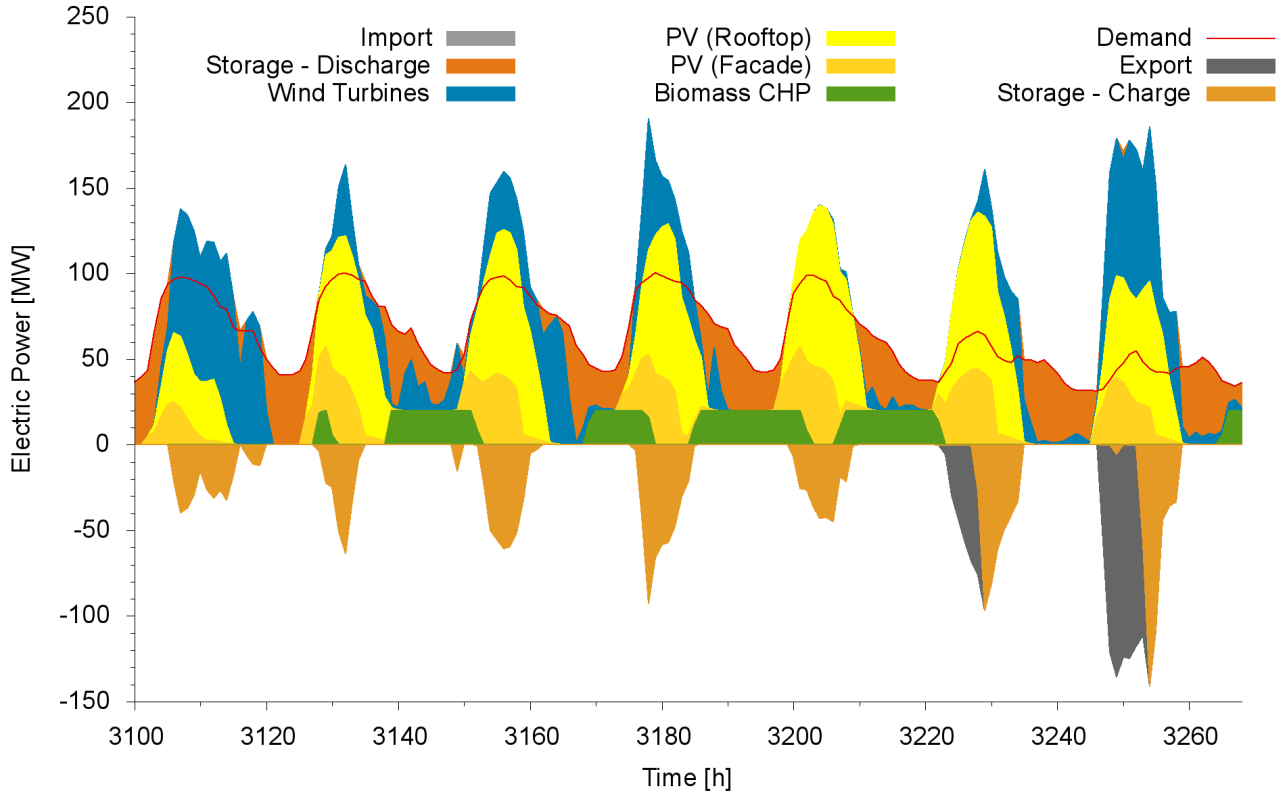


Fig. 4: Electricity demand and supply for one week in spring

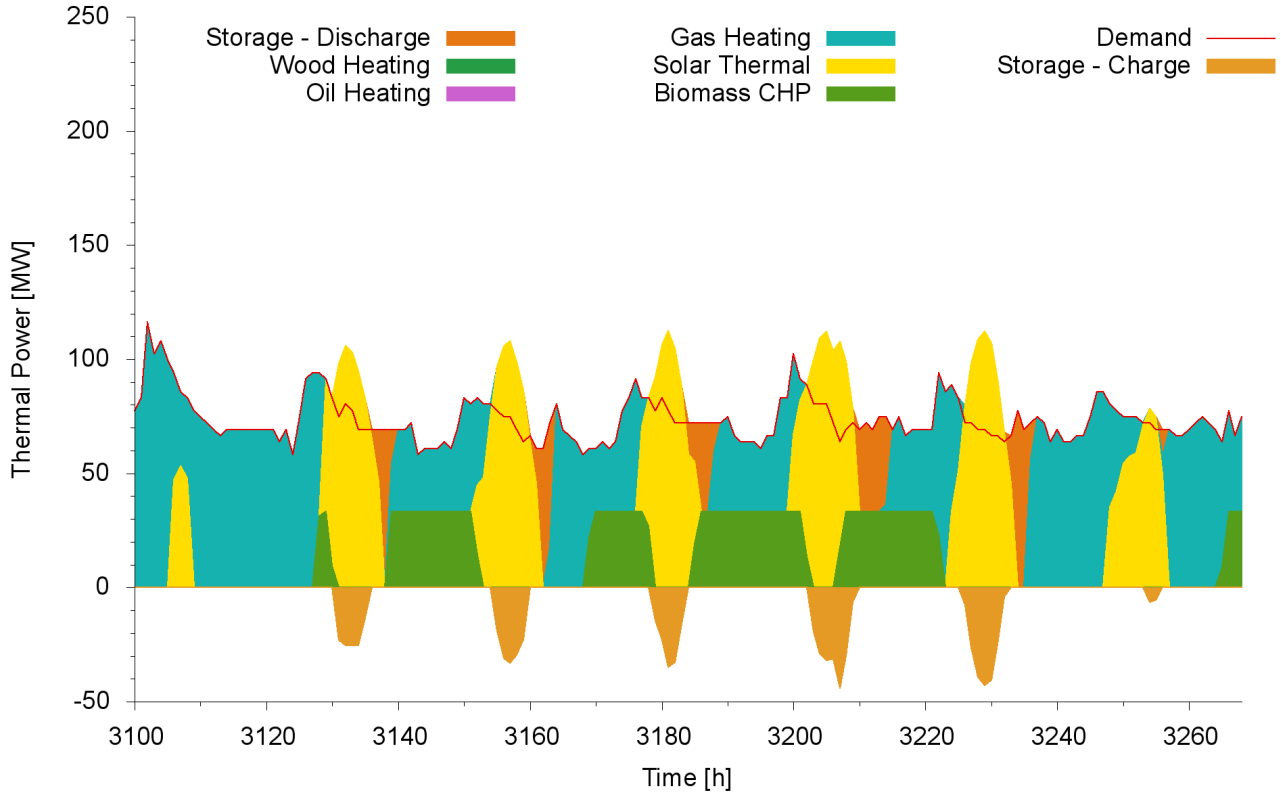


Fig. 5: Heat demand and supply for one week in spring

Together with the fact that especially the resource potentials and the demand patterns depend strongly on the local conditions, it can be concluded that the model has to be adapted to these specific conditions and that in general it won't be possible to transfer solutions directly from one municipality to another.

Looking at the figures, the necessity of modelling technologies with a high technical resolution can also be verified. As a first example, rooftop and façade photovoltaics will be compared on the basis of their supply curves (Fig. 6, Fig. 7), extracted from the complete figures above. In the model the two technologies differ in their installed capacity, efficiency, angle to the horizontal (rooftop 30 degrees and façade 90 degrees), and orientation (rooftop direction south and façade direction south-east). Three main differences can be observed. The curve of the façade installation reaches its maximum before the one of the rooftop system due to the orientation. The difference in angle results in a lower seasonal influence on the production of the façade system as well as in a squatter and rather levelled shape of the curve. Additionally it leads to lower peak loads and a lower energy production of the façade system per area or installed capacity, respectively, which cannot be drawn from the figures as the installed capacities and efficiencies differ from the rooftop installations. It is clear that the mentioned effects have an impact on the availability of electricity gained from photovoltaics and hence on the supply security and grid loads.

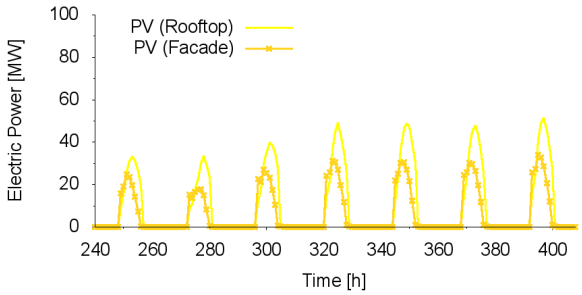


Fig. 6: Comparison of rooftop and façade PV in winter

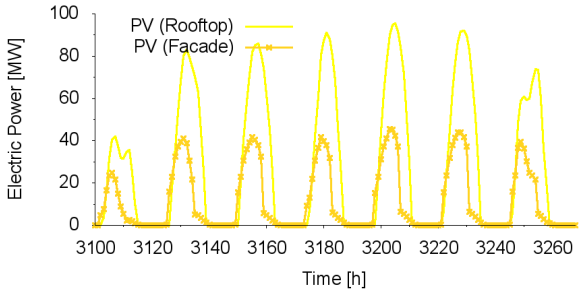


Fig. 7: Comparison of rooftop and façade PV in spring

A second example for the relevance of a high technical definition shall be given with respect to energy efficiency curves compared to annual average values, here exemplified with rooftop photovoltaics and solar thermal installations. While the energetic efficiency of photovoltaics rises with falling temperatures, solar thermal installations decline in efficiency at lower temperatures due to increasing thermal losses to the environment. The latter is especially important as it is directly opposed to the heat demand. A thermal efficiency averaged over time therefore would lead to a shortfall when the heat is needed the most. These effects can also partly be observed in the figures when looking at the switching times of solar thermal installations compared to rooftop photovoltaics (Fig. 8, Fig. 9). In spring the switching times of both systems are pretty much the same but in winter the solar thermal applications start notably later to produce energy and stop much earlier than the photovoltaics. The reason is that during winter when ambient temperatures are low, with solar thermal applications a fair amount of the insolation is needed to cover heat loss to the environment, thus lowering the net output. In times when the

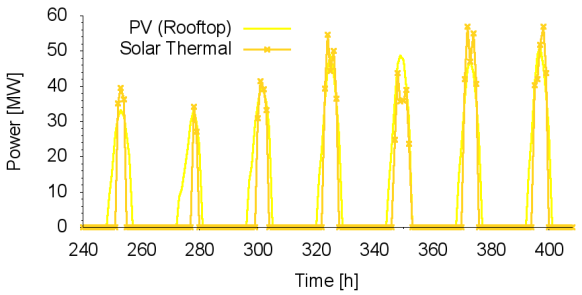


Fig. 8: Comparison of rooftop PV and solar thermal installations in winter

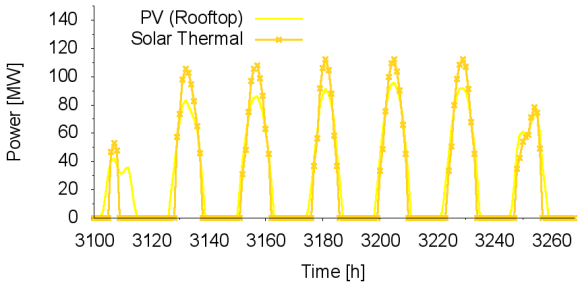


Fig. 9: Comparison of rooftop PV and solar thermal installations in spring

insolation is too weak to provide a net surplus the system is shut down. In this example both systems were orientated southwards but differed in angle (rooftop 30 degrees and solar thermal collectors 45 degrees to the horizontal) which in winter even improves the conditions in favour of the solar thermal system.

4.3 Perfect foresight and dynamic optimisation

The impact of dynamic optimisation and perfect foresight can be seen from the curves of the electrical and thermal storages (Fig. 2 to Fig. 5). It stands out that both storages are charged and discharged consecutively, thus being mainly used as short term storages for anything between a few hours and two days. This doesn't originate from the capacity limits set within the model as these were not reached. Under the premise of perfect foresight it is useful to charge the storage as late as possible to minimise the losses occurring until discharge. Around the 3240th hour (Fig. 4) this results in exporting electricity before filling the storage. This behaviour is not very realistic concerning risk management, of course. It therefore has to be seen as a theoretical optimum providing a lower bound which could be used to evaluate real-life solutions. The most apt solution to integrate risk awareness in this special case would be to swap charging the storage and export as the resulting additional losses could be probably ignored under real life conditions.
The dynamic behaviour of the model becomes apparent several times in winter (245th, 268th, 280th, and 318th hour with electricity, 373th and 398th hour with heat) (Fig. 2, Fig. 3). Taking a look at the electricity figure it can be observed that electricity is imported to fill up the storage only to be immediately discharged again while the import of electricity continues. The reason for this behaviour is that electricity imports are limited arbitrarily to 50 MW, so supply can only be guaranteed either by increasing the installed capacities of the supply technologies or by buffering demand peaks via storage.
With the heat sector the situation is different. Here the storage is not used due to capacity restrictions but to reduce costs as cheaper heat derived from the gas boilers replaces more expensive oil.

4.4 Conclusions and outlook

As a main outcome, the assumption could be validated that for a sound target energy system, and even more for the roadmap to get there, municipalities are in need of a detailed and high-resolution energy system model, tailored to their specific needs.
Even with the partly inconsistent data used for the first evaluations, it became obvious that only highly resolved temporal calculations are able to include effects resulting from fluctuating energy sources, the use of energy storage, and different kinds of interdependencies (cross-sectoral, intra-sectoral, structure and operation, technology and economy). This means also that models which are based on annual calculations and which are currently widely used for the first two steps on the pathway to becoming a smart (energy) city are inadequate for the third step.
To cover all sorts of interdependencies, additionally to the high temporal resolution, a high technical resolution and at least a basic spatial resolution are necessary – this could also be proved with the results gained with KomMod.
The full potential of a high temporal resolution can only be tapped when the level of technical detail is also appropriate. Examples which have an important influence on the whole energy system are the integration of load ramps or the deviation in operation of solar applications due to differences in orientation - features which can’t be properly integrated in annual calculations. A fine technical resolution also has to be integrated due to the fact that with higher shares of inflexible renewable energies, together with the limitation of the use of flexible (fossil) fuels like gas and oil or their use in combined processes, the energy system will become inelastic and less robust than today. Accordingly the interactions of the different technologies become more important and the technical detail in which they are modelled has to be increased to be able to provide solutions applicable to real life environments. The results show this fact in the operation scheme of the CHP plant, as well as in the different operation patterns of the solar technologies, leading to different residual loads.
The necessity for a spatial resolution could be shown in the heat sector but would also occur wherever the topology plays a significant role like it does with networks. Additionally with spatially resolved systems it is possible to split up costs and energy flows for different groups of interest, allowing to take the particular view of private house owners or utility providers.

Furthermore it could be shown that the identified requirements have a notable impact on the optimisation results and that the course chosen to develop KomMod is plausible and in line with these requirements. The next steps will be to implement a spatial resolution, building types and district heating networks, followed by the integration of the transport sector and, of course, to validate KomMod and the first findings also with consistent real data. Later on methods to integrate uncertainty should be evaluated and new methods which allow for the identification of robust paths have to be developed.

5. Acknowledgements

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6. References

[1] United Nations, Department of Economic and Social Affairs, Population Division, http://www.un.org/en/development/desa/population/, last viewed: 26.05.2013
[2] ICLEI - Local Governments for Sustainable Development, http://www.iclei.org/index.php?id=iclei-home, last viewed: 26.05.2013T
[3] Covenant of Mayors, http://www.konventderbuergermeister.eu/index_en.html, last viewed: 26.05.2013
[4] Fraunhofer Institute for Solar Energy Systems ISE, 2013
[5] BRUCKNER T. "*Benutzerhandbuch deeco - Dynamische Energie-, Emissions- und Kostenoptimierung regionaler Energiesysteme*" Institut für Energietechnik, Technische Universität Berlin, 2001
[6] REMME U. "*Zukünftige Rolle erneuerbarer Energien in Deutschland: Sensitivitätsanalysen mit einem linearen Optimierungsmodell*" PhD-Thesis, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart, 2006
[7] RICHTER S "*Entwicklung einer Methode zur integralen Beschreibung und Optimierung urbaner Energiesysteme. - Erste Anwendung am Beispiel Augsburg.*" PhD-Thesis, Universität Augsburg, 2004
[8] Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart "Modellsystem TIMES", http://www.ier.uni-stuttgart.de/forschung/projektwebsites/forum/models/mex2/times.htm, last viewed: 26.05.2013
[9] FOURER R., GAY D. M., KERNIGHAN B. W. "*AMPL: A Modeling Language for Mathematical Programming*" Duxbury Press / Brooks/Cole Publishing Company, 2003
[10] www.ampl.com, last viewed: 26.05.2013
[11] Institut Wohnen und Umwelt GmbH, "Deutsche Gebäudetypologie – Systematik und Datensätze", 2005, retrieved from http://www.iwu.de/fileadmin/user_upload/dateien/energie/klima_altbau/Gebaeudetypologie_Deutschland.pdf, last viewed 26.05.2013

Project –“Morgenstadt: City Insights” - Analysis of Interactions Between Key Factors



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Short Summary

The project „Morgenstadt: City Insights“ is dealing with the complex interactions of city developments. Its research activities on the most important sectors for the cities of the future – mobility, energy, communications, security, buildings, resources and governance – will lay the foundation for creating smart and sustainable system interconnection for urban structures. Different competences of the Fraunhofer Gesellschaft will join forces and combine technology management for essential technology- and organization-based urban systems with practical knowhow of industrial, political and cities partners. A transdisciplinary approach will help identify systems and success factors of cities on their way to future sustainability. As a result of the long-term process best practices towards sustainable and smart urban ecosystems will be identified and complemented by a systemic analysis of innovative processes in cutting edge cities especially with regard to transferability.

Keywords:

Morgenstadt; CityInsights; sustainability; interactions; systemic interconnection; energy; buildings; government.

1. Introduction

The future living space of our growing population will focus on large cities that offer rich social connection, interconnected work and home space as well as all necessary services concerning healthy, comfortable living. As expectations and standards rise, the challenges within city development gain complexity and new approaches to overcome them are required. [1] Even today climate change, infrastructure, economic development and life-quality induced by scarce resources and the mere number of people are ever-present questions for larger cities. Ecological sustainability as well as pursuit of economic prosperity are the two key issues for cities in the future. Both goals can be achieved by recognizing cities as future markets for sustainable concepts of mobility, building, communication, energy generation, production and consumption. But these concepts will inevitably link different technology sectors and products with each other in a much stronger way than today. Solutions will increasingly have to overleap sectorial boundaries and combine multiple technologies, as well as interconnect different sectors. [2]

As Europe’s largest application-oriented research organization the Fraunhofer Gesellschaft has long expertise in city development. 12 Fraunhofer Institutes have introduced various innovative approaches in their research field. Now their expertise will be combined and focused in the collaborative, transdisciplinary research team “Morgenstadt: City Insights”. Partners from the industry,

from interested cities and international value partners further enhance this team. The concept of this network creates a strong background in precise research, innovative applications and integrated urban solutions. Together they will use their knowledge in key factors such as mobility, energy, communications, security, buildings, resources and governance, to create a foundation for smart and sustainable urban solutions of tomorrow. By creating such variable insights, problems like natural catastrophes that concern almost all research fields can be addressed in one multidimensional approach.

Hereby the goal of the project is to synchronize emerging urban demands and global best-practice approaches in a strategic research project and to thereby develop the basis for innovation of new strategies, products and urban solutions.

2. Research subject – Morgenstadt: City Insights

The research focus of the “Morgenstadt: City Insights” is to create a knowledge foundation about the urban environment and the interconnection of its key factors. Cities nowadays face various challenges that cannot be solved from only one key factor or separately in each key factor. Therefore, interactions between the key elements have to be analysed. By integrating the identified solutions of key factors into one systemic and cross-sectoral approach, the cities of the future will be put in a position that allows them to combine unique solutions and to provide basis for entering new markets for sustainable urban systems.

The key factors that are represented in the Morgenstadt: City Insight research mobility, energy, communications, security, buildings, resources and governance have been chosen because of their large impact on city developments and their high interaction forming the basis of current challenges. One of those challenges is for instance transportation of masses of people in very short time and during rush hours. What are the future ways of guaranteeing this kind of mobility or a better one? How can we avoid traffic jams and trains running late? Which vehicles and technologies will help lowering energy demand on transportation? Already at this stage we can see a connection between two key factors: talking about future *transportation* is impossible without regarding future *energy* sources, ways of energy transmission and technology for storing produced energy. One innovative solution to create energy for transportation is the concept of “plus-energy houses”, which may use surplus energy for supplying electric cars.

That fact brings us to the third key factor: *buildings*. Growing cities need to provide standards for new buildings, concepts for retrofitting, strategies for the arrangement of and especially approaches for energy efficiency of future cities. Another important aspect in growing cities is density, asking for well-balanced concepts which take into account surface areas, height and distance of and between buildings as well as for transportation systems and their roots.

In addition to the impact of buildings on energy challenges, recent years also introduced many challenges for the security of buildings, such as being resistant to floods, earthquakes or fire as well as to terror attacks. Through the example of Hurricane Sandy in New York City, which is one of the represented Cities in Morgenstadt: City Insights, it is demonstrated, that the before mentioned key factors interact with the key factor *security* for urban environments. Security, as in article 3 “Systemic view on cities – New York City after Hurricane Sandy” mentioned, is a cross-sectorial component influencing every other field, especially in those cities at risk (i.e. in New York City with natural disasters). Here, security in traffic and transportation, security of buildings, security of energy resources, such as nuclear power plants and very recently the security of personal data is an ever-growing issue. How can we create easy access and interaction with information all around the city without risking data leakage or attacks in the network? Communication is gaining more and more importance in our everyday life and now we have the chance to use it to create better systems for our city of the future.

The last important key factor also connects to most of the above mentioned: *resources*. Every new building, car or security system will someday fail or need to be replaced. We have to start thinking about the whole cycle our resources complete before implementing them. Waste, recycling and reuse of material will gain more weight as *resources* get scarce and space for collecting waste

material becomes rare.

Insight into all those key factors and their interaction will be created by analysis of six global cities with good reputations about their development and their ideas for the city of the future. New York, Berlin, Freiburg, Singapore, Tokyo and Copenhagen are the chosen cities. All of them are already working at developing their cities and preparing them for future challenges. For each city a defined number of known best practices will be investigated. Used legislative standards and technical concepts, financial programs and roadmaps, political incentives and laws will be examined to get an objective overview of state of the art and ambitious solutions.

For analysis of each city, the project is divided into three working steps. First, analyse urban best practice worldwide. This step covers the capture of today´s challenges and concepts on the partner level. The methodology will be based on expert interviews and meta-studies of existing knowledge and approaches. The second step explores leading cities in on-site field research. Researchers will spend several months for on-site and in-depth analysis in represented cities. For each study a detailed report will be compiled. The third research module deals with identifying of requirements for innovative concepts. The result will be a summary of the preceding research covering a wide range of global best practice. After concluding a catalogue if synchronized requirements and a broad insight into global best practice will be used as the sound foundation of the consecutive Morgenstadt research stage (2013-2015).

3. Systemic view on cities – New York City after hurricane Sandy

To show the systemic interaction of different key factors, we will introduce the “New York Cities actions” [Q] after hurricane Sandy. In the following we will review the reaction of the New York government and the changes causes on one of our urban research objectives by a natural catastrophe.

3.1 New York City

With 8.24 million inhabitants New York City (NYC) exceeds all other cities of the USA. By 2030 it will be furthermore home to over nine million people. Growing into one of the largest metropolitan areas worldwide, it has to face immense challenges to adapt to the current situation. Most of New Yorks infrastructure and buildings satisfy only last century’s standards and therefor have to undertake great changes in order to master climate change, changes in society and security of both natural and human attacks. Since 2007, Mayor Bloomberg is facing these changes with an unprecedented city wide effort. He created the PlaNYC 2030 [Q] in order to prepare his city for population growth, climate changes and economic risks as well as to offer a rich quality life for all future inhabitants. In order to pursue these goals, a network of 25 city agencies has been created and significant progress has been made on the defined milestones and long-term goals.

In 2007, NYC set a goal to reduce GHG emissions by more than 30% by 2030 compared to 2005 levels. The PlaNYC describes a series of actions that have yielded significant progress toward this goal. Many initiatives have been already started to reach that goal. For example the “Greater greener buildings plan (GreenNYC)” that was introduced to create awareness of energy efficiency, especially in larger building complexes, and to enforce new building standards by 4 local laws and some further tax incentives. On the other hand, GreeNYC tries to accomplish an open mind-set in New Yorks inhabitants and offers counselling on any questions about energy saving, waste reduction, and rational usage of resources. The PlaNYC also approaches other sectors. Traffic should be improved, affordable housing should be created, waste management and recycling should be further advanced.

3.2 Consequences of hurricane Sandy

2012 at the end of October hurricane Sandy hit the coast of New York. Although this coast has always been vulnerable to flooding and storms, Sandy brought great damage to many people and

buildings. 43 people had to give their lives in consequence of the events. 200 homes were destroyed completely and another 500 homes have major structural damage. The reconstruction process will take a lot of time and require financial investments around 71.4 billion dollars. Many weeks passed with lack of resources like petrol, electricity or food. Now half a year after Sandy, you can still see the consequences for those regions. Some buildings are being repaired; some rebuild and others are totally lost. This example shows us to some extend how climate change can create new challenges for cities and it also shows us the importance of climate resilience to prevent damages in such dimensions. The natural catastrophe also shows how many different key factors need to be combined to create innovative solutions against this problem. To use only governmental means, would cause the endangered regions to be evacuated and resettled. On the other hand, security measures like protections walls and water drainage systems cannot be standalone solutions, if the buildings are made of light material or on a bad foundation. Even the buildings cannot themselves prevent any damage such an event would cause on a region because it cannot influence the impact on streets, wires or vehicles. To create an overall approach you have to consider the interconnections and synergies between all factors involved. Therefor we can evaluate the best-practice reaction of New York government to those events in order to give some insight into urban systems.

3.3 Governmental reaction

The PlaNYC [3] is a constantly reviewed and changing plan. It adapts to unknown situations to redefined awareness and to current research progress. One key element of the PlaNYC has been to create a resistant building structure in coastal areas with high risks for flooding and storms. Therefor City's Comprehensive Waterfront Plan tries to identify the outreach of natural catastrophes at the coast of NY. Now after Sandy a living example of the importance of this element, efforts were increased and solutions are sought. Even one week before Sandy hit, the Office of Long Term Planning, initiated an Army Corps study [4] about steps to reduce the impact of coastal storms. Usually those studies take years to be completed, but after Sandy the problem became much more immediate. So these are the steps that will be undertaken to create a more climate resilient New York City.

3.3.1 Future Flood Zone changing

Since Sandy in many cases exceeded the given Flood Insurance Rate Maps (FIRMs), that were indicating risky zones based on previous flooding. Considering this the Federal Emergency Management Agency (FEMA) will update those maps and include recently damaged zones. It should also remove additional impediments to flood-resistant construction, and modify regulations to mitigate potential negative effects of flood-resistant construction on the streetscape and public realm.

Those maps will also be used for future building codes, since they should apply for all houses inside the endangered zone. Until the final adoption of those maps in 2015 the department will address those zones on basis of the non-binding maps. In 2015, the building codes will be advanced on the new map base and regulations will also address those regions.



Fig. 1: Areas within which text Amendment would apply, [4]

3.3.2 Flood Resilience Zoning Text Amendment [4]

To give the people rebuilding their houses best insight in their opportunities, the DCP has proposed a Flood Resilience Zoning Text Amendment. This includes several steps. First it should enable all people at risk of storm surges or coastal flooding to create a more climate resilient home for themselves. Therefor, the current data of Sandy was integrated into a map of New York City, by the Federal Emergency Management (FEMA). This map contains information about the zones in New York being at risk of natural catastrophes, and also creates the basic zoning step for some climate resilience guidelines. These guidelines mainly consist of new building codes required for all endangered zones.

3.3.3 Rezoning

On January 31 2013 the Mayor´s Office created the Executive Order No. 230 to enable owners of buildings inside the new Federal Emergency Management (FEMA) flood risk zone to build climate resilient. Previously some height limitations of building codes were in conflict with latest flood-resilient standards. Therefor these limitations will be suspended to guaranty the additional flexibility required for further steps. Now people can rebuild to a higher elevation and thus follow the new building codes for flooding areas. To prevent misuse of these changes, the executive order will expire and be replaced by a full zoning text amendment.

3.3.4 Building Codes

The proposed text amendment is created to enable those buildings destroyed or damaged by Sandy as well as those buildings being build new in such a region to be designed and constructed based on most current research results on flood standards. Building codes [5] apply to all buildings being new and all improvements that exceed 50% of the market value of those buildings. They are regulated by the Federal Emergency Management (FEMA) Flood Insurance Rate Maps (FIRMs) that defines a 100-year flood zone as well as different flood proof heights (Base Flood Elevation (BFE)) for each part of that zone. The buildings are divided into 2 different zones and apply 3 different flood-proofing methods.

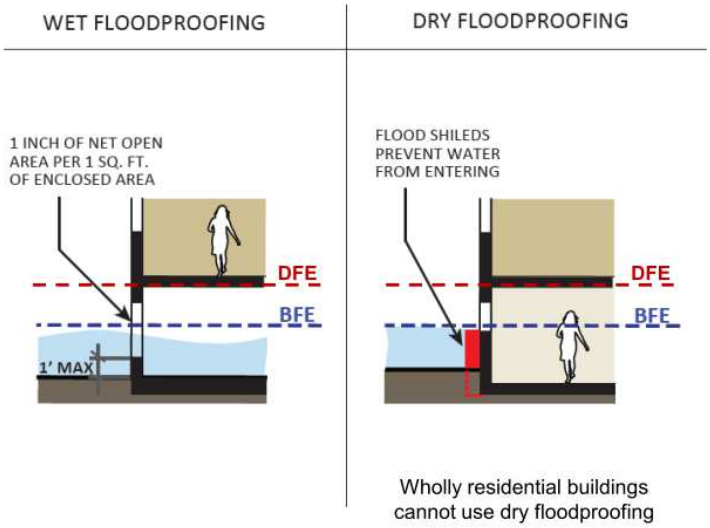


Fig.:2 Wet and dry floodproofing, [5]

In order to be protected buildings at risk have to be elevated above the BFE. The building part below the BFE can be either wet-flood proofed or dry-flood proofed. Wet floodproofing allows flood waters to enter the enclosed areas of a house. In contrast, dry floodproofing prevents the entry of flood waters.

The wet flood proofing method can be applied to all building types, but it is not practical for areas that are to be used as living space. It requires 1 inch of net open area per 1 square feet of enclosed area. Thus a flood should be directed to bypass under the building and create less damage since its impact is redirected. The dry flood proofing can only be applied to buildings that are not exclusively residential buildings [5]. In order to prevent damage it applies flood shields at the elevated level and thus protects the house by sheltering from the impact.

The A zone that was now extended to further coastal regions is required to elevate the lowest level of their buildings above the Base Flood Elevation (BFE). The building must be wet food proofed and the enclosed space under the BEF level can only be used for parking, storage or building access. Commercial or buildings with different usages can also be protected by dry flood proof spaces below the BFE that are not residential.

The V zone is endangered by high-velocity wave action. Therefore the building needs to be elevated on piles or columns and can only use breakaway walls to enclose the level below BEF. By creating such a large space, it offers less resistance to waves and thus receives less damage.
Those new buildings codes should not only prevent damage in times of crisis, but also protect against higher flood insurance premiums. In spite of the changes many conflicts between several building codes make it difficult for owners to rebuild or retrofit, and further regulations will be necessary to easy the application.

3.3.5 Further steps of Text Amendment:

In addition to the above mentioned building codes the text amendment [Q] addresses the potential effects to flood resistant construction in the streetscape and also regards protection of non-building related infrastructure. To achieve this not only the buildings height will be measured in respect to the BFE, as shown before, but also mechanical systems, off-street parking and building access have to be provided above the grade. Additionally the streetscape has to be adapted to these flood proof requirements.

3.4 Systemic interconnections

At reviewing this event and its consequences for the whole city of New York, one may see how much of the key factors interact and how their connections have to be integrated into solutions in order to overcome the challenges of security in NYC in the future. We will present a partial systemic view on solutions and the events caused by Sandy.

3.4.1 Mobility

The entire damaged infrastructure has to be rebuilt or repaired after hurricane Sandy. Although rebuilding infrastructure seems not to be an interconnected step, when you look at the connections to other fields you can see how important mobility becomes in this context. Regarding the interaction between mobility and security, you realize that an effective infrastructure is necessary to enable fast evacuation on short notice, especially in endangered areas.. Streets have to be built in a way that allows bypassing even while the flooding starts making mobility difficult. Also right after the catastrophe, mobility of rescue teams and first aid has to be possible. Sometime after the immediate danger the mobility will be necessary to transfer resources for reconstruction as well as to transfer waster from broken buildings. Later on mobility becomes necessary to transfer food and medicine to inhabitants. Particularly the elderly are suffering the effects of the climate disaster, because they are often isolated and have no contact with outside. Viewing these connections the infrastructure of risk areas becomes more focused.

3.4.2 Communication

In the first waves of a natural catastrophe communication is the essential part to protect people from damage. How to communicate a disaster fast to a large area? Here the interconnections to governance on one side and buildings on the other side create a direct information pipeline. Important data about danger, evacuation plans and further proceedings has to be made available by the government. Thus there can be no restrictions on such datasets and no long hierarchical confirmation lines that would prevent information to be communicated. On the other hand people have to receive that kind of communication. At the same time many options are connected to buildings that are the primary living space of the population. Buildings could include danger alarms, automatic protection systems being controlled by central institutions, or even alarm buttons to warn nearby people of perceived dangers. For improving communication in between inhabitants, Saviour, fire service, automatic protection systems or central institutions you cannot ignore those connections and still have a successful concept. Only combined they build a reaction channel for better handling catastrophes.

3.4.3 Governance

In a first approach you could say that the governance has no influence on natural disasters. They cannot prevent them from happening and they cannot influence the damage they leave. But again, if you look at the other influences the government has, you can see easily, as in the reactions on Sandy, how much they can achieve. In this example the governance interacts with the buildings by giving guidelines and instruction to provide resilient building structures. They also provide codes for the placement of wires and thus affect the energy delivery in the aftermath. Furthermore the government can develop a concept to purchase storm-damaged properties, as happened in New York. New York governor has announced a $400 million plan to purchase homes which were destroyed by Hurricane Sandy and preserve the land permanently as undeveloped coastline. [6]
Thus they enable a quicker start for reconstruction and a much better base for the first aid and rescue troops. With their interaction to those two key factors, buildings and energy they have a large influence on danger prevention and on fast recovery after disasters.

3.4.4 Buildings

Buildings have already been mentioned in most other comparisons. They do have a strong connection to the resources they are built of, to the energy they use, to the guidelines by governments they are built after, as well as to security and communicational availability inside them. Along with affecting the wellbeing of their occupants, buildings affect the nearby as well as the

global environment. As the main living and working space in cities buildings interconnect all key factors into applicable measures and methods.

3.4.5 Resources: energy and water

Resources as well as buildings play a large role in between many other key factors. Resources are scarce and have to be used wisely. They are the key to new and innovative technologies, unknown improvements and financial incentives.

There is a number of households, that is still without power or water after Superstorm Sandy. Energy as well as water has direct connection to the consequences of or reactions to Sandy. And if you look closely, Sandy exceeded all previous catastrophes in this area. This is in part due to climate change and therefor strongly dependent on the interconnections between resources (energy and water) and governance as well as resources (energy and water) and buildings. Large parts of energy usage and carbon footprint are located in buildings. In this context resilience become very important for urban cities of the future. We need robust and climate adapted buildings as well as infrastructure and innovative decentralised systems in order to accept the challenge of further effects of climate change. In order to build energy efficient buildings we need strong governmental guidance and incentives, as well as functional resources that do not damage the environment and still offer the same comfortable living space.

3.4.6 Security

Especially in the example of Sandy security shows its cross-sectorial character. The uppermost objective of the governance is the security of their people from any damage on their lives, their finances of their comfort. Therefor buildings, infrastructure, energy and water supply, communication privacy and limited resources are all used in respect to the wellbeing and safety of the people using them.

4. Conclusion and Outlook

The Climate change, resource depletion, population growth, increasing consumption, individual mobility and climate resilience are dangers and questions that are all directing our attention to the development of our cities. They will be the anchor of our future living quality, economical markets and network structures. Considering such a large impact, the conception redefinition of urban environments has to be a key research field.

The enormous challenges that our future cities have to face can only be solved by creating an intuitive but deep insight into the systemic interaction of key factors inside a city. As shown in the example of New York City no solution can focus on only one key element if it is to be successful. New York City´s “superstorm” Sandy and its consequences show how climate change face cities with new challenges. The natural catastrophe also shows how many different key factors need to be combined to create innovative solutions against this problem. To use only governmental opportunity, would cause the endangered regions to be evacuated and resettled. On the other hand, you cannot handle without government, often as a key driver. Security measures like protections walls and water drainage systems cannot be standalone solutions, if the buildings are made of light material, false construction or on a bad foundation. To create an overall approach you have to consider the interconnections and synergies between all factors involved. Now NYC is developing a long-term plan to cope with extreme weather events that will get the lights back on quickly, keep the gas stations open, ensure the hospitals maintain power, and guarantee a working transportation system. Furthermore the first Executive Order allowed home and property owners who are rebuilding after Hurricane Sandy to meet new flood standards without violating zoning codes. It will become apparent in the future, if those measures had a holistic approach.

To consider such dynamic and interconnected research fields, a new way of multidisciplinary and interactive research groups have to be formed as well as new structures for perceiving, processing and evaluating urban research data. Also solutions have to increasingly overleap sectorial boundaries and combine multiple innovative technologies from different expertise fields into one

greater step of development.

Many urban environments have already developed various solutions to increase energy efficiency, reduce carbon emissions, create strong governmental participation and at the same time provide rich and healthy living for their population. Those concepts are important, but require the next step into necessary changes of urban systems. New relations between information, people, products and resources form the centre of an innovative loop over the next few decades and into sustainable urban cities. This will only happen if representatives from different business sectors, research institutes and governance officials join together for recreating urban systems.

The “Morgenstadt: City Insights” takes this first step into exploration and refinement of our future.

5. References

[1] LENNARTZ, M. W. “*Ist bei Bevölkerungsrückgang der Wachstumsfokus noch zeitgemäß.”* Green building nachhaltig planen, bauen und betreiben, URL: http://greenbuilding-planning.schiele-schoen.de/123/17807/gb21211_12-14/Ist_bei_Bevoelkerungsrueckgang_der_Wachstumsfokus_noch_zeitgemaess_Leben_und_arbeiten_im_Spannungsfeld_urbaner_Siedlungs_und_Entwicklungspolitik.html, Volume 11/2012, pp. 12-14.

[2] VON RADECKI, A. “*Morgenstadt: CityInsights”*, URL:http://www.morgenstadt.de/content/dam/morgenstadt/de/documents/Projektbeschreibung_Morgenstadt-CityInsights_FhG_eng.pdf; 2012, pp. 3-6.

[3] BLOOMBERG, M. R. “*PlaNYC*”, URL:http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_2011_planyc_full_report.pdf, 2011.

[4] Department of City Planning, “*Climate Resilience”,* URL: http://www.nyc.gov/html/dcp/html/climate_resilience/index.shtml.

[5] SLATKIN, H. “Climate Resilience” URL: http://www.nyc.gov/html/dcp/pdf/climate_resilience/presentation_sandy.pdf, 2012.

[6] FAZIO, C. A., STRELL, E*. “Government Property Acquisition in Floodplains After Hurricane Sandy”.* New York Low Journal, URL:http://www.newyorklawjournal.com/PubArticleNY.jsp?id=1202590055801&Government_Property_Acquisition_in_Floodplains_After_Hurricane_Sandy&slreturn=20130414041522; 2013.



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Towards Sustainable Knowledge Ecosystem with Open Data, Co-creation and User Empowerment

Urban ecosystem, as called by Alberti [1] urban ecological space, encompasses the total natural capital and flows on which a city depends to meet the long-term needs of its inhabitant. In order to involve inhabitants to co-creation of sustainable ecosystem on can facilitate the development of the knowledge ecosystem, which by definition of Nonaka et al [2] is organic configuration of dynamic virtual and physical places where one shares a context with others to create meanings. The explicit information is transformed to internalised knowledge in knowledge creation processes. The purpose of this paper is to understand how the creation of meanings and knowledge can be supported and what kind of services city can develop for the users to support their environmental friendly decision making processes and behaviour.

More precisely this paper focuses on the services, which emphasizes the role of information and knowledge as a method for user empowerment in urban ecosystems guaranteeing user involvement. The goal of this paper is to present and analyse two potential service solutions for improving the user empowerment in the knowledge creation processes towards sustainable ecosystem.

Two practical case studies are described by using document analysis, observations and focus group interviews. They demonstrate how public sector can through open collaboration provide the knowledge and power needed for sustainable user decisions. One case study is representing the virtual interface for sustainable local energy system design, where traditionally separated information is gathered to one database. The system aims to help users to have comprehensive facts in order to make their decisions concerning energy solutions. The other one is a physical place, Urban Mill, for knowledge creation, which aims to provide a common platform for different stakeholders of local ecosystem. The co-working place offers a platform for city officials and researchers to co-create sustainable innovations.

Based on user experiences the success of platform services provided by city cannot be fully assessed. However the results can be reflected back to the literature. When considering the service portfolio, city should strive to support the development of sustainable knowledge ecosystems. It is not only operational service provision but a strategic choice to effect to the societal challenges. The city as service provider needs to redefine its role. The sustainable and environmental friendly behavior can be strengthening within platforms, which provide positive user-experience, open data and social collaboration.

The results indicate that in order to support sustainable behavior the user centric approach is not only about designing sustainable solution. The more significant factor is to provide processes, which empower the users to make their own decisions. The comprehensive and shared knowledge is one of the most important elements of these processes. The empowering processes are the small initiatives towards sustainability strategies as the two case platforms indicated. One could have more research of identifying different ways for sustainable behavior among users.

Keywords
Urban ecosystems; open information, knowledge; user involvement; co-creation.

1. Introduction

Commonly the concept of the ecosystem reflects a national society aspect, including the network of all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations [3], [4], [5]. An ecosystem is the totality of organisms and environments that interact interdependently [6]. If ecosystem is considered to be sustainable, it is a biological environment and series of habitats that is able to thrive and support itself without outside influence or assistance. In ideal sustainable ecosystems, everything is already provided within the ecosystem for life to survive. Additionally urban ecosystem, as called by Alberti [1] is urban ecological space, encompasses the total natural capital and flows on which a city depends to meet the long-term needs of its inhabitant.

Ecosystem management is a process that aims to conserve major ecological services and restore natural resources while meeting the socioeconomic, political and cultural needs of current and future generations [7],[8]. Ecosystem management acknowledges that the interrelation of socio- cultural, economic and ecological systems is paramount to understanding the circumstances that affect environmental goals and outcomes. These definitions connected to ecosystems are capturing societal wide phenomena including both natural and human environments. The processes are in regime level and are managed e.g. by different policies and regulations.

In order to involve inhabitants to co-creation of sustainable ecosystem one can facilitate the development of the knowledge ecosystem, which by definition of Nonaka et al. [2] is organic configuration of dynamic virtual and physical places where one shares a context with others to create meanings. The explicit information is transformed to internalized knowledge in knowledge creation processes. Drucker [9] argues that knowledge is the only meaningful resource today. Nonaka [2] continues that knowledge is one of the most important assets to create values and hence, sustainable competitive advantage. Knowledge is individual and shared resource, which according to Bronfenbrenner [10] develops e.g. to sustainable behaviour in micro-, meso-, exo-, and macro- subsystems, which constitute the settings and life space within which an individual develops. In this model, each of the subsystems influences the individual and the other subsystems. This paper argues that in order to achieve the sustainable ecosystem from individual perspective, city can effect both to the individual subsystems and social knowledge ecosystem by providing the virtual and physical platforms as a service supporting sustainable knowledge ecosystems.

2. Platforms

2.1 Open data

More precisely this paper focuses on the virtual and physical platforms as services. They emphasise the role of information and knowledge as a method for user empowerment in urban ecosystems. Open data refers to the idea that data produced by the public sector should be freely available for everyone to use and republish without any restrictions from copyright, patents or other mechanisms of control. Advocates of open data claim that there are many kinds of benefits with the approach. Having access to relevant information offers a possibility for citizens to contribute in decision-making. This is considered important in moving towards participatory democracy in which users are engaged in a more direct dialogue with the city in contrast to representative democracy.

In order for data to be considered open it will need to meet certain criteria. These criteria have been adopted from Open knowledge Foundation [11]. Open data is material, which is not classified in order to protect identities or avoid security problems. The data must be possible to find and available as a whole in a convenient and modifiable form. The data must be provided under terms that permit reuse and redistribution including intermixing with other datasets. There should be no discrimination against fields of endeavor or against persons or groups. For example, non-commercial restrictions that would prevent commercial use, or restrictions of use for certain purposes e.g. only in education, should not be implemented. The data must be available in an open data format, whose specification is publicly and freely available and places no technical or monetary restrictions for the use [12], [13], [14] and [15]. Open data can be available both in virtual and physical platforms.

2.2 Knowledge co-creation process

Knowledge management theories [24] focus on the social nature of knowledge creation. Nonaka and Takeuchi [24] have a comprehensive, even critical view on knowledge creation, which includes a broad set of processes that underpin a double spiral movement between (a) tacit and explicit knowledge and (b) individual-group- -wide co-creation levels. Tacit knowledge was first coined by Polanyi [26] and it is that which is in the mind of the individual. It is intangible and difficult to describe. By contrast explicit knowledge is tangible. Explicit knowledge is everything that is written down or otherwise encoded within an documents, systems and processes. [27], [24] and [28]. Open data is explicit by its nature.

Nonaka and Konno [25] have used the knowledge cycle to illustrate the interaction between tacit and explicit knowledge in the process of knowledge creation, knowledge sharing and learning. The knowledge learning cycle can also be called a SECI- process (Socialisation, Externalisation, Combination and Internalisation). Socialisation (from individual tacit knowledge to group tacit knowledge) is a process of creating common tacit knowledge through shared experiences. A "field" of interaction, where individuals share experiences and space at the same time can be built for socialisation, thereby creating common unarticulated beliefs or embodied skills. Externalisation (from tacit knowledge to explicit knowledge) is a process of articulating tacit knowledge into such explicit knowledge as concepts and/or diagrams, often using metaphors, analogies and/or sketches. A dialogue intended to create concepts from tacit knowledge triggers this mode. Combination (from separate explicit knowledge to systemic explicit knowledge) is a process of assembling new and existing explicit knowledge into systemic knowledge. Often, a newly created concept should be combined with existing knowledge to transform it into something tangible. Open data has its role in this phase of knowledge creation process. It serves as a raw material for combination. In the phase of internalisation (from explicit knowledge to tacit knowledge) a process of embodying explicit knowledge into tacit, operational knowledge such as know-how. These four modes of knowledge take place in a continuous knowledge learning cycle [24], [25] [29]. The next question is what are the requirements of the physical and virtual platforms where knowledge co-creation takes place.

2.3 Virtual and physical platforms for user involvement

The interest in this paper is in virtual and physical platforms Nonaka et al. [37] have described in the qualitative manner the characteristics of the physical, mental and virtual platforms for sharing the knowledge – they are also defined by Japanese word “ba”. Knowledge co-creation needs many ba, which exist on multiple levels and are connected to each other organically to form a greater ba. It is possible to connect different ba to an evolving, larger whole. The structure reminds network with hubs, knots and links in between. The experience of becoming part of a whole larger than oneself is worth thinking about. Good ba is like an instrument. The music doesn’t come from the instrument. The music comes through the instrument when someone plays it skillfully.

High quality ba have their own field and atmosphere, that help people and groups to focus on what is most important, and that provide access to their deeper sources of creativity. These platforms need an open boundary that on the one hand provides a cocoon in which to do creative work, and that on the other hand provides openness and a flow of new perspectives, people and ideas that come with it.

Good ba happens not outside but in the midst of activities. Building ba in the sense of task accomplishment, it is important that everyone has equal access to the centre, with every participant in a good platform at the same distance from the centre. However, the centre is not a fixed point. In ba, anyone has the potential to be a centre, and the centre can change as the context evolves. Ba is a sphere that is constantly moving along an evolving trajectory. There is also need to understand imaginative seeing: Innovation and inspiration start with seeing differently. The capacity to see differently and deeply is crucial and yet difficult to develop. It involves suspending one’s judgment and allowing reality to emerge.

Good ba embodies the diversity of experience and talent. A good platform enables essential dialogues, which allow participants to share their views and experiences and to see themselves through one another. The quality of people’s conversations is one of the most important measures of the quality of platform and the vitality and health of a system.

Good ba needs creative chaos, care, and love in order to tap into people's highest level of energy and commitment. The energy of ba is provided by its self-organising nature. To make ba a self-organising platform, it is important to create conditions that allow for autonomy, chaos, redundancy, and variety, and that foster the development of love, care, trust, and commitment. In order to assess the services supporting sustainable knowledge ecosystems it is essential to focus on their ability to foster love, care trust and commitment which best can be achieved through positive user experience. In the studies of user experiences of physical and virtual places Nenonen & Kojo [23] modified trough abductive reasoning Diller's et al [24] classification of experience for assessment. The developed model has six dimensions: the atmosphere, the frequency, the functionality, the familiarity, the narrative and the importance.

3. Method and sample

3.1 Method

The research is based on data was gathered through two case studies using document analysis, observations. Additionally data was gathered by interviewing both the people involved in the development of the knowledge co-creation platforms as well as the users of the platforms. The goal of this data gathering was to get user experiences connected to both platforms.

They demonstrate how public sector through open service platforms can support the knowledge co-creation. One case study is representing the virtual platform for sustainable local energy system design, where traditionally separated information is integrated with new energy data. The other case study is a physical platform for knowledge co-creation.

The gathered data was analysed by using a six-dimensional model that has been developed by Nenonen and Kojo [23] to capture the intangible elements of the experience of place. The framework can be used in analysing, developing and designing user centric platforms. The six-dimensional (the atmosphere, the frequency, the functionality, the familiarity, the narrative and the importance) framework of the experience of place is applicable for a variety of space segments including also virtual and physical platforms for experiences.

The atmosphere is related to indoor environment and the solutions - how they fit and affect human senses. According to Nenonen & Kojo [23] the dimension of the atmosphere includes the elements that are affecting the holistic sense-experience: smell, taste, sight, feel, and hearing. Also different cognitive symbols (such as signs) relates to this dimension.

The frequency experience refers to activities happening in the certain rhythm and tempo. Dimension of the frequency is connected with the use of time, sense of time and rhythm of time. The dimension includes e.g. the sense of history or the sense of short or long period of use.

The dimension of the functionality indicates how supports the activities and the performance that is done there. It also includes the easiness to switch between different purposes. The dimension of familiarity of the place refers to easiness of the use and e.g. effortless adoption to the use.

The dimension of narrative means the constancy and coherency of the story. Features such as identity, brand, and purpose relate to this dimension. The dimension of the importance expresses the significance and meaning for the users. It relates to tangible and intangible values as part of the experience. The meaning is related e.g. to the concepts of appropriation, belonging, ownership, control and privacy.

3.2 Case 1 Virtual Platform: Energy data interface

The first case study is a virtual platform for sustainable open and dynamic energy system design, where traditionally separated information is gathered to one database as part of the strategic climate and energy actions of the Finnish City of Espoo. The purpose of opening energy related data is to promote user involvement in innovation regarding sustainable energy system development. The interface aims to help users to have comprehensive and explicit facts in order to make their decisions concerning energy solutions. The integration of the geothermal map, the solar energy map and the weather data provides unique material, which is both inspiring and useful. This interface is combining this data with other existing geo-referenced information. The virtual interface also contains a tool for estimating the hourly energy consumption of building stock. One intention is to demystify the planning of renewable energy by visualizing timing mismatch of energy production

and consumption. The platform makes it possible to openly compare different solutions and to choose optimal solutions for energy production and consumption balancing.

3.3 Case 2 Physical Platform: Urban Mill

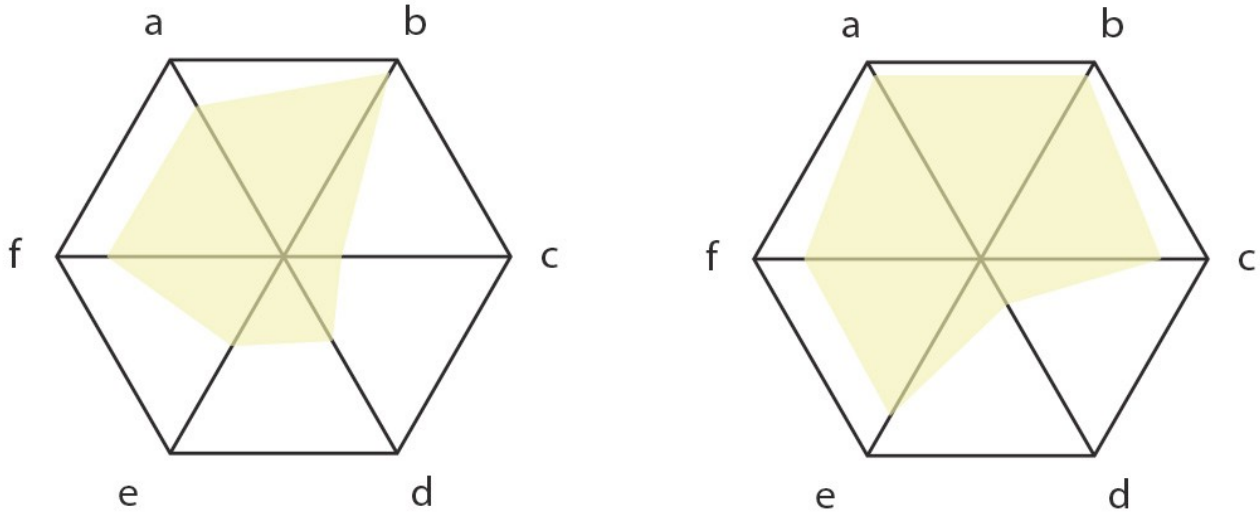
The other case study is a physical platform for open data and knowledge creation. Urban Mill aims to provide a common co-creation place for different stakeholders of the local ecosystem. The co-working place is open for city officials, researchers and businesses to co-create new sustainable innovations. Urban Mill is a demonstration of an emerging thematic boundary zone for urban innovations. Urban Mill has 1300 sqm of working and co-creation place and foremost brings together the research and innovation actors of Built environment development, Ubiquitous and Responsive City ICT, Urban services and Urban life transformation. Urban Mill's start-up phase was launched in January 2013 as a joint effort of the City of Espoo, Aalto University, Aalto University Properties Ltd.

Urban Mill is a platform for open collaboration. There is no absolute control of the collaboration and no hierarchal leadership. This platform provides a concrete place, space and identity for the joint actions and brings together specialized research teams under one roof, still without being exclusive in any way. The space is flexible and can be transformed for different purposes. It defines itself more as a service than as a concrete facility.

3.4 Case analysis

By filtering the gathered data by using the six-dimensional model one were able to identify the common themes in content but also to illustrate the weight of the comments by visualising the analysis in Figure 1. The gathered data was analysed as single data and as combined data clusters of the user experiences. An interval scale was used to rate each of the six dimensions.

Dimension	Scale and Qualities
a) atmosphere	1 weak – 6 strong
b) density and frequency of time	1 stable – 6 changing
c) functionality	1 single use – 6 multi-use
d) familiarity	1 difficult – 6 easy
e) narrativeness	1 weak – 6 strong
f) importance	1 non-memorable – 6 memorable



Case 1 Case 2

Figure 1. The user experiences of the platform

4. Results

The analysis of data indicates that there are differences and similarities of the virtual and physical platforms. Both of the platforms had a significance and importance for users: they were experienced as memorable. Additionally they had strong atmosphere: in virtual platform this was based on cognitive triggers and in physical platform more to holistic sense-environment of partly rough space. The third common factor in experience was the experience connected to time: both platforms were changing.

The clearest difference of the platforms can be seen in the functionality dimension. The virtual platform has a clearly defined use: energy system design. Physical platform on the other hand is only offering a multiuse platform. Especially the virtual platform is lacking possibility to interaction. Another difference in the case platforms concerns the narrative of the cases. Physical platform, Urban Mill was an empty test laboratory, which means that the building has already its history. By branding the place step by step and filling the place with different activities e.g. by evolving student project growing in the psychical environment. The recycled furniture and dynamic atmosphere provides inspire both for an individual and collective memory. Story has been formed little by little. This aspect is mostly lacking in the virtual platform, however the application prototype remembers the cached information so it forms a personal user continuum.

Dimension of familiarity is low in both cases. The interview results indicated that the platforms were not easy to use. The familiarity can be developed by increasing the guidance and signs and care in both virtual and physical interfaces of co-creation platforms.

To conclude the analysis the considerations concerning success of provided services are following:
- Importance reflects to proposition that the platforms are memorable – this strengthens the relationship between the platform and the user. It can be seen as a seed for the commitment and trust.
- Atmosphere is strong in both cases: one can consider if it has consequences for different types of users – the strong atmosphere is not self evidently positive or negative, but can exclude some user segments.
- The changing nature of the platform was one of the third common dimensional factors. The dynamics might has some effects to the willingness to commit to the platform – the changing nature can also be connected to the phase of platforms: they change due to the fact that the concepts are on their embryonic phase.

5. Conclusions

Based on user experiences the success of platform services provided by city cannot be fully assessed. However the results can be reflected back to the literature. When considering the service port folio, city should strive to support the development of sustainable knowledge ecosystems. It is not only operational service provision but a strategic choice to effect to the societal challenges. City as service provider need to redefine its role. The sustainable and environmental friendly behavior can be strengthening with platforms, which provide positive user-experience, open data and social collaboration.

The results indicate that in order to support sustainable behavior the user centric approach is not only about designing sustainable solution. The more significant factor is to provide processes, which empower the users to make their own decisions. The comprehensive and shared knowledge is one of the most important elements of these processes. The empowering processes are the small initiatives towards sustainability strategies as the two case platforms indicated. One could have more research of identifying different ways for sustainable behavior among users.

The limitation of the research is the analysis of user experience based on qualitative data only. However user empowerment and end-user co-creation can be studied by using data from case histories and a large amount of very varying user scenarios. Further studies could focus on key performance indicators and analysis of effectiveness of described solutions. However the achievement of quality “ba” is a matter of qualitative and activity based solutions more than a measurable and financial topic. The idea still is to enhance co-creation by supporting love, care and trust within different platforms – virtual and physical.

6. References

[1] ALBERTI M. (2008). “Advances in urban ecology: ıntegrating humans and ecological processes in urban ecosystems,” Seattle, WA: Springer Science Business Media, LLC.

[2] NONAKA I, TOYAMA R and KONNO N. (2000). ‘SECI, Ba, and leadership: a unified model of dynamic knowledge creation’. Long Range Planning, 33, pp 5-34.

[3] Edquist C., Systems of Innovations, Chapter 7 in The Oxford Handbook of Innovation by (Fagerberg J. et al.), Oxford University Press, New York, USA, 2005.

[4] Ståhle P., Sotarauta M, Pöyhönen A,; Leadership of innovative environments and organization, the Future Committee, Parliament of Finland, 2004

[5] Miettinen, R. National Innovation System: Scientific Concept or Political Rhetoric, Edita, Helsinki, 2002.

[6] Shaffer JD. Food system organization and performance: toward a conceptual framework. Am J Agric Econ. 1990;62:310–218.)

[7] Brussard Peter F, Reed Michael J and Tracy C Richard 1998 Ecosystem Management: What is it really? Landscape and Urban Planning 40: 9-20.)

[8] Szaro, R., Sexton, W.T., and Malone C.R. 1998. The emergence of ecosystem management as a tool for meeting people’s needs and sustaining ecosystems. Landscape and Urban Planning 40: 1-7

[8] Szaro, R., Sexton, W.T., and Malone C.R. 1998. The emergence of ecosystem management as a tool for meeting people’s needs and sustaining ecosystems. Landscape and Urban Planning 40: 1-7

[9] Drucker, P. F. (1993). Postcapitalist Society. New York: HerperCollins Publishers.

[10] Bronfenbrenner U. Ecological systems theory. In: Vasta R, ed. Six Theories of Child Development: Revised formulations and current issues. London: Jessica Kingsley; 1992:187–249.

[11] http://opendefinition.org/okd/ (site accessed 16.4.2013)

[12] Jacubiec & Reinhart 2012 Jakubiec J. Alstan, Reinhart Christoph F., Towards Validated Urban Photovoltaic Potential And Solar Radiation Maps Based On Lidar Measurements, Gis Data, And Hourly Daysim Simulations, Building Technology Program, Massachusetts Institute of Technology, Cambridge, MA 2012

[13] Keirstead 2007 Keirstead J., 2007. Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy 35 (2007) 4128–4141. sekä Bergman N. & Eyre N., 2011. What role for microgeneration in a shift to a low carbon domestic energy sector in the UK? Energy Efficiency 4:335-353.

[14] Rousi Antti, 2013, The value factors of the private sector affecting the implementation of local energy solutions and their consideration in urban planning in the city of Espoo, Master's thesis, Aalto University, School of Engineering, Energy Technology Department

[15] Ruckenstein, M., Suikkanen, J., Tamminen, S. 2011. Forget Innovation. Focus on value creation. Edita Prima Oy, Helsinki. Pages 44–48.

[16] Nonaka, I. and Takeuchi, H. 1995. The knowledge-creating company: How Japanese companies create the dynamics of innovation. New York: Oxford University Press.

[17] Stenmark, D. 2001. Leveraging the tacit organisational knowledge. Journal of Management Information Systems. Vol. 17, No. 3. Winter 2000–2001. pp. 9–24.

[18] Cortada, J. 1998. Rise of the knowledge worker. Boston. MA: Butterworth Heinemann.

[19] Schön, D.A. 1983. The Reflective Practitioner, New York, USA: Basic Books.

[20] Nonaka, I. and Konno, N. 1998. The concept of ba: Building a foundation for knowledge creation. California Management Review, Vol. 40, No. 3, pp. 40–54.

[21] Tuomi, I. 1999. Corporate Knowledge – Theory and Practice of Intelligent Organizations, Finland: Hakapaino, pp. 323–326.

[22] Nonaka, I., Schamer, O. and Toyama, R. 2001. Building ba to enhance knowledge creation. An innovation at large firm, http://www.dialogonleadership.org/Nonaka_et_al.html (site accessed 2.2.2002), pp. 1–16.

[23] Nenonen, S. & Kojo, I. 2013 Experience of Places - A Six dimensional model to Capture the User Experience. Conference Proceedings of 12th Eurofm Research Symposium FM For a Sustainable Future 22.-23.5.2013 Prague. Pp. 76-86.

[24] Diller, S., Shedroff, N. & Rhea, D. (2005). *Making Meaning: How Successful Businesses Deliver Meaningful Customer Experiences,* New Riders Press, Berkeley.

Intensity and Spatial Influence of Urban Parks:

A case study in Sao Paulo, Brazil



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Summary

The main purpose of this ongoing research is to assess the cooling effects of vegetation in urban microclimate. Considering the influence of Leaf Area Index – LAI, this study will quantify the intensity and spatial distribution of the microclimate effects in border regions for urban parks, such as Trianon Park, located at Paulista Avenue in downtown São Paulo/ Brazil. Considering Trianon park as a large mass of vegetation with few sparse areas, an average leaf area index for the entire park was estimated based on two indirect gap-fraction method, the LAI-2000 plant canopy analyser (LI-COR) and a camera system with eyefish lens (Nikon Coolpix 4500). The hemispheric photographs were analysed using can-eye software. Microclimatic meteorological data was obtained in two areas of the park during four consecutive days of measurements, beginning on 28th October 2012. This database was important to adjust the ENVI-met model to local conditions before starting the parametric studies. Parametric simulations on ENVI-met were developed to investigate the effect of the park on its surroundings, indicating the influence of LAI measured previously. Results indicated that, concerning the intensity of the effect, the average difference between air temperatures inside the green areas (LAI=2.5) and the surrounding streets is about 2ºC at 2 p.m. and the extension of the effect can reach 10 m from the park.

Keywords: urban vegetation, urban microclimate, leaf area index, ENVI-met.

1. Introduction

Vegetation plays an important role in moderation of urban climate. It varies according to the mesoscale circumstances, but in any case vegetation can give a significant contribution to the climatic conditions [1]. Areas covered by plants have some common properties by which they differ from build-up and hard surface unplanted areas. Leaves of plants absorb most of solar radiation which impinges upon them. A small part of of the radiant energy is transformed by photosynthesis into chemical energy and in this way reduce the rate of heating of the urban space [2].

Previous studies have shown the vegetation benefits in urban environment, which include: microclimate modifications [3,4,5], removal of air pollutants [6,7], tree shading as passive cooling for buildings façades [8,9], influence in human health and aesthetic value of green areas [10,11,12].

Considering the microclimate, vegetation is important due to its properties on energy balance. According to Penman-Monteith method [13], the equation for evapotranspiration rate by plants is direct related to the quantity of stomata in the surface of leaves. In this sense, the density of leaves,

which can be represented by the leaf area index – LAI, is an indicator of gas exchange (oxygen and carbon dioxide) as well as the water vapor loss in transpiration.

LAI is a dimensionless variable and is defined as one-half the total green leaf area per unit of ground surface area [14] drives the within and the below canopy microclimate, determines canopy water interception, radiation extinction, and water and carbon gas exchange. LAI is a key parameter in models describing the exchange of fluxes of energy, mass (e.g. water and CO_2), and momentum between the surface and the planetary boundary layer [15].

This study is part of an ongoing research about the impact of vegetation on urban microclimates, using predective models such as ENVI-met. This computational model considers the density of leaves to simulate the micro scale interations of surface-vegetation- atmosphere.

2. Methodology

2.1 Area of Study

São Paulo is located in the Southeast region of Brazil. It is a sprawling megacity which metropolitan area houses almost 19 million inhabitants, distributed in an area of 8051km^2. Nowadays, São Paulo is characterised by a heterogeneous urban structure, which has been caused by the rapid growth of the city during the last century. One of the effects of this growth is the social conflict of high-rise office towers close to poor informal settlements.

For decades, downtown has suffered a continuous degradation process and has gradually been abandoned by its residents. The city's plan distribution is very uneven, the metropolitan area of São Paulo experiences simultaneously massive urban sprawl in its peripheries and population decrease in its central parts Now the average density in the city centre is approximately only 64 inhab/ha [16] in spite of a high built density.

Today, 48% of the territory of São Paulo is significantly lacking in plant cover of any type. Although the Environmental Atlas of São Paulo [17] indicates adequate arborization with more than 7m^2 of green area per habitant, some other neighbourhood in downtown area has almost zero (Sé, Republica). The highest temperatures were found in the central area without green areas and the lowest in urban parks.

The municipal district of São Paulo has 35 urban parks distributed throughout the city, with a total area of 1,579 hectares, corresponding to 1.12% of the total area of the municipal district. In the downtown area, there are seven urban parks and this study focuses on Tenente Siqueira Campos Park (or Trianon Park), situated on Paulista Avenue.

2.2 Field Measurement at Trianon Park

2.2.1 LAI Measurements

There are two main forms to obtain the LAI values: the direct and the indirect methods. The first one can be accessed directly by using harvesting methods such as destructive sampling or by non-harvesting litter traps during autumn leaf fall period in deciduous forests [18].

The indirect methods consist in measurements of light transmission through the tree canopy. It can be calculated by Beer-Lambert law, which defines the empiric relation between radiation intercepted by the canopy and the total incident solar radiation. For this study, two methods were applied based on gap fraction distribution: using the instrument LAI-2000 Plant Canopy Analyzer (LI-COR) and the technique via hemispherical canopy photography [19], between August and September of 2012.
Although the park is crossed by Alameda Santos Street, it has a pedestrian bridge to connect the two separated parts. During planning process, a grid of 20x20m was created over the site plan of

the park to define points for measurements (figure 1). The Area 1 was located close to the main entrance of the park from Paulista Avenue, which has low-density trees with 6 points for LAI measurements. The Area 2 is in the middle of the second block of the park and it has a very dense group of trees (points 10-22).

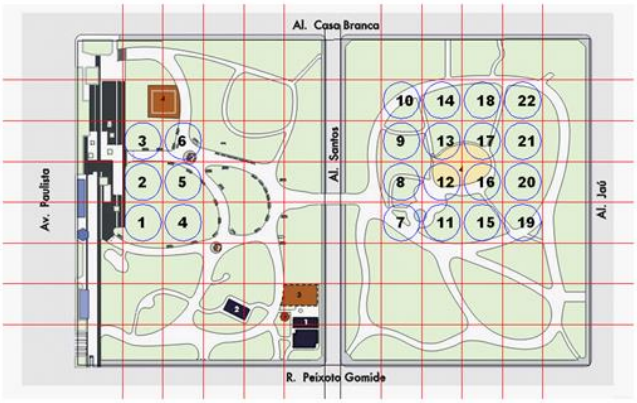


Fig. 1: Location of 22 points for LAI measurents at Trianon Park



Fig. 2: LAI-2000 Plant Canopy Analyser
Source: LI-COR

The LAI 2000 (figure 2) is a portable instrument that calculates Leaf Area Index (LAI) and other canopy attributes from light measurements made with a “fish-eye” optical sensor (148° field-of-view). Measurements made above and below the canopy are used to calculate canopy light interception at five zenith angles (7 º, 23 º, 38 º, 53 º, 68 º), from which LAI is computed using a model of radiative transfer in vegetative canopies Moreover there is an in-built optical filter that rejects incoming radiation with wavelengths below 490nm in order to minimize the radiation scattered by the canopy [20].

To reduce the margin of error in the results, there is an option to use 5 different view restricting caps, which serves to limit the azimuthal field of view of the optical sensor in circumstances that it is necessary or desirable to block part of the view. For the conditions of Trianon Park view restricting caps were used to remove the operator from the sensor’s view and to reduce the required clearing size for above-canopy readings in this dense urban park.

Pre-sensitivity tests of the equipment LAI-2000 were conducted in the surrounding of the Faculty of Architecture and Urbanism of the University of Sao Paulo/ USP. The estimate value for LAI with the LAI-2000 was made using the single sensor method to collect readings outside and below the canopy. These tests were made in two days on July/ 2012 with different sky conditions and using 90 º and 180 º view caps.

According to the best results obtained during pre-tests at USP, the same conditions were considered at Trianon Park. The single sensor method was used for measurements with 90° view cap and under a very uniform overcast sky conditions. This helped to avoid sun glare or sun flecks during field measurements. To obtain the LAI values for each point in the park, 4 measurements were performed below the canopy (figure 3a) and 1 external to the canopy (figure 3b).

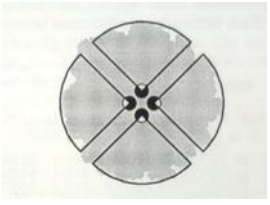
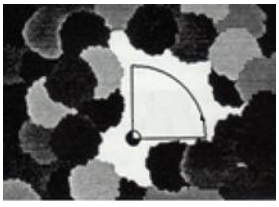

(a)

(b)

Fig. 3: Internal points with the cover of 90° (a) and external point with the cover of 90° (b).

The results of LAI values in all points varied from 1.46 to 3.86, and are shown in Figure 4. The average value of LAI in the 22 measured points was 2.52.

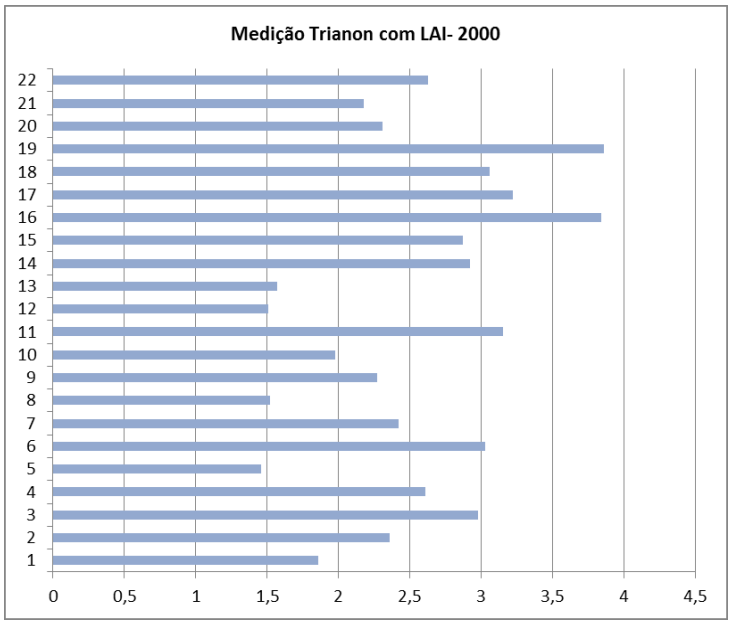


Fig. 4: LAI values measured at Trianon Park (22 points).

Hemispherical canopy photography is a technique for studying plant canopies using photographs acquired through a hemispherical (fisheye) lens from beneath the canopy (oriented towards zenith) or placed above the canopy for downward looking. Furthermore, the use of fish-eye lens allows the gap fraction to be evaluated in all viewing directions, which increases the accuracy of the derived biophysical variables (LAI) and there is a potential to characterize the azimuthal distribution of the foliage and the departure to non-random leaf arrangement. In addition, it is also possible to derive estimates of the leaf area index for canopies growing on sloppy terrains [21].

For Trianon Park, a coupled system based on a fish-eye lens (Nikon FC-E8) and a digital camera (Nikon FC-E8) were used under overcast sky conditions. The hemispherical photographs were taken on August 15 of 2012, from12h to 15h. The analysis of all photographs were done using Can-Eye model.

Firstly, the camera and lens were calibrated to define optical center and projection function. Then, each image was pre-processed in the model. The pixel brightness values for the blue band are extracted from each RGB image to achieve maximum contrast between leaf and sky, because absorption of leafy materials is maximal and sky scattering tends to be highest in that band [22, 23]. Thresholding procedures were applied in order to identify the optimal brightness threshold and distinguish vegetation from sky.

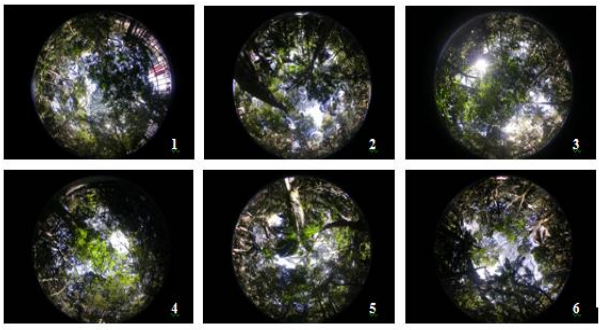


Fig. 5: Results of hemisferical photographs (1-6) taken at Trianon Park



Fig. 6: Color classification and image pre-processing using Can-Eye model

Comparing the final results from both LAI measuring systems, it can be seen that the average LAI values had few differences, varying between 2.14 (hemispheric photographs) and 2.52 (LAI-2000), calculate from 22 defined points at Trianon Park.

Each system has its specific measuring details and the choice has to consider the local conditions for the studies. In this sense, the Trianon Park has a dense arrangement of trees distribution with few spots among them. For these characteristics, the technique using hemispherical images had a better application comparing with LAI-2000 instrument as it evaluate an average LAI for a determined area, but not for a single tree. Overestimated values can be found using LAI-2000 as it considers not only leaves but other elements such as branches and trunk.

3. Preliminary ENVI-met Simulations

3.1 ENVI-met Model

The micro scale model ENVI-met [24] was chosen for this study due to its advanced approach on plant-atmosphere interactions in cities. The numerical model simulates aerodynamics, thermodynamics and the radiation balance in complex urban structures with resolutions between 0.5m and 10m according to the position of the sun, urban geometry, vegetation, soil and various construction materials by solving thermodynamic and plant physiological equations.

The model calculates the energy balance for long and short waves, considering total radiation, air fluxes, air temperature, humidity, local turbulence, reflection from buildings and vegetation. Based on the studies of Deardorff [25] and Jacobs [26], it also implemented a numerical model to calculate the main variables related to plant physiological behaviour: transpiration, evaporation, latent heat flux, water exchange, stomata resistance, leaf temperature and energy balance for soil-vegetation system [27].

To adjust the model, previous climate monitoring was carried out from September 28th to October 1st of 2012 at the park. With this database as a starting point, preliminary studies were done for the initial simulations in ENVI-met. These parametric studies were important to adjust the model main variables and to verify the influence for each parameter in the input data. Before inserting the green areas, it was fundamental to adjust the output values to the measured climatic conditions of the city of Sao Paulo.

3.2 ENVI-met Parametric Simulations

ENVI-met model, instead of using LAI, considers the parameter Leaf Area Density – LAD to calculate plants physiology. According to the ENVI-met plant database, there are 11 types of vegetation, which have specific characteristics according to the following aspects: CO_2 fixation (C_3 or C_4 plants), minimum stomata resistance, short-wave albedo, height of the plant, total depth of the root, Root Area Density - RAD and Leaf Area Density – LAD.

LAD is a parameter defined as the total one-sided leaf area (m^2) per unit layer volume (m^3) in each horizontal layer of the tree crown. The LAD profile was calculated by integrating LAI values [28]. For this study, a vegetation data basis was created based on the previous data survey mentioned before that pointed out the main tree species used in the city of Sao Paulo and their canopy characteristics quantified by Leaf Area Density – LAD.

Based on LAI measurements results, the ENVI-met simulations consider a medium canopy with LAI value of 2,5. The tree is 20m high and its leaf density started 4m above the ground to avoid obstruction for wind flux at the pedestrians' level. The parametric tree model had ellipsoid leaf area distributions with maximum LAD located in the middle height of the crown (Figure 7).

The input data for the simulations are presented in Table 1, based on previous parametric studies carried out to adjust the model. The input area domain was created with information from the park and its surroundings. Two receptors were considered for simulations: one in the middle of the park and another one in the sidewalk without vegetation to give specific information for each point.

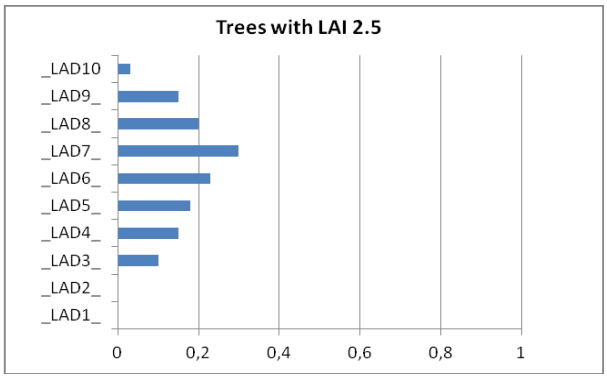


Fig. 7: LAD (Leaf Area density) (m2/m3) in 10 layers of the tree model (LAI=2.5)

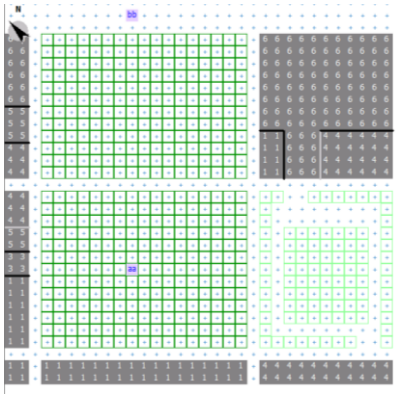


Fig. 8: The input area domain for ENVI-met simulations

Table 1: Input configuration data applied in the ENVI-met simulations.

Start Simulation at day	**28.09.2012**
Wind Speed in 10m ab. Ground [m/s]	**0.1**
Wind Direction (0:N/ 90:E/ 180:S/ 270:W)	**200**
Initial Temperature Atmosphere [K]	**283**
Specific Humidity in 2500m [g Water/ kg air]	**9.5**
Relative Humidity in 2m [%]	**79**
Initial Temperature Upper Layer (0-20cm) [K]	**287.6**

4. Analysis of Results

From the results of simulations, the receptor located in green areas of the park showed a reduction up to 2.0ºC compared to air temperature in the sidewalk. Over paved areas the simulations showed an average air temperature of 26.5ºC at 14h, while 24ºC under the canopies.

The results for superficial temperature indicated that trees have a significant impact by lowering the surface temperature by up to 29ºC. The tree canopy blocks part of the direct solar radiation and avoid the rapidly surface warming up. In the street, the superficial temperature varies from 41ºC to 45ºC, while in the green areas, it goes between 26ºC and 27.5ºC.

Concerning the intensity of the effect, the average difference among air temperatures inside the green areas and the surrounding streets is about 2.0ºC. For surface temperatures, the dense tree shading (LAI=2.5) has shown average differences of 17ºC under the canopy. In that sense, green areas can be an important strategy to mitigate the warming up effect in cities due to the shading and evapotranspiration process.

Regarding the spacial distribution of vegetation, results show that the effect is very local, and the influence of green areas doesn't go very far from the green borders at pedestrian level. Measurements at Trianon Park showed that the effect for air temperature can be felt under the canopy and approximately 10m away from the canopy. As an indicator to urban planning, green areas should be better distributed in small groups of trees than a large park.

The effect of tree canopy shadow has also a great potential to ameliorate the microclimate and mitigate heat stress in a hot humid climate. On the other hand the shade efficiency of trees will depend on the type of plants and the amount of leaf density. Because of this parameters such as Leaf Area Index and Leaf Area Density are fundamental to improve the positive impact of vegetation, considering the plant local influence.

5. Acknowledgments

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6. References

[1] WILMERS F. "*Effect of Vegetation on Urban Climates and Buildings".* Energy and Buildings, No.15, 1991.

[2] GIVONI B. "*Impact of Planted Areas on Urban Environmental Quality- A review".* Atmospheric Environment. Vol 25, No. 3, 1991, pp.289-299.

[3] YU, C.; HIEN, W. N."*Thermal benefits of city parks".* Energy and Buildings, Lausanne, v.38, p.105-120, 2006.

[4] EMMANUEL M.R. "*An Urban Approach to Climate-Sensitive Design – Strategies for the Tropics*". Spon Press, 2005.

[5] YU C., HIEN W.N. "*Thermal benefits of city parks*". Energy and Buildings, Vol. 38, 2006, pp. 105-20.

[6] DIMOUNDI A., NIKOLOPOULOU M. "*Vegetation in the Urban Environment: Microclimatic Analysis and Benefits*". Energy and Buildings, Vol. 35, No.1, 2003.

[7] NOWAK, D. J.; MCHALE, P. J.; IBARRA, M.; CRANE, D.; STEVENS, J. C.; LULEY, C. J. 1998. Modeling the effects of urban vegetation on air pollution. In: Gryning, Sven-Erik; Chaumerliac, Nadine, eds. Air pollution modeling and its application XII. New York; Plenum Press: 399-407

[8] HEISLER, G.M., "*Effects of individual trees on the solar radiation climate of small buildings".* Urban Ecol. 9, 337–359, 1986.

[9] SANTAMOURIS M. "Energy and Climate in the Built Environment". James and James, London, 2001.

[10] ULRICH, R. S. "*The therapeutic role of greenspace*", paper presented at the Greenspace and Healthy Living National Conference, Manchester, 2002.

[11] ULRICH, R. S. "*View through window may influence recovery from surgery*", Science 224 pp. 420 – 421, 1984.

[12] ULRICH, R. S. "*Influences of passive experiences with plants on individual wellbeing and health*", in Relf, D. (ed) *The Role of Horticulture in Human Well-Being and Social Development: A National Symposium*. Timber Press, Portland, Oregon pp. 93 -105, 1992.

[13] MONTEITH, J.L. *"Evaporation and environment"*. pp. 205-234. In G.E. Fogg (ed.) Symposium of the Society for Experimental Biology, The State and Movement of Water in Living Organisms, Vol. 19, Academic Press, Inc., NY, 1965.

[14] CHEN, J. M.,BLACK, T. A. *"Foliage area and architecture of clumped plant canopies from sunfleck size distributions".* Agricultural and Forest Meteorology, 60: p.249-266, 1992.

[15] LI, Z., GUO, G. "*A suitable vegetation index for quantifying temporal variations of LAI in semi-arid mixed grassland".* Canadian Journal of Remote Sensing. 36(6): 709-721, 2010.

[16] Meyer R.M.P et *al.,* "*Sao Paulo Metrópole".* Sao Paulo. Editor University of Sao Paulo, 2004.

[17] SVMA, " *Atlas ambiental de Sao Paulo*", 2002.

[18] ONG, B. L. "*Green Plot Ratio: An Ecological Measure for Architecture and Urban Planning".* Landscape and Urban Planning, vol.63, p.197-211, 2002.

[19] WEISS, M., BARET, F. CAN-EYE V6.1 "*User Manual".* EMMAH laboratory (Mediterranean environmentand agro-hydro system modelisation). French National Institute of Agricultural Research (INRA), 2010.

[20] JONCKHEERE, I.et al. "*Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography*". Agricultural and Forest Meteorology 121: 19–35, 2004

[21] JONCKHEERE, I. G. C., MUYS, B., COPPIN, P. R. "*Derivative Analysis for In Situ High Dynamic RangeHemispherical Photography and Its Application in Forest Stands*". IEEE Geoscience and Remote Sensing Letter, 2, 296-300, 2005b.

[22] JONCKHEERE, I., NACKERTS, K., MUYS, B., COPPIN, P. "*Assessment of automatic gap fraction estimation of forests from digital hemispherical photography*". Agricultural Forest Meteorology, 132, 96–114, 2005

[23] GONSAMO, A., DISNEY, M., PELLIKKA, P.,"*The computation of foliage clumping index using hemisphericalphotography*", Agricultural and Forest Meteorology,149, 1781-1787.

[24] BRUSE M., "*Simulating the Effects of Urban Environmental on Microclimate with a Three-Dimensional Numerical Model*". In: Climate and Environmental Change, Conference Meeting of the Commission on climatology, Evora, 1998.

[25] DEARDORFF, J.W., "*Efficient Prediction of Ground Surface Temperature and Moisture with a Inclusion of a Layer of Vegetation".* Journal of Geophysical Research, Colorado, 83, 1978.

[26] JACOBS, C.M.J., "Direct Impact of Atmospheric CO_2 Enrichment on Regional Transpiration". Wageningen Ph.D. Thesis. Agricultural University, Netherland, 1994.

[27] BRUSE M., SKINNER C. J. "*Rooftop Greening and Local Climate: A Case Study in Melborne*". In: Biometeorology and Urban Climatology at the Turn of the Millennium, WMO, pp. 21–25.

[28] LALIC, B.,MIHAILOVIC, D. T. "*An empirical relation describing leaf-area density inside the forest for environmental modeling*" J.Appl. Met. 43(4) 641-645, 2004.

ECR Energy City Graz-Reininghaus



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1. Short Summary

The City of Graz is currently the fastest growing capital city in Austria. The demand for living space has grown rapidly in recent years and, according to forecasts, will continue to grow in the coming decades. In this context, the upcoming major construction volumes require sophisticated growth which meets requirements of sustainability. This was the motivation behind the development of the research project “ECR Energy City Reininghaus”. “Reininghaus” is a former brewery site and the biggest underdeveloped urban area in the City of Graz. The research project ECR aims to develop urban strategies for the new conception, the construction, the operation and the restructuring of the city district Graz Reininghaus. In order to cope with this complex task, a large transdisciplinary team, including five institutes of the Graz University of Technology, worked together on this research project. Furthermore, the development of several demonstration projects is planned for this area. The most advanced of these demonstration projects, called “Plus-Energy Network Reininghaus South” [6], will be presented in this paper.

Keywords: CO_2 neutral city district / plus energy buildings and networks / framework plan energy

2. The City District Graz Reininghaus

The overall aim of the research project *Energy City Graz-Reininghaus* (ECR) [1] is to support the developing activities of the municipality of Graz to establish a new city quarter in the area called “Reininghaus”. The area Reininghaus is an underdeveloped plot of land (a former brewery area) near to the city center of Graz (about 1800 m distance to the main square) with about 110 hectare space and a possible full capacity for about 12000 future inhabitants on a maximum net floor area of about 560000 m² (*Fig. 1* and *Fig. 2*).

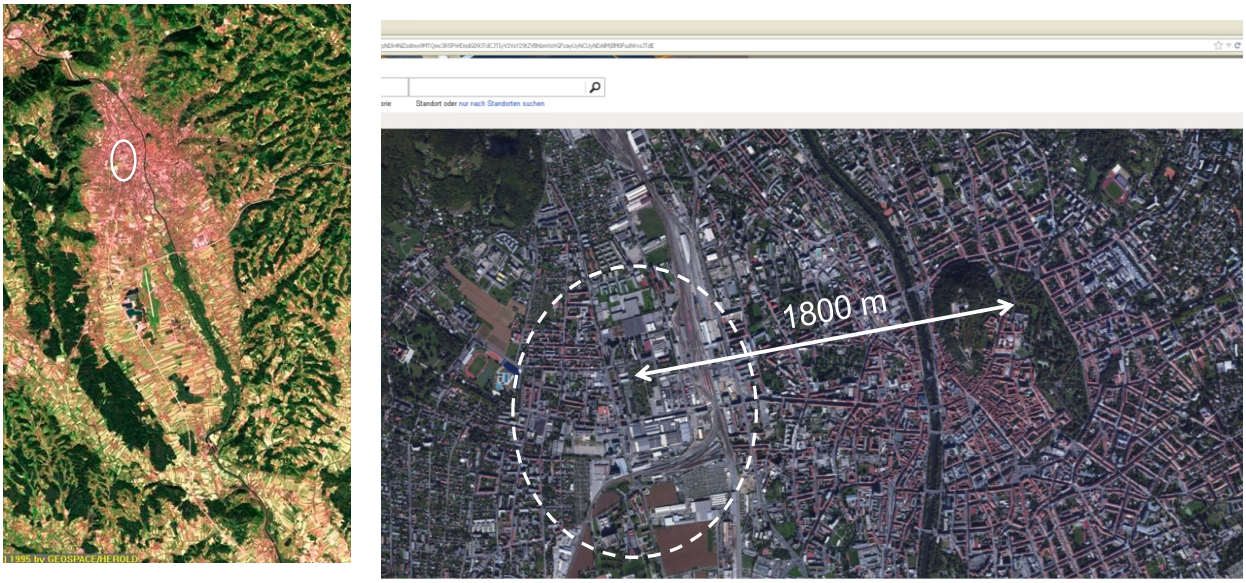


Fig. 1: left: city area of Graz, right: location of the Energy City Graz-Reininghaus, source: City of Graz, Executive Office for Urban Planning, Development and Construction



Fig. 2: Aerial photograph of Graz-Reininghaus, source: City of Graz

3. The Research Approach

In the scientific community there is a long tradition of working on the energy efficiency and/or sustainability of one building. Typical research teams in this field consist of an architect, an energy planner and an expert in the field of building physics. Usually, the review systems in these cases are relatively limited and the task is clearly defined and manageable. The extension of the review system to a group of buildings or even to a whole city district increases the complexity of the task in three different ways:

The number of system components increases

On the one hand, working on the “district scale” means dealing with at least hundreds of dif-

ferent buildings and on the other hand, the number of the involved stakeholders (individuals and institutions) increases.

The interaction between the system components increases
One important interaction lies in the architectural design of the space between the individual buildings to create streets and squares. Another important interaction between the individual buildings lies in the technical infrastructure, which creates different kinds of networks (district heating, electricity supply, water supply, wastewater sewer)

The review time increases
In contrast to when working on the realization of one building, which, may be completed within a few years, the development of a whole district means planning in decades.

The following findings have to be taken into account: According to the above-mentioned increase of the complexity of the project itself, the complexity of the project management increases, which leads to a dramatic increase of time consumption in that field. The limitation of the research projects to a duration of three years means that they are limited in their scope of action to a small time slot of the whole development. Because the parameters of the development cannot be predicted for such a long working period, the development scenarios are a fundamental aspect of the project work. Another consequence of the long period of development lies in changing the level of abstraction, which increases and leads straight to thinking on the level of typologies.

4. The Research Team

One fundamental component in the research setup is the formation of the research team and the communication structure between all relevant stakeholders. Consequently, the City Planning Department (Stadtbaudirektion) of the City of Graz, the Graz University of Technology and the County of Styria (Department 17A energy economics and general technical affairs), have worked together to process the submitted lead-project. The Environmental Department of the city of Graz and the Graz Energy “Energie Graz” provide additional professional input for the project. The research team of the Graz University of Technology, represented by the Institute of Urbanism, is composed of the Institute of Thermal Engineering, the Institute of Technology and Testing of Building Materials and the Institute of Process and Particle Engineering. The Department of Geography and Regional Science of the University of Graz supports the project as regards climatological assessment. Several companies and external experts are involved with the project team, this currently being ECO-World Styria,.

5. Framework Plan Energy

The research project [3,4] is based on the idea of designing an energy self-sufficient and CO_2- neutral city district. For this reason an “energy framework plan” covering the whole district has been developed [5]. The framework energy plan concerns various fields of investigation. Electric energy, thermal energy and embodied energy has to be taken into account as well as the methods of urban design and the rules and mechanisms of the local authorities. The work plan is structured as follows:

- Survey study of supply and demand, locally available energy potential versus demand
- Development and simulation of different scenarios for the overall energy concept
- Development of default values for further development

5.1 Survey study of supply and demand

In order to provide a comprehensive analysis of the future supply and demand in the area,

the waste heat opportunities of the companies in the neighbourhood have been investigated as well as the possibility of using geothermal potential. On the demand side, different scenarios for the further development of the city quarter have been created. Different levels of heat protection of the buildings as well as different scenarios for building density have been taken into account. As a result of these investigations, demand and supply scenarios for heating and electricity have been developed. Figure 4 shows an example of the preliminary results of the energy potential analysis, which are part of the final report of the potential assessment for reference framework energy [1]. The color of the Quarter provides information about the coverage regarding heating demand. The electricity is indicated with “+” in areas where it is easy to meet the demands and “–“ in ones requiring energy, because the self-generation is not sufficient.

As a result of the potential analysis, the heat demand may be covered with endogenous resources (regional by solar and geothermal use). Furthermore, it will be possible to use the waste heat from the surrounding industrial plants, which is sufficient for the supply of the city district. However, the electrical demand cannot be satisfied using only photovoltaic systems.

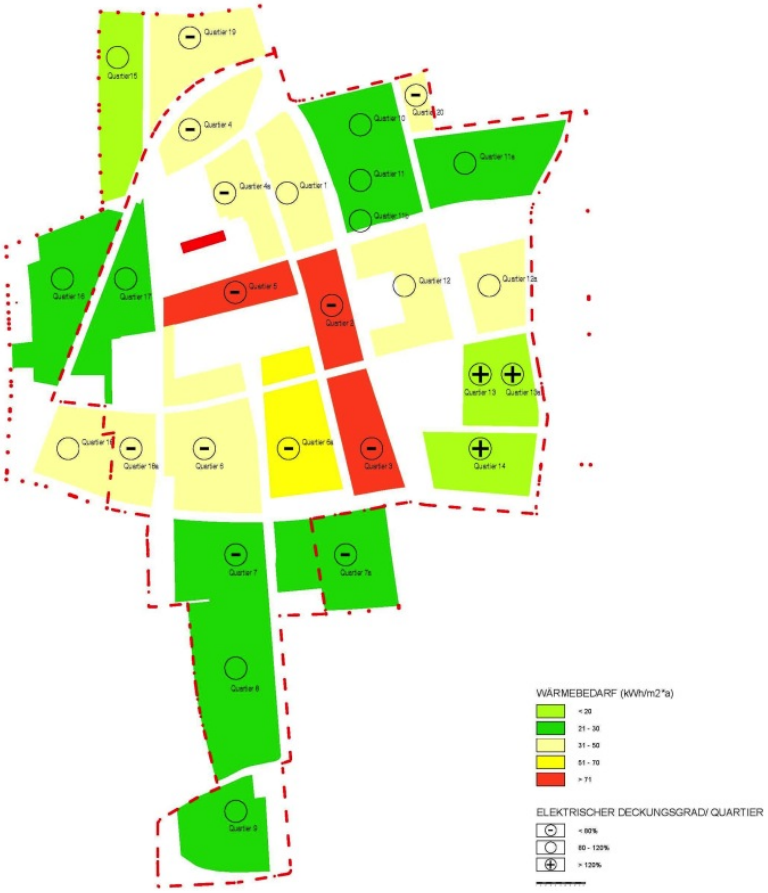


Fig. 3: possible heating demand coverage by using local heat resources and possible electricity demand coverage with photovoltaic on the quarter level. Source: ECR Coreteam & City of Graz, Executive Office for Urban Planning, Development and Construction [3]

In addition, the project team searched for and investigated similar research and development projects on a national level as well as on a European level. The contact with several project teams was initiated in order to compare experiences. One of the most promising projects in this context is “NACHASPERN” – the sustainable city district "Aspern" and the city district Freiburg-Vauban [LIT]

5.2 Development of different scenarios for the overall energy concept

The initial working hypothesis describes the conception of an energy self-sufficient city district. This should be seen as a visionary approach to force the project team to examine local energy potentials as far as possible and to anticipate upcoming future developments.

The main focus of the examination is the aim of the inter-linkage of buildings and industrial energy resources as more or less sustainable energy producers. Central supply solutions will be confronted with semi-centralized and decentralized possibilities of inter-linkage. For example, taking advantage of the cooling energy potential of the existing brewery cellars or the waste heat of industrial processes already located in the city district (Fig. 4).

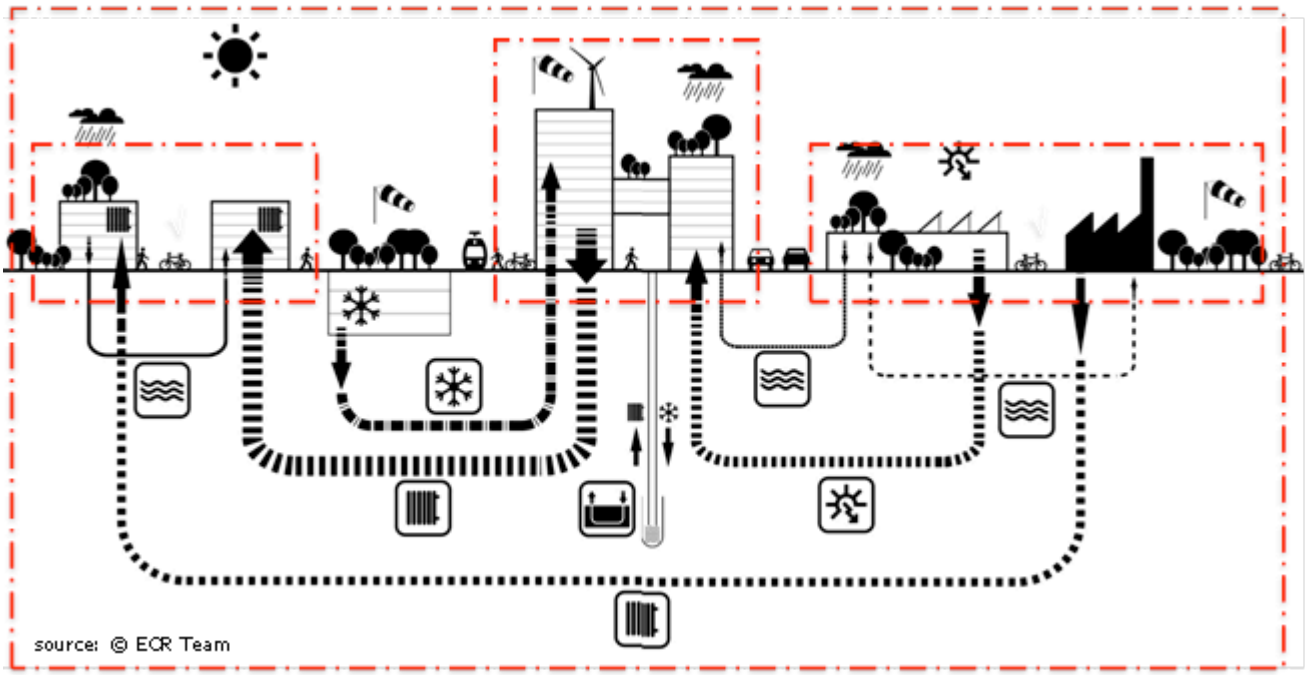


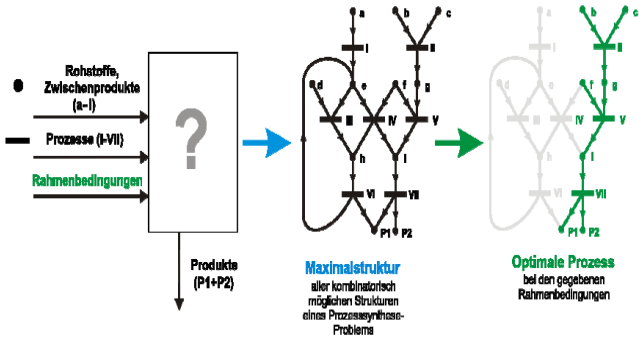
Fig. 4: schematic sketch to illustrate the changing of single system borders to a holistic approach

One possible approach is the investigation of technical building equipment (energy saving heating and ventilation systems, avoidance of air conditioning). In addition, urbanistic attempts (activation of possible energy potentials, natural heat of the earth, building density, best possible climate-oriented positioning of buildings, solar activation of roofs and facades, use of process heat, block-type thermal power station, feeding of the energy surplus to communal networks) have to be taken into account.

The simulation and optimization of the whole energetic system is a very complex problem. Several sources of energy can be processed to a variety of energy sources within a large set of technologies and nets. The question arises how to investigate such a complex system. The project team decided to follow two different, parallel approaches.

The “design-based” approach is open to a large variety of optional components which can be interlinked to an energy system. It can be done by Process-Network-Synthesis (PNS) on the basis of energetic and economic parameters for the technologies considered [10]. The Process-Network-Synthesis is able to combine these parameters with sufficient energy systems and optimizes a setting of a maximum structure to enable an optimization of a chosen objective simulation function like costs or greenhouse gas emissions (e.g. CO_2).
The method is the outcome of an ongoing development within the framework of process

technology. The structural heart of the method is a bipartid graph method (P-graph-method) which models all respective process networks that can be applied in advance and provides combinatorial rules to find the most feasible network solutions of the generated process network (maximum structure). Relevant technologies and the related flows of materials and energy (in this project especially electricity and heat) enter the maximum structure. This maximum structure is the initial point for a precise evaluation of all feasible process networks. Over a branch-and-bound optimization routine, all raw materials, energy flows and intermediates are linked to the desired products at the end of production/demand chains and can be computed with the help of software built around the p-graph method.



Maximum Structure **Optimum Structure**

Source: p-graph, basic software employing this method is freely accessible from www.p-graph.com/pnsstudio.

The final result of such an optimization process greatly depends on the system environment (costs of resources, technologies, transport, restrictions, spatial planning, …). According to the specific cost of building applicable facility networks, the most feasible structure (optimum structure) is generated.
Energy optimizations of smart energy systems for urban areas have been recently described in different projects [11, 12]. Fig. 5 shows an overview of the chosen approach describing the special framework conditions of this project.

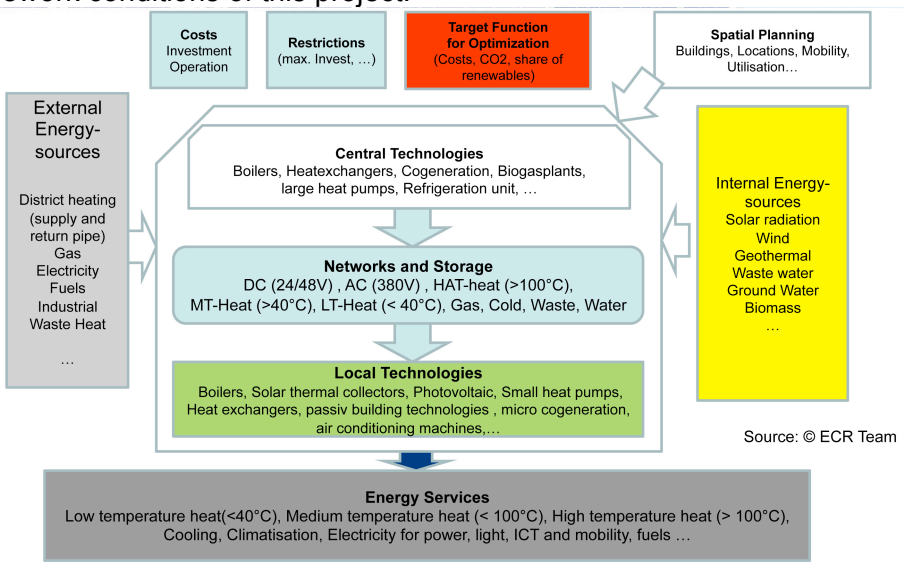


Fig. 5: Systematic approach of the process-network-synthesis, source: Hans Schnitzer, TU Graz

The most resource efficient and economically feasible process networks of the generated maximum structure can be calculated with PNS. Setting the economic value added as target value provides an efficient way to optimize energy networks. It is also possible to optimize an ecological target value (e.g. finding the process networks with the lowest CO_2 emissions) but this is not considered in the project. However, an ecological assessment (e.g. ecological

footprint evaluation) could be added additionally after the project, simply by taking the final result of the PNS-optimization into account.

In contrast to the previously mentioned “design-based” approach, the “assessment approach” focuses on a small variety of optional energy system components. The design of the energy system is mainly created on the basis of proposals made by the planners and developers responsible. Thermal simulations have to clarify the determination of relevant system parameters. In the case of the presented project, the use of thermal energy from waste water resulting from an industrial process is explored. The temperature of the waste heat is increased by a heat pump process and distributed to a district heating system which provides energy for heating and domestic hot water. The inquiry will be carried out with a simulation tool called TRNSYS [LIT]

5.3 Development of default values for further development

The research project ECR focuses on two different levels. On the one hand, it deals with the development of the city district Reininghaus itself. The key objective is the development of a comprehensive energy concept regarding urban, thermal and building engineering for an entire city district. An overall energy master plan will be an integral part of the “Charta Reininghaus” (agreement on the development of buildings) and will set preliminary standards for future investors. On the other hand, the project has to work out generally valid results that can be helpful in similar development projects. In this regard, the followings aspects have to be worked out.

- The initiation and supervision of the development process for the energy-optimized and sustainable city district Graz-Reininghaus.
- Development of energetically specific values for the anchorage in private-legal contracts between the City of Graz and future investors.
- Concepts for the suitable integration of the energetically specific values in local plans/ regulations (City Development Concept STEK Graz, City-District-Development)
- Concept Graz-Reininghaus and Development Plans for the 20 city-quarters.
- Drawing-up of recommendations and founding of a knowledge base for future energy-optimized city developments in Graz and the County of Styria

6. Plus-Energy Network Reininghaus South

The multifunctional neighborhood *Plus Energy Network Reininghaus South* (+ERS) is realized within the urban planning area of Graz-Reininghaus. The project aims at optimizing the energy concept of the single buildings as well as of the building cluster in order to achieve a plus-energy standard within the residential neighborhood. The research project partners are the Aktiv Klimahaus Ltd (Investor) and AEE INTEC - Institute for Sustainable Technologies, Nussmüller Architects ZT Ltd and Graz University of Technology.

With the realization of Plus Energy Network Reininghaus South (+ESR), a flagship building will be put into practice, which sets economically, technically and organizationally innovative solutions for the construction of Plus-energy linked building concepts of the future. The Plus-Energy attempt will not be limited to the building-level, but will operate on the level of a multi-functional building-linking concept. In the first step, the single building will be optimized and changed from an energy consumer to an energy producer. In the second step, synergies within the building-linking concept lead to a further optimization of the system.

The new, multi-functional neighborhood is split into two parts, the first being the front building complex (*Fig. 5* on the left marked with a blue line). It will consist of offices and commercial premises with a supermarket and apartments for elderly people (assisted living) on the first floor. This complex (net floor area of about 23 000 m²) developed by “WEGRAZ Gesellschaft für Stadterneuerung und Assanierung m.b.H.” will form a block along Peter-Rossegger-Straße and provides shelter for the twelve residential multi-family houses behind. The second part (*Fig. 5* on the left marked with a red line), was designed for residential use (net floor area of about 10 000 m²) and consists of 12 „Point houses“ with 143 flats.

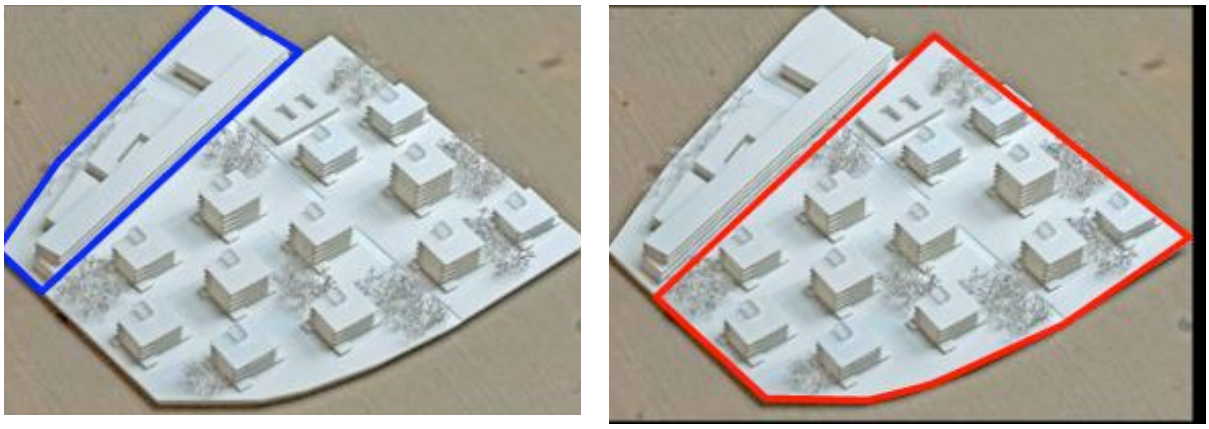


Fig. 6: Reininghaus area on the left picture (Source: ECR Coreteam & City of Graz, Executive Office for Urban Planning, Development and Construction and a model of the planed buildings on the right side of the picture, Source: AEE INTEC & Nussmüller Architects ZT Ltd

The starting point of the project development is the optimization of the energy concept of each single residential building: both the optimization of the energy supply by so-called “energy piles” and photovoltaic modules and also efficiency measures and the reduction of energy use on the part of the residents.. The next step is to optimize the heating network that connects the twelve residential buildings. Finally, the biggest impact will be the establishment of the heat network with the front building complex. The expected consumption pattern of the office and commercial premises diverges from the one of the residential buildings. Therefore a high potential for lowering peak loads is evident. To guarantee the overall goals aiming towards sustainability, the research project will be assessed using the TQB building certification system both in the planning stage and during the in use stage with the use of a monitoring project [7,8,9]. Fig. 8 shows the first building realization of the Plus Energy housing flagship building in Graz-Reininghaus.



Fig. 7: Building site Plus Energy Building in Graz-Reininghaus



Fig. 8: Completion of the first Plus energy Building in Graz-Reininghaus

7. Sustainable urban development

In order to ensure the high sustainability of the future urban neighbourhood, ECR sustainability aspects were already being considered in the early planning stage. Furthermore, the sustainability evaluation has been carried out based on different system boundaries described in the following.

7.1 Sustainability management in ECR-project

The upcoming CEN/TC 350 standards provide different approaches for facilitating the sustainability of buildings. Thereby, social, economic and environmental aspects as well as technical and functional performance should be included and fulfilled simultaneously.

To show the pros and cons concerning sustainability performance of urban development, different development scenarios based were evaluated. During the last decades, various building certification systems has been placed on the market. In our case we decided to apply the DGNB assessment method for urban neighbourhood development. The results indicate that parameters such as building density and system boundary are important aspects in the context of Life Cycle assessment aiming at improving sustainability performance in urban neighbourhoods.

7.2 Sustainability assessment of Plus-Energy network Reininghaus South

The evaluation of the sustainability assessment [8] is based on the ÖGNB building certification system. The assessment is divided in the five main areas: Location and Equipment, Economy and Technical Quality, Energy and Supply, Health and Comfort and Building materials and Construction.

A maximum of 1000 points can be reached, 200 in each assessment area. The assessment includes qualitative as well as quantitative criteria. The present building reached 880 points with a heating energy demand of 7,22 kwh/m2*a. The final assessment result is shown in Figure 9.



Fig. 9: Completion of the first Plus energy Building in Graz-Reininghaus

8. Conclusion and Outlook

A broad and comprehensive discussion with different project partners is necessary to cover all fields of district/ urban development and to consider all the different demands and needs. This does, however, take a lot of time and requires a great deal of effort on the part of the project partners.
What remains open are political questions e.g. how to deal with the waste heat from industry and what may be stipulated for private companies and investors?
Dealing with energy supply on urban scale also raises questions on how to guarantee the energy supply without the need for building a backup system (local waste heat vs. district heat).

Looking at the process, it is obvious that urban development requires the involvement of many stakeholders and many (different) interests as well as the solving of complex issues, which will require time. Technical questions can be solved far more easily than other questions.

The expected result for the *Plus Energy Network Reininghaus South* is that the successful implementation of the project will create an exemplary role model and demonstrate the economic feasibility of plus energy networks for housing. It will both contribute to a CO_2-neutral building portfolio and enable a self-sufficient and sustainable operation of buildings while improving the user comfort

A major innovation within the subproject *Plus Energy Network Reininghaus South* will be that, in contrast to already existing case studies, the successful integration of the project in the energy network will demonstrate the use of energy monitoring over a certain period (proof of concept of the network idea).

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References

[1] Federal Ministry for Transport, Innovation and Technology (BMVIT), Austrian Research Promotion Agency (FFG), *ECR Energy City Graz - Reininghaus: Urbane Strategien für die Neukonzeption, den Bau, Betrieb und die Umstrukturierung des energieautarken Stadtteils.*
http://www.hausderzukunft.at/results.html/id5854
http://download.nachhaltigwirtschaften.at/hdz_pdf/events/20091009_hdz_workshop_tu-graz_ecr.pdf

[2] Federal Ministry for Transport, Innovation and Technology (BMVIT), Austrian Research Promotion Agency (FFG), *Themenworkshop: Zukunftsfähige Siedlungs- und Stadtentwicklung,*
http://www.hausderzukunft.at/results.html/id6619

[3] RAINER E, HOFBAUER K, TATZBER F, TRAJANOSKA B, LAZAR R, *Endbericht, Potenzialabschätzung, Rahmenplan Energie Graz-Reininghaus, Stand im Forschungsprojekt ECR, Recherche und Analyse von Referenzprojekten,*

Energiepotenziale Graz-Reininghaus, 2012
[4] GEIER S, *+ERS Plusenergieverbund Reininghaus Süd, Presentation im Themenworkshop: Zukunftsfähige Siedlungs- und Stadtentwicklung, Haus der Zukunft in der Praxis, Dienstag, 29. November 2011, Wien*
http://www.oegut.at/downloads/pdf/tws-stadtentwicklung_vortrag-geier.pdf
[5] RAINER E, *Haus der Zukunft Plus Leitprojekt ECR Energy City Graz-Reininghaus und sein erstes Stadtquartier +ERS Plusenergieverbund Reininghaus Süd, Forum Green Cities, FH Regensburg, 30.09.2011*
[6] RAINER E, *City Developments in small steps exemplified by Graz West, VUT Brnó, 17.10.2011*
[7] PASSER A, KREINER H, CRESNIK G, MAYDL P, *GenormteNachhaltigkeit? Nachhaltige Gebäude – Planung, Betrieb und Bewertung, enova, FH Pinkafeld, 2010*
[8] RAINER E, HOFBAUER K, MACH T, PASSER A, *ECR Graz -Reininghaus, enova, FH Pinkafeld, 2010*
[9] Federal Ministry for Transport, Innovation and Technology (BMVIT), Austrian Research Promotion Agency (FFG), monitorPLUS, http://www.ecology.at/monitor_plus.htm
[10] FRIEDLER F, VARGA JB, FAN LT.: Decision-mapping: a tool for consistent and complete decisions in process synthesis. Chemical Engineering Science (50) 1995, pp 1755-1768
[11] NARODOSLAWSKY M, STEINMÜLLER H, STÖGLEHNER G, PÖSCHKO E, EDER M, NIEMETZ N, SANDOR N, et al, Energieversorgung Braucommune in Freistadt, FB-Vision Neue Energien 2020, Freistadt, 2010
[12] MAIER S, GEMENETZI A, EDER M, NARODOSLAWSKY M, Optimal Renewable Energy Systems for Industries in Rural Regions, Conference Papers, 8th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Dubrovnik, Croatia, 2013

Literature.

FLUCH, J.; BRUNNER, C.; MUSTER-SLAWITSCH, B.; MOSER, C.; SCHRANZHOFER, H.; HEIMRATH, R.: Optimised Storage and Energy Efficiency Concepts in Industries, Commerce and District Heating Business: Based on Tool SOCO – Model and Measures Identified. – in: Chemical Engineering Transactions, 35 (2013), in press

FLUCH, J.; BRUNNER, C.; MUSTER-SLAWITSCH, storage optimization concepts in industries, commerce and district heating businesses, Chemical Engineering Transactions, 29, 493 – 498

TRNSYS. (2012). Solar Energy Laboratory (SEL), Wisconsin, USA.

Wien 3420 Aspern Development AG, ÖGUT, AIT, e7; NACHASPERN – „Nachhaltiger Stadtteil "Aspern, Wegweiser für eine zukunftsweisende Stadt- und Siedlungsentwicklung“

M. BUCHERT, D. BUNKE, H. Franz, J. Lange, C. Nobis, C. Sperling, G. Steimer, R. Tiltscher „Nachhaltige Stadtentwicklung beginnt im Quartier“, Ein Praxis- und Ideenhandbuch für Stadtplaner, Baugmeinschaften, Bürgerinitiativen am Beispiel des sozial- ökologischen Modellstadtteils Freiburg-Vauban; Institut f. angewandte Ökologie, Forum Vauban.

Social performance assessment of buildings according to the European standard prEN 16309



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Summary

Social sustainability aspects of construction and construction works are discussed in various contexts and thus address a vast amount of topics, aims and objectives. This paper describes the concept that has been developed for the assessment of buildings by the European Committee for Standardization (CEN).

It was still in the beginning of this century that sustainability had a high focus on environmental aspects only. But, when defining in 2003 the working program for developing standardised methodologies in the standards of CEN TC350, all stakeholders committed to all three dimensions of sustainability: developing assessment standards for the environmental, economic and social performance of buildings. Over the years Europe-wide consensus was sought and found on how to measure social performance aspects that define and influence the building user's health and comfort, safety, accessibility, etc.

Following the standard's methodology, by means of 22 main social performance aspects it allows now to characterise a building's social performance. The new draft standard (prEN 16309) has been finalized recently with the methodologies for this assessment. It represents a comprehensive view on all 22 aspects that determines the social performance of the building-use as part of the building's life cycle. The assessment of the 22 aspects is carried out and presented in 7 information modules, each representing major activities in the building use: e.g. using the building, maintaining it, repairing, refurbishing, etc. All the processes of these activities may define how the building is performing for the user in terms of comfort, safety, etc. The methodology successfully follows the same structure and philosophy as applied in the CEN TC350 standards for environmental and economic performance assessment.

Furthermore there is a close relation of the CEN TC350's building assessment framework to the European regulatory framework, in specific to the CPR (Construction Product Regulation) which is outlined and discussed.

Keywords: social sustainability, social performance of buildings, CEN TC350 standards, EN16309, methodology, social indicators, CPR

1. Sustainability assessment in different views

There are many angles for making an assessment of the performance in sustainability: from evaluating the sustainability of a small and single object or product to assessing the worldwide consequences of policy choices. Sustainability is a "container" word that on itself

does not set limits to the objects of assessment, to the boundaries of the assessment nor to the type of indicators of assessment.

Ness et al. [1] have given a categorization of sustainability assessment methods by differentiating their temporal focus. Methods or tools can either be retrospective (indicators and indices) or prospective (integrated assessment) or both (product-related assessment). Indicators and indices may cover single aspects e.g. I/O energy flows or several aspects; the latter being non-integrated like the UNCSD indicators or integrated like the ecological footprint. Integrated assessment methods also have a spatial focus and serve as policy instruments (Environmental impact assessment, strategic environmental assessment, risk analysis, vulnerability analysis, system dynamics, etc.). Among the product-related methods are life cycle assessment and life cycle costing which can be either attributional ("retrospective") or consequential ("prospective").

Finkbeiner et al. [2] have introduced a "Maslow pyramid" for sustainability assessment approaches: At the bottom of Maslow's pyramid of human needs are basic needs like breathing and food, followed by needs for safety and love in the middle part and on the top reside esteem and self-actualization. Finkbeiner et al. have situated Life cycle thinking as a qualitative and broad concept at the bottom. Then quantitative but single aspects like carbon footprinting are next, followed by life cycle assessment covering all environmental impacts quantitatively. Above are resource efficiency and eco-efficiency assessments that combine environmental and economic indicators. On top of the pyramid is the full life cycle based sustainability assessment with the social dimension added.

Halog/Manik [3] have set up an integrated framework for assessing a system's sustainability. In the core is the assessment of the three dimensions (ecological, economic and social dimension) according to the methods that have been established (life cycle assessment, materials flow analysis, etc.) or that are currently developed (social life cycle assessment). This is supplemented by methods for integrating stakeholder interests via AHP and by system modelling methods.

Within the complex landscape of numerous sustainability assessment methods being more analytical or more policy related, more programme- or tool-oriented, covering various issues quantitatively or qualitatively, etc. the presented CEN TC350- assessment methods need to be positioned firmly. Standardisation anyway is a matter of conventions, of good communications and of positioning an assessment in order to avoid Babylonic confusions. The following sub-chapters address some of the controversial issues concerning social building performance assessment and shall thus serve to describe the focus and to set the limits of the CEN TC 350- assessment method.

The series of standards of CEN TC350 follows a mandate of the European Commission providing harmonised methodologies for the sustainability assessment of construction products and works. The standards enable comparability of the results of sustainability assessments of buildings. A system (principles, data requirements and methodologies) for the assessment is provided and the impacts and aspects are defined that can be expressed with quantitative or quantifiable indicators, which are measured or calculated. It applies to all CEN-CENELEC standards that EN-standards reflect a common view and that existing and applied methodologies are within the scope of the respective standards. The standards of CEN TC350 do not intend to constrict or predetermine scientific LCA of buildings that is driven by research interests and will often focus on specific questions. But for rules and regulations, for building certification and for assessment schemes it is important that common and transparent rules are developed to ensure that results are comparable.

The CEN TC350 standards are developed as a basis for tools for the assessment and design of more sustainable buildings. The methodologies defined in the CEN TC350 standards are not intended for product comparisons and are not meant for selecting products by consumers or buyers. The standards allow product manufacturers and product developers to evaluate the contribution of a product to the sustainability performance of a building.

1.1. Social versus Societal

Contrarily to the environmental or economic assessment the meaning of the social assessment is not so clear-cut. In Tritthart/Rohracher [4] a matrix was developed to provide a structure in which the elements of social sustainability of buildings are integrated. The columns held the aspects as they occur during the building's life cycle stages, i.e. from social impacts of the production of building materials and components, during the design stage, during the construction process, during the use and finally at the end-of-life stage. In the rows social issues according to the 'system-level' of its impact were situated, i.e. from social aspects of using the building itself to social impacts on the neighbourhood / local environment and then to the broader impacts on society at large.

Although it is the dedicated aim of the CEN TC350-work to take into account the whole life cycle it became apparent that, at this point of time, it was only the impact of the building on the user that could be covered in a European standard. Several issues beyond this narrow focus were discussed, e.g. stakeholder involvement, responsible sourcing, architectural quality, etc. but were lacking a generally accepted calculation method. The impacts on the neighbourhood were limited to loads caused by the building in use (e.g. noise, glare, etc.) not comprising any possible benefits or issues like increased traffic, etc.

The societal evaluation would describe the impact of the building and the use of the building in a wider context. Possible questions of this wider context are: What effect has this building (e.g. a big office building) on the movement of people (transportation) in a public infrastructure, what is its effect on the supply of public space, what need for facilitating services and utilities in the direct neighbourhood (e.g. a data server-centre on the supply of electricity, gas, water, data grid, etc.) will arouse? Are regional employment possibilities generated? Is the cultural heritage of the community affected by the building?, etc. The choices to make depend on the point of view: is it the building that is assessed or is the scope to assess the impact that the specific building has on societal systems?

The above mentioned issues are part of urban planning considerations that among others deal with interaction between buildings, between buildings and infrastructure, e.g. buildings and energy supply systems, and between buildings and (local) society, etc. These "higher level" design issues need different, e.g. consequential assessments.

CEN TC350 assessment methodology is limited to the social performance of the building in its use, that means where there is a "user". The user is every person that is regularly entering into the building, employees, residents, janitors, service personnel, etc.

1.2. Process-assessments and Social life-cycle-assessment

The stages of the life cycle of the building comprise several typical processes, to name the most important ones: design process, production processes, construction process, operating process, demolition process, recycling processes. The processes have a direct impact on all persons that are involved in these processes, in specific on workers that are hired to run them. There are many instruments and tools that deal with environmentally sound process management, e.g. the EMAS as defined most recently in the EU-Regulation 1221/2009.

Social implications of the processes are covered also by a variety of legal and of voluntary instruments. Some of those building related matters are: occupational health issues, safety of workers in specific on a construction site, corporate social responsibility (CSR) commitments of the companies that are involved. Some are to be assessed in accordance with methodologies and criteria defined in Regulations or Directives while others follow a standardised methodology. For instance the assessment of processes and applied policies in a company is covered by the ISO standard ISO 26000.

Social life cycle assessment (SLCA) evaluates the social impacts that occur during the life cycle of a product. In the current early stage of the development of SLCA, the methodology draws on elements that are set by human rights, life cycle thinking (e.g. for procurement

decisions of authorities), and corporate social responsibility. Instruments and methods of related fields are often further elaborated and provide inputs for SLCA, e.g. the working environmental LCA (WE-LCA) and social impact assessment. Of specific interest is the identification of 'hot spots' of social relevance, like child labour or illegally employed construction workers.

An important constituent of SLCA is the stakeholder concept. A stakeholder is defined according to ISO 26000 as individual or group that has an interest in any decision or activity of an organization. Stakeholder engagement is an activity undertaken to create opportunities for dialogue between an organization and one or more of its stakeholders, with the aim of providing an informed basis for the organization's decisions. In SLCA, categories (impacts, like working conditions and rights, health, security, etc.) are in a first step assigned to stakeholder groups – typical stakeholder categories are "worker", "consumer", "local community" and "society [5]. If it is a building that is assessed the primary/main stakeholder to take into account is the building user.

A precondition of the CEN TC350 standards was to restrict on the building performance and not to deal with process management decisions. However, the consequences from processes on the user of the building are assessed. Building management decisions are e.g. decisions on maintenance (e.g. cleaning intervals), on repair and refurbishment of the building. In some buildings even the operation of HVAC systems is centrally influenced, e.g. hot water temperature or heating system set points. These issues evidently determine the social performance of the building and have to be included in the assessment. Examples for management decisions that do not have an effect on the performance but are albeit crucial for the satisfaction of the users are the provision of a help-line or of documentation.

1.3. Integrated building assessment

Since the 1990's several building assessment systems have been developed in many countries in the world. The starting point was without doubt environmental concerns but human needs like good indoor climate and questions that touch both social and environmental aspects like public transport connections and proximity to services have often been integrated, too. Nevertheless these issues were stringed together rather arbitrarily and not systematically. For a discussion of the most well-known assessment systems and their strategies to integrate social aspects and impacts refer to Tritthart/Rohracher [4].

In the last years some research projects have been conducted to advance towards integrated building assessment. Within the LEnSE project for the first time a differentiation into the three dimensions of sustainability was introduced: the ecological, the economical and the social one. A comprehensive list of criteria was compiled by reviewing existing systems and literature. Some criteria were elaborated and a generic method to arrive at an aggregated result was proposed [6].

SuperBuildings was a research project funded by the European Commission under the FP7 Cooperation Programme project (http://cic.vtt.fi/superbuildings/). Its aim was to go one step beyond standardization by considering the output of the standardisation processes and focus on the validity of sustainable building indicators, on comparability of assessment results, benchmarking criteria and the usability of indicators in building processes. Sustainability assessment requires a substantially more complex approach compared to those for environmental and health aspects only. Consequently the project dealt with the question, how an assessment system needs to be structured and what it needs to contain in order to deal with the full complexity of sustainability assessments. In specific it was found that indicators of most assessment schemes do not cover the full range of sustainability issues.

The SuperBuildings-experts recommended that the subjects of concern should follow the three "dimensions" of sustainability: the environmental, economic and social dimension. In each dimension the subjects of concern (which are also referred to by the term "areas of protection", "safeguard subjects" or "areas of concern") are split into values specific to this dimension (like e.g. biodiversity, human health, etc.) and into stability aspects (like social

equity or economic prosperity). Specific goals could be consequently defined and indicators that could show the performance of the object of assessment. Different stakeholders need appropriate aggregation of indicators and emphasis on their area of interest e.g. depending in which stage of the building's life cycle they are engaged.

In addition to the common categories such as land use, resources, energy (which can be classified as resource inputs) and resulting impacts (e.g. on health and on local and global environment and on financial matters) further categories relating to the outputs in terms of benefits resulting from the use of the building will need to be included into consequential sustainability assessments. Sustainability requires a long term perspective. Consequently topics such as durability, resistance (resilience) and adaptability as design parameters come to the forefront [7]

In the concept of CEN TC350, technical and functional aspects play an important role as requirements that are set up by regulations, by clients, by architectural design and by the choice of materials and construction techniques. But the building's performance according to these aspects is not assessed. The functional design, followed by the technical design of a building (or part of a building) is excluded from an assessment according CEN TC350. However all what is resulting from this design (or from the existence of a building) is scope of the CEN TC350 assessment. The projected or realised functionalities and technical performance are handled as basic background or as the "fundament" of the assessment and consequences or impacts that are caused by them are assessed. The figure 1 shows the relevance of the technical and functional aspects within the building assessment and other assessment methods.

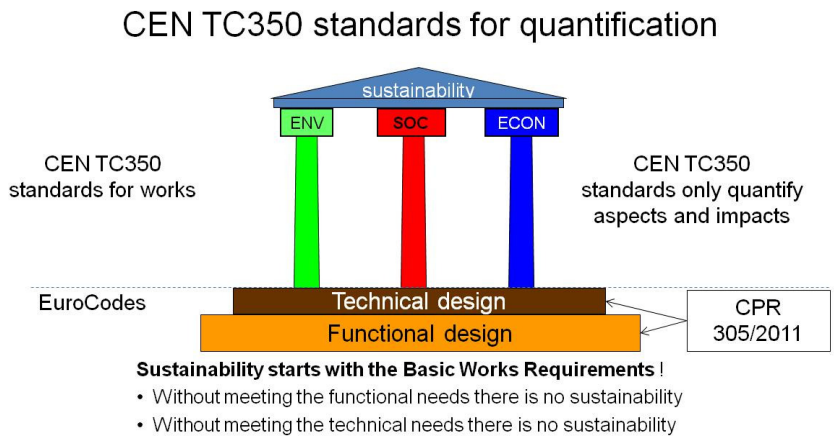


Fig 1: Greek temple graphic

2. Mandate to a common language

For a declaration of sustainability and in general for reliable information on sustainability a common language is prerequisite [8]. It took almost ten years from the first initiatives to have a whole set of standards available for sustainability assessment of buildings and of construction products. The construction sector agreed with the European Commission to develop a common language for communicating environmental performance of products and to develop a set of European standards for this purpose. The aim of the mandate M/350 "Sustainability of construction works" was to develop voluntary horizontal standardised methods for the assessment of the sustainability of construction works and core rules for the product category of all construction products. The standards in the suite of CEN TC350 describe the harmonized methodologies for assessment of environmental, social and economic performance of buildings and building products over their life cycle. In particular, the environmental performance of products is described in the Environmental Product Declarations called EPD (according ISO 14025).

Most of the sustainability standards - all environmental assessment standards - are finalised and available now. The package of standards will be completed with the standard on social performance methodology (EN16309, in 2013) and with the standard on life cycle costing methodology (EN16627, in 2014). The standards provide the indicators, the methodologies for measuring and quantification of the indicators, and provide the communication format. The parameters for measuring sustainability are selected and agreed indicators as used and widely accepted across Europe. We have 22 environmental parameters (indicators), 6 aspect categories for describing social performance and 3 indicators for quantifying the economic performance of a building. Of course the environmental performance parameters, the social parameters and the economic parameters are interlinked and inter-depending.

There is a vast literature on sustainability indicators and indicator systems, and requirements on both. In accordance with the CEN procedures at the start of the standardisation process the existing French and Dutch national standards were taken into account including the aspects, impacts and their indicators. In the CEN TC the National Standardisation Bodies and other expert-stakeholders representing European industry associations, architects and contractors associations, consumer organisations and program owners are represented. This community evaluates and selects proven and widely applied indicators for describing and quantifying accepted aspects and/or impacts of sustainability.

3. Sustainability information down the construction chain

The standards then deliver a whole ‘basket’ of sustainability indicators, they do not qualify buildings or construction products, therefore are applicable across Europe. A program, e.g. BREEAM, DGNB, etc. or national/regional rules or regulations, or even a building owner, or private consumer, may set minimum or maximum values to the building performance. Programs are helping to process all the parameters into qualifications; they use (or have announced to use) the CEN TC350 standards for collecting the data on product performance (EN15804 based EPD's) and apply them in the environmental, social or economic assessment of the building; amongst others the environmental assessment according EN15978. After quantification of the building's impact over its lifecycle these programs have their own methodology for qualifying on the basis of grouped parameters, giving different weight to different parameters. Unfortunately this is not always very transparent and well communicated. It is good and acceptable that programs compete but the rules for qualifying sustainability performances need a standardised and all transparent methodology yet.

A sustainability assessment is much more than collecting data in a spreadsheet. It requires competence of the assessor on the use of the building, the construction process, the end-of-life processes, but also on adapting scenarios and corresponding product data given in the EPD. But on his turn the manufacturer - the sole owner of the EPD and liable for his declaration - cannot limit his assessment to his production process only: all upstream information must be included in the assessment. This is followed by scenario based downstream aspects and impacts of the product. This makes product life cycle assessment complex and costly. "The level playing field, fairness and transparency has a price". The functional and the technical performance of a construction product is depending on the building system and it requires scenarios in order to make a useful declaration on a quantified contribution of the product to the sustainability. Comparing products and selecting products based on environmental performance stated in an EPD is only possible under strict conditions. In practice a direct comparison by means of EPDs is impossible: the scenarios in the life cycle should be identical. EPDs are the input for a holistic building assessment taking into account the functional and technical performances in a building context. For a producer this also means that his contribution to an higher sustainability (environmentally, socially and economically) of course should be done by big and small improvements on every step in the building chain.

4. Methodology

CEN TC 350/ WG 5 has been working on standards for social assessment of buildings. A framework standard has been published (EN 15643-3:2011) introducing the basic concepts and containing the categories that constitute the social assessment according to CEN TC 350. The new draft standard prEN 16309:2013 was finalized recently and will be sent to formal vote in summer 2013. It lists the indicators that are used to determine the performance of a building for the framework-categories. For all indicators the calculation method is given. In addition it contains detailed guidance on some essential notions, e.g. on specifying the rules describing the scenarios.

This methodology standard prEN16309 tracks the relevant aspects for the building's use ranging from "normal use" for the building user, as well the impact on the use of the building during maintenance operations, during repair and during refurbishment. Similar to the assessment of the environmental and the economic section, assessment is done in modules. The social assessment is based on 22 aspects (each using a number of appropriate indicators) which systematically are applied on the whole use stage (and consequently communicated in 7 information modules). The methodology corresponds to the same modular structure and philosophy as applied in the CEN TC350 standards for environmental and economic performance assessment. However this generation of the standard prEN16309 is limiting the social performance assessment to the use stage of a building.

Building life cycle – Use Stage	
Building-related characteristics	**Control and user interactions related characteristics**
Accessibility 1) Accessibility for people with additional needs 2) Access to building services Adaptability 3) ease of potential for adapting to other use Health and comfort 4) Thermal characteristics 5) Characteristics of indoor air quality 6) Acoustic characteristics 7) Characteristics of visual comfort 8) Spatial characteristics Impacts on neighbourhood 9) Noise 10) Emissions 11) Glare/ overshadowing 12) Shocks/vibrations Maintenance and Maintainability 13) Maintenance Operations Safety and security 14) Resistance to climate change 15) Accidental actions (earthquake, explosions, fire and traffic impacts) 16) Personal safety and security against intruders and vandalism 17) Security against interruptions of utility supply	Health and comfort 18) Thermal comfort 19) Indoor air quality 20) Visual comfort pacts on neighbourhood 21) Emissions Safety and security 22) Security against intruders and vandalism

Fig. 2: Table of social aspects for assessment (corresponds to table 1 in prEN16309)

4.1. Boundaries of the assessment

The object of assessment is the building, its foundations and external works within the area of the building's site and any temporal works associated with the building's use (including refurbishment). It is possible to restrict the assessment to a part of a building but this has to be reported explicitly. Next to the social aspects measured for the user of the building, social aspects caused by the building or the building use that effect the direct neighbourhood of the

building are pursued: noise, emissions like odours, glare and overshadowing and shocks/vibrations. The guiding principle for this choice was to encompass the neighbours' health and comfort-related issues that can be attributed directly to the building. Thus the assessment reaches as far into the neighbourhood as direct effects that are caused by the building.

The social performance of the building is on the one hand based on functionalities of the building that facilitate specific use, comfort of use, health and well-being etc. This also includes users with specific needs and even options and potentials for future users or changed use (e.g. adaptability, flexibility). On the other hand it has been proven in studies and by experience that users prefer to have the possibility to control their environment and in specific the comfort conditions (room temperature, level of luminance, ventilation, etc.). So in prEN 16309 the aspects of the categories are distinguished into building fabric related and control related aspects (see fig.2).

For the assessment detailed information on the physical characteristics of the building has to be compiled. This is the building model. It describes the shape and size of the building, the technical systems, the arrangement, type and size of building elements (e.g. windows, staircases, etc.), comfort levels, etc.

4.2. Life cycle stages and information modules

The life cycle stages are in general distinguished into before-use-stages (production of building materials and components, construction), the use stage and after-use-stage. All 3 dimensions of a sustainability assessment (environmental, social and economic) are based on these life cycle stages and results of assessments are presented per life cycle stage. As specified before, the standard prEN16309 limits the assessment to the use stage.

In parallel to the environmental and economic assessment the methodology is structured in information modules. Each lifecycle stage is represented by several information modules. The use stage is split up in 7 information modules: the use (information module B1), maintenance (information module B2), repair (information module B3), replacement (information module B4), refurbishment (information module B5), operative energy use (information module B6) and operative water use (information module B7). The information modules B2 to B7 enable and support the functional and technical performance of the building over its life time (the time of use of the building). This modular approach requires to specify scenarios for each of the information modules but then allows to assess how activities, circumstances and conditions impact the user in using the building. In applying the defined aspects of assessment over the 7 information modules a simple but very comprehensive matrix approach defines the assessment methodology.

4.3. Scenarios: first and most important performance indicator

Needless to say that the future of a certain building is never predictable. Assumptions have to be made for the use of the building in terms of the service life, the type and pattern of use, the change of use over time, but also on the type and frequency of maintenance, repair, replacements and even refurbishments to maintain the technical and functional performance of the building. This also includes social performance related scenarios to energy-use and water-use that facilitate the use of the building. The more detailed the scenarios for all the information modules are specified, the more detailed information on the social performance can be evaluated and can distinguish performances of different building designs.

The assessment for each information module starts with defining and specifying the scenario.

Scenarios shall be realistic and representative (ref. to EN15643-1). They are based on the technical and functional specifications for every building and thus are building design specific and depending on the use of the building. So the building and use specific descriptions of scenarios will be key information to be linked to the assessment outcome. Rather vague and

less detailed scenarios will result in outcomes open for many disputes. The objective and use of the (social performance) assessment as well as the timing of the project (conception phase, planning phase, construction phase) will allow to specify the scenarios in different levels of details. Describing scenarios certainly will show to be a crucial task of the assessor before starting with the checklist of indicators per aspect category. The level of details and the importance of the influence on the aspects should be well balanced: on one hand the assessor should consider all efforts of a very comprehensive assessment task and on the other hand he should avoid a very complex assessment that is not justified by the objective and use of the assessment. For an eventual verification of the assessment by an independent verifier the descriptions of scenarios and their level of details, probably will be the most important information part to confirm. The checklist results per information module and per social aspect indicator are rather objective performance statements then.

4.4. Principle steps of the assessment in EN16309

The course of the assessment has been anticipated to proceed along the following steps:

It will start with identifying the goal of the assessment and the intended use of the object of assessment.

This is followed by the specification and description of the functional equivalent, the specification of the reference study period, the system boundaries and the building model. The functional equivalent is the summary of the functional and technical requirements for the building as specified in principle by the owner/user of the building and predefined by rules and regulations to be applied for functions and technical solutions. Main inputs for this first assessment step are the client's requirements and legal requirements. The functional equivalent serves as the basis for comparisons of assessment results for various designs for a building.

The architect's design of functions and technical solutions to the demands from client and regulations then is to be described in referring at least to these demands. It may be obvious that a very detailed functional equivalent will limit the freedom of design whereas a functional equivalent specified in very general demands on functionalities of the building may invite for very creative and different solutions for a building.

In a third step the scenarios are developed for all information modules of the use stage. This of course needs to be guided by all-time related information: the reference study period (service life of the building equal to the length of the use time) and the frequencies of maintenance, repairs and replacements, etc.

The checklist for the standardised aspects then is the fourth step in the assessment methodology. This is the main part of the assessment and is the evaluation of the aspects per indicators as determined in prEN16309. Several of the indicators are quantitative which means that they can be calculated following the specified method. Where possible the standard provides a mandatory minimum list of items. Otherwise only examples of social performance indicators are given in the checklist. This European standard had to take into account that Member States in Europe specify their regulatory demands for buildings (following the 7 Basic Requirements for Construction Works according the CPR 305/2011) in different ways: very specific solutions and rather general formulated functional performance demands. Assessment scheme owners may issue a specific checklist that is more appropriate for a building type and for the regional/national situation.

For the assessment a series of calculation sheets were developed and examples are given in the annex of the standard prEN16309 (only an excerpt of these sheets is given for illustration). It is envisaged to give the sheets to the full extent in a Technical Report.
The final steps in an assessment are the Reporting, Communication, and Verification. Verification shall be applied if there is an intention to make results of the assessment publicly available.

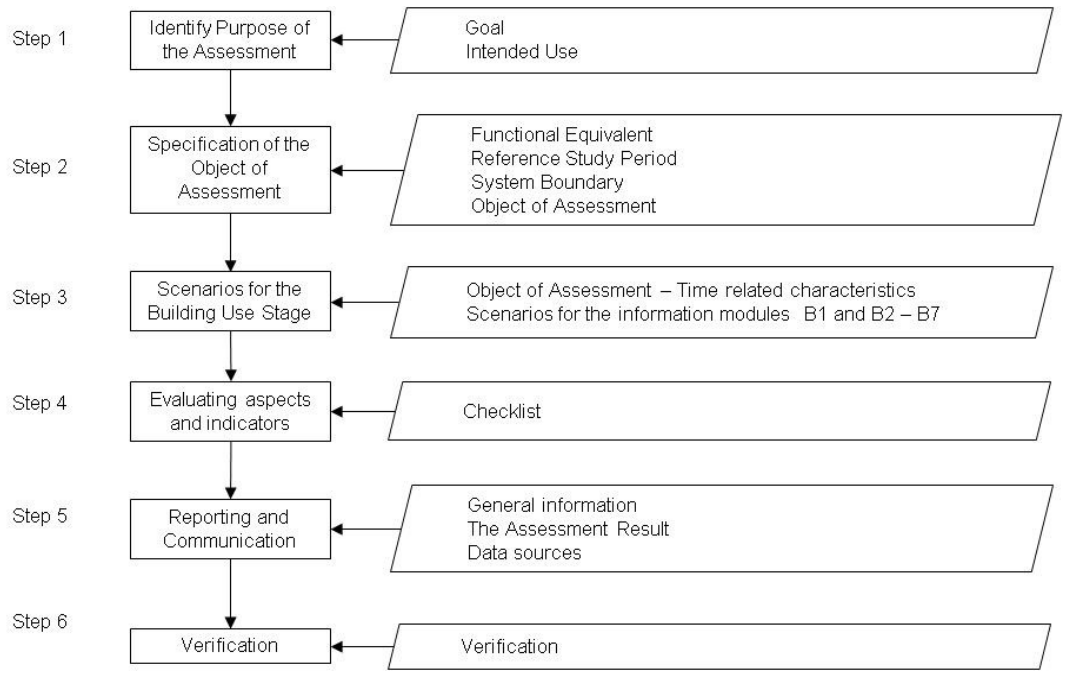


Fig. 3: Steps in the process of assessment in prEN16309

5. Relation to the Construction Products Regulation and its Basic Requirements (BRCW)

5.1. Sustainability in the Construction Product Regulation

The most important fact in terms of the assessment and communication of sustainability of construction products in Europe is represented today by the Construction Products Regulation adopted on 9 March 2011 (CPR). CPR aims to ensure reliable information on construction products in relation to their performances, including the environmental performances. This is achieved by providing a “common technical language", offering uniform assessment methods of the performance of construction products. These methods have been compiled in harmonised European product standards (hEN) and European Assessment Documents (EAD).

The CPR has already entered into force and will be fully applicable starting from 1 July 2013. What has changed from the previous Construction Product Directive EU N. 89/196/EEC is that the manufacturer of a product is kept liable for the declared product performance not only during the use stage of the product but also during the installation stage before use and after use in the end-of-life.

Within the CPR a new 7th Basic Requirement for Construction Works (BRCW) - "sustainable use of resources" - is added to the existing 6 BRCW´s. Regulators are struggling with this basic requirement to works. CEN TC350 standard experts are convinced that the standards provide all means to meet any need for quantifying and judging on the use of resources. However, this does not mean that sustainability is now specified in the CPR: There is no immediate and direct link between the CPR and a legal demand for a manufacturer to declare the sustainability for his product; not yet. Some Member States think that other rules and regulations do cover already the sustainable use of resources and no new and additional requirement for information is necessary. Other Member States feel the need to impose a demand to quantify this "sustainable use of resources" in the built environment. Whether this then will result in a demand for "essential product characteristics" is unsure for the moment.

5.2. Member State Notification, mandates to CEN product TC's

As noted above, this does not mean that sustainability is now specified in the CPR. It requires several procedural steps and a lot of administrative actions and adaptation of product standards. Foremost a national legal demand for this sustainability information on a product is required to start this procedure. In case it requires indeed new information from construction products, then Member States have to inform (notify) Europe, i.e. the European Commission, that all products that wish to be applied in their buildings shall provide that information: "essential product characteristic(s)". Then a procedure is started where the European Commission mandates the Technical Committees (TC) of CEN/CENELEC (the European Standardisation Body) to include these "essential characteristics" in the Annex ZA of the harmonised European product standards (hEN) for construction products. The European Commission should deal with sustainability product characteristics, like they have to do and did for the "usual" mechanical, thermal, acoustical, chemical product characteristics. By mid 2013 we have the situation that both the BRCW nr. 3 ("hygiene, health and the environment") and the BRCW nr. 7 ("sustainable use of resources") have led to a situation that more and more countries are putting up requirements to the environmental performance and sustainability performance of buildings. And, crucial, this then already has led to new requirements for declaring product characteristics. The Netherlands, France, Germany and Belgium have already submitted or are on the verge of submitting decrees and rules for demanding environmental product information on construction products.

In order to prevent that these new national (or even regional) requirements for product information are becoming a "barrier to trade", it requires a mandate from the European Commission that, certain and defined product characteristics related to sustainability, are from now on also "essential characteristics" and are to be included in the manufacturers declaration of performance (DoP) when the product is applied in one or more of the EU-countries. The declaration of performance will be mandatory for all construction products according to the Construction Products Regulation (CPR 305/2011) per 1-7-2013.

6. Conclusions

This paper describes the new standard prEN 16309 and shows that a building's social performance can be assessed now parallel to its environmental assessment. The methodology of assessment defined in prEN 16309 uses the same general topics and is structured in the same way as the environmental part of sustainability assessment: e.g. system boundaries, life cycle information modules, scenarios, etc.

Like the environmental and the economic performance assessment standards from CEN TC350 the new standard prEN16309 is assessing the performance of buildings and in particular the effect of the building on the user of the building. This standard has, apart from the effect on the direct neighbourhood, boundaries that exclude societal effects caused by the building and its use: spatial planning, zoning, infra-structure (traffic systems, utilities and utility supply), employment, etc., are subject of other assessment systems that apply a consequential analysis of sustainability performance. The sustainability assessment of buildings (and construction products) in the suit of standards of CEN TC350 quantify or describe the sustainability aspects of it attributionally.

Furthermore the scope of the social performance assessment according prEN16309 is limited to the lifecycle use stage. Some indicators are quantitative indicators, in specific the indicators for the indoor performance and comfort aspects. But there are also indicators for social aspects where a performance of the building cannot be measured and quantified within the possibilities of a standard. For these indicators a descriptive performance is attributed and assessed systematically in a checklist.

For the functional and technical related performance indicators of the building that have a social impact on the building user, the checklist methodology refers to the existence of applicable national or international requirements. Depending on the building type and on the

building use the client and / or the assessor decide whether the social indicator is relevant. Most of the specified social performance indicators and measures are mandatory in the checklist however some are given as examples.

The CEN TC350 standards provide methodologies for measuring and describing but do not qualify what is sustainable or not: this is left to national or private tools that use evaluation, benchmarking, weighting and rating systems, based on the results of the assessments by the before mentioned methodologies.

The social performance assessment specified in prEN 16309 is very comprehensive however the principle is based on a matrix assessment. The methodology is following the LCA system of the environmental and economic methodology standard. Scenario building per information module should serve at the same time all three dimensions of sustainability. There is a dynamic development in the last years to shift the LCA method towards a broader life cycle sustainability assessment, see for instance the call for paper in the International Journal of Life cycle Assessment [9]. The standard prEN 16309 takes an adequate step in this direction.

All CEN TC350 standards are or will be available soon, as first generation standards. Stakeholders in Europe now have to gain experiences in working with the standards and in using the assessment results. Until summer 2013 there has not been a case study according to the prEN 16309 though. Their feedback will be used to find further European agreement on how to revise and update these standards. For future revisions the limitation of prEN 16309 to the use stage and an extension to even more social aspects will probably be points of discussion.

7. References

[1] NESS B, URBEL-PIIRSALU E, ANDERBERG S, OLSSON L. *“Categorising tools for sustainability assessment”*. Ecological Economics, Elsevier. 2007, Volume 60, pp. 498 – 508.

[2] FINKBEINER M, SCHAU E, LEHMANN A, TRAVERSO M. *„Towards Life Cycle Sustainability Assessment“*. Sustainability, MDPI, Basel. 2010, Volume 2, pp. 3309 – 3322.

[3] HALOG A, MANIK Y. *“Advancing Integrated Systems Modelling Framework for Life Cycle Sustainability Assessment”.* Sustainability, MDPI, Basel. 2011, Volume 3, pp. 469 – 499.

[4] TRITTHART W, ROHRACHER H. *“The social sustainability of construction works – Challenges for integrating social dimensions into the sustainability assessment of buildings”.* Proceedings World Sustainable Buildings Conference 2011 Helsinki. ISBN 978-951-758-531-6. Theme 6.

[5] BENOIT C, MAZIJN B (eds.). *“Guidelines for Social Life Cycle Assessment of Products”.* ISBN: 978-92-807-3021-0. United Nations Environment Programme, 2009.

[6] LEnSE PARTNERS. “Stepping Stone 2. Development of a sustainability assessment methodology. Framework and content”. http: www.lensebuildings.com. 2007.

[7] LUETZKENDORF T, HAJEK P, IMMENDOERFER A, LUPISEK A, NIBEL S, HÄKKINEN T. *“Next Generation of Sustainability Assessment – Top Down Approach and Stakeholder Needs”.* Proceedings World Sustainable Buildings Conference 2011 Helsinki. ISBN 978-951-758-531-6. Theme 4.

[8] GARGARI C, HAMANS C, TORICELLI M. *“The Building Sector commitment to promote the sustainability of construction products: a common European approach for the Environmental Product Declaration”.* Techné. Journal of Technology for Architecture and Environment, Florence, ISSN 2240-7391, Iss. 5, 2013.

[9] ZAMAGNI A. *„Life Cycle Sustainability Assessment“.* International Journal of Life Cycle Assessment, Springer Berlin / Heidelberg, Vol. 17, Iss.4, 2012, pp. 373-376.

C4

Green Products

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Using life cycle based environmental assessment in developing innovative multi-functional glass-polymer windows



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Short Summary

The HarWin (Harvesting solar energy with multifunctional glass-polymer windows) FP7 project focuses on the development of innovative windows and their integration in buildings. These innovative windows aim at improving significantly the energy efficiency of windows and buildings and performing environmentally well on a life cycle base. The improvements are based on reduced material usage and weight, reduced thermal conductivity and energy consumption and hence, reduced environmental life cycle impacts. The innovation lays in the integration in the window of intelligent phase changing materials and novel glass-polymer composites with wavelength management capability. As windows are multi-component and multi-functional systems, an appropriate Life Cycle Environmental Assessment (LCEA) method is needed. Based on an evaluation of best available methods and tools for LCEA an adapted method for windows is proposed. This paper furthermore discusses how the method proposed can be used efficiently during the development process of the innovative window.

Keywords: Ecodesign, Energy related Product, Life Cycle Environmental Assessment, Multi-functional windows, Product Environmental Footprint, recyclability

1. Introduction

Windows are complex entities, not only as stand-alone objects (i.e. they are composed of several materials and they are designed to fulfil several functions) but also in their integration in the building (i.e. interaction with the interior and exterior environment). Although the primary function of a window is to allow daylight to enter a building and to provide visibility of the exterior environment, they fulfil many more functions. They provide protection against heat and cold (thermal insulation), prevent noise nuisance (i.e. acoustical protection) and create an attractive appearance of the building. They however might fulfil even more functions such as allowing for ventilating the building and protection against injuries and break-ins. Often, an overall acceptable solution needs to be found as an improvement of the performance of one of the functions may lead to the worsening of another one (e.g. improvement of the heat resistance often results in a reduction of the visible transmission factor). This overall optimum is moreover highly determined by the context. Both the desired and achieved window performances are amongst others determined by the function of the

building, the climatic context, local conditions and the user behaviour.

To fulfil the multitude of functions, windows are composed of several components. They typically consist of a glazing, a frame, sometimes with the integration of a ventilation grid, a gas filler and auxiliary materials. Currently, several technologies exist for each of these components and have evolved rapidly during the past centuries to improve the window performance for one or several of its functions. The glazing has evolved from single glazing to multi-layer glazing filled with air, a noble gas, or a vacuum space. Low-emissivity coatings were added to further improve the thermal insulation of the glazing. Similarly, the window frames have improved in terms of heat resistance; and air and water tightness. As the windows are often one of the weakest points in the building envelope regarding its heat resistance (with an insulation value of approximately three times worse than the rest), improvement is still needed. Innovative concepts are furthermore required to tackle the drawbacks of the new technologies to date such as high weight and material usage of multi-pane glazing. Searching for innovative windows with the above goals is the aim of the FP7 HarWin project [1]. The innovation lies in the integration in the window of intelligent phase changing materials and novel glass-polymer composites with wavelength management capability.

The aim of the HarWin project is furthermore to ensure that the newly developed innovative windows will not only have additional technical, functional and energetic functionalities, but that these will also present an overall improved environmental performance over their life cycle. For this purpose, a life cycle environmental assessment (LCEA) method is required which could be used during the development phase of the innovative multi-purpose window.

Several studies were performed in the past to calculate the environmental impact of windows as a set of components, as a stand-alone product or as integrated in a building ([2], [3], [4], [5], [6], [7], [8], [9], [10]). These studies confirm that windows are complex entities and their integration in the overall building design should be taken into account [3], [4]. The studies furthermore confirm that their performance and related required characteristics do not only depend on the climatic context, but also on specific (local) conditions (e.g. shadowing, orientation), function and user behaviour. LCEA studies of windows highlighted the importance of the use stage and recommend considering carefully this life cycle stage [3], [4], [5]. The life span of the window and its components were furthermore identified as important characteristics, which is determined by the durability of the components, the window design and its integration in the building (e.g. level of disassemblability) [2], [4], [9]. It is therefore important that the $LCEA_{HarWin}$ method explicitly takes into account durability, recyclability, reusability and recoverability of windows.

An overview of existing LCEA methods is given in section 2 of this paper. The proposed $LCEA_{HarWin}$ method and its integration during the design process of the innovative windows (i.e. ecodesign) are discussed in section 3. The final section describes the conclusions and steps forward.

2. Existing Life Cycle Environmental Assessment Methods: overview

Several potential methods are available which could be used within the context of HarWin. Four methods were analysed: EN 15804:2012 [11], Product Environmental Footprint (PEF) [12], Methodology for Ecodesign of Energy-related Products (MEErP) [13] and Resource Efficiency Assessment of Products (REAPro) [14]. The ISO 14040:2006 and ISO 14044:2006 standards on Life Cycle Assessment (LCA) were moreover considered as general framework [15], [16]. The results of the analysis are briefly summarised in the subsequent subsections.

The four methods were analysed in terms of:

- Life cycle approach in order to avoid burden shifting across product life cycle stages;
- Multi-criteria approach in order to avoid burden shifting across environmental impact categories;
- Alignment with the International Life Cycle Data System (ILCD) recommendations because the ILCD impact categories and models are widely supported by LCA experts in the scientific community [17];
- Allowing for consistent design decisions;
- Transparency;

- Data quality requirements (as a prerequisite for good quality results);
- Covering durability, recyclability, reusability, recoverability issues (as identified in previous research as important issues).

2.1 EN 15804:2012

The European Standard EN 15804:2012 provides core product category rules for all construction products and services [11]. The standard "*provides a structure to ensure that all Environmental Product Declarations (EPD) of construction products, construction services and construction processes are derived, verified and presented in a harmonised way*" [11]. Although in principle, the standard recommends to include all life cycle stages, only the production stage (raw material acquisition, transport to manufacturer and manufacturing) is strictly required. If all life cycle stages are covered, the information should be subdivided in several predefined modules. Reuse, recovery and recycling potentials at the End-of-Life (EoL) stage of the product are not included in the system boundary and, if included, should be communicated in a separate information module.

The EN 15804 requires a multi-criteria environmental assessment considering 7 default impact assessment categories: global warming [kg CO_2 eq.], ozone depletion [kg CFC11 eq.], acidification for soil and water [kg SO_2 eq.], eutrophication [kg $(PO_4)^{3-}$ eq.], photochemical ozone creation [kg ethene eq.], and depletion of abiotic resources elements [kg Sb eq.] and fossil fuels [MJ net caloric value]. Although the EN 15804:2012 requires to use the characterisation factors according to the ILCD recommendations for all categories except for abiotic depletion potential, the required units do not all coincide with these of the ILCD recommendations. Extra environmental information is furthermore required regarding resource use and output flows.

From the analysis, it was concluded that the EN 15804 has a different goal than what is aimed at in HarWin and therefore does not seem to be fully appropriate for HarWin. The main reasons are the following: recycling is not taken into account, there is no comprehensive list of impact categories and the impact assessment models are not completely in line with the ILCD recommendations. Some aspects can however be taken from the standard when developing the $LCEA_{HarWin}$ method, such as the time and technology related specific requirements for data quality.

2.2 Product Environmental Footprint (PEF)

The PEF method is a multi-criteria measure of the environmental performance of any type of product throughout its life cycle [12]. It has been developed by the Joint Research Centre of the European Commission and published as an annex of the recommendation linked to the Communication "*Building the Single Market for Green Products - Facilitating better information on the environmental performance of products and organisations*" [18]. PEF information is produced for the overarching purpose of seeking to reduce the environmental impacts of products taking into account supply chain activities (from extraction of raw materials, through production and use, to final waste management).

The PEF method considers 14 default impact assessment categories: climate change [kg CO_2 eq.], ozone depletion [kg CFC-11 eq.], eco-toxicity – freshwater [CTUe], human toxicity – cancer effects [CTUh], human toxicity – non-cancer effects [CTUh], particulate matter/respiratory inorganics [kg PM2.5 eq.], ionising radiation – human health effects [kg U^{235} eq.], photochemical ozone formation [kg NMVOC eq.], acidification [mol H+ eq.], eutrophication – terrestrial [mol N eq.], eutrophication – aquatic [kg P eq. (fresh water) and kg N eq. (marine)], resource depletion – water [m^3 water use related to local scarcity of water], resource depletion – fossil [kg antimony (Sb) eq.], and land use [Kg (deficit)].

From the analysis it was concluded that the PEF method seems appropriate for the LCEA of windows within the HarWin project because of several reasons. The environmental impact categories are comprehensive and the related indicators, models and characterisation factors are in line with the ILCD recommendations. The PEF method follows a two-step procedure (i.e. screening and final PEF) which seems most appropriate for HarWin (see section 2.3). The prescriptive guidelines furthermore ensure consistent and comparable results. The data quality

requirements guarantee that results are based on good quality data which is an important characteristic of this method. Recycling, reuse and energy recovery are all included, both at the start and end of the product's life cycle. However, no specific indices are calculated which emphasise the durability, recyclability, reusability or recoverability as such.

2.3 Methodology for Ecodesign of Energy-related Products (MEErP)

The MEErP methodology provides guidance to analysts and stakeholders involved in the preparatory studies for implementing measures under the recast of the Ecodesign Directive [19]. A structured approach is proposed to analyse environmental, economic and technical performances of product alternatives and comprises seven tasks: scope definition, market analysis, analysis of consumer behaviour during use and EoL, description of technologies, environmental and economic assessment, consideration of design options and setting up a stock model. The analysis comprises a base-case (i.e. the average product representing the EU market in terms of resources efficiency, emissions and functional performance), a Best Available Technique (BAT) case representing the best commercially available product with the lowest resources use and/or emissions and Best Non Available Technique (BNAT) case which refers to an experimentally proven technology that is not yet brought to market.

The environmental method gathered in the EcoReport tool recommended by MEErP proposes 9 environmental impact categories: Greenhouse Gases [kg CO_2 eq.], acidification [g SO_2 eq.], Non Methane Volatile Organic Compounds [g], Persistent Organic Pollutants [ng Teq. of TCCD], heavy metals to air [mg Ni eq.], Polycyclic Aromatic Hydrocarbons [mg Ni eq.], Particulate Matter [mg PM10 eq.], heavy metals and PAH emissions to water [mg Hg/20 eq.] and eutrophication [mg PO_4 eq.]. An indicator on critical raw materials is moreover proposed.

From the analysis it was concluded that the MEErP methodology is relevant for HarWin because windows are typical ErP belonging to the scope of the Ecodesign Directive. The MEErP methodology has however been developed for policy purposes and therefore may not be suitable to be used as such in a product development process. The main reason is that it concerns a simplified environmental impact assessment method that is not compliant with the ILCD recommendations. Nevertheless, the MEErP approach to identify a base-case, BAT and BNAT; and to calculate the benefits of an improved product compared to the base case both at the product level and setting up a stock model for environmental analysis is useful for the HarWin project.

2.4 Resource Efficiency Assessment of Products (REAPro)

In 2011 the European Commission (EC) published its "Roadmap to a Resource Efficient Europe" indicating objectives, strategies, milestones and actions to be undertaken in order to improve the resource efficiency of the European Union [20]. In line with this policy initiative, the REAPro method has been developed by the JRC upon mandate from DG Environment, between 2009 and 2012. It has been developed to be used in the framework of various product policies, including the EcoDesign Directive [19], EU Ecolabel [21] and Green Public Procurement [22].

The REAPro method was developed to support transparent identification of potential resource efficiency measures for products and assessment of their improvements potentials on a life cycle perspective. The REAPro method aims at assessing the performances of products according to six resource efficiency and waste management criteria and at using results to identify relevant improvement product measures [14]. The criteria address the recycled content rate, the re-usability, recyclability, recoverability rate of a product; the use of hazardous substances in a product and the durability of a product.

From the analysis it was concluded that the REAPro method seems appropriate to be applied to the HarWin windows for its specific focus on resource efficiency, which is not the case for any of the other considered methods. Its application would allow to identify trade-offs between material efficiency performances during production and EoL stages with energy efficiency during the use stage. Its recyclability and durability indices could also be used to explore windows' design opportunities to improve its recyclability and remanufacturability. Although the REAPro is a multi-

criteria life cycle approach in line with the ILCD recommendations, it does not comprise data quality requirements and is not as prescriptive as for example the PEF method.

3. LCEA method for HarWin and its implementation during the design phase

3.1 Proposed LCEA method for HarWin

Based on the conclusions of the analysis, a hybrid (i.e. based on a combination of features of the different methods studied) LCEA approach has been proposed for HarWin. The most important characteristics of the proposed LCEA $_{HARWIN}$ method are the following (referring to the original method for each specific feature):

- the method is life cycle based: it considers the life cycle of the window from extraction of resources to end-of-life treatment (ISO 14040 and ISO 14044);
- the method comprises a multi-criteria environmental impact assessment in line with the PEF method. Moreover, additional environmental information is proposed for four impact categories (mineral resource depletion, eutrophication, photochemical ozone formation, and fossil resource depletion) using the EN 15804 recommended indicators and impact assessment models so that EPDs can easily be developed;
- the method includes indicators of material efficiency (REAPro method);
- the method is based on an iterative assessment process (PEF method) which allows:
  - a screening assessment (based on generic data)
  - a detailed assessment (based on specific data and revised/refined building and window models);
  - a final assessment (based on final specific data and final building and window models);
- the method consists of a comparison of the new developed innovative window with a base case window and BAT window (MEErP methodology),
- the method allows to draw conclusions on the macro-scale (i.e. European continent) based on the results of the assessment of performances at the product level (MEErP methodology).

In previous studies the use stage was identified as very important in the life cycle environmental impact of windows due to its integration in the building and related heat losses/gains resulting in an energy demand for heating and/or cooling, and because of energy demand for lighting when not enough daylight is provided. In consequence, particular attention needs to go to the estimation of the operational energy use and the determination of the part to be assigned to the windows. Hence, the impact of implementing HarWin windows on the building energy consumptions will be investigated by using dynamic computational simulations. A state-of-the-art energy modelling tool, IES <VE> [24] will be employed to carry out the investigation. The IES <VE> is a suite of building performance modelling tools based around a single integrated data model. It is comprised of a series of individual modules including climate, geometric modelling, solar shading, energy and carbon, lighting, airflow, value/cost and egress modules, linked by a Common User Interface (CUI) and a single Integrated Data Model (IDM), which allows data input being passed among different applications. In addition, three building types have been identified as the baseline building models, which are an office building, a secondary school and two residential buildings (i.e. a detached house and an apartment building). A series of climatic locations will also be selected in the simulations to represent the typical climate zones in Europe. Two types of simulations will be conducted with an attempt to better understanding the HarWin windows impact; one is the steady-state simulation to provide the heating and cooling loads and the other is dynamical simulation to provide detailed information from the component level up to the building level.

3.2 Implementation during the development process of innovative windows

The $LCEA_{HarWin}$ method will support key development decisions and dissemination activities. In particular, it is proposed that the $LCEA_{HarWin}$ method will be used in the development phases of the HarWin R&D project (See Fig. 1). Integrating environmental aspects during the design process, often called ‘ecodesign’, has been widely discussed in the literature during the last two decades

(see e.g. [25], [26], [27], [28], [29], [30], [31]). The technical report ISO/DTR 14062:2002 "describes concepts and current practices relating to the integration of environmental aspects into product design and development" and discusses several models of integration [31]. One model, based on the so-called "Pahl&Beitz model" proposed in the nineties by the "Design for X" community [32], aims at proposing various actions (e.g. definition of objectives, analysis, decisions) to be carried out at each phase of the development process (i.e., Planning; Conceptual design; Detailed design; Testing/Prototyping; Market launch; Product review [31]) in order to improve the product environmental performances.

Based on this generic model, the $LCEA_{HarWin}$ method will be applied in the context of the HarWin project for different purposes during the four main phases of the development process of the innovative windows:

- During the planning phase (Phase 1): to identify the key environmental performances that should present the innovative window (based on the simplified application of the method to state of the art windows and on the literature);
- During the conceptual design phase (Phase 2): to analyse the environmental impacts of design concepts alternatives of the new window (e.g. concerning architecture, typology of materials in frame and glazing) and to help partners making informed choices;
- During the detailed design phase/Testing/Prototyping (Phase 3): to analyse the environmental impact of technical design alternatives (e.g. thickness of glazing, exact reference of materials, manufacturing process) and to allow partners on informed decisions;
- For the closure of the project (corresponding to the "market-launch" and "product-review" phases for the ISO 14062 model) (Phase 4): to analyse global performances so that they can be communicated and that further developments can be identified.

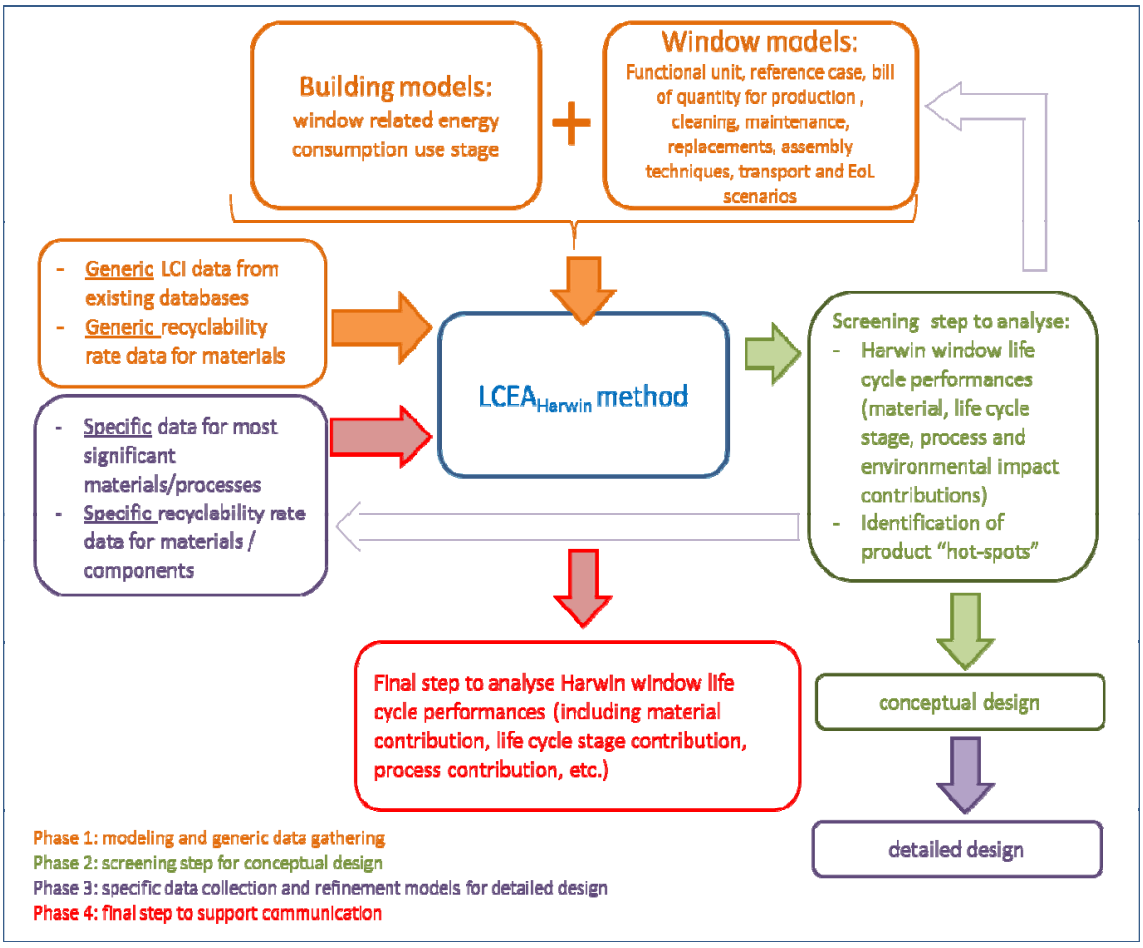


Fig. 1 Schematic representation of the implementation of the $LCEA_{HarWin}$ method for the development of innovative windows

4. Conclusions and steps forward

Based on the analysis of existing initiatives to assess the life cycle environmental impact of windows, a hybrid method was proposed combining the strengths of each of these methods within the context of the HarWin project. The result is a life cycle multi-criteria environmental impact assessment method, entitled $LCEA_{HarWin}$ method, based on an iterative LCA approach, with the robustness of following the recommendations of ILCD. Additionally, the $LCEA_{HarWin}$ method comprises material efficiency indicators to assess the recycled content, recyclablility, recoverability and durability of the windows. The method moreover allows for drawing conclusions on the macro-scale. The next steps of the HarWin project comprise the building modelling and related approaches for allocating energy losses of the building to the window; and related data gathering. The proposed LCEA method will then be tested on state of the art windows and during the design process of the innovative windows and will be used to take decisions related to the development of the innovative window.

5. References

[1] HARWIN. "*Harvesting solar energy with multifunctional glass-polymer windows*". 2013. http://www.harwin-fp7.eu/ [accessed April 2013]

[2] ABEYSUNDRA UGY, BABEL S, GHEEWALA S, SHARP A. "*Environmental, economic and social analysis of materials for doors and windows in Sri Lanka".* Building and Environment; 2007, Volume 42, pp. 2141-2149.

[3] CITHERLET S, DI GUGLIELMO F, GAY JB. "*Window and advanced glazing systems life cycle assessment*". Energy and Buildings; 2000, Volume 32/3, pp. 225-234.

[4] KIM KH. "*A comparative life cycle assessment of a transparent composite façade system and a glass curtain wall system*". Energy and Buildings; 2011, Volume 43/12, pp. 3436-3445.

[5] STAZI F, MASTRUCCI A, MUNAFO P. "*Life cycle assessment approach for the optimization of sustainable building envelopes: An application on solar wall systems*". Building and Environment; 2012, Volume 58/0, pp. 278-288.

[6] SALAZAR J, SOWLATI T. "*Life cycle assessment of windows for the North American residential market: case study*". Scandinavian Journal of Forest Research; 2008, Volume 23/2, pp. 121-132.

[7] SYRRAKOU E, PAPAEFTHIMIOU S, YIANOULIS P. "*Environmental assessment of electrochromic glazing production*". Solar Energy Materials & Solar Cells; 2005, Volume 85/2, pp. 205-240.

[8] Circe, UNESCO, ESCI-UPF, Tecnalia. "*Technical background study in support of the development of the EU Ecolabel and GPP criteria for office buildings. Draft Technical Analysis*". European Commission - Joint Research Centre; 2011, Seville, http://susproc.jrc.ec.europa.eu/buildings/docs/Draft%20Report%20Task%203.pdf [accessed April 2013].

[9] JRC-IPTS, AEA, CWCT. "*Developing an evidence base for windows and external doors. Task 1: Definition and Categorisation. Task 2: Economic and Market Analysis*". Draft - Work in progress, European Commission - Joint Research Centre; 2012. http://susproc.jrc.ec.europa.eu/windoors/docs/Task%201%20&%202.pdf [accessed April 2013].

[10] WEIR G, MUNEER T. "*Energy and environmental impact analysis of double-glazed windows*" Energy Conversion and Management; 1998, Volume 39/3-4, pp. 243-256.

[11] EN:15804. "*Sustainability of construction works - Environmental product declarations – Core rules for the product category of construction products*". In: European Committee for Standardisation; 2012.

[12] EUROPEAN COMMISSION. "*Annex II: Product Environmental Footprint (PEF) Guide to the COMMISSION RECOMMENDATION on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*". European Commission; 2013.

[13] COWI Belgium, VAN HOLSTEIJN EN KEMNA BV. "*Final Report. Methodology for Ecodesign of Energy-related Products. MEErP 2011. Methodology Report. Part 1: Methods*". European Commission - DG ENTR; 2011, Brussels http://ec.europa.eu/enterprise/policies/sustainable-

business/ecodesign/methodology/files/meerp_methodology_part1_en.pdf [accessed April 2013].
[14] ARDENTE F, MATHIEUX F. Report 3 of the Project "*Integration of resource efficiency and waste management criteria in European product policies – Second phase: Refined methods and guidance documents for the calculation of indices concerning Reusability/ Recyclability/ Recoverability, Recycled content, Use of Priority Resources, Use of Hazardous substances, Durability (final)*". European Commission - Joint Research Centre; 2012, http://lct.jrc.ec.europa.eu/assessment/projects#d [accessed April 2013].
[15] ISO 14040. "*Environmental management - Life cycle assessment - Principles and framework*". International Organisation for Standardisation; 2006, Geneva.
[16] ISO 14044. "*Environmental management – Life cycle assessment – Requirements and guidelines*". International Organisation for Standardisation; 2006, Geneva.
[17] EC-JRC-IES. "*International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context*". European Commission – Joint Research Centre - Institute for Environment and Sustainability; 2011, http://ec.europa.eu/environment/eussd/product_footprint.htm [accessed February 2013].
[18] EUROPEAN COMMISSION. "*Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: Building the Single Market for Green Products Facilitating better information on the environmental performance of products and organisations*". European Commission, 2013.
[19] DIRECTIVE2009/125/EC. "*Directive of the European Parliament and of the Council establishing a framework for the setting of Ecodesign requirements for energy-related products*". European Union, 2009.
[20] EUROPEAN COMMISSION. "*Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions Roadmap To A Resource Efficient Europe*". European Commission, 2011. http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm [accessed April 2013]
[21] REGULATION EC. "*Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel*". European Union, 2010.
[22] EUROPEAN COMMISSION. "*Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: Public procurement for a better environment*". European Commission, 2008.
[23] ALTING L. "*Life Cycle Engineering*". Concurrent Engineering; 1991, Volume 1/6, pp. 19-27.
[24] VE Software, http://www.iesve.com/ [accessed April 2013]
[25] BOKS C, MCALOONE TC. "*Transitions in sustainable product design research*". International Journal of Product Development; 2009, Volume 9/4, pp. 429-449.
[26] BREZET H, VAN HEMEL C. "*Ecodesign: a promising approach to sustainable production and consumption*". 1997, UNEP, Paris.
[27] MATHIEUX F, REBITZER G, FERRENDIER S, SIMON M, mFROELICH D. "*Ecodesign in the European Electronics Industry - An analysis of the current practices based on cases studies*". Journal of Sustainable Product Design; 2001, Volume 1/4, pp. 233-245.
[28] MILLET D, BISTAGNINO L, LANZAVECCHIA C, CAMOUS R, POLDMA T. "*Does the potential of the use of LCA match the design team needs?*". Journal of Cleaner Production; 2007, Volume 15, pp. 335-346.
[29] NAVIN-CHANDRA D. "*ReStar: a design tool for environmental recovery analysis*". International Conference on Engineering Design; 1993.
[30] SIMON M, EVANS S, MCALOONE TC, SWEATMAN A, BHAMRA T, POOLE S. "*Ecodesign Navigator*". Manchester Metropolitan University, Cranfield University & EPSRC; 1998, ISBN 1-871315-74-3.
[31] ISO 14062. "*Environmental management - Integrating environmental aspects into product design and development*". International Organisation for Standardisation, 2002.
[32] PAHL G, BEITZ W. (1996). "*Engineering design: a systematic approach*". 1996, Springer, London.

Carbon footprint of green roofs in Singapore



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Short Summary

Due partly to the government incentives introduced under the sky rise greenery initiative, green roofs are common in the tropical Singapore compared with the other eco-roof types. With limited land and natural resources within national boundaries Singapore is unique, as most system components for green roofs have to be imported from elsewhere while waste has to be incinerated. The main focus of green roof studies in this unique Singapore setting so far has been the in-use performance benefits in terms of cost, energy and water savings without considering the life time performance. However, resource costs as well as benefits need to be considered in the decision to promote any strategy.

This paper discusses preliminary results from a study that aims to develop a life cycle carbon footprint based decision framework for selecting eco-roof strategies. The results indicate that the carbon footprint of green roofs depends on the construction details and system components used. The end-of-life waste disposal contributes significantly to the carbon footprint, even with system expansion to include avoided electricity generation as a result of green roof waste incineration, main method used for waste management in Singapore.

Keywords: green roofs, life cycle assessment, carbon footprint, tropical climate, Singapore

1. Introduction

Rooftops represent approximately 50% of impermeable surfaces in urban areas. The potential use of rooftops to moderate the effects of climate change, such as extreme rainfall and temperature, has introduced three eco-roof strategies; green (living), blue (water managing) and white (heat reflecting). While a green roof is a conventional roof covered with a layer of vegetation, blue roof stores water using flow controls, such as downpipe valves, gutter storage systems and cisterns. A white or a cool roof is designed to maintain a lower roof temperature compared to a traditional roof by painting white or applying a reflective coating. The benefit of white roof is limited to temperature modifications while both green and blue roofs can, in addition, provide storm water management. Green roofs can also improve air quality and provide biodiversity through habitat creation.

Singapore is a thriving world class city with over 5million population living in high-density housing in a land area of around 700km^2. Despite land constraints, Singapore is covered in

a high level of greenery due mainly to conscientious planning over decades. Making optimum use of land, while ensuring green space is maintained at 8m^2/person and increasing greenery in high-rise buildings to 50ha by 2030 are goals of the Singapore Sustainable Development Blueprint [1]. With therapeutic value of greenery in reducing stress already established [2, 3], green roofs are an established strategy used commonly in Singapore to soften the harsh urban environment and to improve the quality of life.

Increased roof insulation due to plants and substrate layers of a green roof could reduce the building cooling loads [4-6] while protecting the roof layers otherwise exposed to the natural elements [7, 8]. The potential reduction in urban heat island effect by introducing green roofs has already been established [9, 10]. However, concerns over increased first cost and structural loading were reported as hindering wider uptake of green roofs in Singapore irrespective of the conducive climate [11]. Skyrise Greenery Incentive Scheme introduced by the Singapore government agency NParks aims to address this issue by funding up to 50% of the installation cost of green roofs (and green walls). Since its inception in 2009, over 200 developments have been funded by the scheme.

Current green roof research internationally and in Singapore concentrate mainly on the performance benefits in terms of cost, energy, water savings and carbon reduction [12, 13]. However, for a holistic evaluation of any strategy, resource costs as well as benefits accrued over the lifetime needs to be considered prior to incentives to promote their wider uptake. Bianchini and Hewage [14] in a life cycle assessment study of green roof materials highlighted the need to find alternatives to current materials in order to lower the associated environmental impact. This is especially applicable in resource constrained Singapore where all materials used in green roofs are imported from elsewhere.

1.1 Background

This paper considers the life-cycle performance of alternative green roof systems commonly used in Singapore with concrete roof slabs. While acknowledging the broad range of benefits from green roofs such as reduction in storm water runoff and urban heat island effect, improvements in habitat and urban air quality, reduction in noise and energy use in buildings, the paper is limited to implications of building energy use. Green roofs in Singapore have been reported to reduce the annual energy consumption by up to 15% [11]. While the energy savings depend very much on the baseline selected for the study, the above estimates were based on the u-value of the green roof options, without the effect of soil moisture and the plant shading. While soil moisture could increase the thermal conductance, plant shading could reduce the solar gain and the roof surface temperature.

Accessible, intensive green roofs which are also known as roof gardens are more common in Singapore compared with extensive roof gardens which are inaccessible. While roof gardens are built on-site layer by layer, and therefore tend to be continuous in construction, extensive green roofs can be either build-up or use modular systems that generate an instant effect. Although a modular system provides easy access to the roof structure in case of water damage or alternative use at a later stage compared with the build-up system, the resource use of the two systems, modular and continuous, vary widely.

2. Life cycle assessment of alternative green roof options in Singapore

To assess lifetime environmental performance of alternative green roof options in Singapore based on wider environmental considerations such as energy use and carbon emissions, three green roof systems commonly used on concrete slab roofs are considered; continuous intensive, continuous extensive and modular extensive.

First, the data on material sourcing, typical construction details, maintenance practices and waste disposal scenarios for these systems were collated from industry sources and a

streamlined life cycle assessment (LCA) was conducted. Established databases on materials and products used in construction sector are not available in the Asian region unlike in Europe, New Zealand and Australia. Therefore, the LCA in this study relied mainly on literature and where overseas databases are used these have been modified to reflect the local conditions.

Then, the reduction in cooling energy use as a result of different green roof options was modelled using *EnergyPlus* (version 7.2) thermal simulation software. To estimate the relative overall benefit of green roof, an exposed roof with a PVC water proofing membrane was used as the base case.

Finally, a sensitivity analysis was conducted to assess the validity of the assumptions used in the assessment and their impact on the results of the study.

2.1 Continuous intensive green roof system

Commonly known as roof gardens, typical substrate thickness of this system varies from 250–1200mm. For this assessment, a green roof with 700mm thick substrate layer is selected. While 80% of the roof area is covered with shrubs (roughly 0.5m high) the rest is covered with ground cover plants.

2.2 Continuous extensive green roof system

An extensive green roof with a 100mm thick substrate layer with ground cover plants is considered.

2.3 Modular extensive green roof system

A light weight polypropylene tray system with 70mm thick substrate layer and ground cover plants is selected.

Maintenance of extensive system involves weeding, pruning and fertilising three times a year, while around 10% of the plants need to be replaced annually. Watering needs depend on the type of planting with up to 5l/m^2/day and 12l/m^2/day for ground covers and turfing, respectively.

Unlike extensive green roofs, regular maintenance is necessary for intensive green roofs and the maintenance frequency could vary from daily to fortnightly depending on the building. The plant replacement rate is about 20% per annum while daily water demand could be as high as 25l/m^2 for medium size trees. Either a full-time or a part-time gardener would be necessary due to the need for frequent stability and pest attack tests of shrubs and trees, higher fertilizer demand and for watering.

The end-of-life waste disposal practices for green roofs are not established in Singapore. Although it is possible to recover most components, the waste handling scenarios suggested varied from one supplier to the other. While it is likely to reclaim the drainage layer and substrate materials, the low value products of the remaining layers mixed with dirt are likely to be sent to landfill. The plants and plant media removed are likely to be taken back to the nursery for composting and re-use, respectively. According to industry sources, trays last only for 5–6 years. Although the plant tray can be re-used the supplier indicated that once removed trays are currently sent to landfill.

In Singapore incineration is the main waste management method used due to lack of landfill space. Tan et al. [15] reported that the waste incineration process releases 1.6kgCO_2/kg of waste incinerated, although the energy use for the same was not indicated. In 2008, waste-to-energy plants in Singapore incinerated 2.45million tonnes of waste [16] and generated 1.048millionMWh of electricity [17]. On this basis, waste-to-electricity generation is

427.8kWh/tonne. While 20% of the electricity thus generated is used in the incineration process, diesel use to initiate the incineration process in the year 2008 was 0.005kg/kg according to National Environment Agency [18]. Currently less than 3% of total electricity generation in Singapore comes from waste incineration. Although, electricity generated by waste-to-energy releases higher emissions relative to other electricity generation methods being used, it eliminates the dependence on imported fossil fuels.

3. Methodology and assumptions

An assessment of the energy consumption and waste production associated with acquiring the raw materials, producing the green roof materials, transporting the materials to the construction site, constructing the green roof, maintaining the green roof, and disposing the materials at the end of the life span for three strategies were conducted using life cycle assessment methodology to establish energy and carbon footprint. This is limited only to the parts of the building and roof that are affected by the change in materials across the roof types. The green roofs are assumed to be established on a hypothetical five-storey office building with a 1000m^2 roof area.

3.1 Green roof system resource use

3.1.1 Useful life

The useful life of green roof systems in Singapore is not established yet, as the systems are a recent development in Singapore. Wong [11] in his study used 40years as the useful life of green roofs in Singapore, while Kosareo and Ries [7] used 45years for green roofs in the USA. Considering that the buildings in Singapore are demolished long before the end of their useful life, to accommodate changing building demands, a shorter useful life of 20years is used in this study.

3.1.2 Modular tray

Trays used in the modular construction system are produced in Singapore using recycled polypropylene. Although the use of recycled plastics eliminate the resource use associated with oil extraction and polymer manufacture, there is a resource cost associated with recycling and recovery process. Due to lack of data on recycled polypropylene tray manufacturing process in Singapore, inventory data from literature [19] are used with current Singapore specific waste management practices [20] and electricity data [15] for production of recycled polypropelene pellets. Resource requirements for plastic moulding has been added to this based on ecoinvent data modified to represent Singapore grid electricity. It is assumed that the trays are replaced at 5-year intervals.

3.1.3 Origin of materials and components

Most materials used in green roof systems such as drainage layers, filter layers, substrate and plants are sourced from overseas. Although the substrate composition can vary from one green roof supplier to the other, main ingredients are, recycled construction waste (bricks/clay tiles), pumice, minerals and organics. Substrate materials are predominantly sourced from Malaysia and Indonesia. Seedlings grown in polyethelene bags generally come from Malaysia. Green roof drainage components, filtering and roof protection layers used in Singapore are mainly sourced from Germany.

3.1.4 Transport

For imported products and materials, land transport within the source country, shipping to Singapore, and lorry transport within Singapore are included. It is assumed that the return trip for land transport is empty while ships carry other goods on their return journey. A 25km

distance by lorry from green roof site to supplier's yard and from yard to waste management facility at the end of useful life is also included [21].

3.1.5 Waste management

Due to lack of established practices for end-of-life waste management the following scenario was used based on suppliers' data. All materials and components removed are transported to the supplier's yard. The drainage layer and substrate material are washed and cleaned for re-use. All the other under layer products used in build-up system along with modular trays (except drainage system) are sent to waste management facility. It is assumed that 10% of drainage layer (due to odd-sizes) and substrate material are also sent to waste management facility. Plants are chopped and composted at the supplier's yard. Plant media is re-used at the supplier's yard.

3.1.6 Data sources used

Embodied energy and CO_2 emissions of drainage materials, filtering and roof protection layers are based on *ecoinvent* (version 2.1) data. Since recycled waste is the main ingredient in substrate, resources use for substrate is considered to be limited to transport (shipping and road transport). Resource uses for seedlings are considered to be limited to polyethelene bags and road transport. Energy and emissions of fertilisers are based on New Zealand data [22]. All diesel vehicles used in Singapore are assumed to conform to EURO 4 emissions standards [23] and modelled using *ecoinvent* data.

Energy intensity of current grid electricity in Singapore is not published. This was established using electricity mix data reported by Tan et al. [15], data on electrcity generation technologies reported by Kannan et al. [24] and waste-to-energy data from National Environment Agency [18].

3.2 Green roof system cooling energy benefit

In order to estimate the reduction in cooling energy requirement of a building, due to the addition of the different green roofs, a hypothetical 5-storey office building located in Singapore was modelled for annual energy requirement to maintain 24^{o}C internal temperature, between 7am and 9pm during the weekdays using *EnergyPlus* (version 7.2) [25] simulation software with the earth roof module. The benefit of cooling due to the green roof system is considered to be limited to the floor directly beneath the green roof.

3.3 Sensitivity analysis

To validate the results of the life cycle assessment two variations to the base case are considered:
Scenario1: green roof useful life is 30 years
Scenario 2: tray system is replaced at 7 year intervals rather than 5 years.

4. Results and Discussion

For a holistic evaluation of the benefit of green roofs, it is necessary to identify the energy and emissions avoided due to reduction in grid electricity use. As a first step, the energy intensity of current waste incineration process which supply 2.3% (in 2008) of grid electricity used in Singapore was established.

4.1 Energy intensity of Singapore electricity

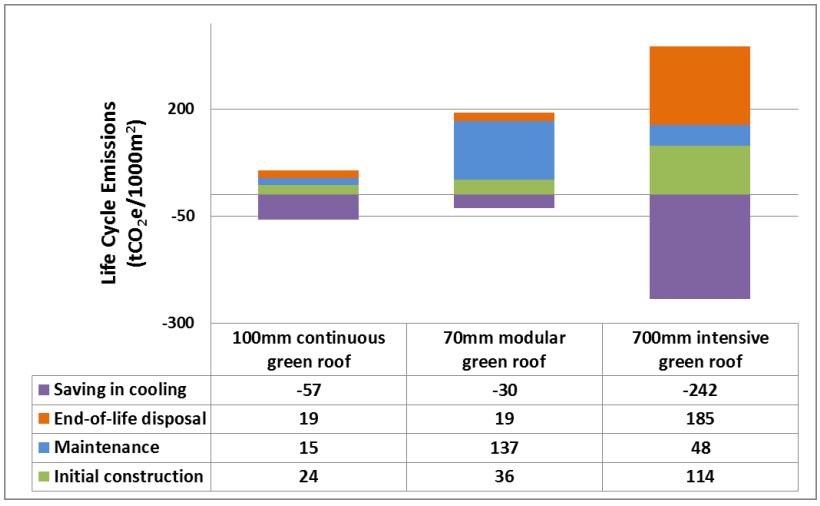
Based on National Environment Agency data in 2008, 1kg of waste incineration used 0.35MJ of primary energy. Therefore, a kWh of electricity generated from waste incineration uses

0.82MJ/kWh. Based on a fuel mix which uses 75.8% natural gas, 21.6% fuel oil, 0.3% diesel and 2.3% waste [15], the primary energy of Singapore's grid electricity would be 8.28MJ/kWh. If the transmission network losses which have been estimated to be 2.5% on average [15], are included energy intensity of Singapore grid electricity increases to 8.49MJ/kWh.

Therefore a unit of electricity saved as a result of green roof would save 8.49MJ of primary energy while also avoiding 601gCO_2eq emissions. However, the resource uses for establishment, maintenance and end-of-life disposal would entail energy and emissions costs. These are discussed next.

4.2 Carbon footprint of green roof systems used in Singapore

The results indicate that the life stage responsible for the majority of carbon emissions depends on the green roof construction system; continuous or modular. For continuous construction, the majority (over 70% of the total) of emissions are a result of initial construction, irrespective of whether it is an accessible or inaccessible green roof. For modular construction system the maintenance contributes the most emissions with around 90% of the total. This could be expected due to the short useful life of the tray, even though the trays are produced of recycled polypropylene in Singapore. Total emissions associated with the modular extensive green roof system are three times that of continuous extensive green roof while emissions of intensive green roof system are six times that of continuous extensive green roof. The total emissions due to different green roof systems including the reduction in cooling energy requirement as a result of green roof are shown in Figure 1.



	100mm continuous green roof	70mm modular green roof	700mm intensive green roof
Saving in cooling	-57	-30	-242
End-of-life disposal	19	19	185
Maintenance	15	137	48
Initial construction	24	36	114

Figure 1: Lifetime emissions associated with common green roof systems used in Singapore including the benefit in cooling energy savings (without system expansion)

During the 20-year useful life considered in this study, only continuous extensive green roof system saves sufficient electricity to pay off the emissions released as a result of green roof system. The cooling energy savings are only 15% and 70% respectively for extensive modular tray and intensive green roof systems related emissions. However, any waste generated as a result of establishment, maintenance and end-of-life disposal of green roof system components can result in avoided electricity generation using other fossil fuel sources. Even if the system boundary considered for green roof systems is expanded to include the waste-to-electricity generation, the performance of both extensive modular tray and intensive green roof systems improve marginally, with only 17% and 75% of the lifetime emissions recovered during the 20-year period as avoided emissions due to energy savings. Although waste-to-electricity generation avoids generation using imported fossil fuels the process is emissions intensive.

4.3 Performance with longer useful life

Although only a 20-year period was considered as the useful life in this case, previous green roof studies have considered a longer useful life of 40–45 years due to the ability of green roofs to extend the useful life of roof membranes. If the useful life of green roof systems in Singapore is considered to be 30-years, then the embodied emissions of the intensive green roof system can be recovered as avoided electricity emissions due to cooling energy savings over this period. However, due to relatively short useful life of trays which leads to higher embodied emissions, the modular tray green roof system does not pay back even over the longer 30-year period.

4.4 Performance with longer replacement cycle for modular tray system

Even with a longer replacement cycle of 7years instead of 5years considered in the base case, the embodied emissions of modular tray extensive green roof system cannot be recovered over the extended 30-year useful life. Although the contribution to the total by the maintenance stage is now reduced to 63% of the total from initial 90%, the cooling benefit provided by the roof is not sufficient to pay back the emissions associated with the system.

5. Conclusions

This paper considered the carbon footprint of different green roof construction systems used in Singapore. The study suggests that the total carbon footprint and the life stage at which most emissions are released depend on the green roof construction system used. The results also indicate that the modular tray system, which is popular in Singapore due to the instant effect, is not a sustainable practice in terms of carbon footprint as the emissions investment cannot be recovered.

This research, however, was limited to cooling energy benefit of green roof systems. The advantages of using green roofs extend beyond cooling energy reduction, which were not considered here. For a true evaluation of environmental performance of green roof systems, the impacts on stormwater management also need to be included.

6. Acknowledgements

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7. References

[1] MEWR and MND. "*A Lively and Liveable Singapore: Strategies for sustainable growth".* Ministry of the Environment and Water Resources and, Ministry of National Development Singapore, 2009.

[2] VELARDE M D, FRY G and TVEIT M. "*Health effects of viewing landscapes: Landscape types in environmental psychology".* Urban Forestry & Urban Greening, 2007, Volume 6/4, pp. 199–212.

[3] ULRICH R S. "*Health benefits of gardens in hospitals*". Proceedings Plants for People International Exhibition Floriade, Haarlemmermeer, Netherlands, 2002.

[4] NIACHOU A, PAPAKONSTANTINOU K, SANTAMOURIS M, TSANGRASSOULIS A and MIHALAKAKOU G. "*Analysis of the green roof thermal properties and investigation of its energy performance".* Energy and Buildings, 2001, Volume 33/7, pp. 719–729.

[5] TAKEBAYASHI H and MORIYAMA M. "*Surface heat budget on green roof and high reflection roof for mitigation of urban heat island".* Building and Environment, 2007, Volume 42/8, pp. 2971–2979.

[6] WONG N H, CHEONG D K W, YAN H, SOH J, ONG C L and SIA A. "*The effects of*

rooftop garden on energy consumption of a commercial building in Singapore". Energy and Buildings, 2003, Volume 35/4, pp. 353–364.

[7] KOSAREO L and RIES R. "*Comparative environmental life cycle assessment of green roofs".* Building and Environment, 2007, Volume 42/7, pp. 2606–2613.

[8] TEEMUSK A and MANDER U. "*Rainwater runoff quantity and quality performance from a greenroof: The effects of short-term events".* Ecological Engineering, 2007, Volume 30, pp. 271–277.

[9] ROSENZWEIG C, GAFFIN S and PARSHALL, L. "*Green roofs in the New York metropolitan region".* 2006, Columbia University Center for Climate Systems Research and NASA Goddard Institute for Space Studies.

[10] BANTING D, DOSHI H, LI J, MISSIOS P, AU A, CURRIE B A and VERRATI M. "*Report on the environmental benefits and costs of green roof technology for the city of Toronto".* 2005, City of Toronto and Ontario Centres of Excellence – Earth and Environmental Technologies (OCE-ETech): Ryerson University, Ontario. 88pp.

[11] WONG N H, TAY S F, WONG R, ONG C L and SIA A. "*Life cycle cost analysis of rooftop gardens in Singapore".* Building and Environment, 2003, Volume 38/3, pp. 499–509.

[12] CASTLETON H F, STOVIN V, BECK S B M and DAVISON J B. "*Green roofs; building energy savings and the potential for retrofit".* Energy and Buildings, 2010, Volume 42/10, pp. 1582–1591.

[13] GETTER K L, ROWE, D B, ROBERTSON G P, CREGG B M and ANDERSEN J A. "*Carbon sequestration potential of extensive green roofs".* Environmental Science and Technology, 2009,Volume 43/19, pp. 7564–7570.

[14] BIANCHINI F and HEWAGE K. "*How "green" are the green roofs? Lifecycle analysis of green roof materials".* Building and Environment, 2012, Volume 48, pp. 57–65.

[15] TAN R B H, WIJAYA D and KHOO H H. "*LCI (Life cycle inventory) analysis of fuels and electricity generation in Singapore".* Energy, 2010,Volume 35/12, pp. 4910–4916.

[16] ZHANG D, KEAT T S and GERSBERG R M. "*A comparison of municipal solid waste management in Berlin and Singapore".* Waste Management, 2010, Volume 30/5, pp. 921–933.

[17] NEA, Waste Management, Available at: http://app2.nea.gov.sg/news_detail_2009.aspx?news_sid+20090811677203539951, accessed on 14th September 2012.

[18] MUSTAPHA M F. "*Auxiliary energy use for waste incineration". Personal communication*, Manager Private Waste Facilities, National Environment Agency Singapore, 2012.

[19] VIDAL R, MARTÍNEZ P and GARRAÍN D. "*Life cycle assessment of composite materials made of recycled thermoplastics combined with rice husks and cotton linters".* The International Journal of Life Cycle Assessment, 2009, Volume 14/1, pp. 73–82.

[20] NEA. *Solid Waste Management Infrastructure*. 2002, National Environment Agency Singapore Available at: http://app2.nea.gov.sg/wastemanagementinfrastructure.aspx, Accessed on 21 April 2013.

[21] TAN R B H and KHOO H H. "*Impact Assessment of Waste Management Options in Singapore".* Journal of the Air & Waste Management Association, 2006, Volume 56/3, pp. 244–254.

[22] LEDGARD S F, BOYES M and BRENTRUP F. *"Life cycle assessment of local and imported fertilizers used on New Zealand Farms".* Fertilizer and Lime Research Centre, Massey University, New Zealand, 13pp.

[23] SILITONGA A S, ATABANI A E and MAHLIA T M I. "*Review on fuel economy standard and label for vehicle in selected ASEAN countries".* Renewable and Sustainable Energy Reviews, 2012, Volume 16/3, pp. 1683–1695.

[24] KANNAN R, LEONG K C, OSMAN R and HO H K. "*Life cycle energy, emissions and cost inventory of power generation technologies in Singapore".* Renewable and Sustainable Energy Reviews, 2007, Volume 11/4, pp. 702–715.

[25] CRAWLEY D B, LAWRIE L K, WINDELMANN F C, BUHL W F, HUANG Y J, PEDERSEN C O, STRAND R K, LIESEN R J, FISHER D E, WITTE M J and GLAZER J. "*EnergyPlus: creating a new-generation building energy simulation*

program”. Energy and Buildings, 2001, Volume 33/4, pp. 319–331.

Life Cycle Energy Performance of Semi-Transparent Building-Integrated Photovoltaic (BIPV) Windows in Tropical Singapore

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Short Summary

Sustainable buildings seek not only to increase energy efficiency, but also to adopt renewable technologies in its design. As such, semi-transparent building-integrated photovoltaic (BIPV) is gaining popularity among architects and building designers, mainly due to its ability to contribute towards a zero-(or even plus) energy building. Semi-transparent BIPV windows not only generate electricity but also allow daylight into the building and reduce the need for artificial lighting. As with other window façade elements, their incorporation will however, increase the cooling load due to solar heat gains. This is even more pertinent in tropical climates where temperatures are high all year round.

This paper examines the life cycle environmental performance of a commercially available double-glazed semi-transparent BIPV module for window application under the tropical conditions of Singapore. Energy simulations were performed in *EnergyPlus* with measured data on optical, thermal and electrical properties of the semi-transparent BIPV glazing in tropical conditions. Subsequently, a life cycle assessment was conducted to determine the long term performance in terms of energy and carbon emissions.

Keywords: building-integrated photovoltaic (BIPV); solar windows; energy performance; life cycle assessment; tropical climate

1. Introduction

Improving the energy performance of façade elements is a key challenge in improving building energy efficiency, because they are the interface between indoor and outdoor environments. In addition, adopting renewable technologies such as solar photovoltaic is becoming more popular due to the shift away from consuming fossil fuels. As such, building-integrated photovoltaic (BIPV) is considered to be an emerging glazing technology for building façade elements [1,2]. When fully integrated with the building, BIPV is able to replace conventional building materials and also to generate electricity. As part of the building façade, semi-transparent BIPV not only affects building energy efficiency through power generation, but also via its thermal properties and daylight transmission. Several researchers have studied their application and combined energy savings potential in different climatic regions [3-6]. Considering that semi-transparent BIPV has multifunctional capabilities, its design and application will require optimization to ensure that the installed systems achieve maximum outcome. Such optimization will also strive to encourage real-life adoption of semi-transparent BIPV, considering that the current costs of BIPV systems are high. Due to relatively long lifespan (typically 25 years) of BIPV systems, long-term implications should also be taken into account when designing for such systems.

In this study, the integration of a commercially-available double-glazed semi-transparent BIPV module in an office building window was studied through a computer simulation under Singapore's tropical climate. The potential electricity savings, due to electricity generation and daylight transmission, when installed in an office building was estimated and compared with that of conventional double-glazed windows. In adopting a long term view in designing of renewable systems, a life-cycle perspective was used to study its energy and carbon emissions, in terms of GHG emissions intensity (gCO_2eq/kWh), energy payback time (years) and energy return on energy investment.

2. Research methodology

This research was conducted in two stages: building energy study and life cycle environmental performance study. First, a simulation study was conducted to identify the potential energy savings of semi-transparent BIPV windows using Singapore's typical meteorological year weather file. The simulation was performed in *EnergyPlus*, which is a building energy simulation software developed by the United States Department of Energy [7]. *EnergyPlus* has various program modules capable of simulating building cooling/heating loads, daylighting and photovoltaic systems. *EnergyPlus* results have been validated through analytical, comparative and empirical tests to ensure reliability [8,9]. For this study, "*EnergyPlus* v7.0" was used.

The life cycle assessment (LCA) performed in this study evaluated the production, maintenance, use and end-of-life disposal of the double-glazed semi-transparent BIPV module in accordance with the recommendations by the International Energy Agency [10]. Although the generic framework of LCA has long been established under the International Organisation for Standardisation [11,12], it was only recently that a methodology guideline specifically for LCA of photovoltaic systems was introduced. The guidance published by International Energy Agency (IEA) includes photovoltaic-specific parameters used as inputs in LCA, choices and assumptions in the life cycle inventory data analysis and modelling approaches. The specific indicators, as recommended by IEA, used in this study are: greenhouse gas emissions (GHG) and cumulative energy demand (CED). The GHG emissions during the life-cycle stages of the BIPV system were estimated as an equivalent of CO_2 (denoted as $kgCO_2eq$) using an integrated 100-year time horizon using the global warming potential factors published by the Intergovernmental Panel on Climate Change (IPCC) [13]. The CED describes the consumption of fossil, nuclear and renewable energy sources along the life-cycle of a good or a service. The energy sources included in the CED indicator result are: fossil, nuclear, biomass, hydro, primary forest, wind and solar.

The impact indicators were further processed into GHG emissions intensity of BIPV electricity, energy payback time (EPBT) and energy return on energy investment (EROEI). EPBT, measured in years, was calculated relative to the average grid electricity currently used in Singapore. EROEI, expressed as energy generation per unit of energy input, denotes the units of energy for each unit invested in the production process.

2.1 Building energy study

A mid-floor plan of an office building was defined with building geometry, façade properties, climate and main orientations as shown in Table 1. *EnergyPlus* simulations were used to determine annual cooling load, artificial lighting requirements and photovoltaic electricity generation. The characteristics of the double-glazed semi-transparent photovoltaic modules used for the calculation of electricity output, daylight transmission and thermal calculations are shown in Table 2. As Singapore's topical climate results in buildings being dominated by cooling due to high ambient temperatures all year round, heating was not considered in the study. A central cooling system with a 3.37 coefficient of performance (COP) was chosen for the building to comply with local building legislation requirements [14,15]. This COP was used with the cooling loads, as indicated by the simulation, to determine the electricity consumption of the cooling system. The Window-Wall-Ratio (WWR) was varied from 10-100% on all four façade orientations to derive the optimum WWR. The details of this study have already been published elsewhere and readers are referred to that study

for further details [16]. The annual energy simulation results thus obtained were compared to a totally opaque wall (0% WWR) to derive the respective net electrical benefit.

Table 1: Description of office building model for EnergyPlus simulations

Parameters	
Total simulated area	800 m^2
Floor-to-ceiling height	3.0 m
Window aspect ratio (height: length)	1:10
Window-to-wall ratio (WWR)	10 – 100 %
Illuminance setpoint	500 lux
HVAC temperature setpoint	22 °C
Occupancy	0.2 person/m^2
Lighting	10 W/m^2
Equipment	8 W/m2
Infiltration rate	0.1 air changes per hour
Ventilation rate	3.0 m^3/(s.m^2)
Operational hours	0900 – 1800 hrs (weekdays only)

Table 2: Characteristics of double-glazed semi-transparent BIPV module system

Pamameters	
Module area (mm x mm)	989 x 930
Efficiency [%]	5.01
SHGC	0.154
U-value [W/(m^2K)]	1.67
Visible light transmittance [%]	6.91
Photovoltaic technology	a-Si
Construction assembly	Double glazed unit
Appearance	Standard
Country of Manufacture	Germany
BOS efficiency	0.90

2.2 Life cycle environmental performance study

The study's main focus is the life cycle assessment of production, installation, maintenance, use and end-of-life disposal of a double-glazed semi-transparent BIPV system. The photovoltaic system studied with 3.8 kWp (90% WWR) was assumed to be installed in an office building in Singapore. The module's manufacturing phase resource uses were obtained from the *ecoinvent* (v2.1) database [17,18] and was modified to represent the actual scenario. Representative inverter and balance of system components were also selected from the same database. Singapore's grid electricity mix was considered for the study. Electrical generation supplied to Singapore's national grid comes from 75.8% natural gas, 21.6% fuel oil, 0.3% diesel oil and 2.3% waste incineration [19]. With 2.5% transmission losses included, the carbon emissions of Singapore's grid electricity are 601.0 gCO_2eq/kWh [20]. This highlights an added benefit of BIPV, which is avoiding the national electricity grid transmission losses due to on-site electricity generation.

The following assumptions were used to facilitate modelling.

i. As the module used in this study was manufactured in Germany, the electricity use for manufacturing process was replaced with German medium voltage electricity data extracted from *ecoinvent* database;
ii. The lifetime of the module was assumed to be 25 years. This is the warranty provided by the manufacturer and is also in accordance with the IEA recommended life expectancy;
iii. The degradation of the module over time reduces the module electricity conversion efficiency. Therefore a linear degradation reaching 80% of the initial efficiency at the end of the 25 years life time was used;

iv. The inverter life was assumed to be 15 years and therefore one replacement with an identical inverter during the BIPV system life time was included;
v. The remaining Balance of System (BOS) included the façade installation, mounting energy use and electric installation on-site (Singapore). These were modified with Singapore grid electricity data.
vi. Transportation of module from Germany to Singapore using shipping was included, with the shipping distance obtained from an online shipping distance calculator [21];
vii. The solar cell modules were deemed to be non-recyclable due to lack of reliable scientific data and were considered to be disposed as solid waste in Singapore.

3. Results and Discussion

3.1 Building energy study results

A parametric analysis on the WWR was conducted to investigate the effect of the double-glazed semi-transparent BIPV module on the building's energy efficiency, as compared to a totally opaque wall (0% WWR). The net total electricity saving for each individual WWR was calculated by subtracting the cooling demand increase, from both the photovoltaic electricity generation and lighting energy savings.

Figures 1 and 2 illustrate the energy simulation results for the east and west orientations. With both east and west within the direct sun path of Singapore, the photovoltaic electricity generation increases considerably with increasing WWR. This phenomenon is also encountered for the lighting electricity savings as more light is transmitted to reduce the need for artificial lighting. Higher WWR also increases the solar heat gain through the façade which increases the cooling demand required to maintain the zone at the desired temperature. The net total savings, which are almost linear, increase on average at 1.8 kWh/m^2/yr and achieve 18.0 kWh/m^2/yr maximum for both east and west orientations.

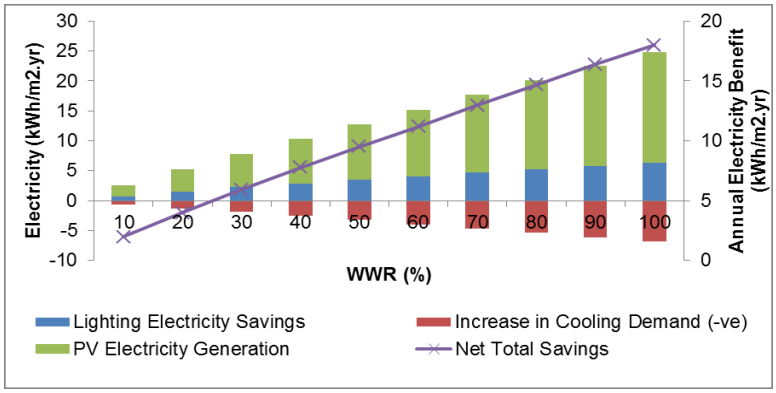


Figure 1: Annual electricity performance and benefit for east orientation

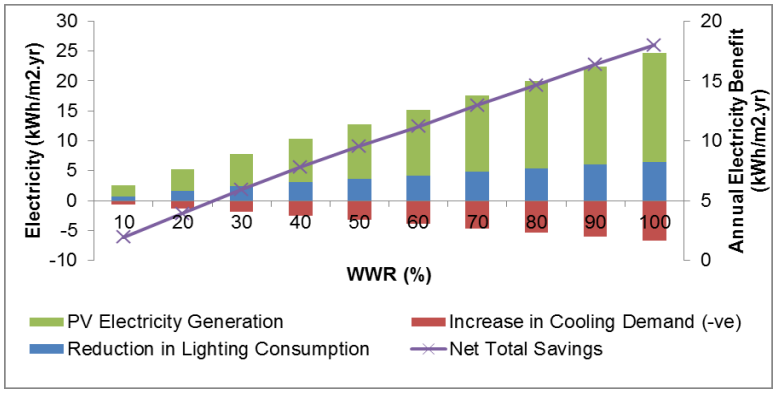


Figure 2: Annual electricity performance and benefit for west orientation

Energy simulation results for north and south orientations are shown in Figure 3 and 4, respectively. The results show a similar linear trend to that of east and west orientations. The net total savings increase at approximately 1.6 kWh/m^2/yr for each 10% increase in WWR, and peak at 100% WWR, with 16.0 and 16.4 kWh/m^2/yr, respectively. These results indicate the potential of installing semi-transparent BIPV modules on facades which are not directly in Singapore's sun path. Photovoltaic electricity generation on these facades is comparable to the east and west orientations as Singapore's highly diffused sky conditions allow north and south orientations also to receive a considerable amount of sunlight. The increase in cooling demand is also lower due to reduced direct solar radiation. Thermal gains due to diffused light, that is deemed 'cooler', are lower.

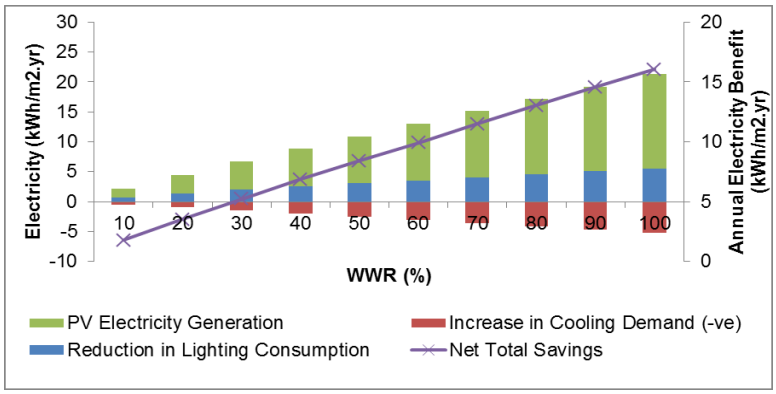


Figure 3: Annual electricity performance and benefit for north orientation

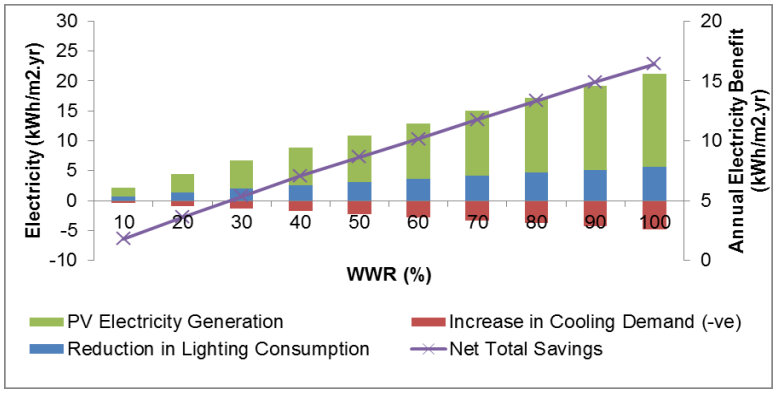


Figure 4: Annual electricity performance and benefit for south orientation

These results indicate that double-glazed semi-transparent BIPV has the potential to be widely adopted on all orientations in Singapore's context. While it would be theoretically ideal to use 100% WWR in buildings, it might not be feasible even in highly-glazed buildings. WWR could be limited in actual installations due to framing, wiring and trunking requirements for BIPV systems. As such, a reduced WWR of 90% was adopted for the subsequent LCA study. The annual electricity benefit for east, west, north and south orientations with 90% WWR are 16.4, 16.3, 14.6 and 14.9 kWh/m^2/yr, respectively.

3.2 Life cycle environmental performance study results

The life cycle emissions and life cycle energy demand of the 3.8 kWp BIPV system components are presented in Table 3. End-of-life disposal of individual components is included in these estimates.

Table 3: Life cycle emissions and energy of 3.8 kWp BIPV system

	GHG emissions ($kgCO_2eq$)	Cumulative Energy Demand (MJ)
Double-glazed BIPV modules	4744	87533
Integrated facade construction	3239	51905
Module installation	2	27
Electrical system installation	219	2850
Inverter (including replacement)	738	13061
Total	8942	155,376

The total life time electricity benefit for the BIPV system if installed on four main orientations, as obtained from the simulation and adjusted to account for module degradation, is shown in Table 4. The BIPV system considered here is capable of generating 65.8–73.6 kWh of electricity over its 25-year lifetime, depending on the orientation of the façade. In addition, the system has a cumulative energy cost of 155GJ in terms of primary energy as shown in Table 3.

Table 4: Total life time electricity generation of BIPV system

	Annual Electricity Benefit			
Year	East	West	North	South
1	3280	3275	2915	2983
2	3252	3247	2892	2960
3	3224	3220	2868	2936
4	3196	3193	2845	2913
5	3168	3165	2821	2890
6	3141	3138	2797	2866
7	3113	3111	2774	2843
8	3085	3084	2750	2820
9	3057	3056	2727	2796
10	3029	3029	2703	2773
11	3001	3002	2679	2749
12	2973	2975	2656	2726
13	2945	2947	2632	2703
14	2917	2920	2609	2679
15	2890	2893	2585	2656
16	2862	2866	2561	2633
17	2834	2838	2538	2609
18	2806	2811	2514	2586
19	2778	2784	2491	2563
20	2750	2756	2467	2539
21	2722	2729	2444	2516
22	2694	2702	2420	2492
23	2666	2675	2396	2469
24	2639	2647	2373	2446
25	2611	2620	2349	2422
Total (kWh)	73633	73684	65806	67568

*Note: Values may not add up due to rounding

The GHG emission intensity of BIPV generated electricity on the various orientations is presented in Figure 5. East and west orientations' emission intensities are similar at 118 gCO_2eq/kWh each whereas the values are 133 and 129 gCO_2eq/kWh for north and south orientations, respectively. The results are slightly higher compared with previous a-Si PV system studies where GHG emission intensities were reported to be between 18–50 gCO_2eq/kWh [22]. The emissions intensity depends not only on the PV module efficiency but also on the national transmission grid losses of the location. Singapore being a small land area electricity distribution loss is relatively low at 2.5%.

However, the emissions intensity of PV generated electricity is less than a quarter of the current gird electricity (601g/kWh) in Singapore.

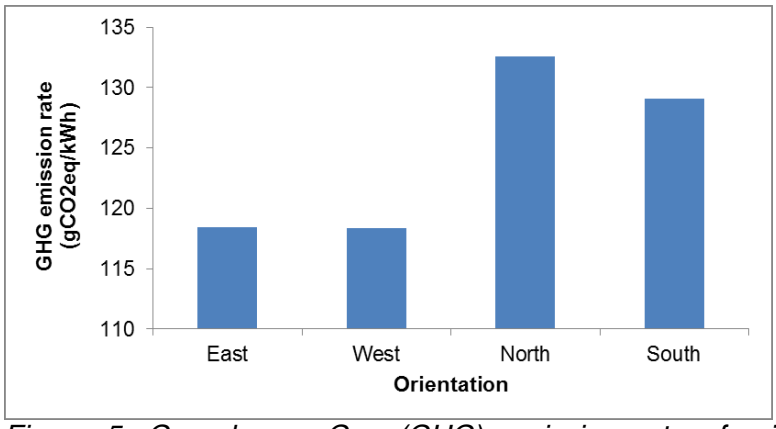


Figure 5: Greenhouse Gas (GHG) emission rates for investigation BIPV system for various orientations

Figure 6 illustrates the results of the energy payback times (EPBTs) of the investigated BIPV system adopting double-glazed semi-transparent modules over 25 years. The simple EPBT indicate a range of approximately 5.8-6.6 years for the payback. And, if avoided transmission grid losses are included (BIPV provides on-site generation), the EPBT values will be even lower at 5.7-6.4 years. East and west orientations achieved EPBT of 5.7 years where as north and south values were slightly higher at 6.4 and 6.3 years respectively. As compared with previous studies where EPBT for a-Si PV systems ranged between 1.8–3.5 years [22], the values obtained for the investigated BIPV system are higher which is due to the non-optimum module tilt and modules not facing the location's sun path directly.

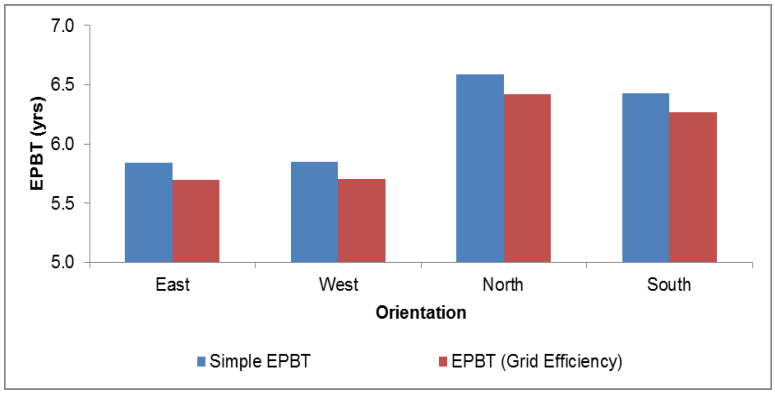


Figure 6: Energy payback times (EPBT) comparison (including and excluding grid efficiency) for BIPV system facing four main orientations

Figure 7 presents the EROEI ratios for the investigated BIPV system's four façade orientations. As expected, east and west achieved the highest EROEI ratios of 4.0. The south façade is next at 3.7 and the north façade obtained the lowest EROEI of 3.6.

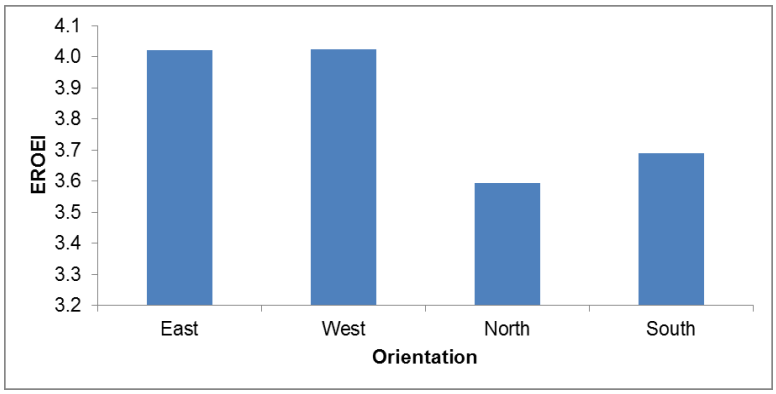


Figure 7: Energy Return on Energy Investment (EROEI) ratios for investigation BIPV system for various orientations

4. Conclusions

This paper considered the long term environmental benefits of applying double-glazed semi-transparent BIPV windows in Singapore at the single-building scale. The results suggest that semi-transparent BIPV windows are feasible on all facades in Singapore, due to the highly diffused nature of the skylight. A streamlined life cycle assessment considering energy and carbon emissions was also performed, for a highly glazed building with 90% WWR. The GHG emission intensity of PV generated electricity is at most a quarter of the emission intensity of current grid electricity in Singapore. The energy invested in the BIPV system is recovered in six years if the current grid transmission losses are considered. The energy return from the BIPV system considered is around four times the energy investment for the system.

The study reveals that there is significant potential for semi-transparent BIPV windows to be applied in Singapore's buildings. The potential areas for practical application go beyond orientations that fall within the direct sun path to those that do not.

5. Acknowledgments

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6. References

[1] BAHAJ A.S., JAMES P.A.B., AND JENTSCH M.F., 2008. "Potential of emerging glazing technologies for highly glazed buildings in hot arid climates". *Energy and Buildings*, 40(5), pp. 720-731.

[2] CHOW T.T., LI C, AND LIN, Z., 2010. "Innovative solar windows for cooling-demand climate". *Solar Energy Materials and Solar Cells*, 94(2), pp. 212-220.

[3] RADHI H., 2010. "Energy analysis of façade-integrated photovoltaic systems applied to UAE commercial buildings". *Solar Energy*, 84(12), pp. 2009-2021.

[4] LI D.H.W, LAM T.N.T., CHAN W.W.H. AND MAK, A.H.L., 2009. "Energy and cost analysis of semi-transparent photovoltaic in office buildings". *Applied Energy*, 86(5), pp. 722-729.

[5] WONG P.W., SHIMODA Y., NONAKA M., INOUE M. AND MIZUNO M., 2008. "Semi-transparent PV: Thermal performance, power generation, daylight modelling and energy saving potential in a residential application". *Renewable Energy*, 33(5), pp. 1024-1036.

[6] YUN G.Y., MCEVOY M. AND STEEMERS L., 2007. "Design and overall energy performance

of a ventilated photovoltaic façade". *Solar Energy*, 81(3), pp. 383-394.
[7] CRAWLEY D.B., LAWRIE L.K., WINDELMANN F.C., BUHL W.F., HUANG Y.J., PEDERSEN C.O.,STRAND R.K., LIESEN R.J., FISHER D.E., WITTE M.J. AND GLAZER J., 2001. "EnergyPlus: creating a new-generation building energy simulation program". *Energy and Buildings*, 33(4), pp. 319-331.
[8] WITTE M.J., HENNINGER R.H., GLAZER J. AND CRAWLEY D.B., 2001."Testing and validation of a new building energy simulation program". *Proceedings of Building Simulation* 2001, IBPSA,
[9] OLYSEN E.L. AND CHEN Q.Y., 2003. "Energy consumption and comfort analysis for different low-energy cooling systems in a mild climate". *Energy and Buildings*, 35(6), pp. 561-571.
[10] INTERNATIONAL ENERGY AGENCY (IEA), 2011. *Methodology Guidelines on Life Cycle Assessment of Photovoltaic Electricity*, IEA PVPS Task 12, Subtask 20, LCA Report IEA-PVPS T12-03:2011.
[11] ISO 14040:2006. *Environmental management – life cycle assessment – principles and framework*. International Organisation for Standardisation (ISO), Geneva.
[12] ISO 14044:2006. *Environmental management – life cycle assessment – requirements and guidelines*. International Organisation for Standardisation (ISO), Geneva.
[13] FORSTER P., RAMASWAMY V., ARTAXO P., BERNTSEN T., BETTS R., FAHEY D.W., HAYWOOD J., LEAN J., LOWE D.C., MYHRE G., NGANGA J., PRINN R., RAGA G., SCHULZ M. and VAN DORLAND R., 2007. *Changes in Atmospheric Constituents and in Radiative Forcing*. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [SOLOMON S., QIN D., MANNING M., CHEN Z., MARQUIS M., AVERYT K.B., TIGNOR M. and MILLER H.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[14] Singapore Standard SS530:2006. *Code of Practice for energy efficiency standard for building services and equipment*. Spring Singapore.
[15] BCA, 2013. *Green Mark for New Non-Residential Buildings* (Version NRB/4.1). Building and Construction Authority, Singapore. Downloaded from http://www.bca.gov.sg/GreenMark/green_mark_buildings.html accessed December 2013.
[16] NG P.K., MITHRARATNE N. AND WITTKOPF S.K., 2012. "Semi-transparent Building-Integrated Photovoltaic Windows: Potential Energy Savings of Office Buildings in Tropical Singapore". *Proceedings of 28th PLEA Conference*, 7-9 November 2013, Lima, Peru.
[17] FRISCHKNECHT R., JUNGBLUTH N., ALTHAUS H.-J., DOKA G., HECK T., HELLWEG S., HISCHIER R., NEMECEK T., REBITZER G., SPIELMANN M. AND WERNET G., 2007. Overview and Methodology, *Ecoinvent Report No.1*. Swiss Centre for Life Cycle Inventories, Dubendorf.
[18] JUNGBLUTH N., STUCKI M. AND FRISCHKNECHT R., 2009. Photovoltaics. In DONES r. (Ed.) et al., Sachbilanzen von Energiessystemen: Grundlagen fur den okologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Okobilanzen fur die Schweiz. *Ecoinvent Report No. 6-XII*, Swiss Centre for Life Cycle Inventories, Dubendorf, CH.
[19] Energy Market Authority of Singapore. 2007. *Energy for growth. National energy policy report*. Singapore: Ministry for Trade and Industry. Available from, http://app.mti.gov.sg/data/pages/2546/doc/nepr.pdf.
[20] TAN R.B.H., WIJAYA D. AND KHOO H.H., 2010. "LCI (Life cycle inventory) analysis of fuels and electricity generation in Singapore". *Energy*, 35(12), pp. 4910-4916.
[21] Portworld, 2013. *Distance Calculator*. Available from: http://www.portworld.com/map/ [1 March 2013]
[22] PENG J., LU L. AND YANG H., 2013. "Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems". *Renewable and Sustainable Energy Reviews*, 19, pp. 255-274.

Medium-rise structural timber apartments: Luxury or long-term carbon storage solution?



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Short Summary

The Australian construction sector contributes almost a quarter of the nations carbon emissions and the main strategy to address this has been to reduce the operating energy of existing buildings and by regulating energy consumption of new buildings. However there has been less focus on minimising the embodied energy of new construction projects. Engineered timber products have been used in a number of large building projects to replace heavier materials as a structural alternative whilst providing benefits such as aesthetics and the capacity to store carbon. Cross-laminated timber (CLT) has found a market in apartment buildings in Europe with a growing number of projects using the product for both structural floors and walls up to 9 storeys high. Australia's first major CLT building stands 10 storeys high and is currently being marketed as a sustainable city apartment alternative to reinforced concrete. This paper looks at the perception of consumers towards this new construction innovation in an attempt to understand whether Australian residents will accept sustainable timber use in apartment living.

Keywords: Cross-laminated timber; apartments; embodied-energy; sustainable construction.

1. Introduction

Australians are gaining an increasing awareness of environmental issues and sustainable construction due to continued publicised debate and recently implemented carbon tax, rising energy prices and a string of government subsidies provided to homeowners for energy saving technologies [1][2]. Whilst much of the focus in reducing the construction industries' environmental impact has been on operating energy, there is a growing importance to minimise the embodied energy in homes and apartment buildings [3][4]. Building legislation currently controls issues relating to operating energy but it has no restrictions on the energy embodied in a new building's construction materials [5]. Shortage of land for detached dwellings in the city of Sydney (New South Wales) and the high cost of providing infrastructure to a spreading city have lead to the government encouraging high-density apartment living through both state and local government policy changes and land use rezoning [6]. Apartment projects make up the majority of revenue in Australia's new construction market and this is expected to continue in the near future [7]. Apartment buildings in Sydney are predominantly built with a structure of reinforced concrete columns and floor slabs with a variety of materials used for dividing walls and facades [8]. The recent completion of Australia's first and the world's tallest structural timber apartment block has provided a reduced embodied energy option when compared to the typical concrete construction methodology [9]. It has also been marketed for its sustainable attributes whilst providing equivalent or greater facilities, aesthetics and comfort compared to inner city concrete apartments.

This paper examines the opinion of NSW residents towards environmental sustainability, the use of timber as a sustainable material in new residential construction, and their willingness to live or purchase an apartment in a medium-rise timber structural building. This paper also presents the process of data collection and analysis of an online survey. The results of the survey reveal that most of the participants prefer concrete construction in apartments even though they believe there should be an increase in the use of sustainable materials and that timber is a more environmentally sustainable material. Finally, this paper presents strategies for increasing the acceptance of timber both as a sustainable building material and as an alternative structural solution to reinforced concrete apartment construction.

2. Timber apartment construction

2.1 Australian apartment construction

Structural timber apartment construction is limited in Australia due the market dominance of materials such as steel, reinforced concrete and masonry used in these projects. Increasing population densities requiring taller buildings, stricter building codes and standards as well as an established workforce and technologies all support the use of heavy materials in medium and high-rise apartment construction. The majority of apartment projects in NSW are built with reinforced concrete floor plates and columns. The national code of construction does not permit apartments greater than three storeys to be built out of structural timber elements so alternate design solutions are required to achieve compliance [5]. This costly and time consuming process in addition to the strict fire and acoustic performance requirements for apartment buildings has resulted in heavy material utilisation in these types of projects until recently. Timber research and testing has shown that engineered timbers such as CLT have the capacity to perform predictably in fires in addition to providing acoustic performance that satisfies local regulations with the addition of some simple cement screeds to the floor, insulation systems and floor coverings [10][11][12]. The increased speed of construction compared to reinforced concrete has made medium-rise apartments using CLT panels appealing to developers for financial and time saving reasons. Reduced site manpower will also assist building companies to decrease the risk of site injuries and the cost of safety compliance [13]. In addition to time, cost and safety benefits the opportunity to source CLT panels from sustainable plantations and its capacity to store carbon during its life cycle is motivating construction companies in Europe and Australia to implement this innovative construction methodology [14][15][16].

2.2 Cross-laminated timber apartments

A few years after the erection of the eight and nine-storey CLT apartment structures named ‘Bridport house’ and ‘Stadhaus’ in London the construction of ‘Forte’ has recently been completed. Forte is a ten-storey CLT apartment building in the Docklands area of the city of Melbourne, Australia. Despite being slightly taller than the preceding CLT apartment blocks one of its main differences is it’s positioning in the private apartment market where it competes against similar luxury grade concrete apartments rather than in the affordable/public housing market. The adoption for this timber building innovation in the private housing market will depend not only on providing financial benefits to developers but also on the dynamic preferences and choices of prospective investors and occupants [17]. Research in Europe has found that cost premiums associated with sustainable construction provide disincentives to purchasers whereas a recent Australian study revealed that homeowners would pay extra for sustainable materials in new detached dwellings [18]. Housing material research reveal that consumers desire the warm and aesthetic attributes of timber but are still concerned with its perceived structural, safety and longevity issues when comparing timber with heavy materials such as concrete and masonry products [19]. Despite the existing data covering some aspects of consumer perception towards sustainability and the use of timber in residential housing the completion of Australia’s first structural CLT apartment block presents an opportunity to test how the market will view this innovative construction methodology.

3. Research method

The purpose of the research was to obtain data that reflected NSW resident's perception of sustainability in residential building, their understanding of timber as an environmentally beneficial material and their inclination towards occupying and owning medium-rise timber apartments. The data would be analysed and results used to develop strategies to increase the acceptance of timber as an environmentally sustainable alternative for heavy building materials in apartment construction. Online questionnaire surveys were used to allow for rapid distribution, wider coverage and to increase the efficiency of data collation and analysis. The sample group was chosen to provide a mix of residents occupying and/or owning units or detached dwellings and having a background of either construction or non-construction related employment. Construction related participants were contacted through construction companies, industry associations and professional affiliations. Non-construction workers were accessed through friends, family and work colleagues and snowballing technique was used to increase the size of this group. The survey was distributed via a link embedded in an email sent to participants to enable completion of the surveys at their own convenience and to maintain anonymity. The potential participants were then reminded 2 weeks after initial distribution by email, phone and personal contact except in the case of surveys distributed through industry associations and snowballing. Final response rate was estimated at 15% with 310 responses received. The questionnaire included sections on demographics, attitudes to sustainable construction, material preferences for medium-rise units and willingness to pay a premium for these dwellings. The survey commenced in December 2012 and data was collected for approximately 3 months.

4. Observation and analysis

Participants in the questionnaire were occupants and residents of both units and detached dwellings in NSW with the majority coming from suburban areas surrounding the city of Sydney (84%). This figure was made up of those living in inner Sydney (59%) and outer Sydney (41%). Close to half of the participants came from a construction related profession (48%) and the remaining 52% had no construction background. Construction professions/workers included project managers, property professionals, developers, architects, engineers, builders, quantity surveyors and trades in order of greatest representation to least. Females were underrepresented as they made up only 35% of participants whereas there is an equal amount of men and women in NSW between the ages of 18 and 64 [20]. A comparison of the age distribution of the survey participants with the NSW population shows a similar percentage spread and this is presented graphically in Figure 1.

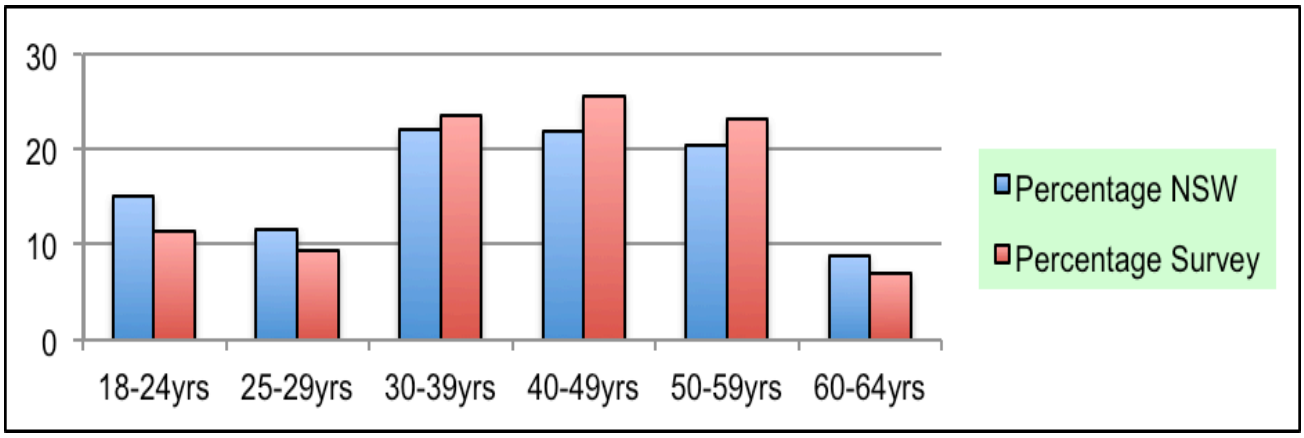


Figure. 1: Age distribution comparison between survey participants and NSW population

4.1 Sustainability and sustainable building materials

Participants were asked whether society should focus more on sustainability and whether there should be an increase the use of sustainable building materials in residential construction. They were also asked if they believed that timber was an environmentally sustainable building material.

There was almost full agreement that society should focus more on sustainability (90%) and that sustainable materials should used to build new residences (94%). Undecided votes for these questions were 7% and 4% respectively with negative responses for each question totalling just 3%. Two thirds (65%) of participants favoured timber as an environmentally sustainable building material with 29% unsure and 6% rejecting the proposition. Age, gender, construction background made little difference to the responses with a maximum variation of 9% above or below the mean.

4.2 Home occupants attitudes towards medium-rise structural timber units

Participants were also asked seven questions specifically about their perception of living and owning a unit in a ten-storey structural timber apartment. These included the reasons for preferring to live in a concrete or timber unit and some of the benefits and concerns they would have about the timber structure. They were also requested to nominate whether they would expect to pay more for a unit in a timber residential apartment block or a typical reinforced concrete apartment block and how much extra they would expect to pay.

4.2.1 Willingness to live or purchase a unit in a timber apartment block

21% of respondents would prefer to live in a 10-storey timber structural unit over one built with reinforced concrete which is just over double the proportion of people willing to purchase a unit in a timber apartment block (10%). 36% of the females surveyed were willing to live in a timber unit but only 12% of the males. This percentage gap increased when it came to purchasing, with 20% of females and just 6% of males willing to buy into medium-rise timber construction. Participants with a construction background were less willing to live in a timber unit block (16%) and even less would like to purchase (7%) whereas 26% of non-construction workers would live in timber units and 14% would buy. Age groupings also provided different rates of willingness to live and buy timber units with both the 25-29yr and 60-64yr age groups varying significantly from other age groups. These results along with those mentioned above are found in Table 1.

Table 1: NSW residents' preference for timber over concrete units.

Demographic group	**Prefer to live in timber medium rise unit to a concrete unit (%)**		**Prefer to purchase a timber medium rise unit to a concrete unit (%)**	
	Timber	Concrete	Timber	Concrete
All responses	21	79	10	90
Male	12	88	6	94
Female	36	64	20	80
Construction	16	84	7	93
Non-construct.	26	74	14	86
Age group				
18-24	19	81	8	92
25-29	5	95	11	89
30-39	25	75	9	91
40-49	23	77	12	88
50-59	25	75	14	86
60-64	16	84	6	94

4.2.2 Willingness to live or purchase a unit in a timber apartment block

As recorded in Table 1 there were only a small percentage of participants willing to purchase a timber apartment (10%). Reasons provided for the choice of buying a unit with a structure composed of timber over concrete included sustainability, aesthetics and acoustics. The reason for participants choosing concrete structure for units is listed in Figure 2 and these have also been

analysed by work background. The top three reasons for all participants to choose concrete units were structural performance, fire resistance and its tested performance. Participants with construction background showed the greatest concern for the fire resistance, tested product, financial and acoustic characteristics. Non-construction workers selected structural capability, maintenance, durability and insect resistance as the most important characteristics.

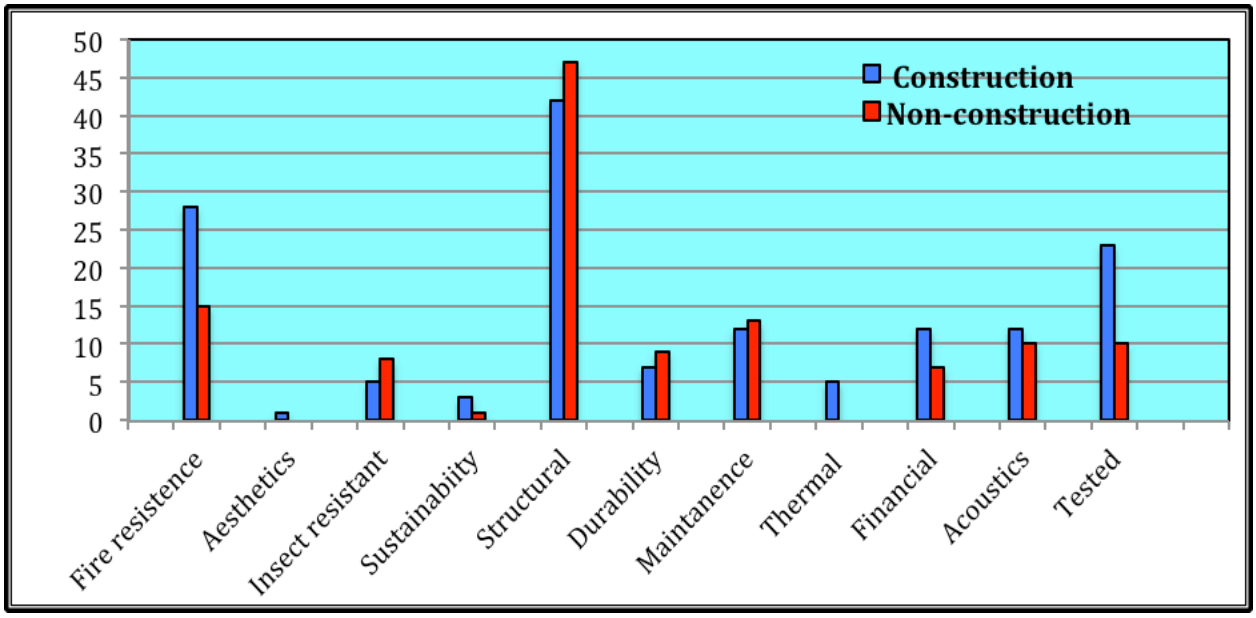


Fig. 2: Reasons to purchase concrete over timber structure in medium-rise apartments (by number)-Comparison by construction or non-construction industry background.

4.2.3 Benefits and concerns of living in a timber apartment

Participant's opinions of some of the benefits and concerns associated with living in a ten storey timber unit block was analysed, with sustainability, aesthetics and less expensive being the most commonly chosen benefits. Following these came indoor air quality, acoustics and structural attributes. Other benefits mentioned included pioneering project, innovation, and thermal comfort. The top three concerns for prospective occupants were fire resistance, insect attack and structural stability, and to a lesser degree water damage, purchase price and acoustics. Participants raised maintenance, deforestation, thermal mass capabilities and high strata levies as other concerns of less importance. These results are presented in Table 2.

Table 2: Main benefits and concerns of potential occupants of a tall timber apartment.

Benefits	**No. Chosen**	**%**	**Concerns**	**No. Chosen**	**%**
Sustainability	163	35	Fire resistance	173	34
Aesthetics	158	34	Insect	118	23
Inexpensive	65	14	Structural	106	21
Indoor air quality	48	10	Water damage	46	9
Acoustics	24	5	Expensive	24	5
Structural	10	2	Acoustics	8	8
TOTAL	**468**	**100**	**TOTAL**	**508**	**100**

In regards to participants expectations of whether timber units should be cost comparable to concrete units there was little difference between the percentage of those who believed that timber should cost more (37%) and those that thought concrete should be more expensive (38%). The remaining 25% considered that the unit cost should be the same regardless of the structural material. These proportions are presented in Figure 3.

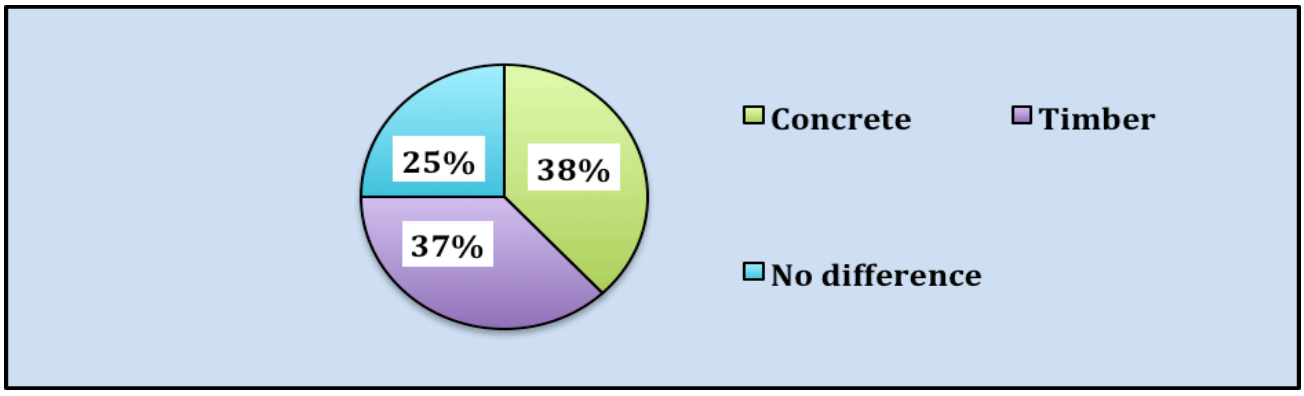


Fig. 3: Would you expect to pay more for a timber or concrete unit

The participants who chose either timber or concrete units to be more expensive to purchase were also asked how much extra they would expect to pay for that type of unit. They were given 7 options: these included $5000, $10,000, $15,000, $20,000, $25,000, $30,000 and a participant-determined premium. Only the first 5 options were selected and the percentages of each selection are shown in Table 3. The median expected additional cost for both the timber unit and concrete unit was similar with figures of $15,600 and $16,000 despite dissimilar distributions around the mean.

Table 3: Additional amount expected to be paid for a concrete or timber unit

Amount above typical unit price	**Concrete %**	**Timber %**
$5000	13	4
$10,000	15	32
$15,000	20	24
$20,000	43	28
$25,000	9	12
$30,000	0	0
Other amount	0	0
TOTAL	**100**	**100**

5. Discussion

A mixed section of NSW home occupants with both construction and non-construction work backgrounds are strongly in favour of increasing societies' action on sustainability in general and specifically increasing the use of sustainable materials for residential building. The majority believe that timber is an environmentally sustainable building material however they demonstrated a reluctance to either live or purchase a unit in a medium-rise structural timber apartment block in favour of the traditional reinforced concrete structure. This represents a separation between their ideals and their intended actions. This could be related to a number of the factors listed below.

- Misperceptions surrounding structural adequacy of timber in taller buildings due to the lack of information distributed about medium-rise timber construction technologies.
- Fear of the combustible nature of timber in tall buildings despite legislative requirements related to the protection and escape of occupants being mandatory in all Australian apartment buildings.
- Familiarity and acceptance by the construction industry and general public of reinforced concrete apartment construction which has been proven to fulfill all building codes and standards and has predictable costs, experienced designers and trades people in the market.

- Projection of common negative perceptions of residential timber performance such as insect and water damage onto larger residential timber construction projects.

In addition to these issues potential occupants, investors and owners need to be assured that they will not pay increased maintenance costs, strata levies and receive an acceptable return on their investment. A number of strategies are suggested below to address the fore mentioned barriers to the acceptance of medium-rise structural timber construction.

1. Increase marketing to educate the demand side of the market about the structural capacity, fire resistance, acoustic and thermal benefits and suitability of timber for use in apartment construction to compliment the recent media campaign that promotes the aesthetic and environmental benefits of timber.
2. Produce a clear and simple report on the effects of carbon tax on the price of timber, concrete, steel and other heavy materials used in the residential building industry.
3. Publicly showcase innovative construction methods that seek to reduce the environmental impact of the construction industry.
4. Include innovative timber building design and construction technologies into university curriculum to educate future construction professionals on sustainable building options.

All these strategies aim to increase the education of both construction professionals and the general public regarding the benefits of timber use in medium-rise apartment construction in order to help dispel persistent misconceptions about negative timber characteristics. They also reveal the need to address the embodied energy issues in construction to compliment the continuing efforts to reduce the operating energy in Australia's building stock as part of the nations carbon reduction strategy. This study will be followed by a set of qualitative interviews that target the supply side of the apartment market with interviews to a broad range of construction professionals.

7. Conclusion

Heavy materials such as steel, concrete and masonry dominate the current market for medium and high-rise apartment construction in Australia. Advances in engineered timber and innovative design has seen CLT used in a growing number of projects in Europe and the first ten-storey timber apartment block in Australia. Although CLT construction has been shown to deliver advantages of speed, safety, cost and carbon reduction when compared to reinforced concrete, the private consumer market for apartments built of timber is yet to be convinced of these benefits. Ongoing education on the benefits of timber to both the general public and construction professionals is required if structural timber apartment construction is to become a long-term environmentally sustainable alternative to current construction methods.

8. Acknowledgements

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9. References

[1] INDEPENDENT PRICING AND REGULATION TRIBUNAL. "*Changes in regulated electricity retail prices from 1 July 2012".* IPART, NSW, April 2012, ISBN 978-1-921929-74-8.

[2] THE ALLEN CONSULTING GROUP. "*The carbon price mechanism and the property sector"*. Allen Consulting Group, Melbourne, 2011, ABN 52 007 061 930

[3] MWASHI A, WILLIAMS R, IWARO J. "*Modelling the performance of residential building envelopes*". Energy and Buildings, 2011, Volume 43, pp. 2108-17.

[4] BLENGINI G, DI CARLO T. "*The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings*". Energy and Buildings, 2010, Volume 42, pp. 869-80.
[5] ABCB. "*National Code of Construction*". Volume 1, CanPrint Communications, ACT, 2012, ISBN 1-921453-78-6.
[6] KELLY J, WEIDMANN B, WALSH M. *"The housing we'd choose*". Grattan Institute, Melbourne, June 2012.
[7] BCI AUSTRALIA. "*Ambiguous markets-Succeeding in the new normal: Australian construction market outlook 2013/14*". BCI Economics, Sydney, 2013.
[8] KELLY A. "*Multi-unit apartment and townhouse construction in Australia*". IBIS World Industry Report E4112, Sydney, 2012.
[9] NIELAND A. "*Utilising wood in construction systems in tall buildings: Part 1-Introduction*". Wood Solutions, http://www.woodsolutions.com.au/Resources/Using-wood-in-construction-systems-in-tall-buildings-one?id=340772. Viewed 8 May 2013.
[10] CRAFT S. "*Fire performance of cross-laminated timber*". CLT Handbook, FPInnovations, Canada, 2011, Chapter 8, pp. 1-28.
[11] FRANGI A, FONTANA M, HUGI E, JOBSTL, R. "*Experimental analysis of cross-laminated timber panels in fire*". Elsevier, Fire Safety Journal, 2009, Volume 44, pp. 1078-1087.
[12] GAGNON S, KOUYOUMJI J. "*Acoustic performance of cross laminated timber assemblies*". CLT Handbook, FPInnovations, Canada, 2011, Chapter 9, pp. 1-46.
[13] WOOD SOLUTIONS, "*Heavy timber construction systems: Cross-laminated timber*". 2011, pp. 1-16.
[14] MAHALLE L, O'CONNOR J, BARRY A. "*Environmental performance of cross-laminated timber*". CLT Handbook, FPInnovations, Canada, 2011, Chapter 11, pp. 1-34
[15] ROBERTSON A. "*A comparative life cycle assessment of mid-rise office building construction alternatives: Laminated timber or reinforced concrete*". University of British Columbia, Vancouver, Master thesis, 2007.
[16] SAMUELSON L. "*Demands on quality regarding timber as construction material and timber frame houses in Germany*". Chalmers Technical University, Goteborg, Master thesis, 2002.
[17] ZINAS Z, JUSAN M. "*Housing choice and preference: Theory and measurement*". Procedia, Social and Behavioral Sciences, 2012, Volume 49, pp. 282-292.
[18] THOMAS D, DING G, CREWS K. "*Sustainable timber use in the Australian housing market: Are consumers willing to pay the price*?". Proceedings of the XVIII World congress, Istanbul, 2012.
[19] GOLD S, RUBIK F. "*Consumer attitudes towards timber frame houses-selected findings of a representative survey among the German population*". Journal of Cleaner Production, Elsevier, 2009, Volume 17, pp. 303-309.
[20] AUSTRALIAN BUREAU OF STATISTICS. "*Estimated resident population by single year of age, NSW*". 2012, Category no. 3101.0 Australian demographic statistics, Canberra, viewed 8 February 2013.

Optimization of wood based structural elements - Concepts for increased resource efficiency



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Short Summary

In several research projects of the Department of Structural Design and Timber Engineering (ITI) at the Vienna University of Technology (VUT) the combination of timber products with other conventional building materials and components, e.g. glass, steel and lightweight wood particle concrete was explored with the purpose to optimize structural performance, usability energy-efficient and ecological profile of composite systems [1, 2, 3, 4]. A number of show cases mixing different material elements are presented e.g. timber-glass, timber-steel and timber-lightweight concrete, use for beam, columns, shear walls and floor constructions.

Keywords: Sustainable building, sustainable redevelopment, wood based structural elements, resource efficiency

1. Introduction

The global population is expected to have grown by 30% to around 9 billion by 2050, and people in developing and emerging economies will legitimately aspire to the welfare and consumption levels of developed countries. 70% of the 9 billion people that are predicted to live on Earth in 2050 are expected to live in urban areas [5]. Driven by population growth and urbanization, the building sector has a huge impact on the gross domestic product (GDP), on the job market, on the quality of life, etc. At the same time, the construction industry adds to the shortage of resources, to waste production, and water and air pollution.

Developed countries currently account for the majority of the world's existing building-related energy demand and CO_2 emissions. The construction sector is the largest consumer of raw materials in the EU and construction and demolition activities account for about 33% of waste generated annually [6].

Buildings play an important role when it comes to controlling climatic change through the reduction of CO_2 emissions in the production of building materials; during the construction phase itself; during the use of the buildings; during the recycling and destruction process; and in deposits. Unless the maintenance and exploitation of buildings as well as the construction of new buildings changes fundamentally, the EU objectives to reduce CO_2 emissions and the consumption of non-renewable resources may not be reached [7].

Nowadays, construction techniques in Europe are mainly based on the use of industrially produced materials such as steel, reinforced concrete, bricks, plasterboards, etc. Especially during the past two centuries, they have largely replaced natural materials that had been used for thousands of years, including wood, stone, and clay. In Europe, more than 80% of all buildings consist of reinforced concrete. At the same time, European forests were over-exploited in the past centuries. They have only been protected by forestry laws since the end of the 19th century. These laws target

a sustainable forestry management, and forests have indeed fully recovered thanks to reforestation. As a matter of fact, they could produce 30 to 50% more wooden raw material than is harvested today.

The European countries have to face profound changes in the demand for buildings (e.g. quantity, high living quality, size, functionality, flexibility, expected lifetime and low energy consumption). The technical possibilities have multiplied, new materials and new construction methods appeared and finally a set of completely new requirements concerning environmental aspects and criteria of sustainability has to be translated into the built reality. Wood as a sustainable and an ecological material has an excellent chance to be an alternative construction material in urban areas.

2. Motivation

In the past ten years, an increasing demand for flexibility has been observed when it comes to the use of buildings; for fast construction processes; revitalization and restoration of existing stock; and also for the aesthetic quality of buildings. Many professionals argue that current mineral-based and heavy on-site construction techniques may not fully meet these requirements and search for alternatives that use a higher percentage of lightweight and pre-fabricated materials with better ecological profiles.

Cultivated forests that are exploited on the basis of sustainable forestry can deliver a whole range of products - from cellulose, paper and pellets to wood-based hybrid building elements and high quality visible wood products with a high added value -, thus stimulating local industries, reducing the consumption of fossil-based energies and the emission of greenhouse gases.

The building market has always been the most important mass market for timber products. In the past few years, an increasing number of wood-based buildings have been constructed in Central and Western Europe (e.g., single-family houses, multi-story condominiums, schools, hospitals and office buildings). Timber constructions with more than two stories make up less than 5% of the building market in Austria [8]. The European countries have to face profound changes in the demand for buildings. The building codes are in constant revision, actually nearly all European countries allow at least 4 stories buildings in timber as regular solutions and pilot projects had been built up to 10 stories.

The renewable raw material “wood” is available in a sustainable way; the basic technologies are well known and good examples of wood-based building already exist. However, the potential of using wood in the building sector is still highly underestimated. Wood as a sustainable and an ecological material has an excellent chance to be an alternative construction material in urban areas. So from 1996 to 2009 the world production capacity of glue laminated products increased from 1 Mio. m^3 to nearly 5 Mio. m^3. Austria holds a leading position with regard to the export of sawn wood and timber industry products. More than 50% of the world production comes from Germany and Austria.

The technical possibilities have multiplied, new materials and new construction methods appeared and finally a set of completely new requirements concerning environmental aspects and criteria of sustainability has to be translated into the built reality.

In several research projects of the Department of Structural Design and Timber Engineering (ITI) at the Vienna University of Technology (VUT) the combination of timber products with other conventional building materials and components, e.g. glass, steel and lightweight wood particle concrete was explored with the purpose to optimize structural performance, usability energy-efficient and ecological profile of composite systems [1, 2, 3, 4].

The developments focus on wood as renewable resources, waste and manufactured products of the forest industry. These technologies provide structurally efficient components for low-energy constructions, supporting rapid-assembly modular construction with increased efficiency through the use of prefabricated dry elements, thereby opening opportunities to reduce carbon emissions.

The ecological impact of the most performing structural elements was analyzed in case studies with regard to life-cycle analysis, following the whole fabrication chain of all components, and comparing

the results to conventional ways of construction in order to demonstrate the competiveness of the developed wood-based systems. Consequently, further improvements with regard to life-cycle costs are tracked down. To check on the potential for future market implementation, the ecological impact and the economic feasibility were also analyzed.

A cost optimization is possible by replacing parts of the expensive timber material by mineral-based materials as cement, anhydride, magnesia, clay or dry sand and to combine these mineral layers with the timber parts to structural elements. These should be prefabricated and allow a rapid erection without use of much water.

The research project results benefit at several levels of the European industry. Firstly, it offers utilization for waste products of the wood industry, thereby improving the exploitation of the utilization chain of forest products. Secondly, it provides a marketable component system for building construction that optimally uses timber sections. Thirdly, it contributes to reducing carbon emissions by storing forest waste in construction elements for a long period instead of burning it for warmth or energy. The results are especially beneficial to wood rich countries in Europe with wood production chains as well as a concrete tradition. In a larger context, such products support rapid-assembly construction methods that use prefabricated dry elements to increase construction efficiency.

Several show cases of mixing different material elements will be presented e.g. timber-glass, timber-steel and timber-lightweight concrete, use for beam, columns, shear walls and floor constructions.

3. Wood based structural elements

With the purpose to optimize structural performance, usability energy-efficient and ecological profile of composite systems in several research projects of ITI/VUT the combination of timber products with other conventional building materials and components, e.g. glass, steel and lightweight wood particle concrete was explored [1, 2, 3, 4]. The developments focused on wood as renewable resources, waste and manufactured products of the forest industry. They are briefly described in [1, 2, 3, 4] and clarified by an example.

These technologies provide structurally efficient components for low-energy constructions, supporting rapid-assembly modular construction with increased efficiency through the use of prefabricated dry elements, thereby opening opportunities to reduce carbon emissions.

As a representative example for these developments the application of cement bonded wood composites as structural sandwich panels illustrates the extent of the interrelationships involved in the development of complex system solutions to increase resource efficiency.

3.1 Application cement bonded wood composites as structural element

Mixtures of cement and wood-particles have already been developed around 1900, but they found their application mainly in non-structural building material such as insulating boards; many products are on the market using cement-bond wood wool, wood fibers or prefabricated powder for applications in surface finishing. More recent developments deal with wood-concrete bricks, complete walls for housing and wooden chips as insulation material. Many products have been patented and industrialized [9].

The development of these lightweight wood-concrete systems leads to a new, highly competitive generation of polyvalent multi-material building components (*Fig. 1*). The application of wood-based, cement-bonded products could be considerably increased if applicability in structural elements is given. These propose to develop wood-concrete compounds as a structural material, and to combine it with timber components into structural composite floor and wall elements, additionally providing further benefits for building physics and fire safety.

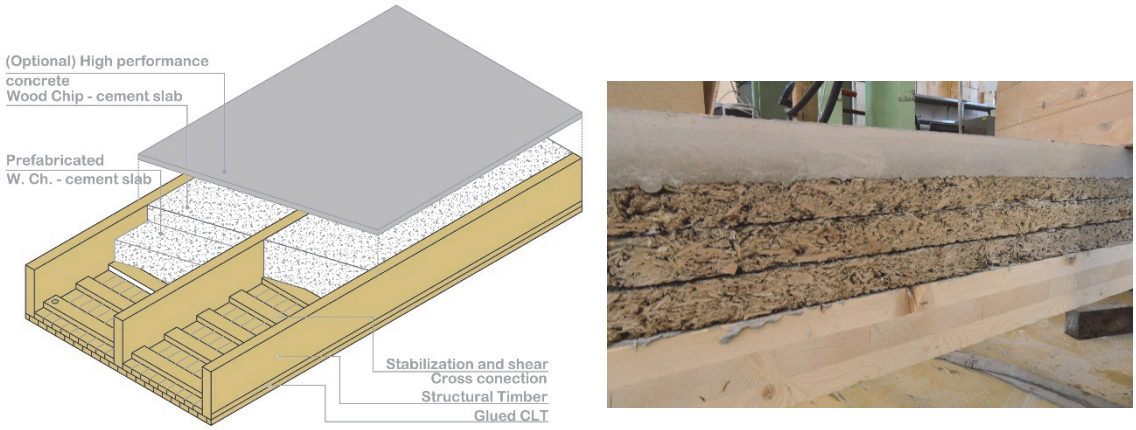


Fig. 1: Lightweight wood-concrete floor element

This technology combines existing concrete tradition with organic renewable resources as an alternative to conventional concrete or masonry, thereby opening opportunities to reduce carbon emissions through the reduction of cement use and increased use of wood for construction since the carbon dioxide stocked in the wood is preserved for several decades instead of burning it.

As a structural model analogy on material level, the wood fibers in different forms, i.e. saw dust, chips, strands, wool etc., in the wood-concrete compound allow for a load-bearing truss embedded in the concrete, being able to transmit compression and also a certain tension (Fig. 2). Different wood-concrete compound compositions can be arranged in the section of a structural element with the result that they provide the necessary structural performance where it is needed: higher compression strength in the compressive (bending) zone where little tensile strength is required; well-balanced tensile and compression strength in the section core to absorb shear forces; higher tensile strength and little compression strength in the tension zone to support the structural timber elements in tension and for absorbing local stress concentrations in shear connections to the timber components.



Fig. 2: Development of lightweight wood-concrete

The use of composite products of timber and lightweight wood-concrete was to be supported and stimulated by comprehensive and scientifically robust background data, which was presented in user-friendly and adapted tools for engineers [1, 2 and 4]. The following stages among others were proposed to achieve relevant results compatible to industrial applications:

- ⇨ Development and optimization of wood light-weight concrete using recycled wood particles and new additives (*Fig. 2*),
- ⇨ Strength tests and evaluation of the physical properties of the lightweight wood-concrete,
- ⇨ Design of structural components made of lightweight concrete connected to timber sections,
- ⇨ Evaluation of the thermal and sound insulation behavior,
- ⇨ Analysis of the experimental results to develop design concepts,
- ⇨ Fire resistance by explorative tests,
- ⇨ Optimization of the manufacturing methods,
- ⇨ Studies regarding the ecological impact.

3.2 Economic feasibility and ecological impact

The first generation of timber based multi-story buildings are characterized by an “abundant” use of massif timber panels (cross-laminated timber - CLT) and a prudent overdesign of additional layers to fulfil or overfill the requirements concerning acoustic and fire behavior [10 and 11]. The structural systems for the floors and the structures for the vertical loads were often not optimized: thick massive floor panels instead of less wood consuming rib or sandwich construction and massive wood panels for all wall elements instead of optimized use of structural columns and the minimum quantity of structural shear walls together with a maximum of light nonstructural separation walls.

Other cost reduction measures could be the use of vertically orientated “balloon” systems (vertical elements more than one story high) instead of horizontal platform systems (one-story high elements, protection needed for the “open” platform).

Further cost optimization is possible by replacing parts of the expensive timber material by mineral-based materials as cement, anhydride, magnesia, clay or dry sand and to combine these mineral layers with the timber parts to structural sandwich elements. These sandwiches should be prefabricated and allow a rapid erection without use of much water. A good example for this kind of composites is the cement bonded wood particleboards (or wood wool boards) which are used and produced since several decades in the European countries [9]. The combination of these cement bonded panels with structural timber panels is a promising strategy to reduce cost, to increase fire resistance and sound protection (mainly impact sound on floors and walls), to increase the thermal storage capacity (24 hours cycle) and to maintain the good recyclability with the possibility to burn the composite after use to profit of the thermal capacity of the wood.

The comparison of today’s market prices for the basic building materials (concrete and sawn timber boards) shows that, in spite of the high energy consumption for production and distribution, the price of 1 m^3 concrete delivered on the site is surprisingly low. On the other hand, sawn timber boards cost 5 times more, representing the real cost (mainly labor for planting and harvesting trees, secondary transformation with a small percentage of non-renewable energy).

In order to recognize the potential for future market implementation and to demonstrate the competiveness of the developed multi-layer systems, the economic feasibility and ecological impact of the most performing structural elements were analyzed in several case studies [12].

Four different variants of floor elements were examined (Fig. 3): variant 1 (components: CLT and three wood chip concrete layers), variant 2 (components: CLT and two wood chip concrete layers), variant 3 (components: CLT, two wood chip concrete layers and reduction of the amount of the screws) and variant 4 (components: wooden planks and two wood chip concrete layers).

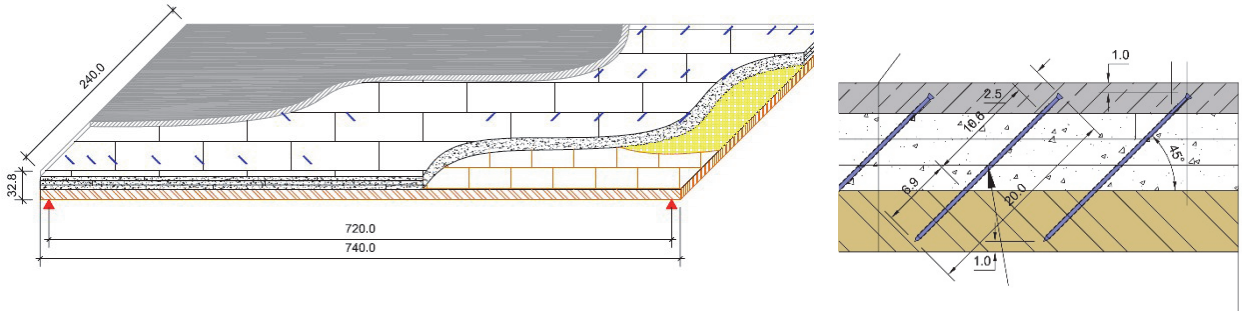


Fig. 3: Different variants of floor elements

The difference between the variants 1 (three wood chip concrete layers) and 2 (two wood chip concrete layers) explains themselves through the reduction of the amount of the glue areas (two instead of three). Variant 4 shows that the reduction of the wood cross-section and the use of simple wooden planks have a large influence on the price (Table 1).

Table 1: Price of different variants

Variant	Wood-concrete layers	Price (€/m²)
1	3	173
2	2	150
3	2	143
4	2	104

From the ecological point of view the lightweight wood-concrete floor elements were examined by two end of life (EOL) scenarios. Two different presumptions were considered. A “standard” scenario expects the commercial way of waste management - demolition of the elements with following burning in a waste incinerating plant and land filling of the ashes. A “best case” scenario expects a prospective way of waste management, more expensive because of the needed equipment. It presumes a profit of the recycling potential, but providing the separability of each main materials of the element during the demolition.

The comparison represents that the lightweight wood-concrete floor elements are an adequate alternative to the massive timber as well as conventional concrete floor elements. On the subject of the ecological index “Acidification Potential (AP, SO_2-eqv.)” the lightweight wood-concrete sandwich floor element variant 4 has particularly better ecological value as the massive timber floor elements (Fig. 4).

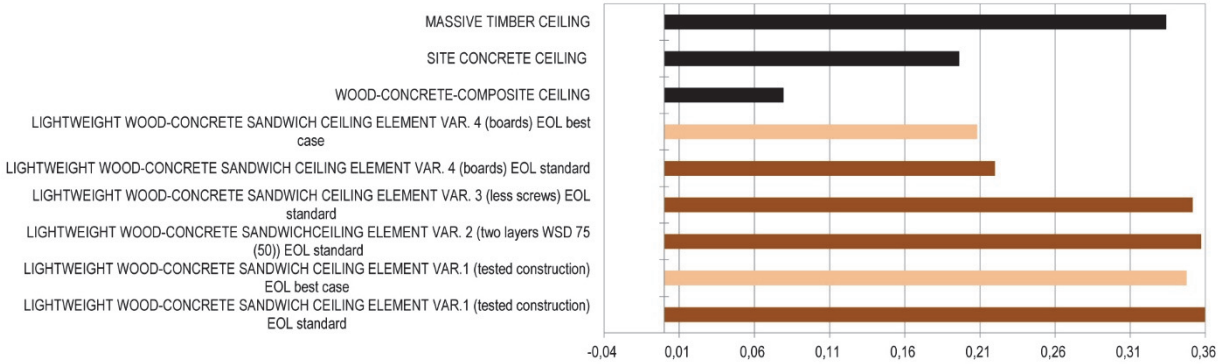


Fig. 4: Ecological index Acidification Potential (AP) of different ceiling element variants

The comparison of the ecological index “Global Warming Potential (GWP 100, CO_2-eqv.)” shows that the lightweight wood-concrete sandwich floor elements variant 3, variant 2 and variant 1 (EOL best case/standard) have a minus value, this means, that they stored more CO_2, than it released during the manufacturing and disposal progress (Fig. 5).

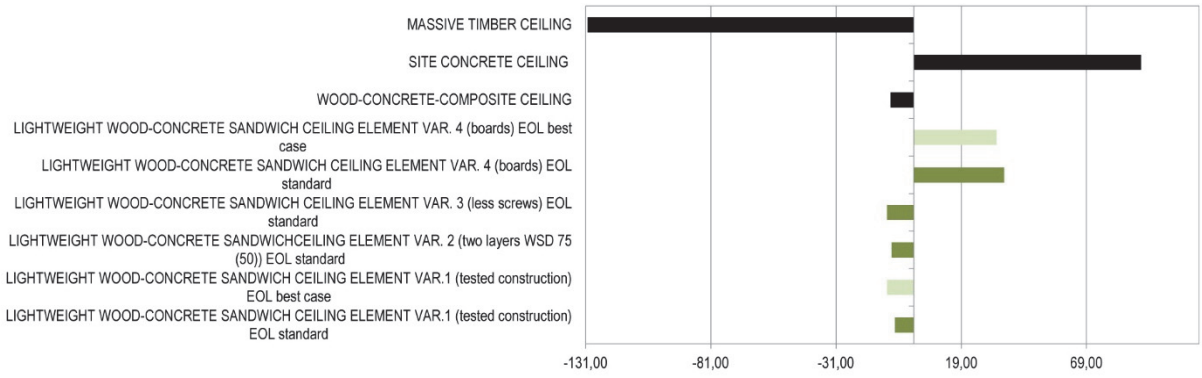


Fig. 5: Ecological index Global Warming Potential (GWP 100) of different ceiling element variants

Concerning the ecological index measure of need for non-renewable energy (PEI ne, MJ) all variants of the lightweight wood-concrete sandwich floor element have a value to 60 MJ for 1m^2, the lightweight wood-concrete sandwich floor element variant 4 (EOL best case) has a value near 0. This means that the amount on non-renewable energy needed for production of this element is nearly the same as the benefit of the end-of-life-processes - Recycling, burning, land filling...- (Fig. 6).

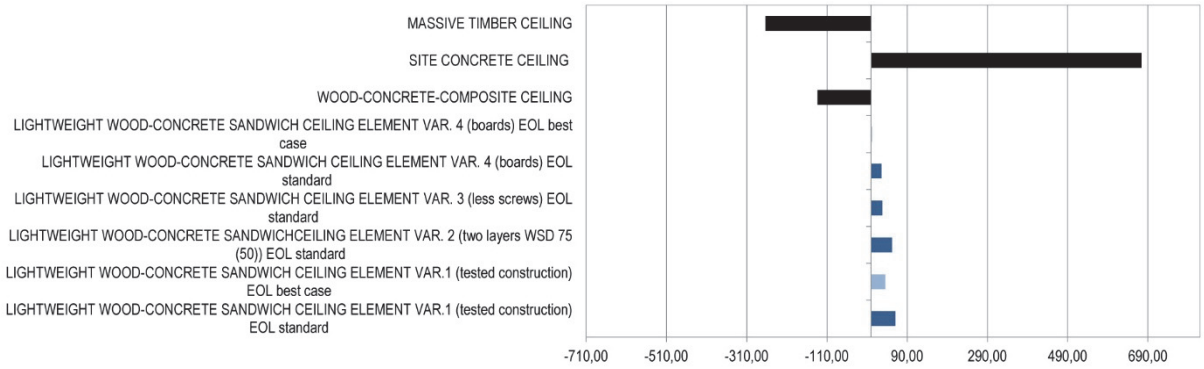


Fig. 6: Ecological index measure of need for non-renewable energy (PEI ne) of different ceiling element variants

Consequently, further improvements were tracked down with regard to life-cycle analysis, following the whole fabrication chain and end-of-life-processes of all components and comparing the results to conventional ways of construction.

4. Conclusions

The research project results benefit at several levels of the European industry. Firstly, it offers utilization for waste products of the wood industry, thereby improving the exploitation of the utilization chain of forest products. Secondly, it provides a marketable component system for building construction. Thirdly, it contributes to reducing carbon emissions by storing forest waste in construction elements for a long period instead of burning it for warmth or energy. In a larger context, such products support rapid-assembly construction methods that use prefabricated dry elements to increase construction efficiency.

To reach a comparable or higher market share in the multi-story sector – necessary to guarantee a constant high demand of timber products able to absorb the production capacity of the reforested forests – timber-based buildings must be economically competitive. The strategies to increase use of timber in multi-story buildings are:

- ⇨ Combination of wood with cheaper, non-combustible mineral materials for cost and fire resistance optimization,
- ⇨ Full use of prefabrication with the goal of reducing erection time,
- ⇨ Increase specific knowledge about timber by professionals, students and builders,
- ⇨ Realize intelligent and attractive pilot projects.

Incontrovertibly, there are also certain pending questions related to the research: manufacturing performance of the multi-layer system and market acceptance of the proposed building technology due to the economic competitiveness. The newly developed system shall be promoted through the initiation of pilot applications. Initiation of pilot projects will provide the possibility to experience the practicality and applicability of the developed composite systems, and create different design and application solutions. Any modification proved to be necessary at architectural and structural design stages may be reached as a result.

5. Acknowledgement

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6. References

[1] WINTER W, FADAI A. „*Mischbauansaetze beim mehrgeschossigen urbanen Bauen - Zur moeglichen Rolle von Naturbaustoffen*“. Holzbautage Innsbruck 2012 - Nachhaltige Stadtentwicklung mit Holz, Universitaet Innsbruck; Holzbaulehrstuhl, Innsbruck, 2012, pp. 85 – 89

[2] FADAI A, WINTER W, GRUBER, M. "*Wood Based Construction for Multi-Storey Buildings. The Potential of Cement Bonded Wood Composites as Structural Sandwich Panels*". World Conference on Timber Engineering, Auckland, New Zealand, 2012, pp. 125 – 133

[3] HOCHHAUSER W, WINTER W, FADAI A. "*Entwicklung von verklebten Holz-Glaskonstruktionen, Bemessung und Anwendung*"; in: "Glasbau 2013", herausgegeben von: Technische Universität Dresden, Institut für Baukonstruktion; Ernst & Sohn. Verlag für Architektur und technische Wissenschaften Berlin, Berlin, 2013, DOI: 10.1002/stab.201390063, ISBN: 978-3-433-03039-4, pp. 185 - 200.

[4] FADAI A, TAVOUSSI TAFRESHI K, WINTER W. "*Wood-based construction in urban context concepts for increased ressource efficiency*"; DREVOSTAVBY 2013, Volyne, Tschechien; 27.03.2013 - 28.03.2013; in: "DREVOSTAVBY 2013", a Stredni prümyslova skola (Hrg.); Vyssi odborna skola a Stredni prümyslova skola, Volyne (2013), ISBN: 978-80-86837-51-2; pp. 161 - 166.

[5] UN-HABITAT, http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2917 State of the world's cities 2010/2011: bridging the urban divide. Earth scan, London and Washington DC, 2010

[6] EEFA The European Environment State and outlook 2010. Material resources and waste. European Environment Agency, Copenhagen, 2010.

[7] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community’s greenhouse gas emission reduction commitments up to 2020.

[8] STINGL R, ZUKAL M.L, TEISCHINGER, A. “*Holzbaustudie Oesterreich Holzbauanteil in Oesterreich. Statistische Erhebung von Hochbauvorhaben”,* Zuschnitt Attachment att., September 2011, 23, proHolz Austria, Vienna; ISBN: 978-3-902320-84-1

[9] STÅHL A. “*Cement-bonded wood composite as structural element in internal walls*”, Master's thesis, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, 2011

[10] KARAKUSEVIC P, MANNEWITZ S. “*Future Wood – Cross Laminated Timber, A case study & CLT Master-class: How to design and construct with Cross Lam-inated Timber*”, Bridport Place: Designing with CLT, September 14, 2011

[11] MIKKOLA M. “*Future Wood – Cross Laminated Timber, A case study & CLT Masterclass: How to design and construct with Cross Laminated Timber*”, Stora Enso Building Solutions, September 14, 2011

[12] DEPARTMENT OF STRUCTURAL DESIGN AND TIMBER ENGINEERING (ITI) “*Forschungsprojekt 824892; Weitgespannte Flachdeckensysteme in Holzspanbeton-Verbundbauweise”*, Research Report, Vienna, in Progress

C5

Green Products

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University of Minho, Portugal

Environmental improvement of building insulating cladding system

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Short Summary

Cladding systems performances are considered always more relevant in determining sustainability values of building constructions [1]. Insulating envelopes are the mediating elements between outdoor environment and indoor spaces of a building: they are responsible of heat transfer and regulation of energy flows through the wall [2].
The present work aims to improve the performance of an existing commercial product [3] through the application of smart materials called PCMs (Phase Change Materials). These substances have been applied for many years in building industry because, due to their high heat storage capacity, they help decreasing thermal peaks inside buildings and reducing energy consumption required by cooling systems [4].
Analysis of previous researches on materials insulating properties [5] and on building products requirements [6] has been carried out in order to provide an adequate background and to find a good solution to integrate PCMs into the cladding system.
The new material which has been developed, aimed at improving insulating properties, is a composite panel made of a cellulose fibre matrix (obtained from recycling processes of cardboard) and PCMs as additives in the mixture.
The environmental improvement of the product obtained with the present research consists of the following features:

- the use of widely available waste products such as cardboards as base material [7];
- the development of a new smart material which is able to increase the insulation properties in specific and critical conditions through the use of PCMs;
- the achievement of a product which turns recyclable to obtain a new insulating panel, because the presence of PCMs powder doesn’t contrast the recycling process of paper.

Properties of the new composite material have been tested and compared to those of a commercial insulating panel. Results have shown the possibility to improve in dynamic thermal conditions the insulating properties of building envelopes.

Keywords: PCMs; Thermal Insulation; Cladding System.

1. Introduction

The present work aims to improve the thermal and environmental performances of a building cladding system. [3] Specifically the research focuses on the analysis of the insulation layer and carries on the development of a new composite material suitable to replace the actual products.
The reference product is “PIZ Cladding System” (Fig. 1), a prefabricated envelope for civil and industrial buildings produced by PIZ S.r.l. It is made of double-layered panels installed with dry technique on aluminium anchoring guides. Internal layer is made of 45 mm expanded perlite and has insulating function while external layer is a covering and aesthetical skin made up of a 9 mm fibre-reinforced cement mortar.

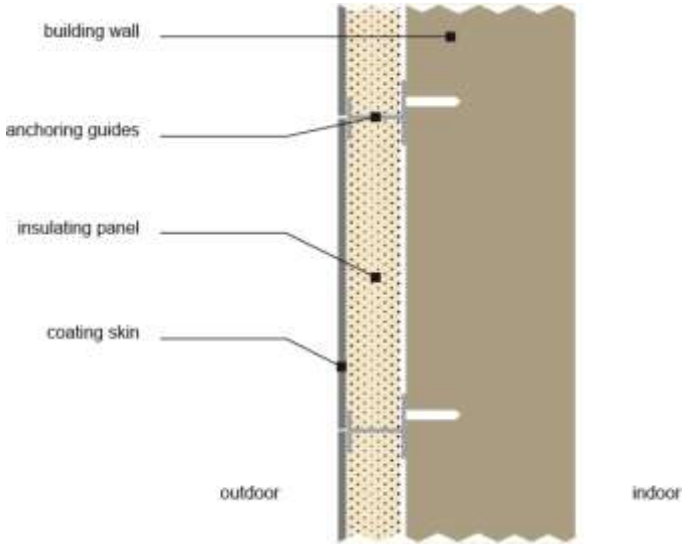


Fig. 1: PIZ Cladding System components

The required properties of a building insulating panel have been selected in order to set adequate tests for the material characterization. Those qualities depends on European normative [6], sustainability requirements [8] and innovations introduced on the market by latest commercial products. The main properties concerns:

- sustainability, which can be improved through the use of waste products as base material for new building components and through the achievement of better insulating and resistance properties;
- static thermal insulation, which can be improved by introducing air particles into the material structures;
- dynamic thermal insulation, which can be improved by increasing walls thickness or achieving high heat storage capacity;
- lightness, which can be improved by introducing air particles into the material structures;
- flexural resistance, which can be improved by high cohesion through the material fibres;
- fire resistance, which can be improved by adding retardant substances;
- water resistance, which can be improved by adding anti-humidity substances.

Experiments on composition and productive process have been done in laboratory scale in order to face each outlined aspects. Afterwards tests have been conducted in order to verify the effectiveness of the processed solutions. Finally comparison between cellulose samples and perlite panels actually employed in “PIZ Cladding Systems” has come to the conclusion that the new composite material developed represents a valid alternative for the sustainable improvement of the product.

2. Materials

2.1 Cardboard scrap

Recycling industry is a crucial resource for international industrial system. In recent years, the market of secondary raw materials has increased, thanks to the improvement of separate collection system.
Regarding the recycling of paper and cardboard, in the last decades the collection of waste products in Italy increased of about 1 millions of tons, while the industrial use of those secondary raw materials increased of just 300.000 tons. [11] This indicates that the current production and collection of waste paper is marked by an oversupply. To develop new products starting form waste materials helps to provide a sustainable answer to this overproduction problem.
Paper recycling is a well consolidated industrial process which gives undeniable economical and environmental advantages. Depending on cellulose fibres properties different kind of products has been produced starting from waste material. In building industry, taking advantage of insulating function of cellulose fibres, paper scraps has been recently employed as thermo-acoustic insulating material. [12]
In the presented work, the thermal insulation quality of cellulose fibre has been investigated and enhanced through the addition of smart materials. The result is the production of a new composite material.

2.2 PCMs

One of the main causes of energy consumption in buildings is the increasing use of indoor heating and cooling systems [13]. Comfort inside architecture spaces can be obtained with well known temperatures and humidity values (about 16-22°C and 40-70% respectively). [14]
The study of insulating system applied on the perimeter walls permits to improve the maintenance of thermohygrometric values needed to carry on indoor activities. For this reason envelope material performances affect the energy consumption and the environmental impact of a building project. In recent years Façade Engineering has acquired an increasingly important role to enrich projects related to new or renovated architectures. [1]
Application of Phase Change Materials (PCMs) in building industry have been studied for many years [4] and has recently proposed on the market in the form of building components by European chemical companies (Basf SE, Rubitherm GmbH). [15] The role of PCMs inside insulating material is to reduce the heat transfer through the perimeter walls. Those substances have high heat storage capacity that can be set at useful temperatures in accordance with their phase transition temperature.
In order to reduce energy consumption in summer, PCMs thermal storage should be activated when temperatures exceeds the comfort zone. For the present work two kinds of Paraffine substances have been selected: Rubitherm PX28HC, with phase transition at 28°C, and Micronal Basf DS600, with phase transition at 26°C. [15]

3. Production process

During this research has been possible to synthesize a new composite material with thermal insulating properties through the mixing of cellulose fibers and PCMs. The first ones give low thermal heat conductivity (suitable for winter periods in static condition), the second ones confer high thermal storage capacity (suitable for summer periods in dynamic condition).
Production process has been reproduced on laboratory scale through the use of a pulper machine which permits to simulate paper recycling. (Fig.2) Cardboards derived from industrial scraps (provided by Ghelfi Ondulati S.p.A.) [16] has been processed with water into the pulper machine (a). A wet pulp has been obtained (b) and chemical substances, in liquid (d) or powder (c) form, has been added into the mixture in order to enhance resistance and insulating properties of cellulose fibers.
The wet pulp chemically modified has been placed into stamps and processed in a heater in order to drain water (e). Settings in time and temperatures vary with material compositions and quantities. As a result a dry solid panel has been obtained (f).

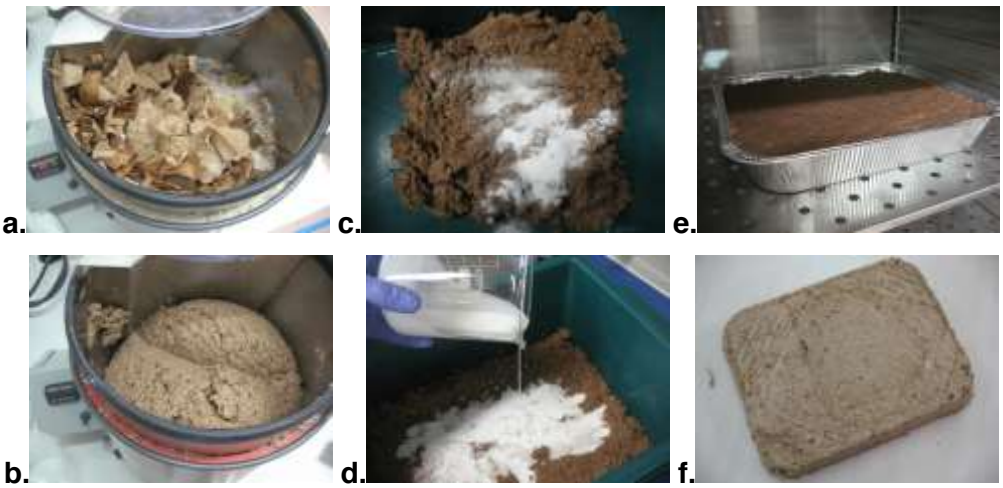


Fig. 2: Composite material production process

4. Properties

4.1 Durability

In order to preserve the sustainability of a product it is necessary to ensure an adequate life time. Resistance properties of materials are related to the durability time of a building components. Following the CPR's requirements [6], specific additives has been selected for their ability to confer water and fire resistance properties to cellulose fibers. The introduction into the cardboard pulp of those substances, which doesn't contrast with the recycling process of the composite material, permits to improve the life cycle of the product.
After laboratory tests the suitable quantities of additives has been chosen. [10] In order to improve fire resistance and confer fungicidal effect, an addiction of 30% of Borate Salts [17] has resulted adequate. In order to improve water resistance, an addiction of 15% of Basoplast Basf [18] has resulted effective.

4.2 Lightness and mechanical resistance

Environmental improvements of a product are achieved also with appropriate physical properties related to its application. Lightness and mechanical resistance are important qualities for building components and a good compromise between those two factors needs to be find in order to produce an effective insulating panel.
Measurements on composite material samples produced for this research demonstrates that the attempts to improve lightness has the effect to reduce flexural strength at the same time. In fact, extremely light samples haven't been considered suitable to be subjected to mechanical test. Anyhow it has been possible to produce cellulose panel with pourous or perforated structures with significant weight loss and good flexural resistance compared to commercial panels.(Fig.3) [9] Weight and flexural strength comparison between the selected materials are listed in Table 1.

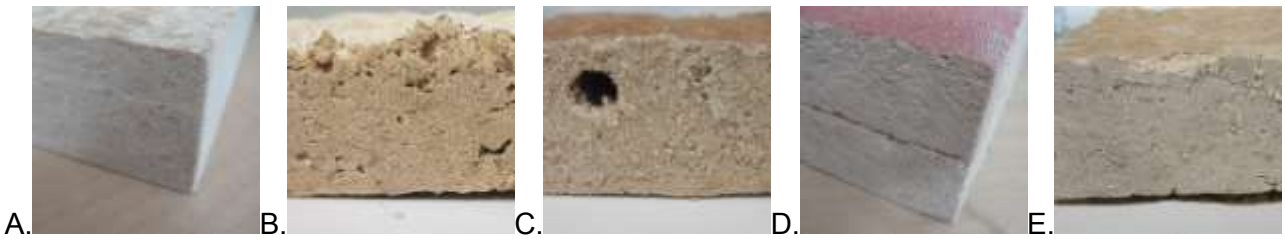


Fig. 3: Materials samples selected for the experimental tests.

Table 1: Physical properties comparison between perlite and cellulose fibre panels

	Material	Density (kg/m^3)	Flexural strength (kPa)
A	Expanded perlite panel with cellulose fibre	145	282.95
B	Pourous panel of cellulose fibre and PCMs	180	170.75
C	Perforated panel of cellulose fibre and PCMs	215	375.80
D	Expanded perlite panel	260	650.50
E	Compact panel of cellulose fibre and PCMs	215	390.25

Those data demonstrate that the new composite material developed with cellulose fibers and PCMs would be an appropriate insulation layer for PIZ cladding systems mechanical requirements.

4.3 Thermal conductivity

The main criterion to certificate the environmental impact of a building is the thermal conductance of its perimeter closures (U value, measured in W/m^2K). This value depends directly to the thermal conductivity of each material that composes stratification into walls (λ, measured in W/mK). [19]
Commercial PIZ Cladding System produced with expanded perlite panels has well known thermal conductance values. Assuming to replace the insulation layer of PIZ Cladding System with the cellulose panels produced with the present research, different thermal conductance properties will be obtained.
Using a heat flux meter test, the λ value of each specimens has been measured and U value of a PIZ Cladding System has been subsequently calculated. Resulted are listed in Table 2.

Table 2: Thermal properties of a PIZ cladding system with different insulating materials

	Insulating material	PIZ U value (W/m^2K)	λ of insulating material (W/mK)
A	Expanded perlite panel with cellulose fibre	1.10	0.050
B	Pourous panel of cellulose fibre and PCMs	1.15	0.052
C	Perforated panel of cellulose fibre and PCMs	1.20	0.055
D	Expanded perlite panel	1.31	0.060
E	Compact panel of cellulose fibre and PCMs	1.38	0.063

Those data demonstrate that the new composite material developed with cellulose fibers and PCMs would be an appropriate insulation layer for PIZ cladding systems thermal requirements.

4.4 Thermal inertia

The most relevant improvement achieved with the new composite material has been conferred by PCMs thermal storage effect. Their power to improve the environmental sustainability during the product working phase has been validated by laboratory tests.
A thermostatic chamber (represented in Fig.3) has been constructed and temperature variation of typical summer days has been reproduced switching a lamp inside it. Samples of insulating material have been placed on the perimeter wall and, using a heat flows probe, the insulating capacity of each panel has been compared.

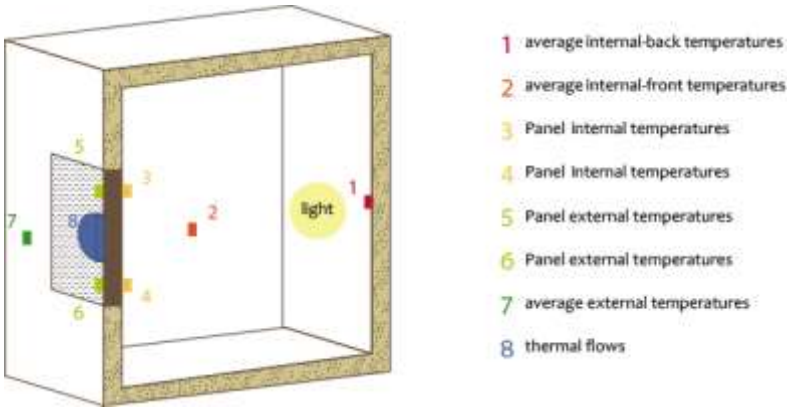


Fig. 3: Thermal flows tests equipments scheme

Thermal test starts when the lamp has been switched on. Temperature inside the chamber starts at 20°C and quickly reaches the value of 35°C in 90 minutes. Once the lamp has been switched off the temperature inside the chamber slowly decreases. Measurements of temperatures [in °C] and thermal flux [in W/m^2] have been represented in Fig. 4. Three material samples with dimensions 200x200x45 mm have been compared:

- Expanded Perlite panel with cellulose fibres;
- Cellulose fibres panel and Micronal Basf PCMs with temperature change at 26°C;
- Cellulose fibres panel and Rubitherm PCMs with temperature change at 28°C.

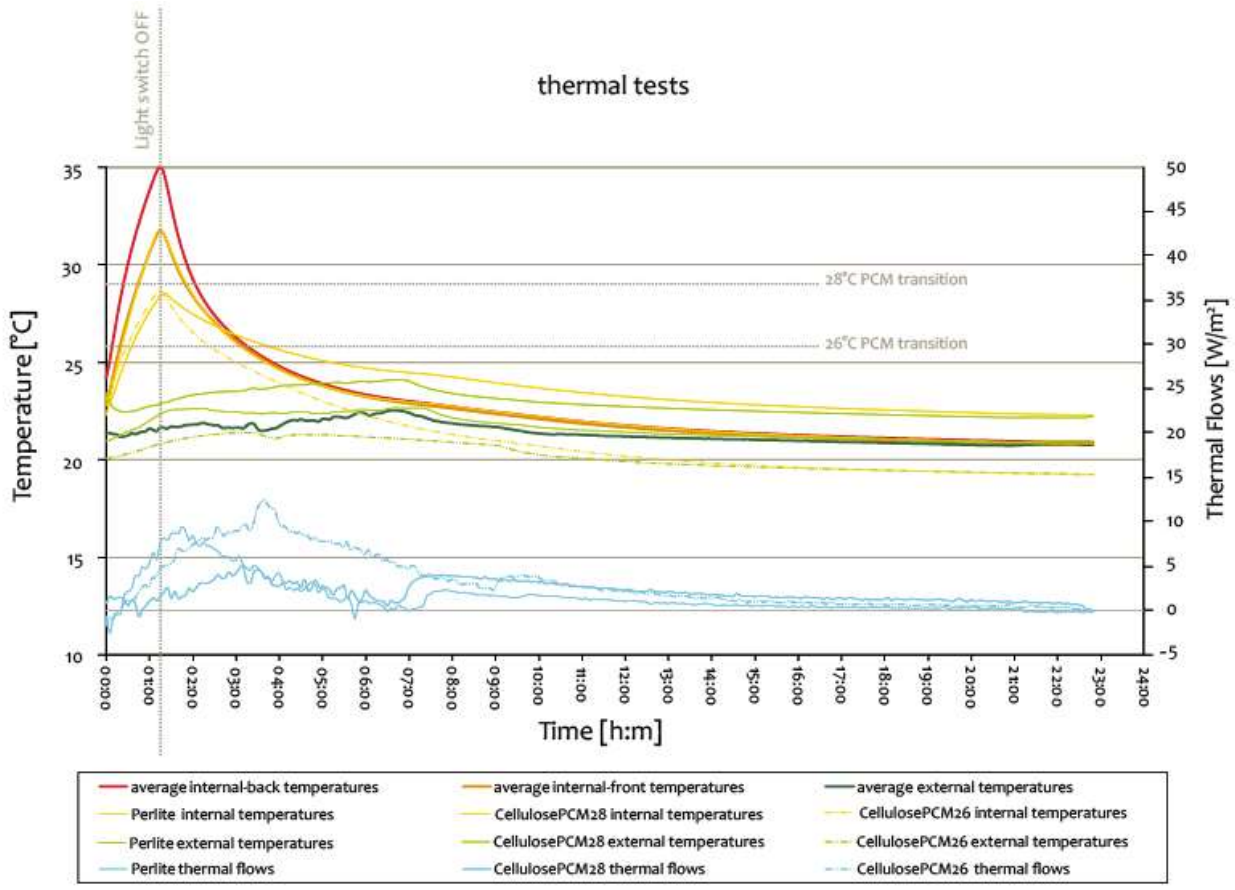


Fig. 4: Thermal flows and temperature measurements

Calculating the area under the thermal flows curves, it is possible to compare the amount of thermal energy which passes through the panel in a definite period time. Area variation during thermal test is represented for each panel in Fig.5 and some significant results are listed in Table 3.

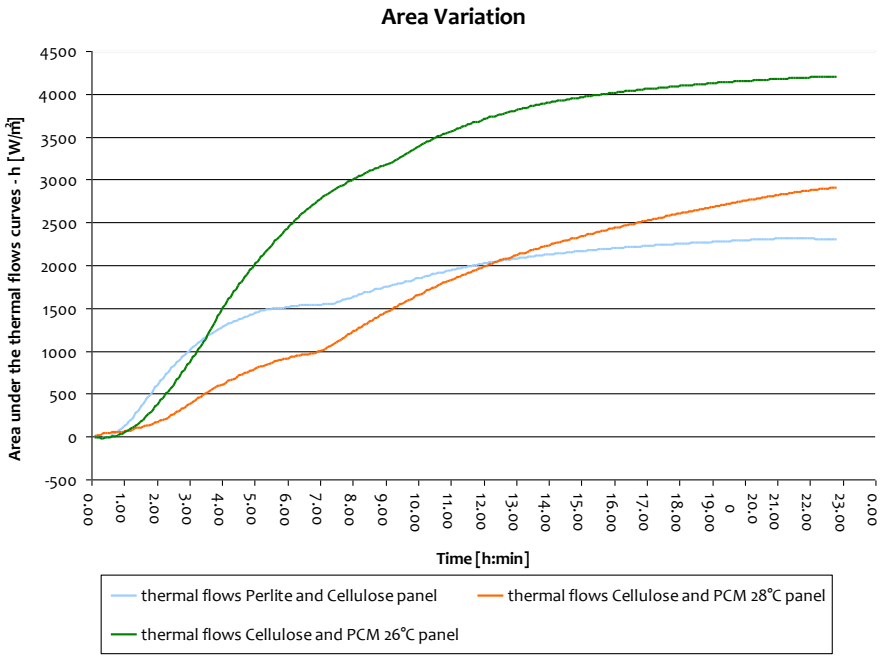


Fig. 5: Area variation under thermal flows curves

Table 3: Area under the thermal flows curves

Insulating material	Area [h(W/m²)] at time *[h:min]*			
	3:30	*6:30*	*12:30*	*18:30*
Perlite	19.26	25.50	34.13	**37.66**
Cellulose PCM 28	**8.33**	**15.87**	**34.10**	43.94
Cellulose PCM 26	18.99	43.53	62.59	68.44

It is possible to notice that Cellulose-PCM panel with phase transition at 28°C has the better performance up to 12:30 hours of thermal test. After that time Perlite panel acquires better results thanks to its better thermal conductivity. Cellulose-PCM panel with phase transition at 26°C gives a good insulation till 3:30 hours of thermal tests when its thermal flows becomes higher than whose of Perlite panel.

5. Conclusion

The method adopted for developing a new building insulating panel in accordance with sustainable requirements has been described. The improvement process starts form the choice of recyclable materials with insulating properties like cellulose fibres, with the aim to find a solution for the cardboard scraps over-collection problem. The enhancement of product lifetime through the maintenance of material resistance properties has been faced with the selection of specific additives which also allow further recycling process. The implementation of insulating properties has been achieved with the addition of PCMs whose operating principles has the effect to reduce the energy consumption of buildings.
All the underlined aspects have been validated by laboratory tests and numerical values. Density, flexural strength, thermal conductivity and conductance of the new composite material developed resulted comparable to those of Perlite actually employed in PIZ Cladding System. While the new product gives better results in dynamic conditions thanks to the thermal storage effect of PCMs which help to reduce the heat transfer when temperature reaches high typical summer values. Those thermal tests suggest that PCMs could be effective for the reduction of cooling systems energy consumption during summer periods.
As stated in the recent European Commission Recommendation of 9 April 2013 (2013/179/UE), measurement and information on the environmental performance of materials, products and

services must comply with the life cycle method. It means that instead of estimating the material impact, it would be more appropriate to estimate the effect that this new material confers to the life cycle of the product in which it is used. As highlighted by recent researches [20], to focus exclusively on the assessment of energy consumption in the use phase involves the shift of environmental impacts to the other phases, with a prevalence on building materials' production. For this reason the application of a building envelope made of secondary raw materials as recycled cardboard should not represent a risk, because it ensure low environmental impact even in the early stages of pre-production and production. These qualitative evaluation on the potential benefits of reducing the impact in the early stages of pre-production, production and use will be verified and quantified with the Life Cyle Assessment.

6. Acknowledgements

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7. References

[1] BROOKES ALAN J., MEIJS MAARTEN, Cladding of Buildings, Fourth edition, Taylor & Francis, Abingdon 2008.
[2] BRUNORO SILVIA, Efficienza energetica delle facciate. Standard, requisiti, esempi per l'adeguamento e la riqualificazione architettonica, Maggioli editore, Santarcangelo di Romagna 2006.
[3] PIZ Cladding System, www.piz.it
[4] CABEZA L. F., CASTELL A., BARRENECHE C., DE GRACIA A., FERNÁNDEZ A. I., Materials used as PCM in thermal energy storage in buildings: A review, Renewable and Sustainable Energy Reviews 15 (2011 pp. 1675–1695).
[5] PFUNDSTEIN MARGIT, GELLERT ROLAND, SPITZNER MARTIN H., RUDOLPHI ALEXANDER, Insulating Materials: principles, materials, applications, Birkhauser, Munich 2008.
[6] Construction Products Regulation (CPR 305/2011).
[7] Assocarta, "L'industria cartaria nel 2009", Edizione Tecniche Nuove.
[8] FASSI ALESSANDRO, MAINA LAURA, L'isolamento ecoefficiente : guida all'uso dei materiali naturali, Edizione Ambiente, Milano 2006.
[9] GARBAGNOLI P., MUSITELLI M., DEL CURTO B., PEDEFERRI M.P., Development of cellulose panels with porous structure for sustainable building insulation, World Academy of Science, Engineering and Technology 2012, 71:1198-1202
[10] GARBAGNOLI P., MUSITELLI M., DEL CURTO B., PEDEFERRI M.P.,Study and characterization of insulating panels for sustainable buildings made by waste cardboard and PCMs, CLIMA 2013 Congress, Prague
[11] COMIECO, Raccolta, riciclo e recupero di carta e cartone, 16° rapporto 2010, (www.comieco.org)
[12] CAVALERI ANDREA, CONTU DAVIDE, Process for manufacturing insulating material, United States Patent Application Publication, 20 October 2011
[13] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal European Community, 2010.
[14] BENEDETTI CRISTINA, Manuale di architettura Bioclimatica, Maggioli, Rimini, 1994.
[15] Basf SE (www.micronal.de); Rubitherm GmbH (www.rubitherm.de).
[16] Ghelfi Ondulati S.p.A. (www.ghelfiondulati.com).
[17] Borax Inc. Borates in Flame Retarding CelluloseMaterials. Products Data Sheet. (www.borax.com).
[18] Basoplast Basf (www.basf.com)
[19] MORANDOTTI MARCO, Trasmittanza termica e involucro edilizio, metodo di calcolo e valutazione prestazionale, Progettazione degli elementi costruttivi della Facoltà di Ingegneria Civile dell'Università di Pavia, A.a. 2009/2010.
[20] PALEARI M., LAVAGNA M., Life Cycle Assessment and Zero Energy Residential Buildings, Life Cycle Assessment e ottimizzazione ambientale: esempi applicativi e sviluppi metodologici, Atti del VII Convegno Scientifico della Rete Italiana di LCA, Milan, 2013.



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The environmental footprint of plastic pipe systems within the built environment

Short Summary

The European Plastics Pipes and Fittings Association (TEPPFA) deems it important to have an insight into the integral environmental burdens encountered during the life-span of particular plastic pipe system applications within the built environment. With this framework in mind, TEPPFA has set up a project with the Flemish Institute for Technological Research (VITO). The aim of this project is to carry out several life cycle assessment (LCA) studies from the cradle to the grave. The LCAs of several plastic pipe systems outline the various environmental aspects which accompany the pipe systems, from the primary extraction of raw materials up to and including the end of life (EoL) treatment after their reference service life time. To get a better view on the advantages and disadvantages from an environmental point of view of a pipe system in plastic compared to its main competing non-plastic material, LCA comparisons were made. The conclusions of the comparative LCA studies show that the average environmental impact of plastic pipe systems in general are lower than the average environmental impact of piping systems made out of traditional materials.
This paper reports on the LCA of some specific plastic pipe systems with the final aim of providing a clear environmental product declaration (EPD), thus raise the awareness amongst developers, installers and users, of the potential environmental impacts and benefits over the complete life cycle. In addition some comparisons for the environmental impact category global warming (CO2 footprint) are presented and discussed.

Keywords

Plastic pipe systems, life cycle assessment (LCA), environmental product declaration (EPD), European sector approach, sustainable construction and housing.

1. About TEPPFA

TEPPFA stands for The European Plastic Pipes and Fittings Association. It is a trade association representing the key manufacturers and national associations of plastic pipe systems. TEPPFA is actively involved in the promotion and acceptance of plastic pipe systems for all applications. It has a

voluntary initiative, commitment to develop EPDs for several types of plastic pipe systems. The EPD initiative of TEPPFA aims to measure the environmental impact of plastic pipe systems throughout their entire life cycle and to communicate about the results by means of EPDs.

2. Life Cycle Assessment (LCA) of plastic pipe systems

LCA is a standardized tool that assesses the environmental impact of products, processes and/or systems throughout their entire life cycle. LCA quantifies the potential environmental effects of a product, a process or a system over its entire life cycle, meaning that the extraction of raw materials, the production of materials and the product, the use and the end-of-life treatment are taken into account.

TEPPFA created cradle-to-grave LCAs consistent with ISO 14040 [2], ISO 14044 [3] and the pre and final EN 15804 [4] and EN 15942 [5].norms. The overall objectives of the TEPPFA LCAs are:

- to analyse the environmental impacts of different applications of plastic pipe systems in selected application groups;
- to investigate the relative performance of various plastic pipe systems at the system level in order to show that material choices cannot be made at the product or material level only;
- to use the results of the LCA-studies of the plastic pipe systems for business-to-business communication by means of EPDs;
- to compare the environmental footprint of the plastic pipe systems with the environmental footprint of non-plastic pipe systems.

Within the TEPPFA framework the environmental impact categories as defined in EN 15804 are considered [4].

Table 1: The environmental impact categories considered in the LCAs

Abiotic depletion:	exhaustion of natural resources
Acidification potential:	emissions from manufacturing processes resulting in acid rain
Eutrophication:	over-fertilisation of water and soil
Global warming:	insulating effect of greenhouse gases, such as CO_2 and methane
Ozone layer depletion:	depletion of the ozone layer in the atmosphere caused by emissions of pollutants
Photochemical oxidation:	photochemical reaction of sunlight with primary air pollutants, that leads to chemical smog

3. Environmental Product Declaration (EPD) of plastic pipe systems

The EPDs for plastic piping systems provide LCA-based information from the cradle to the grave. The EPDs are provided in a standard communication format according to the EN 15942 [5]. The EPDs can be downloaded from the TEPPFA website (http://teppfa.eu/sustainability-a-environment/-epd.html). TEPPFA created the EPD framework. The member companies that produce plastic pipes and fittings provided their life cycle inventory (LCI) data to TEPPFA. Then the LCAs are carried out by VITO, critically reviewed by an external and independent expert from Denkstatt and Third Party Reports and EPDs are created and published on the TEPPFA website. The process reflects a European sector approach for EPDs.

4. Overview of the LCAs and EPDs for plastic pipe system applications

- Sewage and drainage applications (non-pressure):
  - PVC-U solid wall sewer pipe system [12]
  - PVC-U multilayer (foamed core) sewer pipe system [13]
  - PVC-U multilayer (core of foam and recyclates) sewer pipe system [14]
  - PP structured (twin) wall sewer pipe system [15]
  - PP solid wall sewer pipe system [20]**
  - PP structured wall multilayer sewer pipe system [20]**
- Water and gas distribution applications (under pressure):
  - PE water pipe system [8]
  - PVC – U water pipe system [9]
  - PVC – O, MRS 31,5 MPa, water pipe system [10]
  - PVC – O, MRS 45 MPa, water pipe system [11]
  - PE gas pipe system [19]**
  - PE water pipe system installed by directional drilling technology **
- Soil and waste applications in the building (non-pressure):
  - PP pipe system [6]
  - PVC-U pipe system [7]
  - PP low noise pipe system [18]**
  - PVC-U low noise pipe system [18]**
- Plumbing, hot & cold applications in the building (pressure):
  - PEX solid wall pipe system [16]
  - Polymer, aluminium, polymer multilayer pipe system [17]
  - PP-R pipe system [21]
  - PB-1 pipe system**
- Rain gutter applications:
  - PVC-U rain gutter system**

** In preparation

5. Some results for plastic pipe systems

5.1. Sewage and drainage applications

The functional unit of the sewer pipe systems that have been studied has been defined as: “the below ground gravity transportation of sewage over a distance of 100 m by a typical public European plastic pipe system and its alternative concrete pipe system from the entrance of a public sewer system to the entrance of the waste water treatment plant, over their complete reference service life of 100 years, calculated per year”.

PVC-U solid wall sewer pipe system
The environmental impacts of the PVC-U solid wall sewer pipe system is mainly caused by the product stage (raw materials) and the construction process stage (excavation of the). When comparing the PVC-U solid wall sewer pipe system with a concrete sewer pipe system fulfilling the same functional unit, we can conclude that for most environmental impact categories the contribution of the concrete pipe system is relatively lower, although the difference is not significant. Only for global warming of the PVC-U solid wall sewer pipe system has a lower contribution (see Figure 1).

PVC-U multilayer (foamed core) sewer pipe system
The technical possibilities of the plastic pipe systems provide excellent tools to fit these systems to many different requirements. A new product in which a reasonable amount of plastic is replaced by air reduces the environmental impacts dramatically in most environmental categories. When considering a multilayer sewer pipe system instead of a solid wall sewer pipe system, the environmental impacts are reduced significantly. At the same time the environmental impacts of a

PVC multilayer foam core pipe system results in a lower contribution in comparison to the environmental impact of a concrete pipe system and this is valid for all environmental impact categories considered. Figure 2 presents the comparison for global warming.

PVC-U multilayer (core of foam and recyclates) sewer pipe system

In this type of PVC-U multilayer pipe system the virgin PVC material in the core of the pipe wall is replaced partly by foamed virgin PVC and recycled PVC. When considering this multilayer sewer pipe system instead of a solid wall sewer pipe system, the environmental impacts are reduced significantly. At the same time the environmental impacts of this multilayer pipe system with a core of foamed PVC and PVC recyclates results in a lower contribution in comparison to the environmental impact of a concrete pipe and this is valid for all environmental impact categories considered. The use of recyclates further reduces the CO2 equivalent. Figure 3 presents the comparison for global warming.

Figure 1: Comparative environmental profiles: PVC-U solid wall versus concrete sewer pipe systems

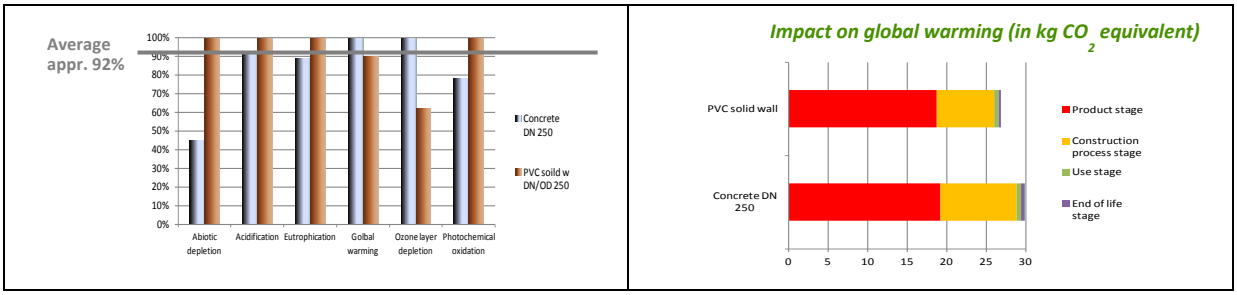


Figure 2: Comparative environmental profiles: PVC-U multilayer (foamed core) versus concrete sewer pipe systems

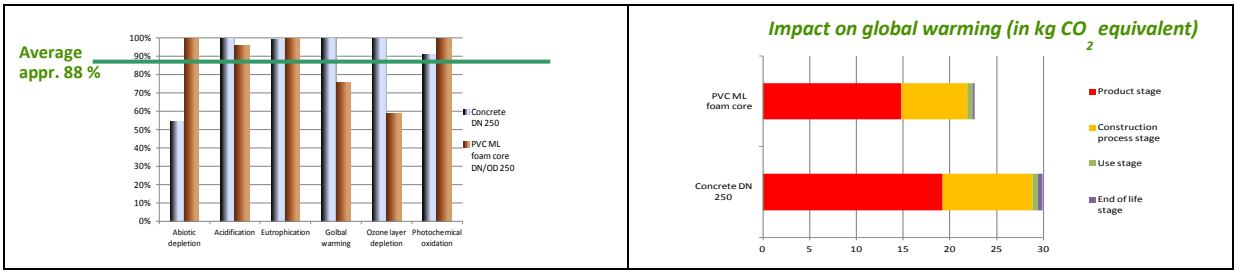
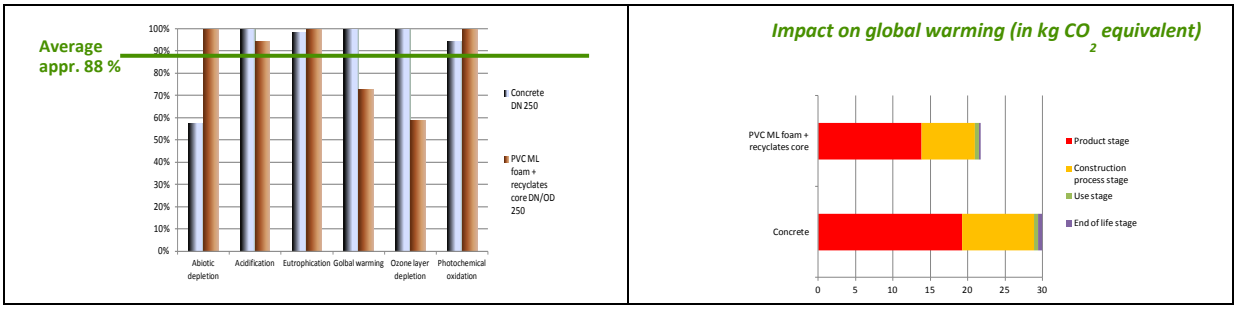


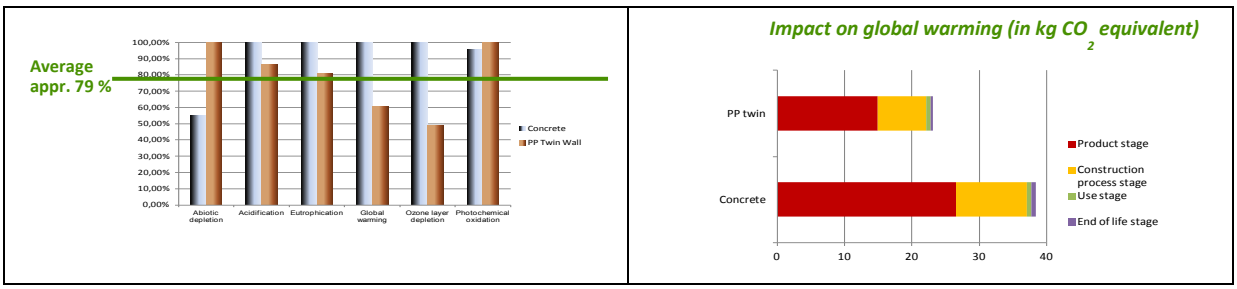
Figure 3: Comparative environmental profiles: PVC-U multilayer (core of foam and recyclates) versus concrete sewer pipe systems



PP structured (twin) wall sewer pipe system

In this LCA study DN/ID 300 PP and DN 300 mm concrete piping systems are compared. When considering a PP sewer pipe system with a structured (twin) wall in comparison to a concrete sewer piping system this results in a relatively lower contribution for all environmental impact categories considered. The excellent environmental behaviour of PP twin wall sewer piping system is again an evidence on the innovative nature of plastics. Figure 4 presents the environmental comparison.

Figure 4: Comparative environmental profiles: PP structured twin wall versus concrete sewer pipe systems



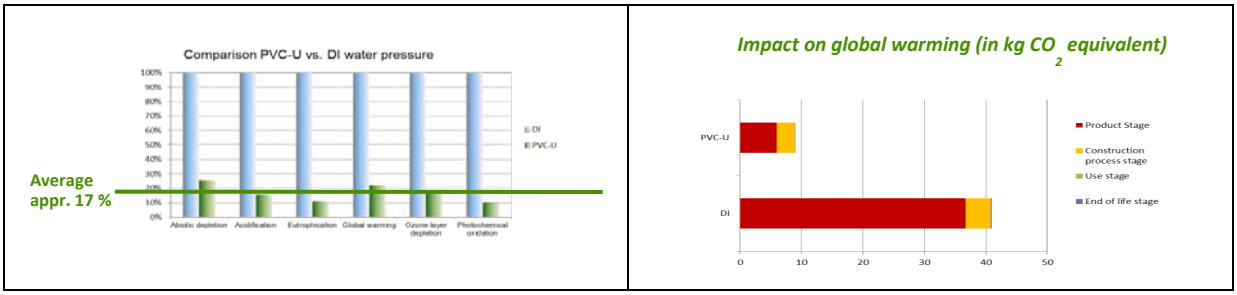
5.2. Water and gas distribution applications

The functional unit of the water and gas distribution pipe systems that have been studied has been defined as: “the below ground transportation of gas/drinking water, over a distance of 100 m (from the exit of the water plant to the water meter of the building), by a typical public European plastic pipe gas/water distribution system and its alternative ductile iron pipe system over their complete reference service life of 100 years, calculated per year.”

PVC-U water pipe system

The environmental profiles of the PVC-U water pressure pipe system is mainly caused the raw materials (PVC) during the product stage and by the construction process stage (mainly due to excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of the PVC-U water distribution pipe system is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 5).

Figure 5: Comparative environmental profiles: PVC-U versus ductile iron water pipe systems



PVC-O water pipe systems (bi-oriented)

Two PVC-O bi-oriented water pipe systems have been assessed: the PVC-O 31,5 MPa pressure and the PVC-O 45 MPa pressure pipe system for water distribution. Both environmental profiles are dominated by the product stage (raw materials production) and by the construction process stage (excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of both PVC-O water distribution pipe systems is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 6 and Figure 7).

Figure 6: Comparative environmental profiles: PVC-O (31,5 MPa) versus ductile iron water pipe systems

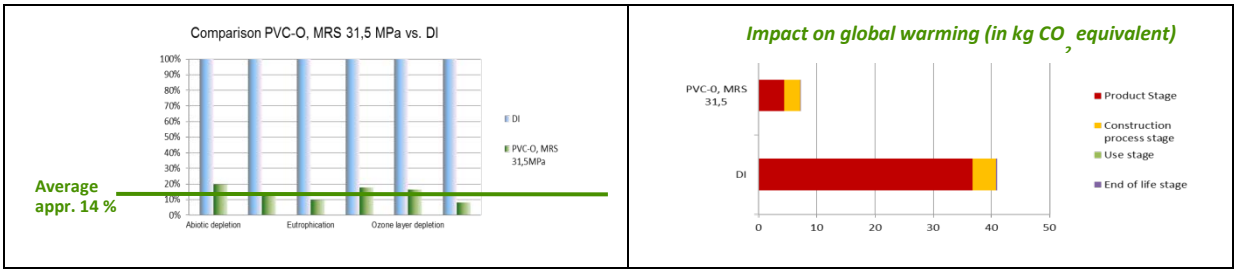
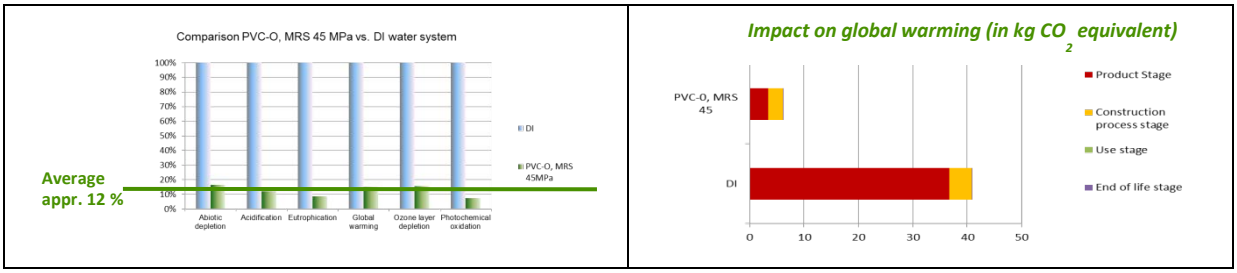


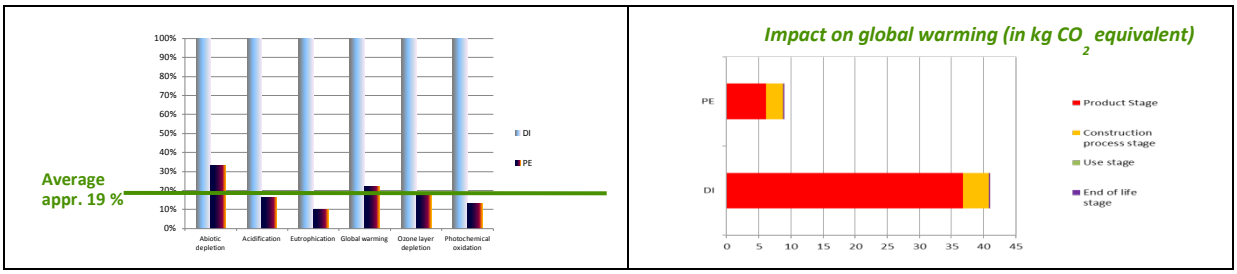
Figure 7: Comparative environmental profiles: PVC-O (45 MPa) versus ductile iron water pipe systems



PE water pipe system

The environmental profiles of the PE water pressure pipe system is mainly caused the raw materials (PE) during the product stage and by the construction process stage (mainly due to excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of the PE water distribution pipe system is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 8).

Figure 8: Comparative environmental profiles: PE versus ductile iron water pipe systems



5.3. Soil and waste applications in the building

The functional unit of the soil and waste pipe systems that have been studied has been defined as: “the yearly impact of different soil and waste gravity drainage systems’ installation into a typical European 100 m² apartment, incorporating a bathroom, separate WC, kitchen and washroom, considering the reference service life of the pipe systems to be aligned with the 50 year of reference service life of the apartment”.

Plastic soil and waste pipe system

The environmental profile of the PVC-U and PP soil and waste pipe systems is mainly determined by the product stage and more specifically by the production of the different pipe system components. When considering the environmental impact of a PVC-U and the PP soil and waste pipe systems compared to a ductile iron soil and waste piping system it results in a significantly lower contribution for all the environmental impact categories considered (see Figure 9 and Figure 10).

Figure 9: Comparative environmental profiles: PVC-U versus ductile iron soil and waste pipe systems

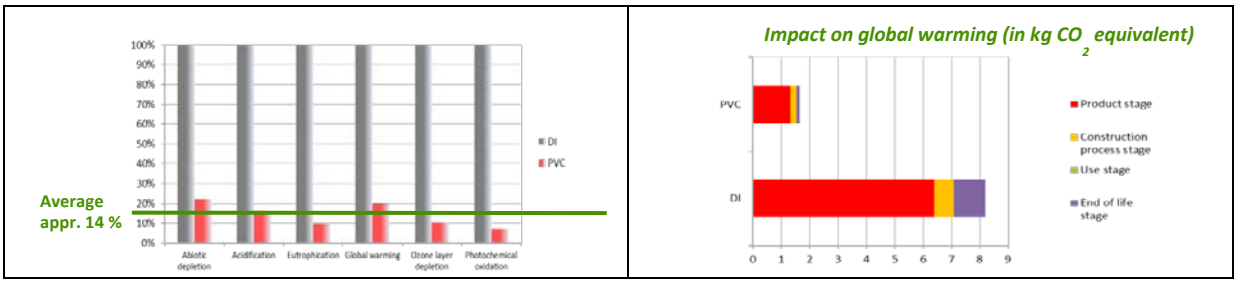
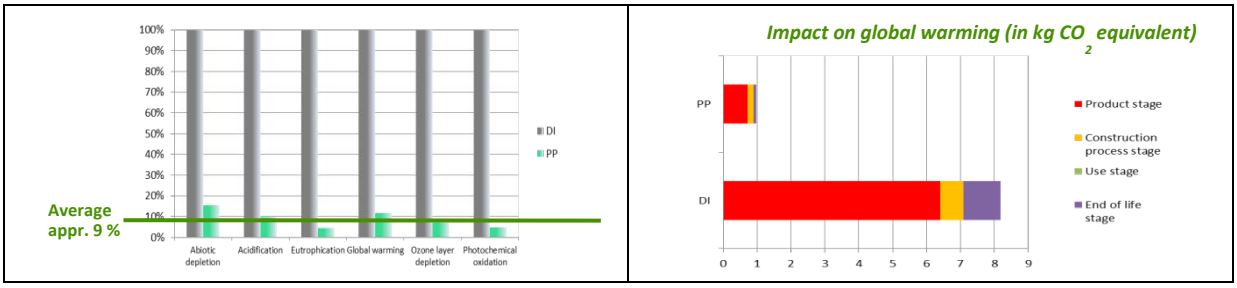


Figure 10: Comparative environmental profiles: PP versus ductile iron soil and waste pipe systems



5.4. Plumbing, hot & cold applications in the building

The functional unit of the hot and cold pipe systems that have been studied has been defined as: “the pressure supply and transport of hot and cold drinking water, from the entrance of a well-defined apartment to the tap, by means of a hot and cold drinking water pipe systems’ installation, supplying a 100 m² apartment, incorporating a bathroom, separate WC, kitchen and washroom, considering the reference service life of the pipe systems to be aligned with the 50 year reference service life of the apartment. The environmental profiles are calculated per year.”

Plastic pipe systems for hot and cold

The environmental profile of the PEX solid wall and the polymer – aluminium – polymer multilayer pipe systems for hot and cold water in the building is mainly determined by the product stage and more specifically by the production of the different pipe system components. When considering the environmental impact of the plastic pipe systems for hot and cold water compared to a copper hot and cold pipe system it results in a significantly lower contribution for all the environmental impact categories considered (see Figure 11 and Figure 12).

Figure 11: Comparative environmental profiles: PEX solid wall versus copper hot and cold pipe systems

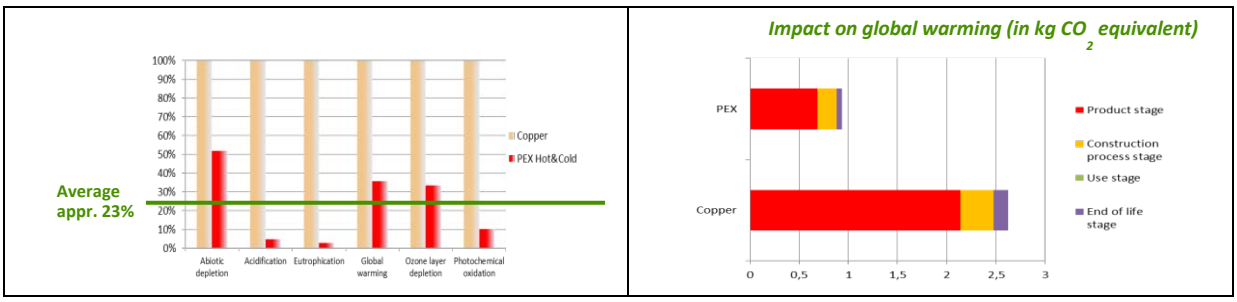
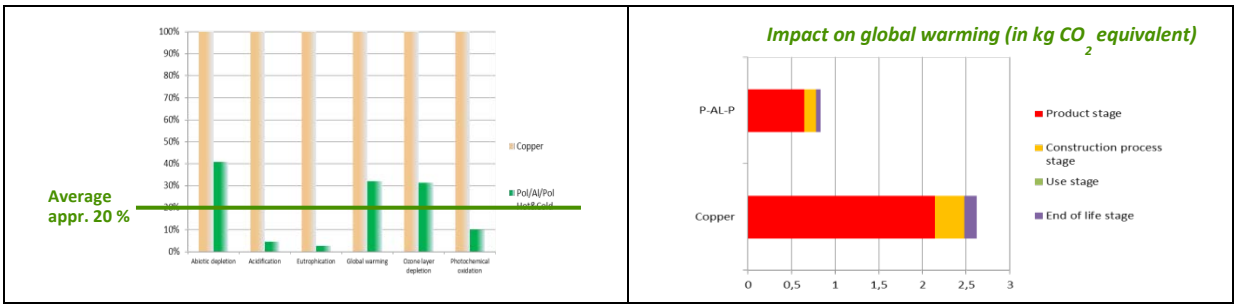


Figure 12: Comparative environmental profiles: Polymer/Al/polymer versus copper hot and cold pipe systems



6. Conclusions

The development of EPDs allows a comprehensive insight in the environmental impact of plastic pipe systems over their entire life cycle.

The results of the LCAs indicate that the impact of plastic pipe systems on the environment is relatively lower compared to the environmental footprint of main non-plastic piping materials.

The contribution of plastic pipe systems to global warming (CO2 footprint) is for all plastic piping systems that have been studied lower in comparison of pipe systems made out of competing materials for the pipes.

TEPPFA is committed to develop new EPDs for other types of plastic pipes and fittings.

TEPPFA members are committed to further reduce the environmental impact of plastic pipe systems.

References

[1] ISO 14025, (2006), Environmental labels and declarations -- General principles.
[2] ISO 14040, (2006), Environmental management – Life cycle assessment – Principles and framework.
[3] ISO 14044, (2006) Environmental management – Life cycle assessment – Requirements and guidelines.
[4] (pr)EN 15804: Sustainability of construction works – Environmental product declarations – core rules for the product category of construction products (draft, 2008);
[5] (pr)EN 15942: Sustainability of construction works – Environmental product declarations – Communication format – Business to Business (draft, April 2009).
[6] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PP pipe system for soil and waste removal in the building (according to EN 1451)” 2010/TEM/R/232
[7] SPIRINCKX CAROLIN, KAROLIEN PEETERS and KATRIEN BOONEN “Life Cycle Assessment of a PVC-U pipe system for soil and waste removal in the building (according to EN 1329)” 2011/TEM/R/114
[8] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PE pipe system for water distribution (according to EN 12201)” 2010/TEM/R/228
[9] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment of PVC-U pipe systems for water distribution (according to EN 1452)” 2010/TEM/R/117
[10] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment a PVC-O (bi-oriented, MRS 31,5 MPa) pipe system for water distribution (according to ISO 16422)” 2010/TEM/R/117
[11] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment a PVC-O (bi-oriented, MRS 45 MPa) pipe system for water distribution (according to ISO 16422)” 2010/TEM/R/117
[12] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U solid wall sewer pipe system (according to EN 1401)” 2010/TEM/R/234
[13] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U multilayer sewer pipe system with a foamed core (according to EN 13476)” 2010/TEM/R/242
[14] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U multilayer sewer pipe system with a core of foam and recyclates (according to EN 13476)” 2010/TEM/R/244

[15] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PP structured (twin) wall sewer pipe system (according to EN 13476)” 2011/TEM/R/112
[16] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PEX pipe system for hot and cold water in the building (according to EN ISO 15875)” 2010/TEM/R/230
[17] SPIRINCKX CAROLIN, KAROLIEN PEETERS and KATRIEN BOONEN “Life Cycle Assessment of a Polymer/Al/Polymer composite pipe system for hot and cold water in the building (according to EN ISO 21003)” 2011/TEM/R/110
[18] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life cycle assessment of a PP and a PVC low noise pipe systems for soil and waste removal in the building)” 2012/TEM/R/12
[19] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a PE pipe system for combustible gas distribution (according to EN 1555)” 2013/TEM/R/14
[20] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a smooth walled polypropylene (PP) mono- and multilayer sewer pipe system” 2012/TEM/R/
[21] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a Polypropylene random copolymer (PP-R) pipe system for hot and cold water distribution in the building (according to EN ISO 15874)” 2013/TEM/R/16

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Short Summary

The project SymBio$_2$ is the research and development of a hybrid façade system that uses the concept of symbiosis of building systems with the controlled and regulated production of microalgae on the building façade. The research explores the behaviour of thin flat panel microalgae photobioreactors in the configuration of a double skin façade where aerolic and fluid exchanges between the building and the photo bioreactors are optimized [4], [5]. The purpose of the research is to demonstrate the economic and technical feasibility of this new approach to producing microalgae. A demonstrator project on an industrial building in Nantes is under development. The project intends to show how this system can be adopted commercially on different building typologies by a large scale demonstrator.

Keywords: Photobioreactor, microalgae, facade, farming, symbiosis

1. Introduction

The building facade is the principle element of communication with the surroundings. It is essential in optimizing the energy performance of buildings both in solar gains, daylight and insulation. The question is whether it can do more whilst still satisfying aesthetical requirements? The future of high performance facades is beyond rendering buildings energy neutral but turning buildings energy positive and productive. Existing systems for transforming energy on building facades include wind turbines, photovoltaic's and solar thermal panels. These take energy and transform it in to other useful forms of energy with differing success.

The principle of using photobioreactors on facades to grow microalgae is very similar to solar thermal panels but instead of only absorbing and converting solar energy it absorbs CO_2 from photosynthesis. The photobioreactors whilst producing microalgae filter waste in symbiosis with the host building. When combined appropriately it can be used to enhance the aesthetics of buildings providing new revenue sources / energy, optimising internal energy performance and processing waste. It is a system that can be adopted for both new and existing buildings.

2. Façade system

2.1 Facades Introduction

The design of a building façade is traditionally the job of the architect and is normally a balance between cost, aesthetics and performance. The choice of façade system varies significantly although environmental regulation has imposed minimum performance criteria in many countries. Initial regulation was very specific about glazing limits and insulation requirements. The regulation is moving towards integrated building performance criteria based on energy performance per m^2. This new approach takes into account the role of the façade as part of the building ecosystems that influences natural ventilation and day lighting.

The role of the façade when designed correctly can help maximize daylight in interiors reducing lighting requirements, reduce cooling and heating loads by minimizing heat losses and gains through the façade whilst at the same time give a building a positive visual identity. In recent years there has been a growing trend in highly glazed building facades to increase transparency. This has posed significant issues for engineers to conform to regulatory requirements on energy performance, thus the advent of the high performance facade which aims to achieve these often contradictory aims. Maximising daylight whilst controlling heat gain is one such contradiction hence the adoption of multi layered facades such as double skin façade systems.

2.2 Microalgae Photobioreactors in a double skin facade

One of the key design criteria of the system we propose for our microalgae photobioreactors is that they are placed in a double façade configuration. There are many benefits of this configuration both on building performance and for the production of microalgae. Aesthetically it also ensures the transparency sought by architects currently. Other than an aesthetic choice, traditional benefits cited of double façade systems over single skin facades include improved thermal comfort, visual comfort and acoustic comfort with the potential of using the cavity to drive natural ventilation as a solar chimney. These benefits help with reducing energy consumption [5], [7]. Negative impacts of these systems are increased costs owing to an additional façade layer and fire regulation problems in certain countries.

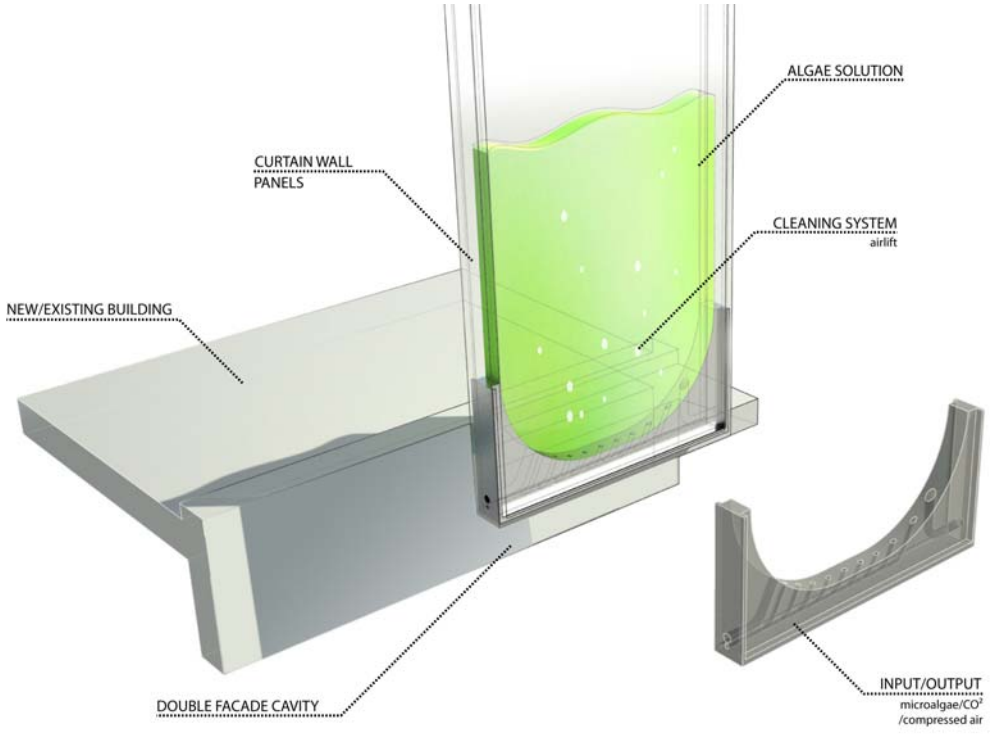


Fig. 1 SymBio$_2$ Photobioreactor configuration

The configuration proposed for our system is to place the photobioreactors in the outer skin layer. This maximizes the solar incidence on the microalgae mixture thus optimising production. The cavity layer is then used as a buffer zone that helps control the temperature of both the microalgae and the office space. The optimal temperature range for the microalgae analysed is between 19°C and 25°C which is very similar to that required by humans. Therefore by controlling the temperature of this zone through temperature exchanges between different areas of the building or evacuation of hot air, the temperature of the microalgae can be controlled [6]. The photobioreactors also act as a natural brise soleil. When the microalgae are in optimum production the photobioreactors are completely opaque preventing any light from passing through the panels. The research has shown that the predominant orientation of the photobioreactors should be south facing otherwise the production levels of the microalgae will not be high enough. The research conducted has shown that a 50/50 split between photobioreactor panels and transparent panels will provide the building with enough natural light for balancing daylight and heat gains. This split might vary according to location. In areas with very high solar incidence the ratio of photobioreactors may increase.

The flat photobioreactors act as a form of double glazing except that instead of an air void there is a liquid layer. This liquid layer varies in opacity according to the stage of photosynthesis of the microalgae. The choice of microalgae also impacts the colour of the liquid layer with both red and blue coloured microalgae available. Depending on the growth cycle of the microalgae it might have two phases turning from green to red.

3. Symbiosis with building

The symbiosis with buildings appears as one promising way to reduce capital and operating cost of photobioreactor technologies. Large scale illuminated areas are available, some costs like glasses can be shared, and the configuration in a double skin façade allows aerolic and fluid exchanges between the building and the photobioreactors to reduce needs in thermal regulation and nutrients supply (especially if CO2 sources are available). Optimisation of the symbiosis is here critical, as the final interest of the concept will be the result of mutual benefits obtained between buildings and microalgae needs. As explained previously the correct choice of microalgae will ensure that the building temperature requirements and that of the microalgae are similar to ensure the greatest synthesis between the two systems.

Depending on the type of building the symbiosis varies between the photobioreactors and the host building. Current research has looked into the possible exchanges between residential, commercial and industrial buildings. The first demonstrator project examined in this first stage of research is a waste incineration plant. The symbiosis identified in this project includes significant amounts of CO_2 as waste but also nitrate and heat exchange. Pluvial grey water collection can also be used in the microalgal solution. Therefore according to each situation of the photobioreactors on a building facade a thorough examination both in terms of thermodynamics and effluents needs to be conducted taking in to account all inputs and outputs. When proposed for new buildings rather than existing buildings the needs of the photobioreactors can be combined with that of the host building from the start bringing additional possibilities for symbiosis.

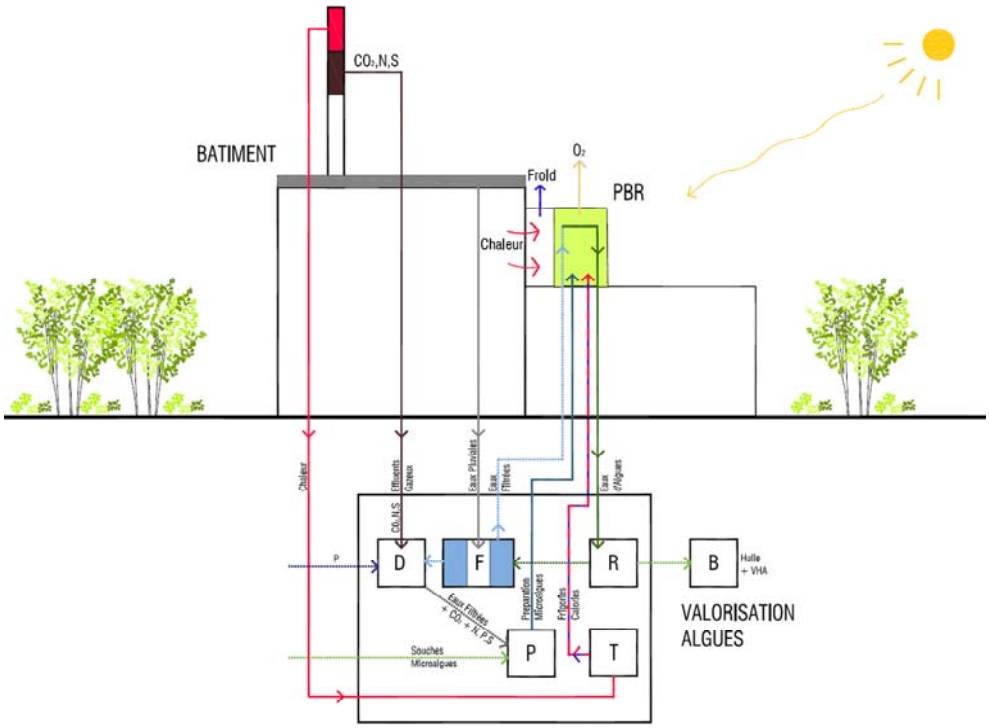


Fig. 2 Symbiosis with industrial plant

4. Flat panel photobioreactors

4.1 Microalgae production

Microalgae growth is based on the photosynthetic assimilation under illumination of inorganic carbon and mineral nutrients dissolved in the medium. The cultivation of photosynthetic microorganisms will thus require:

- A light supply like sunlight,
- An inorganic carbon source (such as dissolved CO2),
- Mineral nutrients (major nutrients such as N, S, P sources and micronutrients as Mg, Ca, Mn, Cu, Fe, etc.),
- Set culture conditions (pH, temperature).

Among all those growing parameters, light has to be considered with special attention, as light is the principal energy source of photosynthesis. Cultivation systems for microalgae are as a consequence characterized by a broad diversity, ranging from open ponds (open systems) to photobioreactor technology (closed systems) [4].The actual microalgae biomass production is mainly based on open systems. Such systems are the cheapest one and they can be easily extended today to a large scale. They suffer however from several limitations which are inherent to their operating principle. Owing to the direct contact with the atmosphere, there is especially a high risk of biological contamination (other microalgae species, bacteria, predators, etc.). Only resistant species can thus be cultivated long-term in such systems. In the opposite, closed geometries reduce risks of external contamination and a better control of culture conditions is obtained. With an optimal design and control, such technology allows reaching the highest productivities which could be achieved with vegetal, including plants and microalgae. In solar condition, the limit will be here

fixed by the solar energy entering the cultivation system and by its use in the culture bulk.

However, closed geometries suffer from several limitations, also inherent to their operating principles. Culture confinement increases the risk of biofilm formation, leads to oxygen accumulation in the culture (toxic effects), and overheating can occur (especially in solar conditions due to the large amount of infrared light collected). Unlike open systems where the only way to prevent external contamination or carbon limitation is to close the systems (working then with photobioreactor technology), the limits of closed geometries can be at least partly overcome by appropriate engineering of photobioreactors (e.g. by adapting mixing conditions to increase heat and gas-liquid mass transfer or to prevent biofilm formation). However, this most often results in increased cost and complexity. As the photobioreactor is the only system that allows maximal productivity to be obtained, great efforts are currently being made to develop new technology devoted to mass scale production. Current mass scale production comes mainly from extensive open systems easier to build and operate, i.e. open ponds or raceway systems. However, it may well be that in the near future a suitable closed technology will be devised that meets the criteria for mass-scale intensified production of photosynthetic microorganisms.



Fig. 3 Examples of raceway technology - open system – on left, and flat panel photobioreactor (closed system) on right (both are here operated in artificial light).

When considering the photobioreactor only, its specific implantation in building façade also introduces technical challenges. The system geometry has to respond to architecture constraints, light capture has to be optimized to guarantee maximal performances, the process has to be robust with ideally a continuous and automated operation during several months. The design of the system reveals here critical, as well as the applied within mixing conditions, or the material used
Regarding all those aspects, recent scientific work has brought new insights into how such systems might be achieved, especially by clarifying the parameters governing photobioreactor productivities and establishing engineering bases to optimize and scale them. Based on those principles and by also introducing constraints of a building integration, a specific photobioreactor has been designed. Thin flat panel photobioreactors were here found to maximize light exposure, while allowing mixing optimisation to avoid progressive biomass fouling on glass surfaces. Thin systems were here retained as photobioreactor depth is a relevant parameter, as it fixes the volumetric productivity which would have also a decisive impact on the global production process [1], [2], [3]. Increasing volumetric productivity will indeed allow high biomass concentration and thus lower harvesting cost, and will also lower the culture volume to be managed and so energy consumption for mixing and thermal regulation. All these aspects will contribute to a positive energy balance at the overall process level.

The fine tuning of all engineering parameters will request a direct evaluation in representative con-

ditions of a building symbiosis. This will be the aim of the demonstrator project which will integrate thin flat panel photobioreactors in a small scale building. Photobioreactors efficiency (biomass production, energy consumption) and robustness (continuous operation during several weeks) will be here assessed in solar outdoor conditions for a microalgae species of economic interest. Results will also be confronted to available models, which have been developed to predict biomass production and energy consumption as a function of meteorological conditions (then feeding the techno-economic model described next). Hydrodynamics conditions will also be optimised to prevent from fouling and to optimise CO2 fixation.

5. Microalgae

5.1 Why microalgae

The aquatic environments still conceal many treasures. At the base of the trophic chains, microalgae implement unique physiological and biochemical strategies to adapt to all environments. They are the biosynthetic progenitors of most of the natural substances of aquatic origin. They produce approximately half of the atmospheric oxygen and use simultaneously the greenhouse gas carbon dioxide to grow photo-autotrophically, i.e. at the expense of light and minerals. Their exceptional biodiversity with species in three out of four kingdoms of eukaryotic live (www.tolweb.org) makes of them a new economical frontier in various fields, namely health and welfare, food, feed and energy. Most of them produce unique products like small bioactive molecules, pigments, antioxidants, fatty acids, polymers, peptides and sterols. Thus, microalgae can offer different valuable compounds or functions which are still unused or underused.

5.2 Microalgae production

Despite fifty years of microalgae prospection, cultivation and the development of many cultivation technologies, the actual level of microalgae derived products remains very limited to few niche markets that can be listed: Astaxanthin from Haematococcus pluvialis, Beta-carotene from Dunaliella sp, Phycocyanin from Spirulina, DHA (Acid Docosahexaenoic - omega 3 fatty acid), EPA from Nannochloropsis sp (The American microalgae producer Aurora is now claiming EPA from Nannochloropsis sp cultivation), Dry Biomass from Spirulina, Chlorella, Aphanizomenon Flos-Aquae (AFA), Odontella, Aquaculture Special food from cultivation of strains such as Nannochloropsis, Phaeodactilum, Skeletonema T-iso, Pavlova, Tetraselmis .Bioactive compounds for cosmetic niches from cultivation of strains such as Porphyridium, Neochloris, Thalassossieraa and many others with production volumes of several hundred kg per year.

5.3 Microalgae costs

The reason for the low volumes is mainly due to the high costs of algae biomass and algae derived products with respect to competitors from natural or chemical origin. Therefore a number of active molecules identified in microalgae have not entered large markets because business models for their commercialization have never proven economic viability. That is the case for instance of Biofuels : C14-C18 saturated/mono-unsaturated. In addition, other active molecules are present in such limited quantities that the cultivation of microalgae for their sole and unique extraction is also uneconomic. Natural carotenoids commonly found in the 1% range in many microalgae, such as lutein or b carotenoid may fetch very high prices reaching thousands of $ per kg. Fucoxanthin and astaxanthin of nutraceutical quality may even fetch prices in the range of $ 7500 – 14000, so that microalgal biomass containing 1% or more of such carotenoids may be worth hundred dollars or more, if the carotenoids can be adequately extracted and marketed. But the corresponding volumes are low, as shown in figure 4.

Product	$/kg Pure	2010 Market Value ($M)	2010 MT (Pure)
Beta-carotene	300	250	833
Lutein	4000	87	22
Astaxanthin *	14000	40	3
Lycopene	4000	66	17
Total		443	874

Table1, : Table illustrating the potential value added by the extraction of carotenoids from microalgal biomass (source BGU – GIAVAP market report)

Similarly, long chain PUFA such as EPA, DHA or Arachidonic Acid sell for several hundred dollars per kg with 3 – 4% biomass content, adding further to the value of algal biomass (source: GIAVAP market report). This value must be gained by a clever processing of a biomass that has been cultivated optimally for this purpose. However applying physiological induction for the hyper accumulation of one component (i.e nitrogen stress, light stress) may have an impact on quantity of the other valuable components.

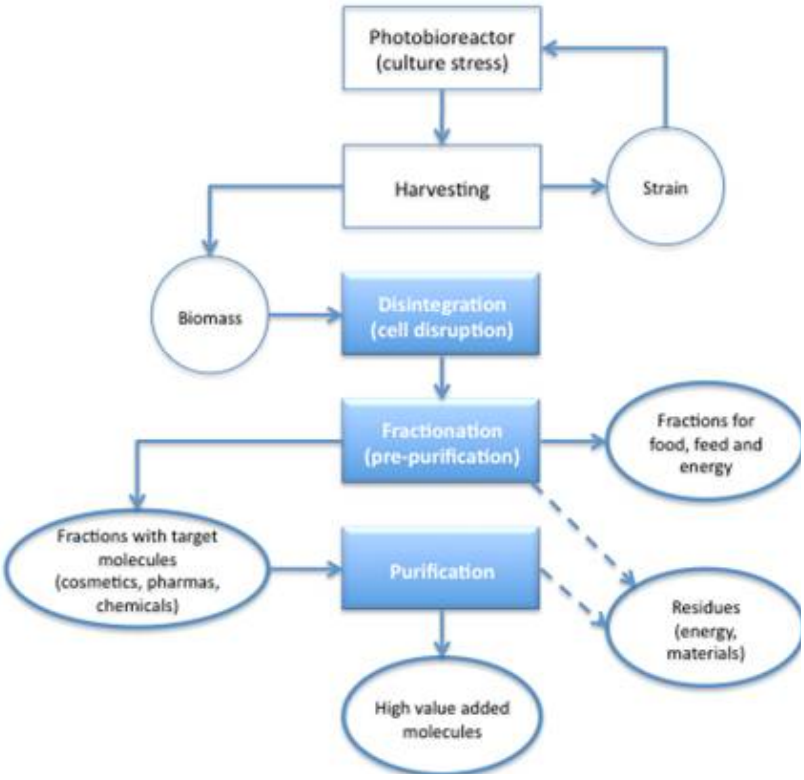


Fig 4 : The overall process of microalgae production and refining

6. Results

The research has shown the feasibility in technical economic terms of growing microalgae in photobioreactor systems. It has identified the optimal configuration of the photobioreactors with estimated production figures for different types of microalgae.

Thermodynamic modelling of the photobioreactors has demonstrated that placing the photobioreactors in a double façade system is the optimum way of growing the microalgae. It has identified the key areas of symbiosis with the building including grey water, CO2 and heat sharing. The production of microalgae in different solar orientations have been modelled to identify which façade orientations are feasible. Predominant south facades are recommended. The research on the photobioreactors themselves have identified the ideal thicknesses for the microalgae culture and functioning requirements to prevent fouling of the system thus the introduction of the airlift system. In order that the system can be justified economically specific microalgae have been identified that already have market potential and have been demonstrated to be cultivable with minimum problems in photobioreactor (closed) systems.

7. Discussion

The future of buildings in the urban environment is more than just being energy neutral but to be energy positive. This objective has taken many forms, as energy harvesting systems such as photovoltaic cells and wind turbines get cheaper and more efficient there has been a large growth in their adoption fuelled by state subsidies. Urban farming and the greening of buildings is seen recently by mayors and planners as one of the most desirable ways of becoming energy positive. Vegetation is seen to symbolise a healthy environment in a city, it helps absorb CO2 and reduce the urban heat island effect.

So what about growing microalgae as a form of urban farming? The benefits are very similar to that of vegetation apart from the aesthetic result. Futuristic tanks on the facades of buildings replace the traditional vegetation. The production of microalgae is one of the most efficient ways of converting solar energy through photosynthesis into biomass. Doubling in quantity every day under the correct conditions, microalgae is seen as the potential answer to the disparition of crude oil if it can be produced cheap enough. Growing microalgae in thin layers is the most efficient way of producing microalgae as it optimises solar exposure. Therefore units similar to that of double glazed systems are optimal. The question is whether architects and clients will adopt the new look and whether it is flexible enough aesthetically to allow them to express themselves sufficiently.

Success will not be just about the design and construction of photobioreactor facades but will rely on the creation of an ecosystem that will support and exploit the microalgae afterwards. Traditional building developers will seek guarantees on the maintenance and exploitation of the photobioreactors during the life of the building.

8. Conclusion

The research has highlighted the key elements of the symbiosis between the photobioreactors and the different typologies of host building. Different scenarios have been modelled in order to optimise the biofacade configuration as well as identify the key economic constraints. The $SymBio_2$ project optimizes the production in the photobioreactor and the harvesting phase by creating a symbiosis between the building and microalgae production. The integration of photobioreactors in a double façade system minimises the impact on net façade costs as well as maximising the symbiosis with the host building. The target is to reduce the cost of microalgae production in order to produce high value molecules at the price of their existing competitor: synthetic molecules from fossil carbon origin or other natural molecules. Doing so the symbiosis between microalgae production and building construction will open new markets for the microalgae industry. The additional environmental benefits of growing microalgae in urban areas is the absorption of CO_2 and the reduction of the urban heat island effect.

9. Acknowledgments

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- Frédéric Frusta - OASIIS, 391 Avenue de Jouques, 13400 Aubagne, France.

10. References

[1] J.PRUVOST, J.F.CORNET, V.GOETZ, J.LEGRAND. "*Theoretical investigation of biomass productivities achievable in solar rectangular photobioreactors for the cyanobacterium Arthrospira platensis".* Biotechnology progress, 28(3):699-714, 2012.

[2] V.GOETZ, F.LE BORGNE, J.PRUVOST, G.PLANTARD, J.LEGRAND. *"A generic temperature model for solar photobioreactors".* Chemical Engineering Journal, 175, 443-449, 2011.

[3] J.PRUVOST, J.F.CORNET, V.GOETZ, J.LEGRAND. *"Modeling dynamic functioning of rectangular photobioreactors in solar conditions".* AIChE Journal 57, 7, 1947-1960, 2011.

[4] A.CARVALHO, L.MEIRELES, X.MALCATA."*Microalgal reactors: a review of enclosed system designs and performances".* Biotechnol Prog 2006;22(6):1490–506

[5] E.GRATIA, A.DEHERDE. *"Optimal operation of a south double-skin façade"*. Energy and Buildings, Volume 36, Issue 1, January 2004, Pages 41–60.

[6] W.DINGA, Y.HASEMIA, T. *YAMADABA "Natural ventilation performance of a double-skin façade with a solar chimney"*, Energy and Buildings, Volume 37, Issue 4, April 2005, Pages 411–418

[7] H.MANZ, T.HFRANK. *"Thermal simulation of buildings with double-skin façades",* Energy and Buildings. Volume 37, Issue 11, November 2005, Pages 1114–1121

A proposal for the information needed with respect to BRCW7: *Sustainable use of natural resources*



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Short summary

The lead indicator should be a combined resource score that incorporates both the quantities and residual lives of the abiotic, fossil fuels, biotic and secondary resources used in a product. Water use should be reported as a separate indicator. At present there is no agreed way of reporting land use, but this is something that should, in the future, be an additional indicator. EN 1990 sets minimum design working lives for various types of structure and if a particular component of a structure is not expected to achieve the intended working life, the life cycle analysis should take into account the impacts of replacement. If the term 'environmentally compatible' is taken to mean that the structure does not release or emit significant levels of dangerous substances, this is already covered by BRCW3: *Hygiene, health and the environment.*

Key words: Construction Products Regulation**,** BRCW7, resource indicators, sustainability, fossil fuels, abiotic resources, biotic resources, water.

1. Introduction

The Construction Products Regulation [1] has introduced a new Basic Requirement for Construction Works (BRCW7) on the topic of the sustainable use of natural resources. The key text of the CPR is:
'*The construction works must be designed, built and demolished in such a way that the use of natural resources is sustained and in particular ensure the following:*
(a) Reuse or recyclability of the construction works, their materials and parts after demolition;
(b) Durability of the construction works;
(c) Use of environmentally compatible raw and secondary materials in the construction works.'

At present there is no guidance at the European level on how producers should implement BRCW7 and provide the relevant information. The basic rule is that a producer is only obliged to provide information if there is a notified regulation requiring this information; in all other cases they may use the 'no-performance determined' option. At present there are few, if any, relevant notified regulations but this may change in the future. The expectation is that the requirement for information on BRCW7 will be driven by industry, for example by an architect who wishes to design a sustainable building or an engineer assessing different options for specifying infrastructure materials.

This paper sets out a view as to the information that should be supplied by a product/materials producer when required or asked to provide information with respect to BRCW7. The reasoning for the proposals is set out and it is recognised that the meaning of words can be interpreted in different ways. The methodology described in this paper should, therefore, be treated as a developed starting point for implementing BRCW7 and it may in time be refined to take into account different interpretations of the words given above.

2. Implementation of BRCW7

The problem with lists is that many readers are busy and often this results in skipping the relevant narrative and simply concentrating on the items in the list. With BRCW7 the most important words are in the text before the list and they are '*the use of natural resources is sustained*'. This most important aspect of BRCW7 is to ensure the availability of a resource to future generations and therefore an indicator that includes both quantity and scarcity of a resource is required. Such an indicator has been developed [2] and it is described briefly in Section 4.

2.1 Re-use and recyclability

Most construction products are recyclable at the end of their life (although there are some exceptions such as plastics). Metals have a high intrinsic value and, as a consequence, a high recycling rate but with lower value recyclable products, such as brick, concrete and plasterboard, the achieved recycling rate is controlled by legislation (e.g. banning certain materials from landfill) or by financial means (taxes and incentives). The scope for re-use of a product as opposed to recycling is more limited. Bricks might be re-used in a heritage area to maintain the look of an area. With more utilitarian products, the probability that a building will be found within an economic radius that can re-use elements from a demolished building is low and so the majority of such elements will be recycled rather than re-used. The re-use/recyclability of a structure at the end of its life is more in the hands of the designer/building owner than in the hands of the product suppliers to the original building. Under the declaration of performance, most product producers will be able to claim that their product is fully re-useable or recyclable at the end of its life in the structure, but there are some exceptions, e.g. paint, and some products are only recyclable in a different form. For example, the constituents of concrete are not recyclable in their original form, but only in the form of products, e.g. a precast beam, or as recycled-concrete aggregate. The declaration of performance for a constituent standard is likely to include wording such as 'Products made with (constituent)' are, with rare exceptions, fully recyclable at the end of their intended working life'.

2.2 Durability

EN 1990 [6] defines minimum design working lives for different types of structures. If the declaration of performance or the technical specification indicates that a component of a structure is unlikely to achieve the intended working life, the life-cycle analysis should include the impacts of replacement, including the resources required for such replacement.

2.3 Environmentally compatible

The exact intent of the bullet point '*Use of environmentally compatible raw and secondary materials in the construction works'* is more subjective. Our interpretation of this wording is that there are two points within the one phrase. The first is that the materials used should be environmentally compatible and this is taken to mean that they do not release or emit significant levels of dangerous substances during construction, during the in-use phase or during the end of life phase. This aspect of performance is already covered by BRCW3: *Hygiene, health and the environment*. A series of amendments to product mandates have been or are being issued by the European Commission that requires the producer to provide information on the potential release, emission or content of dangerous substances if the product is to be placed on a market with a notified regulation. The same approach may be used to provide information to satisfy non-notified

regulations and customer requests for information. Consequently this aspect of performance is already adequately covered and further information under BRCW7 is not needed.

The second point relates to the use of secondary materials. Secondary materials may be by-products of industrial processes, e.g. fly ash from burning coal to produce electricity, or recycled materials. The lead indicator described in the Section 4 takes into account the use of secondary materials. The use of recycled materials may, or may not, be the most environmentally compatible solution.

3. Resource Indicators in EN 15804

CEN/TC350 is pushing strongly to have its suite of indicators used as the measure of satisfying BRCW7. The resource indicators for the environmental pillar of sustainability are given in EN 15804 [3] and listed in Table 1. While the abiotic depletion potential (ADP) indicator for non-fossil resources give an obscure measure of sustainability, i.e. relative to antimony, the ADP-fossil fuels treats all fossil fuels as being equally (un)sustainable and simply reports the net calorific value. When information is provided in this format, different specifiers and users cannot make consistent comparisons of the 12 indicators and select the most sustainable materials or products.

Table 1: Resource indicators given in EN 15804

Indicator	**Unit per functional or declared unit**
Abiotic depletion potential (ADP-elements) for non fossil resources	kg Sb equiv
Abiotic depletion potential (ADP-fossil fuels) for fossil resources	MJ, net calorific value
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ, net calorific value
Use of renewable primary energy resources used as raw Materials	MJ, net calorific value
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value
Use of non-renewable primary energy, excluding non-renewable primary energy resources used as raw materials	MJ, net calorific value
Use of non-renewable primary energy resources used as raw materials	MJ, net calorific value
Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, net calorific value
Use of secondary material	kg
Use of renewable secondary fuels	MJ, net calorific value
Use of non renewable secondary fuels	MJ, net calorific value
Use of net fresh water	m^3

CEN/TC350 has no product specific indicators for the social and economic pillars of sustainability. Without such indicators, it is likely to be concluded that bio-fuel is the answer to energy needs and this is likely to have a devastating effect on the food supply/price in third world countries and the loss of habitat to native people.

As manufacturers of products are likely to be required to provide EN 15804 compliant Environmental Product Declarations (EPDs) in the future, it is assumed that the information on the indicators given in Table 1 will be provided by the product manufacturer and the raw data needed to generate these indicators is available. It is, therefore, proposed that the raw data used to

generate the first 11 resource indicators is also used to provide a Combined Resource Score (CRS). This will provide a rational and transparent way of comparing solutions and demonstrating how well in relative terms they satisfy BRCW7. The procedure for undertaking this calculation is described in Section 4.

The one indicator kept separate in this proposal is the net use of fresh water. This EN 15804 indicator is unsuitable for providing information with respect to BRCW7 as it is the measure of net water use with no factor taking into account the sustainability of the water supply; BRCW7 has to include a measure of the sustainability of the water use.

In our previous paper [2], water-use was combined with the other resources, but subsequent discussions show that the majority of those who expressed a view prefer to keep it as a separate indicator. There is some logic in this approach as the way the characterisation factors are determined is different to those for the other resources. In the longer term it will be necessary to combine all the indicators for the three pillars of sustainability into a single score. Our aim is to have the water-use score set at such a level that it can simply be added to the CRS.

A way of including the sustainability of the water use is given in Table 2. The net water use is multiplied by a characterisation factor based on the availability of water and the impact on other users to give a water-use impact score. The factors given in Table 2 are tentative and they may be refined as a result of further analysis of the impact of such factors and in the process of reaching a consensus on the values.

Table 2: Characterisation factors applied to water

Region	**Characterisation Factor per cubic metre**
Water is always plentiful	5
Irrigation water having no consequences on water availability or quality to downstream users	14.6
Periods of restriction on non-essential water use, e.g. watering domestic gardens, washing cars	20
Irrigation water creating shortages or water quality issues to downstream users	60
Months of water shortages to industry or agriculture every year	130
Water availability is always a critical issue	250

An EN 15804 compliant EPD also contains no measure of bio-diversity or land-use. The authors believe bio-diversity is not a measure of resource sustainability and therefore it should not be included under this element of an EPD, but it must be included in an EPD as soon as there is an agreed measure. Land is a resource and a resource that is not infinite. At present there is no agreed measure of land-use, but when a suitable indicator is agreed, this should be part of the package that is used to measure performance with respect to BRCW7.

4. Lead Indicator: Combined Resource Score

The University of Dundee has developed a methodology for combining 11 of these indicators into a single ‘Combined Resource Score’. In the published paper [4] the term ‘Current Scarcity Score’ was used, but the word ‘scarcity’ was not liked by industry and in the context of use with EN 15804 the term ‘Combined Resource Score’ seems more appropriate.

Industry will be expected to produce EN 15804 compliant EPDs in the future and so pragmatism dictated that this reality is accepted and that we should modify our approach, i.e. not require the reporting of the quantities and residual lives of the resources used, and accept that this information will be provided indirectly via the EN 15804 indicators. It is our view that the input information used to calculate the EN 15804 indicators should also be used to determine a Combined Resource

Score, which is a transparent and rational way of combining 11 of the resource indicators. This Combined Resource Score could be used as the key measure for reporting information with respect to BRCW7.

4.1 Residual life

The Combined Resource Score (CRS) is based on the concept of residual life (as is the abiotic depletion potential). There are several measures of residual life, Table 3, and the 'Mineral resource' used in the determination of the residual life should be regarded as providing the current best estimate of the availability of primary resources to future generations.

Table 3: Measures of a mineral resource's availability

Mineral reserve	Part of the resource that has been fully geologically evaluated and is commercially and legally mineable
Reserve base	Mineral reserve plus those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics
Mineral resource	All identified resources that have a natural concentration of the mineral or a body of rock that is, or may become, of potential economic interest as a basis for the extraction of a mineral commodity
Hypothetical resource	Unidentified resources which are similar to known mineral bodies and may be reasonably expected to exist in the same producing district or region under analogous geological conditions
Speculative resource	Unidentified resources that may occur either in known types of deposits in favourable geological settings where mineral discoveries have not been made, or in types of deposits as yet unrecognised for their economic potential

The global use of a resource is the sum of the extracted resource plus the resource obtained from recycling less the resource placed in strategic stockpiles. For primary resources it is the rate of extraction that matters, as this is the measure of depletion of reserves. While the reserves of key resources have increased over the last 50 years [5], so has the rate of use.

Predicting future rate of use is fraught with difficulties:

- Will it be a function of the increasing population?
- Will we become more resource efficient?
- Will there be alternative materials?
- Will innovation create new demands or replace existing demands?
- Will economics force changes?

Consequently residual life should not be regarded as a 'tablet of stone' but the best current estimate and it is accepted that these values must be periodically reviewed and updated. A review of the residual lives should be undertaken every few decades or when there is a significant change in reserves or rate of use.

The current estimates of reserves and rates of extraction have been used for the determination of the residual lives in this methodology. The reality is resource availability will, in the view of the authors, be a significant issue (and could even be a cause for conflict) in the future and Europe should start now to use less of the resources that are predicted to become scarce over the next centuries.

Reporting the quantity of resources with relatively short residual lives is important in focussing the mind on the need to preserve resources, and unfortunately the abiotic depletion potential does not provide such a focus. The quantities of resources include wastage, as is normal in life-cycle analysis.

4.2 Combining quantities with different residual lives

If the sustainability of different solutions is to be compared, it is essential to be able turn these quantities of resources into a single CRS. The CRS is a single numerical value that reflects the impact of resource use on future availability. It is the sum of the quantities of resources used times their characterisation factor per unit volume of resource. The CRS may be calculated for a unit of product, a functional unit, or the structure over part or all of the life-cycle; however, it is only sensible to compare structures over the life-cycle, as comparisons at other stages may give misleading conclusions. Product information on BRCW7 provides the building blocks for making such as assessment. As is normal with environmental indicators, a low CRS is better for the environment/society than a high CRS.

The details of the method of calculation are given in reference [2].

As is normal in life-cycle analysis, the resources used to provide the facilities employed to manufacture energy or products (the capital goods) are not taken into account on the assumption that these will be a secondary effect.

A number of potential characterisation models were assessed [4]. It is appropriate that the characterisation factor per unit volume of resource should be proportionally greater for resources with the shorter residual lives, as these should be the priority for reducing their use. Given the uncertainties with predicting very long residual lives, particularly with respect to patterns of use, the ideal characterisation model should have modest changes in values at residual lives over, say, 2000 years. If for construction it is accepted that the most concern should be for those resources with residual lives less than, say, 750 years, and that the residual life of all resources used in construction is likely to be proven in time as being at least 100 years, a wide range of characterisation factors per unit volume of resource between these residual lives is appropriate. These characterisation factors are the CRSs per unit volume of resource.

For these reasons, the hyperbolic curve (Figure 1) has the best properties of a number of models that were assessed.

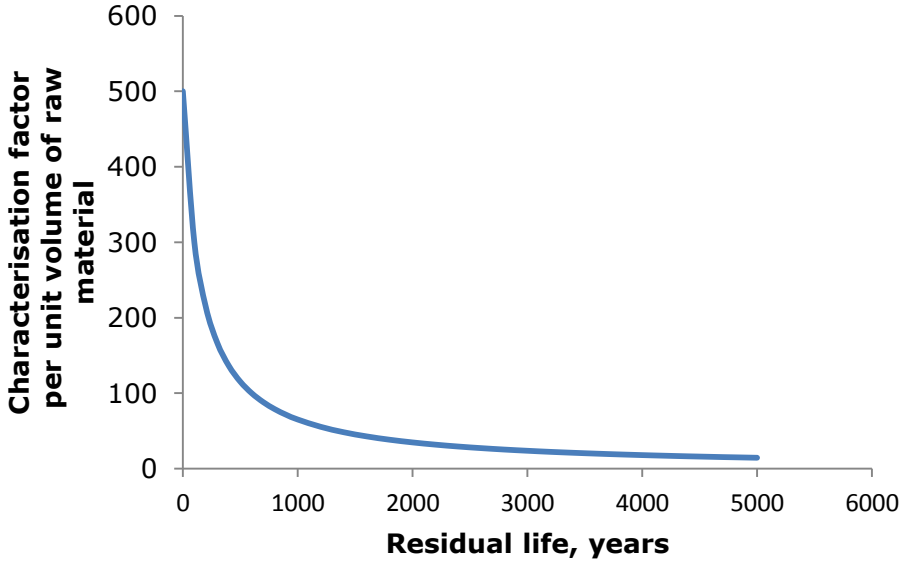


Figure 1: CRS per unit volume of resource

The value of the characterisation factor increase rapidly for residual lives of less than 850 years, i.e. discouraging the use of the scarcer resources, and change little at long residual lives, with their very large uncertainty. With such a curve, the CRS per unit volume of resource will never be zero. As there may be small impacts of resource use that are not covered by the other indicators, always having a positive CRS has merit. The characterisation factor per unit of resource is given by the equation:

Characterisation factor per unit of resource = 75000/(150 + residual life in years) [Eq 1]

This equation gives characterisation factors of 300.0, 65.2, 34.9, 23.8, 18.1 and 14.6 for residual lives of 100, 1000, 2000, 3000, 4000 and 5000 years respectively. Given the uncertainties associated with such long residual lives caused mainly by uncertainty in the rate of use, there should be no significant differences in the characterisation factors between resources with long residual lives. This is achieved by assuming a maximum residual life; any resource that has a residual life longer than this value has the same characterisation factor. As stated previously, the prime purpose of the resource indicator is a measure of availability to future generations; other impacts of resource extraction and processing are covered by other indicators.

It is the author's view that there should be a single master list of residual lives that is freely accessible and the list is maintained by an independent body such as one of the European Joint Research Centres. This list together with the publically-available characterisation curve means that the system is transparent to users.

4.3 Energy use

If energy is taken from the national grid, the resources used are based on the European/national average [7]. Table 4 gives the resources used to generate 1kW/h of electricity and these resources are used to determine the CRS when power use is based on the European average. If a national fuel mix is not available, the European fuel mix should be used in calculations. If however, the power comes from a documented greener source, e.g. hydroelectricity, the producer may use this for determining the CRS.

Table 4: Combined Resource Score (CRS) for 1 kW/h of power based on the European average

Energy Source	Quantity of Resource per kW/h, m^3	Characterisation Factor	CRS
Hard coal	$3.16x10^{-5}$	$5.56x10^{-2}$	$1.76x10^{-6}$
Brown coal	$2.32x10^{-5}$	$1.09x10^{-2}$	$2.53x10^{-7}$
Crude oil	$5.23x10^{-6}$	$5.00x10^{-2}$	$2.61x10^{-7}$
Natural gas	$2.31x10^{-5}$	$3.33x10^{-2}$	$7.71x10^{-7}$
Biomass	$3.86x10^{-6}$	0	0
Hydroelectricity	-	0	0
Nuclear (Uranium)	$9.66x10^{-13}$	$6.25x10^{-2}$	$6.04x10^{-14}$
Other	-	0	0
Total CRS per kW/h			**$3.04x10^{-6}$**

4.4 Secondary materials

Many secondary materials, which include recycled materials, have a finite residual life. For example, blastfurnace slag will only be produced when iron is made from primary ores. The current political will in Europe is that secondary resources are preferable to primary resources and to reflect this will, the characterisation factor per unit volume of resource is the lowest used in this system and independent of the residual life. As there is an additional benefit in the reduction of waste, the characterisation factor is set at 5.0, which is lower than the minimum of 14.6 used with primary resources.

It should be noted that the resources needed to process and transport secondary resources are taken fully into account in an identical way to primary resources. Consequently using secondary materials may not always provide a lower CRS, e.g. when the energy requirement to process and transport them is significantly greater than those needed for primary resources.

A principle of the system is that the benefits of a reduced CRS go to the manufacturer that actually uses the secondary resources. For example if on average p% of a resource is recycled materials, all users of that resource cannot claim p% recycled materials: they can only claim what they use. The aims of this approach are to reward manufacturers who use secondary materials with a lower CRS and create markets for such materials.

4.5 Biotic resources

The CRSs applied to biotic resources where there is a residual life ≥ 5000 years is the minimum value (14.6). This CRS per unit volume of resource is to cover the impacts not covered by the other indicators. The resources used to plant, fertilise, cultivate, harvest, process and transport are taken into account in the same way as for primary resources.

Water use is recorded in a separate indicator and this can be significant factor with respect to the impact of using biotic resources in areas of water stress.

Land use and biodiversity are two significant issues with respect to using biotic resources but there is no agreed way of including land use at present and biodiversity should be covered by a separate indicator (it is not yet included in the EN 15804 indicators).

4.6 Raw Materials Initiative

The system also takes into account the recommendations of the Raw Materials Initiative [5] by converting the supply risk and economic importance of a natural resource into an equivalent residual life and this equivalent residual life is used when it is shorter than the one described here. This process is detailed in reference [2]. Other parts of the world may have similar issues and a similar approach could be taken with resources that are of concern to them. There is also a case for excluding such a refinement from the analysis from globally-sourced products.

5. Example

An example application of the Combined Resource Score to a product is given in Table 5. The CRS calculations for a DN 300 polyethylene pipe were undertaken and the results are shown in Table 5. It should be noted that this example is for the pipe itself and not for the complete piping system.

Oil, gas and hard coal make the largest contribution to the CRS. Water use is also significant in the manufacturing of the pipe, although this is not part of the product CRS. It should be noted that when presented in terms of score-per-length of pipe, the scores are very much sensitive to the mass per unit length value used. The resulting product CRS plus water is similar in value to that of a concrete pipe [2].

One issue is that the pipe CRS is not a ‘functional unit’, i.e. it does not represent the impact of the ‘pipe in the ground’. A pipe of this type requires a bedding layer and a capping layer and the equivalent concrete or cast iron pipes do not normally require these layers. This illustrates why comparisons should never be made at the product level.

*Table 5: Resources used and CRSs for DN 300 polyethylene pipe**

Resource[A)]	Quantity, m^3/m length of pipe	Residual Life, yrs	CRS
Oil	$2.65x10^{-2}$	100	8.42
Gas	$2.74x10^{-2}$	150	7.68
Hard coal	$2.62x10^{-3}$	90	1.31
Brown coal	$5.11x10^{-8}$	460	$6.64x10^{-2}$
Sulfur	$9.29x10^{-7}$	70	$3.17x10^{-4}$
Iron	$7.99x10^{-7}$	100	$2.40x10^{-4}$
NaCl	$1.62x10^{-4}$	5000	$8.71x10^{-5}$
Limestone	$1.82x10^{-6}$	5000	$2.64x10^{-5}$
Sand	$1.17x10^{-6}$	5000	$1.70x10^{-5}$
Bauxite	$5.00x10^{-8}$	280	$8.72x10^{-6}$
Zinc	$1.33x10^{-8}$	170	$3.12x10^{-6}$
Bentonite	$1.10x10^{-7}$	5000	$1.61x10^{-6}$
Gypsum	$1.43x10^{-6}$	5000	$7.68x10^{-7}$
Dolomite	$7.39x10^{-7}$	5000	$3.98x10^{-7}$
Olivine	$4.82x10^{-7}$	5000	$2.60x10^{-7}$
Shale	$1.46x10^{-8}$	5000	$2.13x10^{-7}$
Uranium	$5.55x10^{-11}$	80	$3.87x10^{-8}$
Biomass	$8.90x10^{-4}$	5000	0.00
TOTAL CRS	**$5.75x10^{-2}$**	**-**	**17.48**
Water[B)C)]	$2.43x10^{-1}$	3600	4.85
Product CRS plus water			**22.33**

[A)] System boundary is the gate of the manufacturing plant. [B)] The applied characterisation factor is 20 per cubic metre. [C)] Sixth Framework Programme, 2008 [8] *Energy and raw materials information acquired from [9] and [10].

6. Conclusions

6.1 Information on the sustainable use of natural resources (BRCW7) is best provided using a Combined Resource Score that encompasses 11 of the 12 resource indicators given in EN 15804.

6.2 The proposed lead indicator:

- is policy relevant, e.g. it provides information with respect to BRCW7;
- is coherent and complete as a resource indicator except for land-use, which has no agreed indicator;
- uses a principle (residual life) fully accepted by CEN/TC350;
- includes the impact of using secondary (including recycled) materials;
- is transparent (the residual lives and characterisation factors should be publically available);
- is applicable to different levels of economic activity;
- permits data to be aggregated and disaggregated;
- uses input data that is available, i.e. data needed for EN15804 compliant EPDs;
- is easy to communicate (measure of quantity and availability).

6.3 As materials are combined into particular units that are built into infrastructure and buildings with additional materials to make them function (e.g. the example pipe described) true comparisons cannot and should not be made at the product level.

6.4 Water-use should have its own indicator and it is proposed that the net water-use is multiplied by a characterisation factor related to scarcity and impact on other users.

6.5 Land-use should be included as an indicator when an agreed method for taking this into account.

6.6 Recyclability at the end of life is more a matter for the designer of the structure than the product supplier.

6.7 Environmental compatibility is covered by BRCW3.

6.8 To avoid incorrect assessment, all three pillars of sustainability should be included in the assessment of the sustainable use of natural resources.

7. References

[1] COMMISSION OF THE EUROPEAN COMMUNITIES, *The Construction Products Regulation* (EU) No 305/2011 adopted on the 9 March 2011.

[2] HARRISON T A, JONES R, DYER T and HALLIDAY J, *A tool for measuring resource sustainability*, XVI ERMCO Congress – Verona, 21-22 June 2012.

[3] EUROPEAN STANDARDIZATION COMMITTEE, *Sustainability of construction works — Environmental product declarations — Core rules for the product category of construction products*, EN15804, 2012.

[4] HARRISON T A, JONES R, DYER T and HALLIDAY J, *Sustainable use of natural resource project – Phase 2A Report, 2011,* http://www.snr-project.org.

[5] EUROPEAN UNION DG Enterprise and Industry, *Critical raw materials for the EU – Report of the ad-hoc group on defining critical raw materials,* 2010, http://ec.europa.eu/enterprise/policies/raw-materials/documents. Accessed 20/07/2010.

[6] EUROPEAN STANDARDIZATION COMMITTEE, *Eurocode — Basis of structural design*, EN 1990: 2002/A1: 2005.

[7] COMMISSION OF THE EUROPEAN COMMUNITIES, *Europe's Current and Future Energy Position. Demand - Resources - Investment*, Commission of the European Communities, Brussels, 2008

[8] EUROPEAN COMMISSION SIXTH FRAMEWORK PROGRAMME, NEEDS - *New Energy Externalities Developments for Sustainability*, Deliverable D15.1 “LCA of Background Processes”, 2008.

[9] TNO, *Eco-profiles of the European Plastics Industry - Pipe Extrusion*, Plastics Europe, Brussels, 2010.

[10] BOUSTEAD, I., *Eco-profiles of the European Plastics Industry - High Density Polyethylene (HDPE)*, Plastics Europe, Brussels, 2005

C6

Green Products

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A Comparative Analysis of Life Cycle Impact Assessment Methods for Building Materials



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Short Summary

Life Cycle Impact Assessment (LCIA) is a phase of the Life Cycle Assessment that aims to evaluate the magnitude and significance of the environmental impacts of a product system throughout the life cycle of the product. LCIA is the weakest but the most important phase of the method due to uncertainties of the components and approach differences between methods.

Spatial differentiations are effective in evaluating and determining the significance of environmental impacts. Therefore, most countries have created LCIA methods aimed at assessing their own environmental situations. In addition, some countries have created LCA tools that evaluate the environmental impacts of building materials and developed LCIA methods. There are different approaches between LCIA methods. One of the important differences is the point that environmental categories evaluated quantitatively in the system. Accordingly, mid-point (problem-oriented approach), end-point (damage-oriented approach), and methods which combine two approaches have been developed. There are a lot of controversy that assess benefits and shortcomings of each approach. The methods are also different in specific aspects, such as the quantity and the concept of selected impact categories, the environmental models developed for the characterization phase, normalization and weighting factors.

This study aimed to evaluate and compare current LCIA methods for building materials such as BEES (Building for Environmental and Economic Sustainability), Bre- Environmental Profiles (Building Research Establishment), BPIC / ICIP (Building Products Innovation Council -Industry Cooperative Innovation Programme), ATHENA Impact Estimator, BEPAS (Building Environmental Performance Analysis System) and BELES (Building Environment Load Evaluation System). These comparisons are based on the ISO 14040 standard framework. As a result of the study, differences in the methods are seen in the selected impact categories and category numbers, the point which environmental categories evaluated quantitatively, selected category indicators and models, normalization factors and weighting methods like panel method, distance to target method and willing to pay method. This study emphasizes that continent or country specific LCIA methods for building materials need to be created.

Keywords: Life cycle impact assessment methods; building materials; environment; locality

1. Introduction

High production quantities of the building materials in the building construction and the use of them in a wide area in the world make the environmental impacts of the building materials important. Not only properties, types, application conditions and performance of the building materials but also the environmental effects should be known by the architects. Factors like decisions, transportation, technology, labor, legal arrangements, patterns of use may be decisive in the formation and the control of the environmental impacts of the building materials. Assessment of these impacts provides the reduction of their harmful effects on the environment and the selection of environmentally friendly materials. Life Cycle Assessment (LCA) is a tool that evaluates

environmental impacts of the products including the building materials or services in the entire life cycle defined as cradle to grave. LCA consists of four phases according to ISO 14040. These are goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA) and interpretation [1]. In the study of Junnila, it is stated that there are still uncertainties in the components of LCA despite the common use of it; data analysis phase contains atleast uncertainty and LCIA phase is one of the most vulnerable phases [2].

LCIA aims to evaluate the magnitude and the importance of environmental impacts of a product throughout the life cycle. In LCIA phase consisting of mandatory and optional elements, the selection of environmental impact categories, category indicators and the characterization models, classification of these categories, calculation of category indicator results according to the selected characterization model are the mandatory elements. Normalization, grouping and weighting are the optional elements. Spatial differentiations are effective in assessing of environmental impacts and determining the degree of importance of the effects in LCIA methods. Therefore, most of the countries which have created LCIA methods aimed at assessing their own environmental situations.The study of European Commission Joint Research Center provided an analysis of existing methods for assessing the potential environmental impacts from emissions and resource use that can be attributed to specific products in the LCA [4]. Besides, in the study of Menoufi, LCIA methods as midpoint approach methods, endpoint approach methods and other methods were analyzed [5]. In addition, some countries like America, England, Australia have created LCA tools that evaluate the environmental impacts of the building materials and have developed LCIA methods.This study focuses on LCIA methods which evaluate environmental impacts of the building materials unlike other studies about LCIA methods.

In this study, it is aimed a comparative analysis of the life cycle impact assessment methods of BEES (Building for Environmental and Economic Sustainability), Bre- Environmental Profiles, BPIC (Building Products Innovation Council)/ ICIP (Industry Cooperative Innovation Programme), Athena Impact estimator, BEPAS (Building Environmental Performance Analysis System) and BELES (Building Environment Load Evaluation System) models, the determination of variables among methods and thus, it becomes a guide to the future LCIA methods that assess environmental impacts of the building materials. Comparisons based on ISO 14040 series standards are made in terms of mandatory and optional elements in LCIA methods. Differences in the methods are primarily seen in the point which environmental categories are evaluated quantitatively. Accordingly, the methods become different as endpoint approach methods, midpoint approach methods and the methods which combine two approaches methods. Other variables are the types and the numbers of the selected environmental impact categories. Differences in the methods are also seen in the selected characterization models, category indicators, normalization factors and weighting methods.

2. Life Cycle Impact Assessment for Building Materials

The building materials, which are the components of the building, change the environmental performance of the building and fulfil their functions after having been installed in the building. The life cycle of the building materials consists of a series of phases, such as raw material acquisition and preparation, manufacturing, packaging, transportation, use, re-use, recycling, disposal [Fig. 1]. Each phase in the life cycle of materials brings with a number of environmental impacts.

Natural resource depletion, energy consumption, water consumption, waste generation, alteration of habitat and their impacts on the health and the environment are the major environmental issues at material acquisition and at the preparation stage. At manufacturing and fabrication stage; energy consumption, water consumption, and waste generation are the major environmental issues. Construction, use, and the maintenance stages include transportation of the product to the site plant, installation of the material in the building, maintenance requirements, durability and anticipated life span of the material. The major issue at this stage is the effect of installation and of the material itself on indoor air quality. Waste is also a concern in these stages. At recycling, reuse, and disposal stages; the building materials constitute an enormous solid-waste problem. Some building materials contain hazardous materials. The stages in the building material life cycle are defined below.

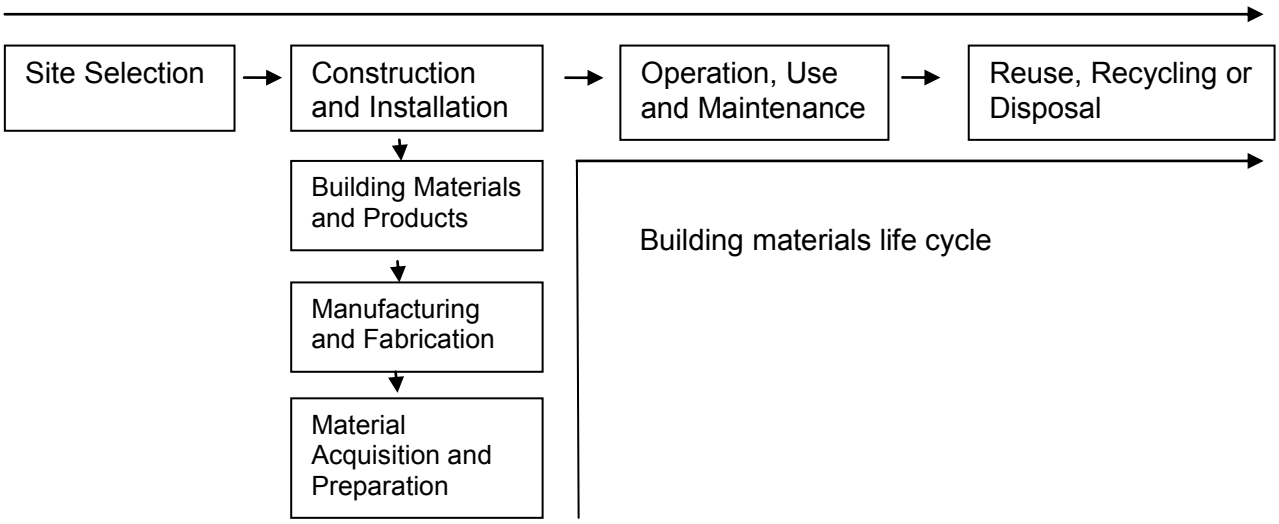


Fig.1: Facility and material life cycle [6]

In the process of material acquisition and preparation, type and quantity of the materials used in the process, type (coal, natural gas, petroleum, nuclear, hydro, wind energy etc.) and quantity of process energy, quantity of process water as inputs become important for LCIA. In addition, short or long transportation distances and transportation types (truck, rail, air, ship etc.) are also important in terms of environmental impacts. The type and the quantity of the materials in the construction process, durability and the useful life of the building materials, the effect of the building materials on building energy consumption like lighting, heating and cooling, type, and frequency of the maintenance are effective. In the disposal process, disposal methods like landfill, incineration etc., the volume and weight of the material and transportation become important. Finally, recycling and reuse properties of the building materials are very effective for LCIA.

The green building community has used LCIA methods to measure environmental performance of the building materials. There are differences among the methods. In these methods, different impact categories are taken into account; different environmental models and equivalence factors are used for the characterization; different reference points are used during normalization; and different ways are used while conducting the weighting phase. In this study, six models used for LCIA for the building materials are compared in terms of these differences.

3. Analysis of existing LCIA Methods for Building Materials

BEES (USA), Bre- Environmental Profiles (England), BPIC/ ICIP Project (Australia), Athena Impact Estimator (Canada), BELES (China) and BEPAS (China) are compared in terms of the mandatory and optional elements according to ISO 14040.

3.1.1 Approach Differences

LCIA methods are divided into three approaches as midpoint approach methods, endpoint approach methods and methods, which combine midpoint and endpoint approach methods. Midpoints are considered the links in the environmental mechanism of an impact category, prior to the endpoints, at which characterization factors or indicators can be derived to reflect the relative importance of emissions or extractions. This approach is referred as a problem-oriented approach. Endpoints are the terminals of the impact chains, which the environmental impacts are quantified. This approach is referred as a damage-oriented approach. There have been many discussions assessing the benefits and shortcomings of each approach [7]. Endpoint approach methods are accepted as more uncertain because of the high modelling and parameter uncertainties, whereas midpoint approaches are accepted as more precise because of the less modelling, the lower parameter uncertainties [8]. UNEP/ SETAC LCA Entrepreneurs proposed to benefit from the

advantages of both approaches; as a result, the methods combining two approaches have developed [9].

BEES, Bre- Environmental Profiles, BPIC/ ICIP, Athena IE, BELES are based on midpoint approach. In these methods, the potential environmental effects are assessed according to the midpoint impact categories like global warming potential, ozone depletion, acidification, eutrophication etc. BEPAS is based on endpoint approach by selecting human health, ecosystem damage, resources, and energy consumption.

3.1.2 Selection of Environmental Impact Categories

In the first or classification part, the emissions and resources in the LCI are assigned to the impact category or categories. Midpoint approaches include global warming, ozone depletion, eutrophication, acidification, photochemical ozone formation, human toxicity, ionizing radiation, ecotoxicity, land use, resource depletion etc. Endpoint approaches include energy, resources, ecosystem etc.

As a result of the examination of the methods, it is seen that all midpoint approach methods assess global warming potential, ozone depletion, eutrophication, acidification, fossil fuel consumption, photochemical smog formation. Mineral resource consumption, land use, water consumption, and ecological toxicity are mostly assessed. Waste, airborne suspended particulates, human toxicity, indoor air quality, ion radiation, noise, and transport pollution are environmental impact categories evaluating at least. BELES assesses human health, ecosystem damage, resources, and energy consumption as the endpoint categories [Table 1].

Table 1: Environmental impact categories and numbers in the methods

	Global Warming	Ozone Depletion	Eutrophication	Acidification	Fossil Fuel Depletion	Smog Formation	Mineral Resource	Land use	Water Depletion	Waste	Ecological Toxicity	Airborne sus.	Human Toxicity	Indoor Air Quality	Ionizing Radiation	Noise	Transport Pollution	Human Health	Ecosystem Damage	Resources	Energy Depletion	**Numbers of the categories**
BEES	x	x	x	x	x	x	x	x	x		x	x		x								**12**
Bre- En.	x	x	x	x	x	x	x		x	x	x		x				x					**12**
BPIC/ICIP	x	x	x	x	x	x	x	x	x		x		x	x	x	x						**14**
BEPAS	x	x	x	x	x	x	x		x	x	x	x										**11**
Athena	x	x	x	x	x	x		x														**7**
BELES																		x	x	x	x	**4**

3.1.3 Selection of Environmental Impact Category Indicators

In the characterization part, the relative effects of all the environmental interventions associated with each of the different impact categories are compared to one another. A reference unit is defined for each impact category as well as the corresponding characterization factors.

For global warming category, Global Warming Potential (GWP) is used and all greenhouse gases are expressed with CO_2 equivalent in the midpoint approach methods that are assessed. There is a consensus on this issue among the methods. For ozone depletion, all midpoint methods are based on World Meteorological Organization Model (WMO), and CFC11 equivalent is used; for acidification, H+ or SO_2 equivalents are used; for eutrophication, there is no consensus among the methods. N, NO_3, PO_4 equivalents are used for the characterization factors; for fossil fuel depletion kg., MJ, SCE or tons of oil equivalents (toe); for smog formation NO_X, ethane, ethylene equivalents

are used. Litre or m^3 for water consumption, kg or tonne for waste and mineral resource consumption, hectare year or the density of endangered and threatened species for land use are used in the methods. Only BEES method assesses indoor air quality with quantity of total volatile organic compounds (VOCs). There is no method for noise among the methods [Table 2].

In BEPAS method, human health is expressed with Disability Adjusted Life Years (DALY) /m^2; ecosystem damage is expressed with Potentially Disappeared Fraction (PDF) of species/ m^2.year; resources are expressed with Fe/ m^2 and energy consumption is expressed with Ce (coal amount converted by heat value) / m^2 [Table 2].

Table 2: Category indicators in the methods

	BEES	Bre-Env.P.	BPIC-ICIP	BEPAS	Athena	BELES
Global Warming	GWP	GWP	GWP	GWP	GWP	
Ozone Depletion	CFC-11 eq.	CFC-11 eq.	CFC-11 eq.	CFC-11 eq.	CFC-11 eq.	
Eutrophication	N eq.	PO_4 eq.	PO_4 eq.	NO_3 eq.	N eq.	
Acidification	H+ eq.	SO_2 eq.	SO_2 eq.	SO_2 eq.	H+ eq.	
Fossil Fuel D.	Kg	Toes	MJ	SCE(standard cool energy)	MJ	
Smog Formation	NO_x eq.	Kg. ethane	Kg. NMVOC	Ethylene eq.	NO_x eq.	
Mineral Resource	Kg	Tonne	Kg	Kg		
Land Use	TED		Hectare. year		TED	
Water Depletion	Litre	Litre	Kilo Litre	m^3		
Waste		Tonne		Kg		
Ecological Tox.	2,4D		kg.1,4-DB	Pb		
Airborne Sus P.	MicroDALYs			Kg		
Human Toxicity		Kg toxicity	1,4-DBeq. DALY'			
Indoor Air Q.	Total VOCs emissions		No methods			
Ionizing Rad.			Kg U235			
Noise			No methods			
Transport Pol.		Tonne. km				
Human Health						DALY/ m^2
Ecosystem Dam.						PDF.m^2. year
Resources						Fe/m^2
Energy Dep.						Ce/m^2

3.1.4 Normalization

In normalization, the results of each impact category are divided by a reference value. Thus, all environmental impact categories are made dimensionless. The major topic here is to use local data as a reference value. This data changes due to the diversification of values,such as population, area, emission rates etc., which depends on the countries.

Reference values used by the methods are shown below. BEES, Bre- Environmental Profiles, BPIC/ ICIP and Athena use the amount of emissions per person per year in the selected region as normalization factors. Unlike the other methods, BELES uses the total environmental load per unit building area of China as a normalization factor. BEPAS does not contain the normalization phase [Table 3].

Table 3: Normalization factors in the methods

BEES	The amount of emissions per person per year in the US
Bre- Environmental Profiles	Annual environmental impact created by a British citizen
BPIC / ICIP	The environmental impact per person per year in Australia
Athena Impact Estimator	Total annual emissions in Canada / Canadian population
BELES	The total environmental load per unit building area of China
BEPAS	Normalization is not used.

3.1.5 Weighting

In the weighting phase, important degrees of the environmental impact categories are specified according to the region or country in which the method is developed. There are different weighting methods such as panel method, distance to target method and willing to pay method.

In panel method, a group of experts representing different stakeholders are created for evaluating environmental impact categories in the order of priorities. In willing to pay method, weighting factors are expressed according to the estimated economic damage or monetary costs required in order to prevent damage for an impact category. In the method of distance to target, weighting factors are usually calculated in accordance with the target values based on political decisions.

It is seen that all midpoint approach methods use panel method. Analytic Hierarchy Process (AHP method), Delphi method, and eco-points method are used for the analysis of the results in the panel method. BEPAS uses willing to pay method for weighting phase [Table 4]. All LCIA methods for building materials include weighting phase.

Table 4: Weighting methods

BEES	Panel method- AHP method, user-defined, considered to be equal to all the effects.
Bre- Environmental Profiles	Panel method-- Eco-points system
BPIC / ICIP	Panel method-- Delphi method
Athena Impact Estimator	Panel method
BELES	Panel method
BEPAS	"Willing to pay" method

3.2 Discussion and conclusions

LCIA methods that vary by countries or even regions are used in order to assess environmental impacts of building materials. Considering the spatial differentiations in LCIA methods, continent or country specific LCIA methods for building materials need to be created.

Most of the methods evaluated in the scope of the study are based on midpoint approach methods. One of the advantages of using midpoint approach is the reduction of the uncertainties in the method. The other is to enable to develop a method that combines with midpoint and endpoint approaches.

Considering environmental impacts of building materials during the life cycle, the effects on air quality such as global warming potential, acidification, photochemical ozone formation, ozone depletion etc.; the effects on water quality such as eutrophication, acidification, etc.; soil effects as alteration of soil, besides, the consumption of non-renewable resources becomes important. Different environmental impact categories are assessed in the LCIA methods discussed. Waste, human toxicity, indoor air quality, dust and noise are at least evaluating the environmental impact categories. However, environmental and human health effects of these categories are great in the life cycle of the building materials. For example, indoor air quality is crucial for the protection of building occupant health and comfort, and the increasing of productivity. Some building materials release toxic gases. Dust affects worker and building occupant health in the material acquisition,

manufacturing, construction and demolition stages. Formation of odours is not assessed as the environmental impact categories in the LCIA methods for building materials. In the material acquisition manufacturing and demolition stages, formation of odours affects air quality. These environmental impact categories should be considered in the life cycle of building materials.

When examined the characterization factor used in the calculation of environmental impacts, there is a consensus for global warming category used CO_2 equivalent, for ozone depletion category used CFC11 equivalent. However, there is no consensus on globally representative characterization models for regional impact categories. For people who study on building and building materials, it is difficult to decide which equivalents are better for characterization factors. A recent comprehensive study of Hauschild M., Goedkoop M. and their friends can be the source on this issue. In this study, it is aimed to identify the best among the existing characterisation models in LCIA. Accordingly, baseline model of 100 years of the IPCC for global warming and World Meteorology Organization (WMO) model are recommended and satisfactory. Other environmental impact categories are evaluated as recommended but in need of some improvements or recommended but to be applied with caution [10].

The amount of emissions per person per year is mostly used as normalization factor in LCIA methods for building materials. Geographic coverage and time coverage are important in order to calculate the factors.

For LCIA of building materials, it is necessary to determine the importance degree of environmental impact categories for a region or a country, because the impact of the environmental category with a high weighting coefficient will be more important in the country that is evaluated, while two environmental impact categories have the same impact score. Although weighting is an optional phase according to ISO 14040, all LCIA methods for building materials include this phase. Panel method is mostly used in these methods. The disadvantage of the distance to target method is that weighting coefficient may change depending on the policy of countries. Only one method uses willing to pay method. Use of this method depends on the determination of economic values of the selected environmental damages for LCIA methods.

Potential environmental impacts and the importance of particular impacts can be quite significant between the countries or regions. Production and manufacturing processes can vary considerably from country to country, as can the types of fuel used, the source of raw materials, transportation distances, and the relevance of specific impact categories. The most accurate findings are usually obtained where product, process, technology, and location-specific data for a building material being studied is used.

4. References

[1] ISO (2006a). "*ISO 14040: Environmental Management– Life Cycle Assessment-Principles and Framework",* ISO 14040:2006(E).

[2] JUNNILA S. "*The environmental impact of an office building throughout its life cycle".* Doctoral dissertation, Helsinki University of Technology, Espoo-Finland, 2- 3, 12-16, 2004.

[3] ISO 14042. "*Environmental management- life cycle assessment- life cycle impact assessment*. Geneva, Switzerland: International Standards Organization (ISO), 2000.

[4] EUROPEAN COMMISSION JOINT RESEARCH CENTRE, Institute for Environment and Sustainability. *"Analysis of existing Environmental Impact Assessment Methodologies for use in Life Cycle Assessment"*. ILCD Handbook, First edition, European Union, 2010.

[5] MENOUFI K A. "*Life Cycle Analysis and Life Cycle Impact Assessment methodologies: A state of the art".* Master Thesis, Universidad de Leiden, Escola Polytechnic Superior, 2011.

[6] THE AMERICAN INSTITUTE OF ARCHITECTS, *"Environmental Resource Guide",* Edited by Joseph A. Demkin, Washington, D.C., Includes 1997 and 1998 Updates.

[7] REAP J, ROMAN F, DUNCAN S, BRAS B. *"A survey of unresolved problems in life cycle assessment, Part 2: Impact Assessment and Interpretation"*. The International Journal of Life Cycle Assessment, 2008, Volume 13, pp. 374–388.

[8] BARE J.C, HOFSTETTER P, PENNINGTON D.W, UDO DE HAES H. A. *"Midpoints versus*

Endpoints: The Sacrifices and Benefits". The International Journal of Life Cycle Assessment, 2000, 5 (6), pp. 319 – 326.

[9] BARE J.C, PENNINGTON D.W, UDO DE HAES H.A., *"Life Cycle Impact Assessment Sophistication".* International Workshop, International Journal of LCA, 1999, Vol. 4, Issue 5, pp. 299-306.

[10] HAUSCHILD M.Z, GOEDKOOP M, GUINEE J, HEIJUNGS R, HUIJBREGTS M, JOLLIET O, MARGNI M, SCHRYVER A. D, HUMBERT S, LAURENT A, SALA S, PANT R. *"Identifying best existing practice for characterization modelling in life cycle impact assessment".* Int Journal Life Cycle Assess, 2013, Vol. 18, pp. 683- 697.

Product Design Aspects of Agro-fibers Biocomposites for Architectural Applications



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Short Summary

The authors are hereby offering through experimental investigation a higher architectural design value for agro-fibres' usage and appliance in architecture. Through binding agro-fibres with bio-based matrices, green biocomposites of a wide variety of forms, textures and colours can be produced. These aspects are of a high importance in architectural applications and are the main key for such materials to compete with conventional fossil-based materials and non-annual wooden products that are still overwhelming the contemporary architectural products' markets. Cereal straw is here applied as the highest agricultural residue worldwide. This paper offers another perspective for agro-fibres biocomposites' applications in architecture.

Keywords:Biocomposites, Product Design, Ecological architectural products, Natural fiber composites, Agricultural residues, Agro-fibers.

1. Introduction

Using agro-fibers and applying them in the form of biocomposites, utilizing bio-based matrices based on renewable resources,can offer the opportunity to produce safe formaldehyde-free materials for interiors. Applying cheap and available natural fibers from the agricultural residues' source would offer not only an environmental balance reflecting society awareness, but also would open a new market for biocomposites' materials with lower prices and acceptable performances. Bio-based matrices binding industrial natural fibers generated from fiber crops cultivated especially for fiber generation leads mostly to products' price increase, leading to green-composites' market limitations. The option of choosing cheaper available fibers from another natural fiber source, as in the case of agro-fibers, is here suggested. The keys to provide attractive products using available production techniques and attractive product designs of higher architectonic qualities replacing the classic un-attractive agricultural residues applications in housing like baling systems, are here thoroughly illustrated.

2. Biocomposites Definition/Illustration

Biocomposites are composed of natural fibers combined by a bio-based matrix created from renewable resources, like linseed oils, or natural fibers combined with an oil-based matrix or artificial fibers bonded with a bio-based matrix. In this paper, biocomposites applied and meant are those green biocomposites composed of natural fibers and bio-based matrices. The authors here

discuss the green agro-fibers' biocomposites, where short natural agro-fibers are the types of fibers applied, which are retrieved from agricultural residues resources, and are bonded with bio-based matrices retrieved and manufactured from annual plant origins that aren't applicable in the feedstock industries.

Within biocomposites, the natural fiber provides extra rigidity to the composite that won't have been reached if the polymer/matrix alone has been applied. In addition, lower density, higher acoustic and insulation performances are always expected as a result of fiber incorporation with the matrix, due to the hollow capillary tubes within the natural plants tissues.
The material performance needs always to be tested and analyzed through the different qualifying techniques, whilst the processing itself can have a great reflection on the design value of the end product of the composite.

3. Alternative Natural Fibre Sources

Agricultural fibres are those natural fibres that are left over after the production of crops whether cereal crops, fruits, vegetables or nuts. The main interest in such annual crops' agriculture is the seed/fruit itself and not the residues left over after harvesting. That's why huge quantities of such residues are so often burnt after re-using relatively small amounts of them in conventional applications. On the other hand, and as the problems of conventional limited usages of stalks, straws, etc aren't completely been solved, fiber application industries are in great thirst to new available and cheap fiber types. Paper, furniture, boards and fiber reinforced composites' industries are examples of such industries that have long depended mainly on wood as a main source. The steady increase in the demand of wood fiber is gradually leading to a worldwide shortage of wood fiber supplies. Since the 1980's, depletion of the world's forests has steadily increased the price of raw wood and wood-based products [5]. One possible solution to this problem lies in the use of annual non-wood plants, where straw specifically is a direct available presenter of them. The following figure, Fig.1 , presents the non-wood natural fibre resources possibility to become a main ingredient in biocomposites with a short comparison showing the advantages when applying agro-fibres.

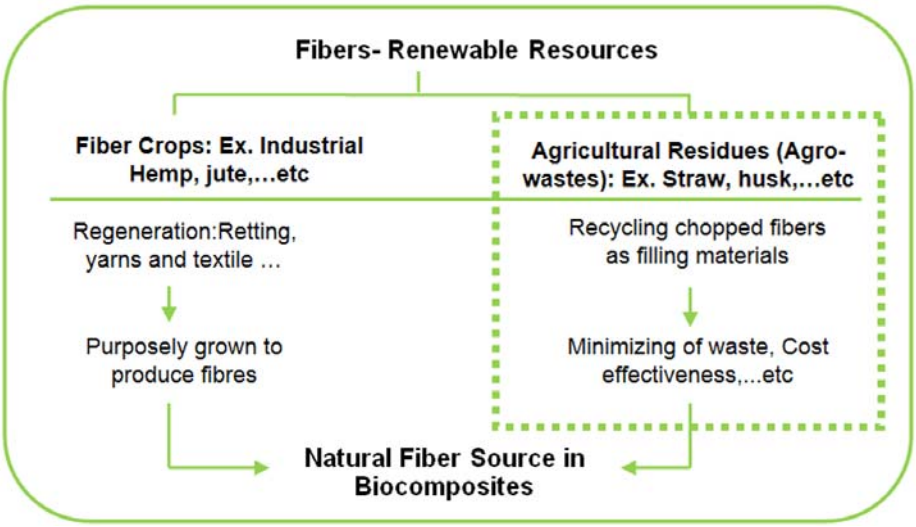


Fig.1 : Sketch illustrating the non-wood natural fiber sources, applicable in biocomposites' manufacturing

The most abundant type in agro-wastes, which is still not given enough that great attention except for feed stock and energy applications that still do not absorb all the available amounts, is the cereal straw. Cereal grains compose up to 72% of the world food of agricultural crops supply

according to the United Nations Food and Agricultural Organization, [7], which reflect the huge amounts of their residues.

Straw, the stem of the cereal plant that remains after the seed needed for nutrition is removed, composes about half the total dry weight of the crop [5]. For many centuries, straw has been utilized as animals feeding livestock, bedding and many other limited applications. However, these limited applications have never been enough to consume the huge straw amounts annually produced worldwide.

In addition, the drawbacks of the straw as an animal fodder increased dramatically the problems of its accumulation. The feed value (digestibility) problems are the main reasons for such drawbacks when used as a fodder due to the chemical structure of straw, [2].

Agricultural fibers' application in architecture is not a new discovered issue, but was already in use since the pheronic ancient Egyptian era when the rice straw was mixed with mud to form bricks that were used to build regular housing. In contemporary architecture, agro-fibers are re-discovered and re-applied, but still in limited applications. The hidden reason might be the un-attractive straw bales' look that still appears directly in our minds when talking about agricultural residues, making their applications next to their other technical difficulties, handling problems and aesthetic limitations, still un-desired from a lot of end-users worldwide, [6].

Therefore, it's discussed here within this paper another method of agro-fibers' appliance to reach a much higher architectonic design value and appearance, depending on renewable based matrices that can bind the agro-fibers in the desired forms, surface finishings and colours, reflecting their ecological nature to the end-user, according to the design required. In this case, and with extra further investigations, such products can compete with and replace existing fossil-based plastic and wooden products that are already present in the contemporary architectural-products markets, those which are applied in the same target applications like cladding, partitions, acoustic panels, etc.

4. Available Agro-fiber Biocomposites in Market and their Processing Possibilities

4.1 Agro-fibers' thermoplastic biocomposites

A lot of investigations took place in combining thermoplastic matrices with straw and husk fibers. Most of the available products in the market are combined fossil-based conventional PP, PE and PVC polymers with agro-fibres.From these commercial products: TerraFence™ and TerraDeck™ from recycled plastics and wheat straw, [14], in addition to Ricycled™ from recycled PVC and rice husk, [13]. Products from Resysta® are one of the rare examples of thermoplastic green composites made from mineral oils and rice husk of contents up to 60% by weight, [11].

The common compounding process takes place through the extrusion process, by heating the thermoplastic polymer whether externally or through the mechanical shearing of the inner screw(s), then feeding the chopped fibers according to specified fiber/matrix feeding procedures. Such processing is limited to the short fibers' compounding, which is the expected length that can be gained from the agricultural residues' resources. Long and continuous fibers in this case aren't yet applicable. The heating temperature should be carefully applied and not to exceed a certain limit (around 190-200 Degrees) [4], so as not to cause fiber rapid decomposition and hence failure by compounding and /or un-satisfactory composite performance.

After compounding, the composite can be either directly extruded into a final product through molding, or can be pelletized and packed for a reprocessing procedure through further extrusion or in-

jection in a separate process. These limited processing options leads to limitations in the application area as well. In such cases, non-structural applications are only to be expected.

In other types of plant natural fibers, that are not gained from the agricultural residues, other compounding methods can be applicable in case the fibers are produced long enough as in the case of flax, hemp, kenaf and cotton. In such cases, woven yarns, fleece and fabrics can be manufactured prior to the compounding process. Afterwards, manufacturing technologies possibilities of appliance are much higher. Examples of this are the pultrusion and comingling processes, which result in much higher performance composites. The composites are finalized through hot pressing of the compounded fibers/polymer, releasing and defusing the polymer within the fibers and resulting in a high performance composite.

4.2 Agro-fibers' thermoset biocomposites

Natural fibres are here bonded through thermoset polymers whether synthetic fossil-based or plant-oil bio-based ones.
Commercially, thermoset biocomposites are still not widely available. Inspite of this, high interest in such composites is in ascending demand, due to the known relative higher material performance of the thermoset composites than that of the thermoplastic ones. One of the examples of the successful products present in the market is the cladding products of Duralmond® from Avda. RegiónMurciana – Spain, [12], which is manufactured out of crushed almond husks and classic fossil-based thermoset matrices.
Manufacturing techniques as found in the classic composite industry, includes both 'open mould' (e.g. hand lay-up and spray-up) and 'closed mould 'techniques (e.g. resin transfer moulding, vacuum infusion and compression moulding). Limitations in the case of agricultural residues fibers are the relative short fibers that are normally won from such a source. Most of the compounding techniques are directed in the long fibers, fleece and fabrics direction. In case of thermosetting biopolymers' appliance, high curing temperature of the most current available ones is another limitation to the whole production process, [1].

Unlike classical methods of thermoset biocomposites' production, closed-press molding and open ones were applied and investigated using short free-oriented agro-fibres within the following examples to produce the desired designs. Short straw fibres were bonded with two different types of bio-resins of linseed oil epoxies. Each type of bio-polymer applied has its different processing method so as to reach the desired outcome.

5. Green agro-fibres biocomposites – Case studies

Inspite of processing difficulties, and limitations in both the molding techniques using short free-oriented fibers, as well as the high curing temperatures, two products of cereal straw short fibers were combined with two types of plant-based epoxy thermoset biopolymers. One of the types cured only in the presence of heat, while the other cured in room temperature. Difficulties were successfully overcome and the product design was correctly fulfilled and applied through choosing appropriate available production methods and enhancing all this into architectural applications.
The following case studies are products designed and produced by the authors and students of the third year in the faculty of architecture- University of Stuttgart within the framework of educational courses. The products are composed up to 40% by weight of fiber contents of cereal straw collected from different origins. The claddings were fixed as an interior and exterior application in an experimental pavilion named Eco-Pavilion which was fully constructed out of recycled materials, and was presented in the annual exhibition of the faculty of Architecture –University of Stuttgart in 2011.
The general criteria for designing the biocomposite, materials selection, processing techniques and their interaction is illustrated within the following sketch:

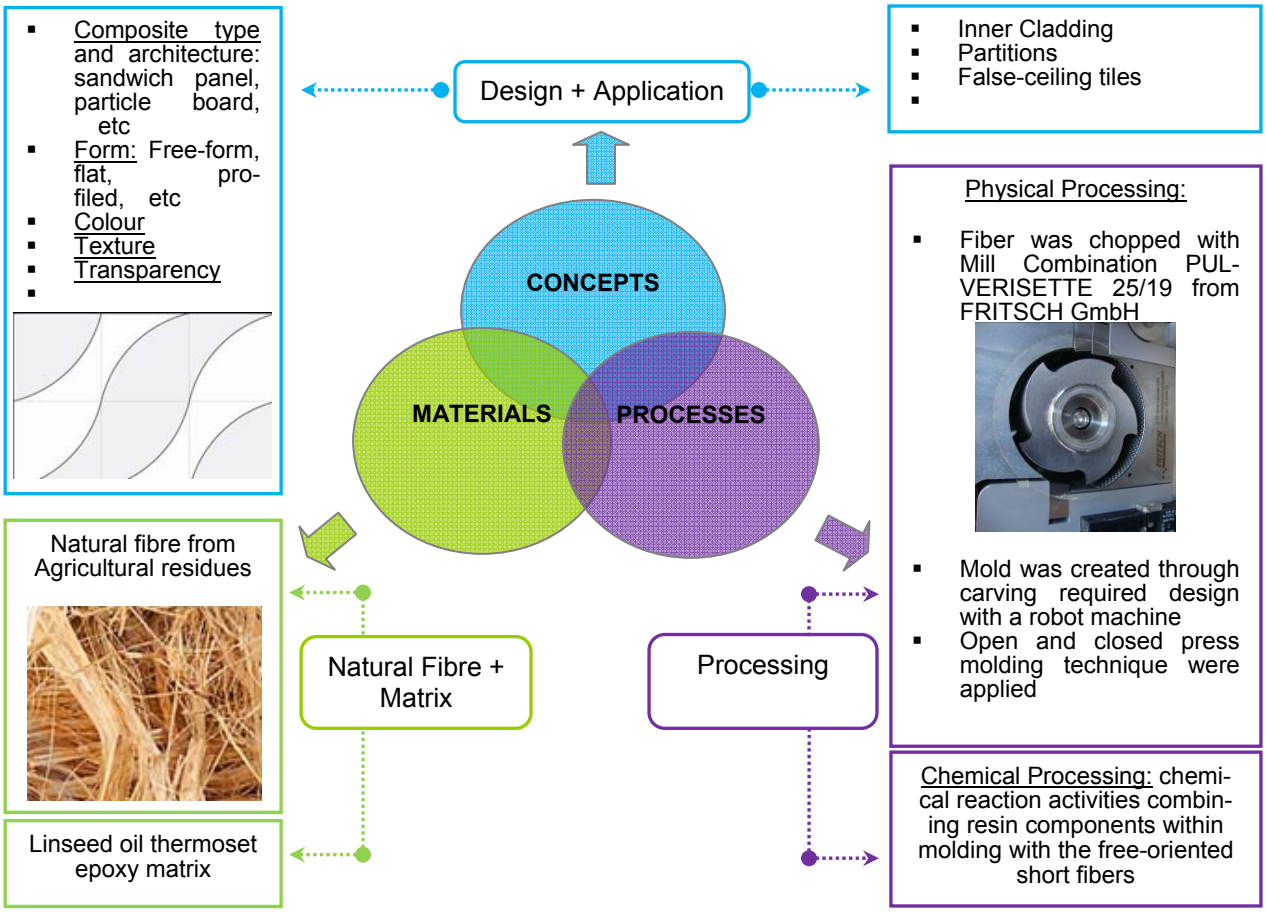


Fig.2 : Sketch illustrating the intersection between materials selection, processing possibilities to meet the desired design fitting into the required application

5.1 Case study – 1: TRAshell

Product description: Free-Form Façade Panels out of cereal straw short fibers and plant-based epoxy resin, 'TraShell', processed by press-molding (cold process).

5.1.1 Materials Applied

Rice straw and other agro-fibers were here applied, like coconut fibers of reddish brown colours and black ash recovered from sawdust and pellets burning to provide necessary colouring. Cereal straw was milled into 1 mm fiber length to maximize the polymer replacement percentage by weight uptill 40% by weight. Milling took place using a chopping machine integrated with a dust absorber, named Cutting Mill Combination PULVERISETTE 25/19 from FRITSCH GmbH. The previously mentioned reinforcing and active fillers were combined with a bio-based epoxy resin based on two components- Gripox® provided by Grizzly LeimGmBH, where component A (resin) is based on linseed oil epoxy and component B (hardener) based on a mixture of organic anhydrides (citric acid, oxalic acid etc) [8]. At room temperature, the fiber-matrix mixture cured in ~ 24 to 48 hours.

5.1.2 Product Design

The first sketch for a complete free-form cladded wall is presented as follows in Fig.3. The free-form panels were designed in two modules (A) and (B) as illustrated, to provide through their combination a desired 3D physical curvatures when the patterns combine as illustrated.

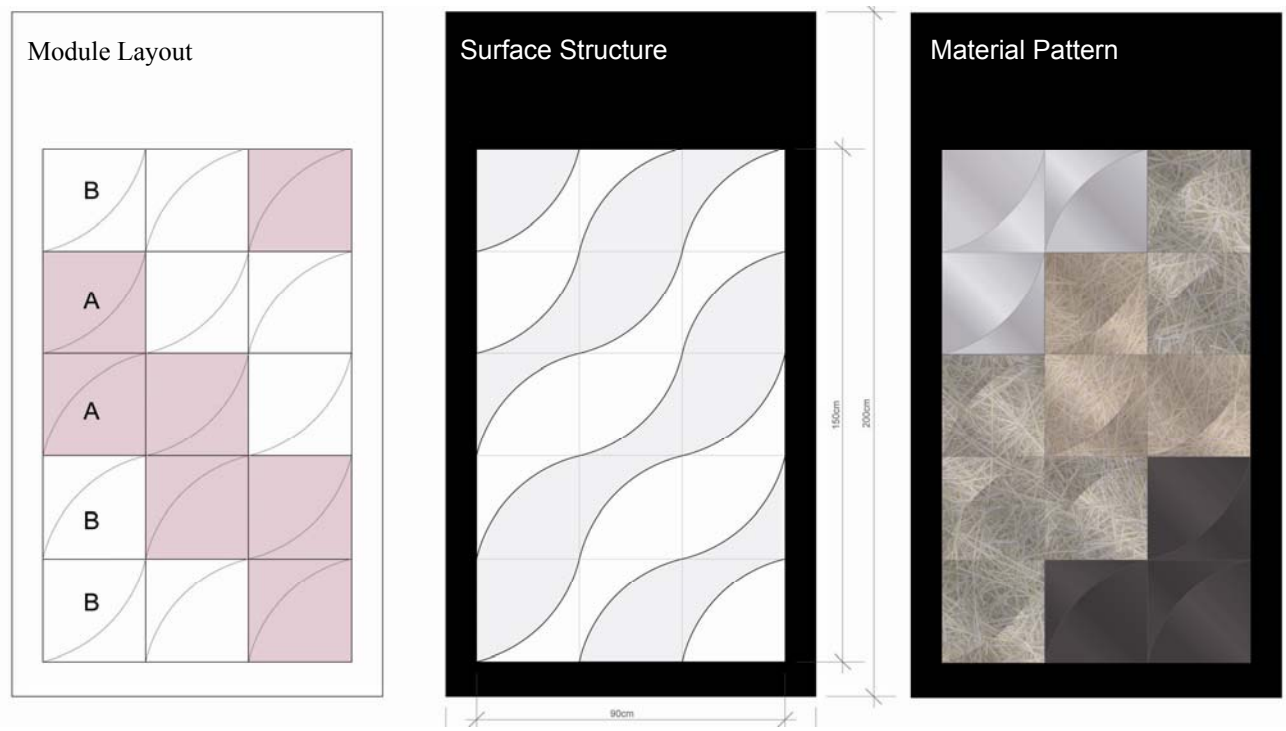


Fig. 3: Product design realized within the Seminar "Do it Yourself" in SS11, supervised by the authors. Students participated in this product: Susanne Hügel, Lousia Scherer, Kerstin Meyer

5.1.3 Mold making and molding technique:

For each designed module, a mold was separately manufactured. Each mold was composed of two pieces, a positive and a negative form. The negative forms were separately carved in a foam block material after a 3D digital drawing of the two design modules using a robot machine, and the negative sides of the molds were created in a different process using another resin and filling tiny stones.

After applying the necessary releasing materials, the mixture of agro-fibers and the bio-resin was distributed in the negative mold then pressed through the positive lid for at least 24 hours in normal room temperature. The hardened composite was then raised carefully from the mold, to harden completely in room temperature for another 24-48 hours.

5.1.4 Outcome:

The resulted panels were stable and fixed successfully on a pavilion's façade for experimentation-Fig.4. Panel surfaces contained no air gaps and the production of both mat and shiny surface finish was also possible. Free-form panels were of 4 mm thickness and 5 cm protrusion to the outside when measured horizontally.

The composite was tested for weathering conditions (according to Free Weathering Test-DIN EN ISO 877) for 12 months as well as mechanically tested. The results were satisfactory and have shown high stability of the material against UV rays and weathering conditions.
Mechanical testing showed comparable stiffness values with existing non-structural materials available in local markets that are applied in interior applications. This reveals the potential of replacing existing conventional materials with renewable resourced products based on agro-fibres and bio-based matrices. Further experimentations and designs should be proceeded by architects, designers and material engineers to reveal more attractive applications possibilities from agricultural residues.



Fig. 4: Left: 'TRAshell' fixed on the Eco-Pavilion (©ITKE) as a cladding element. Right: Mold making using the robot machine at Faculty of Architecture-Uni. Stuttgart- Germany. Right- Down: Closing the upper positive mold with the negative one to create the shell composite. Photos: B. Miklautsch, H. Dahy

5.2 Case study – 2: 'BiOrnament'

Product description: Colored laser-cut flat panels (BiOrnament), processed by: hand lay-up open molding technique.

5.2.1 Materials Applied

Cereal straw fiber was applied and prepared using the same previous method in the first case study.

5.2.2 Product Design

The design sketch illustrates the idea of the pattern, that was applied depending on repating both the positive and negative cutting models that would result from the laser cutting procedures after the flat panels were separately manufactured. The product theme depended on the rhythm and diversity within unity using a repetitive pattern with different colourings after a specific design.

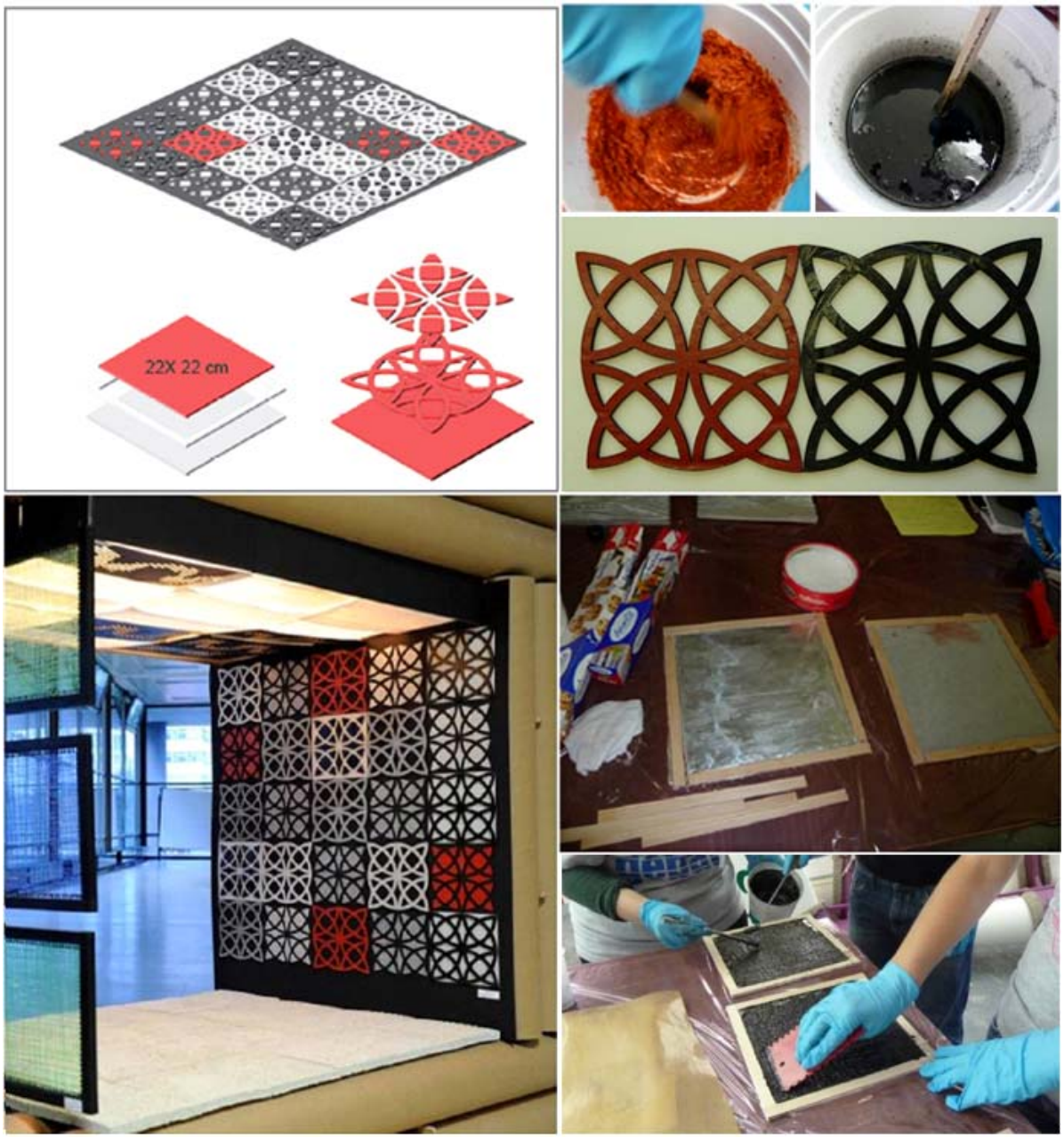


Fig. 5: Product design sketch, panel production stages and the final BiOrnament product after fixation on the experimental Eco-Pavilion (©ITKE). Photos: B. Miklautsch, H. Dahy.

The product and design were realized within the Seminar "Do it Yourself" in SS11, supervised by the authors. Students participated in this product: Anke März, Gregory Tarkhounian, Nora Woborny

5.2.3 Mold making and molding technique

The fibers were bonded with a linseed epoxy based thermoset polymer, PTP®-L provided by B.A.M. (Bio- Composites and More GmbH). The binder was prepared through a mixture of 3 components A, B and C, where Component (A): bio-based epoxy resin (concentration 55-65%), Component (B) hardener (concentration 35-45%) and Component (C) : additional PTP accelerator (concentration 2,5-5%), which is only activated by heat [9]. This is considered a disadvantage of the matrix in this case, for the extra energy usage.The mixture of the resin components reacted then rapidly after the fiber mixture uptill 40% by weight under high temperature (130° C) and finally polymerizes. The fiber should be dry enough to be properly bonded by the matrix.

The mold was composed of a metal flat plate surrounded by long flat edges, with extra openings on the edges for excess resin's release. After applying high temperature releasing agent to the mould, the fiber/matrix mixture was distributed horizontally and pressed. The final upper pressing of the mixture within the mold is not mandatory in this case.

5.2.4 Outcome:

The produced flat panels were cut by a laser machine according to an oriental design as shown in Fig.5 . The panels were from 2-4 mm thickness and of 25x25 cm dimensions. They were successfully colored through natural pigments that were applied during the mixing stage.The produced cladding panels were fixed as an interior application in the experimental pavilion. Samples were taken from the produced panels and free weathering was applied as declared in the previous case study. The visionary observation showed stability of the samples' appearances and colours after 12 months against UV rays and natural weathering.

-The outcome of the illustrated case studies show that the recycling of agricultural residues towards architecture and building industry still have so many potentials and beauty that need further work and investigations. Design possibilities are wide and open for further developments in the field, and the manufacturing of products of higher architectonic qualities that can compete in contemporary markets to replace conventional fossil materials is therefore applicable using agri-fibers.

6. Challenges illustration

6.1 Compatibility with polymers

Compatibility of the natural fiber with the thermoset resins in specific is still problematic due to the hydrophilic nature of the natural fibers in opposition to the hydrophobic nature of the resins. This causes plasticity nature during the compounding process that causes undesirable lower mechanical properties than expected. That's why alkali-treatment was the solution for many researchers to overcome the uncontrolled humidity in the natural fiber, through strengthening another aspect in the fiber-resin adhesion factors, which on the other side causes chemical wastes with recovery difficulties. On the other side, the fiber's combination with thermoplastics is pushed back with the limited processing temperature (maximum 200 degrees), otherwise the natural fiber would decompose. That's why the compounding of the natural fibers with thermoplastics are limited to plastics with relatively low-melting points like PP and PE [3].

6.2 Manufacturing techniques

6.2.1 Humidity control

One of the main problems is the humidity control, which is one of the main drawbacks of natural fibers. Chemical modifications can improve this problem to a great extent, however has its own problems concerning releasing chemical wastes and cost effectiveness.

6.2.2 Machining

Short agro-fiber composites are processed using the common plastic machinery, including extrusion, injection molding and thermoforming. In case of thermoset composites' processing, limitaions of short fibers' applications widely exist, as these techniques are mainly based on long fibers' processing. Technologies for production of straw mats should be further applied to increase the opportunity of the fiber's processing potentials and manufacturing possibilities, especially for agro-fiber thermoset composites.

6.2.3 Dust control during chopping

One of the main problems in the chopping process is the huge dust released causing dust clouds, with risks of lung diseases. Therefore, a milling/dust-absorber machine was applied in the fibers' preparation procedures, Fig.6, where the chopping system was integrated with a dust absorber and collector system, preventing dust clouds to exist.



Fig. 6: The chopping machine is integrated with the collector and dust absorber, supported by FRITSCH [10]

7. Conclusions

Current applications of straw-based biocomposites and boards are still in the early stages of development. Chemical modifications which are classically applied on the natural fiber before compounding to optimize the fiber/matrix interface quality releae toxic chemical wastes that are difficult to be treated. Hence, other compatible matrices with the natural fiber with the least

possible applied chemical modification should be further investigated. One of the suggestions would go further towards bio-based polymers which are derived from a much nearer to the natural fiers' base than a fossil-base. In this case, further investigations on life time of the final product and aging should be properly examined so as to suit different applications in building industry.

Straw can have much further applications when straw mats are applied in industry on much wider scales. In addition, the problematic transport problem when moving huge volume of the loose straw or even the bales themselves can be much decreased, especially when straw mats can be directly manufactured in fields and transported in this form to industrial applications. Furthermore, better waste management criteria to move straw towards more industrial applications, should take place.

In addition, further efforts are needed to take place to raise up the level of the architectural applications and reach up to much more attractive architectural products. Colouring, textures and forms are important keys in the architectural design of the products. With the help of natural pigments, laser cutting, free-form panels' manufacturing, more attractive products could be reached replacing the conventional ones based on fossil and non-annual wood available contemporary in the market.

8. References

[1] FOWLER PA, HUGHES JM, ELIAS RM. *"Review Biocomposites: technology, environmental credentials and market forces"*. Journal of the Science of Food and Agriculture, 2006, Volume 86, pp.1781-1789

[2] HAN, YW, ANDERSON AW. *"The problem of rice straw waste: a possible feed through fermentation".* Econ.Bot. 1974,Volume 28, pp. 338-344.

[3] KARKOODI, AR, LEDUC, S. et al. *"Mechanical properties of recycled polypropylene/SBR rubber crumbs blends reinforced by birch wood flour"*.(Report) 2012. Article from: Polymers and Polymer Composites

[4] POTT GT. "*Natural Fibers With Low MoistureSensitivity"* . Natural Fibers, Plastics and Composites .Wallenberger et al. Kluwer Academic Publishers. The Netherlands,2004, Ch.8, pp.118

[5] SUN, RC. *"Cereal Straw as a Resource for Sustainable Biomaterials and Biofuels"*. Elsevier Science, 2010, pp. 1-5.

[6] VUONG, L. "Straw Bale Construction in China: A comparison of obstacles between Northern and Southern rural areas for the use of Straw Bale Construction as an energy efficient building alternative". 2004, University of Puget Sound- National Science Foundation and Michigan State University, P.R.E.M.I.U.M. Program

[7] United Nations Food and Agricultural Organization (FAO): http://www.fao.org

[8] Technical data sheet of Gripox – provided from Grizzly Leim GmBH (http://www.grizzlyleim.de/techsheets/42111K.pdf)

[9] Technical data sheet of PTP ® - provided from B.A.M.- Biocomposites and More GmBH

[10] http://www.fritsch.de/produkte/mahlen/schneidmuehlen/pulverisette-2519/

[11] http://www.resysta.com/de/

[12] http://www.duralmond.de

[13] http://www.ricycled.com

[14] http://www.naturescomposites.com/composite-lumber-products.html

Challenging ETICS



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Short Summary

The results from the investigation of the question whether insulating elements from components of the ETICS can be produced with sufficient static properties due to a new support structure as defined by wInterface to be produced as facade elements in a individualized industrial series production provide a new and significant solution to the challenge of deconstructing ETICS according to the Regulation (EU) No 305/2011 basic requirement for construction works No. 5, 6 and furthermost 7 Sustainable use of natural resources [1] which now has come into force.

Keywords: ETICS, ETIC, TICS, WDVS, Regulation (EU) No 305/2011, thermal refurbishment, EIFS, prefabricated cladding system, large panel system,

1. Introduction

The aim of this work is to investigate the question of whether it is possible to manufacture insulating elements from components of the ETICS, with static characteristics sufficient to be brought into use as prefabricated parts for exterior wall insulation in thermal renovation as well as new construction.

Only under this condition can the sensible use of individualized industrial series production of EIFS cladding panels be made possible on the basis of modern imaging methods of measurement. The use of this computer-based technology also enables the optimization over the entire manufacturing process.

Conventional EIFS facade insulation layers are produced directly and in conjunction with the existing facade in laborious hand work. To the cost driving disadvantages of difficult working conditions on the vertical wall and all the quality and time loss due to the barely controllable influences of the weather and to the long lasting burdens on the inhabitants by disturbing of privacy, noise and waste add the equally long-lasting obstruction of traffic especially in high-traffic roads in urban areas.

Through the conjunction with the facade these conventional ETIC systems cannot be dismantled. Thus they do not meet the basic requirement for construction works No. 5, 6 and 7 of the Regulation (EU) No 305/2011, which also prescribes the process of deconstruction at the end of use to be considered. Sufficient static properties provided prefabricated EIFS façade elements produced to accurate dimensions can be a possible solution to this challenge due to the possibility of their demounting.

2. EIFS insulation elements of the wInterface system

As an approach to solving this problem, EIFS elements for thermal insulation of buildings with a novel load-bearing structure have been defined by wInterface along with a method of manufacturing, which allows a customized industrial series production of precisely fitting EIFS façade elements.

In addition to the cost efficient EIFS made from EPS other EIFS have been accredited on the basis of insulation materials such as mineral wool, wood fibreboards or PUR / PIR showing accordingly different characteristics. Is to be noted that all components of these accredited EIFS are in principle suitable as component for the construction of these facade elements.

In contrast to the large, storey-high facade insulation elements in sandwich construction with window openings as it was developed in the Large Panel Insulation Technology (GEDT)[2] for thermal insulation improvement and renovation of old buildings and in distinction to the various forms of wood frame construction examined in the research program Haus der Zukunft and published in the project report plusFassaden [3], the wInterface insulation elements are usually arranged as simple rectangles between components like windows and balconies. The entire wood frame construction of such elements can be replaced by wood fibreboard when using the load-bearing structure of the wInterface insulation elements.

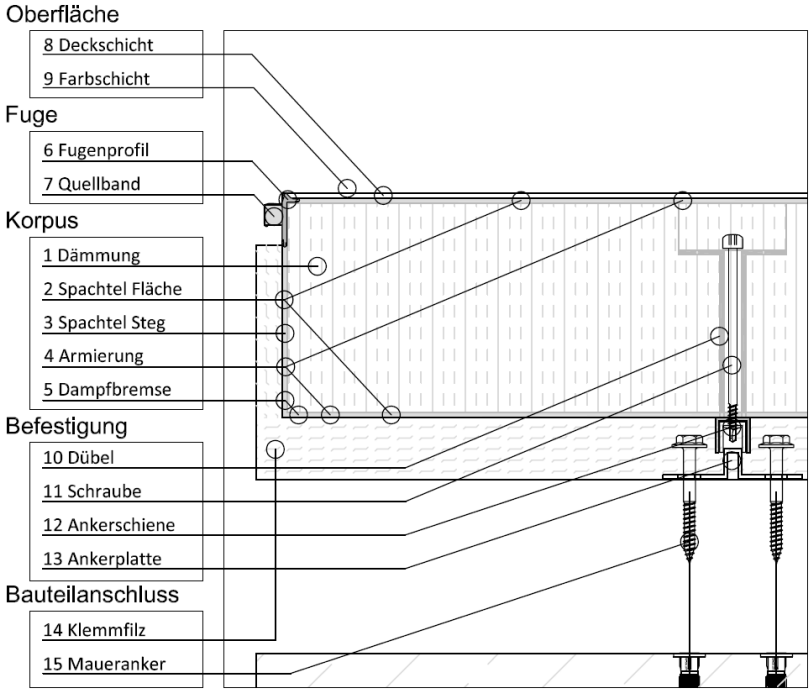


Fig. 1 Components of the EIFS insulation elements

2.1 System specification of the EIFS insulation elements:

Body of thermal Insulation (1): made from EPS, mineral wool and organic materials like wood fiber insulation or PIR
Adhesive (2, 3): Klebespachtel (4% organic compound) or Dispersionsspachtel; Option: Additive for quick setting; Addition to curing to dense vapor barrier on the inside.
Reinforcement (4): glass fibre, glass fibre; Option: diagonal in the fixed links
Surfaces (8): mineral or thin plaster; + pigment layer: Silicone resin dispersion,
Edges (6): Edge profiles made of plastic and metal
Gap to the wall (14): Mineral wool (Klemmfilz) on the inner surface of the EIFS elements directed towards the building to avoid ventilation

Vapour barrier (5): can be laminated on the inside against vapor diffusion or utilized as a coating or spraying of a suitable layer of vapor barrier in the course of production facilities. If possible, the element materials (as shown above at adhesive) should be tuned to each other so that an additional layer can be omitted and a high potential for dehydration is provided.
Formation of the joint (7): the gaps can be closed weather tight by a commercially available, pre-compressed sealing tape. There are for example pre-compressed multi-function bands made of durable elastic, fine-pored polyurethane foam for sealing to standard for defined gaps (Bauanschlussfugen) in a wide range usable with a water tightness proven to 600 Pa. The use of profiles for edge protection and joint edge profiles has also proved useful.

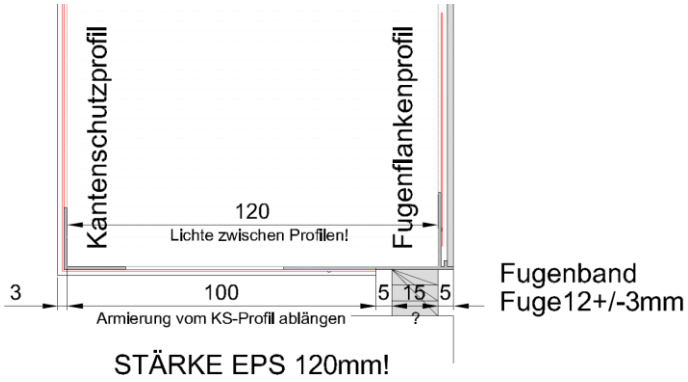


Fig. 2 Joint with pre compressed sealing tape and joint surface profiles

Fixing: The mounting of the insulating elements takes place by means of EIFS dowels (10) for a pointwise screw connection (11) to rails (12) which in turn are secured at their upper and lower ends via an anchor rail (13) to the wall. During assembly the rails (12) can be attached at their lower ends to the anchor rail (13) of the lower, already mounted elements and when dismantling single EIFS elements can be unscrewed through the joint (7) from the anchor rail. The rails (12) make an additional reinforcement of the system.

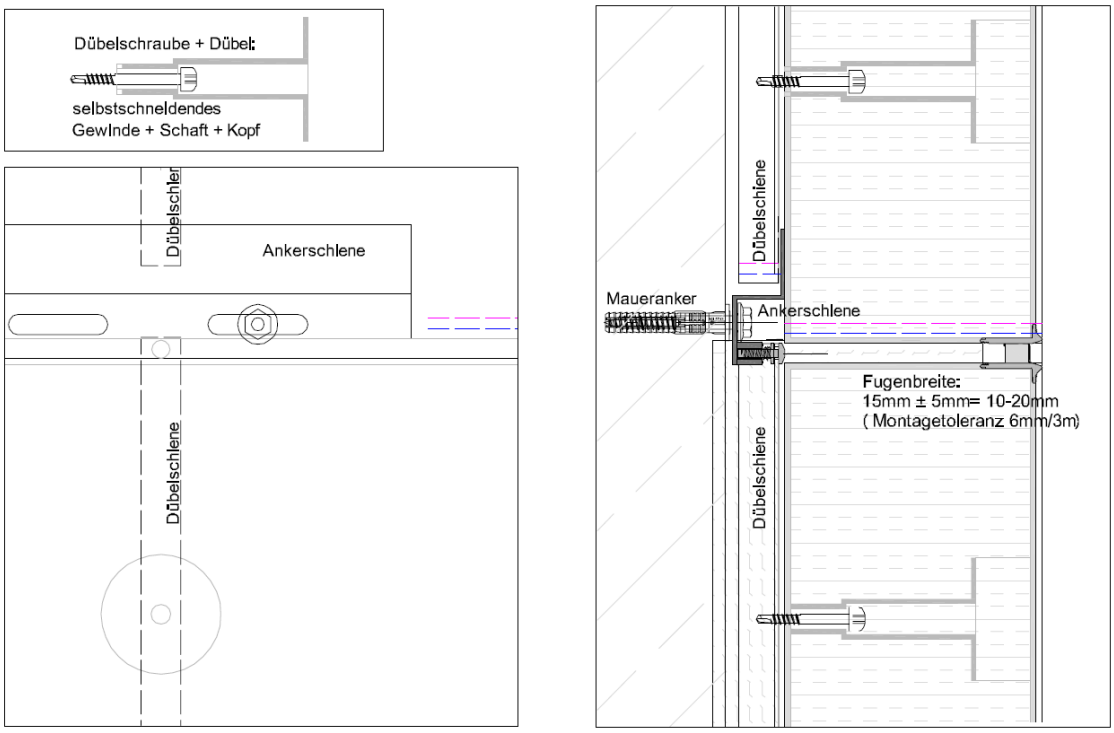


Fig. 3 Mounting system with ETICS anchor, anchor bolt, rail and anchor rail

2.2 Ensuring functionality and usability

Static sufficient properties will be stated in this work, when functionality and usability are demonstrated by the fact that under normal loading as wind suction on the order of 1,000 N/m², the deflection of the EIFS elements remains limited to the length-dependent maximum value of L/200 and that extraordinary loads such as wind suction on the order of 2,500 N/m² [4] and more do not lead to fracture of the EIFS elements or their mounting system.

3. Computational models of the deflection

The outer and inner stresses which may act on the elements must be detected to analyse the structural requirements of the elements. These are essentially dead weight, wind load, thermal stress and rain pressure.

In this survey of the basics a strong focus lies in the understanding of the interrelationships of important variables such as element thickness, insulation materials, coating materials (adhesives, reinforcements), fixings (dowels, fixing bars) on the achievable strength. The aim is to establish a computational model, by which three applications can be met:

- First, it serves to provide the proof of stability for individual projects. This is true both for the pilot projects as well as for future projects when the system is certified. Even then the stability analysis for each project must be provided by a structural engineer.
- Second, it provides the basis for the mathematical proofs in the context of certification and for the computational assessment of further developments.
- Third, the computational model is also the basis for the automated design (dimensioning and verification of stability) of the facades as part of the interface of the facade designing tool of the control software. The individually from the geometry derived facade elements must be automatically checked for stability. The same applies to manually by the designer adapted items.

The requirements for the static arising from external influences (weight, wind, temperature, etc.) are to be considered from two aspects: on the one hand, the failure of the element (eg, fracture) under extraordinary stress conditions (eg storm or fire), here it is important to know the load at which failure can occur. On the other hand, for the serviceability the deflection of the elements hast to be limited to a size-dependent maximum value under normal load conditions.

The study of the specific requirements for the statics and the survey of the basics was done in cooperation with Ingenieurgemeinschaft Kaufmann – Kriebernegg ZT-GmbH (IKK). The main findings are that exposure to wind in Austria lies normally in the range from 500 N/m² to 1,000 N/m², up to this load the maximum deflection of the elements must be less than a L/200. Higher loads (eg storms) fall into the category of extraordinary burdens, in which case the elements must remain intact as far as that no hazard to persons or property can occur. Furthermore, the shape changes due to temperature variations are expected in the order of less than 2 mm and thus can be easily absorbed by the joints.

For the calculation of the elements regarding the serviceability two computational models were developed. Basis of the deflection is the following formula:

$$f = \frac{5}{384} \times \frac{l^4 \times q}{E \times I}. \quad (1)$$

Where f is the maximum deflection and l represents the length of the component. The load is represented by the linear load q. The modulus of elasticity E is a material constant and I is the area moment of inertia that depends on the geometry of the component. In contrast to l and q, which are given for a particular component and a particular load, the modulus of elasticity and the area moment of inertia of the elements must be derived for the assembled components. Principally there are three options available for this approximation:

1. Hollow profile of adhesive: Here, the modulus of elasticity of the adhesive is used to calculate the moment of inertia for a hollow box. This approach can be chosen because the influence of the insulating material due to the low modulus (about 3.4 N/mm² for EPS as opposed of 6,500 N/mm² for the adhesive) is negligible. However, the calculation of the moment of inertia of the hollow body is both very complex and on the other hand a reduced value for the E-modulus has to be used for the adhesive due to the extremely small wall thicknesses. Since there is no suitable model for decay of the E-modulus, this approach was not further pursued.
2. Total cross-section method or n-digit procedure (Gesamtquerschnittsverfahren): In this approach, the whole body is broken down into parts of the same material and for each part of the body the area moments of inertia are calculated separately. For the total body, the elastic moduli and the area moments of inertia are summed weighted. The individual weighting factors are derived from the ratio of the modulus of the component to a fixed factor (usually the highest modulus of all components). These weighting factors are referred to as "n". Detailed information about this method can be found in [5].
3. Composite: In this method, the area moment of inertia of full section is used and the E-modulus is calculated from the E-moduli of the individual components. For this, the whole body is decomposed as with the total cross-section method. The moduli of elasticity of the parts are either added or their reciprocal values are added depending on whether they lie parallel or in series to the overall direction of the stress. Detailed information about this method can be found in [6].

Both methods give similar results for the expected deformation for the relevant loads (1,000 N/m²). For thinner elements with an insulation thickness of 120 mm, the total cross-section method gives about half as large values as the composite method. For thicker elements with an insulation thickness of approximately 200 mm arise in both methods the same values.

4. Testing

4.1 Deflection

Several prototypes were build and investigated to check if the computational models are suitable for predicting the deflection, which method produces better predictions, and to balance or derive the parameters for the models (material properties, geometric parameters, etc.) on the one hand and as a guide for deciding between different design variants on the other side.

Wind pressure tests were conducted on the test bed of Bauphysiklabors of the Graz University of Technology to gain information about the bending and fracture behavior of the elements. Here, pressure was applied the elements gradually up to a load of max. 4,000 N/m² while measuring the deflection

For these wind pressure tests 20 2,000 x 1,500 mm wide specimens were manufactured. These were designed concerning their inner structure just as they are to be used later. Here at the prototype three resp. four parameters have been varied. Each parameter can take one of two values, each representing an "extreme" value. The parameters are shown in more detail in the following.

- Adhesives: Two different adhesives were used for the bars and the top surfaces to get a feeling of the different behavior of a wide range of possible adhesives. On one hand, a pure cement adhesive, on the other hand a cement based adhesive with a high proportion of dispersion.
- Bars: In order to better assess the impact of the bars to the total static elements with and without bars have been tested. Elements without bars are composed of two EPS blocks with 750 mm in width and 2,000 mm in length joined together with a special EPS-adhesive to form a homogeneous block with the final dimensions. For elements with bars the standard EPS boards with 1,000 mm in length and 500 mm in width were used. In latter the bars are produced using the previously described adhesives.

- Insulation thickness: To examine the statics of the elements in a wide field of usage, the elements were implemented with two different insulation thicknesses. Firstly, working with 120 mm thick EPS boards to the other with 200 mm thick plates. This doubling corresponds to halving of the heat conductance value.
- Insulation material: In addition to the EPS based elements two elements have been produced with two types of mineral wool insulations (larger boards and smaller plates). Here, only the variants with bars and cement adhesive according to the combination 5 from the summary table were manufactured.

From these parameters, a total of eight variants result. In addition, derived from the combination with thinner insulation thickness, cement adhesive and with bars (variant 5) elements with mineral wool boards and mineral wool plates as insulation have been build. Two versions of each of the ten resulting specimens were manufactured. The following table represents all ten variations resulting from the above combinations.

Tab 1: List of types of elements for deflection testing

Variant	Adhesive	Bars	Thickness	Material
1	Dispersion	with bars	120 mm	EPS-board
2	Dispersion	without bars	120 mm	EPS- board
3	Dispersion	with bars	200 mm	EPS- board
4	Dispersion	without bars	200 mm	EPS- board
5	Cement	with bars	120 mm	EPS- board
5a	Cement	with bars	120 mm	MW- board
5b	Cement	with bars	120 mm	MW-plate
6	Cement	without bars	120 mm	EPS- board
7	Cement	with bars	200 mm	EPS- board
8	Cement	without bars	200 mm	EPS- board

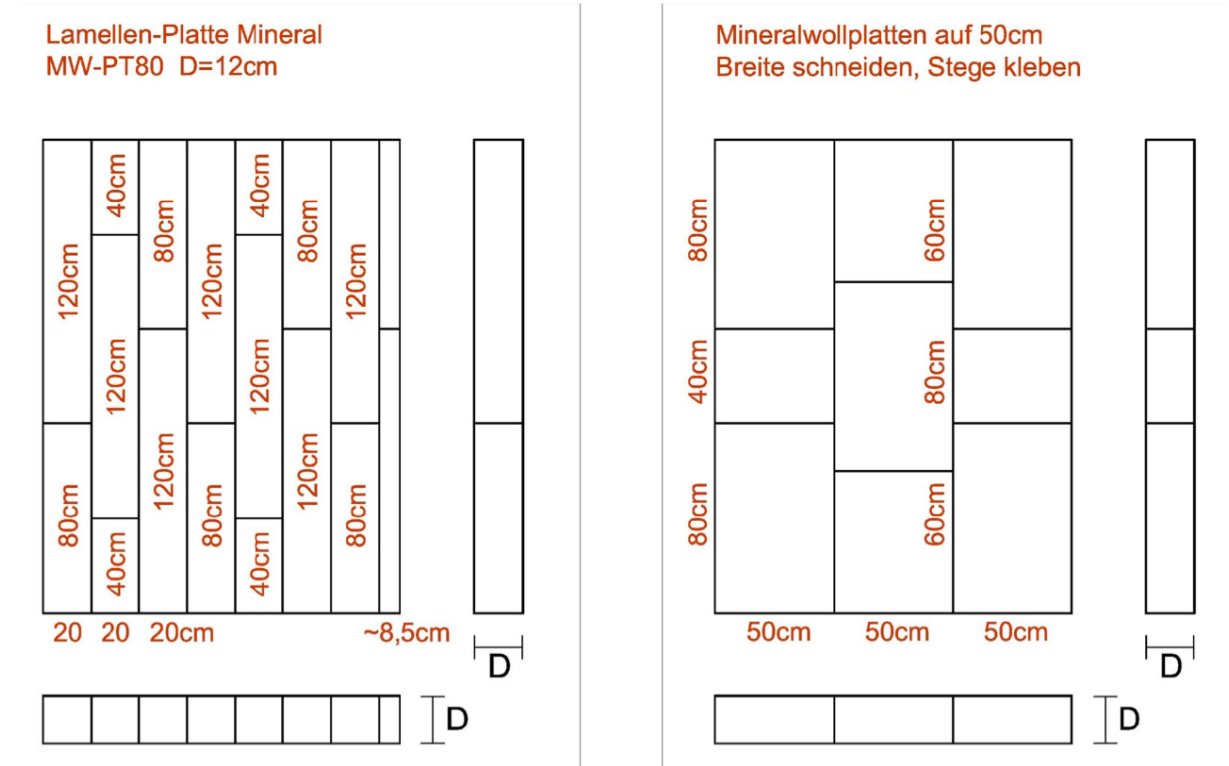


Fig. 4: Construction details of mineral wool elements. Left: plates. Right: boards.

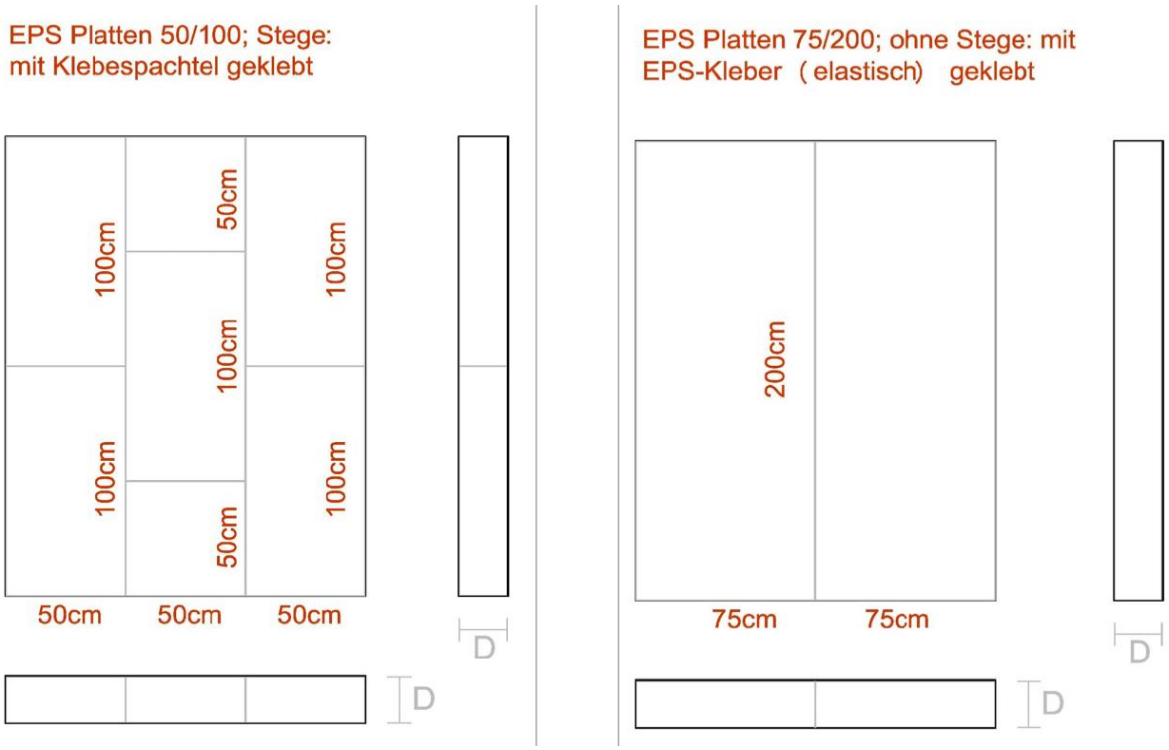


Fig. 5: Construction details of EPS elements. Left: with bars. Right: without bars.

4.2 Pull out tests

Based on the ETAG 017 32 specimens were made in total. In these test elements different variants of anchors (standard dowels, helical dowels, and threaded rods) were used. These were connected in different ways with the insulating body. On the one hand they have been directly applied through the insulating material; on the other hand they are nested into a bar between two halves of an insulation board. In addition, a part of the samples was performed with reinforcing mesh. The samples were clamped on a tensile testing machine and a force-distance curve was recorded. The specimens for the pull out test are 400 x 400 mm wide and have thickness of 160 mm. The following table gives an overview of the different variants.

Tab. 2: List of variants of specimens for pull out test

Nr.	Bezeichnung	Stück
1	Dowel in material	2
2	Dowel in bar	4
3	Dowel with reinforcement	2
4	Dowel in bar with reinforcement	2
5	Threaded rod	2
6	Threaded rod with reinforcement	2
7	Pre-test built 1	1
8	Pre-test built 2	1
9	Pre-test built 3	1
10	Pre-test built 4	1
11	Helical dowels in bar	2
12	Helical dowels in material	2
13	Threaded rod straight	2
14	Threaded rod straight with reinforcement	2
15	Threaded rod L-shaped	2

16	Threaded rod L-shaped with reinforcement	2
17	like 16 but with different adhesive	2

The experiments were performed in two different batches. The variants 7-10 were pre-test builts to test the procedure and the clamping of the specimen. In the first batch, the variants 1-10 were tested. In the second batch, the remaining variants were tested plus two specimens of variant 2 for comparison purposes. The test elements of the second batch were not fully cured due to the cold weather during the manufacturing.

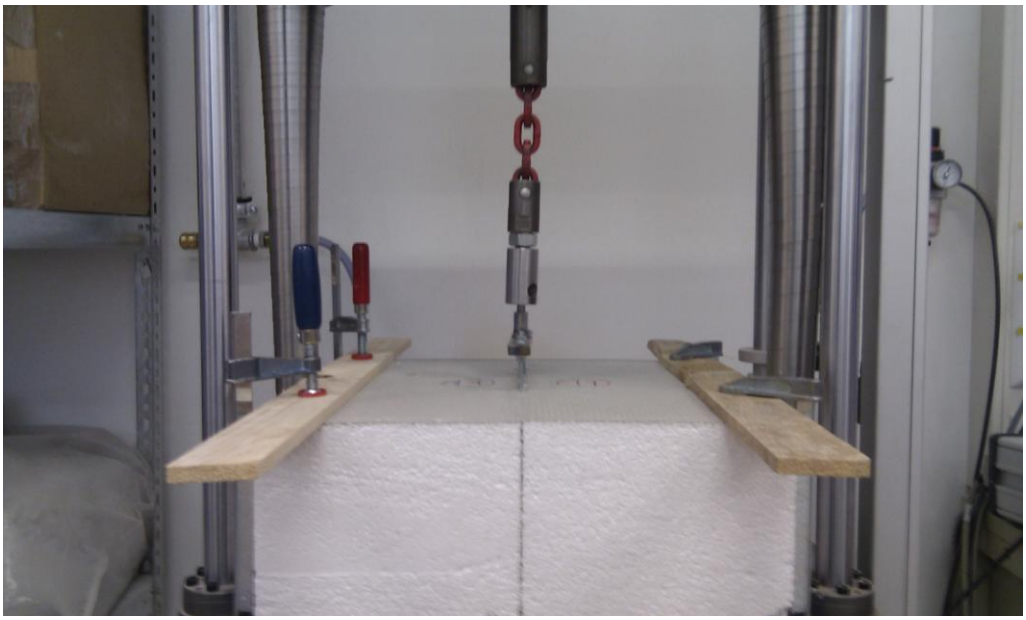


Fig. 6: Test set up pull out test.

5. Results of deflection

5.1 Failure Limits

The results obtained in the wind pressure tests have not only met but far exceeded the expectations. Although the computational models showed ex ante that the deflection should be within the permissible limits of a L/200, but it was not clear whether the items would handle the load at all or whether they would be damaged by the stress. The experiments have shown that the elements have less deflection than predicted by the models and beyond are also close to indestructible. Besides the measurement of the deflection it was tried to destroy all the elements by increasing the load to such an extent until there is a failure of the elements. Here, however, it was examined that the test bed could not keep up the pressure at a load between 3,500 N/m² and 4,000 N/m². Only one element (mineral wool board) broke at a load of about 3,800 N/m². All other elements have left the test bed intact. For comparison, this burden is equivalent to a heavy storm.

Tab. 3: Results of deflection tests (red values are lower than L/200)

Type	max Load N/m²	max De-flection mm	Deflecion at load X N/m² in mm 1000	1500	2000	2500	3000	3500
1 A	1000	17,5	17,5					
1 B	1000	24,3	24,3					
2 A	1000	31,1	31,1					
2 B	1000	38,8	38,8					
3 A	2500	34,4	13,2	19,9	26,9	34,4		
3 B	3000	34,1	7,0	12,1	18,6	25,3	34,1	

4	A	2500	35,8	9,8	17,2	26,6	35,8		
4	B	3000	43,8	8,2	14,8	23,0	32,9	43,8	
5	A	2500	15,3	1,9	4,4	10,2	15,3		
5	B	3500	25,8	1,8	3,8	9,8	15,3	20,3	25,8
5a	A	2500	14,3	1,1	3,0	7,2	14,3		
5a	B	2000	5,9	1,0	1,6	5,9			
5b	A	2500	16,8	1,3	3,1	8,7	16,8		
5b	B	3000	19,4	0,9	3,0	7,4	13,1	19,4	
6	A	2000	16,5	3,4	9,8	16,5			
6	B	2500	22,8	5,2	10,9	16,8	22,8		
7	A	3000	5,4	1,0	1,5	2,1	3,3	5,4	
7	B	3000	6,2	1,0	1,6	2,3	3,9	6,2	
8	A	3000	8,5	0,5	1,2	2,9	5,4	8,5	
8	B	3000	8,4	1,4	2,2	3,5	6,1	8,4	

5.2 Verification of mathematical models

Since the width of the part due to the mounting situation is not affecting the result in the experiments, the calculations were performed for components with a width of 1000 mm.

Tab. 4: Comparison of results of computational models and measurements

Type		Length [mm]	Width [mm]	Thick-ness [mm]	Area [m²]	Load Meas. [mm]	1000 GQS [mm]	[N/m²] VW [mm]	Load Meas [mm]	1500 GQS [mm]	[N/m²] VW [mm]	Load Meas [mm]	2000 GQS [mm]	[N/m²] VW [mm]
5	A	1,860	1,000	130	1.86	1.9	5.5	10.3	4.4	8.2	15.4	10.2	10.9	20.5
5	B	1,860	1,000	130	1.86	1.8			3.8			9.8		
6	A	1,860	1,000	130	1.86	3.4	6.0	13.5	9.8	9.0	20.3	16.5	12.0	27.0
6	B	1,860	1,000	130	1.86	5.2			11.0			16.8		
7	A	1,860	1,000	210	1.86	1.0	2.9	2.8	1.5	4.4	4.2	2.1	5.9	5.5
7	B	1,860	1,000	210	1.86	1.0			1.6			2.3		
8	A	1,860	1,000	210	1.86	0.5	3.5	3.9	1.2	5.2	5.8	2.9	7.0	78
8	B	1,860	1,000	210	1.86	1.4			2.2			3.5		

The table shows, for four different specimens for three different strains (1,000 N/m²; 1,500 N/m²; 2,000 N/m²) in each case the measured deflection, the deflection of the total cross-section method (GQS), and of the composite method (VW). The values at GQS are in the thin components as mentioned about half the size of the values of VW. However, the measured values in these components at the higher loads showed larger values as predicted by GQS. Thus VW provides higher values for safeness for the dimensioning.

6. -Results of pull out tests

For each element, a force-distance curve was recorded and characteristic values were derived. On one hand, the maximum tolerable force was determined and the associated distance. On the other hand, for the distances of 1 mm, 5 mm and 10 mm the respectively there achieved forces were determined. The table provides an overview of these values represents the paths are given in millimeters and the forces in Newton.

Tab. 5: Results of pull out tests

Type		distance max. Force	max. Force	Force 1 mm	Force 5 mm	Force 10 mm
1	A	50.3	614	31	226	364
1	B	31.4	685	43	333	517
2	A	3.5	930	519	898	
2	B	5.2	899	543	895	
2	C	45.3	1,346	354	714	849
2	D	33.0	1,608	511	955	1,160
3	A	21.3	1,075	142	394	644
3	B	9.4	776	269	623	764
4	A	17.7	816	270	569	710
4	B	6.3	897	454	854	
5	A	2.3	1,357	113	907	690
5	B	0.5	536	30	75	120
6	A	4.4	2,140	1,054	1,883	1,311
6	B	4.7	3,195	1,479	282	2,130
7	A	65.7	1,107	131	374	532
8	A	71.7	1,149	88	323	500
9	A	58.6	1,272	580	699	854
10	A	59.3	1,083	215	505	693
11	A	43.7	960	326	777	816
11	B	65.4	1,133	298	791	826
12	A	55.1	1,414	194	469	636
12	B	47.0	1,326	84	425	627
13	A	0.6	17			
13	B					
14	A	2.4	303	138		
14	B	0.4	168			
15	A	0.6	147			
15	B	0.4	18			
16	A	0.6	216			
16	B	2.2	461	408	406	410
17	A	13.8	336	43	121	248
17	B	15.4	339	30	137	246

The missing values in the variants 13-16 result in large part from the fact that the elements were not completely cured. Figure 4 shows the force-distance curves of the examples of variant 1. Almost the same maximum forces are reached, as in most variants. However, these are achieved in different distances.

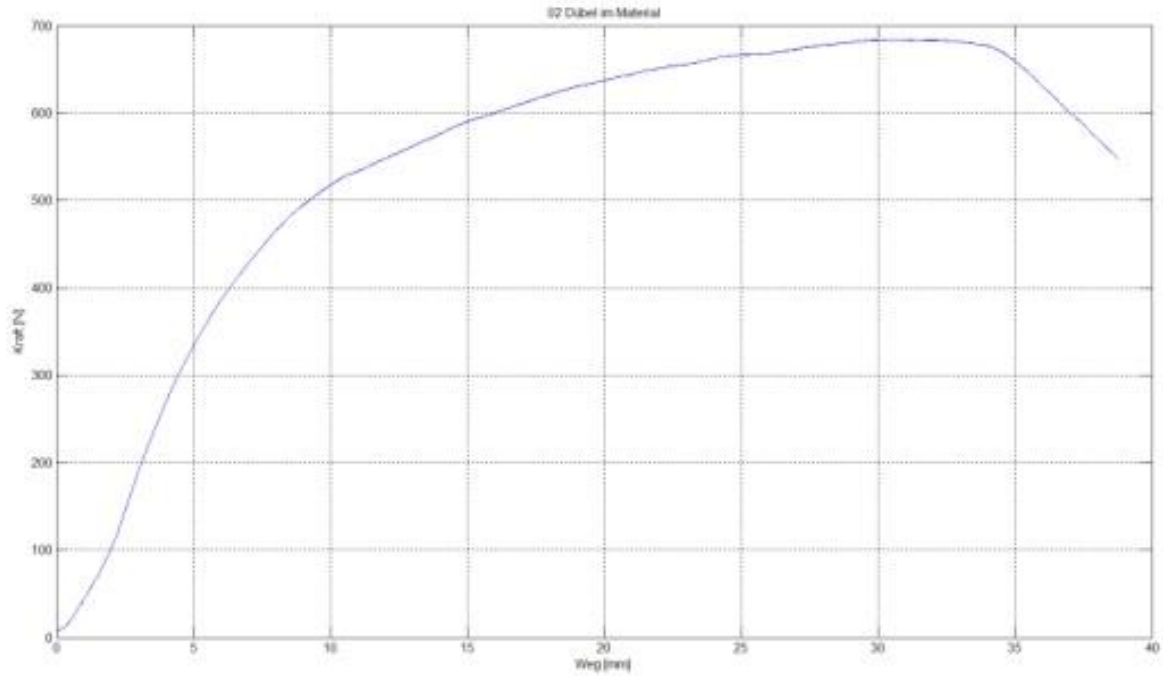


Fig. 7: Force-distance curve for variant 1B.

For Austria, as already described with the wind pressure tests, wind loads between 500 N/m² and 1,000 N/m² are expected in the normal case.

The dowels that are fixed only in the material (variant 1) reached in the experiments both a payload of about 600 N/m², but it was only after 30 mm resp. 50 mm distance. This would result due to plastically deformation of the EPS board in a degree of freedom for the dowels in the insulating material around this distance and after unloading the element could move freely along this distance. Thus, the facade would wobble.

However, as per m² more than one anchor is used - conventional EIFS, there are between four and eight dowels - which requires a load per dowel about 125 N/m². The dowels reach this capacity in both trials after 3 mm to 5 mm distance. These values are within the range, where the EPS may be deformed elastically. This means that on the one hand after the relief the elements are not free to move and second, this distance can be reduce by an initial load on the dowels during the mounting process, which was not done for the elements in the trials.

The pull out tests have shown that the extraction forces already can be coped with standard dowels directly mounted in the insulation material (variant 1), which are sufficient in areas with low wind load. For increased wind loads the dowels can be either combined with the bars or the number of dowel per square meter can be increased.

7. Discussion

The results of the static tests show that a minimum total thickness of the elements should be kept above: Tmin = 150(±10) mm = th.insulation 120 mm + adhesive 10 mm + plaster ~10 mm +mineral wool 30(±10) mm. This minimal overall thickness of the elements of 150 mm is also in terms of construction physics as well as from an economic perspective a sensible lower limit for conventional ETIC systems.

The static laboratory analyzes show that a maximum span of the elements of H max = 3,000 mm can be achieved. In further development this is the margin in order to produce storey high elements.

From the static tests with the production of the prototype and from the ongoing production of EIFS

elements for the first pilot project, the following potential for the optimization of construction, mounting and manufacturing process can be identified: The pull-out tests have shown that even with simple alternatives to the EIFS wall plugs better results can be achieved, especially when they are brought in bond with the adhesive layer. This approach promises to be purposeful for optimizing the development of the fastening system without dowels in combination with joints that operate with the two-stage sealing system and joint profiles. This brings advantages in terms of the stress of the sealing material and a greater security against the ingress of rain and it even allows drying out of the elements due to the intrusion of rain under absolute extreme weather conditions. This approach also simplifies the manufacturing process by eliminating a part of the substructure with plugs, screws and rails, while allowing the joint profiles to hold the cuboid of insulating material together during the curing of the adhesive.

8. Conclusion

The investigations carried out on EIFS elements have shown that insulating elements from components of the ETICS can be produced that have static properties that ensure the maintenance of functionality and usability even under extreme conditions. Thus EIFS elements can be prefabricated, which are suitable to be mounted as the exterior wall insulation for use in thermal renovation and new construction. Due to their possibility of disassembly they also meet the basic requirement for construction works No. 5, 6, and 7 of the Regulation (EU) No 305/2011 which now entered into force.

With this evidence, the foundation for the development of individualized industrial series production of EIFS cladding elements has been established. From use of these computer-based technologies can be expected, that the economic and ecological optimization of all areas in the entire production process of external wall insulation for buildings will finally begin.

Acknowledgment:
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9. References

[1] Regulation (EU) No 305/2011 of the European Parliament and of the Council of, *annex 1, basic requirement for construction works, 7 Sustainable use of natural resources*, 9 March 2011
[2] SIEDER, M.; REYER, E. *Zum Trag- und Verformungsverhalten großformatiger Fassaden-Dämmelemente unter statischer Mitwirkung der außenseitigen Putzdeckschicht* „Die Bauphysik“ Heft 1/2004, S. 14-24, Verlag Ernst & Sohn, Berlin
[3] HASELSTEINER, E. *plusFASSADEN Internationaler Know-how- und Wissenstransfer über „intelligente Fassadensysteme“ für österreichische AkteurInnen und KompetenzträgerInnen*; Berichte aus Energie- und Umweltforschung 50/2011, Ein Projektbericht im Rahmen des Programms Haus der Zukunft; Mai 2011 Hg. BMVIT, Wien
[4] Norm *DIN 1055-4:2005-03: Action on structures - Part 4: Wind loads* Beuth Verlag
[5] HANSWILLE, G.; STRANGHÖNER, N.; *Leitfaden zum DIN-Fachbericht 104 Verbundbrücken*, Ernst & Sohn, 2004 (p. 104 ff.)
[6] FÖLL H., *Einführung in die Materialwissenschaft I*, Universität Kiel, Skriptum (Kapitel 7.1.4)

Mesuring the U_g-value of window glazing



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Short Summary

A mobile sensor for measuring the U_g-value of window glazing was developed and tested. The sensor consists of two half-shells that are put onto the two sides of the glazing to be measured. One side of the glazing then could be heated up if necessary and the temperature signals on the two sides are measured. An analysis software transfers the transient temperature signals into the U_g-value of the glazing. The sensor allows short measurement times of about 10 minutes for double glazing and 20 minutes for triple glazing as well as a high accuracy of about ± 10% or ± 0.1 W/(m^2K), whichever is higher. The sensor covers the whole range of U_g-values between 0.5 W/(m^2K) and 4 W/(m^2K), which is typical for glazing found in the building stock. The sensor allows measurements on façade glazing as well as on inclined glazing, e.g. roof windows. Due to the option to actively heat up one side of the glazing, measurements can be made even if there is no temperature difference through the glazing. This is a big advantage compared to other measurement devices of this type, which can only be used in winter or when the environmental conditions are favourable.
A first prototype of the sensor was produced and successfully tested and validated in the laboratory as well as in field tests. A commercialization of the sensor is planned.

Keywords: U_g-value; measurement device; window glazing; energy-efficient buildings.

1. Introduction

Windows are an energy sensitive part of the building façade. However, after a window is incorporated into the façade, it is very difficult to determine the thermal insulation value of the glazing, especially if no product information about the glazing is available. There are some existing methods to measure the U_g-value of a glazing. These are devices based on temperature measurements like simple tools (e.g. [1]) that give more a rule of thumb than an exact value, or more sophisticated devices, like e.g. the U_g-meter of the company Helantec [2]. All these devices can only be used in winter or when a significant temperature difference between the inside and outside air exists. Precise measurements in the laboratory also can be used, but here the glazing has to be dismantled and transported to the measuring facility. A measurement device for the U_g-value that gives fast and accurate results independent of the temperature conditions and that can be used on-site is not state-of-the-art.

2. Sensor description

2.1 Measuring principle

Almost all commercial devices that measure the thermal insulation value of a glazing rely on stationary conditions, that is a constant temperature difference between the glazing surfaces. The U_g-value then is calculated from the measured temperatures of the glazing surfaces and the ambient (e.g. [1] or [2]) or from the temperature difference and the heat flux (e.g. guarded hot plate). These measurement principles all have some advantages and disadvantages:

- Measuring the temperature difference and the heat flux (typically in the laboratory) is very accurate, but the glazing has to be dismantled and transported to the measuring facility (no on-site measurements are possible).

- Measuring the temperatures on the glazing surface and the environment on-site can be a very fast method, but the accuracy is not so good. Even if high-quality sensors are used (e.g. [2]), there is no control of the outer and inner heat transfer coefficients during the measurement. Additionally, there has to be a significant temperature difference between the glazing surfaces which means, such measurements can only be performed during winter or similar conditions. And last not least, the glazing has to be in stationary condition which is very difficult to verify.

These considerations led us to a measuring principle that had to include the following points:

- The analysis must be transient to achieve short measuring times (independence of stationary conditions).
- The sensor must include components for active heating and it has to control the outer and inner heat transfer coefficients (independence of environmental conditions).
- The components must be of superior quality to achieve good accuracy.

This resulted in the measuring principle depicted in Figure 1.

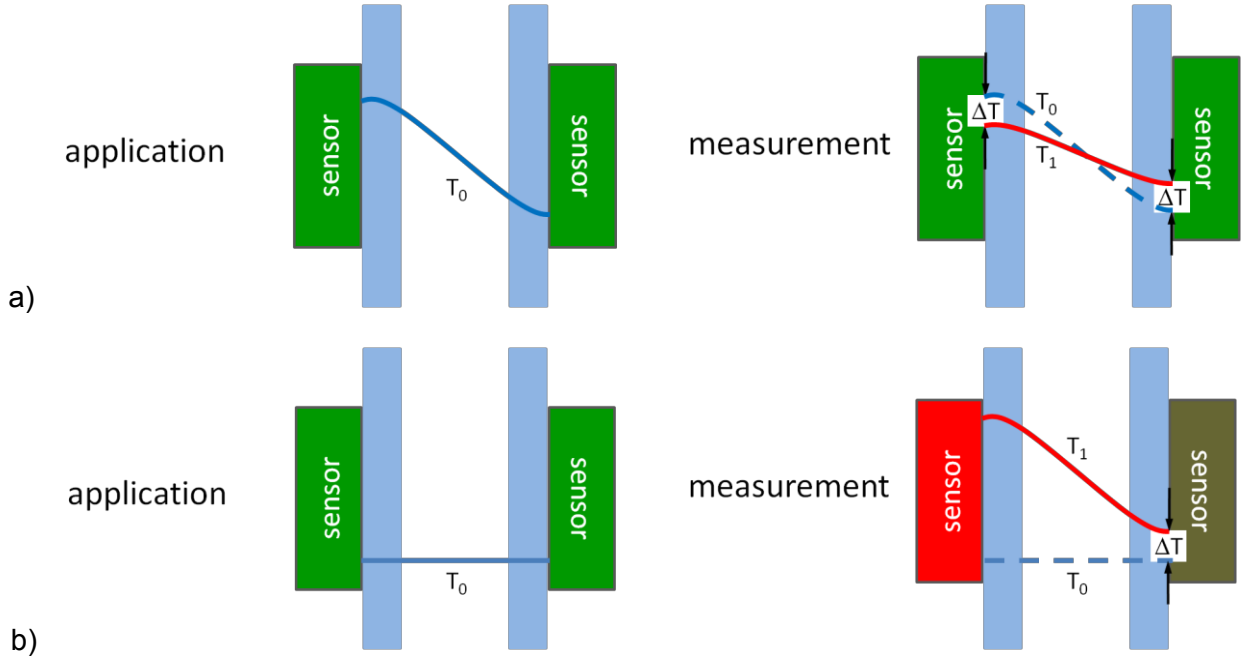


Figure 1: Measuring principle of the U_g-value sensor: If a temperature gradient exists (a) the passive temperature change is measured (no active heating); if no temperature gradient exists (b) one side will be heated up and the temperature rise on the other side is measured.

2.2 Sensor setup

The measuring principle was realized in a device consisting of two identical half-shells as depicted in Figure 2. A heating foil covers and protects the sensors for temperature and heat flux. Behind is the thermal insulation to eliminate environmental influences, which effectively sets the heat transfer coefficients to the ambient air to 0 W/(m^{2}K). A separator provides mechanical stability and allows the mounting of the backside equipment: the pump for the suction cups (not shown in Figure 2), the rechargeable battery, the transducer board for the measuring signals, and the WLAN transmitter. The data are received by the analysis software on a PC, where the measurements are controlled and the U_g-value is calculated.

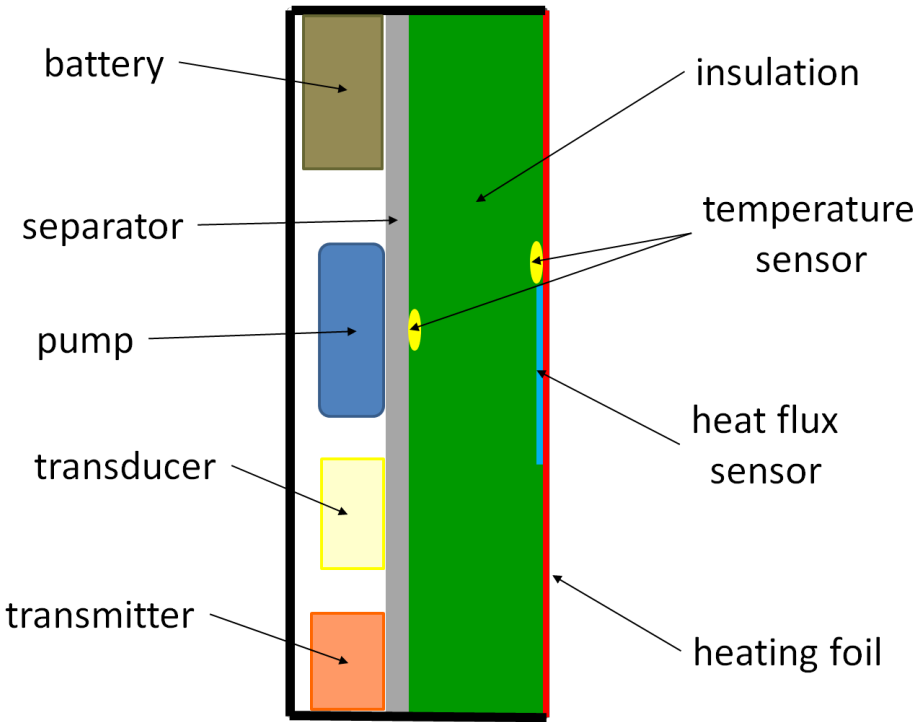


Figure 2: Cross-section of a half-shell of the U_g-value sensor (the glazing will be on the right). Both half-shells are identical.

Not shown in Figure 2 are the suction cups - placed in the four corners of the heating layer - that allow a quick and easy mounting of the half-shells.

2.3 Sensor control

The measurements can be controlled by the analysis and measurement software. At first, the thickness of the panes and the gap has to be determined with an accuracy of ± 0.1 mm. This can be done e.g. with the GlassBuddy® [3]. Afterwards, the sensor half-shells are put onto the glazing and the measurement is started. Dependent upon the glass surface temperatures, the passive mode (a) or the active mode (b) will be used. After an adequate measurement time (typically 10 minutes with double glazing and 20 minutes with triple glazing) the measurement is stopped and the analysis can be started. The software calculates the heat transmission coefficient of the glazing and gives a U_g-value of the glazing that is directly comparable to the DIN-value by adjusting the results to standardized conditions. This means, that a roof glazing with an U_g-value of 1.1 W/(m^{2}K) that has an effective U_g-value of 1.3 W/(m^{2}K) due to the inclination and the temperature conditions, will be measured as 1.1 W/(m^{2}K).

2.4 Sensor prototype

After successful laboratory tests with self-made sensors, a first prototype was built by the company Netzsch (see Figure 3). The prototype contains all the components that most probably will be used later on in the commercial product. With this prototype, a sensor that was very close to the intended commercial product could be tested.



Figure 3: First prototype of the U_g-value sensor.

3. Results

3.1 Validation measurements

First tests were carried out in the laboratory under defined conditions. The samples were double and triple glazing with variations in glass thickness, spacer distance, gas filling, and low-e-coating, but all had known U_g-values. They were measured with the prototype at room temperature and had no temperature difference, so the active mode (b) was used. Some of the samples were measured in an inclined position like in roof windows. A second set of tests followed with samples under temperature difference. These were varying kinds of double glazing that were installed in our institute building as windows and doors. Here, in addition to the active mode (b) the passive mode (a) was tested. Typical measurement times were 10 minutes for double and 20 minutes for triple glazing. The results of the measurements are depicted in Figure 4.

The measured data of the U_g-value correspond very well with the standardized values. The error bars in Figure 4 represent the measuring range in case of repetition measurements. As can be seen, almost all measurements lie within the project goal for the range of accuracy which is given by the green area (± 10% or ± 0.1 W/(m^{2}K), whichever is higher). The error bars show that the reproducibility also is very good.

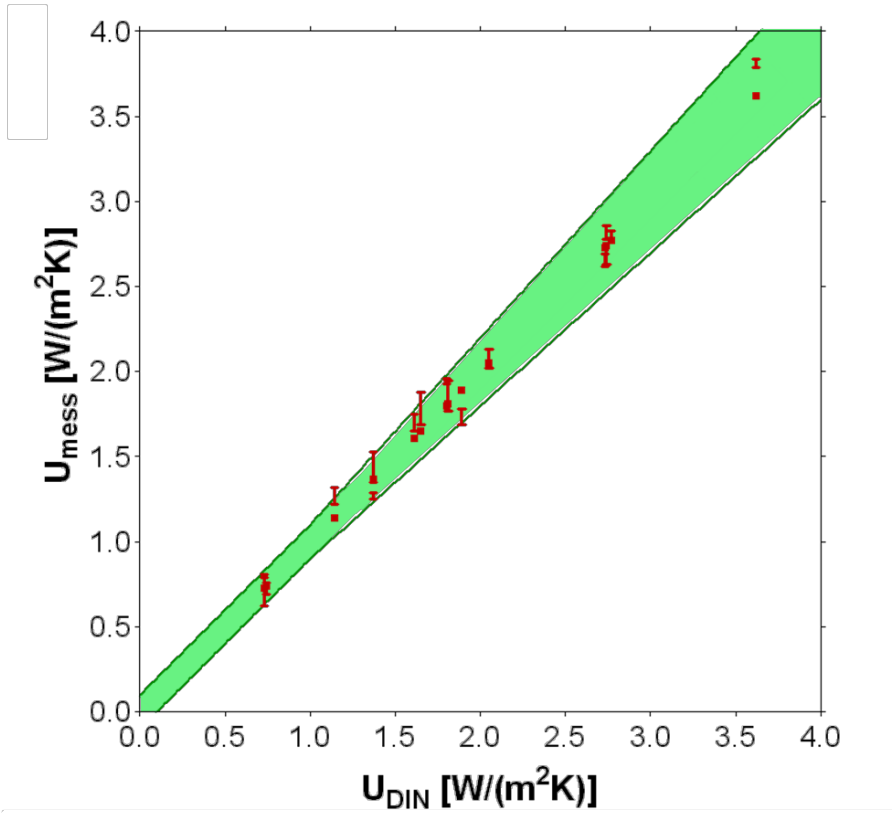


Figure 4: Comparison of U_g-values measured with the prototype compared to standardized values. The error bars represent the range of the measured values and the green area is the project goal for the range of accuracy.

3.2 Field test

After successful validation of the sensor with known samples, a field test with unknown glazing was performed. Here, only the assembly of the measured glazing was known, but not the actual U_g-value. In some cases, the U_g-value at the time of production given by the producer was available. Table 1 gives an overview of the measured glazing with their U_g-values calculated according to standards.

Table 1: assembly and properties of the glazing investigated during the field test.

no.	assembly	year of manufacture	inclination	$U_{g,DIN}$ [W/(m²K)]
1	6/10/4 (air)	1982	|	3,0
2	6/10/4 (air)	1982	|	3,0
3	4/14/*4 (argon, low-e)	2010	|	1,1
4	4/14/*4 (argon, low-e)	2010	|	1,1
5	*6*/14/6 (argon, low-e)	2010	|	1,2
6	6LSG/11/*6 (krypton, low-e)	2005	/	1,1
7	6LSG/11/*6 (krypton, low-e)	2005	/	1,1
8	4*/8/4/8/*4 (argon, low-e)	2011	/	0,8
9	4*/12/4/12/*4 (argon, low-e)	2011	|	0,7
10	4*/12/4/12/*4 (argon, low-e)	2011	|	0,7

The field test should give first feedback about the handling and convenience of the sensor as well as about its accuracy under “real conditions”. Therefore, all the measurements were performed in “real” buildings like the offices of the Project Management Jülich – the control center for this project on behalf of the German Federal Ministry – and some private apartments of our employees or their willing neighbours. The field test took place in late winter and early spring 2013 with corresponding weather conditions like moderate to cold outer air temperatures and sometimes direct solar radiation on the glazing to be measured (Figure 5). Both measuring principles, passive mode (a) and active mode (b) were used. The results are depicted in Figure 6.



Figure 5: Field test of the prototype with provisional anti-fall guard on façade glazing (left) and on roof glazing (right).

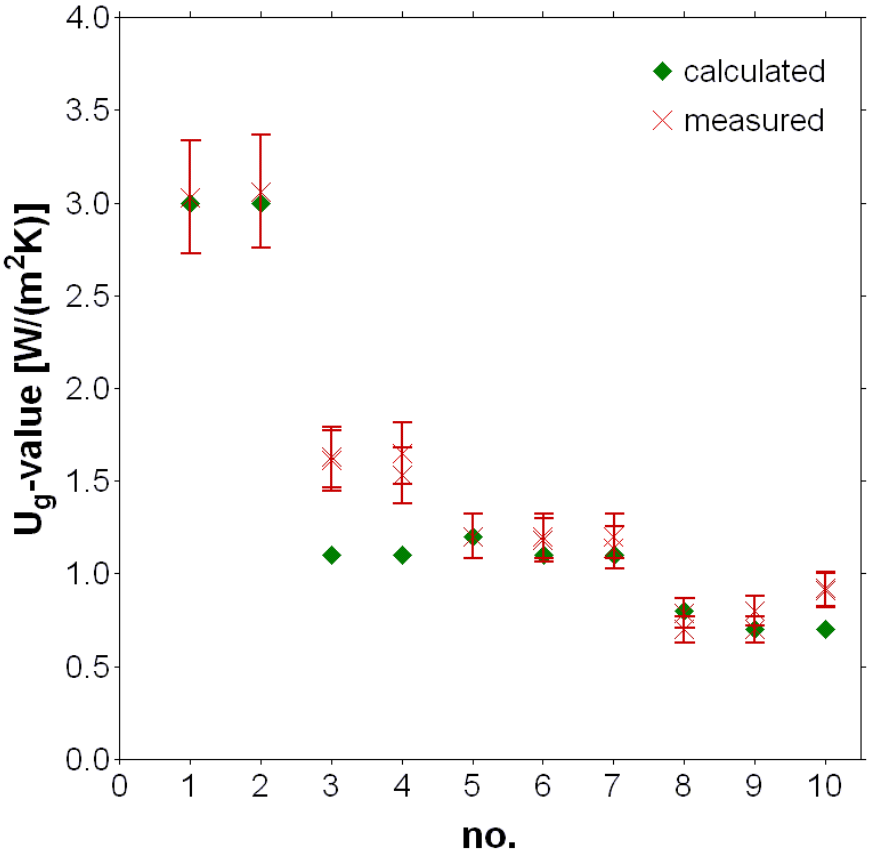


Figure 6: U_g-values of the field test glazing measured with the prototype and calculated according to standards. The error bars represent the accuracy of the prototype (± 10% or ± 0.1 W/(m^{2}K), whichever is higher) according to the validation measurements.

The results in Figure 6 show a very good agreement for the old glazing no. 1 and 2 (no low-e-coating and air filling) as well as for many of the newer glazing (with low-e-coating and argon or krypton filling). However, there are significant differences for glazing no. 3, 4, and 10. It must be noted, that all the measured values for glazing no. 3, 4, and 10 resulted in higher U_g-values than the calculated data, which is more plausible than lower values would be. In addition, the repetition measurements confirmed these higher U_g-values. Therefore, the measured values seem more reliable to us than the calculated values, even if this leads to the conclusion that the thermal performance of glazing no. 3, 4, and 10 deviates from the calculated value. There's a good chance, that the actual U_g-values of glazing no. 3 and 4 will be surveyed in the near future. If this happens, we will have the opportunity to compare our measurement results with reliable data.

4. Conclusions and Outlook

A new mobile sensor for measuring the U_g-value of glazing on-site was developed and a first prototype of the sensor was tested. The prototype allows short measuring times of about 10 minutes for double and 20 minutes for triple glazing. During validation measurements, we found an accuracy of about ± 10% or ± 0.1 W/(m^{2}K), whichever is higher. The sensor covers the whole range of U_g-values between 0.5 W/(m^{2}K) and 4 W/(m^{2}K), which is typical for glazing found in the building stock, and it is suitable for façade glazing as well as inclined glazing like in roof windows.

The sensor is an efficient tool to determine the thermal performance of unknown glazing on-site, e.g. when evaluating the energy savings potential of window refurbishment. It can also be used to check the current state of glazing, e.g. when there are doubts about the insulation value, and it gives a reliable indication if further measures should be initiated.

One open point is the influence of the weather conditions on the accuracy of the measurements. Even if the prototype worked very well in direct solar radiation during the field test, conditions that favour an inhomogeneous temperature distribution across the glazing like strong direct solar radiation especially in combination with partly shading of the glazing could be problematic. This will be investigated in further tests.

If the tests are successful, the sensor will be commercialized by the company Netzsch under the label $U_g$lass. The product should be available end of this year.

5. Acknowledgements

This research was carried out as part of the project "Development of a new evaluation tool to determine the energy savings potential of window refurbishment including effects of glazing, frame and connection" and was funded by the German Federal Ministry of Economics and Technology by resolution of the German Federal Parliament.

[1] Fensterglas-Test, simple tool to check the quality of your glazing, URL on 04/29/2013 www.fensterglas-test.de

[2] U_g-meter for measuring the heat transmission coefficient of glazing, company Helantec, URL on 04/29/2013 http://www.helantec.de/index.php/en/products/special-products/ug-meter

[3] GlassBuddy®, multi-functional tool for the analysis of flat glass, URL on 04/30/2013 http://www.bohle-group.com/shop/bohle_glassbuddy_plus_BEN:::998:: ::7679.html

[4] *GLASER S. (Red.) "Entwicklung eines neuartigen Bewertungstools zur Bestimmung des Energieeinsparpotenzials von Fenstern bei Sanierungsmaßnahmen unter Berücksichtigung von Verglasung, Rahmen und Anschlüssen"*. Final report to BMWi project (FkZ 0327654K-Q), downloadable at www.fenstercheck.info

Identification of building materials influence on robustness and uncertainty of single houses LCA.



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Summary

The assessment of environmental performances of buildings is now commonly based on a life cycle approach. The current studies highlight the problem related to the robustness and reliability of LCA. Calculation of building LCA conveys uncertainties due to: calculation model, data used into calculation and LCA user's level of practice. This study only concerns by the uncertainties related to the data used for calculation. The aim of this study is to identify the building materials and elements which have the highest influences on the environmental performance of single houses and those having the highest contribution to the uncertainties of the environmental performances of houses. A statistical method is used, it consists in two analyses: a sensitivity analysis and an uncertainty analysis. This methodology is applied to 16 single houses with different structure typologies and different location in France. Four different groups of building materials and elements are identified: materials with small sensitivity and small uncertainty; materials with small sensitivity but large uncertainty; materials with large sensitivity but small uncertainty and materials with large sensitivity and large uncertainty. This study can be useful for the stakeholders, on showing the key parameters on which they must pay attention during the designing phase of the in the project.

Keywords: Buildings life cycle assessment, sensitivity and uncertainty analyses

1. Introduction

Environmental harmful activities differ from one sector to another, but it is well known that one of the biggest contribution related to GHG emissions, ozone depletion, energy demand, destruction of natural habitats, etc., are due to the building sector [1]. Urgent changes are then required relating the energy saving, production and application of materials, use of renewable resources and to reuse, recycling of building materials and minimisation of GHG emissions [2]. However to be able to focus on the pertinent and most sensitive aspects of the building sector, it is fundamental to accurately quantify which part of the life cycle of which element has the main contribution to the environmental impacts. To do so, and since more than 30 years, scientific community have developed and validate life cycle assessment (LCA) methodology [3]. Considering ISO 14040, LCA methodology consists in four steps: goal and scope definition, creating the life-cycle inventory, assessing the environmental loads and interpretation of results [4]. The reliability of LCA in building sector as in the other industrial sectors is affected by the uncertainties and variability related to the data used for calculation, the methodology used and the user's knowledge. This study focuses only in the uncertainties and variability of the database used for calculation. The reliability and the robustness of results in building sector are more complex than the other industrial sectors, not only due to the complexity of buildings but also due to their very long service life which makes this sector unique in comparison to other complex products. This induces large difficulties on how to assess the whole life-cycle of building due to the facts that the energy during the use phase as well as its nature will drastically change during the 50 years of its use. Furthermore, the service life of building materials and elements can be lower than the building itself due to factors such as failure, dissatisfaction or change in consumer needs. Finally, a building project is a multi-stakeholders project which induces modifications all along the construction phase and uncertainties on the exact amount of materials used. Uncertainties in the environmental product declaration (EPD) are also controlled by the same type of uncertainties than for other industrial sectors: environmental database quality, technological variation between materials' production plant, distance of transportation, different methods used for the demolition of materials etc., [5]. Due to these uncertainties and variability of database the results of LCA in building sector are not robust and reliable.

Two main problems require urgent solutions: the minimisation of the environmental impacts of building sector and the minimisation of the uncertainties of the database used for the calculation of building performances. To do so, we need first to quantify the uncertainties and variability of data used for calculation and then identifying the biggest contributors in LCA results. The environmental performances of buildings are calculated by the decomposition of the project in building materials and elements. The elements such are the windows, solar water heater etc., were preferred to be treated as building element and not decomposed in materials as their lifetime is defined at that scale. This choice can also be justified by SETAC who recommend paying attention to reference flows and not necessarily distinguish every materials [6]. The key purpose of our study is the identification of key data and assumptions that have the highest influence on the result. The methodology used is based on a statistical method and includes both sensitivity and uncertainty analysis. Actually, a parameter which has a small uncertainty but large uncertainty may be just important as a parameter with larger sensitivity but smaller uncertainty.

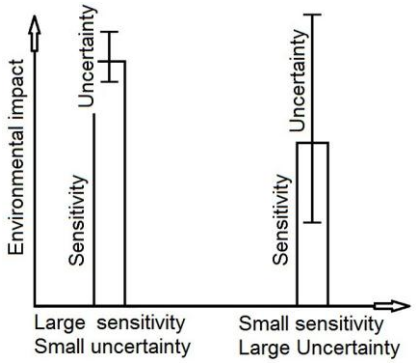


Fig1: The difference between an input with large sensitivity but small uncertainty and an input with small sensitivity but large uncertainty

Based on the relative contribution of the environmental impacts of materials to the environmental impacts of buildings (sensitivity analysis) and the relative contributions of the uncertainties of environmental impacts of materials to the uncertainties of the environmental impacts of buildings (uncertainty analysis) we have identified four different groups:

- Group 1: building materials and elements that have a small contribution to the environmental performances of buildings (small sensitivity) and a small contribution to the uncertainties of these performances (small uncertainty);
- Group 2: building materials and elements that have a small contribution to the environmental performances of buildings (small sensitivity) but a great contribution to the uncertainties of these performances (large uncertainty);
- Group 3: building materials and elements that have a great contribution to the environmental performances of buildings (large sensitivity) but a small contribution to the uncertainties of these performances (small uncertainty);
- Group 4: building materials and elements that have a great contribution to the environmental performances of buildings (large sensitivity) and a great contribution to the uncertainties of these performances (large uncertainty).

In fig. 2 we have summarize the four different groups of building materials and elements.

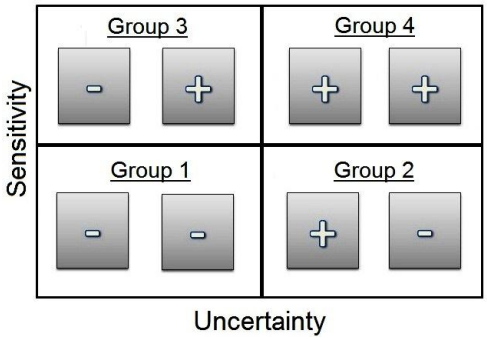


Fig 2: The four groups identified in function of sensitivity and uncertainty ("+" indicate 'large', and "–" indicate "small')

The description of the methodology is presented in the next section. Once the methodology is described it is applied in 16 single houses.

2. Methodology

2.1 Contribution analysis

A possible solution is the identification of materials which have the highest influence on the environmental performances of buildings as well as the identification of materials which have the highest influence on the uncertainties of the environmental performance buildings.
To do so we have to perform the contribution analysis. This consists in a combined sensitivity and uncertainty analysis. The sensitivity analysis is used for the identification of input variables that have large contribution on the output result. The uncertainty analysis is used for the identification of the inputs variables that most influence the uncertainties of the output.

2.1.1 Sensitivity analysis

The sensitivity can be used to simplify data collection and analysis without compromising the robustness of a result or to identify crucial data that must be thoroughly investigated. A possible definition of normalized sensitivity is the ratio of the relative change in output induced by a unit relative change in input. For an output variable *z* which depends on *n* inputs variables $x_1,x_2,\ldots,x_i,\ldots,x_n$ and their dependence which is expressed by a function *f* the normalised sensitivity of an inputs x_i is calculated:

$$S\left(x_i\right)=\left(\frac{\partial f}{\partial x_i}\right)_{X^0}\times\frac{x_i^0}{z^0} \quad (1)$$

Where: $X^0=(x_1^0, x_2^0,\ldots, x_i^0,\ldots, x_n^0)$ is the nominal scenario for which the values might be the mean the median or the mode. In our case we have used the mean values. And the z^0 is the nominal output calculated by the equation:

$$z^0=f\left(X^0\right) \quad (2)$$

In the special case where the output *z* is a sum of inputs x_i the equation of normalized sensitivity will have the form:

$$S\left(x_i\right)=\frac{x_i^0}{z^0} \quad (3)$$

2.1.2 Uncertainty analysis

Parallel to the sensitivity analysis we can perform an uncertainty analysis. For a random variable $X=(x_1;x_2;\ldots x_i,\ldots x_n)$, with a relation between the real value (in this study, we used the mean value), the input value that we have measured and its uncertainty can be written as: $x_i=x_{mean}\pm\varepsilon_{x_i}$. The degree of uncertainty is expressed by its standard deviation:

$$\sigma_{x_i}=\mathrm{var}\left(x_i\right)=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i-x_{mean}\right)^2}=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\varepsilon_{x_i}\right)^2}=\sigma_{\varepsilon_{x_i}} \quad (4)$$

Standard deviation for a random variable measures the spread of the uncertainties in inputs variables [7]. Let consider an output *z* which depends on *n* inputs variables $x_1,x_2,\ldots,x_i,\ldots,x_n$ and their dependence which is expressed by a function *f*. After Hoxha *et al* [8] the relative contribution of uncertainties of each input variable to the uncertainty of output z can be expressed by the equation:

$$RC_{M2}=\frac{\Delta x_i}{\Delta z}\times 100 \quad (5)$$

where: $\Delta z=\sum_{i=1}^{n}\sigma_{x_i}\times\left|\left(\frac{\partial f}{\partial x_i}\right)_{X^0}\right|$, and $\Delta x=\sigma_{x_i}\times\left|\left(\frac{\partial f}{\partial x_i}\right)_{X^0}\right|$

2.2 Life cycle assessment of building

From the European Standard EN-15978 [9] the environmental performances of buildings are function of: energy and water used during the use phase of buildings and environmental performances of building materials and elements cotribution. In our study we will consider only the building materials and elements contributor. For a decomposition of the building in *c* building materials and elements the environmental performances of building I_f can be calculated as:

$$I_f=\sum_{i=1}^{c}I_{f,i} \quad (6)$$

The environmental performances of building materials $I_{f,i}$ are function of three key data which are: the environmental impact declaration (EPD), the number of use of material during the service life of the building and the quantity of material used during the construction. The equation proposed for the evaluation of $I_{f,i}$ is:

$$I_{f,i}=m_i\times k_{f,i}\times n_i \quad (7)$$

where: m_i is the mass of material *i* used during the service life of building;
$k_{f,i}$ is the environmental impact for the impact category *f* of life cycle of one unit mass of the building material *I*;
n_i is the number of time that the material I has to be used during the service life of the building.
From Aktas and Bilec [10], n_i is calculated by equation:

$$n_i = \frac{LB}{LM_i} \qquad \forall n_i \in R \tag{8}$$

LB is the service life of the building and LM_i is the service life of material.

2.3 Contribution analysis applied to building LCA

When contribution analysis is applied to the previous equation describing the environmental performances of buildings (equation 6), the partial derivative (simple sensitivity coefficients) of the different building material or element is equal to 1:

$$\frac{\partial I_f}{\partial I_{f,i}} = 1 \quad \forall i \in [1, c] \tag{9}$$

The equations of normalized sensitivity of materials have the form of:

$$S\left(I_{f,1}\right) = \frac{I^0_{f,1}}{I^0_f};\ \cdots\ S\left(I_{f,i}\right) = \frac{I^0_{f,i}}{I^0_f};\ \cdots\ S\left(I_{f,c}\right) = \frac{I^0_{f,c}}{I^0_f} \tag{10}$$

where:

$$I^0_{f,i} = m^0_i \times k^0_{f,i} \times n^0_i \tag{11}$$

is the nominal value of environmental performance of material *i* calculated by the nominal value of mass, impact coefficient and number of use of material during the service life of building. The nominal value are here considered as the mean values.

$$I^0_f = \sum\nolimits_{i=1}^{c} I^0_{f,i} \tag{12}$$

is the sum of nominal value of environmental performances of materials.

In our case the physical concept of the normalized sensitivity coefficients are that they measure the relative contribution of material impact to the building impact.

Also we have to perform the uncertainty analysis for a complete contribution analysis. The relative contributor coefficients after the equation (5) have the form:

$$RC_{M2}\left(I_{f,1}\right) = \frac{\sigma_{I_{f,1}}}{\Delta I_f};\ \cdots\ RC_{M2}\left(I_{f,i}\right) = \frac{\sigma_{I_{f,i}}}{\Delta I_f};\ \cdots\ RC_{M2}\left(I_{f,n}\right) = \frac{\sigma_{I_{f,n}}}{\Delta I_f} \tag{13}$$

Where:

$$\Delta I_f = \sum\nolimits_{i=1}^{c} \sigma_{I_{f,i}} \tag{14}$$

In the next section the methodology is applied in 16 houses.

3. Study

3.1 Presentation of houses case studies

In this study are modelled a sample of 16 French single houses. The surface are of these houses varies between 91 m^2 to 298 m^2, and they present more than 2400 m^2. They have different types of structure (reinforcing concrete structure, wood structure); different types of wall (block concrete, clay brick, cellular concrete block, wood, etc.,); different types of thermo insulation (rock wool, glass wool, wood wool, etc.,); different types of tiles (clay, concrete, slate); etc.

3.2 LCA data and uncertainties sources

The environmental impact of each building material is based on values from the French environmental products declaration (EPD) available in INIES database [11]. The variability due to these inputs variables comes from the fact that for the same material or elements there are different EPDs supplied by different producers. In the case where different EPDs were available, the mean

and standard deviation is calculated, and in the case where only one EPD was available, it isn't consider any types of variability.
The mean for the mass of material is considered that defined in the project and the standard deviation is calculated using a ratio for the coefficient of variation equal to 12% [12] that corresponds approximately ±30% of uncertainty about the mean value. The mean and standard deviation for the number of use of material during the service life of building are calculated using different references. In the table 1 we have presented the data used.

Table 1: Expected lifetime of materials. Mean value and standard deviation are calculated from a number of reference values for each material. Minimum and maximum values are also shown.

		Service life				Number of data	
Materials	Elements	Min	Mean	Max	SD		References
Non-structural clay	Tiles	15	49.44	100	19.09	N=18	[11,18,19,21,25,26,28,29,32]
Non-structural concrete	Tiles	20	48.9	120	24.28	N=28	[11,13,18,19,27,31]
	Mortar for plastering wall	15	36.52	100	15.75	N=36	[11,13,21,25,27]
	Windows sill						Similar to window
	Mortar for floor laying						Similar to Porcelain stoneware
Non-structural steel	Garage door	10	18.57	35	7.48	N=19	[13,16,20,25]
	Uprights and rails						Similar to plaster
	Thermostat	10	15.22	22	4.66	N=9	[18,27,28,31]
	Gas boiler	8	12.87	20	5.72	N=4	[18,28,31]
	Radiator	20	24.64	40	6.34	N=14	[18,27,28]
	Steel door	10	33.89	60	14.42	N=19	[18,19,27,28,31]
	Valves/towel dryer	10	16.25	25	4.41	N=12	[13]
	Electric heating	10	11.67	15	2.88	N=3	[18,32]
	Thermodynamic water heater	15	20	30	7.07	N=4	[18,28,31]
Non-structural wood	External and internal doors	10	37.15	80	16.67	N=58	[11,13,14,16,18,19,21,23,26,27,28,31,32]
	Cabinet for sink						Similar to sink
	Shutter	10	28.75	60	10.97	N=36	[13,18,20,22,24,27,28,31]
	Paneling	10	33.26	100	16.54	N=46	[13,14,17,19,20,24,27,28,31,32]
	Parquet	10	46.15	100	20	N=39	[13,15,18,20,21,23,27,28,29]
Thermal insulation	Glass wool	20	38	60	15.49	N=10	[11,18,21,27,31]
	Rockwool	20	37.5	60	15.85	N=10	[11,18,27,31]
PVC	Shutter	15	25.05	40	9.33	N=18	[11,18,24,27,28,31]
	Paneling	15	27.14	50	12.19	N=7	[11,18,19,24,27,28]
	Pipes	15	25.64	60	9.34	N=22	[11,16,18,19,26,27,28,31]

	Coating	15	21.67	30	4.33	N=9	[11,18,19,27,28]
Bitumen	Waterproofing	5	27.78	60	16.9	N=50	[11,14,16,17,18, 19,21,27,28,31]
Plaster	Products for false ceil- ings/suspended ceilings/Wall cov- erings	15	33.14	70	13.17	N=68	[11,14,16,18,21, 26,27,28,31,32]
Polystyrene		5	26.56	60	16.9	N=16	[11,17,18,27,28, 31]
Polyurethane	Thermal and acoustical insula- tion	20	37.14	60	16.03	N=7	[11,18,21,24,27, 31]
Linoleum		5	22.32	50	9.88	N=32	[16,17,25,27,28, 31]
Polyethylene		15	28.12	60	15.34	N=8	[11,18,19,27,28]
Solar hot water panels	Water heater	10	23.21	60	13.53	N=14	[11,1318,19,21,2 8,29,30]
Window	PVC	20	33.06	50	10	N=18	[1,6,7,8,9,17,20]
	Bois	15	37.76	60	12.92	N=29	[11,13,14,18,19, 20,21,27,28,31]
	Aluminium	18	37.1	60	12.89	N=21	[11,16,18,19,27, 28,31,32]
Paint	Paint	5	15.64	50	8.92	N=83	[11,13,14,17,18, 20,24,26,2731,3 2]
	Varnish						Similar to Paint
Electrical installation	Outlets/light- switch/ mini- breakers/ lamps/etc.	5	19.31	60	9.4	N=204	[11,13,16,20]
Porcelain	WC	15	27.92	50	10.54	N=12	[11,13]
	Sink	15	26.43	40	8.99	N=7	[11,13]
Acrylic	Bathtub	10	27	50	11.12	N=13	[11,13,17]
Enameled sandstone	Kitchen sink						Similar to sink
	Shower plate						Similar to bath- tub
Porcelain stoneware	Paving	10	47.3	100	23.37	N=26	[11,13,15,17]
Natural stone	Tiles						[11,18,19,23,28, 31]
Zinc	Gutter system	10	18	30	5.87	N=10	[18,22,26,28,29, 31]
Aluminum	Shutter	15	30	60	11.45	N=30	[16,18,19,22,27, 28,31]
Copper	Pipes	30	40	60	17.32	N=3	[18,27]

4. Results

In the fig 3 are shown the results obtained from the sensitivity analysis and uncertainty analysis of 16 houses. Classification of materials in four groups is done with a cut off of 10%. For the global warming potential indicator are identified four groups of materials in function of their contribution to sensitivity and uncertainty of results.

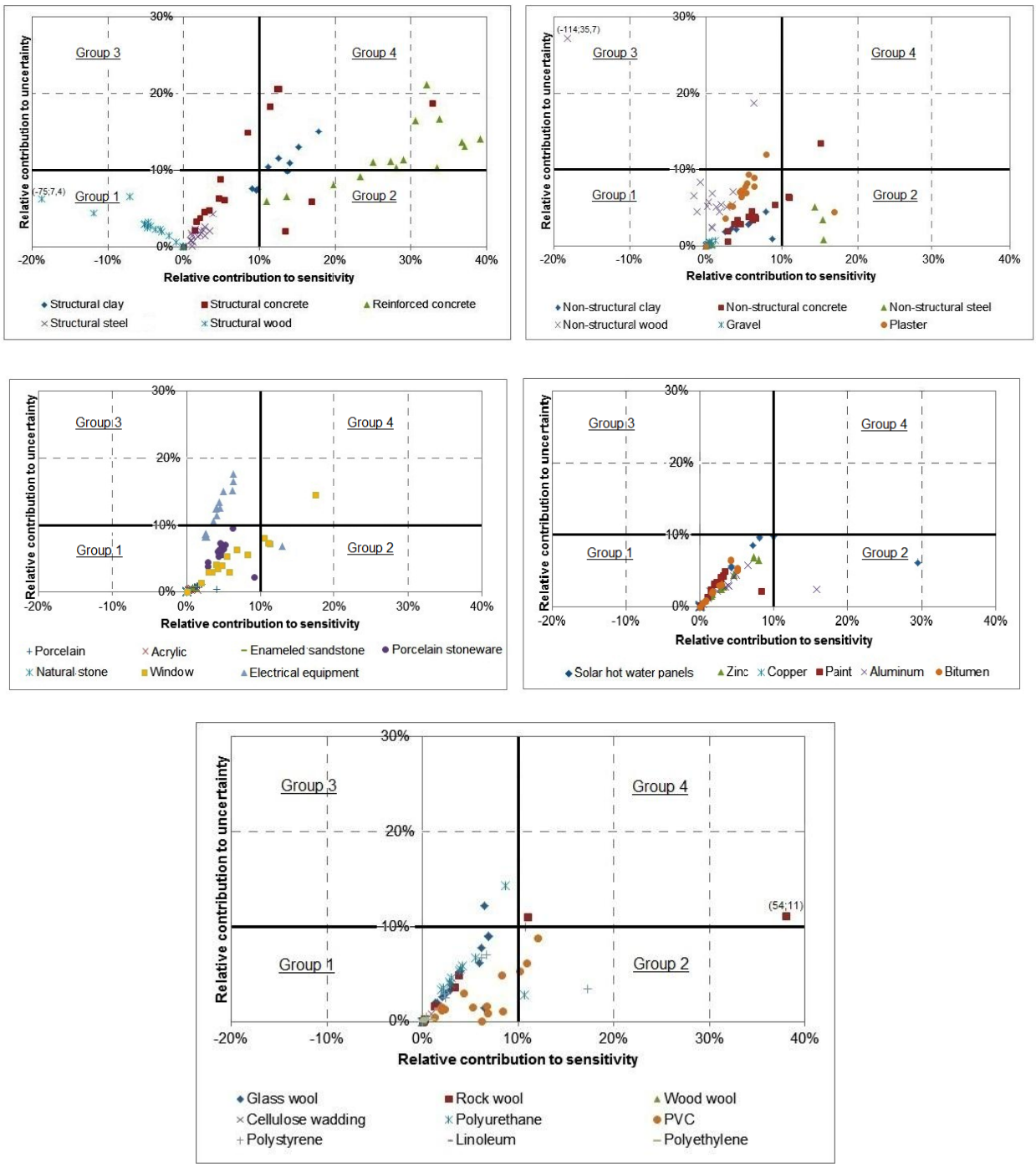


Fig 3: Results obtained of materials and elements for 16 houses

In the figure 4, we have summarize the forth groups of materials classified according the results calculated and presented in figure 3.

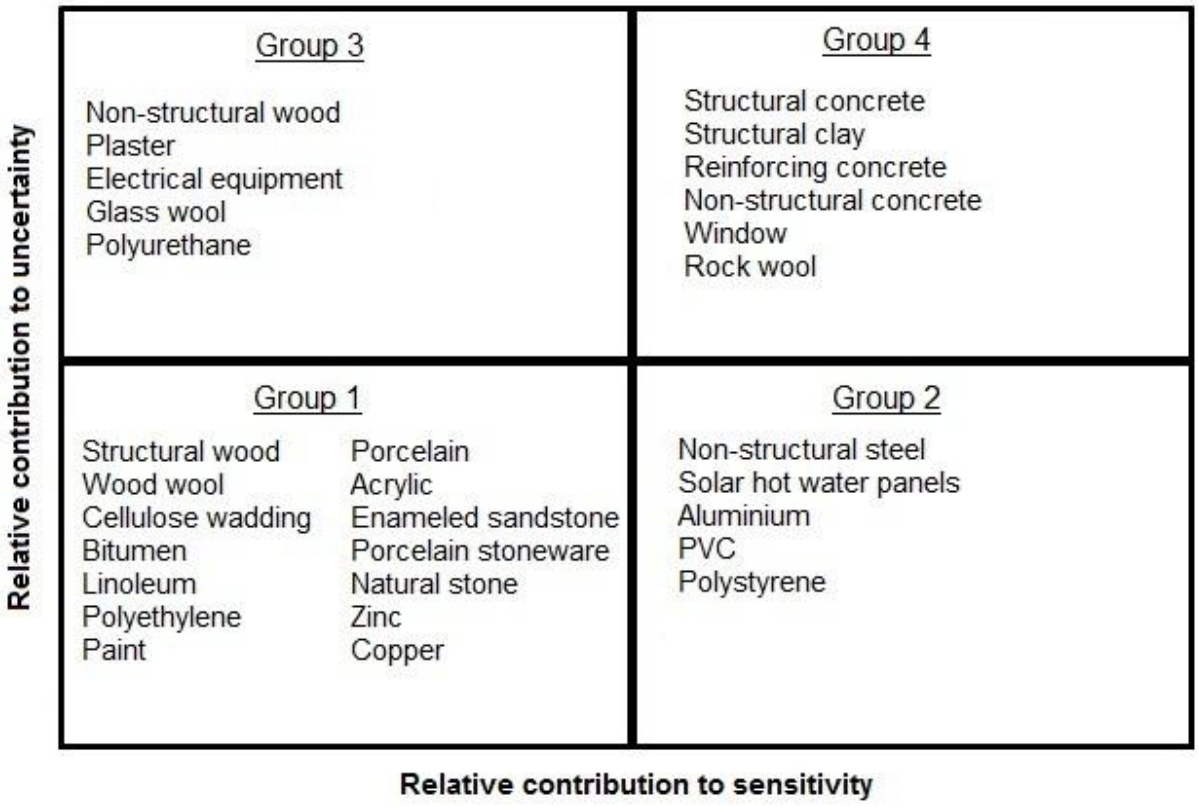


Fig 4: Building materials classified in four groups

5. Discussion

For the global warming potential indicator, the first group of materials with a small sensitivity and a small uncertainty are: non-structural steel, non-structural clay, gravel, linoleum, cellulose wadding, wood wool, polyethylene, porcelain, acrylic, enamelled sandstone, porcelain, stoneware, natural stone, paint. This is the group of materials for which the relative contribution to the impact of houses and its uncertainties can be considered as negligible. In the second group with large sensitivity and small uncertainty, the materials: non-structural steel, pvc, polystyrene, aluminium, solar hot water panels, plaster. These are the materials with a great contribution to the impact of houses, but their uncertainties can be considers as negligible. In the third group of building materials and elements with a small sensitivity but large uncertainties we identified the glass wool, non-structural wood and plaster. These materials have not the greatest contribution to the environmental performances of houses, but their uncertainties influence highly the uncertainties of the environmental performance of houses. Due to their uncertainties the environmental performances of houses aren't robust and reliable. And in the fourth group with large sensitivity and large uncertainty, we identified the materials such as: reinforcing concrete, structural clay, structural concrete, non-structural concrete and rock wool. This is the group where the materials have a great contribution to the environmental performance of houses as well as to the uncertainties on the environmental performance of houses. A special attention is recommended for the materials of the fourth group. We have accepted a largest possible cut off value of 10%. This can be a discussion point, due to the fact that the classification of materials will change for another value. Also this can be improved, but whatever the cut off value the result presented for the 16 houses will not change and the materials of fourth group will be classified always as the most critical data.

6. Conclusion and Perspectives

This paper is focused on the calculation of contribution of the building materials to the single

houses LCA, and the contribution of their uncertainties to the uncertainty of the single houses LCA. To do so, the methodology used is based on sensitivity and uncertainty analyses which identify the parameters having small contribution to the output and small contribution to the uncertainty of output, the parameters having small contribution to the output and large contribution to the uncertainty of output, the parameters having large contribution to the output and small contribution to the uncertainty of the output and the parameters having large contribution to the output and large contribution to the uncertainty. Previous studies have been working with Monte Carlo techniques that are relatively computationally heavy to conduct and time consuming. Our methodology is much simpler and when applied to 16 single houses, still allows the distinction of four groups of building. This study can be useful for stakeholders, on presenting the materials which affect the robustness of single houses LCA such as the plaster and material that have most negative impact to the environment such as the rock wool. In this study we have identified the four groups of materials, but further work is needed, in particular considering the cut off value.
A possible perspective of this study is the minimisation of the uncertainties of the materials in the third and fourth group. Another is the research of factors that minimize the environmental performances of materials of second and fourth group.

7. References

[1] Li Zh. *"A new life cycle impact assessment approach for buildings"*. Building and Environment, DOI: http://dx.doi.org/10.1016/j.buildenv.2005.05.034; 2005, Volume 41, pp. 141-1422.

[2] United Nations Environment Programme UNEP. "Sustainable Building and Construction*"*. Division of Technology, Industry and Economics, Paris, France, 2003.

[3] Heijungs R, Guinée J, Huppes G, Lankreijer R, Udo de Haes H, Wegener SA, Ansems A, Eggels P, Duin R, Goede H. *"Environmental Life Cycle Assessment of Products"*. Guide and Backgrounds, CML, Leiden: Utrecht, Netherlands, 1992.

[4] ISO 14040 – International Standardasation Organisation. *"Environmental Management Life Cycle Assessment Princimples and Framework"*. International Standards Organisation, Brussels, 2006.

[5] Khasreen MM, Banfill PFG, Menzies GF. *"Life-Cycle Assessment and the Environmental Impact of Buildings: A review"*. Sustainability, DOI: http://www.mdpi.com/2071-1050/1/3/674; 2009, Volume 1, pp. 674-701.

[6] SETAC. *"LCA in building and construction: A state-of-the-art report of SETAC-EUROPE"*. Hétinstituut voor kwaliteit in de bouw, 1999.

[7] Morgan MG, Henrion M, Small M. *"Uncertainty. A guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis"*. Cambridge University Press, England, 1990.

[8] Hoxha E, Habert G, Chevalier J, Le Roy R. *"Improving the reliability of environmental assessments of buildings"*. CIB World building Congress Construction and Society, CIB publication 254, Brisbane, Australia, 2013.

[9] Norme EN-15978. *"Contribution des ouvrages de construction au développement durable-Evaluation de la performance environnementale des bâtiments-Méthode de calcul"*. France, 2011.

[10] Aktas CB, Bilec MM. *"Impact of service life on US residential building LCA results"*. International Journal of Life Cycle Assessment; 2012, Volume 17, pp. 337-349.

[11] INIES database, DOI: http://www.inies.fr/; 2009 (accessed: 13.03.2013).

[12] Blengini GA, Di Carlo T. *"The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings"*. Energy and Building; 2009, Volume 42, pp. 869-880.

[13] PI BAT. *"Vieillissement des éléments de construction et coût d'entretien. Données pour l'entretien et la rénovation des immeubles d'habitation"*. Office fédéral des questions conjoncturelles, DOI: https://www.google.fr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDEQFjAA&url=http%3A%2F%2Fwww.bfe.admin.ch%2Fphp%2Fpublikationen%2Fstream.php%3Fextlang%3Dfr%26name%3Dfr_843943609.PDF&ei=hVttUZabG4esPaLRgfgG&usg=AFQjCNEe4aqGIEo8ZJGDY_FBWVEwmPVZbg&sig2=cph4YPPhYK5AIU_EQXb3uA; 1995, pp. 110.

[14] Frenandez NP. *"The influence of construction materials on life-cycle energy use and carbon dioxide emissions of medium size commercial building"*. PhD thesis, School of Architechture – Victoria University of Weillington, New Zealand, DOI: http://researcharchive.vuw.ac.nz/bitstream/handle/10063/653/thesis.pdf?sequence=1; 2008,

pp. 154.
[15] Aktas CB. *"Impact of product service life on life cycle assessment results"*. PhD thesis, University of Pittsburgh, Pittsburgh, US, DOi: http://dscolarship.pitt.edu/6376/1/Aktas_CB-2011.pdf; 2011, pp. 124.
[16] SCHL-CMHC. *"La durée de vie utile des matériaux et équipements techniques des edifices résidentiels de moyenne et grande hauteur"*. Rapport de recherché, Canda, DOI : ftp://ftp.cmhc-schl.gc.ca/mah/fr/French_Version_Capital_Replacement_Planning_Manual.pdf; 2000, pp. 74.
[17] MINNESOTA BBUILDING. *"Center for Sustainable Building Research. DOI: http//www.buildingmaterials.umn.edu/materials.html; 2004, (accessed: 13.03.2013)."*
[18] Albano JR. *"Maintenance des bâtiments. En 250 fiches pratiques"*. Deuxième édition. Librairie du MONITEUR, 2005, France, pp. 492.
[19] GREENSPEC. DOI: http://greenspec.co.uk/html/durabilitycontent.html; 2013, (accessed: 13.03.2013).
[20] HOME INSPECTION. DOI: http://www.atdhomeinspection.co/average-product-life.htm; 2010, (accessed 13.03.2013).
[21] CATALOGUESCONSTRUCTION.CH. DOI: http://www.catalogueconstruction.ch/ch/fr/catalogueconstruction.asp; 2009, (accessed: 13.03.2013).
[22] OPAC 38. *"Projet global, qualité entretien. Evaluation des besoins en entretien"*. France, 1993.
[23] Kurti I. *"Ubereinstimmung der Lebensdauer des Konstruktionen und der Funktionellen Zeitgemässheit von Wohnhäusern"*. Periodica Polytechnica Architectura, 1971, Volume 15 (n°3-4), pp. 195-2019.
[24] *QUALITEL HABITAT AND ENVIRONNEMENT. "Référentiel millésime 2012 synthèses, 2012. Qualitel Habitat and environnement: Durabilité de l'enveloppe-outils"*. Qualitel, Habitat and Environnement, Cerqual, France, pp. 16.
[25] *Bahr C, Lennerts K. "Lebens-und Nutzungsdauer von Bauteilen"*. Forschungsprogramm: Zukungt Bau, des Bundesinstituts für Bau-, Stadt-und Raumforschung (BBSR), sowie des Bundesamtes für Bauwesen und Raumordnung (BBR), DOI: http://www.irbnet.de/daten/baufo/20108035025/Endbericht.pdf; 2010, pp. 129.
[26] *Kottje J, Deutsche VM. "Eco-Häuser, Attraktive Häuser mit günstigen Unterhaltsskosten"*. Deutsche Verlags – Anstalt München, 2007.
[27] *Lair J. "Evaluation de la durabilité des systèmes constructifs du bâtiment"*. PhD thesis, Université Blaise Pascal Clermont II, Clermont Ferrand, France, 2000, pp. 431.
[28] *Peret J. "IGuide de maintenance des bâtiments"*. Paris. Ed : Le Moniteurs, France, 1995, pp. 431.
[29] Bosquet S. *"Etude d'un système autonome de production d'énergie couplant un champ photovoltaïque, un électrolyseur et une plie à combustible : réalisation d'un banc d'essai et modélisation"*. PhD thesis, Ecole des Mines de Paris, Paris France, 2003, pp. 169.
[30] Jungbluth I, Bauer C, Dones R, Frischknecht R. *"Life Cycle Assessment for Emergining Technologies: Case studies for Photovoltaic and Wind power"*. International Journal of Life Cycle Assessment, DOI: http://link.springer.com/article/10.1065/lca2004.11.181#page-1; 2005, Volume 10, Issue 1, pp. 24-34.
[31] Unpublished. Data gathered by CSTB from a French Building Property Management company. Various publications from the International Conference on Durability of Building Materials and Component. Guidline for LCC prepared by the division of facilities development (DFD), France, 2013.
[32] Unpublished. Data gathered by Best-Politechnico di Milano-CSTB. 2013.

D1

Energy

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ETH Zurich, Switzerland

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The Energy Sufficiency Path: Basics for Residential Buildings

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Short Summary

Three strategies are needed for the implementation of the ambitious 2000-Watt Society sustainability programme: efficiency, consistency and sufficiency. The 'SIA Energy Efficiency Path' [1] is an instrument that demonstrates that the set goals can be achieved by efficiency and the use of renewable energy sources. Standard values are assumed for space consumption and user behaviour. Fundamental information for sufficiency in the use of energy is still not available.
Sufficiency entails that demands be moderate and restrained. Although technical measures are the most important factors in the field of efficiency and consistency, man and his attitudes and actions are the central point for sufficiency. In this study, the fundamentals for quantifying the sufficiency potential of residential activities will be developed. In this case, we assume moderate sufficiency.

The most important parameters are living space, user behaviour (warm water consumption, electrical devices) and day-to-day mobility (distance, method of transport). The potential for sufficiency is surprisingly high: compared with today's typical behaviour, moderate sufficiency attitudes could almost halve both primary energy consumption and greenhouse gas emissions.

Keywords: sufficiency, eco-sufficiency, residential buildings, rebound effect, user behaviour, living space, 2000-Watt Society, SIA Energy Efficiency Path

1. Context

In Switzerland the energy demands of new buildings by square metre have fallen sharply owing to advanced standards and regulations, and even the renewal rate of existing buildings is increasing slowly. In parallel, however, in the field of buildings, a significant part of the gains in efficiency is offset by elevated consumption. The living space per person is rising continuously, which has a negative effect on total energy consumption and the emissions of greenhouse gases. This development is driven by the still growing prosperity in Switzerland. Starting from the assumption that this positive trend will continue in the future, it is at least questionable whether the turnaround in energy policy with new technologies and efficiency measures alone is possible.
The issue is that the goals are ambitious: The 2050 energy strategy of the federal state simultaneously pursues the phasing out of nuclear power and the reduction of greenhouse emissions. The city of Zurich decided in a referendum to implement the 2000-Watt Society, which entails ambitious reductions in non-renewable primary energy consumption and greenhouse gases.

Although the parameters and the influence of different measures are well known in the area of energy efficiency, the basics are still missing in the area of sufficiency.

2. Scope: The Potential of Sufficiency

The 'SIA Energy Efficiency Path' [1] is an instrument for implementing the stage targets of the ambitious sustainability programme of the 2000-Watt Society in the building sector. It focuses on the implementation of technical solutions by means of efficiency and consistency (use of renewable energies, renewable primary products and closed material cycles).
What remains hidden is user behaviour, which has a decisive influence on the achievement of the objectives.
The 'SIA Energy Efficiency Path' is based on a standardised square-metre consumption of living space per person and standardised user behaviour. Deviations from these standard assumptions have a very large impact on effective energy consumption and the personal targets of the 2000-Watt Society.

In this study, the potential for reducing primary energy and greenhouse gas emissions should be demonstrated; these can be determined by measures of sufficiency and which actors are responsible for them. New construction and refurbishment of residential buildings are considered.

3. Methods

The presented study clarifies and quantifies the potential of sufficiency in the areas of construction (embodied energy), operation and location-based day-to-day mobility.
The methodological basis is a total energy analysis, as elaborated on in the framework of the 'SIA Energy Efficiency Path', which also establishes the methodological link to the 2000-Watt Society.
The 'SIA Energy Efficiency Path' shows how the building and construction sector can reach the milestones of the 2000-Watt-Society programme by 2050. Crucial aspects form the primary energy consumption and greenhouse gas emissions that affect the climate. The difference between the energy values for 2005 (total energy according to official statistics) and the specified goal for 2050 produces a reduction factor of 0.55 for primary energy consumption and 0.34 for greenhouse gas emissions.

This study set up several case studies of different consumptions of living space per person, including variations in user behaviour during building operation and in mobility behaviour. The impact on primary energy consumption and greenhouse gas emissions was determined. Although this study’s title addresses sufficiency, the study also examines the potential of the opposite, namely wasteful behaviour.

In the area of construction, energy savings have been calculated with the methodology according to the SIA fact sheet 'Embodied Energy of Buildings' [2].
In the area of operation in particular, evaluation of the typical power consumption in different households leads to a differentiated picture of the potential, which can be assessed by user behaviour.
In the area of mobility, quantification is possible because of the methodology developed according to the SIA factsheet 'Mobility - Energy Demand depending on the Building Site' [3].

It was important to clarify which type of consumption needed to be calculated relative to the energy-related floor area and which type needed to be considered in relation to the people.

The calculations assume an efficient residential building (target values according to the 'SIA Energy Efficiency Path'), efficient equipment and efficient vehicles ('Fleet 2050' according to [3]).

4. Results

The potential for the reduction of primary energy consumption and greenhouse gas emissions by moderate sufficiency behaviour is considerable.

4.1 Living Space

The variation in living space per person—i.e., energy-related floor area per person—with a constant energy consumption per capita (a concept of the 2000-Watt Society programme) shows clearly that
less living space per person facilitates the achievement of the targets and more living space per person makes it more difficult. With a one-third reduction in the standard living space per person, primary energy and greenhouse gas emission savings of approximately 15% can be reached. This applies to new buildings and refurbishments.
As an additional option for savings in efficiency and consistency, this potential should not be underestimated.
Reducing the Swiss average energy-related floor area of 60 m2 per person can actually be managed by building owners and administrations such as those who manage non-profit residences (cooperatives, public residences) based on occupancy regulations.

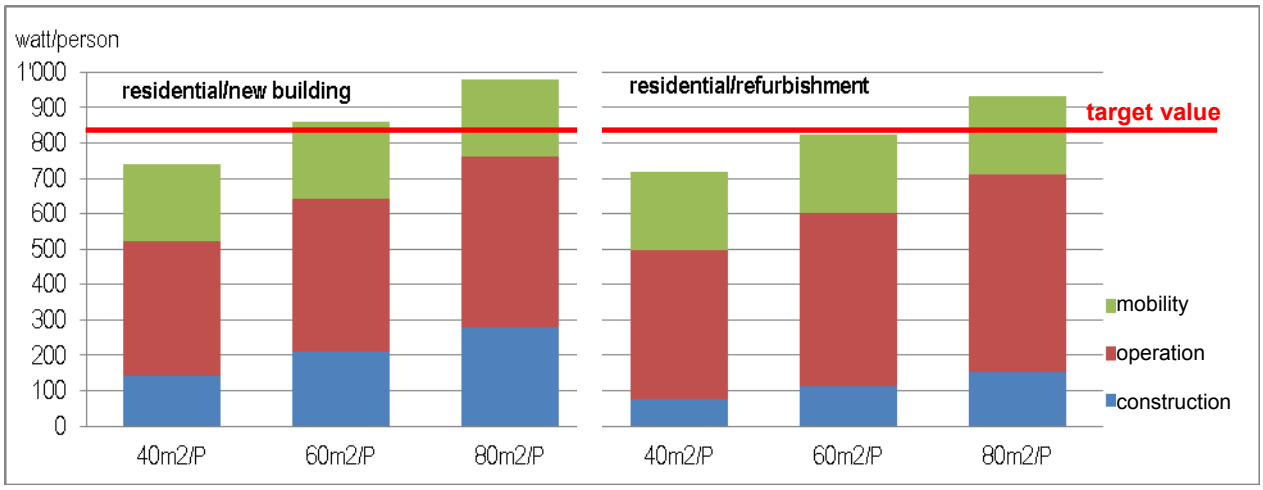


Fig. 1: Influence of variable living space per person on the average annual power consumption of primary non-renewable energy for efficient buildings (data in relation to the energy-related floor area per person), based on average user behaviour.

4.2 User behaviour in the operation of the building

Variable user behaviour during the building's operation changes both the personal and the space-related consumption. In operation, a great deal of potential can be tapped. Residents are challenged in their everyday behaviour and in the procurement of equipment and its use.
Efficiency assumes, then, that the focus of singular energy consumption shifts significantly towards the power-consuming operation of the facilities and lighting.
The greatest influence is that of users on household electricity consumption. The household electricity consumption of a typical two-person household compared with sufficient ones with either moderate or wasteful behaviour reveals an amazing range: the lavish household consumes roughly five times as much electricity as the sufficient one.
In addition, the influence of user behaviour on hot water consumption is substantial.

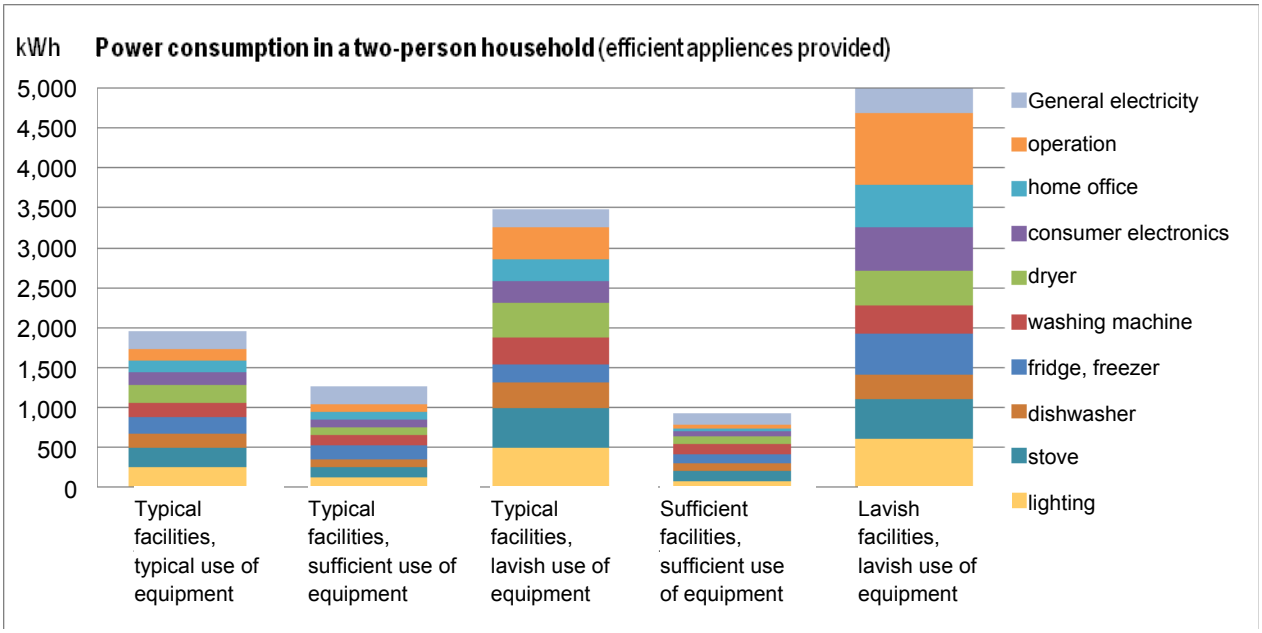


Fig. 2: Household consumption of electricity in a two-person household with 120 m2 energy-related floor area with variable user behaviour and variable facilities.

Two-person household	**typical**	**sufficient**	**lavish**
Examples Facilities			
Cooler / Freezer	Refrigerator (230 litres) with freezing compartment (25 litre)	Refrigerator (200 litres) with freezing compartment (17 litres)	Refrigerator (280 litres) with freezing compartment (24 litres), additional freezer
Home office	1 desktop PC, 1 laptop, 1 printer	1 desktop PC, 1 printer	1 desktop PC, 2 laptop, multifunctional device, laser printer
Use of equipment			
Dishwasher	150 wash cycles per year	80 wash cycles per year	250 wash cycles per year
Washing machine	220 washes per year	150 washes per year	nearly daily
Dryer	2/3 of laundry in dryer	1/3 of laundry in dryer	100% of laundry in dryer

Fig. 2a: Examples of different facilities' respective use of equipment scenarios in a typical, a sufficient and a lavish two-person household.

The potential of sufficiency, however, in almost all areas is smaller than the potential for increased consumption from lavish behaviour. This is partly related to the fact that the underlying values for standard uses are deliberately buried deep in the standards and regulations.
With a moderate attitude toward sufficiency, consumption of primary energy can be decreased in all three areas, construction, operation and mobility, by approximately 18% in new buildings and in refurbished buildings without a significant loss of comfort. The savings in greenhouse gas emis-

sions are smaller, at roughly 10% (this is owing to the relatively low greenhouse gas emissions from today's Swiss electricity mix).
Sufficient user behaviour cannot be prescribed, but incentives can be created. Building owners and governments can have only a very limited influence on user behaviour, such as limiting the initial equipment of the apartments to fewer and smaller devices. Two to four percent in primary energy savings and greenhouse gas emissions over the typical consumption of all three areas of construction, operation and mobility can be achieved through the apartment features provided by building owners and management.

4.3 User mobility behaviour

With variable user mobility behaviour, surprisingly great potential can be tapped. The acceptance of efficiency and sufficiency measures is very different in the field of mobility: what some value as a comfort benefit, such as living in a residential building with reduced parking spaces (with the possibility of travel by foot, by bicycle or by public transport for everyday mobility), for others constitutes an unacceptable sacrifice.
Sufficiency in everyday mobility, particularly in urban areas, is already happening today and is finding a growing number of voluntary followers. The reduced availability of cars, reduced distances in everyday leisure traffic and consistently use of public transport to and from work has halved primary energy consumption and greenhouse gas emissions compared with typical mobility behaviours.

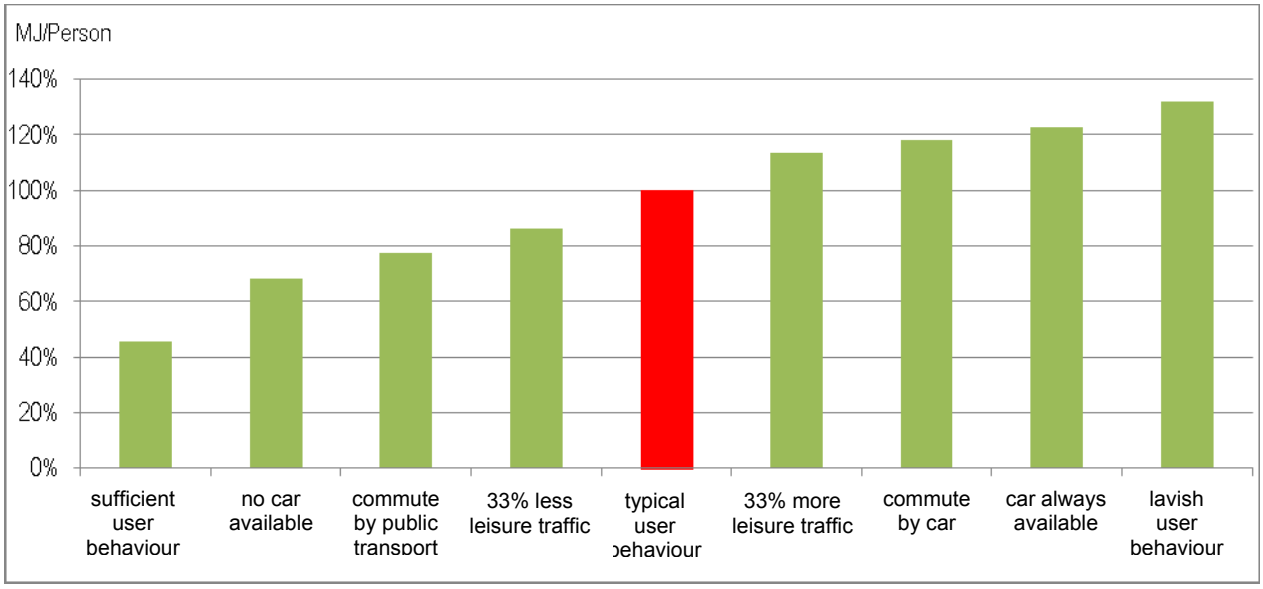


Fig. 3: Influence of sufficient and wasteful user behaviour on the primary consumption of non-renewable energy in everyday mobility in a residential building in the city centre with good public transport.

4.4 Superimposition of areas of influence

If the identified sufficiency areas—variable living space per person, variable user behaviour during operation and mobility—are superimposed, the result is a considerable sufficiency potential:
Even in an efficient building with equipment of the best efficiency rating and energy-efficient cars, moderate sufficiency can reduce primary energy consumption and greenhouse gas emissions by approximately 50%. The achievement of the 2000-Watt Society objective is quite easy to reach with the help of sufficiency. Achieving this goal requires the contribution of all stakeholders, includ-

ing the users of buildings. What is needed is not strong restrictions on the use of goods and services, which are connected to relevant energy consumption, but moderate restraint.

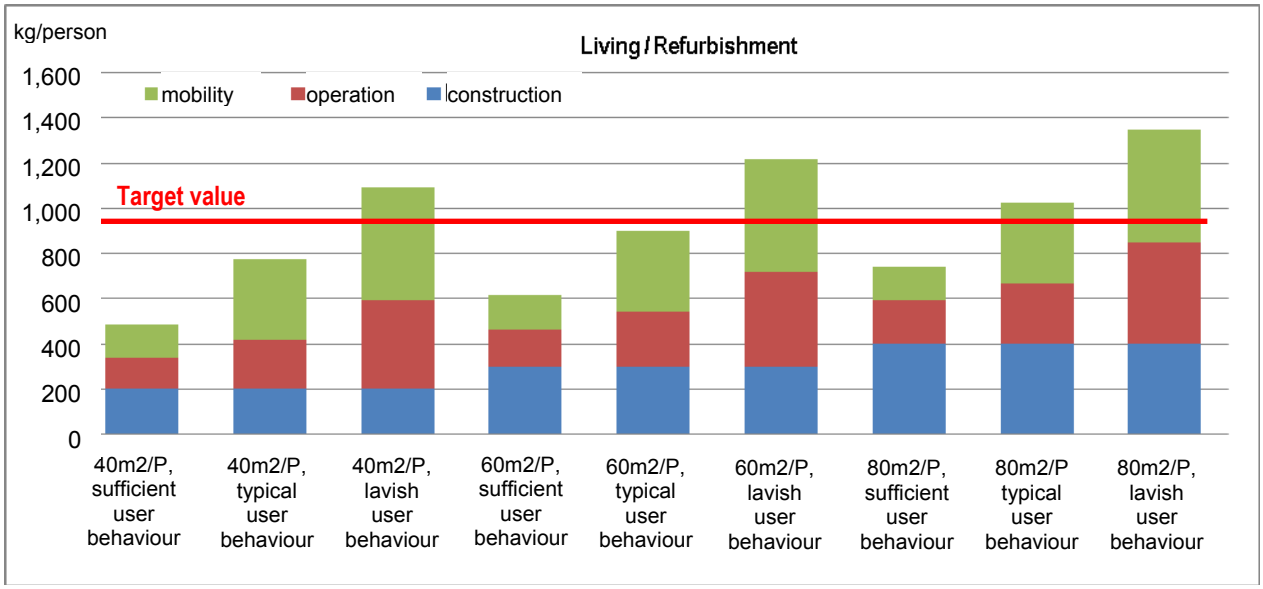


Fig. 4: Greenhouse gas emissions per person with variable living space per person and variable user behaviour in operation and mobility for a refurbished living space in the core of a city with good public transport access and an efficient building with efficient operating facilities, equipment and vehicle fleet.

Whether sufficiency is realised or not lies clearly in the hands of the users. The influence of building owners and authorities is significantly smaller but not insignificant.

Savings from moderate sufficiency by actors (energy efficiency provided) **Initial state according to SIA-Efficiency Path Energy** 100% = target value	 **Living space per person**	 **Heating and warm water, ventilation, light, household appliances ICT+ small appliances**	 **Mobility**
Initial installation building owners	Savings by reducing the standard living space per person by one-third: 15%	Savings from equipment: 2–4%	Savings from equipment: 2–4%
Operation administration			
User (tenant) behaviour		Savings from equipment and user behaviour: 10–18%	Savings from equipment and user behaviour: 12–20%

Fig. 5: Saving potentials for actors engaged in moderate sufficiency. The % figures relate to savings in comparison to typical behaviour and are based on the sum of primary energy and greenhouse gas emissions from the construction, operation and mobility of an efficient building and efficient equipment, operating facilities and vehicle fleet (new construction and renovation).

5. Discussion

Technical measures, as the main focus of efficiency, can be made obligatory by legal specifications, regulatory restrictions on the marketing approval of equipment or the definition of requirements for granting construction projects. They are typically accepted because they do not entail waivers but, on the contrary, a gain in comfort through which the necessary investment can be justified. Sufficiency measures, on the other hand, are usually perceived as a loss of comfort and address the everyday and individual behaviour of residents. Here, legal regulations would have to compete with much larger acceptance problems. Sufficiency can be promoted, for example by occupancy requirements for single housing estates, by economical equipment in dwellings, by waiving parking spaces in single housing estates, by taxes and of course through comprehensive, constantly repeated information.
Implementation measures and motivation are not the focus of this study (see study [5]). When the great potential of sufficiency is to be actually realised, new approaches will be needed in this area (see e.g., [6]).

What this study can offer, however, is a quantification of the potential of moderate sufficiency behaviour, differentiated by actors and differentiated according to individual measures. There are already several examples of how these measures are being implemented voluntarily: The cooperatives in Zurich are currently building car-free housing developments in which the consumption of land per person is clearly reduced compared with the national average. The residential estates that belong the City of Zurich have an average living space per person that is well below what is designated as moderate sufficiency in this study.
Nearly half of all households in the city of Zurich have no car, and even 62% of work trips are made in Zurich by public transport, by bicycle or on foot. This study shows how important the contribution of moderate sufficiency behaviour is for meeting the goals of the 2000-Watt Society concept.

As a digression from this study, the effects of measures of sufficiency in an inefficient building were examined: compared with an efficient building, there is similarly great potential for percentage reduction in inefficient buildings (download of the final report in German [8] www.stadt-zuerich.ch/nachhaltiges-bauen > Fachinformationen).

6. Perspectives

This study has been able to describe moderate sufficiency behaviour for residential buildings and to quantify the different reduction potentials between primary energy and greenhouse gas emissions. This represents an important step towards an objectification of the discussion about sufficiency and its necessary extent. It also allows for an appreciation of the already planned and implemented steps building owners and administrations are taking towards sufficiency. Finally, the study allows users to compare their own behaviour with that of a typical household, a moderately sufficient household and a lavish household.

Crucial for achieving the large reduction potential of sufficiency will be social developments. Sufficiency will establish itself as a desirable and voluntary action only through the personal behaviour of people who are accepted as role models. How such a development can be promoted must be the focus of future work in the broad field of sufficiency.

7. References

[1] The Swiss Society of Engineers and Architects (SIA), 'SIA Energy Efficiency Path, Fact Sheet SIA 2040', 2011

[2] The Swiss Society of Engineers and Architects (SIA), 'Embodied Energy of Buildings, Fact Sheet SIA 2032', 2009

[3] The Swiss Society of Engineers and Architects (SIA), 'Mobility - Energy Demand depending on the Building Site, Fact Sheet SIA 2039', 2011

[4] City of Zurich, TED, Mobilität und Planung, 'Mobilität in Zahlen' (mobility in figures), 2010.

[5] City of Zurich, Building Department, Annette Aumann, Dr. Heinrich Gugerli, Gallati Kommunikation / Faktor Journalisten, 'Nutzerverhalten beim Wohnen' (user behaviour in residential buildings), 2011.

[6] Stadt Zürich und ewz; Energieforschung Stadt Zürich: ein ewz-Beitrag zur 2000-Watt-Gesellschaft, insbesondere Themenbereich 1 Haushalte, Departement der Industriellen Betriebe und ewz, in Bearbeitung. download: www.energieforschung-zuerich.ch

[7] City of Zurich, The Swiss Society of Engineers and Architects (SIA), EnergieSchweiz für Gemeinden '2000-Watt-Gesellschaft Bilanzierungskonzept' (2000-Watt accounting model), 2012

[8] City of Zurich, Building Department, Architekturbüro H.R. Preisig, ARENA Arbeitsgemeinschaft Energie-Alternativen, Planungsbüro Jud, 'Grundlagen zu einem Suffizienzpfad Energie: Das Beispiel Wohnen', (The Energy Sufficiency Path: Basics for Residential Buildings), August 2012 (download of the final report in German [8] www.stadt-zuerich.ch/nachhaltiges-bauen > Fachinformationen)

Residential High-Rises without the usage of Air-Conditioning in Tropical Regions - A CASE STUDY OF THE MET IN BANGKOK



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Short Summary

Is it possible to entirely abolish energy-consuming air conditioning systems and simultaneously maintain a high living quality, a comfortable atmosphere and sufficient natural light in a high density living environment? To find answers to this question, the paper will use the completed case study “The MET” in Bangkok designed by WOHA Architects Singapore. The possibilities of abolishing a/c, will appear in building analyses, interviews with experts and conclusions from detected (measured) acoustic decibel, temperature and wind speed. The substantial questions are: Which existing knowledge and which architectural strategies must be combined and modified to create the optimal system in respect to building energy consumption and low carbon sustainability? What is their impact in terms of architectural design? How will these conditions influence the building typologies, floor plans and detailed openings in housing construction?
The paper will clarify the challenges in the design processes to realize those typologies, façade structures and windows details in tropical conditions.
This paper is part of the dissertation by this author and focuses as its central theme, how the design of a building and façade structures can affect good living quality and interior climate in tropical and subtropical regions without the use of a/c.

Keywords: Low Energy, Residential High Rises, Air-Conditioning, Living Comfort, Energy-Consumption, The MET WOHA Architects, Opening Requirements, Cross Ventilation, Floor Plan Configuration, Façade Structures, Building Typologies.

1. Introduction

This field survey investigates whether a pleasant living comfort with natural ventilation and without usage of air conditioning is possible. The hottest climatic period (April) was selected as research period, in order to determine the worst case or the most extreme and serious condition. There is air conditioning for each residential unit. However, one can assume that when utilizing the building concept the air conditioning might not be necessary. The appropriation of air conditioning meets the comfort requirements of the clients, the wealthy residents, and accounts for the standardization of air conditioning for every apartment in tropical regions. It is the purpose of this proposal to identify whether a comfortable living environment can actually be facilitated without the use of air conditioning.

2. Residential High Rise Project The MET

The MET is a pilot project, not because of its height amounting to 266 meters and thus constituting the tallest residential high rise in Thailand, but because it represents a completely new high rise type. The Singapore architects WOHA have developed a specific solution for a dense construction with natural ventilation in the tropics. “Most tropical high-rise housing in developing countries replicate cold-climate models, with sealed facades and total reliance on air-conditioning and mechani-

cal Ventilation. However, in the tropics light winds, year-round balmy weather, constant temperatures and high humidity make outdoor living desirable. In addition, the environmental conditions high-up in dense and populated Asian cities are preferable to those near the ground – there is more privacy, better views, lower humidity, stronger breezes, better security, less noise and less dust."[1] The project has won numerous awards and prizes. At last it was nominated in May 2013 for the Aga Khan Award for Architecture. The porous structure of the building enables the natural ventilation of the 370 residential units. The building consists of three residential towers, the interspaces are open and therefore, a good ventilation of the overall structure is possible (fig. 1). These basic structures are merely connected via bridges and walkways which facilitate the building with half-public communication zones and private recreational areas with green surfaces (fig. 3).
Moreover, the exposure is optimized. None of the rooms requires artificial lighting throughout the day. Only the kitchen in its closed version (e.g. floor type 29 in the middle part of the house) requires artificial exposure. However, the partitions are not supporting and can therefore be removed upon request.
Vertical cultivation and high-rise gardens provide additional conditioning of fresh air (fig. 2).



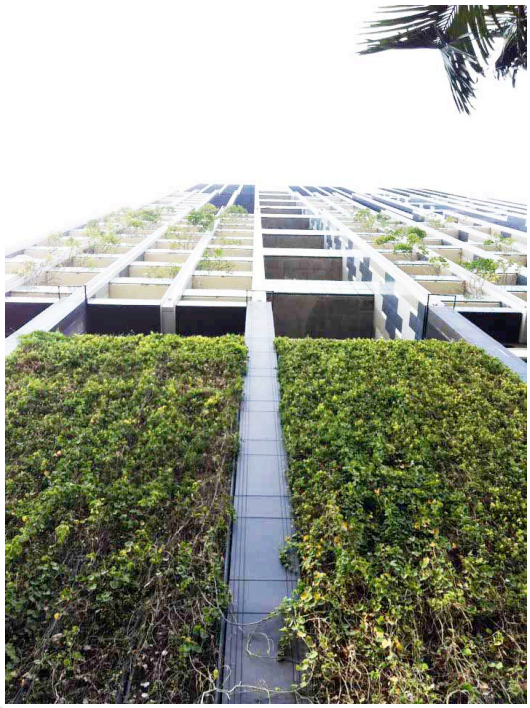
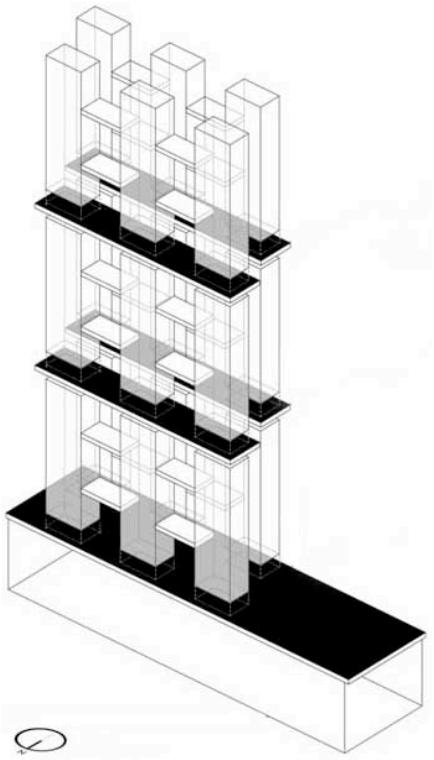


Fig. 1. Façade View the MET, Fig. 2. Vertical Cultivation the MET
© Ferdinand Oswald; Photo: Ferdinand Oswald

3.0 Climate Conditions Bangkok

The climate in Bangkok is warm and has a relatively high humidity. On principle, the climate can be distinguished according to three seasons. Summer, winter and the rains. The latter is triggered by the monsoon climate. The urban island-heat-effect causes a temperature increase and prevents excessive cooling during the night. Within these night hours the temperature in Bangkok therefore declines by 5 - 10 degrees Celsius. The prevailing climate urges people to use air conditioning throughout the whole year. The Bangkok residents actuate these aerations particularly during the summer months (March to July) (fig. 4)



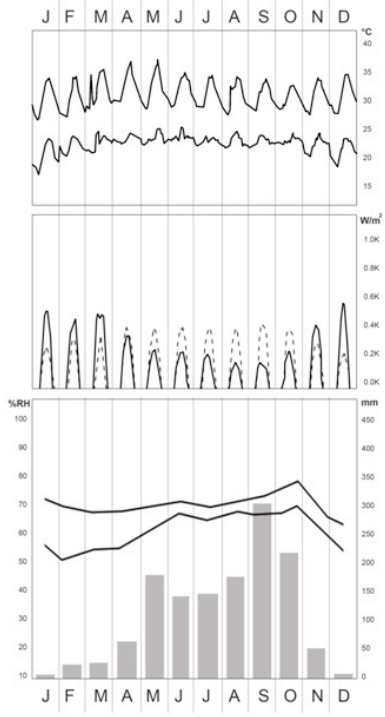
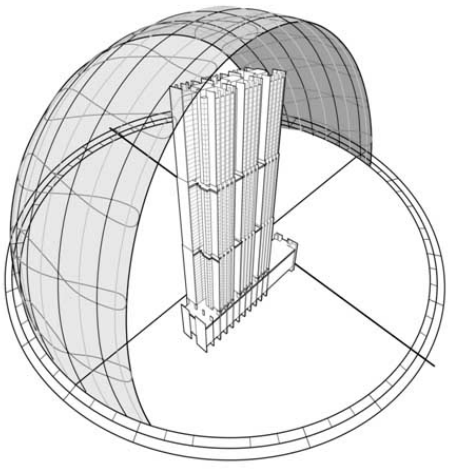


Fig. 3. Integration of Community Decks, Fig.4. Weather Bangkok © Dr. Nirmal Kishnani (1,2)

3.1 Wind direction and solar altitude

At this location the major wind direction is predominantly oriented from north. The building is transverse to this wind direction and can therefore ideally absorb the wind within its porous structure and openings (fig. 6).
The static basic structure of the building is based upon a supporting construction, which is arranged in north-south direction. Thus, these protruding features function not only as essential architectural design elements but principally serve as shields for window openings, because the building was situated parallel to the course of the sun (east-west) (fig. 5).



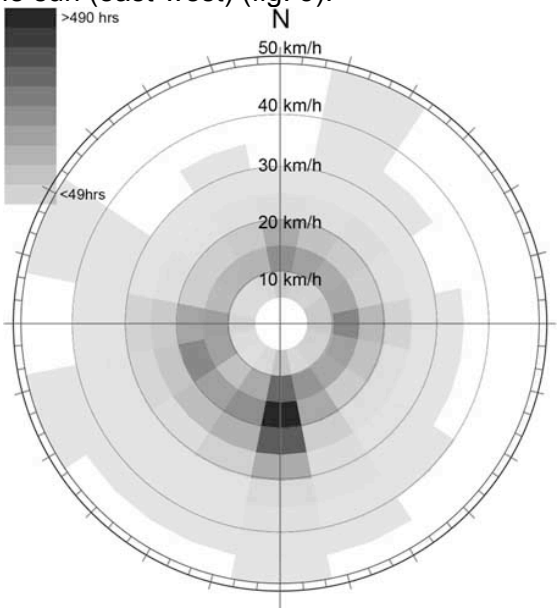


Fig. 5. Sun Course over the MET, Fig. 6. Wind Direction and Wind Speed © Nirmal Kishnani (3,4)

3.2 Wind currents

Wind currents exist in vertical and horizontal direction. The horizontal weather winds produce wind pressure and suction. They collide with vertical wind currents and their intensity is therefore mitigated. Thus, both wind currents provide for a variety of air movements and the wind can ideally infiltrate the apartments. The vertical wind currents originate from temperature and pressure differences and take place within the building structure and between the residential towers (fig. 7 and 8). This uplift that triggers various air circulations is utilized by swallows that can continuously be watched around the building. With their enclosed basic structures and flat building facade surfaces other high rise buildings cause undesired one-sided and strong air currents. These lead to extreme wind blows that are uncomfortable for pedestrians and that are also avoided by gliders at a greater height.

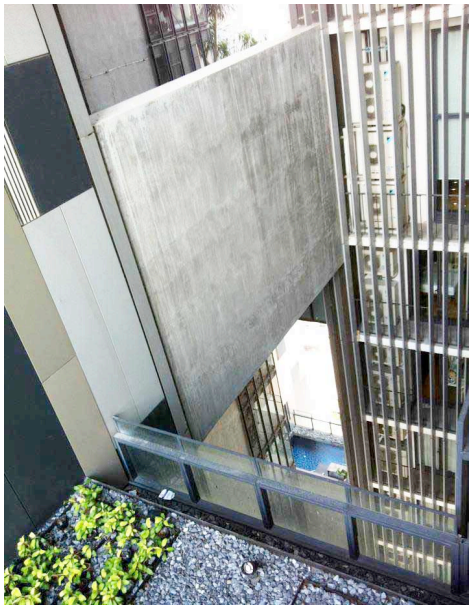




Fig. 7. and 8. Building Structure the MET ; © Ferdinand Oswald; Photo: Ferdinand Oswald

3.3 Wind speeds

Due to Bangkok‘s vicinity to the sea a sufficient wind strength within the city can be expected throughout the whole year (fig. 6). At increasing altitude the wind speed increases steadily. At the street level, the wind speed is almost zero. Measurements at the Sathorn Road displayed a wind speed of only 0.52 meters per second (m/s). This air flow cannot even be noticed as a slight breeze (wind strength 0-1)[2].
Nevertheless, 65 meters further, along the ground floor entrance area leading up to the MET, there is a very high air circulation of 6.13 m/s. The measurements on spot correspond to the wind strength 4, a moderate breeze (fig. 9). Even at the ground floor the building structure creates wind currents. This appoints to the efficiency upon which the building structure directs the wind downwards.

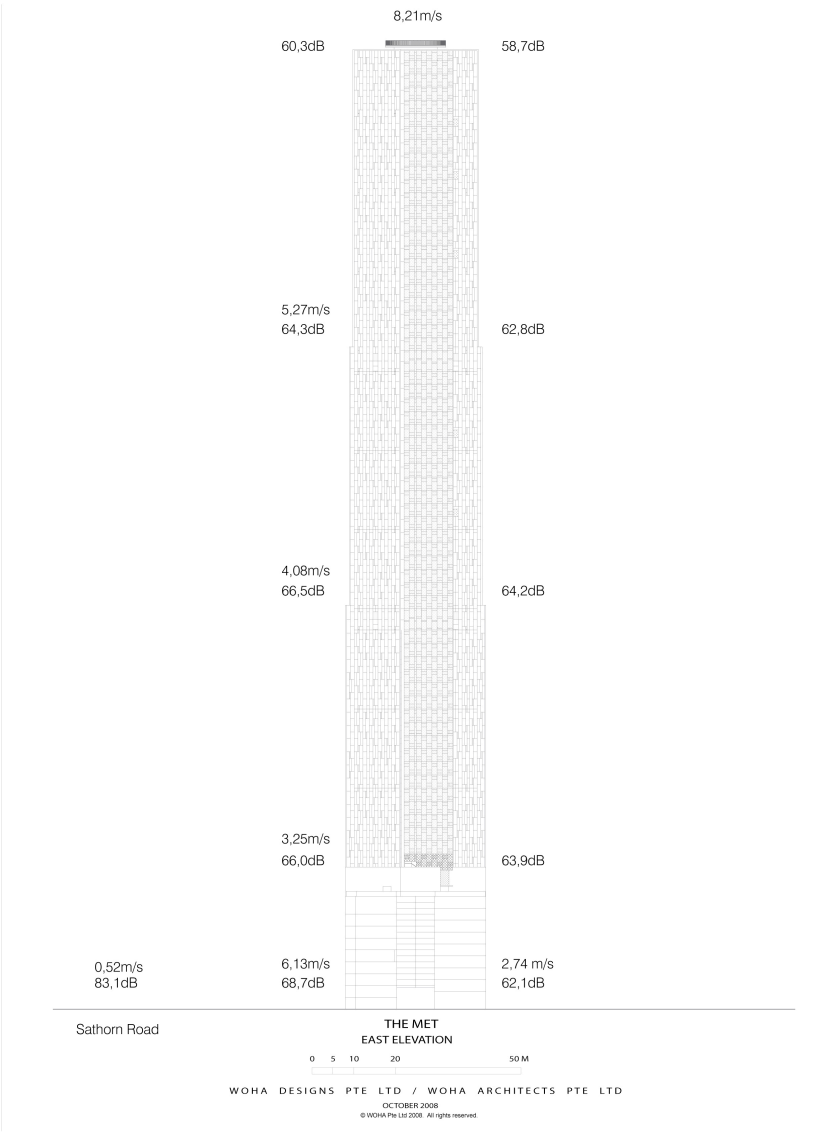


Fig.9. Results Wind Speed and Decibel; © Ferdinand Oswald, WOHA (5)

Due to the higher wind speed at increasing altitude there are less cultivations at higher storeys. In the upper third of the building there are hardly any balconies with trees and cultivations (fig. 10). The WOHA architects are widely experienced at transposing cultivations upon residential high rises. It is probable that the strong winds up to a height of 260 meters adversely affect the plants. In consideration of the strong wind strengths the stability of the trees must be ensured. Moreover, the evaporation at the surface of the leaves as implicit result of the wind presents a danger. Due to the lesser contact surface of the winds and the possible prevention from leave separation, small-leaved plant species are more suitable for an environment that is exposed to wind [3].
Nevertheless, the higher residential units (top third) are in particular demand. (Despite the higher costs of top-storey residential units in comparison to the lower two-thirds of the building, these vacant top-apartments are seldom. Status: April 2013.) They provide better views, facilitate a better ventilation (stronger wind speed) and a better air quality. The top wind speed has been measured at the roof top of the building. The wind speed accounts for 8.21 m/s and therefore corresponds to the wind strength 5 (Beaufort) that is identified as fresh breeze. The measured vertical wind current at the top storey reaches a similar wind strength. It is caused by the uplift and the channel-shaped interspaces of the residential towers reinforce this chimney effect.

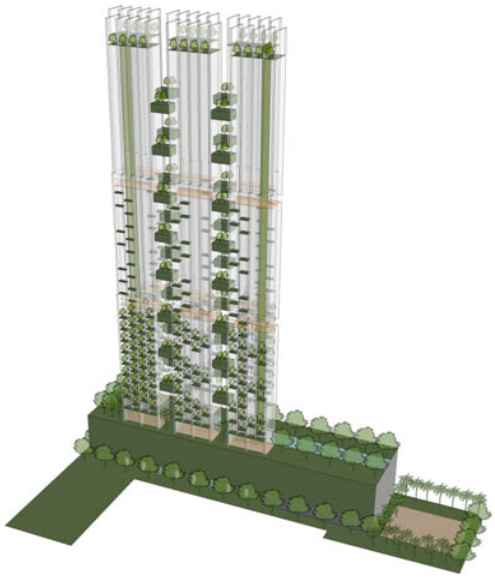


Fig.10. Integration of Greening, © Dr. Nirmal Kishnani (6)

3.4 Impact of water areas on comfort

Water areas are located in the common areas and some of the apartments are allocated with private pools. The air as it is cooled off by water circulates within the building structure and can eventually flow into the residential units. In the entrance area the pleasant breeze, the shade, and the influence of the numerous bodies of water establish a comfortable place to linger. In this area air measurements accounted for a temperature of 32.3 degrees Celsius. Simultaneously, the temperature at Sathorn Road was 4.2 degrees Celsius higher (36.5 degrees Celsius) (fig.11).

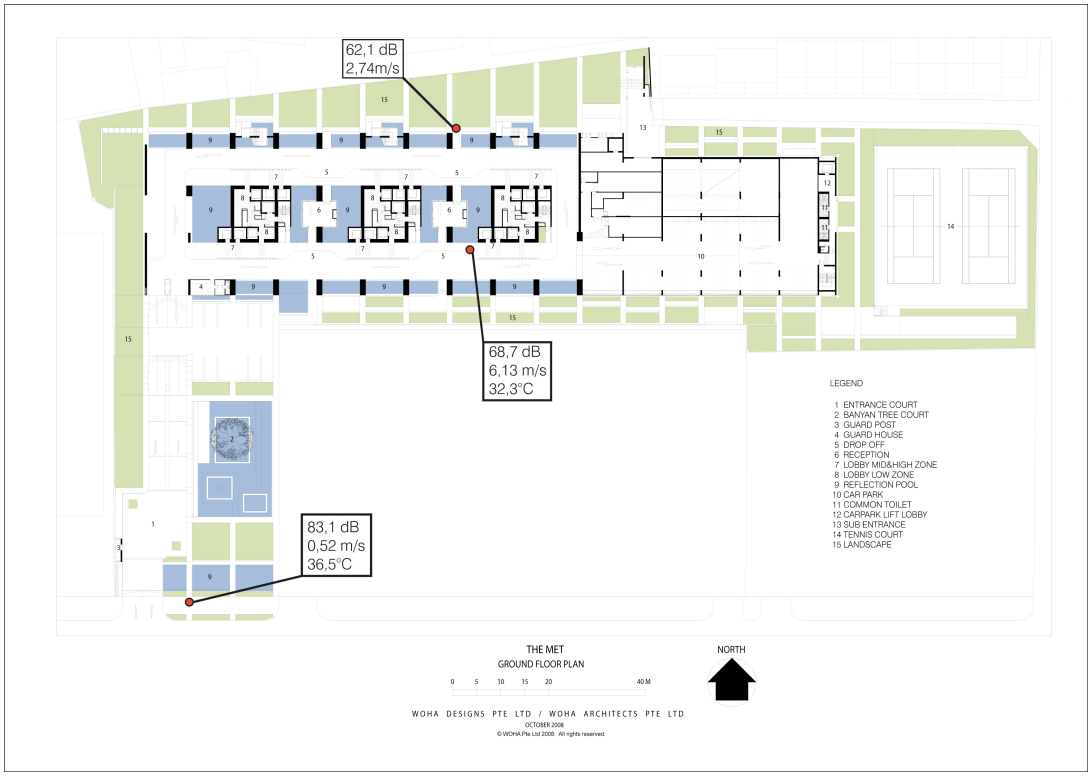


Fig.11. Ground floor the MET - Wind Speed, Decibel and Temperature
© Ferdinand Oswald, WOHA (7)

4.0 NATURAL VENTILATION

Natural ventilation enables a renunciation of air conditioning. This requires a closer investigation of the following three levels of the building:

1. The porous structure of the building as it is already described above.
2. The floor plan configuration which must facilitate cross ventilation.
3. The openings must meet numerous requirements and comply with external influences.

These will be elaborated according to the following points:

4.1 Floor plans

The three residential towers each contain a core development with two residential units. One unit is oriented towards north, the second unit faces south; both are staggered in reverse order. This enables an air entrance from the rear of the residential units and a very efficient cross-ventilation (fig. 12). Numerous windows can be opened from north and south in order to provide thorough ventilation. However, the hallway between several rooms must be partially ventilated (dependant on the floor plan type). According to the standard floor plan of the middle units (storeys 29th to 46th) there are two bedrooms with integrated bathrooms that are located at the facade side. Cross ventilation of the bedrooms is only provided when the doors are open. This leads to privacy restrictions. The opening of the balcony door and the tilting-window in the bathroom allow for an one-sided ventilation. However, due to the absence of the cross ventilation its efficiency during the hot climate period is disputable (fig. 13). A solution to the problem in terms of this floor plan type is difficult. The room layout of the large bedroom in combination with the bathroom facilitates continuous cross ventilation. The cross ventilation can also be implemented in the living room and kitchen without any restrictions. If the small bedrooms were connected to both facade sides they would be conceptualized as through rooms without a hallway.

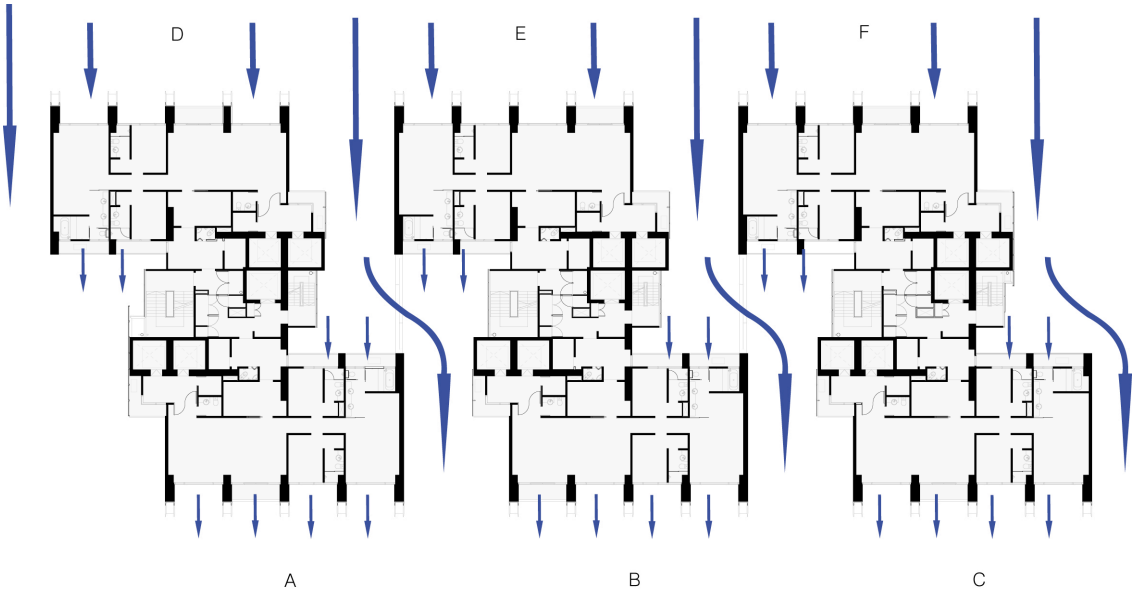


Fig.12. 29th Floor Plan the MET with Wind Circulation; © Ferdinand Oswald, WOHA (8)

4.2 Openings

Altogether there are 14 doors and window flaps that can be opened for the purpose of cross ventilation within one residential unit (Exemplified according to unit 29C, middle area, storeys 29-45 there are 9 window flaps, 4 doors to the canopied area, and one sliding door to the balcony). Although there are only 3 doors and 2 window flaps along the back facade side, there is sufficient air current throughout the residential units. Theoretically, there are 196 different ventilation combinations that result from these 14 openings (fig. 13).

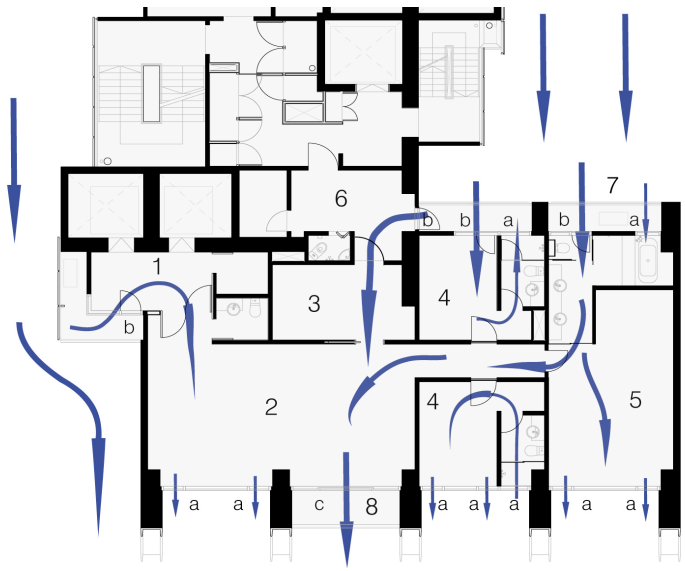


Fig.13. 29th Unit C Floor Plan the MET with Openings Categorization
© Ferdinand Oswald, WOHA (9)

Moreover, an air current in longitudinal direction can be actualised, for instance from the northern bedroom through the living room. The apartment entrance door was designed to be air-permeable and therefore allows for a continuous air current. It is made of vertical wooden staves and exhibits the necessary permeability for the air current to circulate onto the openings in the living room (fig. 14a). The window flaps can be folded out from beneath. This tilting mechanism anticipates the penetration of rain. In terms of the intense monsoon-rains in the rainy season this mechanism is an indispensable attribute for windows located at the outer facade. A suitable dosage of the air current via the ideal opening cross section is problematic. The loggia doors and window flaps allow only for a thorough opening or closing (fig. 14c). Merely the balcony sliding door enables a fine adjustment of the opening cross section. Thus, the air current volume and – intensity cannot be perfectly controlled. A needlessly high air change might be created. This excessive air speed triggers for instance a situation in which loose papers get blown away. One solution could be the development of window openings that allow for a decided control of the opening cross section. An example here could be the traditional wooden struts window of the old Tulous of the Fujian region in China (fig. 14 d and e). These can be regulated manually and with minimal movement of the element. However, the disadvantage here is that the shut-off struts no longer ensure light transmittance. Throughout the research project Structure and Facade, the IAT - Institute of Architecture Technology, Graz University of Technology is currently developing opening systems that meet these requirements. It is yet to be identified which cross sectional opening shape and size may represent the ideal opening for natural ventilation (fig. 15 c).In contrast to the overhead window flaps, the loggia doors have no locking function. Therefore, problems alluding to excessive draft are triggered. The loggia doors thunk shut with a loud bang. One way to solve this problem would be the appropriation of different adjustable opening angles in order to fix the doors.

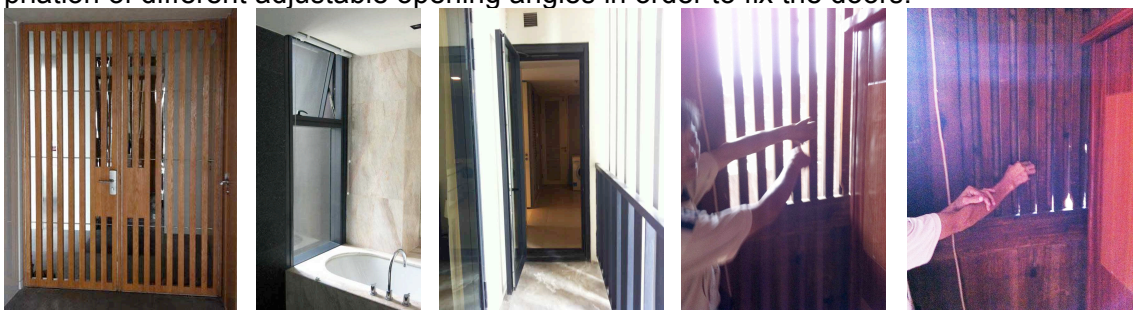


Fig.14. a) Porous Unit Entrance Door the MET, b) Top Hung Window the MET, c) Loggia Door the MET, d) Opened Sliding Window, Tulou China, e) Closed Sliding Window, Tulou China;
© Ferdinand Oswald; Photo: Ferdinand Oswald

4.3 Noise exposure road traffic

The noise exposure caused by road traffic at one of the most frequented roads in Bangkok accounts for 66.6 decibels (dB) at the middle part of the building and is therefore relatively high. The attempt of closing the window in order to create comfort did not improve the situation in terms of noise exposure. The windows are provided with single glazing and do therefore not contribute to soundproofing. Furthermore, the decentrally assembled cooling units are directly attached to the window. Even when the windows are shut the actuated air conditioning creates tremendous noise within the residential unit.
Noise measurements at the southern facade averting the street displayed only a slight noise reduction. This is justified by the fact that the adjacent building situated further south reflects the traffic noise back to the MET.
On average the noise exposure is only 2 dB lower than on the facade facing the street. At increased building altitude the noise exposure declines. On top of the building the decibels are least, at the middle part of the building they are very high. The higher acoustic measurements at the middle part of the building are justified by the fact that the adjacent building on the opposite side reflects the sound back (fig. 9).
The Hong Kong Housing Authority has used the so-called Noise Reducing Window (fig. 15 a). The window is constructed using two glass plates behind each other. Thus, the wind must pursue a labyrinth-like way and the acoustic waves cannot penetrate the interior of the room. Moreover, the perforated acoustic absorber is attached to the window reveals in order to transmit the noise. ."[4]
When taking into account the diversion of the wind flow the question is raised whether there is still sufficient wind speed inside the apartments. The wind pressure must reach a specific strength in order to facilitate efficient cross ventilation. A further development and investigation of this issue is perfectly reasonable, because the noise exposure of road traffic within Asian cities is usually very high. Unfortunately, it is likely that Bangkok's road traffic might increase within the next years, as the Thai government has started subsidizing the registrations for cars. Thus, it can be assumed that the noise exposure caused by vehicles in road traffic is on the rise.

4.4 Air pollution

"The motor vehicle traffic is one of the main causes of air pollution. Particularly in urban areas, the exhaust gases cause serious adverse effects on people and the environment."[5] However, air pollution caused by road traffic at the MET does not present a problem. Although the building is located at one of the most frequented thorough fares of Bangkok, the air quality is very good.
This is justified according to the following, "In the 90s Bangkok grew so fast that the air quality dropped to a miserable level. The government has enacted emission regulations, ensured the widespread introduction of unleaded petrol, and issued a regulation that allowed cars with catalytic converters only. In addition, simple but effective measures were carried out, for example, paved roads in order to stir less dust. The air quality in Bangkok is now better than American standards stipulate."[6]
The Thai government subsidizes gas-powered cars. "Although today conventionally powered vehicles emit fewer pollutants than a few years ago, the emission of exhaust gas components such as benzene and soot particles continues to present significant environmental impacts. Especially the pollutant emissions of diesel engines earn much criticism."[7] Thus, gas-powered vehicles are less harmful to the air than gasoline-powered vehicles. Unfortunately, the production of gas-powered cars will now be abolished in Thailand. In terms of the air pollution problem in other Asian cities the appropriation of air filters should be considered. However, the use of such air filters would possibly diminish the air current to a degree that might be no longer sufficient. At the same time an exposure through window openings should be facilitated. A material specification that meets the requirements of translucency, weathering, and air cleaning should be deployed (fig. 15 b).

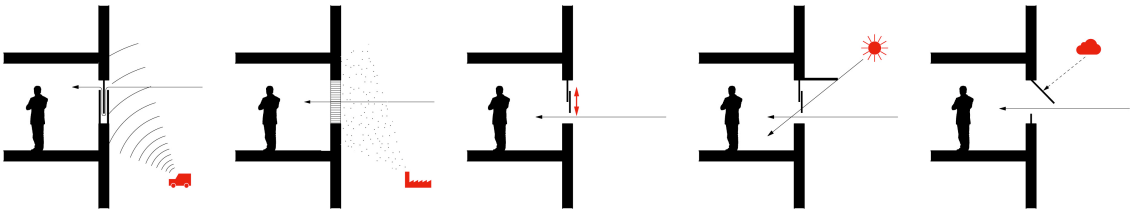


Fig.15. Requirements for Openings : a) Traffic Noise Load – Noise Reduction Window b) Air-Pollution Filter Window, c) Dimension of Window Width, d) Sunscreen, e) Rain Shield
© Ferdinand Oswald

5 CONCLUSION

Due to the existent floor plan structure natural ventilation and the simultaneous renunciation of electronic air conditioning is enabled within the residential units of the MET. The measurements and the evaluation demonstrates that, even within Bangkok's hot season, natural ventilation and air currents do allow for a pleasant living comfort. The problematizing standards of the openings (fig. 15) can be added up to within one window. However, this requires openings that meet all these needs simultaneously.
The requirements of noise, air filtering, opening cross-section, as well as sun and rain protection must therefore be equally achieved upon this single opening.
Upon enquiring [8] the employees of the MET about the use of air conditioning, the survey led to the following results:
The experience of the staff revealed that most residents of the MET actually renounce the use of air conditioning. This thesis is based on the numbers taken from power consumption measurements within the individual units. The investigations of Dr. Nirmal Kishnani [9] confirm these numbers. "45% of the residents say, that they have low to moderate dependence and reliance on air-conditioning." The idea of returning to the passive natural air conditioning is currently difficult to implement among tropical cities. The electricity prices are low, facilitating a relatively affordable operation of the refrigeration systems. Air conditionings are easy to get and easy to install. Mostly these are assembled already in advance by the client or operator of the building, since this adds up to the expectations of the patronage.
Mistakenly, the air conditioning seems to present the only assumable answer to the external factors of heat, humidity, noise, and air pollution. The air conditioning is a deeply-rooted standard that meets the need of comfort in a self-evident and simple manner. Surprisingly, the floor plan conceptualizations and openings of older residential properties in Bangkok contain functioning cross ventilations without air conditioning. The invention of the decentralised air conditioning has changed the types of housing in the last 50 years thoroughly. We need to focus on and prove the assumption that the adaptation and reinterpretation of traditional housing typologies for new residential buildings aspires to a realization of the living comfort in a sustainable way. The MET proposal has become a pioneer project in its own right, representing architectural innovation in tropical regions.

Graphics

(1) *Graphic: Integration of community decks, © Dr. Nirmal Kishnani*
KISHNANI, N. Dr. "Greening Asia, Emerging Principles for Sustainable Architecture", FuturArc (BCI Asia) Singapore, pp. 263, 2012, ISBN 978-981-07-0116-1
(2) *Graphic: Weather Bangkok, Copyright: © Dr. Nirmal Kishnani*
KISHNANI, N. Dr. "Greening Asia, Emerging Principles for Sustainable Architecture", FuturArc (BCI Asia) Singapore, pp. 266, 2012, ISBN 978-981-07-0116-1
(3) *Graphic: Sun Path over the MET, © Dr. Nirmal Kishnani*
KISHNANI, N. Dr. "Greening Asia, Emerging Principles for Sustainable Architecture", FuturArc (BCI Asia) Singapore, pp. 267, 2012, ISBN 978-981-07-0116-1

(4) *Graphic: Wind direction and Wind speed, Copyright: Dr. Nirmal Kishnani KISHNANI, N. Dr. "Greening Asia, Emerging Principles for Sustainable Architecture",* FuturArc (BCI Asia) Singapore*,* pp. 266, 2012, ISBN 978-981-07-0116-1

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(8) *Graphic: 29th Floor Plan the MET with Wind Circulation, © WOHA Pte Ltd, October 2008 and Ferdinand Oswald*

(9) *Graphic: 29th Unit C Floor Plan the MET with Openings Categorization, © WOHA Pte Ltd, October 2008 and Ferdinand Oswald*

References

[1] BUSENKELLER M., COCHALA SCHMAL, P. *"WOHA Breathing Architecture".* DAM Deutsches Architektur Museum, Frankfurt am Main, Germany, Prestel Munich, London, New York., pp. 80. 2011, ISBN 978-3-7913-5186-5

[2] JOHN O.E., "*Encyclopedia of world climatology"* Springer, 2005, GWAPO KO GWAPO KAAU KO and BEAUFORT SCALE, "The Definition of the Beaufort Scale", https://en.wikipedia.org/wiki/Beaufort_scale. Status: May 20, 2013

[3] NOLL P. Dipl. Ing. (FH), *Interview*, Horticulture and Gardening GbR, Heidelberg, Germany, Status: May 20, 2013.

[4] FUNG A., *"Green & Healthy in a High-Rise Density Enviroment – The Hong Kong Housing Authority`s Exerience"* The Noise Reducing Window, Environmental Protection Department (EPD), Speech by Mrs. Ada Fung, director of the Housing Authority Hong Kong, on March 22, 2013 at the International Conference "High Density & Living Comfort" at the IAT - Institute of Architecture Technology, Graz University of Technology, organised by Ferdinand Oswald and Prof. Roger Riewe, www.cn-at2013.tugraz.at.

[5] For environmental benefits of car gas http://www.autogastanken.de/de/umwelt/umweltvorteile.html. Status: May 20, 2013

[6] Environmental toxins – air in big cities, Focus Online Wissen: http://www.focus.de/wissen/mensch/tid-12217/umweltgifte-luft-in grossstaedten_aid_342639.html. Status: 09.05.2013

[7] Cf. Reference: Environmental benefits of car gas

[8] DANUDECH K., Interview on April 4 2013 with Sales Manager Ms. Jenitar Eve RCA and Technical Director Mr. Korn Danudech at the MET Bangkok.

[9] *KISHNANI, N. Dr. "Greening Asia, Emerging Principles for Sustainable Architecture",* FuturArc (BCI Asia) Singapore*,* pp. 264, 2012, ISBN 978-981-07-0116-1

Criteria For Low Energy Buildings



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Short Summary

The Recast of the Directive on the Energy Performance of Buildings (the EPB Directive) came into force on 9 June 2010. EU member states should until 9 June 2012, publish the relevant laws and administrative regulations necessary to implement its provisions. European regulatory efforts towards increasing energy efficiency of buildings are focusing on a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Such requirements should be the first step into low or zero energy buildings.

In this paper the consideration on different indicators for requirements of low energy and nearly zero energy buildings are presented. The scope of the paper is to show that none of the buildings system (like hybrid or natural ventilation) can be excluded from using in such buildings. This conclusion is crucial for integrated energy design process as designer should not be limited to specific number of systems solutions.

In the paper the calculation of three systems are presented (natural ventilation, DCV ventilation and mechanical ventilation with heat recovery). It was shown that, the choice of indicator for requirements should include not only the useful energy (heat), but also electricity (heater) and other non-energy operating costs (filters). The correct ratio is multi-dimensional, and its range depends on the used assumptions.

The given consideration shows that the estimation of energy requirement cannot be done using only one indicator eg.: useful, final or primary energy. Such approach may leads to excluding some systems that can be other than recommended.

Keywords:Low energy buildings; energy criteria; LCC

1. Introduction

Directive 31/2010/EU [1] requires the introduction of nearly zero-energy buildings but does not specify a minimum or maximum harmonized requirements and detailed guidance framework procedure for calculating the energy performance of building. Member states have to define what that means exactly for them. Taking into account the local conditions in the definition does not preclude the adoption of a uniform methodology in all Member States.

The Directive defines a nearly zero-energy building as a high energy performance building and requires the determination of the ratio of primary energy. Very low or almost zero energy demand

of the building should be covered from renewable energy sources or renewable sources produced on-site.

Based on the definition given in the directive, the nearly zero-energy building is technically *net zero energy* building that is consuming 0 kWh/(m^2a) energy (however it is not clarified what kind of energy should be taken into account: final, primary, supplied). According to the rule of optimal costs laid down in Directive almost net zero net energy building is defined as a building determined using the rules of the national methodology of optimal costs, consuming more than 0 kWh/(m^2a) energy. In order to clarify the general definition it was necessary to specify which energy flows should be included in the evaluation of energy performance and how the primary energy factors should be used to calculate the ratio of primary energy of building. To standardize the methodology the overall definition of the balance border with the inclusion of active solar systems and wind power, as well as technical clarification of the term "near" contained in the Directive becomes an essential element.

Methodology of the cost optimal and requirements defined of its use indicates use as an indicator a final or delivered energy, as they are associated with costs. Primary energy can be defined as an additional indicator, as used for its determination the primary energy factors include biased (not related to the quality of the building) political aspect. However, many Member States selected as requirement a primary energy supplemented by other requirements. The requirements have technical and economical quality which means that they must refer to existing technologies and be set as economically viable. This cost-effective level by the European Commission may be determined by the cost optimal methodology described in Regulation EC 244/2012 [2].

In this paper the consideration on different indicators for requirements of low energy and nearly zero energy buildings are presented. The scope of the paper is to show that none of the buildings system can be excluded from using in such buildings. This conclusion is crucial for integrated energy design process as designer should not be limited to specific number of systems solutions.

2. Energy in requirements

Genesis of formulating energy requirements is derived from the early twentieth century. With the development of technology and the decreasing availability of raw materials it began to formulate the energy requirements for buildings. At the beginning heat loss was the main issue, so a maximum heat transfer coefficient for a single partition or the entire building were given. Since 1995, Poland has introduced requirements for the maximum permissible value of useful energy for residential buildings in kWh/m^2a, which coincided with the publication of the method for calculating this value. From the point of view of energy performance of buildings it was the only requirement, although by then some first calculations of final energy and thus costs were given. For other types of buildings maintained the requirements for building components such as heat transfer coefficients and the surface area of the glass partitions. In accordance with the adoption of the climate package, published directives on buildings, measures to reduce energy consumption have become systematically harmonized. In connection with the implementation of Directive 91/2002 on the Energy Performance of Buildings Member States were obliged to publish the so-called. minimum requirements. A summary of these activities is provided in online accessible publication titled Implementation of the Energy Performance of Buildings Directive (EPBD), Country Reports 2008, Brussels, 2008, ISBN 2-930471-29-8, EAN 9782930471297) [3]. During the implementation of the EPBD some research aimed at comparing the requirements from the various Member States were carried out. Examples of such works are Intelligent Energy for Europe projects called TABULA and ASIEPI. In comparison the rules adopted in Poland in 2008 are the least demanding of all member countries.

The requirements for nearly zero energy building consist of several specific requirements. These include primary energy and useful energy, as well as the tightness of the building and in the case of non-residential buildings useful energy for cooling.

An expressing requirements in units of primary energy is burdened with charges of adjusting object location (same building with electric power for heating has to be three times better than a building

supplied with district heating networks). If we assume, that the requirements should be independent of the location then the variables that affect the energy consumption of the building are the quality of envelopes and windows of the building, the efficiency of installations, climate and standard usage. Determination of whether the building have good or bad energy performance will be easy to define, regardless of its location. In this case, the requirements can be formulated in units of final and useful energy. Otherwise, if the distinction is primary energy it will not be able to conclude what is the energy performance of the building itself.

In conclusion, each indicator adopted for the requirements has its advantages and disadvantages, which should be know when deciding to choice it. Poland in the proposal of the new requirements for buildings plans to introduce partial requirements and primary energy requirements.

3. Traps of useful and final energy

In guidelines of Passivhaus Institut in Germany, the Austrian standards, definitions used in countries such as Sweden, Denmark, Norway and Finland requirements are always formulated with regard to the rate of useful energy demand for heating and ventilation rather than rate of final energy demand. So it is defined by the passive house standard according to Passivhaus Institut in Germany. Building achieved the passive standard if:

- usable energy demand for heating and ventilation does not exceed 15 kWh/m^{2}a,
- primary energy demand for heating, ventilation, hot water, auxiliary equipment, lighting, all the building equipment, household appliances and electronics, cooking, etc. does not exceed 120 kWh/m^{2}a.

Requirements for low energy standards should also be related to the rate of useful energy demand for heating. The indicators should not be taken into account additional energy consumption by auxiliaries.

Statement of requirements as indicators of final energy demand is a big mistake and can lead to increased energy consumption in buildings. For example, in buildings where the ground heat pump is the heat source the total efficiency of heating system will be about 3.0. With this performance achievement of final energy demand equivalent to 15 kWh/m^{2}a occurs with a usable energy demand for heating and ventilation equal to 45 kWh/m^{2}a. The achievement of final energy demand equal to 75 kWh/m^{2}a occurs with a usable energy demand for heating and ventilation equal to 225 kWh/m^{2}a. This means that when heat pump system with heating efficiency of an average 3.0 is used the buildings which should have passive standard are only low energy buildings, and low energy buildings are much worse than currently build.

The problem of final energy can be solved using the method cost optimal methodology. The calculation of the global cost is performed according to the methodology given in the comparative Commission Delegated Regulation 244/2012 (EU), using the method of financial calculations, from the formula:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right] \quad (1)$$

where:

- τ means the calculation period (30 years for residential and public buildings and 20 years for non-residential buildings),
- $C_g(\tau)$ means global cost (referred to starting year τ_0) over the calculation period,
- C_I means initial investment costs for measure or set of measures j,
- $C_{a,i}(j)$ means annual cost during year i for measure or set of measures j,
- $V_{f,\tau}(j)$ means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0),

$R_d(i)$ means discount factor for year i based on discount rate r to be calculated according to (2)

$$R_d(p) = \left(\frac{1}{1+r/100} \right)^p \tag{2}$$

where p means the number of years from the starting period and r means the real discount rate.

Calcutalion of global cost is performed on the basis of knowledge (estimation) of the final energy. Therefore, the determination of the requirements should be done using LCC methodology. It follows that the requirements laid down by the LCC will be different for different power systems.

4. The paradox of useful energy ratio - case study

In order to show the paradox of using in the requirements the useful energy the calculation of the energy demand for ventilation in the single family house were provided. It was assumed that the heat loses through external envelopes are constant and only ventilation system was taken into account.

According to Polish standard the hygienic air flow rates for single family house with two bathrooms and kitchen with gas cooker are: 2x50 + 70 = 170 m^3/s. It was assumed that ventilated volume of the building is 300 m^3, and ratio of n_{50}=3 air change per hour (for natural ventilation system). The total outside air flow is then:

$$V_{ve} = V_0 + V_{\inf} = \frac{170}{3600} + \frac{0.05 \cdot 3 \cdot 300}{3600} = 0.047 + 0.013 = 0.06 \quad m^3/s \tag{3}$$

The heat transfer coefficient for heat loses for natural ventilation is equal:

$$H_{ve} = \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn} \right) = 1200 \cdot \left[1 \cdot V_0 + 1 \cdot V_{\inf} \right] = 1200 \cdot \left[1 \cdot 0.047 + 1 \cdot 0.013 \right] = 72 \quad W/K \tag{4}$$

The heat transfer coefficient for heat loses for mechanical ventilation with heat recovery of 85% is equal:

$$\begin{aligned} H_{ve} &= \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn} \right) = 1200 \cdot \left[(1-\eta_{HR}) \cdot V_f + 1 \cdot V_x \right] = \\ &= 1200 \cdot \left[0.15 \cdot 0.047 + 1 \cdot 0.00875 \right] = 18.96 \quad W/K \end{aligned} \tag{5}$$

Where V_x:

$$V_x = \frac{V \frac{n_{50}}{3600} e}{1 + \frac{e}{f} \left(\frac{V_{su} - V_{ex}}{V \frac{n_{50}}{3600}} \right)^2} = \frac{300 \frac{1.5}{3600} 0.07}{1 + \frac{0.07}{15} \left(\frac{170 - 170}{300 \frac{1.5}{3600}} \right)^2} = 0.00875 \quad m^3/s \tag{6}$$

For the mechanical ventilation n_{50}=1.5 1/h and the *e* and *f* coefficient were taken from standard EN 13790.

In Table 1 the summary of heat transfer coefficient for natural and mechanical ventilation is given.

Table 1: Heat transfer coefficient for ventilation

Ventilation	Heat transfer coefficient [W/K]
Natural	72.00
Mechanical	18.96

On the basis of the calculated values of heat transfer coefficient for ventilation the heat demand for whole year can be estimated. The calculation was done using Warsaw climate data and using monthly calculation method. In Table 2 the results of the calculation are presented.

Table 2: Heat demand for ventilation

Ventilation	Heat demand [kWh/a]
Natural	7031
Mechanical	1852

It can be noticed that heat demand in case of the mechanical ventilation is about 3.8 times less than for the natural ventilation. However in the mechanical ventilation additional energy for fans is required. Using the national regulation [4] it was assumed that in the mechanical ventilation two fans (each of 80 W) are installed and the ventilation is working whole year. For such data the energy demand for electricity was calculated.

$$E_{el} = 160 \cdot 8760 = 1387 \quad kWh/a \tag{7}$$

Taking into account the energy consumption of fans the mechanical ventilation system needs 1852 kWh of thermal energy and 1387.2 kWh of electrical energy. For the determination of the useful energy for heating only thermal energy needed to heat the ventilation air taken into account, while omitted larger and more expensive part associated with the electricity. A more complete assessment of the two systems is when referring them to the primary energy or costs. In the case of natural ventilation system thermal energy of 7031 kWh/a, is about 3.8 times higher than for the mechanical ventilation with heat recovery 1153 kWh/a. If we take into account the primary energy or costs, the mechanical ventilation system with heat recovery needs 1852 kWh/a + 3*1387 kWh/a = 6015 kWh/a primary energy to 7031 kWh for natural ventilation system, so that the difference is significantly reduced.

The first conclusion that must be drawn here is that the eligibility criterion in units of useful energy (heat) eliminate from the analysis a components necessary for the operation of technical systems including ventilation.

The second conclusion from the analysis is 3.8 times higher thermal energy consumption by natural ventilation system. Assessing qualifications or eliminations from the list of recommended technology, based on just the heat demand can lead to false results. After taking electricity consumption, it appears that natural ventilation is not much worse than mechanical. This means that at least should be allowed to be used along with mandatory recommendation.

The third conclusion is that eligibility criteria of useful energy should be supplemented by other forms of energy necessary for the operation of technical systems.

Natural ventilation is unpredictable and in many situations is not working. Demand controlled ventilation (DCV) eliminates the disadvantages of natural ventilation, making it works regardless of

weather conditions, and also by the ability to control ventilation can adjust the air flow in each room to the needs of users. In practice, the possibility of reducing the air flow is used in the absence of people or at night. Most of the central mechanical ventilation units has three levels of performance. Selection of these units is made in such a way as to meet the hygienic performance requirements for middle level of ventilation unit performance. Installed in the units programmers allow individual time programming of the air flows. Inhabitants reduce airflow during their absence, and increase it in the summer in order to disperse of the heat gains. Sometimes they turn down mechanical ventilation and open windows (which from the point of view of the Polish regulations is not allowed).

In the case of demand-controlled ventilation it is possible to individually adjust the air flow to the ventilation needs in each room. The degree of this adjustment depends on the technical sophistication of the system. Below, the estimation of the ventilation air flow reduction in accordance with the technical capabilities of both ventilation systems and the impact of the reduction on the heat and electricity consumption are presented.

4.1 Mechanical ventilation with heat recovery

Mechanical ventilation should work whole year, for 8760 hours. In presented case study the calculated hygienic air flow is equal 170 m^3/h. The second step (II) in the mechanical ventilation unit provide 200 m^3/h (first step (I) gives 100 and third (III) 400 m^3/h). It was assumed that in the winter ventilation unit on II step only during the presence of all inhabitants for example during 12 hours a day, at other times is running at I step. In the summer, during the day (approximately 10 hours) in order to disperse heat from the solar gains a ventilation unit is operating at III step and at the rest of the day at II step. This assumption is justified if we assume that the priority of people is the most out of the ventilation system. In practice, in the summer ventilation system is used to set hygienic air flow requirements and the heat gains are being removed by opening of the windows. In accordance with Polish ventilation regulation a ventilation air flow for the calculation can be reduced by 40%.

Average hourly flow of ventilation air supplied during the heating season by the air handling unit is (5840 * 170 + 0.6 * 170 * 2920) / 8760 = 147 m^3/h, and in the summer is 170 m^3/h, therefore to calculate the electricity consumption of the fans we can assume that the ventilation unit operates all year round on the second step providing 200 m^3 of air per hour. From this assumption the heat transfer coefficient for mechanical ventilation with 85% of the heat recovery is equal:

$$H_{ve} = \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn} \right) = 1200 \cdot \left[\left(1 - \eta_{HR} \right) \cdot 0.6 \cdot V_f + 1 \cdot V_x \right] = \\ = 1200 \cdot \left[0.15 \cdot 0.6 \cdot 0.047 + 1 \cdot 0.00875 \right] = 16.55 \quad W/K \tag{8}$$

The heat demand for this case is equal to 1616 kWh/a.

Calculation of electrical energy consumption should be made on the basis of the technical specifications of the selected ventilation unit. After analyzing of several air handlings units it can be assumed that on the second step the fan power is equal to 150 W (see Table 3).

Table 3: Fan power at given air flow rate of selected air handling unit

Step of working	Air flow [m^3/h]	Fan power [W]
I	100	38
II	200	150
III	400	600

For such data the energy demand for electricity was calculated.

$$E_{el} = 150 \cdot 8760 = 1314 \quad kWh/a \tag{9}$$

Taking into account the energy consumption of fans the mechanical ventilation system with 85% heat recovery needs 1616 kWh/a of thermal energy and 1314 kWh/a of electrical energy.

Assuming primary energy factors (gas primary energy factor = 1.1 and electricity 3.0) and energy cost (0.54 PLN/kWh for electricity and 0.20 PLN/kWh for gas, 1 euro = 4 PLN) the total primary energy demand and total operating costs can be calculated. The results are presented in Table 4.

Table 4: The primary energy and total operation cost of mechanical ventilation with heat recovery

Parameter	Heat	Electricity	Total
Primary energy [kWh/a]	1.1*1616	3*1314	5720
Cost [PLN/a]	1616*0.20	1314*0.54	1032.76

4.2 Demand Control Ventilation (DCV)

Ventilation DCV is a type of mechanical exhaust ventilation in which the area of the inlet openings are regulated and the buoyancy force is supported when needed (at times when the temperature difference is too small to produce adequate buoyancy). The buoyancy force is supported by low-speed exhaust fan mounted on the outlet duct. The power of such fun for the single family building is about 6-10 W. In the heating period the number of hours in which a temperature is above 12℃ is about 1000. In the summer, the building is ventilated by opening the windows.

The heat transfer coefficient for DCV ventilation can be calculated from following formula:

$$H_{ve} = \rho_a \cdot c_a \cdot \sum_k \left(b_{ve,k} \cdot V_{ve,k,mn}\right) = 1200 \cdot \left[1 \cdot V_0 + 1 \cdot V_x\right] = \\ = 1200 \cdot \left[0.7 \cdot 170/3600 + 1 \cdot 0.00875\right] = 50.2 \quad W/K \tag{10}$$

According to the Regulation on the scope and form of the energy audit using automatically regulated diffusers the ventilation air flow can be reduce by a factor of 0.7.

The heat demand for this case is equal to 4902 kWh/a.

For such data the energy demand for electricity was calculated.

$$E_{el} = 10 \cdot 8760 = 88 \quad kWh/a \tag{11}$$

Taking into account the energy consumption of fans the DVC ventilation system needs 4902 kWh/a of thermal energy and 88 kWh/a of electrical energy.

Assuming primary energy factors (gas primary energy factor = 1.1 and electricity 3.0) and energy cost (0.54 PLN/kWh for electricity and 0.20 PLN/kWh for gas) the total primary energy demand and total operating costs can be calculated. The results are presented in Table 5.

Table 5: The primary energy and total operation cost of DCV ventilation

Parameter	Heat	Electricity	Total
Primary energy [kWh/a]	1.1*4902	3*88	5655
Cost [PLN/a]	4902*0.20	88*0.54	1027.92

The presented analysis of energy demand of three systems: natural ventilation, mechanical

ventilation with heat recovery and DCV ventilation, done on the basis of existing legislation and the given assumptions indicates a significant disadvantage for determining energy standard of buildings in units of useful energy. Forcing investors to use mechanical ventilation leads to some savings during heating period, but that decision has consequences related to the consumption of electricity during whole year. As shown in Table 5 it can lead to higher operating costs of the mechanical ventilation system than DCV. The estimation of the operation cost of mechanical ventilation does not include: the cost of filters replacement and electricity consumption of the heater to defrost the heat exchanger or to heat the inlet air. This is important in the case of high-performance heat exchangers (eg 85% such as that above). Detailed calculation of energy demand for these ventilation systems can be performed using the simulation method. These considerations were carried out using standard balance methods just to address the problem.

5. Conclusions

On the basis of the considerations, the choice of indicator for requirements should include not only the useful energy (heat), but also electricity (heater) and other non-energy operating costs (filters). The correct ratio is multi-dimensional, and its range depends on the used assumptions.

As it was presented in the analysis the total primary energy demand can be higher for systems with lower energy demand for heating (DCV ventilation vs. mechanical ventilation with heat recovery). In some cases the additional energy demand for electricity for fan can provide higher primary energy demand for whole building. Also the operational cost are higher in the case of mechanical ventilation with heat recovery. It must be stated that in the cost calculation only energy cost were taken into account.

The given consideration shows that the estimation of energy requirement can not be done using only one indicator eg.: useful, final or primary energy. Such approch may leads to excluding some systems that can be other than recomended.

The paper was focused on requirements for heating period. It should be noticed that requirements only for heat demand decreasing can lead to very good standards in the heating and overheating in the summer. For example, nearly zero-energy buildings in Denmark and Belgium are checked for possibility of overheating. Using Polish methodology of energy demand calculation such indicators are not calculated.

6. Acknowledgements

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7. References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (OJ L 153, 18.06.2010).

[2] Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements.

[3] Implementation of the Energy Performance of Buildings Directive (EPBD), Country Reports 2008, Brussels, 2008, ISBN 2-930471-29-8, EAN 9782930471297)

[4] “Ordinance of Minister of Infrastructure on methodology of energy characteristic calculation for building and dwellings or part of the building of separate technical and usage function and the preparation and presentation of theirs certificates of energy performance” from 6th November 2008.

Where is the embodied CO_2 of buildings mainly located? Analysis of different types of construction and various views of the results



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Short Summary

A set of four buildings with different types of construction was analysed using a Life Cycle Assessment (LCA) in order to identify the main contributors to overall embodied carbon emissions. The results are presented by virtually “cutting” the buildings in two different ways, focusing not only on the building as a whole, incorporating all its various materials, but also on the individual impact of each building element (floor, ceilings, external walls, etc.) on the one hand, and on the impact of a predefined standard enclosed floor space (e.g. basement space, typical floor space, roof space) on the other. The aim of this approach is to clarify what the interrelations of the different individual parts of the buildings are within their overall functional context while at the same time allowing for a meaningful representation and interpretation of their respective impacts with regard to embodied carbon emissions. As a result, different perspectives and levels of detail are covered in the critical impact evaluation of each building, giving a thorough and comprehensible answer to the question of where the embodied CO_2 of the buildings is primarily located. The allocation of carbon emissions to the floor space of each storey, instead of to the floor space of the whole building, demonstrably produces relatively homogeneous results, which facilitate the comparison of the buildings from the sample and their diverse characteristics.

Keywords: buildings; carbon emissions; different types of construction; different perspectives

1. Introduction

Life Cycle Assessment (LCA) has been established as an effective method for evaluating the environmental impact of products and services over their lifecycle. The general LCA procedure is described in the ISO regulations 14040 [1] and 14044 [2]. For LCAs of buildings, the DIN EN regulation 15978 [3] gives a more detailed description of the aspects that require particular consideration in the context of a building. Despite many efforts in recent years to simplify the rather complicated LCA procedure for buildings, in order to make it more easily applicable to the needs of architects and planners, there are still various challenges to be met. An essential one of these is the presentation of LCA results in a way that clearly provides valuable information for the architect regarding which building elements contribute most to the overall environmental impact of a building. As architects characteristically have a strong visual perception of the built environment, it is crucial to provide them with more than just a numerical analysis of a building’s environmental impact in order to help them advance their building designs. A thorough and comprehensible answer to the question of where the embodied CO_2 of the buildings is primarily located requires a critical impact evaluation of a building that incorporates different perspectives and different levels of detail. The key to addressing this challenge and to facilitating LCAs of buildings could be the definition of the functional unit in a more intuitive way than is usually applied in existing studies.

The functional unit is the unit to which all inputs (resources, energy) and outputs (waste, emissions), as well as the environmental impact results of an LCA refer. In this paper, the authors utilize two different functional units: one is a functional unit commonly applied in many existing LCA studies of buildings (1 m² of general floor space per 1 year of the building's lifetime); the other is a functional unit that corresponds to 1 m² of a specific floor space (basement, ground floor, upper floor or loft) per 1 year of the building's lifetime. A building sample of four individual apartment buildings is analysed in a comparative LCA and the results for the embodied carbon emissions of each building element are displayed for both functional units. Two different virtual cutting approaches for the buildings are required in order to properly determine the emission results of the two functional units. A schematic view of the second cutting approach helps visualize the different concepts. In chapter 2, the characteristics of the four buildings from the sample are introduced, followed in chapter 3 by the LCA modelling specifications, which were applied for the calculation of carbon emissions. In chapter 4, the two different approaches to virtually cutting the building are described and in chapter 5, the carbon emission results for both functional units are presented, followed by the conclusion and discussion in chapter 6.

2. Characteristics of the building sample

The building sample consists of four apartment buildings with diverse characteristics.

- **Building 01** is the largest of the four buildings. It contains 111 accommodation units and is a massive construction, mainly of reinforced concrete (floor, ceilings, external and internal walls, roof) and concrete block (internal walls). Insulation materials are the following: recycled glass foam fill, expanded polystyrene, polyurethane foam, mineral wool, and extruded polystyrene. There are five floors above ground and one basement floor (including underground parking spaces). The building has a flat roof planted with vegetation. The energy reference area of this buildings is 12 430 m^2.

- **Building 02** is a medium-weight construction and contains two accommodation units. The construction is mainly of reinforced concrete (floor, ceilings, external and internal walls), timber (ceilings, external and internal walls, roof), and sand-lime brick (internal walls). Insulation materials are the following: mineral wool, recycled glass foam fill, extruded as well as expanded polystyrene, and polyurethane foam. The building has three floors above ground and one basement floor. It has a pitched roof clad in fibre cement. The energy reference area of this building is 350 m^2.

- **Building 03** is a lightweight construction containing three accommodation units. The construction materials are timber (ceilings, external and internal walls, roof) and reinforced concrete (floor, ceilings, external and internal walls). Insulation materials are the following: mineral wool, recycled glass foam fill, foam glass and cellulose fibres. There are three floors above ground but no basement. The building has a flat roof planted with vegetation. The energy reference area of this building is 374 m^2.

- **Building 04** contains four accommodation units and is a massive construction. The materials used for the main construction are reinforced concrete (floor, ceilings, roof) and masonry (external and internal walls). Insulation materials are the following: expanded polystyrene and polyurethane foam. There are two floors above ground and one basement floor. The building has a pitched roof clad in galvanized sheet steel. The energy reference area of this building is 622 m^2.

Details of the building characteristics can be found in the descriptions of mfh01, mfh02, mfh03 and mfh04 in the dissertation by V. John [4].

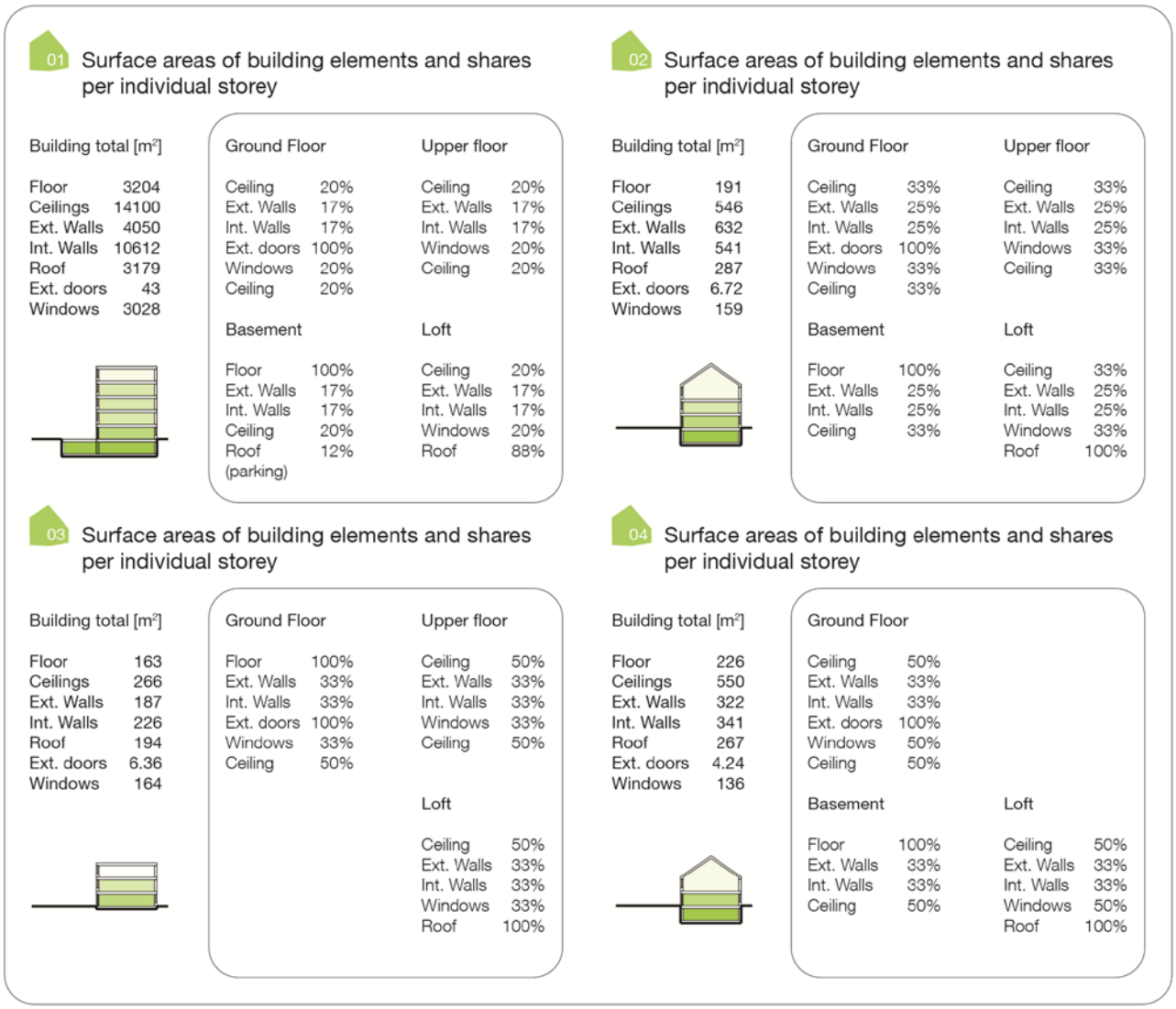


Fig. 1 Surface areas of the building elements and their shares per individual storey

3. LCA modelling specifications

The carbon emission results were calculated using the professional LCA Software SimaPro [5] (version 7.3.0) with the implemented LCI database Ecoinvent [6] (version 2.2). The values indicate the Global Warming Potential GWP 100a (IPCC 2007 GWP 100a V1.02 [7], referring to a time horizon of 100 years for emissions). Included in the calculations are all materials required for the construction, replacement and deconstruction of the building elements (floor, ceilings, external and internal walls, roof, external doors, and windows) over the building's lifetime of 60 years. It is assumed that the main construction materials have a service life of 60 years, while all other materials need replacement after 30 years (with some minor exceptions). All LCA modelling specifications for the buildings can be found in the appendix of the dissertation of V. John [4].

4. Approach: virtual cutting of the buildings

For the presentation of carbon emission results for the four apartment buildings, two different virtual cutting approaches have been chosen for comparison.

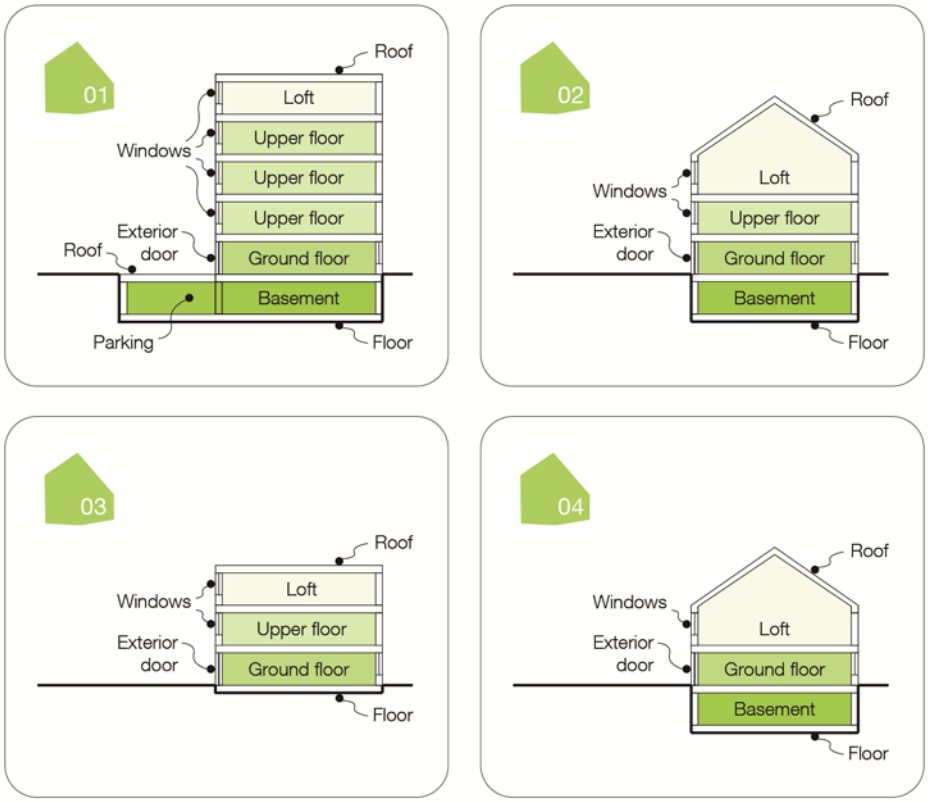


Fig. 2 Schematic view of the floor space characterisations for the virtual cutting approach 2

4.1 Virtual cutting approach 1

The first approach aims at breaking down the total kg CO_2 eq of each building to the functional unit of 1 m² of general floor space (in this case the energy reference area) for 1 year of the building's lifetime. This approach is commonly utilized for LCAs of buildings and facilitates a general comparison of the four buildings by levelling out the huge differences in building sizes. It is, however, not the best way of showing clearly where exactly the main contributors to the final result are situated within the building. When looking at a building from an architect's point of view, there is no such thing as a general 1 m^2 of floor space to which the overall building emission results could be meaningfully allocated. Instead, each storey has its individual contributors to the final result. The floor element, for instance, only contributes to the lowest building storey, while the roof element normally only covers the top storey. Furthermore, the exterior door is usually on ground floor level, while external and internal walls are found on all storeys.

4.2 Virtual cutting approach 2

Consequently, the second approach to virtually cutting the buildings aims at systematically defining four typical storeys within a building according to their specific, typical characteristics. The carbon emissions are then calculated for 1 m² of this specific floor space for 1 year of the building's lifetime. The characterisation of the storeys follows some simple rules defined by the authors:

- **Loft**
  The top storey of the building, defined as consisting of the elements roof, ceiling (at the bottom of the space), windows, and external and internal walls.

- **Upper floor**
  The storey(s) between ground floor and loft, defined as consisting of the elements ceiling (at both the bottom and top of the space), windows, and external and internal walls.

- **Ground floor**
  The first storey above ground, defined as consisting of the elements ceiling (at both the bottom and top of the space), external doors, windows, and external and internal walls.

- **Basement**
  The storey below ground, defined as consisting of the elements floor, ceiling, and external and internal walls.

Within the building sample, two exceptions from these rules were found in the buildings 01 (where, due to the underground parking space, the roof element had to be partly allocated to the basement) and building 03 (where the basement is missing, so that the floor element is allocated to the ground floor instead).

To enable easy and consistent calculation of the individual shares of each building element per storey, the total surface area of each element was divided by the number of events in which it occurs in the building. For instance, in building 01, there are five ceilings within the whole building, as can be seen in the schematic vertical sections in Fig. 1 and Fig. 2. This means that for each event the share of the ceiling is 20%. When computing the values for the ground floor storey, this leads to a total contribution of 40% of the total ceiling surface area, as there is a ceiling element on top as well as on the bottom of this storey. It is worth mentioning that the splitting of the buildings into the four aforementioned storey types leads to the ceilings being counted twice, so that, in the end, the sum of the results for all the storeys of one building is higher than the original total result for that same building. However, this is unproblematic, as this approach aims at comparing the characteristics and embodied emissions of each individual storey rather than those of the whole building. The total surface areas, as well as the shares of all element contributions for each storey, are shown in Fig. 1. Fig. 2 illustrates the main characteristics of each of the buildings from the sample.

5. Carbon emission results for the two different cutting approaches

5.1 Results for virtual cutting approach 1

Fig. 3 shows the results of the embodied carbon emissions analysis for each building element of each building, using the unit kg CO_2 equivalents per 1 m^2 of energy reference area for 1 year. The graph shows clearly that with this virtual cutting method there is much variation in the distribution and relevance of the results for the different elements. While in buildings 01 and 04 the ceilings and the roof contribute the most to the overall environmental impact of the building, for building 02 the external walls and ceilings are most influential and for building 03 it is the roof, windows, floor and ceilings that affect the result most significantly. These graphs reflect the high degree of originality of each building, emphasising its individual characteristics in comparison with the others.

5.2 Results for virtual cutting approach 2

The graphs in Fig. 4 show the results of the second cutting approach and allow a clearer understanding of where exactly the most significant carbon emissions are located within the building. In the graph at the top left-hand corner of Fig. 4, the results for the annual embodied emissions are shown for each of the buildings per 1 m^2 of individual storey floor space of the basement, ground floor, upper floor and loft respectively. Viewing the building elements in this way, the four buildings display fewer individual differences and a more consistent distribution of the carbon emission results than was observed in Fig. 3 using the first cutting method. Of the four buildings, building 01 has the highest carbon emissions for each storey. The percentage values displayed below this graph indicate the differences in environmental impact of the other three buildings from the sample in comparison with building 01. For the basement, the differences in the results of the four buildings vary by a maximum of 27%, the results of the ground floor by 33%, the

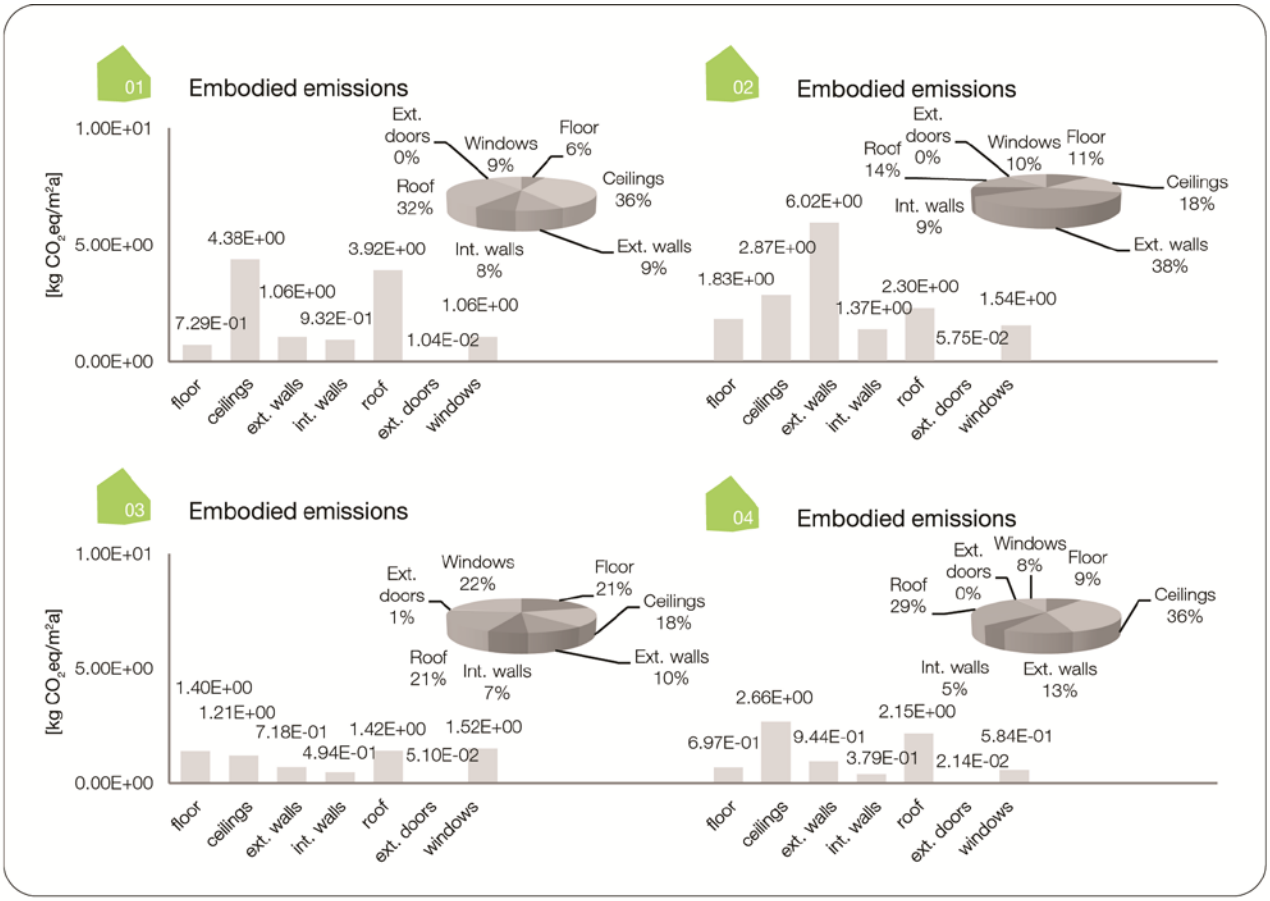


Fig. 3 Embodied carbon emission results (virtual cutting approach 1)

upper floor results by 41%, and the loft results by a maximum of 56%. The individual contributions of the building elements per storey are shown in the graphs at the bottom of Fig. 4. The generally high influence of the ceiling and roof elements for the buildings 01 and 04, the dominant influence of the external walls and ceilings in building 02, as well as the influence of the roof, windows, floor and ceilings in building 03, are also apparent with this second cutting approach. Nevertheless, the buildings resemble each other much more closely when comparing the pie charts of each of their storeys individually than when comparing the buildings as single units. It can be observed by comparison of Fig. 3 and Fig. 4 that by cutting the building into different storeys a more detailed depiction of the embodied carbon emissions for each individual building is obtained, while at the same time a higher degree of similarity within the building sample is perceptible. This enables the determination of the embodied emissions for an average square metre of a basement, ground floor, upper floor and loft. It can be stated, that for this particular building sample a typical square metre of basement contributes 8.07 kg CO_2eq/m^{2}a (±16% deviation) on average, while for the ground floor it is 8.48 kg CO_2eq/m^{2}a (±20% deviation). The upper floor accounts for a mean of 8.04 kg CO_2eq/m^{2}a (±26% deviation) and the loft contributes 14.86 kg CO_2eq/m^{2}a (±45% deviation). Apparently, the basements, ground floors and upper floors of the four buildings have nearly the same environmental impact on average, while the lofts exhibit the largest deviation in their results.

The four graphs at the top right-hand corner of Fig. 4 show the amounts of embodied emissions per 1 m^2 of individual storey floor space for 1 year (y-axis) and the total size of the storey floor space (x-axis) for all four buildings together. For this particular building sample, there appears to be a linear trend, indicating that an increase in total storey floor space leads to an increase in the annual embodied emissions per 1 m^2 of individual storey floor space. However, in order to verify this trend, it would be essential to analyse more buildings, preferably with an energy reference area of ≥ 1000 m^2, as there is a huge gap in the divergence of the sizes of the buildings 02, 03 and 04 on the one hand, and building 01 on the other.

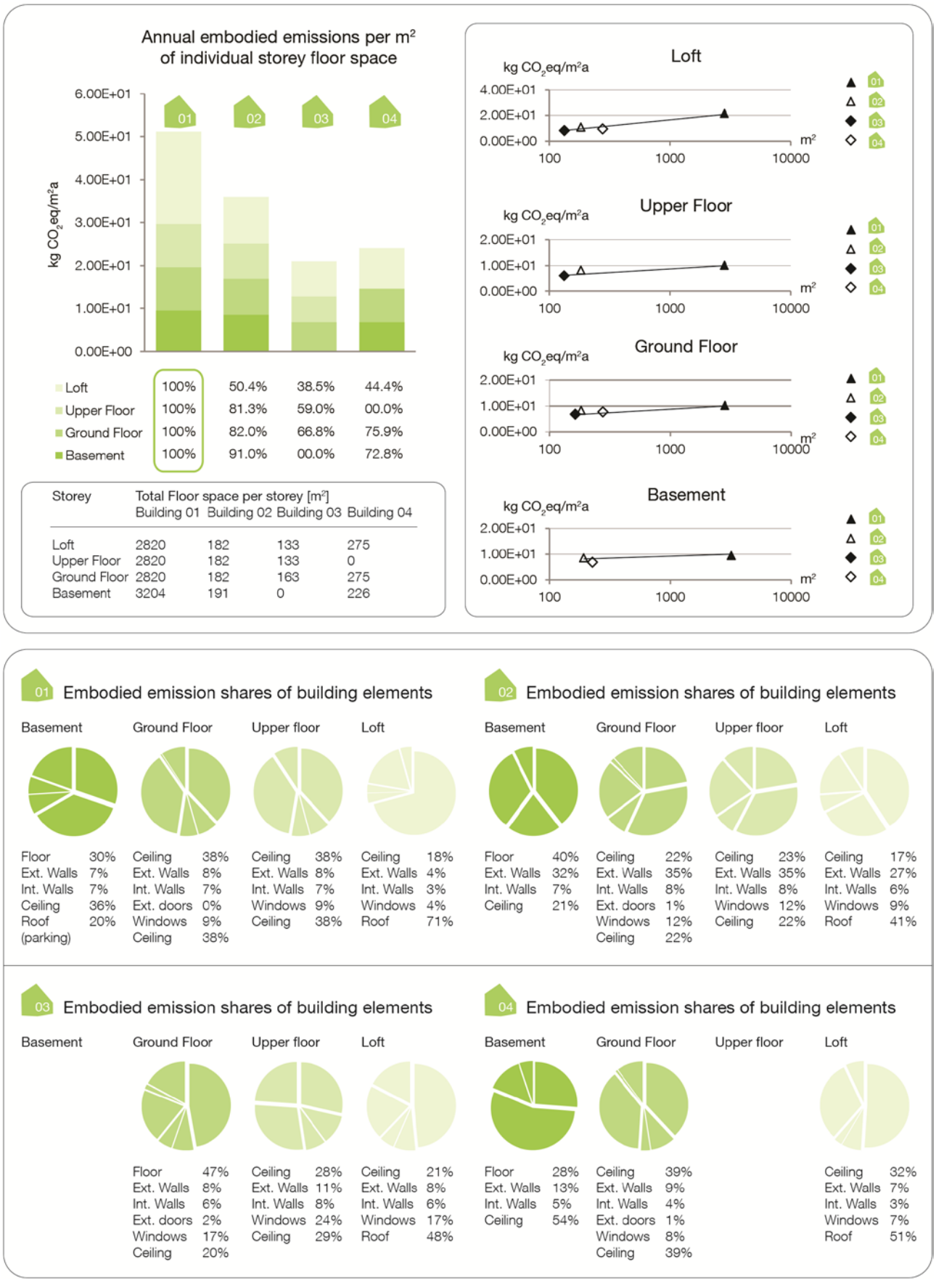


Fig. 4 Embodied carbon emission results (virtual cutting approach 2)

6. Conclusion and discussion

The presented approach of virtually cutting the buildings from the sample in two distinct ways helps to clarify the interrelations of the different individual parts of the buildings within their overall functional context. While the first functional unit can be utilized in order to get a broad view of the embodied carbon emissions of the various building elements of the whole building, the second functional unit enables a more sophisticated allocation of the results, with regard to the anticipated location of the most relevant elements per storey. In their combination, the two approaches allow a meaningful presentation and interpretation of the impact of each of the building elements by showing them from different perspectives and with different levels of detail. It can be observed that the second virtual cutting approach shows fewer individual differences and a more generic distribution of the carbon emission results of the four buildings compared with the results of the first cutting approach. This second approach thus helps to derive a comprehensive and intelligible answer to the question of where the embodied CO_2 of the buildings is mainly located, and, beyond that, helps determine the embodied emissions of an average square metre of basement, ground floor, upper floor and loft with a minimum and maximum deviation from the mean value. As the buildings within the depicted set exhibit a high level of variety with regard to their construction types and the embodied carbon emissions of their individual building elements, the rather high degree of homogeneity of the results as displayed by the second virtual cutting approach is especially remarkable. It was demonstrated that by schematically cutting the buildings on the basis of only a few simple conceptual assumptions about the specifications of each storey, a consistent comparison of a set of diverse buildings is feasible, and that quite similar results can be generated from the direct comparison of the same storey of the various buildings. It was shown, that the carbon emissions results per specific storey floor space of the basements, ground floors and upper floors of the four buildings are nearly the same on average (around 8 kg CO_2eq/m^2a), while the loft exhibits a significantly larger variation in the results than the other storeys. This finding might help in roughly estimating the impact of a standard storey of a building. Determining the impact of a standard storey of basement, ground floor, upper floor and loft can help architects and planners to quickly evaluate the performance of their building design using these values as benchmarks, enabling them to localize which storey and which building elements bear the highest optimization potential for their specific project.

References

[1] ISO INTERNATIONAL ORGANIZATION FOR STANDARDIZATION *„Umweltmanagement – Ökobilanz, Grundsätze und Rahmenbedingungen“*. EN ISO 14040, 2006.

[2] ISO INTERNATIONAL ORGANIZATION FOR STANDARDIZATION *„Umweltmanagement – Ökobilanz, Anforderungen und Anleitungen“*. EN ISO 14044, 2006.

[3] DIN GERMAN INSTITUTE FOR STANDARDIZATION *“Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method”*. German version EN 15978:201, 2012.

[4] JOHN V. *“Derivation of reliable simplification strategies for the comparative LCA of individual and "typical" newly built Swiss apartment buildings”*. ETH Zurich, Zurich, DOI: http://dx.doi.org/10.3929/ethz-a-007607252; 2012.

[5] PRODUCT ECOLOGY CONSULTANTS “*SimaPro LCA Software”*. Available from: http://www.pre.nl/simapro/.

[6] ECOINVENT CENTRE “*Database ecoinvent data”*. Available from: http://www.ecoinvent.org/.

[7] IPCC “*Climate Change 2007: Working Group I: The Physical Science Basis”*. 2007.

D2

Renewables

Chair: Bastian Wittstock
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Zero Carbon Village

Energy self-sufficiency, Modular Prefabrication and Sustainable Building Materials



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Short Summary

Zero Carbon in the building industry is a goal that can be reached by focusing on energy- and resource-efficient solutions and by utilising renewable resources both for building materials and energy supply. By this, buildings and settlements can become CO_2 neutral and independent from fossil energy resources. The project *Zero Carbon Village* has developed solutions in three strands and is planning to implement them in a residential settlement:

1. Efficient modular prefabrication, consisting of a technical part (industrialised prefabrication of building and service modules) and an organisational part (*virtual factory*)
2. Highly energy-efficient and sustainable building materials (straw bales as insulation materials in prefabricated wooden frames)
3. Energy self-sufficiency: Buildings shall be supplied mainly with renewable thermal energy

In the strand of *modular prefabrication*, industrialised mass production of ecological passive houses and modules and the development of a *virtual factory* lead to an improved competitiveness, higher quality, and higher flexibility. Modular building elements can more easily be disconnected and upgraded with respect to changing user expectations (*re-use system*). In the concept of the *virtual factory* existing SMEs (small and medium enterprises) produce building parts in a decentralised way while a central umbrella organisation takes care of logistics and marketing. This concept takes into account the requirements and resources of small companies.

Not only building elements, but also construction materials can be re-used and recycled. Disposal of materials should always be the last option (*cascades principle*). The development of *highly energy-efficient and sustainable building materials* based on renewable resources is an important step towards the reduction of “grey energy”. Straw bales as certified building material play an important role: they have been adapted for pre-fabrication and modular construction, based on results of previous projects (certification of straw bales). Logistics and production processes were optimised as well in order to reach high quality of the building material.

Energy self-sufficiency of the buildings in the settlement is based on the utilisation of thermal energy, which is gained from solar energy and biomass. The *Zero CO_2 Cooler*, a refrigerator running on hot water, is also being developed to be integrated in this system.

Keywords: Renewable building materials; renewable energy; life cycle analysis; life cycle design; sustainable systems for buildings

1. Introduction

A relatively large percentage of energy and resource consumption occurs in the building sector [1]. This concerns the production of building materials, the construction of buildings and also the energy consumption during the use phase caused by the users. Energy for space heating and increasingly for space cooling is needed especially for buildings of low energetic standards. Furthermore, energy for domestic hot water and appliances (like cooking stove, washing machine, light and other electrical devices) is required. Along the life cycle of buildings additional energy and resource consumption results from demolition and disposal of buildings or building parts at the end of their lifetime.

Huge amounts of construction waste are a further consequence of demolition or remodelling of buildings as well as waste at the construction site (packaging, plastic pipes, clippings of insulation materials etc.), which is difficult to recycle or dispose of.

1.1 Project aim

With its high consumption of energy and thus mostly fossil fuels for the majority of processes, the building sector is also one of the biggest perpetrators of CO_2 emissions. But buildings and settlements can become CO_2 neutral and independent from fossil energy resources. To reach this goal, different solutions have been developed to be implemented in a settlement in Lower Austria, containing residential buildings, a community center and an innovative energy supply system.

1.2 Methods

The concept of Zero Carbon Village is based on energy-efficient building solutions (passive house components, improved household appliances, thermal insulation etc.) and on the utilisation of renewable resources for building materials to reach a lower energy demand for production as well as shorter transport distances. In addition to this, deconstruction is considered from the planning process on to promote recycling and composting after the use period. For a further reduction of the carbon footprint it is also necessary to have an energy system using locally available renewable resources.

2. Modular Prefabrication

One of the approaches to reach the aim of resource and energy-efficiency is the standardised prefabrication of components combined with an efficient coordination of the participating companies. With this strategy, waste will be reduced to a minimum as well as unnecessary material consumption through design and installation errors [2].

2.1 Advantages of prefabricated building parts

In the field of industrial prefabrication, manufacturing processes of building components and modules are standardised so that the finished parts are aligned to each other. Therefore the construction time on the building site can be shortened, material waste reduced and assembly faults avoided.

Prefabrication is already possible for large elements, such as complete bathrooms units or rooms with integrated kitchens [3]. Continuation of modularisation should encompass the manufacturing of compatible elements for the building envelope, housing technology as well as appliances. This requires inter alia a well-planned cabling concept for all components of the energy system (supply and demand side). The system of wires and pipes should be kept short and without crossing so that the elements are easy and fast to connect on the construction site. The cabling has to be taken into account already in the planning phase. The design of the floor plan types is important in this context as well if the modules and the housing technology should be combined in an efficient

way while still allowing flexibility.

Beside an efficient connection of the building envelope and housing technology in a high quality, the modular building elements have the advantage of being easily assembled, disassembled and upgraded after their useful life or when user demands change (*re-use system*) (see fig.1) [4].

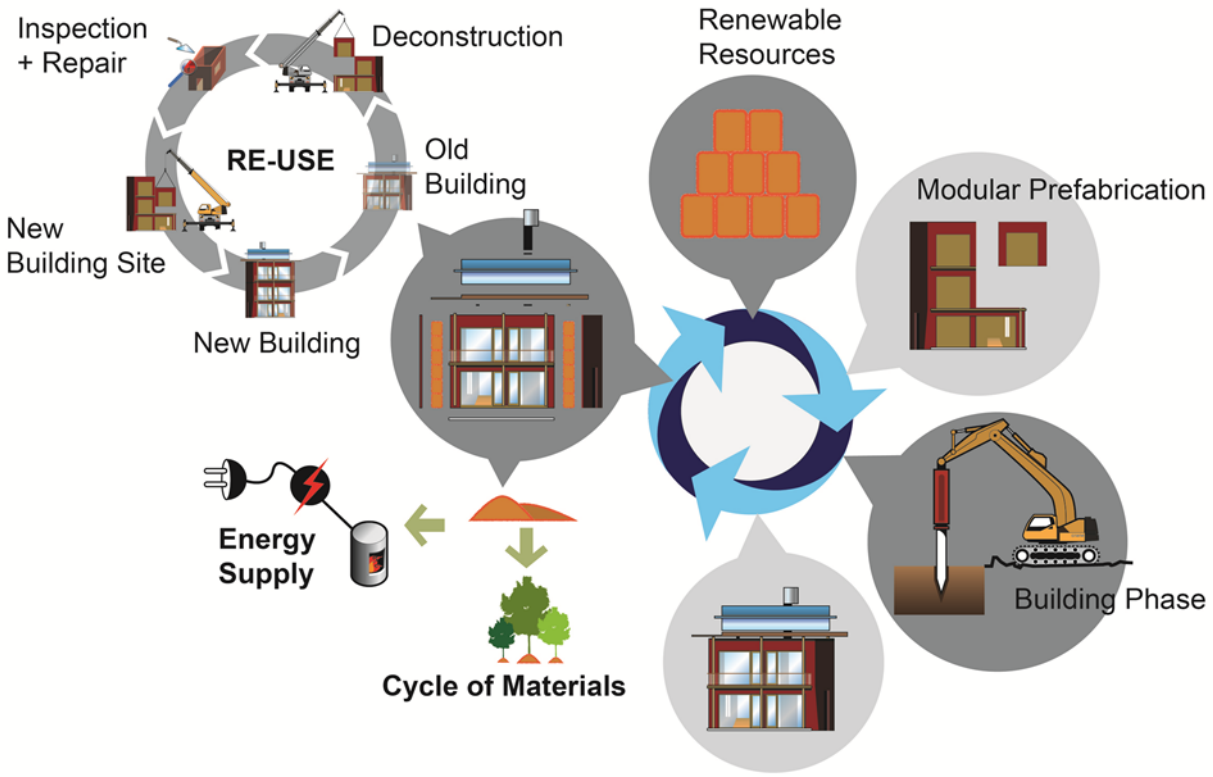


Fig. 1: Life cycle of building materials and components [4]

Waste as well as time and energy can be saved during the building phase through prefabrication of elements and modules. This is not only beneficial for building owners, but also for manufacturers because of a more economic production with higher quality.

2.2 Virtual factory

The production of prefabricated modules can take place according to the concept of the *virtual factory*. In this concept single elements or building parts can be produced in a decentralised way by a network of SMEs (small and medium enterprises) around the key trades builder/carpenter. Logistics and marketing on the other hand are performed by a central umbrella organisation to increase efficiency and competitiveness. The whole process is carried out through integral planning in which also the clients are involved from the beginning. In the virtual factory individual enterprises can continue to work in their own domain and region, but realise major projects together with the other partners.

This organisational concept combined with modular prefabrication is an efficient way of reaching high quality of the manufacturing of buildings and is also perfectly suitable for the use of regional construction materials to contribute to the overall objective, the increase of the regional added value (see fig. 2). [4;5]

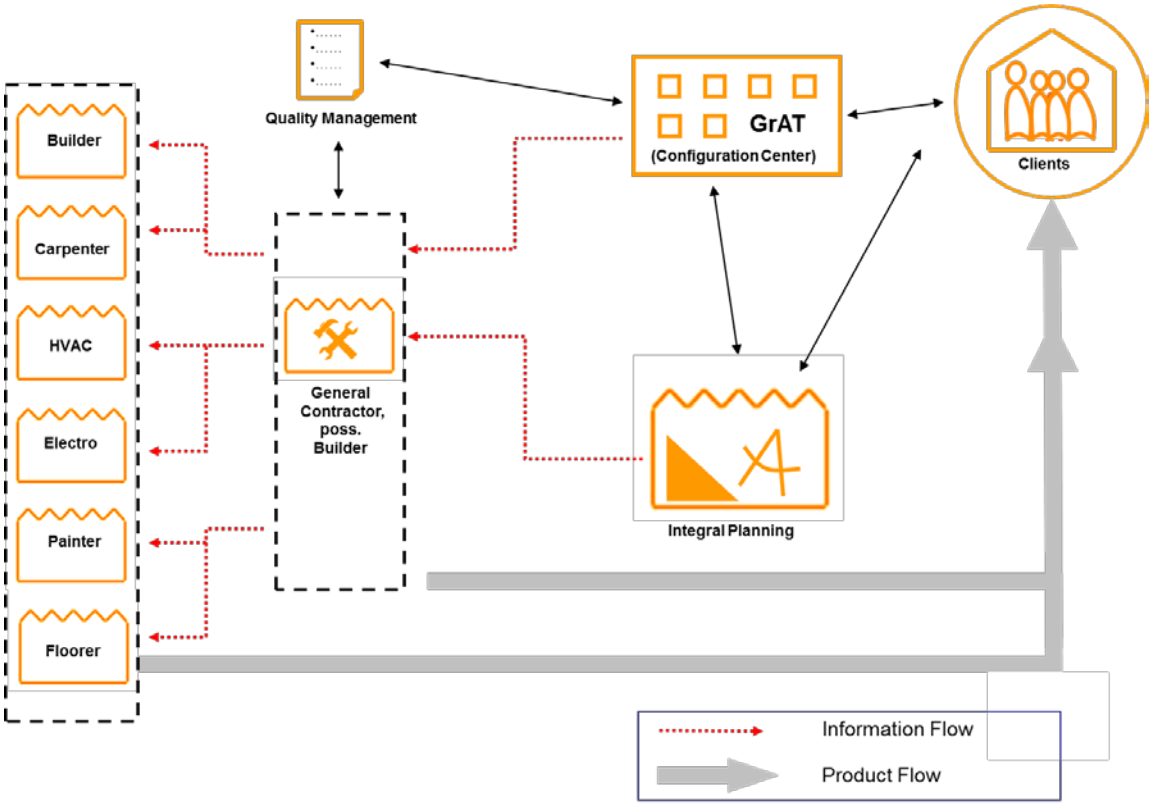


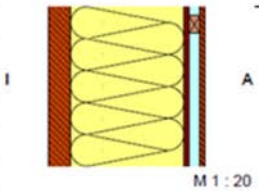
Fig. 2: Virtual factory [5]

3. Sustainable Building Materials

Not only whole building parts and modules, but also individual construction materials can be re-used, recycled or used for energy production, as shown in fig. 1. The degree of recyclability depends on the properties of the used materials as well as their assembly within the construction.

Highly energy-efficient and sustainable building materials based on renewable resources, such as straw bales, have been proven to be functional, and show a very low primary energy demand (PEI) and positive effect for the CO_2 balance of the building [6;7;8]. With the Austrian Technical Approval (ÖTZ) in 2010, the functionality of straw bales as an insulation material has been certified [9]. Because of the simple production process (the raw material straw only needs to be pressed and tied up) the production energy of the straw bales is by a factor of 100 lower in comparison to conventional insulation materials such as EPS, comparing wall constructions with the same U-value. There are several variants for wall construction using wood and straw, one of which is pictured in fig. 3.

AW straw-wood
E-I



		d [m]	λ [W/mK]	R [m2K/W]	GWP [kgCO2eq/kg]	PEI n.e. [MJ/kg]	usage period
1	wooden facade	0,0200			-1,690	2,270	60
2	wooden laths	0,0500			-1,600	4,290	60
3	clay plaster	0,0200	0,810	0,025	0,003	0,343	100
4	straw-bales	0,5000	0,045	11,111	-1,250	0,846	50
5	CLT-wood	0,1280	0,130	0,985	-0,080	4,600	100
	heat transfer resistance			0,170			

			GWP	PEI n.e.	
0,7180	RT =	12,291	[kgCO2eq/m²]	[MJ/m²]	74
	U =	**0,081**	-96,49	390,16	

Fig. 3: Wall construction of renewable and local materials [10]

A first variant consists of whole modules which have been prefabricated and filled with insulation material in the factory. A second option is to prefabricate individual elements and then let SMEs of the virtual factory assemble them on the construction site.

For the second variant, as shown in fig. 3, it is possible to prefabricate the elements made of CLT (cross laminated timber) accurately with a CNC shaper as well as the wooden components for the façade, which then are supplemented on site with the materials straw and clay, which were taken from immediate vicinity. All materials used in this construction can be disassembled and therefore re-used or recycled (see cascade principle in fig. 4).

Disposal of materials, renewable or non-renewable, should always be the last option. A lot of cascade potential however is wasted because of material composites which are no longer separable. Therefore it is necessary to use detachable connections and fittings, which can already be foreseen in the factory. Concerning the re-use and recycle possibilities it is hence important to examine not only single materials but to evaluate the entire construction [10].

Wood-straw wall construction	Useful life	Composting	Product recycling	Material recycling	Thermal utilization	Disposal	Additives	Regional
CLT-wood	100	no	re-use	further use -> e.g. chipboards	yes - 18 MJ/kg	possible after thermal pre-treatment	very small proportion of binder materials (PUR adhesive)	yes
straw bales	50	yes (after opening)	re-use (if necessary cutting/tying -> insulation material)	further use (opening, if necessary baling) -> straw bales, fertilizer, bedding	yes - 17,5 MJ/kg	possible after thermal pre-treatment	thread (hemp, sisal, PP)	yes
clay plaster	100	yes (if only natural additives)	re-use (moistening with water, cleaning -> clay plaster)	further use (moistening with water) -> new clay products	not possible	disposal category 3 possible (but usually composting)	hemp, flax etc. possible	yes
wooden laths (timber, planed, tech. dried)	60	yes	re-use	further use -> e.g. chipboards	yes - 18 MJ/kg	possible after thermal pre-treatment	-	yes
wooden fasade (timber, rough, air dry)	60	yes	re-use	further use -> e.g. chipboards	yes -18 MJ/kg	possible after thermal pre-treatment	-	yes

Fig. 4: Cascades principle [10]

4. Energy self-sufficiency

Demand for electricity keeps rising in private households of EU-27 countries, despite increasingly energy-efficient devices. From 1999 to 2009 demand has risen by 18.5 % [11]. This situation asks for a resource-efficient energy concept that foresees renewable energy sources, such as the one which is planned to be installed in the Zero Carbon Village.

In conventional energy systems in households, most appliances are operated by electricity although they actually provide thermal energy services. In contrast to this, the *energy self-sufficiency* of the buildings in the Zero Carbon Village is based on the maximum utilisation of thermal energy gained from solar energy and biomass. All thermal appliances such as washing mashine or dishwasher are operated by thermal energy. Also the *Zero CO_2 Cooler,* a refrigerator running on hot water, is being developed to be integrated in this system [12], while cooking is provided by biogas.

Through a consequent consideration of the required form of energy and the use of the most appropiate technologies, it should be possible, based on the energy balance (input/output), to reduce the consumption of electrical energy by up to 80% compared to the median consumption of Austrian households [13] (see table 1).

Table 1: energy consumption and saving potential in Austrian households through ZCV energy concept [4;5]

electric loads in households	median	electricity ZCV	electricity reduction to	thermal energy ZCV (excl. heating)
	kWh/a	kWh/a	%	kWh/a
hot water heating	1612	0	0%	1612
recirculation pump	347	347	100%	0
freezer	329	0	0%	189
lighting	298	149	50%	0
cooking devices	291	29	10%	0
cooling devices	263	0	0%	167
dishwasher	222	50	22%	115
heating incl. operating energy	220	10*	5%	6 kWh/m^{2}a**
dryer	178	50	28%	264
washing machine	175	40	23%	126
total	**3934 kWh**	**675 kWh**	**17%**	**2473 kWh**

* ventilation system with heat recovery, not universally valid

** calculated energy demand for heating of the S-House [8]

The settlement Zero Carbon Village is foreseen to contain 80 living units distributed into different multi-storey buildings (two and three floors) as well as terraced houses with an average size of 85 m^2. Thus electrical energy demand for the entire village is about 54 MWh/a and thermal energy demand is about 198 MWh/a (without heating).

Because of measured solar radiation for the chosen location in Lower Austria (global radiation 1559 kWh/m^{2}a, direct radiation 710 kWh/m^{2}a, diffuse radiation 848 kWh/m^{2}a) [14] a theoretical demand for 250 m^2 of photovoltaic panels as well as 767 m^2 of solar collectors has been calculated for the provision of all 80 living units. However, due to imbalanced radiation over the year, especially in winter, a biomass back-up system is necessary to cover the thermal energy demand, using e.g. logs or wood pellets. Technologies for the production of both thermal and electrical energy, such as micro-CHP, are an optimal supplement for solar collectors and photovoltaic systems in winter seasons. For provision of the cooking devices 28 m^3/d of biogas are needed, which can be produced in a local biogas plant close by [5].

5. Results, discussion and conclusion

To reach the project goal, a carbon neutral settlement with an innovative energy supply system, it is necessary to combine the three strands: modular prefabrication, sustainable building materials, and energy self-sufficiency, each of which shows great effects for reducing primary energy demand. For implementation and further replication on a larger scale, they have to be combined while taking into account urban development aspects, since building compounds bring in additional resource-saving options as compared to individual buildings: Building density, number of stories, A/V (surface area/volume) ratio and building orientation are factors that influence the heating energy demand and which are relevant for integration into the urban environment. High density housing thus shows advantages compared to one-family houses [15].

The emphasis on material and energy decisions is seen in a broader scope of different requirements: The dense typologies are complemented by services to target an efficient overall concept, such as collective waste management or mobility concepts (support of public transportation, car sharing programs, charging stations for e-cars, individual parking places exclusively situated at the boundary of the area). The outdoor area can be designed using

environmentally materials for pathways [16] and green areas as well as common kitchen gardens can be provided.

In order to reach sustainable development of the settlement, it is necessary to provide different options for housing and usage so as to attract diverse demographic target groups (varying in age, income, family status, etc.).

Taking into account these planning aspects on a larger scale and combining them with energy and resource-efficient solutions on a technical level thus brings about carbon neutral solutions which can also be up-scaled to urban development.

6. References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19. May 2010 on the Energy Performance of Buildings (Revised Version). Official journal of the European Union L 153/13, p. 1.

[2] WIMMER R, HOHENSINNER H, SCHMIDT W, et al., *"Strategieentwicklung für energieautarke Gebäude*". Haus der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2009.

[3] WIMMER R, BINTINGER R, SCHEICHER G, et al., *"Strategieentwicklung für eine industrielle Serienfertigung ökologischer Passivhäuser aus nachwachsenden Rohstoffen"*. Haus der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2009.

[4] WIMMER R, EIKEMEIER S, BURGHARDT M, "*Zero Carbon Village - Energieautarke Siedlung, Industrielle Forschung*". Haus der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2012.

[5] REISINGER K, WIMMER R, BURGHARDT M, et al., *"Studie Lewari – Vorprojektstudie zur Errichtung von Zero Carbon Village*". Österreichisches Programm für die Entwicklung des Ländlichen Raumes 2007-2013, Vienna, 2013.

[6] GRUBER H, GRUBER A, SANTLER H, *"Neues Bauen mit Stroh in Europa"*. Ökobuch Verlag 4. edition, Germany, Staufen, 2012.

[7] KRICK B., *"Untersuchung von Strohballen und Strohballenkonstruktionen hinsichtlich ihrer Anwendung für ein energiesparendes Bauen unter besonderer Berücksichtigung der lasttragenden Bauweise*". University Press Kassel, Germany, Kassel 2008.

[8] WIMMER R, HOHENSINNER H, DRACK M, KUNZE C, *"S-House – Innovative Nutzung von nachwachsenden Rohstoffen am Beispiel eines Büro- und Ausstellungsgebäudes*". Berichte aus Energie- und Umweltforschung 2/2005, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2005.

[9] WIMMER R, HOHENSINNER H, EIKEMEIER S, et al., "*Stroh-Cert: certification, logistic and quality management for straw bale buildings"*. Haus der Zukunft, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2011.

[10] BOINTNER R, BEDNAR T, EIKEMEIER S, et al., "*Gebäudeintegration - Gebäude maximaler Energieeffizienz mit integrierter erneuerbarer Energieerschließung*". Haus der Zukunft plus, Bundesministerium für Verkehr, Innovation und Technologie, Vienna, 2012.

[11] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production,_consumption_and_market_overview/de (27.05.2013)

[12] WIMMER R, et al., "Zero CO_2 Cooler – der Kühlschrank mit Warmwasseranschluss". Neue Energien 2020, Klima- und Energiefonds, Vienna (forthcoming)

[13] WEGSCHEIDER-PICHLER A, *Strom und Gastagebuch 2008 – Strom- und Gaseinsatz sowie Energieeffizienz österreichischer Haushalte".* Projektbericht, Statistik Austria, Direktion Raumwirtschaft, Energie, Vienna, 2009, p. 37.

[14] METEONORM, "Klimadaten Gemeinlebarn". Radiation period 1981-2000, METEONORM Version 6.1.0.7

[15] BUßWALD P, et al., *"ZERsiedelt - Zu EnergieRelevanten Aspekten der Entstehung und Zukunft von Siedlungsstrukturen und Wohngebäudetypen in Österreich"*. Neue Energien 2020. Klima- und Energiefonds, 2011

[16] HOHENSINNER H, SELLINGER W, MANSTEIN C, *"Nachhaltige Freiraumgestaltung mittels ökologischer und ökonomischer Lebenszyklusbewertung von Bodenbelägen im Außenbereich".* Projektbericht der GrAT, Vienna, 2011

Wood in Carbon Efficient Constructions



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1. Introduction

This paper is based on the findings of the European €CO2 project and its Austrian part EcoTimber. Both projects focus on defining the carbon footprint and primary energy balances of wooden houses during their full life cycle. The project consortium consists of 20 research organisations and companies from Finland, Sweden, Germany, Italy and Austria. The €CO2 project stared in November 2010 and ended in March 2013, while EcoTimber will finish in September 2013 [1].

“Wood is an environmentally friendly material. Wood houses are carbon storages.” These claims have been heard countless times, but often lack scientific proof. Fundamental understanding of how carbon footprint and primary energy balances accumulate during the full life cycle of a building is often missing. Tracking greenhouse gas stocks and flows of wood-based construction materials from cradle to grave is a complicated task, and many methodological questions are still subject to discussions amongst experts. Within the €CO2 and EcoTimber project the aim was to contribute information on this topics and cover the knowledge gap by (1) creating holistic understanding of carbon efficiency in the full life-cycle of a building, (2) by defining technical potential and obstacles for the use of wood in carbon efficient constructions, (3) by developing practical solutions for calculating and optimising the carbon footprint of different wood construction systems and (4) by disseminating results to relevant stakeholders, including construction industry.

The first part of this paper focuses on the methodological considerations of the project team. It will briefly summarise the standards that where applied and give an overview on methodological discussions among the European research partners on topics beyond standards. The consequences of the LCA methods chosen on the Austrian datasets will also be described in brief. The second and major part of the paper is dedicated to the LCAs of wood products and three wooden residential buildings that have been carried out by the authors. Several variations on the buildings and HVAC concepts have been taken into account, some of which will be discussed in detail. The evidence of the results of these building LCAs on the discussion on carbon efficient buildings as well as further research questions will be discussed at the end of the paper.

2. Methodological considerations

Within the €CO2 project assessment concentrated on three environmental impact categories, namely green house gas (GHG) emissions, carbon storage and primary energy (PE non-renewable, PE renewable process and PE renewable feedstock). Standards for Life Cycle Assessment (LCA), the calculation of carbon footprint and environmental product declaration (EPD) were taken into account when deciding on a common calculation method. Life cycle phases were defined and represented according to EN 15804. An overview on relevant standards is given in figure 1. According to the standards, LCA of construction works can be carried out on two levels: product level and building level. As the project covered LCAs for wood products and buildings, methodological issues always had to be discussed on both levels.

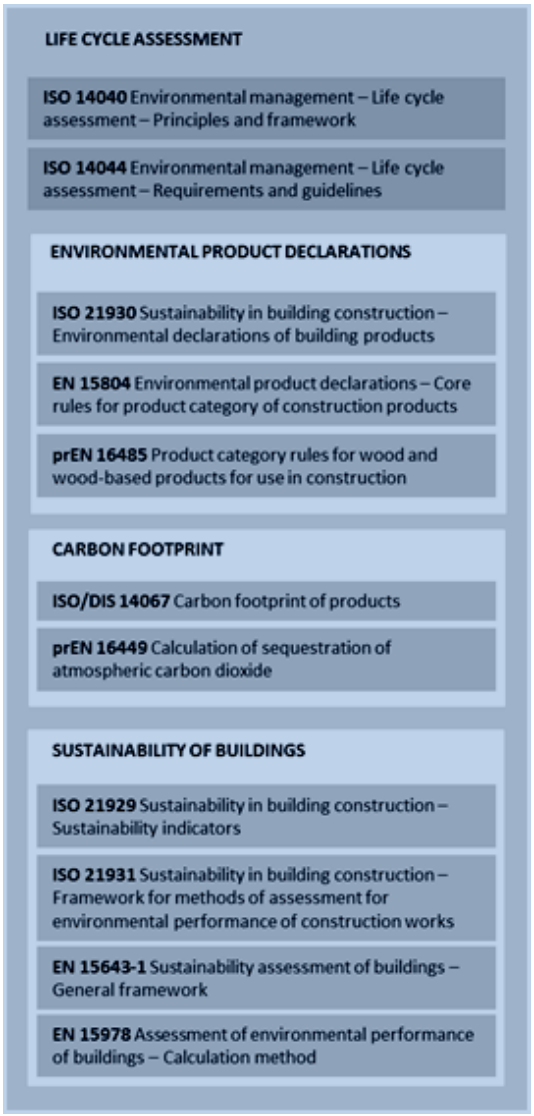


Figure 1: Overview on relevant standards (source: €CO2)

2.1 Databases

The environmental assessment of products and buildings requires a lot of input information, for example on the quality and quantity of materials and elements needed, the impact for their extraction and treatment, the energy demand and supply of the building, maintenance work and end-of-life scenarios. Such information can be taken from assessment tools and databases or be compiled for the specific case. The latter option enables much more precise results but is often too time-consuming. Generic information taken from databases such as ELCD (European reference Life Cycle Database, facilitated by the JRC of the European Commission) [2], GEMIS database [3], the German GaBi [4] or the Swiss Ecoinvent databases [5] is much easier available but may not always represent the materials and processes of a specific product or building. Within the €CO2 project generic and specific data have been compared for certain cases (e.g. data on the wood harvest process in Austria have been compared with Ecoinvent data, see figure 2). For the building case study databases have been combined with specifically imposed data (e.g. in Austria Ecoinvent data and more specific data from the IBO software EcoSoft have been used).

2.2 Special LCA topics

The comparability of case study results, even if based on the same standards is limited, because of the use of different input data but also because of methodological decisions beyond standards. Discussion within the project aimed at the definition of functional units, allocation, service life of products, building elements and whole buildings, system boundaries, energy supply, carbon storage in building elements and consideration of substitution and end-of-life scenarios. A book published on the results of the projects provides detailed information on each of these issues[1].

[1] The book was not published at the time this paper was facilitated. Information on this publication will be available from the project website and directly from the authors.

The use of physical or economic allocation methods to split up input and output flows on two or more co-products was controversially discussed amongst the experts of the project. The topic was especially important to the project as the wood working industry often produces multiple products. On building level, allocation is important for the construction stage (phase A5) for allocating energy to different processes on the construction site. EN ISO 14044 states that allocation must be avoided wherever possible (e.g. through dividing of processes in two or more sub-processes or expanding the product system and including additional functions related to co-products) [6]. If this is not possible EN 15804 foresees the following allocation rules: Use of physical properties such as mass or volume if the difference in the revenue generated by the co-products is low (a difference below 25 % is regarded as low). For higher differences economic allocation, based on market prices or price-relations, should be used [7]. However, this 25 % rule sets an arbitrary boundary that may be problematic for some wood based products.

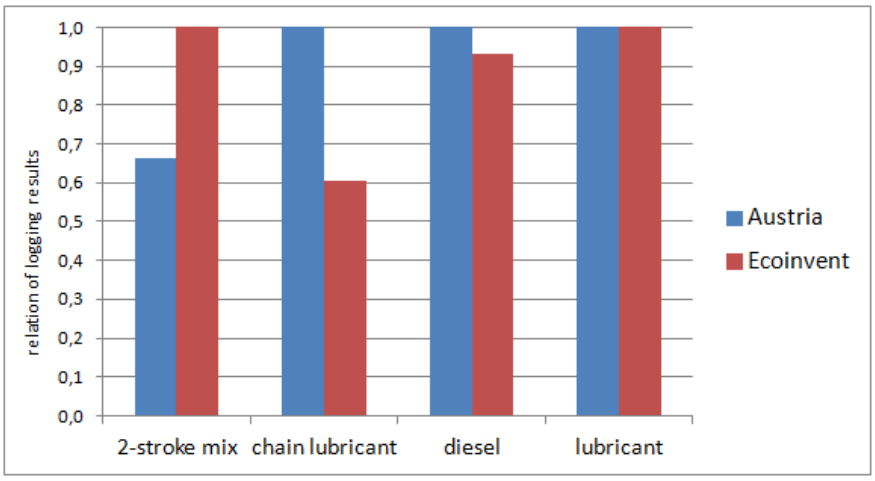


Figure 2: Harvesting Austria compared with Ecoinvent. Data in litre per bank meter from 100 % (own analysis [11])

When analysing the whole life cycle of a building, service life becomes an important parameter for calculation. International and national standards and guidelines recommend different life spans that are often inconsistent. Within the €CO2 project service life of building elements has been determined according to a scientific literature-based background document facilitated by Takano [8]. On building level a service life of 50 years has been decided for common analysis. Although different standards state much longer service lives for wood buildings [9] and products [10], many buildings are reconstructed much earlier for socio-economic reasons.

Other controversial topics are the handling of carbon storage in building elements during the service life of the building and scenarios for the end-of-life phase. When a tree is harvested, the carbon accumulated during its life time is transferred into other pools such as building elements, where it is temporarily stored during the lifespan of the building. In the meantime, assuming sustainable forest management, another tree is panted and accumulates carbon while growing. On a landscape level the carbon stock in living biomass therefore tends to be stable or even rising over time, as harvested trees are compensated by new trees growing [12].

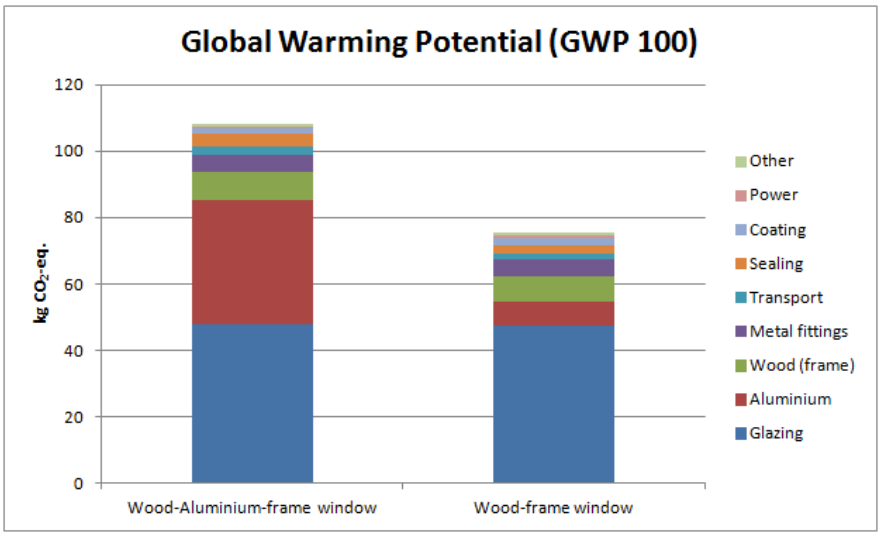
Over the life cycle of a building, there is no change in the carbon stock in the building itself [13]. In the LCA, stored carbon can be indicated by the negative values for carbon feedstock in phases A (production) and B (maintenance), if service life of the product is more than 10 years [14]. At the end of the service life, wood can either be reused (in that case no carbon is released to the atmosphere), decomposed or combusted. In the latter cases the carbon stock is oxidised and re-enters the atmosphere as CO_2. These emissions add to the total GHG emissions in phase C of the LCA. If the burned demolition material is used to replace fossil fuels, a reduction in CO_2-emissions depending on the energy content of the material can be accounted for in phase D (substitution) [15, 7]. This is considered to be one benefit of using wood constructions; however the quantification of these GHG benefits is discussed controversially, because of e.g. varying carbon intensity of the fossil fuel replaced, leakage, soil carbon reduction and uncertainties about how wood will be han-

dled by future waste management systems [15]. According to global total primary energy consumption predictions by the European Environment Agency (EEA), coal will increase its share dramatically until 2030 [16]. Considering this fact replaced fossil fuel should be coal. In present calculations natural gas, which seems to be the domestic marginal energy type, is the replaced fossil fuel according to the agreement in the LCA paper of EPD platform Austria [17]. The benefit of temporal storage of carbon during the service life of the building is more difficult to assess and therefore not displayed in the LCA. A carbon sequestration effect occurs, when the total stock of wood buildings is increasing and lasts until the amount of wood entering the building stock is equal to the amount of wood released when demolishing buildings [18].

2.3 Method and database used for the Austrian case studies

Although many methodological issues have been harmonised for use within the €CO2 project, national case studies are still based on country-specific information and assumptions. For Austria the life cycle of three buildings has been assessed. The assessment is based on a mass balance according to the construction details and a generic data set. Basic data for standard processes like energy and transport systems, basic materials, forestry, disposal processes and packaging materials are obtained from ecoinvent data v2.1. Some additional generic data for raw materials and intermediate products have been established by IBO in the course of product assessments and research projects [21]. All data use the UCTE mix from ecoinvent data v2.1 as electricity source, independent of the factual electricity source (UCTE = Union for the Coordination of Transmission of Electricity). The global warming potential (GWP) is calculated according to IPCC 2007 [19], all other LCIA-indicators (not published here) according to CML 2001 v1.05 [20]. The software EcoSoft (v3.4.2) was used to carry out the calculations [23].
The assessment of the buildings is divided into the life cycle phases A to D according to EN 15978 [22]. Data for construction materials are aggregated from cradle to gate (phase A1-3). Transport from factory gate to site (phase A4) is based on average transport distances of building products in Austria. For the construction process of the building on site (phase A5) only digging, evacuation of excavation material and refilling with gravel were considered. The amount of material losses was calculated according to Takano (2011) [8]. Energy demand for heating and warm water use in the use phase (phase B6) was calculated according to the Austrian energy performance certificate for buildings. Replacement of building products (phase B4) was considered, all other B phases (maintenance, repair and refurbishment) were disregarded. Deconstruction and transport from site to waste treatment (phase C) is taken into account and depends on the material. For module D a typical scenario for the Austrian situation of waste wood treatment is applied. More details on the assessment methods can be found in IBO (2009) [21].

3. Life cycle analysis on product level



For the following products life cycle inventory data was collected: Cross laminated timber (CLT), windows, doors, internal doors, glued laminated timber (GLULAM), wooden floors, solid wood boards and cellulose fibre.

Figure 3: Share of components of GWP100 without considering carbon storage for wood frame and wood-aluminium frame windows. One standard sized (1230 x 1480 mm), triple glazed window (own analysis)

Data for the production of these products was collected directly from manufacturers. Questionnaires have been sent to the companies, covering the following topics: raw material, ancillary input, output, packaging material, production energy, emissions, production waste, wastewater and additional questions to the entire life cycle: delivery, mounting, use phase and end of life. Additionally each plant has been visited at least once to verify the data collected. The LCA calculations were carried out using Simapro LCA software with Ecoinvent database.
Since assessment results can't be published directly, mean values for the share of components of GWP100 without carbon storage for wood frame and wood-aluminium frame triple glazed windows are shown in figure 3 as an example, representative for the different examined products. Considering that a wide range of manufacturers participated in this project, results can be seen as quite representative for Austrian wooden products.

4. Life cycle analysis of three wooden residential buildings

Within the €CO2 project, case studies on building LCAs where carried out in all participating countries. While the production phase A1-3 with an observation period of 50 years was considered by all partners, further emphasis of the research was decided individually for each partner. The aim of the Austrian case studies was to analyse primary energy input and CO_2-emissions over the life cycle of very energy efficient residential buildings (Passive Houses and Nearly Zero Energy Buildings – NZEB). Three existing buildings, one multi-storey building (MSB), one row house (RH) and one single family house (SFH), which represent typical residential buildings according to the Austrian building typology (developed within the EU-project TABULA [24]) have been chosen for this analysis. However, the wood construction systems they incorporate are quite innovative and not yet common (for these building types) in Austria. The external walls of the MSB and SFH are massive wood constructions (CLT panels) with an insulation of mineral wool. The RH consists of post and beam external walls with glass wool in the cavities and a polystyrene external insulation. The roof and ceilings (except for the basement ceiling) of all three buildings are made of CLT as well. All buildings feature a high degree of prefabrication.

Table 1: Overview on three case study buildings (reference cases)

	Multi-storey building (MSB) Mühlweg	**Row house (RH) Steinbrechergasse**	**Single family house (SFH) Schönkirchen**
			
Gross floor area	2.052 m²	668 m²	210 m²
Living area	1.565 m²	531 m²	161 m²
Number of flats	18	5	1
Construction system	massive wood construction, concrete basement	wooden post and beam construction, concrete basement	massive wood construction, brick garage
Heating demand	8,3 kWh/m²a	14,1 kWh/m²a	11 kWh/m²a
Operative energy use	86.875 kWh/a 42,3 kWh/m²a	40.240 kWh/a 60,3 kWh/m²a	2.923 kWh/m²a 13,9 kWh/m²a
Heat generation	combined gas and solar thermal system	pellet boilers	heat pump
Heat distribution	ventilation system, radiators	ventilation system, radiators	ventilation system
Electricity generation	-	PV (151 m² solar panels)	-

The MSB and the SFH have been built according to the Passive House standard (heating demand of less than 15 kWh/m²a according to PHPP calculation software) while the row house was originally designed as a Low Energy House with an average heating demand according to Austrian building regulations. Within the project the row house has been virtually changed into a Nearly

Zero Energy Building by use of PV-cells, mechanical ventilation and additional insulation. The buildings are supplied by different heating systems but are all equipped with mechanical ventilation with heat recovery. Table 1 provides an overview on the three case study buildings.

For all three buildings different parameters have been modified to analyse the effect on the LCA results. Variations include different construction systems (wood, brick and concrete construction for the MSB and SFH; higher and lower insulation standards for the RH), energy supply systems (variation in the heating system for the MSB, additional PV system for the RH), building concepts (with garage or basement for the SFH) and service life (50 and 100 years for all reference cases). Additionally several detailed analysis have been carried out, e.g. focusing on the dominance of building elements and materials. Some of the results will be discussed more in detail on the following pages.

For the RH a dominance analysis on the building elements was carried out to study the contributions of building elements on the overall results for the production phase (phase A1-3). The results are shown in figure 4. The PV system (consisting of 151 m² collector, inverter, electric installations and fastening system for the roof) contributes most to the emissions (almost 30 %), however it also reduces GHG emissions significantly due to the electricity production, as will be explained later in figures 6 and 7. The concrete elements of the basement also have a large impact on the GHG emissions, followed by the roof, floorings and exterior walls. However, energy input for the basement is almost entirely non-renewable while the other elements store significant amounts of carbon and include a higher share of bonded energy which can be recovered at the end of the life cycle (phases C and D). This can be considered as the advantage of wood as a construction material. The results are also valid for the other two case study buildings.

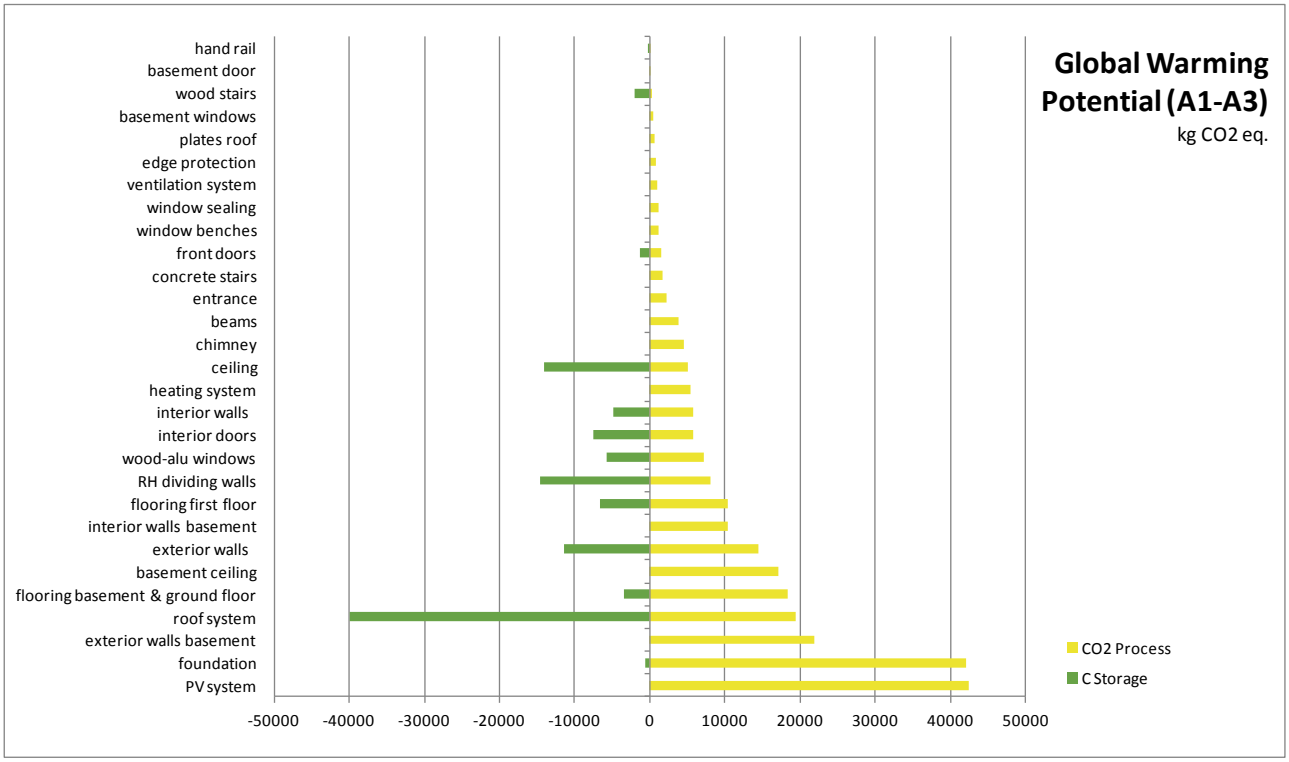


Figure 4: Dominance analysis of GWP from the production of RH components (own analysis)

Figure 5 compares results for the major parts of the buildings in the production phase. However, when comparing results for given three case study buildings it has to be considered that:

- The SFH has an adjoining garage instead of a basement. Impacts of the garage walls, roof, etc. are included in the according building element categories (exterior walls, roof, etc.)

- B6 (energy use) of the row house also includes electricity use for household applications while for the other two buildings this is not included. The electricity use of the row house is almost entirely covered by the PV plant.
- To calculate primary energy of MSB and SFH materials, upper heating values were used while for the SFH lower heating values were considered.

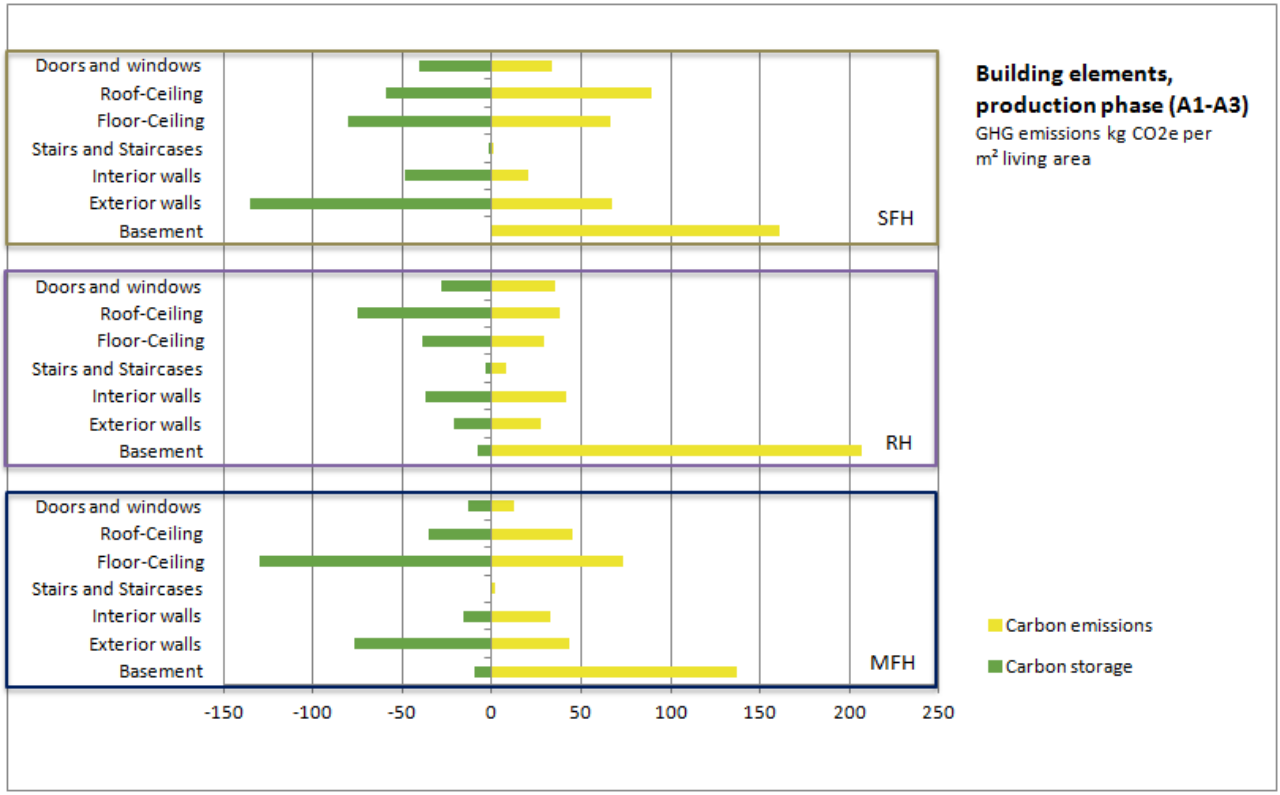


Figure 5: GHG emissions in the production phase (A1-3) for the three case study buildings (own analysis)

Generally more carbon is stored in the solid wood constructions of the MSB and the SFH than in the wooden frame structures of the RH. In all three buildings the non-renewable primary energy use and the GHG emissions caused by walls and roof are increased due to the use of mineral or glass wool and polystyrene as insulation materials. This is especially important for the wooden frame structures since the cavities are filled with glass wool. Alternative insulation materials like cellulose fibres could improve these indicators.

Building service installations are not significant in case of the MSB (gas and solar heating, central ventilation system) and the SFH (heat pump, central ventilation system). However, so far there is only little data available for building service installations and their ancillary materials. Therefore results are subject to uncertainties. More reliable information on building service installations could significantly improve knowledge about the impact of that part of the buildings's life cycle.
When comparing the building concepts of multi-storey building, row house and single family house in terms of primary energy demand per m² in the production and maintenance phase, it is obvious that the dense architectural concept of MSB is the most efficient one.

In figure 6 all life cycle phases over an assumed service life of 50 years (according to €CO2 agreement) for the three case study buildings are compared. Due to this assumption the replacement of materials covered in phase B4 is not very significant. This is due to the presumption that only windows, outside sealing and surface coverings, floor covering and HVAC get replaced once in this period. For all other materials and elements an assumed service life of 50 years and longer is foreseen. It is most significant for the row house as the energy intensive produced PV-plant is exchanged once within the 50 year period. An assumed service life of 100 years significantly in-

creases the primary energy input and GHG emissions for phase B2-5 to a higher level than production phase A1-3, as can be seen in figure 6. In that case production and maintenance phase together may become more important than the energy use of the building. This is a clear indicator that building materials have to be focus of future energy efficient building concepts in the future.

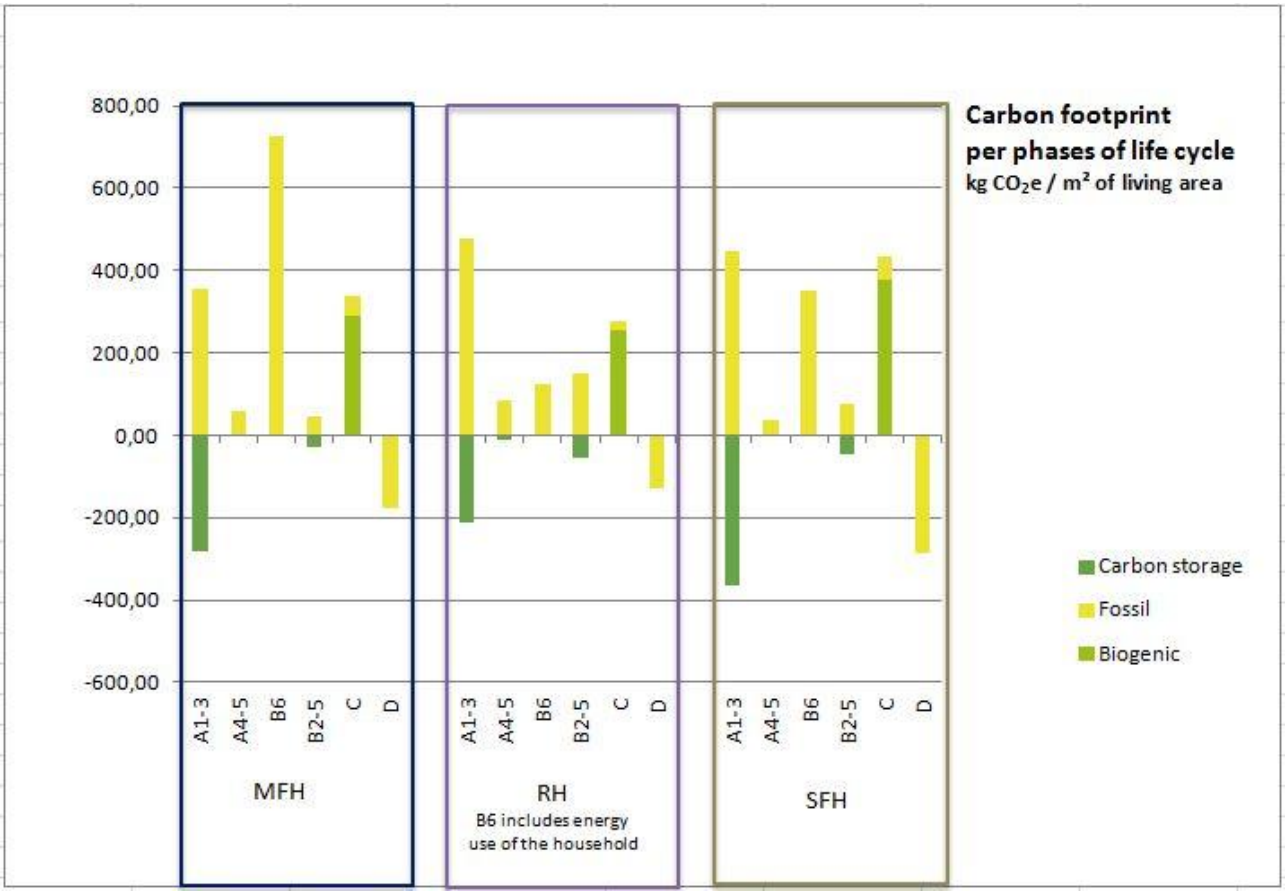


Figure 6: Carbon footprint per phases of life cycle (assumed service life of 50 years) for the three case study buildings (own analysis)

The three buildings are equipped with different building service systems. This has a significant impact on phase B6 (energy use) of the life cycle. The MSB is equipped with a central gas boiler and a solar thermal system which reduces the demand for gas. Nevertheless the non-renewable primary energy demand is quite high compared to the other buildings and contributes to higher GHG emissions. The SFH is heated by a heat pump, the electricity mix is the European UCTE mix. The RH has been designed as a Nearly Zero Energy Building (NZEB) according to the available definitions [25]. The PV-plant has therefore been designed to cover most of the non-renewable primary energy demand of the building for heating, ventilation and household appliances. Nevertheless the total primary energy demand (largely renewable from pellets) for heating and sanitary hot water production is quite high compared to the other buildings. This is due to the low seasonal efficiency of the small scale pellet boilers used for heating and sanitary hot water production. Nevertheless GHG emissions in phase B6 are significantly lower for the RH. This adds again to the future importance of building materials and construction methods (represented in phases A1-3 and B2-5).

The influence of a longer service life (100 years) is apparent from figure 7. This figure compares the results for the primary energy demand of the reference case of the RH over an assumed service life of 50 years (NZEB 50) and 100 years (NZEB 100) with a low energy building alternative (LEB 100 and 50). While the primary energy demand of the production phase remains the same for a 50 and 100 years service life, differences are most visible for energy use and maintenance in

phase B. Generally a longer service life of a building is more energy efficient but service life often depends on socio-economic considerations instead of technical ones.

When comparing the NZEB concept with the LEB concept it is noticeable that non-renewable as well as renewable energy demand are significantly lower for the NZEB. This is due to the additional PV system (non-renewable energy demand) and the surplus insulation and mechanical ventilation system (renewable energy demand). In return primary energy demand in the production (A1-3) and maintenance (B1-5) phases is higher for the NZEB. Nevertheless the NZEB concept pays off in terms of primary energy demand and GHG emissions over the life cycle.

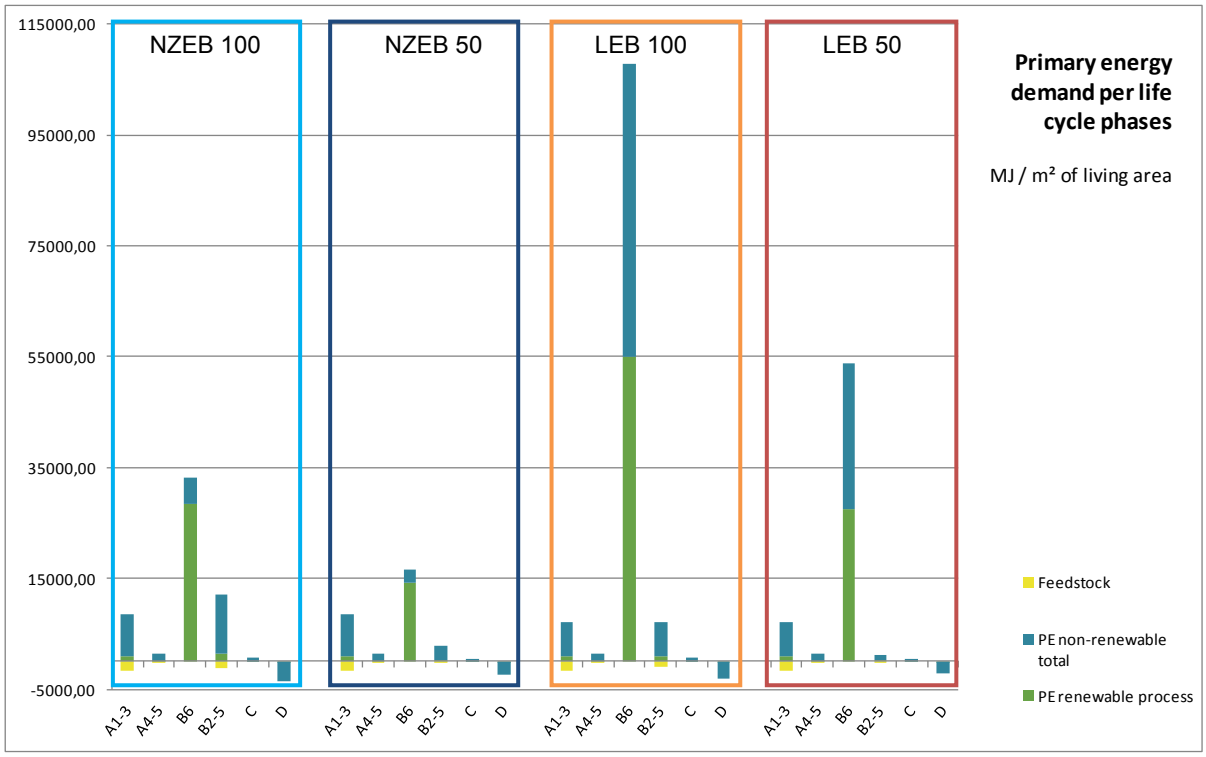


Figure 7: Primary energy demand per phases of life cycle for the RH (own analysis)

5. Conclusions

The projects €CO2 and EcoTimber allowed to discuss methodological issues on LCAs of wood products and buildings within an expert consortium and also add to the knowledge base on wood in the construction sector.

The following lessons have been learned from the Austrian LCA building case studies:

- Energy recovery from wooden residues can be a remarkable benefit for choosing wood for construction material. Nevertheless methodological discussions on how to balance these benefits (e.g. on substitution of fossil fuels) and on how to account for the temporal Carbon storage effect of buildings should not be neglected.
- Wood-framed passive houses with energy-efficient heat supply reduce climate impacts. Generally, massive wood construction systems result into largest amounts of residues and bio-energy potential. More research on the impact of alternative insulation materials would be beneficial.
- High density architecture is more energy and carbon efficient than single family houses. Wood constructions in the multi-storey buildings should therefore be increased. Further research also covering non-residential buildings would be beneficial.
- There will be a shift in the lifecycle carbon efficiency of buildings from use phase to production phase. This is because buildings require less energy for their operation.

- Including all building service installations with their ancillary materials may be very time-consuming and include large uncertainties. Further research is necessary to better cover the environmental impacts of building service installations.

Further important findings from case studies carried out by the other project partners are:

- Site works and foundations seem to have high impact on carbon footprint and primary energy demand. Especially the use of concrete, re-bars and hard insulation boards cause emissions.
- Emissions from construction work and transportation are very case specific. Energy demand from construction work can vary highly depending on the outside temperature, because heating half-finished buildings or pre-fabrication facilities seems to be very energy consuming. Nevertheless, pre-fabrication facilities seem to require less energy than frequent personnel transport to construction sites.
- Design phase does not typically give enough information for carbon footprint or primary energy assessment that is required in standards (EN 15978). Therefore a more flexible assessment scheme for enabling assessment in design phase would be needed.

6. References

[1] Project website: http://www.eco2wood.com/ , access on 24.04.2013

[2] http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm, access on 24.04.2013

[3] http://www.iinas.org/gemis-de.html, access on 24.04.2013

[4] http://www.gabi-software.com/databases/gabi-databases/, access on 24.04.2013

[5] http://www.ecoinvent.org/database/, access on 24.04.2013

[6] International Organisation for Standardisation. *"ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines"* 2006

[7] European Committee for Standardisation (CEN). *"EN 15804 sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products"* 2012

[8] TAKANO, A. "Standards for quantity calculation of building components" Background material for €CO2 project; 2011

[9] Austrian Standards Institute. "ÖNORM B 2320 Wooden residential houses – Technical requirements" (in german) 2010

[10] European Committee for Standardisation (CEN). *"prEN 16485 Round and sawn timber – Environmental Product Declarations – Product category rules for wood and wood-based products for use in construction"* 2012

[11] DOLEZAL F, MOETZL H, DEUTSCH A. "Austrian Research Project ECOTimber – Wood, Used in Sustainable Building Constructions (subproject of ECO2)" In: Fernando Pessoa University (editor): 5th International Conference on Environmentally-Dompatible Forest Products, Porto, 2012

[12] PINGOUD K, POHJOLA J, VALSTA L. *"Assessing the integrated climatic impacts of forestry and wood products"* Silva Fennica, 2010. 44(1): 155-175. ISSN 0037-5330

[13] GUSTAVSSON L, KARLSSON Å. *"CO_2 mitigation: On methods and parameters for comparison of fossil-fuel and biofuel systems"* Mitigation and Adaptation Strategies for Global Change, 2006, 11(5-6): 935-959. DOI: 10.1007/s11027-006-9028-7

[14] International Organisation for Standardisation *"ISO/DIS 14067 Carbon footprint of products – Requirements and guidelines for quantification and communication (2nd draft)"* 2012

[15] GUSTAVSSON L, SATHRE R. *"Energy and CO2 analysis of wood substitution in construction"* Climatic Change, 2011, 105(1-2): 129-153. DOI 10.1007/s10584-010-9876-8

[16] http://www.eea.europa.eu/data-and-maps/figures/global-total-primary-energy-consumption-by-fuel-1, access on 25.04.2013

[17] Österreichische EPD-Plattform für Bauprodukte. *„Allgemeine Regeln für Ökobilanzen. Version 0.2"* 10.02.2013

[18] LIPPKE B, ONEIL E, HARRISON R, SKOG K, GUSTAVSSON L, SATHRE R. *"Life cycle impacts of forest management and wood utilization on carbon mitigation: Knowns and*

unknowns.2011." Carbon Management, 2011, 2(3): 303-333. ISSN 1758-3004

[19] IPCC *„Climate Change Fourth Assessment Report"* 2007

[20] CML – Centre of Environmental Science, Leiden University. *"Life Cycle assessment: An operational guide to the ISO standards. Final Report"* 2001

[21] BOOGMAN P, MÖTZL H. *„IBO-Referenzdatenbank – Wesentliche methodische Annahmen. Version 2.2"* Österreichisches Institut für Baubiologie- und ökologie, Wien, Stand 9.10.2009, German publication only: http://www.ibo.at/documents/LCA_Methode_Referenzdaten_kurz.pdf

[22] European Committee for Standardisation (CEN). *"EN 15978 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method"* 2011

[23] Österreichisches Institut für Baubiologie- und ökologie. *"ECOSOFT 3.4.2: Software for the ecological assessment of building components and buildings"*. http://www.ibo.at/de/ecosoft.htm, status 2012-11-21, actual version: ECOSOFT 5.0, including IBO-database 2012

[24] AMTMANN M, GROSS M. *"Austrian Building Typology – Eine Typologie österreichischer Wohngebäude."* Austrian Energy Agency, Vienna, 2011, German publication only: URL: http://www.building-typology.eu/

[25] ATANASIU B, ENGELUND THOMSEN K, ROSE J, AGGERHOLM S. *"Principles for Nearly Zero-Energy Buildings. Paving the way for effective implementation of policy requirements."* Buildings Performance Institute Europe (BPIE), Brussels, 2011: http://www.bpie.eu/nearly_zero.html

Greenhouse gas emission from construction process of multi-story wooden buildings



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Short Summary

The purpose of this study is to investigate environmental impact for construction process of wood-based building. Detailed data collection from construction work is conducted on three multi-story wooden buildings. Greenhouse gas (GHG) emission value is calculated for production stage (material production and construction) and operation stage of the buildings, and a ratio of the emission from construction process is observed. The results present that construction phase holds about 20-30% of GHG emission in the production stage. In addition, it is shown that material production phase, construction phase and operation phase of the buildings account for approximately 16-35%, 6-10% and 55-78% of the total GHG emission, respectively. Based on the results, feature of the impact for wood-based construction and an issue regarding the data collection are discussed. This study demonstrates a relevance of construction process in a life cycle assessment of buildings. Since the result of environmental assessment is beneficial for the industry in order to optimize their work environmentally, simple and reliable assessment method is required based on further research.

Keywords: Life cycle assessment, Building construction, Wood-based building, Greenhouse gas GHG emission

1. Introduction

In life cycle assessment (LCA) of a building, major attention has been paid on a use phase of a building due to its high share of environmental impact in the life cycle. The reduction of environmental impact during operation of a building has been main target so far. As a result of the effort, the impact from the use phase has been mitigated and importance of the other life cycle stages has increased [1]. In general, construction material production phase has been regarded as the next target of mitigation and the other phase, such as construction phase, have not had priority because of its small proportion of the life cycle environmental impact [2, 3]. It has been reported that the construction phase contributes 2-26%, in many cases less than 10%, of overall life cycle impact of a building [4-10].

However, recent researches mentioned that the construction phase has relevant impact, and the trend of GHG emissions from construction equipment has increased significantly in the last decades [11-14]. They indicated that the process should not be underestimated and attempted to establish the framework for environmental management during the construction phase. The environmental impact of the process should be known to enable to optimize it in practical level.

The objective of this study is to review environmental impact of construction process. Detailed data collection and the assessment in terms of GHG emission for construction process are conducted with wood-based reference buildings. To make a comparative study with reliable data, GHG emission from material production and construction phase of wooden building elements of the buildings are assessed and compared. Manufacturing and installation of all building service equipment and basement are excluded from the assessment. In addition, the emission from operational energy use of the buildings is assessed and a ratio of the emission from construction process is observed.

2. Environmental impact of construction process

In the last two decades many LCA study on buildings and construction have been conducted. In general, building use phase has been dominant in the life cycle environmental impact of a building in terms of energy consumption resulting in GHG emissions. However, in some cases the construction process seems to have relevant impact with a great potential of reducing the environmental burden of buildings. For example, it has been reported that the use phase accounts for 70-98% of life cycle energy use of a building [15], while the construction phase holds 2-26% of the energy use, depending on case studies [4-10].

Some of the most recent researches mentioned that GHG emissions from construction process should not be underestimated. Ahn et al. [14] found that the decentralization of construction processes, which involves often several subcontractors, leads to critical issues in measuring the significance of GHG emissions from construction processes. Furthermore, the uniqueness of each project and the high fragmentation of the building industrial sector make every improvement difficult to pursue. Mora et al. [13] concluded that GHG emission from construction activities is significant and the trend of GHG emissions from construction equipment increased significantly in the last decade.

Gangolells et al. [16] stated that transportation and construction equipment, waste production, and water consumption have significant environmental consequences, implying that any improvements in these areas could be priority targets for reducing the overall life cycle impact of the building. Bilec et al. [17] found for a concrete parking structure that transportation of concrete to the site, particularly for the precast pieces, is the most significant construction process. Guggemos and Horvath [18] reported that work on the structural frame has the largest impacts in the construction phase, mostly due to heavy use of diesel equipment. This finding was also corroborated by Junnila and Horvath [19].

There is an open discussion of the implications of off-site construction as opposed to typical on-site construction. A relevant study was carried out in northern Japan by Nishioka et al. [20], who considered the environmental trade-offs in vertically integrated factory-built housing, which required more materials than a typical home but also performed better. The authors found that the energy and carbon debts incurred by the additional materials are paid off through efficiency gains in less than six years, well below the average lifetime of homes in that area. Kim [21] compared life cycle impacts of a modular and a conventionally constructed home in Michigan, analyzing energy use, material consumption, GHG emissions, and waste generation. This work suggested that solid waste generation, transportation energy, and GHG emissions are significantly lower when modular construction is used.

Quale et al. [22] carried out a comparative analysis of the two different construction methods considering different scenarios and transportation distances. From the results the GHG emission from the use of prefabricated modular systems is lower than traditional systems due to a limited duration of on-site activities, which leads less waste and worker transportation.

3. Methodology

3.1 Reference buildings

Three multi-story wood-based residential buildings are assessed in this study. Basic information of the reference buildings is summarized in Table 1. Functional unit is one m^2 of living area. Although context of the buildings differ each other, the assessment is conducted with the same methodology and accuracy according to the purpose of this study.

Table 1: Basic information of the reference buildings

Name	Location	Structure frame	Gross area (m^2)	Living area (m^2)	Floors	*Operative energy use (kwh/m2/a)
Building A	Germany	Sawn timber panel	726	488	5	63
Building B	Finland	Cross laminated timber	730	548	3	59
Building C	Italy	Cross laminated timber	1840	1398	5	43

*Operative energy use is the secondary energy including electricity and heating/cooling energy

3.2 Impact assessment and system boundary

GHG emission value for material production, construction, and use phase of the reference buildings is calculated. According to normative standard EN15978 [23], included life cycle phases are defined as shown in Table 2.

Table 2: Included life cycle phases and its abbreviation according to EN15978

Product stage (Module A1-3)			Construction process stage (Module A4-5)		Use stage (Module B)
A1	A2	A3	A4	A5	B6
Raw material supply	Transport	Manufacturing	Transport	Construction	Operational energy use

Since specification of basement differs significantly between the buildings and there are several uncertainties in non-wooden building element (e.g. prefabrication of steel staircase), the results of the assessment for the module A are limited to wood-based building element of the buildings in order to make the results comparable.

3.2.1 Module A1-3: Material production

The inventory is carried out from working drawings of the architects and structural engineers. Calculated mass of each component is cross-checked with material order list provided by the constructor. Building service equipment and furniture are excluded from the inventory, even if those are integrated to the building element, due to lack of information. The included inventories are summarized in Table 3.

Table 3: Mass of used materials in wood-based building elements (kg/m^2 of living area)

Material	Building A	Building B	Building C
Sawn timber	133	40	19
Cross laminated timber	20	151	241
Laminated veneer lumber	16	5	2
Glulam	82	40	
Plywood		7	
OSB		7	

Wood fibre board		16	
Gypsum board	82	60	78
Rock wool	12	33	10
Cork			4
Cellulose fibre		5	
Particle board	8		28
Ancillary material	23	2	11
Vapour barrier sheet		0,4	
Water proof sheet	1	3	6
Cement fibre board			14
Window and door	39	57	43

3.2.2 Module A4: Transportation

All information regarding the construction stage is collected by monitoring of construction work and machines and interview with the constructor. Transportation of building components and elements is taken into account according to the real case. The impact from transportation process is calculated by multiplying distance (km) and mass of deliverable (ton) as taking vehicle type into account. Worker transport to the factory or construction site is not included.

3.2.3 Module A5: Construction

Energy consumption during prefabrication of the wood-based element in the factory and on-site assembling of the prefabricated element is monitored. Possible data collection method is case specific due to working system of the constructors. Different methods, which seem to be the most relevant in each case, are applied. In case of building A, real monitoring data of the prefabrication factory and the interviewed information from the constructor were main source. In case of building B, a researcher has been stationed on the construction site and monitored the process everyday with the constructors. Monthly energy consumption data of the prefabrication factory and spent working time for the project in the factory were monitored by the prefabrication company. In case of building C, a special agreement was signed between the client and constructors regarding construction schedule. Therefore, each constructor planned detailed working activity in advance, which helped to collect relevant data.

3.2.4 Module A5: Waste management

Waste from prefabrication and on-site construction work is also considered based on the real case and literatures [24-27]. Waste management methods and transportation to waste treatment facilities are taken into account based on the interviewed information.

3.2.5 Module B6: Operational energy use

The calculation of operational energy use is based on the estimated electricity and heating/cooling energy demand of the buildings. Aggregated annual operational energy demand is summarized in Table 1. National energy mix is applied to the case of building A and C, and actual energy mix of the location is applied to the building B.

3.3 LCA Data

All calculations are conducted with Ecoinvent database V2.2. [28]. Ecoinvent is one of the most well-known LCA database which consists of process based life cycle inventory (LCI) data. Temporal representativeness is year 2000-2007 as annual average. Basically stored data is based on an average of current used technology. European average data is applied to the assessment of the module A1-3, and country average data is applied to the module A4-5. In principle, exact material data is applied for building materials from the database. However when there is not exact data in the database, most relevant material data is applied (e.g. plywood data instead of LVL).

3.4 Uncertainty

Several assumptions regarding the energy use during construction are applied in each case study when certain data is not available. This uncertainty would affect the result to some extent, although it was not estimated. However, every assumption is based on monthly data of the factory, data from similar production line, literature or interviewed information. Therefore, it is supposed that the associated error is not significant in this case.

4. Results and Discussion

4.1 Dominance analysis of the module A

Figure 1 shows GHG emission, from both fossil and biogenic fuel separately, for each phase in the module A of the three reference buildings. Although absolute value of the buildings differ each other significantly, similar trend can be seen. The module A1-3 accounts for 70-80% and the module A4-5 holds 20-30% of the total impact. In addition, the module A4 has relatively high share in the module A4-5, approximately 30% in the case of building A and more than 50% in the case of building B and C. It is remarkable that transportation of building components has higher impact than the actual construction work in the factory and on construction site in the two cases. This result originates in long transportation distance of some building components. For instance in the case of building B, Cross laminated timber (CLT), which is main building component, is delivered from Austria to Finland by ferry and truck. This would be exceptionally long transportation in an ordinary construction process. In the case of building C, there are also several components delivered from abroad. In the case of building A, most of components are delivered from Germany within 400km by truck.

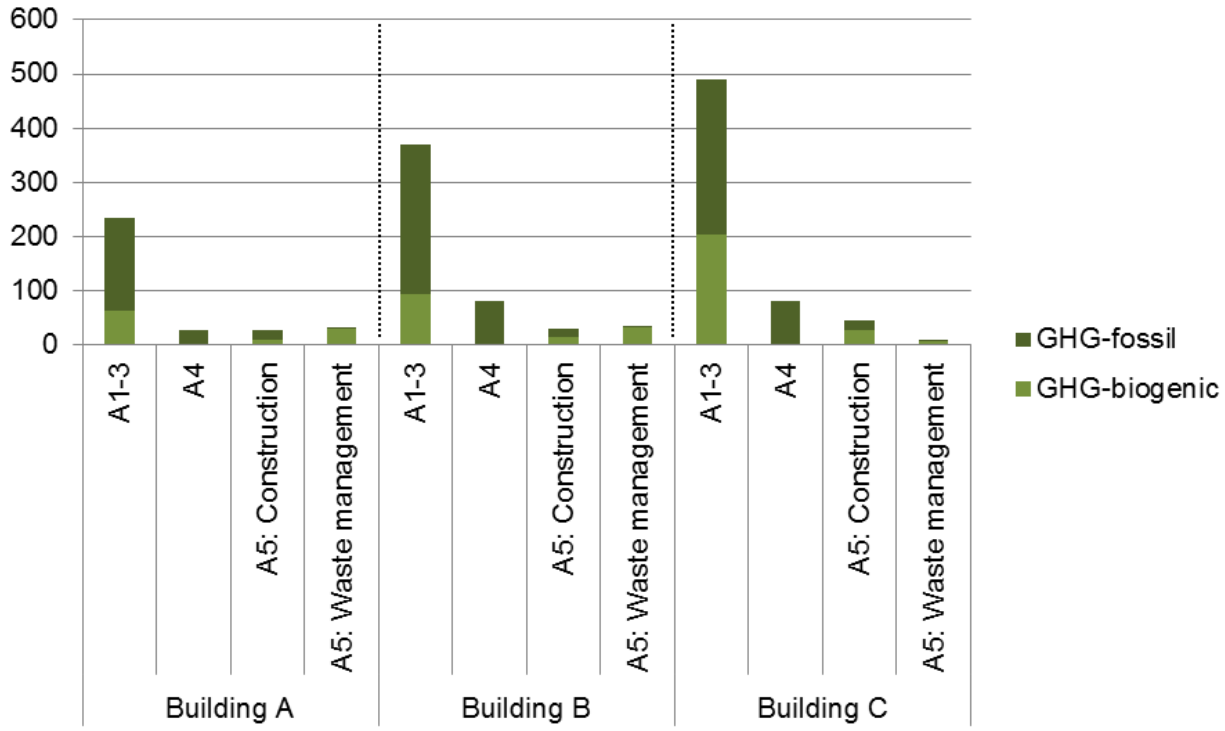


Fig. 1: GHG emission for the module A ($kgCO_2$-eq./m^2)

The module A5: prefabrication process and waste management also have relevant impact. However as shown in the figure, GHG emission from those phases consist of mainly biogenic GHG, which originates in a combustion of wood process residues. Therefore, the emission from the phases decreases significantly if biogenic CO_2 emission is regarded as zero based on the idea of carbon neutrality. This would be a main environmental feature of wood-based construction process. This result would also indicate the importance of the module A4.

4.2 Share of the construction stage

Figure 2 shows GHG emission for the module A and B6 of the three reference buildings. The module A1-3, A4-5 and B6 account for 16-35%, 6-10% and 55-78% of the total GHG emission, respectively.

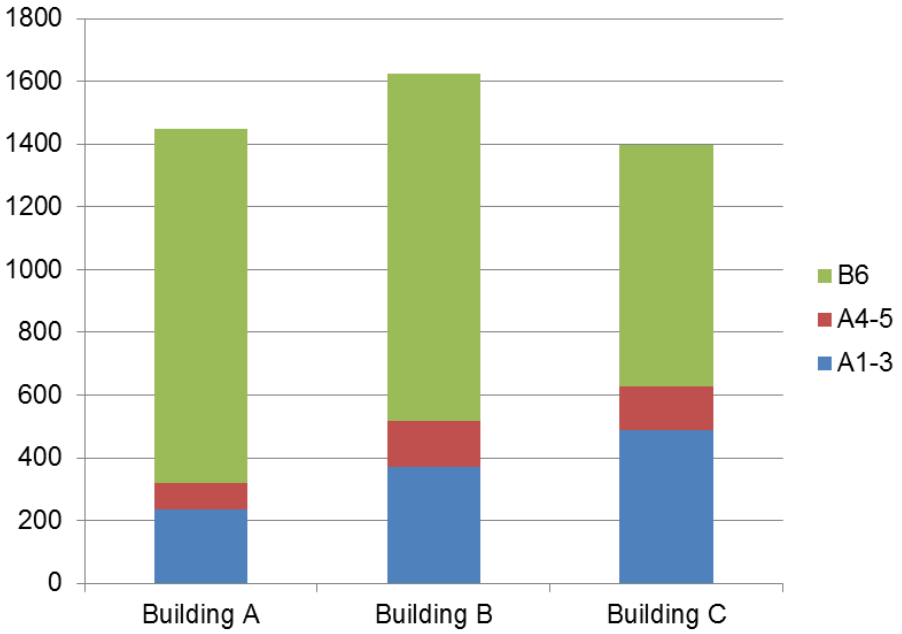


Fig. 2: GHG emission for the module A1-3, A4-5 and B6 ($kgCO_2$-eq./m^2)

The construction stage (A4-5) holds up to 10% of the total sorely. Naturally the share is increasing for the building with lower operational energy demand. This result will change when the other life cycle phases are included in the assessment to some extent. However, the ratio of the module A will also increase when the excluded construction materials and works (e.g. foundation and building services) are incorporated. Since the reference buildings are not high energy standard building, this result deserved to consider further.

Although the sample size is small, the module A4, transportation of building components and elements, seems to have higher priority to mitigate rather than actual construction work, the module A5, in the construction stage of wood-based building elements. Normally, loadage is optimized from economical reason. However, transportation distance is not always in proportion to a price of a product. Thus sometime it would happen to buy a product from far country due to cheaper price, although the same product could be available in a neighbouring city. From environmental aspect, it would be the worst case to order high impact products due to, for instance, inefficient manufacturing technology from far, because of a low price. Some products may be only available from specific location. But except such situation, it is good starting point to consider a balance of cost, environmental impact of product manufacturing and transportation distance and method when deciding construction material in order to mitigate the impact from the construction stage.

4.3 Data collection

It is experienced that data collection from transportation process and waste management is rather simple, while prefabrication process and on-site construction work is difficult to monitor. This difficulty seems to mainly originate in a situation of the industry, for instance rack of resources and time. In addition, data collection from on-site construction work may require special knowledge regarding construction work. In this context, proper planning of construction process is fundamental requirement in order to collect necessary information efficiently.

Since several projects or works happen at the same time in a factory and construction site,

allocation of energy use is one critical issue. Monitoring of each process or production line with, for instance, electrical measuring instrument is relatively easy and accurate way. Recording of working hour for the process or project is also relevant in order to allocate aggregated information, such as monthly electricity and heating energy consumption in the factory.

5. Conclusion

GHG emission for the product, construction and use stage of the three reference wood-based buildings are assessed. Detailed data collection is conducted with the help of the constructors. Since every construction is unique, different data collection method are attempted in each case study according to the situation. The results show that the construction stage has relevant impact and especially transportation process is significant to mitigate GHG emission from the process.

Although an optimization of the construction phase may not have a significant effect on overall life cycle impact of a building, it would have a major impact at an industrial (aggregated) level. The environmental impact of the process should be known to enable to optimize it for constructors and designers. Further study is required in order to collect sufficient samples and pile up the experience in order to set a practicable and reliable assessment method for the construction stage.

6. Acknowledgement

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7. References

[1] VERBEECK G, HENS H. *“Life cycle Optimization of extremely low energy buildings”*. Proceedings of Clima 2007 WellBeing Indoors. pp.8. 2007. Helsinki

[2] SCHEURER C, KEOLEIAN G.A., REPPE P. *“Life cycle energy and environmental performance of a new university building: modeling challenges and design implications”.* Energy and Buildings 35 (2003), pp.1049–1064. Elsevier

[3] ADALBERTH K. *“Energy use in four multi-family buildings during their life cycle”.* International Journal of Low Energy and Sustainable Buildings 2000 (2000), pp.1–22. Elsevier

[4] ADALBERTH K. *“Energy use during the life cycle of single-unit dwellings: Examples”.* Building and Environment, 32(4), pp. 321–329. 1997. Elisevier

[5] COLE R.J. *“Energy and greenhouse gas emissions associated with the construction of alternative structural systems”.* Building and Environment 34(3), pp. 335–348. 1996. Elisevier

[6] Cole R. J. (1998). Energy and greenhouse gas emissions associated with the construction of alternative structural systems, Building and Environment, 34(3), pp. 335–348.

[7] COLE R.J. and KERNAN P.C. *“Life-cycle energy use in office buildings”*, Building and Environment, 31(4), pp. 307–317. 1996. Elisevier

[8] KEOLEIAN G.A., BLANCHARD S, REPPE P. “Life-cycle energy, costs, and strategies for improving a single-family house”. Journal of Industrial Ecology, 4(2), pp. 135–156. 2000. Yale University

[9] JUNNILA S, HORVATH A. *“Life-cycle environmental effects of an office building”. Journal of Infrastructure System* 9-4, pp.157–166. 2003. American Society of Civil Engineering (ASCE)

[10] JUNNILA A, HORVATH A. GUGGEMOS A. *“Life-cycle assessment of office buildings in Europe and the United States”.* Journal of Infrastructure System 12-1, pp.10–17. 2006. ASCE

[11] GUGGEMOS A, HORVATH A. *“Comparison of environmental effects of steel- and concrete-framed buildings”*. *Journal of Infrastructure System* 11-2, pp.93–101. 2005. ASCE

[12] GUGGEMOS A, HORVATH A. *“Decision-Support Tool for Assessing the Environmental Effects of Constructing Commercial Buildings”.* Journal of Architectural Engineering 12, pp.187-195. 2006. ASCE

[13] MORA F.P, AHN C, GOLPARVAR F.M., HAJIBABAI F. SHIFTEHFAR S, AN S. AZIZ Z. SONG A. *"A framework for managing emissions during construction"*. International Workshop on Green Buildings and Sustainable Construction. pp.13. 2009. National Science Foundation (NSF). Cairo
[14] AHN C. REKAPALLI P. MARTINEZ J. MORA F.P. *"Sustainability analysis of earthmoving operations".* Proceedings of the Winter Simulation Conference, pp.2605-2611. 2009. IEEE. Texas
[15] ORTIZ S, CASTELLS F, SONNEMANN G. *"Sustainability in the construction industry: A review of recent developments based on LCA"*. Construction Building Materials 23(1), pp. 28–39. 2009. Elisevier
[16] GANGOLELLS M, CASALS M, GASSO T, FORCADA N. *"A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings"*. Building and Environment. 44(3), pp. 558–571. 2009. Elisevier
[17] BILEC M, RIES R, MATTHEWS H.S., Sharrard A.L. *"Example of a hybrid life-cycle assessment of construction processes"*. Journal of Infrastructure Systems. 12(4), pp. 207–215. 2006. ASCE
[18] GUGGEMOS A.A. and HORVATH A. *"Comparison of environmental effects of steel- and concrete-framed buildings"*. Journal of Infrastructure Systems. 11(2), p. 93. 2005. ASCE
[19] JUNNILA S and HORVATH A. *"Life-cycle environmental effects of an office building"*. Journal of Infrastructure Systems. 9(4), pp. 157-166. 2003. ASCE
[20] NISHIOKA Y, YANAGISAWA Y, SPENGLER J.D. *"Saving energy versus saving materials: Life-cycle inventory analysis of housing in a cold-climate region of Japan"*. Journal of industrial ecology. 4(1), pp. 119-135. 2000. Yale University
[21] KIM D. *"Preliminary life cycle analysis of modular and conventional housing in Benton Harbor, Michigan"*. Master's thesis, School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI, USA. 2008
[22] QUALE J, ECKELMAN M.J., WILLIAMS K.W., SLOADITSKIE G, ZIMMERMAN J.B. "*Comparing environmental impacts of building modular and conventional homes in the united states".* Journal of industrial ecology. 16(2), pp.243-253. 2012. Yale University
[23] EN15978: 2011, Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method
[24] PEURIFOY R, OBERLENDER G. *"Estimating Construction Costs 5th edition"*. McGraw-Hill Higher Education. 2002. Boston
[25] HOLM L, SCHAUFELBERGER J.E., GRIFFIN D, COLE T. *"Construction Cost Estimating: Process and Practice". Pearson Education Inc. 2005. New Jersey*
[26] POPESCU C.M., PHAOBUNJONG K, OVARARIN N. *"Estimating Building Costs".* Marcel Dekker Inc. 2005. New York
[27] BJÖRKLUND T and TILLMAN A.M. *"LCA of building Frame Structures: Environmental Impact over the life cycle of wooden and concrete frames"*. Technical Environmental Planning Report 1997:2. Chakmers University of Technology. 1997. Sweden
[28] ecoinvent Center. Swiss Center for Life Cycle Inventories http://www.ecoinvent.org/database/

Recycling and End-of-Life scenarios for timber structures



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Abstract

In consideration of sustainable buildings, closing life cycle loops becomes more and more important. Up to now reuse and recycling is taken rarely into account in building processes. With rising consumption of wood for energetic use recycling of material becomes more important.
Up to now there are various studies in EU market ([1], [2], [3]) which quantify the usage of wood in market shares. Explicit calculations on recycling of wooden material in the building sector have not yet been done. In general the demand for reclaimed wood products in the building sector will rise due to the fact that the thermal use of wood is the last option in the cascade of use. The preferred option has to be the reuse and the recycling of reclaimed wood. On this option the refinement of reclaimed wood for innovative products as well as the broadening and enhancement of the cascades of reuse and recycling is strongly needed for the timber construction industry. Long-term and resource efficient use of wood from premium quality (like laminated wood, plywood, timber frame construction) is necessary to ensure sustainable construction with wood. In the process of planning wooden construction the deconstruction and reuse / recycling of the products has to be considered too.
This article also shows different recycling scenarios for waste wood management due to the contamination problem of particular fractions. The different waste wood fractions in strength, scale and size will tolerate certain processing options with an emerging range of recycling products.
Aim is a realistic estimation of theoretical scenarios for end of life and their influence on planning processes as well as the influence on life cycle assessment according to EN 15978. In this paper outcomes of the woodwisdom-net research project ECO2– wood in carbon efficient construction – as well as calculations on wood consumption of wide-span timber structures and investigated case studies on a very detailed level are brought together to show the state of art and theories to improve resource efficient usage of wood. In another approach the total demolition of an old wooden house in the Alps was evaluated. It is a typical example for a long-used construction with numerous repair intervals, changes, and additions. This leads to a wide variety of fractions and often to a contamination of wood from preservatives. The fractions of the demolished house mainly consist of small bits and pieces dedicated to different recycling options than wide span structures. The different waste wood fractions in strength, scale, and size will tolerate certain processing options with an emerging range of recycling products.
A better management of its renewable resources supports the material supply of the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preservation and also gain market shares now and in the future.

Keywords: Life cycle; end of life; reuse; recycling; timber structures; ECO2-project

1. Introduction

With a growing importance of wood as significant biomass component of the renewable energy supply, there might be a shortage in the availability of wood in the future [4]. The European Commission therefore proposed inter alia to increase the efficiency in the production and the use of wood. [5] A better management of its renewable resources helps the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preserving and also gaining market shares now and in the future. Solid and glued wood products should have the chance of a second, similar product life instead of recycling without preservation of solid wood properties. Today's most important challenge is to activate the potential of the wood sector to provide construction products fulfilling these requirements.

In consideration of sustainable buildings closing life cycle loops becomes more and more important. Up to now reuse and recycling of existing buildings are not examined widely. Reuse and recycling is taken rarely into account in building processes which is centred on the production, erection and operation of constructions. There is a lack of competitiveness of products within the forest-wood chain concerning the end-of-life strategies. The advantage of wood as a carbon storage can be obtained through reuse and recycling of the material. Only after all options of recycling are exploited the additional advantage of energy recovery should be used. This has a positive effect, which will lead to improved lifecycle assessment (LCA) indicators for wood based products. Finally the production and use phase of existing wood based products can be improved by consequently enhancing the cascades of utilisation.
On the other hand there is a clear need for a life cycle oriented observation of constructions. This includes the dismantling and end-of-life of the buildings. This paper shows the state of art and theories to improve resource efficient usage of wood. A better management of its renewable resources can help the material wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preservation and also gain market shares now and in the future.
With rising consumption of wood as renewable energy source recycling of material becomes more important.

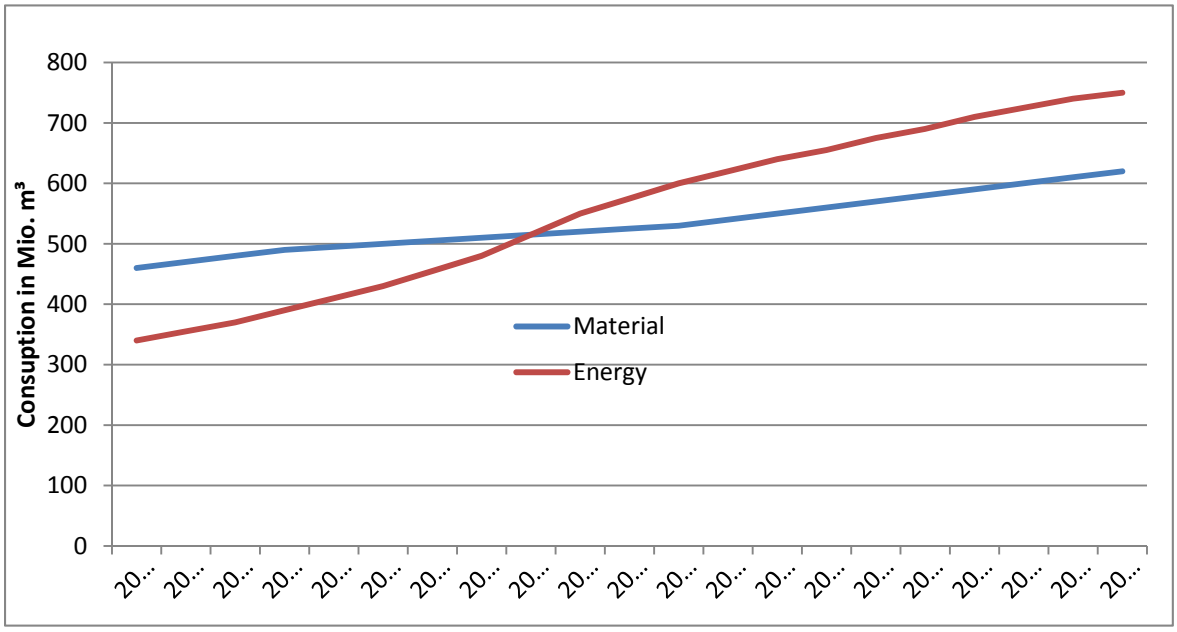


Fig. 1: Consumption of wood for energetic and material use in Europe [6]

As shown in [6] the consumption of wood for material use will rise slowly in the future, whereas the consumption of wood for energetic use will rise dramatically. In Germany wood for energetic use already exceeds the material use in 2012, five to six years earlier as actual calculations from Mantau have predicted in 2010.

This fact causes a rising share of fresh wood thermally used, and a shortage and in long run rising cost for raw material supply of the timber construction sector. The use of good quality, recovered wood not only as energy source reduces this economic pressure. Old buildings can provide the necessary dimensions and quantities of wood. Other sources rely on much smaller dimensions and are less useful. The scope of this paper is an estimation of the quantities and qualities of recovered wood. Additionally there are other fractions a building consists of, which are only side products in this study.
Therefore various research was done estimating the amount of usable material for recycling in wooden buildings and wide-span timber structures. On the other hand related outcomes of finished woodwisdom-net project ECO2 – wood in carbon efficient construction are included in this paper.

2. General framework on recycling of wood

The EU Directives as well as the national laws in many European countries aim at a higher rate of re-use and recycling, which leads to reduced amounts of wastes to be landfilled. The basic principle in the European waste management directive is that materials should be primarily recovered for secondary use, and not until a secondary option, they can be utilised as energy. It is evident that burning for energy is not accepted as recycling anymore in the future. The general idea of the legislation is to prevent waste generation, facilitate its utilisation, and reduce the disadvantages caused by waste management. Materials can be landfilled only if their utilisation is either technically or economically impossible.
The European Union has set an objective to develop itself as a recycling society, where waste generation is avoided, and wastes generated are utilised as a resource. The latest waste directive from 2008 [7] contains an article for re-use and recycling of materials. Among other things, it requires that the member countries have to proceed with necessary actions to recycle materials and products. To fulfill the normative requirements, the industries and R&D are in charge to develop products that can be easily recycled. In the wood product sector, the waste hierarchy is largely underdeveloped, so far. A lot of wood products that could be utilised in secondary product life cycle are burned for energy or are down cycled that they lose material properties of solid wood. On the one hand, this reduces the competitiveness of wood as a construction material not only from the ecological, but also from the business point of view. On the other hand, it offers an obvious opportunity for innovative companies to create new business models, processes and products.
To reach the requirements for recycling, the knowledge about the sources, the quantity and quality of reclaimed wood is necessary.

There are various studies in EU market, which quantify the usage of wood in market shares [1],[2],[3].Up to now no exact evaluation is confirmed on how much recycled wood exists in our building stock and how high the potential of reuse or recycling is from this material source. There is already a small amount from recovered wood used in the production of particle boards or wood fibre products but it is a small share. Explicit calculations on quantities of recovered wooden material in building sector have not yet been done.
Beside precise evaluation about volumes of wooden material for reuse purpose, reuse and recycling faces other obstacles. Wooden material can only be reused if it is not contaminated with harmful substances. Timber has been treated with poisonous chemicals since the beginning of the 20th century, to reduce the risk of mould or to impregnate it against insects. This fact decreases the possibility of reuse and even recycling of reclaimed wood nowadays. For reuse purposes the contaminated wood has to be identified and its amount has to be quantified. Additionally the type of chemical treatment has to be analysed for bio hazardous substances and human-hazard toxicity of treated timber construction. These quantities have to be sorted out and treated according to the rules for hazardous wastes, in Germany the recovered wood regulation [8].
According to German law the term used wood (Altholz) means used wood from production and end user, as far as it is covered by the German life-cycle Resource Management Act.
The used wood is divided up in four categories, in order to decide which wooden material is usable for which waste scenario.
a) *Waste wood category A I:*
Waste wood in its natural state or only mechanically worked that during use was at most insignificantly contaminated with substances harmful to wood

b) *Waste wood category A II:*
Bonded, painted, coated, lacquered or otherwise treated waste wood with no halogenated organic compounds in the coating and no wood preservatives,
c) *Waste wood category A III:*
Waste wood with halogenated organic compounds in the coating with no wood preservatives,
d) *Waste wood category A IV:*
Waste wood treated with wood preservatives, such as railway sleepers, telephone masts, hop poles, vine poles as well as other waste wood which, due to its contamination, cannot be assigned to waste wood categories A I, A II or A III, with the exception of waste wood containing PCBs [9].

Reuse of construction parts is problematic because of a wide spread of unplanned demolition. For optimal reuse the available construction parts have to be identified and classified at least for different end-of-life scenarios. Construction wood and engineered wood products can be dismantled easier than most other parts, because they are used in dedicated layers, they are often used in modular assemblies and they are light-weight. The wooden parts are mostly serialized and the dimensions of certain parts are identical. All these themes make wood suitable for reuse. After the planned dismantling process of removable parts, the rough demolition of monolithic portions can take place. Such fractions may contain smaller amounts of wooden bits and pieces which are reserved for recycling or thermal use.

3. Related outcomes of ECO2-project: wood in carbon-efficient construction

The European woodwisdom research project ECO2 – wood in carbon efficient construction focused on creating holistic understanding of carbon efficiency in the full life-cycle of wooden building and defining technical potential and obstacles for the use of wood in carbon efficient construction. Aim is a clear minimisation of carbon emissions during production, construction and in the full life-cycle. Different case studies on life cycle of wooden products and buildings were examined and energy and carbon balance examined.

3.1 General framework on lifecycle assessment in buildings

According to the standard EN 15978: *sustainability of construction works – Assessment of environmental performance of buildings – Calculation method* the lifecycle of a building is divided up in different modules from A to D. Figure 2 shows the division in phases and the input of residues in lifecycle. In that context all scenarios for recycling and in general end of life of a product are integrated in module C. Modules include deconstruction / demolition (C1), transport to the product's waste processing (C2), waste processing for reuse, recovery or recycling, recovery and/or disposal (C3), disposal (C4).
To show possible benefits and loads of materials beyond the product system boundary, an additional module D is introduced. This means that in module D the recycling potential, the persistence of mineral building products, avoided impacts of thermal energy recovery, embedded renewable energy or carbon stored in the product can be shown. Up to now end-of-life scenarios for wooden products nearly only consist in incineration and energy recovery.

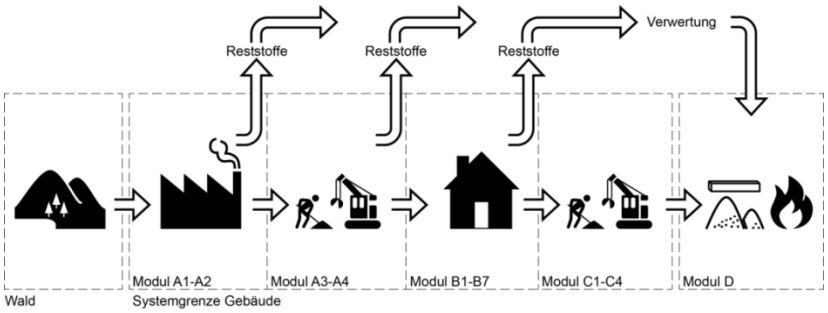


Fig. 2: residues from wood production in different phases of lifecycle

Therefore the treatment of carbon in life cycle analysis is a crucial factor which is not handled equally in LCA calculations up to now. System boundaries for calculation of building LCA were defined. The red line in figure 3 shows a simple system boundary for practical implementation of carbon footprint analysis. An assessment of this system provides information about the impacts of processes to produce, consume and disposed of a unit of a product / building. This approach aims at describing environmental properties of a building in its life cycle. But it does not include induced effects from changes in outputs such as shifts in production and emissions from other products that are displaced by the product being assessed. [11]

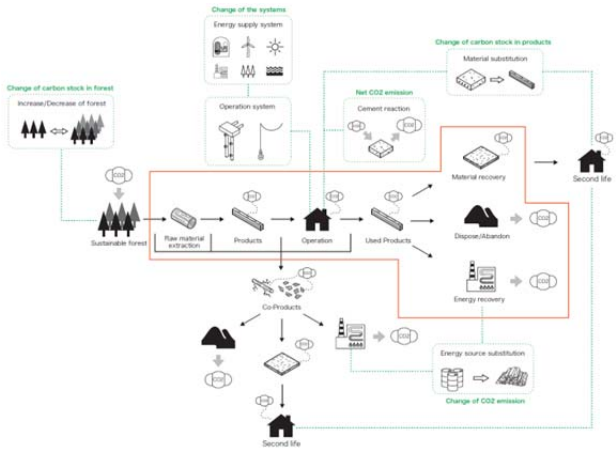


Fig. 3: Holistic picture of carbon footprint related to a wooden building system and simplified system boundary for the system building including only direct environmental effects.

Growing trees in the forest embed carbon in the material. Wood from forest is counted with negative greenhouse gas emissions in module A due to the carbon stored in the product. The biogenic carbon emissions directly attributed to a woodbased product result either from the use of biomass energy in production phase (module A) or from combustion of the product after end-of-life (module C). These emissions are equal to the amout of carbon sequestered in the growing tree which provides the biomass for the wood or the energy used. Prerequisite for that is always that sustainable forestry is applied. Several LCA calculations therefore regard wood as GHG neutral and don´t calculate them at all. This is only the case if calculations include the whole life cycle from production to End-of-life, if the wood is not leaving the forest system and if these forest are not being harvested. LCA calculations done according to the standards of EN15804 and EN15978 do not give instructions for the handling of wood and sequestration of carbon. But according to these standards the carbon and primary energy have to be accounted separately in the different modules. This requires that carbon balance is shown divided up in the modules. Hence wooden materials become a negative value in module A1 and a positive value in C4. Energy gains and the carbon stored in the product (if it is reused or recycled) have to be shown in module D. The overall carbon balance is still zero, but it can be divided among the different modules. By recycling or reusing wooden material at end-of-life for asecond life-cycle, carbon storage gets prolonged.

3.2 Characteristics of wood in end-of-life of LCA

While buildings are seen as a whole in the use phase, for end-of-life it comes down to the specific construction and the materials they are made of. Building components can be decomposed into different layers to get a deeper understanding of their impact at end of life, compare Figure 2. The layers of the building have different exposures, durability and therefore a different life span. The disassembly allows the identification of required service life of building parts and has to be considered in maintenance, inspection, end-of-life scenarios. In modern (timber) buildings different layers are also common to fulfill a wide variety of technical requirements.
Figure 4 shows the different layers of a façade divided into its technical and functional layers. The

primary construction needs to outlast the whole life span, wooden primary construction has high mass and can store a high amount of carbon over this period. The other layers e.g. cladding will be replaced many times and therefore are relevant in terms of recycling potential and burdens / benefits at EoL stage. This can be used as design methodology for the improvement of environmental performance. Through the interdependency of use- and EoL-scenarios, the different layers can seperatly be optimized more easily and then be designed for reuse. The jointing between layers and the frequency of renewal are additional criteria for the end-of-life phase apart from the material impact. [11]

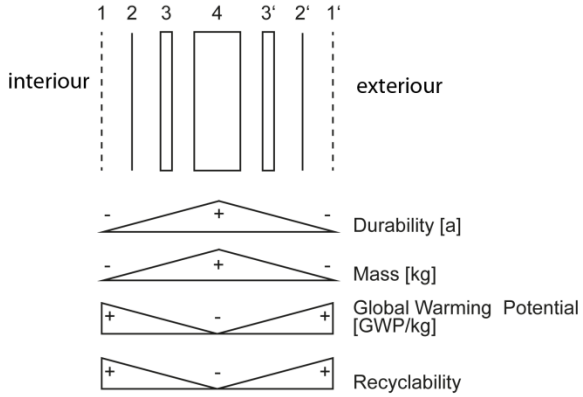


Fig. 4: Sequence of technical and functional layers and weighted influence on EoL impact below. 1) paint 2) cladding 3) functional layer 4) load bearing structure. [10]

In general the options for end-of life module for wooden products are:
Energy recovery:
Energy recovery means that the material gets burned in incineration plants. Then the embedded primary energy stored in wooden products gets released and a heating value is generated.
Incineration with energy recovery is useful for various materials like:
- Wood contaminated with paint / lacquer
- Wood contaminated with toxic substances (like PCP, impregnation)
- Small wooden parts which are bound together with glue
- Other materials that cannot easily be separated.

According to the German used wood categories described previously, energetic recovery is feasible for categories A III to A IV and in parts A II. Module D would contain avoided impact of electricity production and thermal energy recovery and emissions associated with wood combustion.

Material recycling:
"Recycling" means any recovery operation by which waste materials are reprocessed into products, materials or substances; whether it is for its original or new purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" [7].
Material recycling can only be applied for wooden materials in category A I, and there must be a strict selection process to ensure that no contaminated material gets reused. Up to now the selected material for recycling gets used for soft board production only. Module D would contain avoided impacts of forestry, harvesting, wood chips preparation and drying.

Reuse:
"Re-use" means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived." [7]
Reutilization: For example, massive timber construction is deconstructed and reused for the same purpose.
Subsequent use: For example, solid timber construction is deconstructed and then cut into parts to be used as beams for roofing. The compounds are down cycled but the material still has some of

its properties.
This reuse is only useful for wide-span structures and laminated beams that have no material faults. For reuse, it is important that no preventive wood protection is applied to constructions; while for easy deconstruction it is beneficial to screw joints rather than nailing and clipping. This means that recommendations need to be made for design for reuse / recycling [11].

4. Case study on an existing wooden building for calculation of quantities

Aim of this study was a realistic assessment of the material fractions to overcome rough estimations and theoretical scenarios for end of life. Exemplary investigations and calculations are done on an existing cottage in the Alps (Höllentalangerhütte), which is located in a sensitive natural environment. Focus of the study is the primary loadbearing construction, the related claddings, surfaces of interior and exterior and the quality of the parts.
For realistic estimation of material content the methods of building survey, classification of components, parts, materials and documentation for reuse, recycling and disposal of existing constructions were presented in [12]. Results are summarised here.
Basis for the examinations are an overall inventory analysis and documentation of existing construction with classification in qualities and quantities. Used methods were: research with existing planning material, survey on site and examination of material samples for hazardous substances. The work was divided in two parts:
The first part was of theoretical nature and based on a research in the archives for information about the history of the cottage, the development stages over the lifecycle with repairs, refurbishments and extensions. First calculations are done according to existing drawings to get knowledge about quantities and material usage.
In a second part a survey on site checked material dimensions for quantity surveying and also results in drawings of construction details with focus on materials. Damages of construction and possible use of harmful substances were besides documented on site. Material samples were taken to analyse them on harmful substances and wood moisture content was checked as well.

4.1 Case study of a cottage dedicated to demolition

The Höllentangerhütte is located in the northern Alps close to Garmisch-Partenkirchen. It is situated at a height of 1387m above sea level and can only be reached through a small and steep foot path. The cottage was built and completed in for stages and consists of a wooden log house, two-storey timber building with a post and beam construction on a stone masonry cellar and an additional stone building with masonry walls from light-weight concrete blocks. The first part was built at the end of the 19th century, the follow-up building phases were in the beginning and middle of the 20th century. The overall gross external volume is 1650 m³, the net floor area is 511 m².

The amount of wood contained in a historic cottage in the Alps, dedicated to demolition, was evaluated. It is an example for construction with a long life cycle with numerous repair intervals, changes, building extensions, and a conglomerate of different materials.
Thereby reusing and recycling is not possible without a careful separation of the materials, which are non-toxic and toxic. Via pyrolysis and use of spectroscopy harmful substances like polycyclic aromatic hydrocarbon (PAK) and Pentachlorphenol (PCP) in coatings were detected. Result of the analysis showed, that the main part of the timber construction could be reused as further components. Only parts of the façade cladding and materials included in the construction phase of the 1960s contained hazardous substances. Most material from the original cottage is free of harmful substances and is also in good and dry condition. 6.7% of wooden material contains harmful substances, mainly the cladding which is exposed to painting in the last decades of the 20th century.

4.2 Results

Although the cottage Höllentalangerhütte is an example for buildings mainly built from wooden material results show the following. Analysis of material fractions in mass and volume show a high

percentage of massive material in the cottage. The share of wooden material reaches a share of 38% in volume with very simple wooden constructions and a mass of 14 per cent. The main mass is 63% concrete / stone. Complete analysis of construction is shown in figure 5.

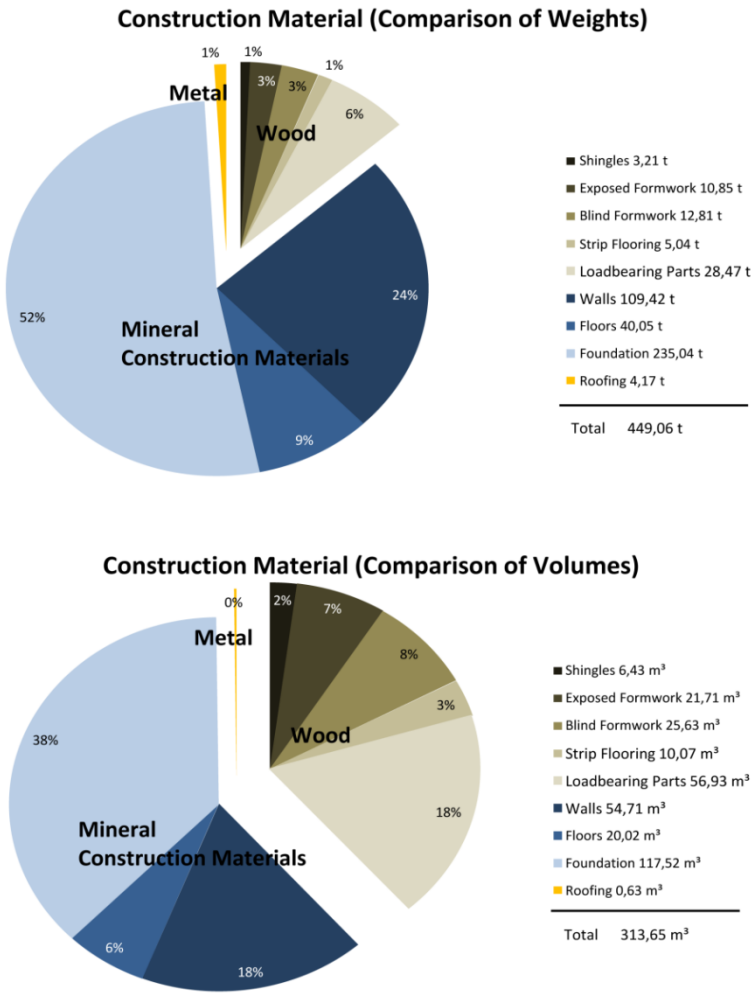


Fig. 5: Construction material – different fractions. Comparison of volume and mass [12]

To compare results to calculations done in chapter 5 a combined value of m³ wood per m² gross floor area is introduced. It is 5,1 m²/m³ or as a reciprocal value 0,20 m³ wood per m² gross floor area. This value shows the amount of used wood in comparison to the m² of gross floor area.

5. Analysis of wide-span timber structures

The problems of the reuse of contaminated wood shift the focus on younger buildings without chemical treatment of the timber construction. Especially the high quality engineered wood products like glulam, solid wood panels or CLT are in focus during data mining. The collection of data is limited to roof structures made of wood, as they are relatively easy to evaluate, compared to wooden buildings, empowering them to make a more meaningful statistic. The available beam dimensions and products of wooden roof structures are well suited for reuse. For evaluating 116 hall structures, as well as other large-scale structures, a wide range of use, size and age, are recorded in tabular form. A comprehensive evaluation but also a heterogeneous result is achieved with these data. The evaluation is adapted as a whole as well as on the individual vehicle types and assessed collectively in the summary statements.
The classification of the parameters starts with the desired result, the amount of used wood. To estimate the amount of used wood, span, beam depth, truss spacing and truss number as input variables are necessary in addition to the truss form and design. To describe the use of wood in a structure sufficiently accurate, it is necessary to explain it according to its shape-defining parameters. This is the consumption of wood in structures in relation to the footprint of the structures. This ratio m²/m³ allows a comparison of the trusses with each other. The relationship is suitable for a general assessment of the truss, since it contains all necessary parameters; with the counter, namely the footprint, which includes span, truss number and spacing, as well as the denominator, consumption of wood. The representation of wood consumption in relation to the floor space for each type of structure is calculated as an own indicator from the averages of the demand for wood and lined up floor spaces according to, compare figure 6. The nominal size of this factor increases the resource savings. With the inverse value one get the amount of exploitable secondary wood/recyclable material per square meter floor space.

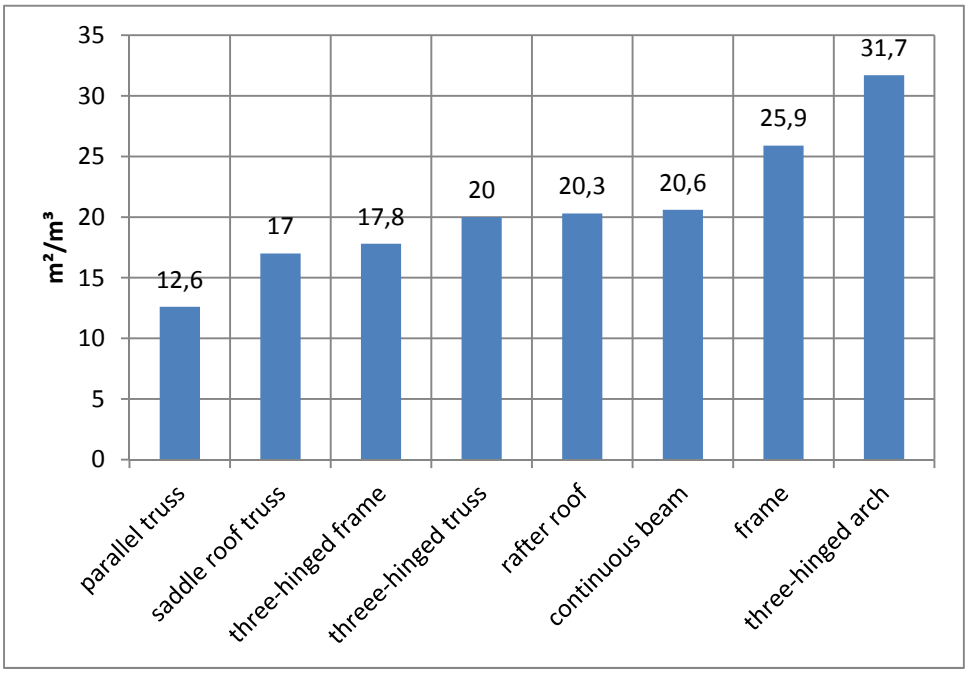


Fig. 6: Comparison of wide-span roof structures shows the covered floor space in relation to 1 m³ of used wood.

The evaluation could be completed with the statement, that the most used trusses have the lowest covered floor space in relation to 1m³ of used wood and therefore have the highest wood consumption. But there is far more to gain from the summary information. The vast distribution of values around the 20 m²/m³ mark shows that regardless of truss type evaluation evenly and properly worked. For the individual systems, no major differences have been expected. The values with the highest deviation of parallel trusses and three-hinged arch trusses are to be clarified separately. Other truss systems are better adapted to the load, such as the saddle roof truss, in

which the distribution of the bending moment is optimized by an increased cross-section at mid-span. Parallel beams, in contrast, will have to bear higher bending stresses due to their constant cross-section; here, an increase in bending moment due to wider spans is simply countered by increasing the dimension of girders or higher trusses. This consequently increases the consumption of wood due to the increased volume over the entire beam length. The three-hinged arch also features a uniform cross-section, but since the load transfer is primarily realized through normal forces instead of bending moment, the structural system can be realized with a smaller cross-section.

6. Results

For future planning the reuse and recycling of existing buildings has to be integrated quite early in the planning process to be able to reuse the materials in the best way. Small scale drawings also show how components are built in and how jointing is done. This information is useful for dismantling.
With existing building documentation fictive mass calculation could be produced which then can be updated by partial surveys. In future architects contracts have to be enlarged to include also reuse of material in early planning stages.

The Höllentalangerhütte, as a case study, reveals that the more than 120 year old wooden construction still is in very good condition and could be reused in large parts. In parts where no maintenance and repairs were applied, like running water around broken rain gutter, the construction is mouldered and cannot be reused. Problems for recycling arise in the usage of harmful substances in paints. Here exact material testing is necessary. In general conclusion can be drawn that this Alpine cottage is an example for a simple building with a minimized construction which allows a high level of reuse. A reduced conglomerate of fractions makes separation easier and the additional economic effort could be limited.
The analysis of wide-span timber structures shows that there is an average amount of 0,05 m^3/m^2 of wood in these structures which equals about 21 kg/m^2 of softwood. Although there are losses due to the removal of construction joints and areas with dowels or nails, there is still a reasonable amount of quality engineered wood which can be reclaimed for a second use phase.
In the planning process for new timber structures design and construction has to integrate various possibilities to extend the life cycle of a product or material:
- Design for reuse
- Modularity of the structural system from components to the structural system
- Use screws instead of nails, clippings
- Extend the life span of the building and the durability of the products
- Easy dismantling of the buildings (connecting devices)
- Avoidance of composite materials
- Avoidance of toxic substances
- Use of waste wood fractions A I (only in parts A II)
- Maintenance, repair, renewal of surfaces (exterior and interior)
- Keep information about existing building through building passport (or sustainability certification)
- The prefabrication in the wood process is an advantage for durability and the end-of-life phase, as the construction has to be designed in modular elements. The replacement of single layers is possible through straight joints, so recycling becomes much easier.

Cascaded use of wood can affect the LCA positively, as carbon storage is prolonged. The material choice for wooden products will be influenced more positively, if the used wooden material is not burned immediately, but used as materials. Therefore, there is a need of a recycling proof and elimination concept for a future use of reclaimed wood of high quality.

7. Conclusion

The European Commission proposed to increase the efficiency in the production and the use of wood [5] and resource efficiency in general [13]. The overall goal must be to increase the long-term availability of renewable but at the same time limited resources for the wood cluster. The

competition for raw materials between stakeholders in the wood cluster will be reduced and the wood utilization with immanent positive effects on climate protection will be optimized. An approach for higher resource efficiency is the implementation of a material flow management in the entire process of timber construction.
The latest waste Directive from 2008 [7] contains an article for re-use and recycling of materials. Among other things, it requires that the member countries have to proceed with necessary actions to recycle materials and products. To fulfill the normative requirements, the industries and R&D should develop products that can be easily recycled.
A better management of its renewable resources helps the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preserving and also gaining market shares now and in the future.
For recycling of existing buildings exact calculation of actual mass and volume as well as building condition is necessary. Therefore drawings (as built) help to calculate overall quantities. They need to be checked on-site with survey. On-site survey focuses on quality of materials. Only on-site reliable information on the qualities of wood and usage of harmful substances can be gained. These analyses are important to choose material for recycling without introducing critical substances in the recycling process. For reuse the classification system has to be improved to the same level as the reclaimed wood classes regarding the contamination. This could be difficult, because the way of reuse is unclear and needs further development.

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8. References

[1] LANG A. „*Charakterisierung des Altholzaufkommens in Deutschland. Rechtliche Rahmenbedingungen – Mengenpotenzial – Materialkennwerte*“. Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft, Kommissionsverlag Buchhandlung Max Wiedebusch Hamburg, 2004, Volume 215.
[2] WEIMAR H. „*Empirische Erhebungen im Rohstoffmarkt am Beispiel der neuen Sektoren Altholz und Großfeuerungsanlagen*“. Sozialwissenschaftliche Schriften zur forst- und Holzwirtschaft, Internationaler Verlag der Wissenschaften Frankfurt am Main, 2009, Volume 9.
[3] MANTAU U. „*Rohstoffknappheit und Holzmarkt*.“ Waldeigentum, Springer Berlin / Heidelberg, 2010.
[4] Holzzentralblatt, November 2012, Leinfelden-Echterdingen, 2012.
[5] GREEN PAPER On Forest Protection and Information in the EU: Preparing forests for climate change SEC(2010)163 final
[6] MANTAU U, et al. “*Real potential for changes in growth and use of EU forests”.* EUwood, http://ec.europa.eu/energy/renewables/studies/doc/bioenergy/euwood_final_report.pdf; 2010
[7] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal L 312 , 22/11/2008 P. 0003 – 0030; http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:01:EN:HTML, 16.07.2012
[8] Verordnung über Anforderungen an die Verwertung und Beseitigung von Altholz Altholzverordnung – AltholzV, from 24.02.2012.
[9] Ordinance on the Management of Waste Wood, Bundesministerium für Umwelt, http://www.bmu.de/files/pdfs/allgemein/application/pdf/wastewood_ordinance.pdf; 25.10.2012
[10] HAFNER A, OTT S, WINTER S. „*Rohstoffverwertung in Nutzungskaskaden*“. Holzbau – die neue Quadriga, Wolnzach, Volume 3/2012 , pp. 41-45.
[11] ECO2-book: www.eco2wood.com; Summer 2013
[12] HAFNER A, OTT S, et al. “*Höllentalangerhütte – case study for end of life reuse and recycling methodologies*”. Proceedings of sustainable building conference, Munich, 2013, pp. 1457-1466.
[13] European Commission 2011/21/ EC of 26 January 2011, Ressourcenschonendes Europa – eine Leitinitiative innerhalb der Strategie Europa 2020, Available at: <http://ec.europa.eu/resource-efficient-europe/index_de.htm; 19.02.2013.

Regulation of displacement ventilation systems combined with surface heating/cooling in passive house office model rooms

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Short Summary

Thermal comfort and indoor air conditions have been studied in model passive house office spaces comparing several heating, cooling and ventilation concepts. Thermal building simulation and computational fluid dynamics (CFD) simulations have been coupled to building and system simulation.
Results indicate that

- regulation of heating and cooling ceilings and floors require considerable heating/cooling capacities in passive house office conditions
- displacement ventilation gives leeway to decreasing ventilation volumina below the level assumed for mixed ventilation

Keywords: Passive house building standard; office buildings; displacement ventilation; surface cooling/heating.

Introduction

Thermal and hygienic comfort problems and increased energy consumption may occur in office spaces built according to the passive house building standard when

- internal and external heat loads entail high energy consumption for cooling in summer,
- high ventilation requirements due to high occupation densitiy produce low relative air humidity – or need for air moisturing,
- heating, cooling, and ventilation appliances are not properly adjusted to each other producing draught, or incomplete air exchange.

Systematic studies on appropriate parameter combinations for office space design have therefore been the aim of a major project [1, 2, 3, 4].
From a follow-up study this contribution selects two topics

- regulation strategies for heating and cooling ceilings and floors
- potential of displacement ventilation for decreasing ventilation volumina below the level assumed for mixed ventilation

Methodology

Thermal comfort
Thermal comfort has been assessed according to ISO EN 7730. This includes the concepts of

general thermal comfort evaluation predicted mean vote PMV, predicted percentage of dissatisfied (PPD), and criteria of local discomfort

- Percentage dissatisfied due to local discomfort from draft (DR)
- Allowable radiant temperature asymmetry
- Allowable vertical air temperature difference between head and ankles
- Allowable range of floor temperature

Air quality, ventilation quality

Air quality has been estimated according to EN 13779:2008 as CO_2 concentration of indoor air with classes IDA 1 to 4 referring to CO_2 concentrations ranging from < 800 ppm to < 1900 ppm CO_2. Ventilation quality is described as normalised air age (air exchange index), with values of 1 for ideal mixed ventilation. Values > 1 indicate efficient air supply often found in displacement ventilation, values < 1 point to locally insufficient air exchange.

Model Spaces and HVAC specifications

Using model spaces, several heating cooling and ventilation concepts have been studied.

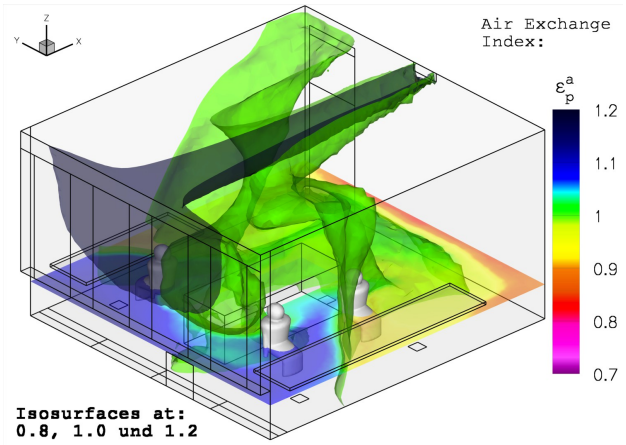


Fig 1. Model office space showing 3 seated persons, furniture and isosurfaces of air exchange index.

The office is occupied from Monday to Friday between 08:00 and 18:00 by three persons with some technical equipment. The heat output of the persons is dependent on the temperature (around 75 W). The technical equipment produces a heat output of 300 W and the heat emission of the light is set to 15 W/m². The inner heat load is reduced to the half from 08:00 to 08:30 and 17:30 to 18:00.

The heat emission of the persons takes place in a cylindrical volume around each person. 20 l CO_2 per hour is exhaled by each person in a cylindrical volume around their heads. In contrast, the heat output of the technical equipment is not localized, only the input of the light is restricted to a volume close to the ceiling by 60 % convection and 40 % radiation.

Systems compared include

- thermally activated ceilings
- plaster ceiling cooling/heating
- suspended overhead cooling/heating panels
- underfloor cooling/heating

differing in their levels of thermal inertness resp. in cooling/heating capacities.

Starting from an initial set of parameters following parameters were varied:

- Set temperatures at the thermal sensor
- Lowering set temperatures during nighttime or during daytime
- Earlier start of heating/cooling facilities (00:00 or 02:00 instead of 06:00)
- Supply air temperatures floating with thermal sensor temperatures with a fixed temperature

difference or
- Fixed supply air temperatures.

Criteria of evaluation were
- courses/trends of air and operative temperatures resp. PMV and PPD values during the coupled phase (24 hours)
- Prevaillance of local discomfort especially draft risk and allowable vertical air temperature difference between head and ankles. (No cases of discomfort resulting from radiant asymmetry or floor temperatures were observed.)

Thermal Building and CFD Simulation Methodology

The simulation method applied here is a combination of dynamic building and system simulation with indoor air flow calculation. Building simulation provides the energetic balance for rooms for periods like weeks, months or years. By coupling with the indoor airflow simulation it is possible to analyze the structure of the flow and to calculate heat and mass transfer in detail for short time periods like some hours or some days. The building and system simulation is carried out by a special version of the commercially available program TRNSYS [5], named TRNSYS-TUD [6] because of the extensions done at TU Dresden. For the transient, nonisothermal and turbulent indoor airflow simulation, the Finite Element Computational Fluid Dynamics (CFD) code ParallelNS is applied, developed at University Göttingen and TU Dresden [7]. Both programs are coupled via PVM (Parallel Virtual Machine [8]) to a calculation system, see fig 2. After a period with pure building simulation for only energetic balance (denoted by the arrow on the left hand side in fig.2) the fully coupled phase including the air flow simulation starts at time $t_{0,0}$. Therefore the calculated wall temperatures ϑ at the defined interface walls will be sent to the CFD-code, which is calculating the heat flux Q between those walls and the indoor air. With these data about convective heat transfer the building simulation program generates a new energy balance (including radiative heat transfer) for the next time step and so on. In addition, the system simulation is coupled in a similar way. Detailed information about radiation and convection at selected sensor positions is sent by ParallelNS to TRNSYS-TUD which calculates the appropriate reaction of the heating or cooling system.

The simulation starts with 14 days of pure building and system simulation using simplified weather conditions, constant temperature of -5° C in winter and a permanently repeating warm day with 30 °C top temperature in summer. The fully coupled simulation including CFD starts on the 15th day at 00:00 and is running until 24:00. It should be noted, that this day is a Monday after the weekend. Resulting data comprise temperature and velocity fields, CO_2 concentration and age of the air, all wall temperatures, sensor data and reactions of the technical system for a period of 24 h.

Thermal comfort can be evaluated by using the information of radiation and convection that is available in every computational cell of the calculation domain.

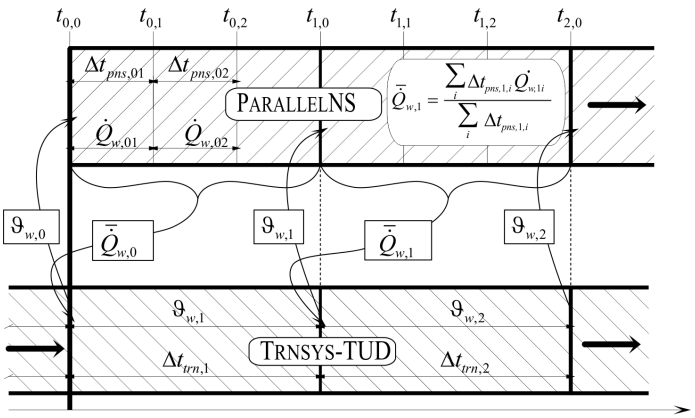


Fig 2. Sketch of coupling strategy between building simulation by TRNSYS-TUD and indoor air flow calculation by ParallelNS in an adaptive time step algorithm.

Four sensors are situated in 0.1 m, 0.6 m, 1.1 m and 1.8 m height between the two persons sitting at one desk, see fig. 1. The operative temperature in 0,6 m height is usually used for control of the systems. In case of concrete core activated ceilings an additional sensor for surface temperature is applied for system control.

Results

Regulation strategies for heating and cooling ceilings and floors

Cooling

Fig 3–6 show PMV values during the coupled phase comparing thermally activated concrete ceilings, plastered ceilings with integrated tube mat, suspended cooling ceiling panel, and underfloor cooling. An initial parameter set and an optimised configuration is shown.

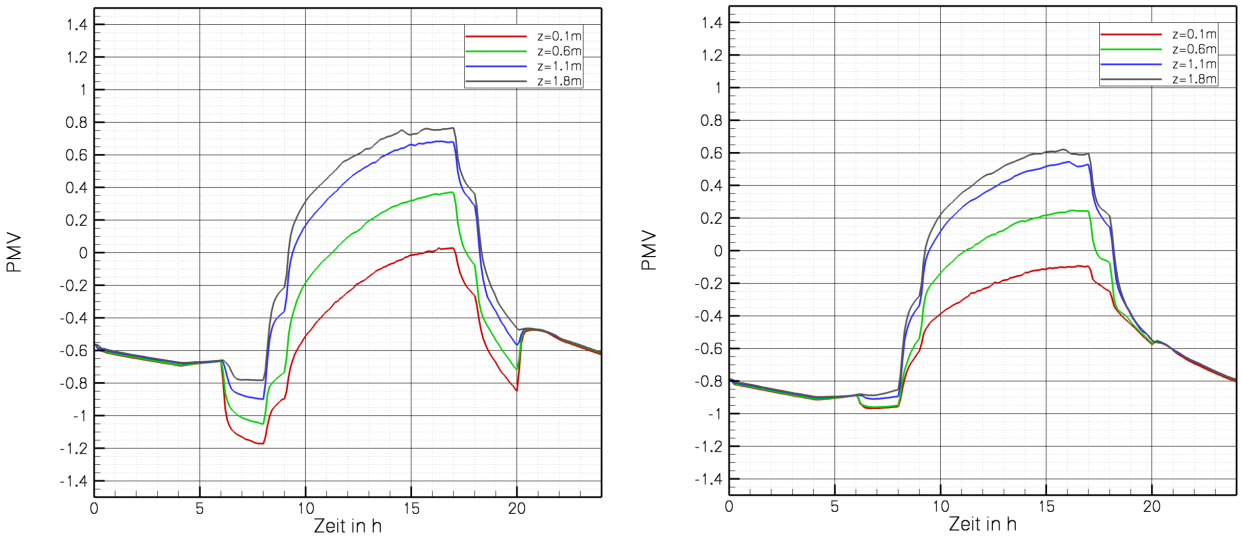


Fig 3. Concrete core activated ceiling, cooling capacity 40 W/m² of 90 % of ceiling area. Temperature sensor in the ceiling surface. Ventilation: Floor swirl diffusers. Left: Set sensor temperature 23 °C, temperature of supply air 4 K below sensor temperature. Right: Set sensor temperature 22 °C, temperature of supply air 1 K below sensor temperature, floating, but max. 22 °C.

The highly inert activated concrete ceiling characterised by rather low cooling capacity produces cool temperatures in the morning. As office activities start, temperatures rise sharply, and cannot be stabilised at a set PMV level of close to zero (left).
In an optimised configuration (right) the decreased set sensor temperature keeps temperatures (and PMV values) at lower levels, but the general situation remains the same. Smaller temperature differences of supply air are visible in the morning around 06:00 to 08:00 with higher PMV values. But as temperature is limited to max. 22 °C supply air takes a role in cooling the model room, indicated by a still high spread of PMV values at different room heights during daytime.

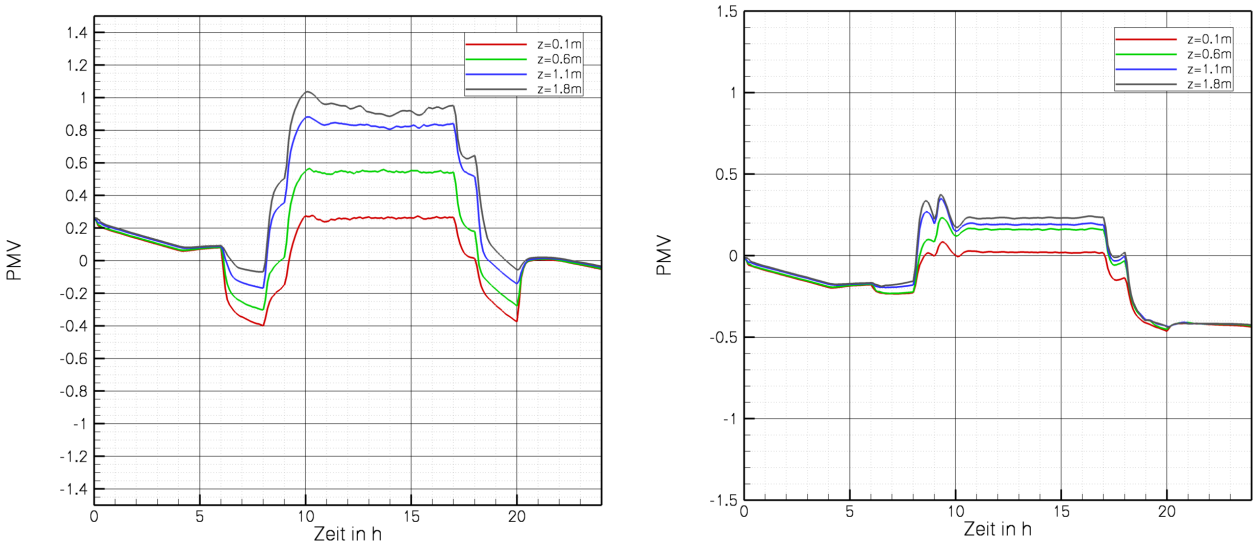


Fig 4. Plastered ceilings with integrated tube mat, covering 85 % of ceiling area, cooling capacity max. 80 W/m², thermal sensor situated at a level of 0.6 m between seated persons. Ventilation: Floor swirl diffusers. Left: Set sensor temperature: 26 °C, temperature of supply air: 4 K below sensor temperature, floating. Right: Set sensor temperature 24.5 °C, temperature of supply air: 1 K below sensor temperature, floating.

The impact of a doubled cooling capacity (80 W/m² vs. 40 W/m²) shows clearly in fig 4. The plastered ceiling with integrated tube mat achieves an even level of temperature (and PMV) which, in the initial configuration (left), is still too high. A considerable spread of PMV values at different room heights indicates additional cooling by supply air due to a temperature difference of 4 K. An optimised configuration (right) with lower set sensor temperature brings PMV values down to levels close to PMV = 0. Supply air temperature difference lowered to 1 K brings PMV values in different room heights close together indicating an homogeneous room climate.

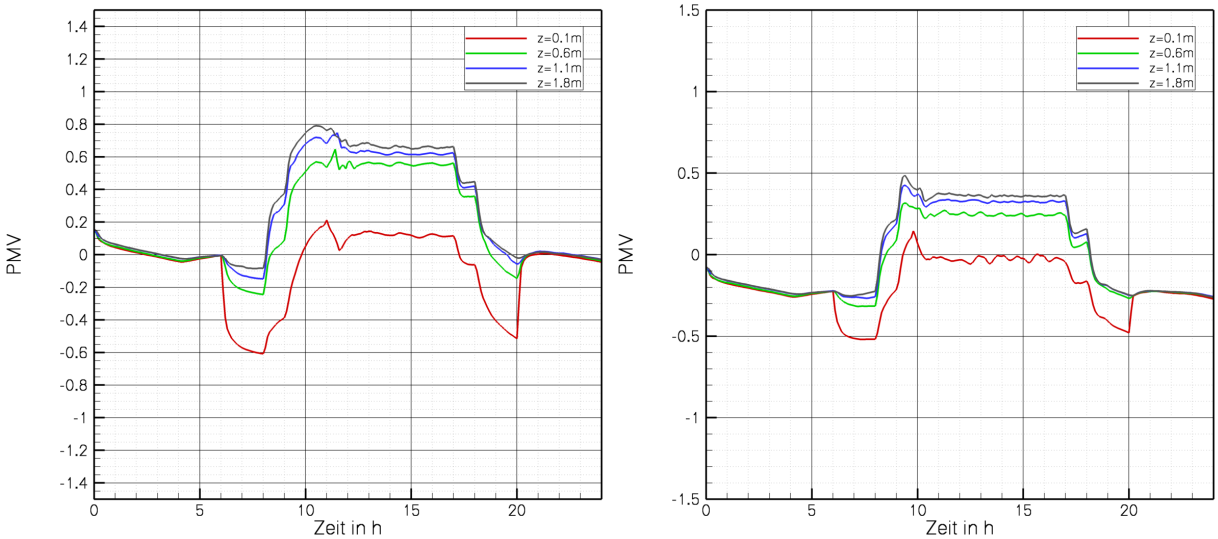


Fig 5. Suspended cooling ceiling panel, cooling capacity 150 W/m², covering 50 % of ceiling area, temperature sensor situated at a level of 0.6 m between seated persons. Ventilation: Displacement flow diffusers. Left: Set sensor temperature: 26 °C, temperature of supply air: 4 K below sensor temperature, floating. Right: Set sensor temperature 25 °C, temperature of supply air: 2 K below sensor temperature, floating.

Quite similar results as in the case of the plastered ceiling (fig 4) are produced by the suspended cooling ceiling panel. Reducing both set sensor temperatures and supply air temperature differences lower both levels and vertical gradient of PMV values.

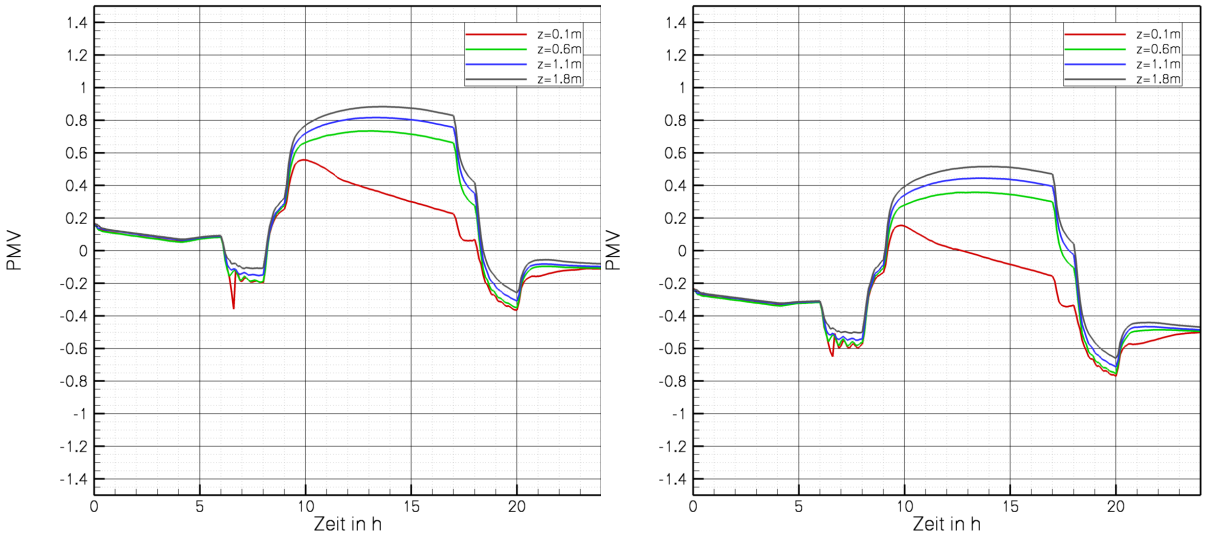


Fig 6. Underfloor cooling, cooling capacity max. 30 W/m², temperature sensor situated at a level of 0.6 m between seated persons. Ventilation: Air grill. Left: Set sensor temperature 26 °C, temperature of supply air: 6 K below sensor temperature, floating. Right: Set sensor temperature 24.5 °C, temperature of supply air: 6 K below sensor temperature, floating.

Despite of a rather low cooling capacity of underfloor cooling the system is capable of producing an even level of PMV values during the day (left) which can be adjusted with a lower set sensor temperature (right). PMV values at floor level (0.1 m) are influenced by the cooled floor surface, at higher height levels of 0.6 m to 1.8 m the influence of a mixed ventilation via an air grill is dominant.

Heating

Fig 7–10 show PMV values during the coupled phase comparing thermally activated concrete ceilings, plastered ceilings with integrated tube mat, suspended heating ceiling panel, and underfloor heating. An initial parameter set and an optimised configuration is shown.

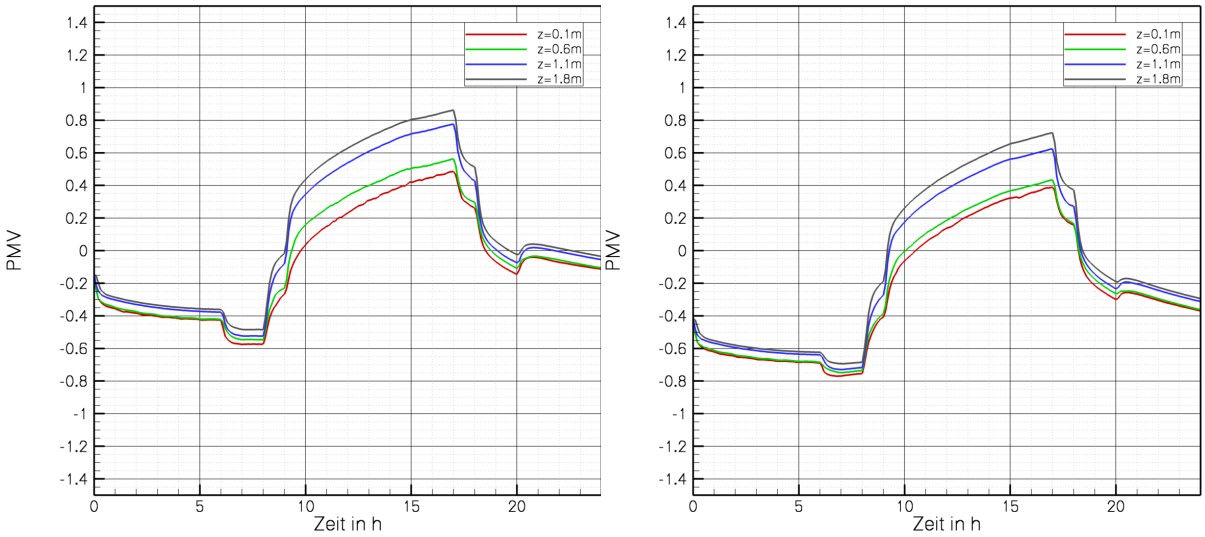


Fig 7. Concrete core activated ceiling, heating capacitiy 30 W/m². Temperature sensor in the ceiling surface. Ventilation: Floor swirl diffusers. Left: Set sensor temperature 24 °C, temperature of supply air 2 K below sensor temperature. Right: Set sensor temperature 22.5 °C, temperature of supply air 2 K below sensor temperature, floating.

Like in the cooling situation (fig 3) the concrete core activated ceiling has no sufficient heating capacity to keep temperatures and PMV values at an even level during the day.

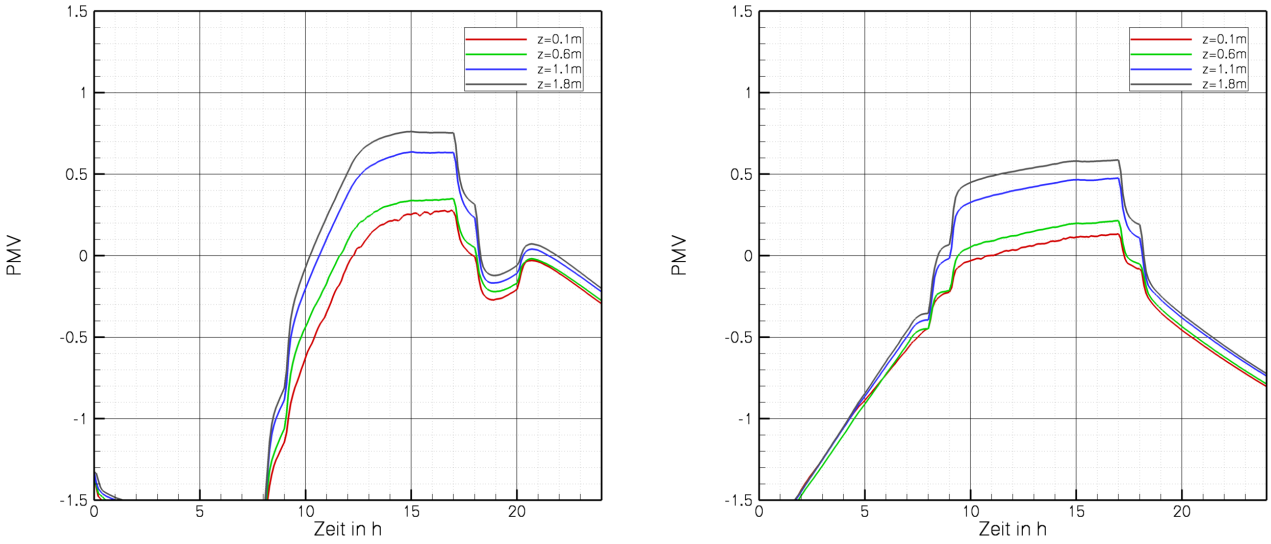


Fig 8. Plastered ceilings with integrated tube mat, heating capacity max. 52 W/m², temperature sensor situated at a level of 0.6 m between seated persons. Ventilation: Floor swirl diffusers. Left: Set sensor temperature: 22 °C, temperature of supply air: 2 K below sensor temperature, floating. Start of surface heating at 06:00. Right: Set sensor temperature 20 °C, temperature of supply air: 2 K below sensor temperature, but limited to 20 °C. Start of surface heating at 00:00.

Start of surface heating only 2 hours in advance of office hours is not sufficient to generate thermal comfort in the morning after a weekend (left). With start of heating at midnight an almost even level of thermal comfort is achieved during the day.

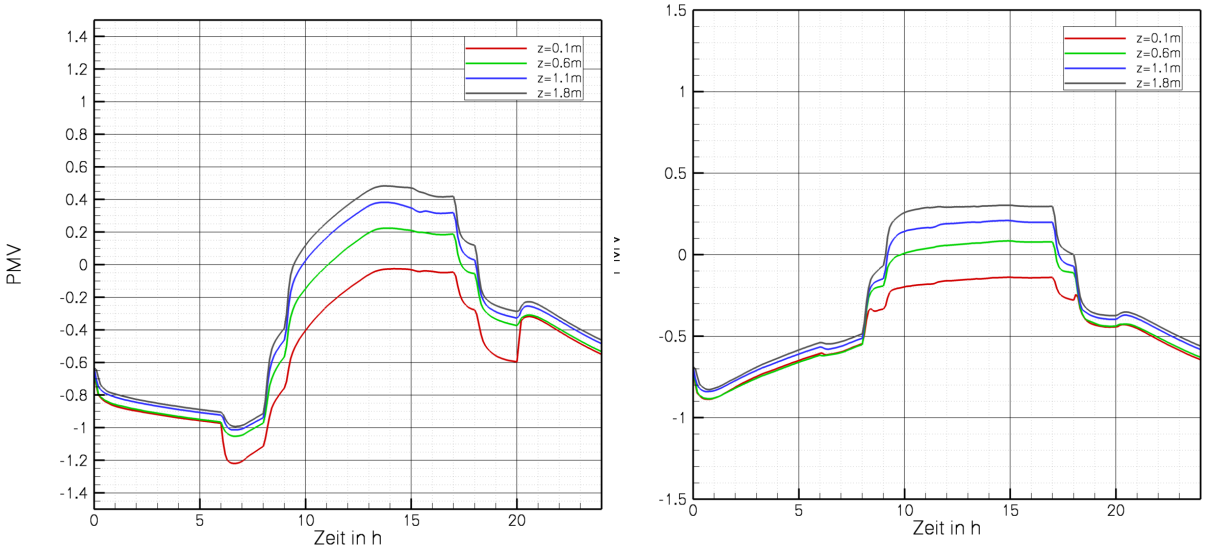


Fig 9. Suspended heating ceiling panel, heating capacity 55 W/m², temperature sensor situated at a level of 0.6 m between seated persons. Ventilation: Displacement flow diffusers. Left: Set sensor temperature: 22 °C, temperature of supply air: 2 K below sensor temperature, floating. Start of heating facilities at 06:00. Right: Sensor temperature 21 °C, temperature of supply air 2 K below sensor temperature but limited to 20 °C. Start of heating facilities at 00:00. Set temperatures lowered from 21 °C to 20 °C during daytime.

It needed a whole set of changed parameters to produce an even level of comfort during daytime with the suspended ceiling panel. Earlier start of heating, lowered set sensor temperature, lowered again by 1 K during daytime, supply air temperature fixed to max 20 °C.

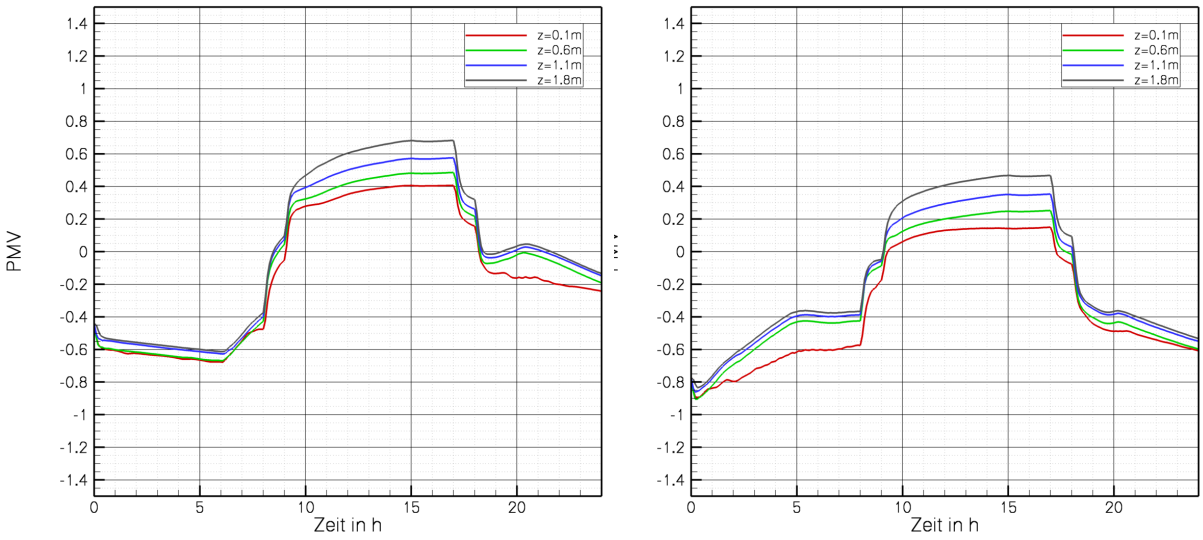


Fig 10. Underfloor heating, heating capacity max. 50 W/m², temperature sensor situated at a level of 0.6 m between seated persons. Ventilation: Air grill. Left: Set sensor temperature 22 °C, temperature of supply air: isothermally floating with sensor temperature. Right: Set sensor temperature 20 °C, temperature of supply air: isothermally floating with sensor temperature. Start of heating facilities at midnight.

Like in the cooling case (fig 6) underfloor heating generates even levels of thermal comfort during daytime. Lowering the level of set sensor temperature and fixing supply air temperature at max. 20 °C decreases PMV to values close to zero.

Potential of displacement ventilation for decreasing ventilation volumina below the level assumed for mixed ventilation

Ventilation rates are set to standard rates of 35 m³/person.h. Results indicate that displacement ventilation seem to be able to transport unmixed supply air along the surface of bodies of persons (and equipment) with low CO_2 concentration in a “convective plume”. Could displacement ventilation give the advantage of using reduced ventilation rates?
Shown below are CO_2 concentrations in ppm at levels of 0.1, 0.6, 1.1 und 1.8 m in the room.

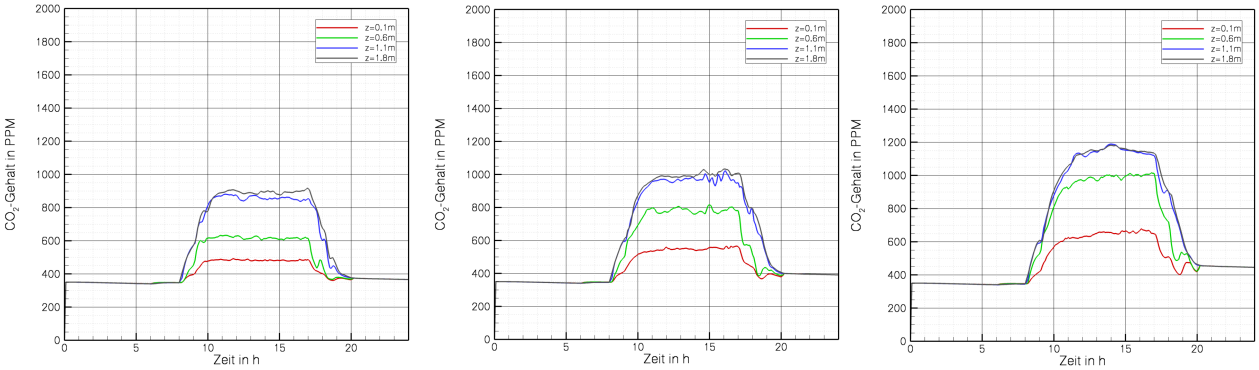


Fig 11. Floor swirl diffusers, concrete core activated ceiling, cooling mode. Left: Standard ventilation rate 35 m³/person.h. Centre: Ventilation rate reduced by 15 %. Right: Ventilation rate reduced by 30 %.

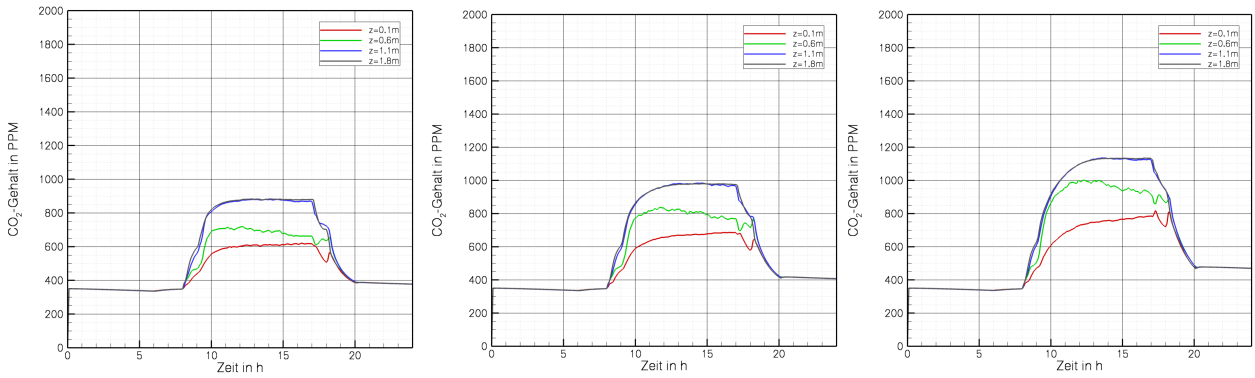


Fig 12. Floor swirl diffusers, concrete core activated ceiling, heating mode. Left: Standard ventilation rate 35 m³/person.h. Centre: Ventilation rate reduced by 15 %. Right: Ventilation rate reduced by 30 %.

In displacement ventilation situations CO_2 concentration levels experienced by seated occupants can be estimated using values in 0.6 m height (green). Air in this region is about to ascend by convection to the faces of occupants. Values in 1.1 m height represent the breathing zone of seated occupants and are usually not different from values in 1.8 m height (blue, black). In mixed ventilation situations at standard ventilation rates (35 m³/person.h) CO_2 concentrations are quite uniformely at levels of 850 ppm (not shown). In fig 11 (cooling situation) and fig 12 (heating situation) levels at 0.6 m are at 600 ppm, and 700 ppm respectively. Lowering ventilation rates by 15 % (center) still ensures lower CO_2 concentration at 0.6 m height than in the case of mixed ventilation at standard ventilation rates. At ventilation rates reduced by 30 % CO_2 concentration rises to moderate levels around 1000 ppm.

Discussion, conclusions

Passive house office conditions are characterised by low heat losses but high heat gains from occupants, electrical equipment and lighting. Such heat gains develop quickly in the morning, vary with varying room occupation and thus disapear in the late afternoon. Quick responses by heating and cooling facilities are required to achieve constant – and avoid rising – temperature levels during the day.
Displacement ventilation gives leeway to decreasing ventilation volumina below the level assumed for mixed ventilation. This is especially welcome in winter conditions when low relative humidity of indoor air tends to cause comfort problems in passive house environments [1, 3].

References

[1] IBO (Hrsg.). *“Handbuch Komfort für Passivhaus-Büros” [Manual of Comfort in Passivhouse Offices]*. Final Report of Project 815 692 funded by “Energy of the Future” (bmvit). Vienna: IBO 2012

[2] GRITZKI R, RÖSLER M, WALTJEN T, ZELGER T: *Komfort für Passivhaus-Büros – Planungsunterstützung mit Hilfe gekoppelter Gebäude, -Anlagen- und Strömungssimulation“.* Bauphysik 35 (2013), Heft 1, pp. 8–15

[3] ZELGER T: *“Komfort-Büro! – Ein Einblick in die thermischen Simulationen”.* IBOmagazin 2/2011, pp. 10–13

[4] WALTJEN T: *“Komfort-Büro! – Ein Einblick in die dynamischen Strömungssimulationen”.* IBOmagazin 2/2011, pp. 4–9

[5] KLEIN S A, DUFFIE J A, BECKMANN W A: TRNSYS - A Transient Simulation Program. ASHRAE Trans 82 (1976), p. 623

[6] PERSCHK A: Gebäude- und Anlagensimulation – „Ein Dresdner Modell“. GI Gesundheitsingenieur / Haustechnik / Bauphysik / Umwelttechnik, Bd. 131, Nr.4, (2010)

[7] KNOPP T, LUBE G,GRITZKI R, RÖSLER M: A near-wall strategy for buoyancy-affected turbulent flows using stabilized FEM with applications to indoor air flow simulation. Computer Meths. Applied Mechan. Engrg. 194 (2005) 3797-3816
[8] GEIST A, et al: PVM: Parallel Virtual Machine – a users guide and tutorial for networked parallel computing, MIT Press, Cambridge, Mass. (1994)

D3

Integrated Design Process

Chair: Helmuth Kreiner
Graz University of Technology, Austria

SB13 Graz



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Merten Welsch works in the Office for Sustainable Building in the German Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) in Berlin. The Office for Sustainable Building is an interface between politics, science and building industry. He is responsible for a wide range of tasks involving research projects for sustainable building. To establish the sustainable building instrument “BNB” as a new standard in the public sector he was responsible for managing the first education courses to the BNB in the federal construction administration and meanwhile trains architects and engineers at several chambers of architects and engineers as well as students at the Beuth University of Applied Sciences in Berlin. Additionally he works in the conformity review body for the certification of federal buildings.

Sustainability in Competitions: New German Federal System to verify the Qualities of Sustainability in Planning Competitions (SNAP)

Short Summary

With the establishment of sustainability requirements for public buildings as well as buildings in the private sector new demands on planners and the planning processes in Germany have arisen. These new quality requirements have to be integrated in architectural competitions. Therefore the new instrument “Classification for Sustainability Requirements in Planning Competitions” (SNAP) has been developed.

Keywords

assessment system for sustainable building (BNB) of German government; architectural competition; new tool; sustainable requirements for competitions

1. Introduction: Sustainability Requirements for Federal Buildings

The federal government is the largest public client and owner and therefore has an exemplary role according to sustainable building. With the establishment of sustainability requirements for public buildings as well as buildings in the private sector new demands on planners and the planning processes in Germany have arisen.

For example, with the introduction of the new “Guideline for Sustainable Building” [1] and the “Assessment System for Sustainable Building” (BNB) [2] for federal construction measures in May 2012, the higher quality standard "Silver acc. to BNB" has to be adhered for all new office buildings. Similar higher quality requirements should also soon be defined for renovation measures

in office buildings or for new schools or laboratory buildings for the federal public sector. In addition there is a steadily growing demand from private investors and developers for certain categories of buildings for building certifications.

Sustainable building is not an independent discipline that could be added up to the usual competition requirements. Sustainable building is based on the principle of integrated planning and holistic qualities of the building throughout its whole lifecycle.

2. Sustainability in Architectural Competitions

2.1 Research Project

Some aspects of sustainable building are always considered in architectural competitions. These can be functional requirements such as the accessibility or economic aspects such as the construction costs or the space efficiency. For special projects also energetic aspects are discussed in competitions. But in general the holistic approach of sustainable building according to the “Assessment System Sustainable Building” (BNB) was usually not been taken into account.

Concerning the planning processes we have thereby to ask ourselves how these new quality requirements on buildings can be integrated in established competition proceedings. For this purpose, an international research project was carried out commissioned by the Federal Ministry of Transport Building and Urban Development (BMVBS) under the title "sustainability requirements in competition proceedings". The research project was processed by ee concept Darmstadt (Dr. Fuchs) in cooperation with the Technical University Darmstadt (Prof. Hegger) and the architectural office H.R. Preisig (Prof. Preisig). The experiences of other European countries were taken into account in the survey, such as the Swiss method “SNARC”]3] or the Austrian method “IEAA” [4].

In order to anchor sustainability goals and requirements as integral components of competition processes it is considered necessary to point-out recommendations regarding the following four central research questions:

- Which sustainability criteria are applicable and relevant for the respective phases and the overall competition?
- How and in what level of detail should these sustainability criteria examined?
- How should the pre-examination results be summarized and presented to the jury?
- How do competition processes need to be structured and executed in order to ensure that sustainability requirements are met throughout all phases?

To answer these questions the research team developed a method called “Classification for Sustainability Requirements in Architectural Competitions” (SNAP).

2.2 The new “SNAP”- Method

The most important principle of the SNAP method is to provide a flexible system with different proposals from which the participants may choose those aspects and recommendations that fit to their specific kind and specific objective of the competition.

Great value has been set upon the aim that the requirement can be integrated in the competitions with reasonable cost for all parties involved. At the same time the method should allow a profound examination of the complex holistic requirements of sustainable building.

The practical results are now available as follows:

BMVBS broschure "Classification for Sustainability Requirements in Architectural Competitions" (SNAP)
This brochure summarizes for all parties – competition organisers, participating planners, jurors, coordinators, experts - the key recommendations of the "Classification for Sustainability Requirements in Planning Competitions" (SNAP).

Excel tool for the assessment of sustainability qualities in competition entries

User instructions for SNAP instrument
The structure and operation of the Excel tool are explained in detail in this brochure.

comprehensive final report with an explanation of the methodology and documentation of the discussion in the accompanying expert panel



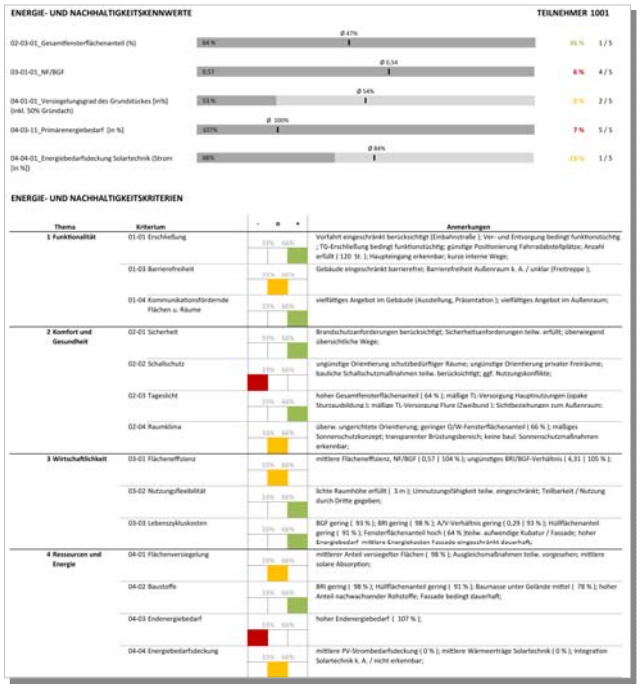


Fig. 1: broschure Classification for Sustainability Requirements in Architectural Competitions" (SNAP)
Fig. 2: results of the pre-examination in „SNAP"

The SNAP method is based on the following principles:

- The SNAP method can be integrated into the established and proven culture of competition proceedings. It constitutes an offer to extend competitions to sustainability aspects.

- Specific recommendations are defined for all phases of planning competitions (preparation, public offer, pre-examination, jury meeting, post-processing).

- Only those 15 sustainability criteria are taken into account that are relevant in this planning phase. These criteria can be demonstrated in competitions with reasonable effort by the planners and can be evaluated with reasonable effort by the preliminary examination.

- The sustainability qualities of the competition entries are assessed by calculations and by design parameters and qualitative assessments of the submitted documents.

- The examiners do the majority of the required calculations. The planners only have to complete a form with selected characteristics.

- Based upon the summarized preliminary results the jury is able to form an independent and profound opinion within a short time.

The following four subject areas can be divided into fifteen criteria with relevance in competitions. For each criteria there can be assigned up to eight additionally specific indicators. The distinction in seven "basic criteria" and eight additional "extended criteria" allows a specification in respect of the relevant competition subject.

subject area	no	criterion (basic criteria underlined)	indicator (task-specific)
design		urban pattern	assessment by jury
		exterior quality	assessment by jury
		building quality	assessment by jury
		image	assessment by jury
functionality	1	infrastructure provision	driveway, supply and disposal, access to underground parking, bicycle parking, visibility of main entrance
	2	public accessibility	public accessibility to building and property, structural requirements for opening internal institutions
	3	disabled access	disabled access for the building and for the outdoor facilities
	4	communication-promoting areas and spaces	internal and external proposal
comfort and health	5	safety	fire protection, safty requirements, clarity, orientation (building and outdoor facilities)
	6	sound insulation	orientation of vulnerable areas against external noise, orientation of private areas against external noise noise abatement measures, conflicts between different uses
	7	daylight	proportion of windows [%], daylightning, relationship of views to outdoor space
	8	indoor climate	orientation of main uses, proportion of windows east / west [%], concept of sun protection, parapets, additional structural sun protection

economy	9	floor space efficiency	effective floor area / gross floor area
	10	flexibility of use	ceiling height, feasibility of conversion, divisibility,
	11	life-cycle costs	realtion of surface to volume [%], proportion of building envelope [%], energy demand [%], energy costs [%], durability of facade, alternative: tool for life cycle costs
resources and energy	12	sealing of land	rate of sealing of the property [%], green roof, solar absorption façade
	13	building materials	proportion of building envelope [%], cubic capacity below terrain [%], renewable resources, durability of facade alternative: tool for embodied energy
	14	energy demand	total energy demand, heating demand, demand on artificial light alternative: tool for total energy demand
	15	covering energy demand	cover energy needs, solar technology (electricity, heat) integration of renewable energy production use of local energy potentials, efficiency of building technology

With the SNAP instrument we now have since January 2013 a new instrument at our disposal. On the one hand SNAP deals with the complex holistic demands of sustainable building in the context of planning competitions, but on the other hand it can be applied practically and without a large investment of time for all parties involved, so that the acceptance of the actors in competitions is ensured.

3. Competitions with sustainability requirements

3.1 Federal Environment Agency at the Bismarckplatz in Berlin

In the competition for the conversion of the office building of the Federal Environmental Agency at the Bismarckplatz in Berlin the claimed sustainability issues in the context of the preliminary review were assessed in detail and interdisciplinary. The jury received profound and comprehensible information about the sustainability qualities of the 20 competition works. Thus, the jury could decide a first place which has very convincing qualities also in terms of sustainability requirements.
.





Fig. 5: site plan
Fig. 6: perspektive interior courtyard
by: gmp Planungsgesellschaft mbH, Berlin and Bernhard und Sattler Landschaftsarchitekten, Berlin

3.2 Federal Ministry for Education and Research at the Kapelleufer in Berlin

The new building for the Federal Ministry for Education and Research at the Kapelleufer in Berlin is a current project realized in public-private partnership ("PPP"). The building is to achieve the highest level of sustainability of the BNB System in gold.

As part of the PPP procurement process the designs of five selected candidates were therefore assessed very accurately in terms of sustainability requirements.By assessing the works with a holistic view, in particular the expected life cycle costs and environmental impacts the sustainability claim could be considered to a reasonable extent.

The building qualities identified in the sustainability assessment were continuously reviewed and clarified in the planning and construction phase. The relevant compliance auditor from the Office of Sustainable Building in BBSR confirmed after the topping out ceremony that the proposed BNB certification in gold is classified as realistic.





Fig. 7 and 8: perspektives
by: BAM Deutschland AG and Amber GmbH in cooperation with architektural office Heinle, Wischer und Partner - Freie Architekten

3.3 Federal Environment Agency in Dessau

For the extension of the Federal Environment Agency in Dessau comprehensive sustainability requirements were defined in the competition, including the objectives to design a zero-energy house and reach the quality level "BNB Gold" after completion.

As a result, a contribution was honored as winner of the competition, that pooled extensive individual aspects of sustainable building in high quality in a holistic concept. These include, for example, the compact building envelope, the absence of a mechanical cooling, the use of PV elements on the roof and in the facade and the use of renewable materials (cellulose insulation, clay panels, clay plaster, flax insulation, wool carpet).

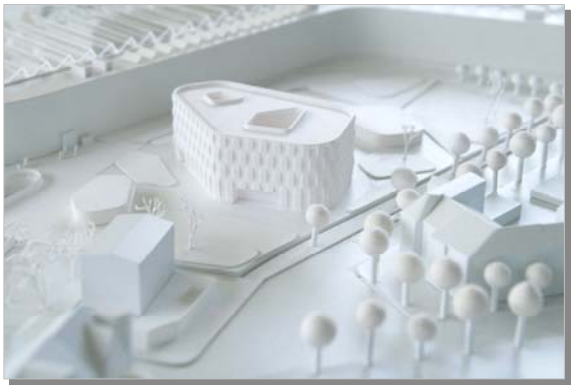




Fig. 9: model
Fig. 10: perspektive
by: Anderhalten Architekten, Berlin

[1] FEDERAL MINISTRY OF TRANSPORT, BUILDING AND URBAN DEVELOPMENT (BMVBS) *"Guideline Sustainable Building"*, BMVBS Berlin, 2013, http://www.nachhaltigesbauen.de/

[2] FEDERAL MINISTRY OF TRANSPORT, BUILDING AND URBAN DEVELOPMENT (BMVBS) *"Assessment System for Sustainable Building"* (BNB), http://www.nachhaltigesbauen.de/

[3] SCHWEIZERISCHER INGENIEUR- UND ARCHITEKTENVEREIN (SIA) *"SNARC – Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt"*, SIA Zürich, 2004

[4] IFZ – INTERUNIVERSITÄRES FORSCHUNGSZENTRUM FÜR TECHNIK, ARBEIT UND KULTUR *"Leitfaden Integration energierelevanter Aspekte in Architekturwettbewerben"*, IFZ Graz, 2010

Debating economic performance aspects of buildings in the context of sustainability assessments


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Summary

Assessing buildings' contribution to sustainable development requires taking into account economic performance aspects as well. Therefore, it is being discussed on a national, European and international level how economic performance aspects can be integrated into sustainability assessments of buildings and which criteria and indicators are appropriate in this regard. The present paper critically examines the current state of respective standardisation activities, assessment practice as well as possible criteria and indicators. In addition, the paper highlights and discusses open questions and problems which are associated with the attempt of evaluating the economic performance of buildings within the context of sustainability assessments.

Keywords: sustainable buildings, economic performance, valuation, cost, economic value, risk

1. Introduction

Within recent years the discussion and debate surrounding „green buildings" has moved on and has been further developed towards the design, construction and management of "sustainable buildings". This has also lead to a transition from describing and assessing predominantly environmental- and health-related aspects of buildings towards assessing a building's overall performance including an analysis of interrelationships and interdependencies between different partial aspects.

In addition, a commonly accepted understanding of sustainability for the construction sector has meanwhile emerged worldwide which is supported and backed-up through international standardization activities (e.g. ISO, 2008). According to this understanding, a building's or construction work's contribution to sustainable development has to be assessed not only by evaluating compliance with current and future requirements concerning functional and technical qualities but also by equally and simultaneously considering environmental, economic and social performance aspects as well. As a consequence, an evaluation of economic performance aspects now forms an integral part of sustainability assessments of buildings.

Within international standardization activities one economic indicator – i.e. life cycle costs - has already been included into the core list of indicators for sustainability assessments (see: ISO, 2011). On a European level, the indicators „life cycle costs" as well as „value" are currently being discussed (see: CEN, 2012).

In contrast to the assessment of environmental- and health-related aspects, the evaluation of economic performance aspects within the context of sustainability assessments of buildings does not yet have a history of decades of experiences. This discussion is just beginning (see, for example, the European SuPerBuildings project, 2012)
As a consequence, within existing systems and tools for assessing and certifying the sustainability of buildings, economic performance aspects are only partly taken into account. Examples for certification systems that do take economic aspects into account are those of DGNB and BNB which have been developed with the collaboration of one of the authors of this paper, Thomas

Lützkendorf. But also for the aforementioned systems there exists the need to further develop assessment basics and standards as well as appropriate economic criteria and indicators.

The aim of the present paper therefore lies in examining and discussing fundamental questions relating to the description and assessment of a building's economic performance, to possible criteria and indicators as well as to scopes of action and possible solutions. Particularly, the following questions will be addressed within the present paper:

- Which overall areas and goals of protection lend themselves for deducing economic performance requirements?
- What is an appropriate perspective for assessing economic performance aspects – a societal perspective and/or the perspective of individual actors and market participants such as owners, tenants, banks, investors, public authorities, etc.?
- What are the differences and commonalities between a specific economic appraisal tailored to the needs of one single actor and a broader, generic assessment of a building's economic performance?
- How is it possible to take into account the perspective and interests of current and future generations within the context of economic performance assessments?
- What are key areas of concern/interest and how can these be reflected through criteria and partial indicators?
- If one accepts the proposition that economic performance aspects are already (or to be more precise: should be) an integral part of sustainability assessments, how is it then possible to evaluate interrelationships and interdependencies between a building's degree of sustainability and its economic value? Is there a loop and/or a circular argument?

2. Discussion of areas and goals of protection

Following a top-down approach and deducing criteria from overall areas and goals of protection turned out to be appropriate and purposeful for complex ("2nd generation") sustainability assessments systems which comply with the current state of standardization according to ISO and CEN. Consequently, the question relating to areas and goals of protection in the field of the economics arises.

Up until now and if at all, economic performance aspects have been considered by focusing on the costs of buildings during their life cycle. The goal was to minimize these costs and to achieve a favorable trade-off between construction and operating costs. This criterion emerged through a bottom-up approach since the assignment of the criteria to particular areas and goals of protection has not been discussed.

Since financial assets and capital are resources as well, the goal of protecting financial resources can be implied in the first instance. Protecting financial resources also contributes to maintaining the actors'/market participants' (financial) capacity to act. However, it is problematic that besides for owner-occupiers which can follow a total-cost-of-ownership approach, costs of buildings during their life cycle can and must be assigned to specific actors. Consequently, the question of the appropriate perspective arises.

The calculation and assessment of life cycle costs is normally carried out by taking the perspective of planners which is usually identical with the perspective of owner-occupiers or public authorities. But for all other market participants, individual or institutional perspectives dominate any assessment of cost-effectiveness. In addition, regarding the criterion life cycle costs there is a conflict of goals from a societal perspective. On the one hand, the input of financial resources during a building's life cycle shall be minimized; but on the other hand, this input of financial resources generates tax revenues and creates/maintains employment. Against this background it becomes apparent that the application of life cycle costs as a criterion for assessing a building's economic

performance has hitherto taken place without proper methodological deduction and theoretical reasoning.

Another possible goal of protection is the “affordability” of buildings. However, whether or not this aspect lends itself for assessing performance in an economic context deserves further discussion and debate. Without doubt, low construction and operating costs can contribute to the affordability of buildings in the sense of eased access to the rental housing market or to residential ownership. For example, for tenants but also for owner-occupiers operating costs are of particular interest as these costs are not only determined through user behavior but also though several building characteristics such as insulation, water-efficient taps, etc. But in most cases and also regarding other property market actors, the affordability of buildings is overlaid by a variety of other factors. For example, in the case of owner-occupiers, the “affordability of a building” is co-determined, amongst other issues, through household income and financial circumstances. As such, and in a strict sense “affordability” (particularly of residential property) is not a trait of buildings per se but a challenge to society.

In contrast, the economic value of single buildings and of building stocks is a clear commodity of protection. The goal is to protect/maintain and, as the case may be, to increase the buildings’ economic value since this contributes to the stability of the economic system. Therefore aspects like value stability, retainability and value development turn into assessment criteria. However, the problem here is that these aspects have not yet finally been transferred into manageable indicators and that appropriate measurement approaches and standards are still to be developed. A further discussion of the current state of theory and practice will be carried out below.

Economic considerations always also have a regional and macroeconomic dimension. For this reason, questions relating to the contribution of construction activities (and also of single buildings) to regional value creating are also sporadically being discussed. Further goals can be seen in the reduction of subsidy expenses (if applicable) and in the decrease of external costs. From the authors’ point of view, particularly a decrease in external costs is an important goal of protection which has not yet received appropriate consideration and discussion. For example, in ISO 15686-5: 2008 Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing external costs are treated as environmental costs and are assigned to the life cycle costs of a building. This appears to be a feasible approach.

3. Discussion of fundamental issues and questions

In the case of buildings and construction works, the general assessment of the economic performance predominantly takes place (in theory) from a societal/macroeconomic perspective (e.g. impact of construction activities on employment, gross domestic product, CO2-reductions, etc.). Therefore, a fundamental difference exists in comparison to the individual/subjective economic efficiency/profitability calculations of single market participants. In such cases, economic efficiency/profitability calculations (which are usually carried out within the context of investment or other decision making processes) are strictly tailored to a specific case and take into account *individual/subjective framework conditions*. An additional characteristic of such calculations is the occurrence of conflicting goals between the parties involved (e.g. between landlords and tenants).

In contrast, existing sustainability assessment and certification systems for buildings usually set/prescribe *average framework conditions* (in the form of conventions) in order to create comparable assessment and certification results. If and to what extent individual interests and perspectives of single groups of actors could (and should) also be taken into account when assessing economic performance aspects in the context of sustainability assessments has hardly ever been examined in the literature and is therefore open for discussion. The authors of this paper would highly appreciate a scientific debate concerning the aforementioned issue.

The definition of sustainable development explicitly emphasizes the necessity of taking into account the needs of both, current and future generations (intergenerational justice). However,

whenever economic performance aspects are assessed as part of a sustainability assessment, usually the position and perspective of the current generation is assumed. Inter alia, this circumstance is reflected in / expressed through the discounting of future cash flows. If and to what extent the (economic) interests of future generations can also be taken into account requires further examination and scientific debate. Possible approaches to allow for such considerations are: diminishing discount rates; a discount rate of zero (or even a negative discount rate); the full Visualization of Financial Implications (VoFI); proof of unindebtedness at a given due date; proof of sufficient capital reserves for maintenance, modernization and deconstruction; or the avoidance of external costs within the scope of a subsequent deconstruction including disposal.

Apparently but at a first glance only, the assessment of economic performance aspects within the context of sustainability assessments of buildings involves a contradiction or a loop/circular argument. On the one hand, and due to the reasons explained above, economic considerations shall be directly integrated into sustainability assessments of buildings. On the other hand, however, a connection is often made between the sustainability of buildings and market participants' willingness to pay, which, in turn, is reflected in the buildings' economic value. The apparent contradiction may be resolved as follows: Besides certain exceptions, sustainability assessments of buildings usually do not involve valuations (in the sense of market valuations) or specific/individual economic efficiency calculations. What can be described and assessed as part of a sustainability assessment is – in the sense of a partial (economic) indicator – the *building-induced contribution to financial risk* (see Chapter 4.4 below). Thereby, the actual property valuation – which considers several further aspects (such as overall market conditions) in addition to sustainability-related value relevant building features – still remains outside of sustainability assessments.

The discussion and agreement on appropriate areas and goals of protection as well as the positioning relating to fundamental issues and questions form the basis for the development of appropriate assessment criteria.

4. Discussion of possible assessment criteria and indicators

4.1 Construction / investment costs

In connection with energy efficient and/or sustainable buildings the construction / investment costs (in the sense of purchase payments) are often at the centre of discussion as the misconception of significantly higher costs in comparison to standard or "conventional" buildings still prevails. But this also automatically reveals a key problem because in order to be able to disclose (additional) costs for sustainable construction in comparison to "conventional" construction there needs to be a baseline or benchmark to define "conventional".
In the case of new buildings, the benchmark or baseline usually is the current state of construction technique or the current state of national legislation and standardization. However, such a baseline or benchmark does not automatically define/specify a particular building or constructive solution but leads to a wide variety of construction variants with quite different construction costs. As such, the choice and determination of the actual reference value for "conventional" construction costs remains problematic. Therefore, an exact definition of what has been (or what shall be) included in the construction / investment cots is required (e.g. selected groups of construction costs, costs for planning/design costs, management, and the plot of land, value added tax, etc.). The respective system boundary depends on the intended usage / scope of the analysis and the applied benchmark (see also section 4.3). It is either common to focus on mere construction costs for the building, equipment and appliances or to disclose all investment costs including costs for the management and the plot of land.

Within some assessment systems and subsidy programs (e.g. in Austria and Switzerland) additional costs for energy efficient/sustainable buildings of up to 10% are being accepted (the difficulty of determining the baseline or benchmark has already been mentioned above). But based on an analysis of completed construction projects it can be argued that, for example, in France and

Germany, energy efficient/sustainable buildings can be realized with relatively low additional construction costs between 5% and 0%. The reason for this lies in the already high level of required performance of “conventional” new buildings in these countries.

As a result of experiences in Germany the authors of this paper favour another approach than debating “additional” costs for sustainable buildings: For many building types and usages an “average budget” can be specified based on past experiences and/or specifications set by public authorities. If such a “budget” is given, it can then be shown that by applying the principles of integral planning, energy efficient / sustainable buildings can be realised within this budget (as the case may be at the upper limit of the budget). An important issue is also the comparability of the specifications of the building under investigation as well as of the budget (base year, system boundaries, region, etc.); if applicable, conversions and validations may be necessary. In any case, following this approach diverts the attention from the level of “additional” costs for sustainable buildings to the compliance with a given budget.

From the authors‘ point of view, mere construction / investment costs cannot be recommended as an appropriate criterion for assessing the economic performance of buildings within the scope of sustainability assessments. Instead, it would be possible to consider *maximum additional costs* or demand *compliance with a given budget* as an additional requirement – e.g. within the scope of assessing life cycle costs.
By all means, the authors’ recommend paying attention to a clear, transparent and traceable depiction of construction / investment costs (in the sense of “additional information” accompanying an assessment results) whenever energy efficient / sustainable building projects are to be presented / showcased. Depicting mere construction costs (i.e. costs of the building without, for example, costs for purchasing the plot of land) has proven useful in this context.

4.2 Life cycle costs / selected costs within the building life cycle

In connection with the description and assessment of the sustainability of buildings and construction works there is widespread consensus that life cycle costs have to be considered at first in order to describe and assess economic performance. An international standard (which is currently under revision) for calculating life cycle costs is available: ISO 15686-5. However, the current structure of the standard is more or less a checklist to declare included cost categories. As such, the existing standard only partially answers currently unsolved questions.

The results of a life cycle cost analysis are influenced, among other issues, through the following parameters:

a) Type and scope of included cost categories
b) Measures and time frame under observation
c) Applied discount rate for calculating net present value / net present cost
d) Assumed inflation rates
e) Price level for utilities supplies
f) Assumed scenarios for maintenance, modernization and end of life

The results of a life cycle cost analysis can only be interpreted / judged (by third parties) in a meaningful manner if the aforementioned parameters are disclosed. Selected parameters will be dealt with in more detail in the following:

a) Type and scope of included cost categories
There are various forms of describing and structuring different cost categories which could be included within a life cycle cost analysis. Basically, a distinction has to be made between a life cycle cost analysis in a strict sense (i.e. only payments-out / costs are considered - LCC) and a life cycle cost analysis in a wider sense (i.e. in addition to costs also income / payments-in are taken

into account – WLC). For describing and assessing the economic performance within the scope of sustainability assessments, a life cycle costs analysis in a strict sense is usually drawn upon. But this approach also bears some problems / open questions; particularly if income arises due to electricity generation by buildings equipped with photovoltaic-systems. If applicable, this income could be treated as “negative” costs.
The life cycle costs of a building are usually comprised of construction costs (DIN 276 in Germany) and operating costs (DIN 18960 in Germany). Up until now, usually not all costs / cost categories according to DIN 18960 are being considered within the scope of life cycle cost analyses in the context of sustainability assessments in Germany. Instead, a selection is made in order to consider building-induced costs only, since only these costs can directly be influenced through decisions made during the planning / design phase (e.g. energy costs, maintenance costs, cleaning costs). But it is still open for discussion whether or not also insurance and financing costs are to be taken into account in order to achieve a better representation of real-life circumstances; this particularly applies in market environments within which favorable lending and insurance conditions are offered for sustainable buildings by banks and insurance companies.
A further area of discussion is whether external costs should be considered within the scope of life cycle costs analyses in the future or if these costs should be accounted for separately. In any case, a consideration of external costs does make sense from the authors’ point of view – particularly when construction projects of public authorities are to be analyzed; in such cases, for example additional fees on energy prices could be a possible approach.

b) Measures and time frame under observation (study period)
To date, the most common practice in portraying building-induced costs along the building life cycle is calculating the net present cost. Building-induced costs occur at different points in the life cycle of a building; also building-induced costs (e.g. for modernization) can be seen as investments into highly illiquid assets. As a consequence, they cannot be compared or summed up directly due to the *time value of money* and the *value of liquidity*. (The last mentioned issue (i.e. how to account for the value of liquidity) has not yet gained much attention and debate within the sustainability assessment related literature.)
The mechanism to account for the time value of money and the value of liquidity is discounting. Costs are discounted back (i.e. converted) to their present value. Net present cost can be defined as the total cost of a building after the time value of money (and the value of liquidity) have been taken into account.
If a life cycle cost analysis in a wider sense is carried out (i.e. if also income / payments-in are considered), then the result of the calculations is the net present value which can be defined as the present value of the payments-in minus the present value of the payments-out.
In either case, it is required to specify an appropriate time frame under observation. And this involves finding a compromise between the growing uncertainty of cost and income projections during the future life cycle (which would call for a preferably short time frame) and the implied goal of taking a long-term view (e.g. in order not to disregard future generations). From a methodological point of view, sustainability assessments of buildings favor taking an identical time frame (as well as an identical building model) for both, life cycle analysis (LCA) as well as life cycle cost analysis. In Germany, for example, the time frame (or reference study period) for both aspects of the assessment is 50 years.
However, the interest in an appropriate assessment of buildings with varying life spans leads to further questions and calls for alternative ways for portraying buildings’ (whole) life cycle costs. Amongst other issues, the concept of equivalent annual cost is being discussed which can be defined as the cost per year of owning and operating an asset over its entire lifespan (see: Davis Langdon, 2007).

c) Choice of the discount rate
The choice of the applied discount rate significantly impacts on both, the resulting net present cost or net present value respectively as well as on the relationship between initial construction / investment costs and follow-up costs. The choice of the discount rate (and also the selection of the

applied discounting model; e.g. exponential or hyperbolic discounting) can be made from a number of different perspectives.
For example, the consideration of interests of future generations requires a preferably low discount rate (usually 0% - 2% are mentioned in the literature). High, or too high, discount rates reduce the relative importance of follow-up costs and of possible future cost-saving effects. This has an adverse impact on the assessment of (additional) measures for improving a building's energy efficiency and degree of sustainability.
The European Commission currently recommends a discount rate of 3% and, in addition, the application of a discount rate which is in line with "market conditions".
Within the context of sustainability assessments, the choice of an appropriate discount rate and the selection of an adequate discounting model are (and shall be) intensely discussed within the literature (e.g. Quiggi, 1997; Evans and Sezer, 2005; Gollier, 2011). From the authors' point of view, this is due to the circumstance that there may be no absolute, objective, or "right" answer to this problem since discount rates for sustainability assessments cannot be deduced mathematically or evidenced empirically. Rather, their selection depends on the context of the assessment (assessment purpose; assessment perspective, type of client, e.g. public authority or industry/business; etc.). As such, the choice of the discount rate needs to be adequately described and justified.

4.3 Cost-Value Ratio

Often the question arises whether or not the economic value created through a construction and/or building project "justifies" the capital invested into this project. Or expressed in other words: investors as well as owner occupiers have an interest in ensuring that the economic value of the building at point of completion is not less than the capital cost of it.
An approach for assessing this worthwhileness of an investment at the date of handover has been developed in Germany (with the collaboration of one of the authors of this paper, Thomas Lützkendorf) within a project concerned with the development of a sustainability assessment and certification system for residential buildings called NaWoh (Nachhaltiger Wohnungsbau – Sustainable Housing). The approach pursued in this project relates the total cost needed to bring a project to a commercially operable status (e.g. purchase of land, buildings, construction and equipment, an investor's profit margin, etc.) to the completed building's Market Value (estimated by applying the income/investment method of valuation) at the date of handover. This *Cost-Value ratio* at point of handover illustrates how worthwhile the investment into a project is at the point of completing the project since it reveals whether or not the capital costs are appropriately related to the current market situation.
This approach particularly lends itself for the assessment of buildings which shall be fully rented right after completion. A further area of application is in the context of modernization/refurbishment projects in order to assess if the capital invested is appropriately related to the potential value increase associated with the modernization/refurbishment measures.
As a side issue, it can be discussed if and to what extent the quality of a sustainable building is already reflected in rent levels and thus, in the current Market Value of the building. This also leads to the general question if and to what extent the property valuation profession and valuation practice already take into account sustainable building issues (see also Chapter 5 below).

By introduction a Cost-Value ratio as an additional indicator into the sustainability assessment of buildings, the market valuation of properties (the traditional domain of the property valuation profession) becomes a basis for calculating this ratio. And this inevitably leads to further questions; notably the question whether or not non-valuation specialists are actually able to accurately assesses a building's Market Value? Property valuation is a complex professional activity backed-up by professional codes, extensive standards and guidelines and usually, carrying out valuations in practice requires extensive expertise and appropriate education and training.
Advocates of a Cost-Value ratio might argue that a detailed property valuation is not really necessary in this context and that simplified valuation methods could be applied by laymen since finding out whether the capital costs are *significantly* higher (or lower) than the Market Value at the

date of handover is sufficient. However, the counterargument here is that several past real estate and financial crises have painfully demonstrated that even experienced valuation professionals occasionally *significantly* under- or overestimate a building's Market Value. Consequently, it needs to be discussed if external expertise (in the form of trained valuation professionals) is necessary whenever sustainability assessments of buildings aim to also assess the worthwhileness of an investment.

4.4 Long-term stability of value and value development / contribution to financial risk

The desire of assessing the long-term stability of value and value development of buildings is closely connected to the goods/commodities and goals of protection as discussed above. In addition, taking a long-term view particularly reflects the perspective and goals of sustainable development. Nonetheless, a medium- to long-term perspective on the economic value of buildings is extremely difficult and associated with various uncertainties. This is due to various reasons: first of all, assessments of the economic value of buildings are *snapshots in time*, they are usually valid only for the specified date of valuation. The concept of a long-term perspective on a building's economic value is termed *mortgage lending value* within the valuation profession; and this concept is controversially discussed since parts of the valuation profession simply deny (for good reasons) that a long-term assessment of economic value can even exist.
In any case, forecasting the future value development of buildings is hardly ever possible. In addition, the value development of buildings depends on many factors (e.g. market conditions) other than building-related characteristics and attributes. Furthermore, integrating the long-term stability of value into sustainability assessments of buildings would mean taking the current Market Value as a starting point for the analysis; and this, in turn, would lead to the very same problems and open questions as discussed in the context of a cost-value ratio above.

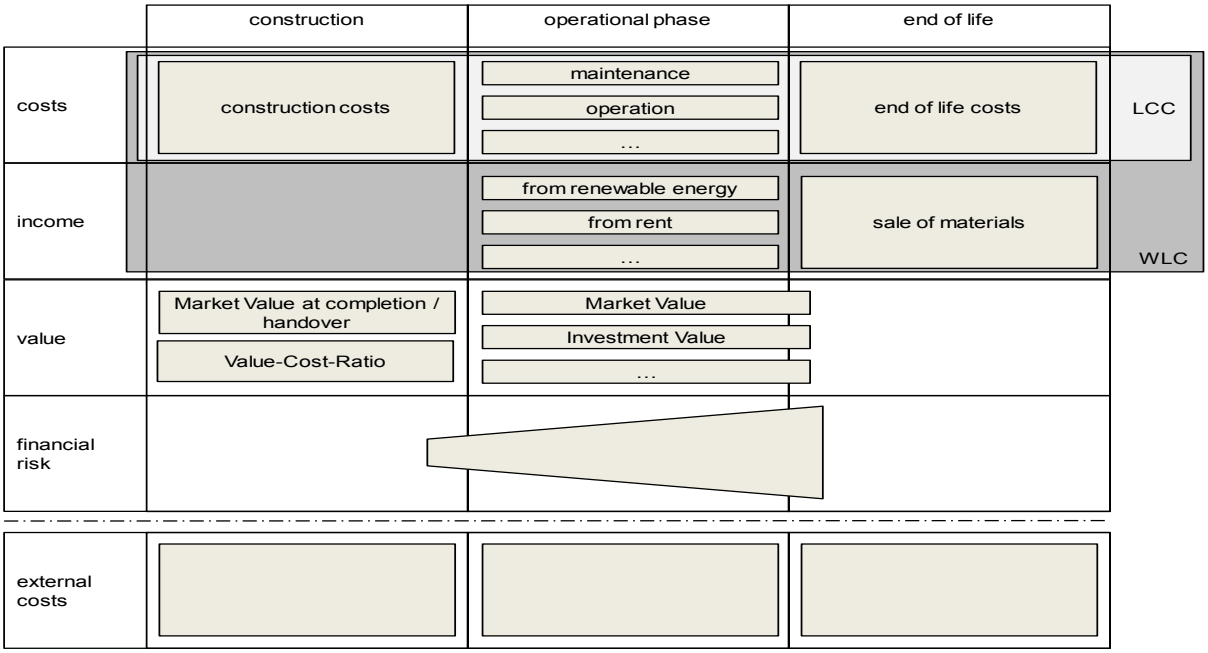
At the moment the German sustainability assessment systems of BNB and DGNB take into account a building's value stability through replacement-indicators which are based on an assessment of the building's usability by third parties and of additional technical-functional building characteristics. As such, not the building's value stability and value development (in a strict sense) are captured through these assessment systems but the building-induced contribution to a (potential/likely) value stability and value development. An additional problem is that assessing a building's usability by third parties and other technical-functional characteristics within the context of evaluating economic performance aspects is somewhat like a repetition (since these characteristics are also assessed within other assessment categories); as a consequence, the multiple impact of these characteristics is often confused with double-counting.

For these reasons the authors of this paper suggest assessing the medium- to long-term *building-induced contribution to financial risk*. In practice, this could be done along the lines of so called property and market rating systems (the rating category "property" is of particular relevance in this context) which are applied by the valuation and financial industry since several years in order to measure and portray the financial risk of property investments and of loans secured by real estate assets (for a further explanation of such rating systems see: TEGoVA, 2012, p. 207-220; Lützkendorf and Lorenz, 2007).

Assessing the building-induced medium- to long-term contribution to financial risk (or to its reduction) allows for both, reflecting the high degree of uncertainty involved and concentrating on building-related characteristics and attributes. However, the approach of assessing building-induced contributions to financial risk within the scope of sustainability assessment systems is currently under discussion and, as a start, needs to be tested in practice.

The following Figure 1 summarizes possible criteria/indicators which have been discussed in Chapter 4 and which could be used for evaluating economic performance aspects of buildings within the context of sustainability assessments.

Figure 1: *Economic performance criteria / indicators along the building life cycle*



5. Sustainability and property valuation – state of theory and practice

Within some sub-markets and in some countries property pricing is increasingly distinguishing between buildings that exhibit different sustainability-related building features and associated physical or operational performance. There is recognition that buildings which are not resource efficient, low carbon in terms of operation and location and which are not equipped to flex to changing occupier needs will not be future proofed in market value terms. As a result, the academic valuation community but also practitioners are discussing the issue of integrating sustainability considerations into the valuation process since more than a decade. More recently, the topic was also taken up and advanced by the large professional organizations and valuation standard setting bodies such as the UK-based Royal Institution of Chartered Surveyors (RICS), the Appraisal Institute in the USA and The European Group of Valuers' Associations (TEGoVA). To date, these organizations have published respective guidance and encourage valuation professionals to consider sustainability issues when undertaking property valuations.

For example, in 2009, the RICS published a global Valuation Information Paper (VIP13) on this topic which was the first attempt of a valuation standard setting body to advice professionals on how to cope with the issue of sustainability in commercial valuation practice. In 2011, the RICS published an Information Paper (IP 22) for UK-application only on how to deal with the issue within the scope of residential valuations. In this paper the RICS also encourages valuers to expand their basic data collection procedures to include a record of any sustainability features, even if they do not currently have an impact on value. Similar advice and associated recommendations have now also been produced by other professional organisations but also by groups of individual practitioners and researchers. An example for the latter case is the NUWEL-guideline for professionals operating in the German, Austrian and Swiss property markets (see: Meins et al., 2012). The following Table 1 provides an overview on existing guidance and guidelines for valuers.

Table 1: *Existing sustainability related guidance, guidelines and requirements for valuers (Lorenz et al., 2013)*

Title / Description	VIP 13	IP 22	VIP 13 (Australia)	EVS 2012 (Information paper on sustainability and valuation)	ImmoWertV	NUWEL	RICS Draft Guidance Note
Publisher	RICS	RICS	RICS Oceania	TEGoVA	BMVBS	CCSR	RICS
Year of Publication	2009	2011	2011	2012	2011	2011	2013 (planned)
Application: Property type	Commercial Property	Residential Property	Commercial Property	All	All	All	Commercial Property
Application: country / region	Global	UK	Australia	Europe	Germany	Germany, Austria, Switzerland	Global
Coverage of sustainability issues	broad	broad	broad (but focus on energy)	broad	Energetic quality	broad (detailed listing of issues)	broad (detailed listing of issues)
Degree of compul-sion / bindingness	informative	informative	informative	informative	mandatory	informative	recommended good practice
Character: generic requirements / detailed recommen-dations	generic	generic	detailed	generic	-	detailed	detailed
Recommendations for valuation reports	-	-	X	-	-	X	X
Recommendations on the extension of the data collection process	-	X	X	-	-	X	X

The topic of integrating sustainability issues into property valuation has a theoretical, methodological, practical and ethical dimension. As such, discussing the issue in detail would lead far beyond the scope of the present paper. Therefore, only selected aspects are briefly discussed below.

Towards a "long-list" of value-relevant factors

Traditionally, valuation professionals have considered a range factors in order to derive an opinion of value. These factors include, for example, national and local market conditions, rent level, functional quality of the building, usability by third parties, letting situation, etc. etc. With the advent of the sustainable development discourse within the valuation profession, "sustainability" has been treated as a somewhat separate category of value-relevant factors. However, recently the perception has emerged that this does not make a lot of sense for a number of different reasons. First of all, traditional valuation methods and practices do take (and have always taken) into account building characteristics which are now termed 'sustainability issue' or 'sustainability aspect'. One example for this is the building's functionality. Consequently, any valuation approach that separates sustainability considerations from the other value-influencing factors is likely to be methodologically incorrect. The methodological separation of sustainability considerations from traditional factors creates the possibility of double counting and does not provide a clear process for evaluating and pricing the sustainability factors. As a result, the valuation profession has started to embed sustainability issues into the traditional "canon" of value-relevant factors and is moving towards a "long-list". An example for such a list can be found in Lützkendorf and Lorenz (2011) and in the already mentioned NUWEL-guideline.

Towards mandatory sustainability related requirements for valuers

Most of the existing sustainability related advice and recommended practices for valuers (as shown

in Table 1 above) are as yet not mandatory requirements enforced by professional organisations but are of informative character only. It is therefore likely to assume that most valuers would hesitate to modify their practices as well as to extend their data collection procedures as this could be seen as an unpaid extra-work. Nonetheless, there are two exceptions to this:
(1) In Germany valuation standards are not developed and enforced by professional organisations but by the state in the form of so-called valuation orders. And in 2011 a revised version of the German valuation order (Immobilienwertermittlungsverordnung, ImmoWertV) came into force. And within this valuation order, the subject property's energetic qualities are listed as a value influencing factor that has to be taken into account within the valuation process. The explicit recognition of the relationship between a building's energetic qualities and its market value can be considered as a very good step into the right direction.
(2) The RICS is currently in the process of adopting a respective guidance note on the issue of sustainability and commercial property valuation (see Table 1 above) to be included in an updated version of the RICS Red Book (i.e. their internationally recognised valuation standards). The content of a guidance note is defined as "recommended good practice" for valuation professionals; deviations from the prescriptions of a guidance note within a valuation assignment have to be explained in writing with the valuation report. As such, a guidance note can be seen as a quasi-mandatory requirement for professional members of the RICS. Since the publication of the guidance note on sustainability and commercial valuation is scheduled for this year (2013) it can be expected that sustainability will now become an integral part of future valuation assignments carried out be members of the RICS.

Towards improved data and empirical evidence
A key concern in connection with the issue of sustainability and valuation is the lack of both, data and information on the sustainability credentials of the property to be valued and, an appropriate empirical evidence base to support / back up an individual valuer's decision on how to price the subject property's sustainability credentials (or their absence) within a given local market environment. Both aspects are currently being addressed by individual valuers, professional valuation organisations and other third parties.
On the one hand, effective mechanisms are being sought and developed to link sales prices (and other financial information such as rental bids) with information on the respective properties' sustainability credentials (e.g. through the increased usage of information contained in energy performance certificate and sustainability assessments). Good examples for this are (1) efforts undertaken by individual German valuation expert bodies who have started to extend their comparable sales databases to include sustainability related information in addtiona to "traditional" variables; and (2) efforts undertaken by the Investment Property Databank (IPD, a globally operating commercial real estate index provider) to integrate envornmental performance information in their real estate indixes (see the IPD EcoPAS initiative).
On the other hand, valuation professionals are either explicitly encouraged (e.g. by TEGoVA) to seek expert advice (i.e. from sustainability assessment experts) and/or to rely on relevant certification results as to a property's sustainability rather than to assess the sustainability of subject property personally because valuers must act within the limits of their professional skills (see: TEGoVA, 2012). Or valuers are encouraged (e.g. by the RICS) to expand their basic data collection procedures to include a record of any sustainability features (if possible), even if they do not currently have an impact on value in order to improve the information available in the marketplace. The last mentioned approach involves the question if and to what extent valuation professionals actually have the knowledge and skills to gather (or even produce) such information personally. This question has been elegantly solved by the RICS: within the already mentioned RICS draft guidance note on sustainability and commercial property valuation it is stated that valuation professinals should personally gathter/generate sustainability related information only if this is in line with their professinal skills (e.g. valuers can analyse an energy bill or asses whether or not the subject property exhibits the potential for solar energy usage, etc.); in all other cases, valuers are encouraged to *ask their clients* (i.e. in most cases the building owners) to provide information on the subject property's sustainability credentials. And if clients cannot deliver this information, then either external (sustainability) experts have to be involved, or, valuers may treat this lack of information as an additional risk factor that can impact on the overall valuation result. In either case, it is likely that the demand for sustainability assessments and/or building performance evaluation and reporting will signifcantly increase due to the aforementioned developments within the valuation profession.

6. Summary and outlook

The present paper has shown that any attempt to evaluate economic performance aspects of buildings within the scope of sustainability assessments reveals a range of unsolved questions and problems which have not yet been sufficiently discussed within national and international research communities. The authors' attempt was not to solve these questions and problems but to highlight them in order to stimulate scientific discussion and debate on these important issues.

The paper has also revealed that two formerly distinct disciplines (i.e. sustainability assessment of buildings and property valuation) are now converging and rely heavily on each other. On the one hand, sustainability assessments of buildings increasingly rely on concepts (Market Value) and methods (income/investment valuation method) originally developed by the valuation profession in order to be able to appropriately describe and asses the economic performance of buildings. On the other hand, the valuation profession increasingly relies on sustainability related information in order to be able to appropriately estimate the economic value of buildings. As such, it appears advisable for both disciplines not to attempt to "reinvent the wheel" but to rely on and make clear reference to the terminology, standards, norms, and definitions which have already been developed and applied within the respective other discipline. This requires dialogue and cooperation between the key representatives and professional bodies of these disciplines.

References

CEN, 2012, *EN 15643-4: 2012 Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance*, Published by: CEN, the European Committee for Standardization

Davis Langdon, 2007, *Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology - Literature Review*, Published by: Davis Langdon Management Consulting, Available at: http://ec.europa.eu/enterprise/sectors/construction/files/compet/life_cycle_costing/literat_review_en.pdf

Evans, D.J. and Sezer, H., 2005, *Social discount rates for member countries of the European Union*, Journal of Economic Studies, Vol. 32, No. 1, pp. 47-59

Gollier, C., 2011, *Pricing the future: The economics of discounting and sustainable development*, Princeton University Press, Available at: http://idei.fr/doc/by/gollier/pricing_future.pdf

ISO, 2008, *ISO 15392: 2008 Sustainability in building construction – General principles,* Published by: International Standardization Organization

ISO, 2011, *ISO 21929-1: 2011 Sustainability in building construction - Sustainability indicators - Part 1: Framework for the development of indicators and a core set of indicators for buildings*, Published by: International Standardization Organization

ISO, 2008, *ISO 15686-5: 2008 Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing*, Published by: International Standardization Organization

Lorenz, D., Michl, P. and Lützkendorf, T., 2013, *Integration of sustainability aspects into property valuation practice in Germany*, Proceedings of the Sustainable Building Conference Munich 2013 (SB13), 23.04.-26.04.2013, Munich

Lützkendorf, T. and Lorenz, D. (2007), *Integrating Sustainability into Property Risk Assessment for Market Transformation*, Building Research & Information, Vol. 35, No. 6, pp. 644–661

Lützkendorf, T. and Lorenz, D. (2011), *Capturing sustainability-related information for property valuation*, Building Research & Information, Vol. 39, No. 3, pp. 256–273

Meins, E., Lützkendorf, T., Lorenz, D., Leopoldsberger, G., Frank, S., Burkhard, H.P., Stoy, C. und Bienert, S. (2011), *Nachhaltigkeit und Wertermittlung von Immobilien, Leitfaden für Deutschland, Österreich und die Schweiz - NUWEL*, Published by: CCRS, Center for Corporate Responsibility and Sustainability, Universität Zürich

RICS, 2009, *Valuation Information Paper 13, Sustainability and commercial property valuation*, Published by: Royal Institution of Chartered Surveyors, London

RICS, 2011, *Sustainability and residential property valuation*, IP 22/2011, Published by: Royal Institution of Chartered Surveyors, London

SuPerBuildings, 2012, *Sustainability and performance assessment and benchmarking of building – Final report*, Available at: http://www.vtt.fi/inf/pdf/technology/2012/T72.pdf

TEGoVA, 2012, *European Valuation Standards 2012*, 7th edition, Published by: The European Group of Valuers' Associations (TEGoVA), Brussels

Quiggi, J., 1997, *Discount rates and sustainability*, International Journal of Social Economics, Vol. 24 No. 1/2/3, pp. 65-90

The interaction between sustainability and quality in building – systemic approach and case study buildings



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Summary

Today sustainability gains a growing acceptance in the building sector and is seen as a trendsetting part for buildings. On the other hand building processes up to date are still only evaluated through price competition and marked by the handling of failures and insufficiencies in the construction and erection of buildings. Positive effects of better building quality are not identified widely.
Therefore this paper examines the interaction and impacts between aspects of sustainability and the criteria of quality in buildings. The analysis is carried out through a sensitivity model and evaluation of results through case studies. Cybernetic modelling is introduced to highlight interactions and their influences on each other.

Firstly the elastic terms of quality in the building context and sustainability are discussed. A sensitivity analysis is made to show the interactions of the different aspects on each other and to work out the important aspects.
Therefore twenty variables are deduced from the firm establishment of the terms, which matter most for this topic. They constitute the set of variables for a sensitivity analysis from Vester. With the sensitivity analysis an impact matrix and an effect system are elaborated to emphasise the critical variables for the processes and variables which matter most.
On these results and for closer inspection of the correlations, sustainable buildings, which are recognised as exemplary representatives, are examined to identify the underlying principals. Processes behind planning and erection of each building were observed critically. The results of the building analysis are then contrasted with the results of the (previous) sensitivity analysis.

An effect system for the creation of sustainable buildings is developed as a cybernetic model. In this model it is outlined which prerequisites are required to develop sustainable buildings. Certain aspects, which generate high impact for the whole system, were emphasised and starting points for improvements elaborated.
True sustainable buildings can only evolve from stronger interactions between the separate disciplines. The first step is to understand the interdependencies and interactions between the variables and then to develop the main factors so that the system changes with the lowest input. In reaching sustainable buildings, design with its complex dependencies has to regain a central position. Client behaviour as well as quality of construction work on site are also fundamental. Motivation of planners and builders and communication between them is highly important.
More training for all parts of the building sector in these issues is necessary. A honest culture of teamwork for the best result rather than only the economic success is fundamental.

Keywords: sustainability; quality in buildings; sensitivity analysis; interaction

1. Introduction

In recent years sustainability has gained growing acceptance in the building sector and is seen as a trendsetting part of buildings. The certification of sustainability with systems like DGNB / BNB, bream etc. have introduced further requirements to building processes. Various guidelines have been developed for this gain. Newly developed calculation tools (e.g. for LCA / LCC calculation) are being used more and more.
On the other hand building processes up until now have still only been evaluated through differences in price and marked by the handling of failures and insufficiencies in the construction and erection of buildings.
Communication and exchange of data is often insufficient. Clients often only look at construction costs without concern for later operational costs.
Positive effects of better quality of buildings are not widely identified or at least not realised consistently with early quality assurance systems. Extra money is spent on sustainability criteria but not invested in obvious quality assurance.
This paper examines the interaction and impact between aspects of sustainability and the quality in buildings. Through this the main influencing factors of the building process on sustainability goals is examined through a sensitivity model and their influence is visualized by analysis of different realised buildings.

2. Main issues and their definition

Firstly the elastic terms of quality in the building context and sustainability, as well as complex interactions are discussed. Then a sensitivity analysis is produced to work out the most important aspects and to show their interaction with each other.

2.1 Quality in buildings

The term quality has a broad meaning. In the ISO standard ISO 9001 quality is defined as a “degree to which a set of inherent characteristics fulfils requirements.”[1] To bring it into practice quality for the building sector can be defined as adherence to agreed properties. According to Trost [2] quality in buildings can be divided into concrete, abstract and indirect characteristics. Technical issues and their realisation belong to the first category, aesthetics and image of the building to the abstract category and indirect issues are communication and cooperation in building sector.
Main objective for quality in buildings is the adherence of the agreed qualities. If the quality is not complied with, we speak of faults, defects / insufficiencies and damages. To the left, figure 1 shows the percentage of faults and defects in building context and how many of these end in damages [3]. To the right, figure 1 shows the reasons for such faults [4].

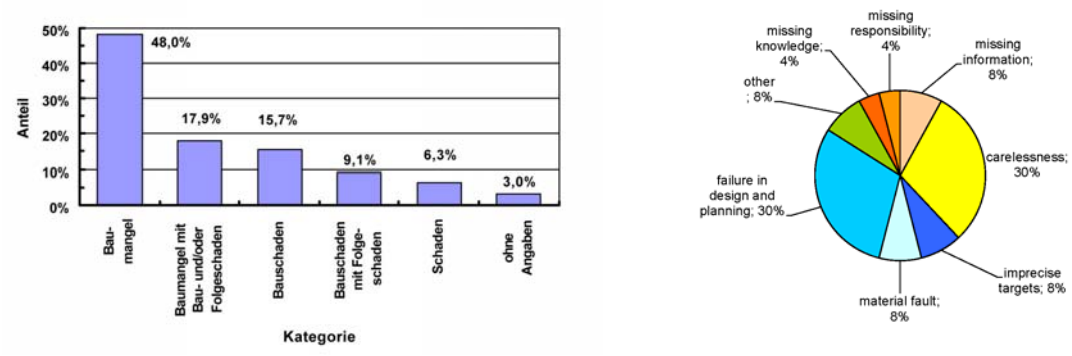


Fig. 1: categories of defects [3] and faults / defects in building sector according to [4]

By looking at these figures the conclusion can be drawn that a high percentage of faults could be avoided by accurate planning and in improvements in communication and knowledge. Knowledge here applies mainly on having sufficient information and explicit dedicated responsibilities.

2.2 Sustainability

The term of sustainability is used according to the sustainability triangular and the definitions underlying the actual certification systems of BNB and DGNB [5]. Individual criteria are included in the considerations on assessable factors for sustainability issues in the building sector. As shown in figure 2 sustainability issues are divided in columns and then subdivided in single issues.

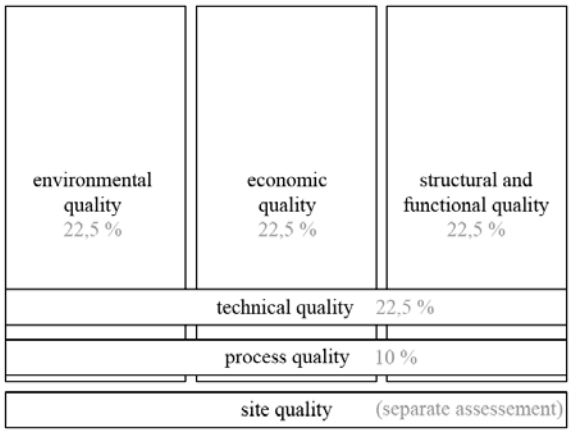


Fig. 2: subdivision of sustainability issues in compliance with sustainability certification schemes

2.3 Complex interactions – cybernetic

Interactions and dependencies have become more complex due to strong division of work, due to specialisation and also advanced communication systems. Therefore problems can often not be solved immediately and without further adjustments further down the line. The solving of one problem often generates problems with other issues. Frequently cause and effects are not easily connected. Complex systems and interactions are dynamic systems. The characteristics for these systems are that even small faults can have a major influence on the whole system.
The building sector is marked by the involvement of many participants, very diverse objectives and a new approach for every project.
In that context cybernetics is introduced to allow visualisation and handling of complex issues and interactions. Cybernetics is an interdisciplinary science to regulate and control open loop projects. It aims at identification of nature and control of complex systems. The systemic approach is introduced with this.

3. Interaction between sustainability and quality in building

To study the interactions between sustainability and quality in buildings twenty variables are deduced from the firm establishment of the terms explained above. Systematic approach is introduced to emphasise on changes of interactions. They constitute the set of variables for a sensitivity analysis from Vester. The most effective variables are filtered trough the impact matrix and effect system. Simulation of individual parts of the system help to visualize the overall effect of changes to the system. Based on these results, sustainable buildings, which are recognised as exemplary, are examined in order to identify the underlying principals and their correlation. The results of the building analysis are then matched with the results of the sensitivity analysis. An effect system for the creation of sustainable buildings is then developed as a cybernetic model.

3.1 Sensitivity model for interactions (according to Vester)

Frederic Vester developed a methodical tool for network thinking [6]. With this tool it is possible to recognise, control and self-regulate networked processes with minimal input. The individual parts of the system depend in many ways on each other and have many direct or indirect interactions. Sensitivity modelling, according to Vester’s model, shows a systematic approach to the analysis of

complex interactions. It also allows to show correlations and reactions in a transparent way. This systemic analysis is basis for the sensitivity analysis according to Vester and results in a cybernetic modelling system which is applicable to all areas of interest.
For an exact representation, three preconditions have to be complied with: right choice of the variables, definition of interactions between variables, linking variables. [6]

3.1.1 Variables and sensitivity analysis

Starting point for the sensitivity model are the variables. Variables are adjustable measurements - points in the system – from which the cybernetic of the system is identified. These variables were defined by carving out core competences for the individual issues and condensing the set to gain a manageable set of variables.
The variables consist of the components of *sustainability*, *quality in buildings* and other factors, which are important for the model. The variables are shown in figure 3. A criteria matrix in the Vester system checks the completeness of the variables. This ensures that no crucial issue is missing.

Impact categories

sustainability	**quality in buildings**	**others**
1 hight of impacts on environment	11 implementation of integral planning	20 legal ajustments
2 hight of material consumtion	12 decisivness of client	
3 hight of construction cost	13 quality control during building process	
4 hight of operational cost	14 intensity of motivation	
5 hight of end-of-life cost	15 intensity of competition	
6 durability	16 communication	
7 improvement of maintenance	17 performance of technical aspects	
8 health of occupants	18 holistic approach to design	
9 comfort of occupants	19 holistic approach to functionality	
10 consumer satisfaction		

Fig.3: variables for sensitivity analysis

3.1.2 Influence matrix

Dependencies of the variables were defined and interferences estimated with the use of the influence matrix. Each variable was examined on its conversion in regard to all the other variables. Dependencies were defined by literature studies, previous knowledge and experience in sustainability certification and quality management certification.

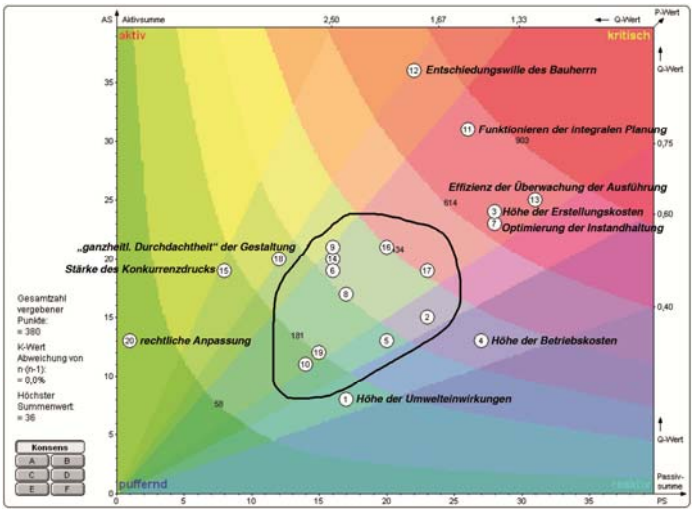


Fig. 4: influence matrix

Figure 4 shows the influence matrix with the parameters and the results. The picture shows the variables very clearly which have most effect on the system. Variables in the red area mark a high influence on others with minimal change. These are: *decisiveness of client, implementation of integral planning, quality control during building process, amount of construction cost and improvement of maintenance*. They are the most critical variables.
Variables which influence the system sparsely but steadily are *holistic approach to design and intensity of competition*. They have a slow but steady influence. Variables in the circle in the centre of figure 3 reach an equilibrium. This means that whenever changes in one variable occur all the actions and reactions of the involved system help to stabilise the system. Changes in these variables cannot influence the system in a big way. But these variables are necessary to keep the system in an equilibrium.
The influence matrix clearly shows that the above mentioned variables within the red area are of major importance to the system. They need to be a focal point in the planning and building process in order to influence sustainability and quality of buildings positively. Therefore main focus in the work was dedicated to these issues.

3.1.3 Effect system

The effect system shows the chain and their reactions. This makes the interactions visible and allows further simulation on scenarios. The effect system only shows real effects and distinguishes between rising or descending effects on the variable included. In that context a dashed line means that a rising of a starting variable results in a lowering of resulting variable. The normal line means that a change in the starting variable also results change of resulting variable in same direction. In general this system shows less interconnections than the influence matrix. Close interactions with reaction coupling can be seen e.g. for variable "*decisiveness of client*" and "*implementation of integral planning*".

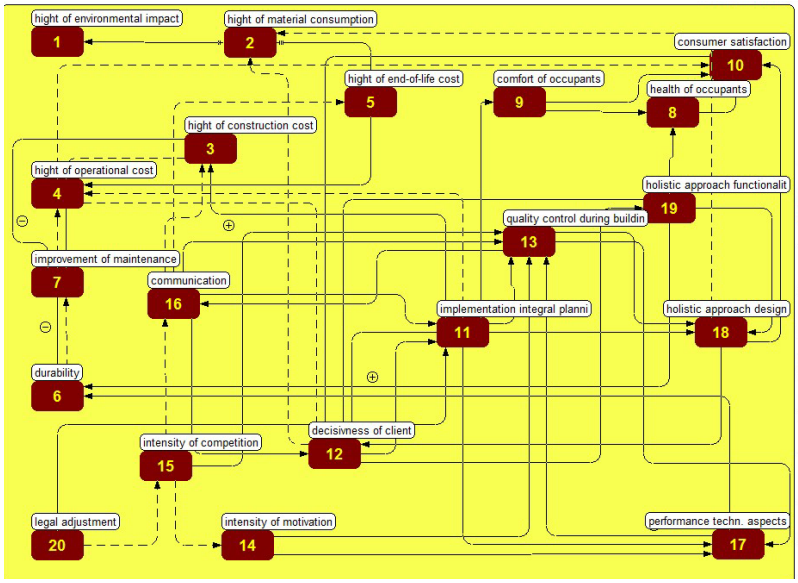


Fig. 5: effect system of interactions between sustainability and quality in buildings

3.2 Comparison of case study buildings

The results of the sensitivity analysis were contrasted with the results of building analysis. Four buildings, publicly approved as sustainable and awarded various awards for sustainable building, were analysed. Buildings serve different uses and are built from diverse materials. For all of them the underlying processes and their interactions where analysed. Analysis was done for the areas of:

- design and connection to site and localities
- planning and building processes
- influence on energy concept
- materiality and processes behind the choices
- cost, maintenance, use of building

3.2.1 Case study buildings

Each building was analysed through plans and interviews with planners. Main focus were: surrounding, design quality and the underlying process to come to these results; planning and building phase including obstacles to reach the goals; trace decision-making process; timeframe for introduction of energetic issues in planning process, material choice, cost / maintenance; user comfort.
For each project a flow-chart was developed to show dependencies of different issues. In figure 6 the chosen case study projects are shown.Analysis of buildings are shown in [7].

Case studies are:

- Hotel in an apple garden, Hohenbercha / Germany (Deppisch Architekten)
- Patchworkhouse (house for two families, Müllheim / Germany (Pfeifer Roser Kuhn

Architekten)
- Multi story dwelling, Zurich / Switzerland (Maier Hess Architekten)
- Community centre, Ludesch / Austria (Hermann Kaufmann ZT GmbH)



Fig. 6: chosen case study buildings (from left to right): Hotel Hohenbercha, Patchworkhouse, Multi-story dwelling Zurich, community centre Ludesch

3.2.2 Results of comparison

The analysis of the processes behind building development shows, that the client played a major role in defining reachable goals at the beginning of the project and helped to achieve them by supporting quality assurance in the construction process. In each project integral planning was implemented at the beginning of the projects. The energetic and technical concepts were developed right at the start with minimal extra impact, adjusted during the process and reflected on construction, cost and maintenance issues. Material choice and health issues for the users were a major task. All decisions had to be justified in regard to cost, gains and maintenance.
An effect system of all interactions was generated to highlight most important variables for case studies.

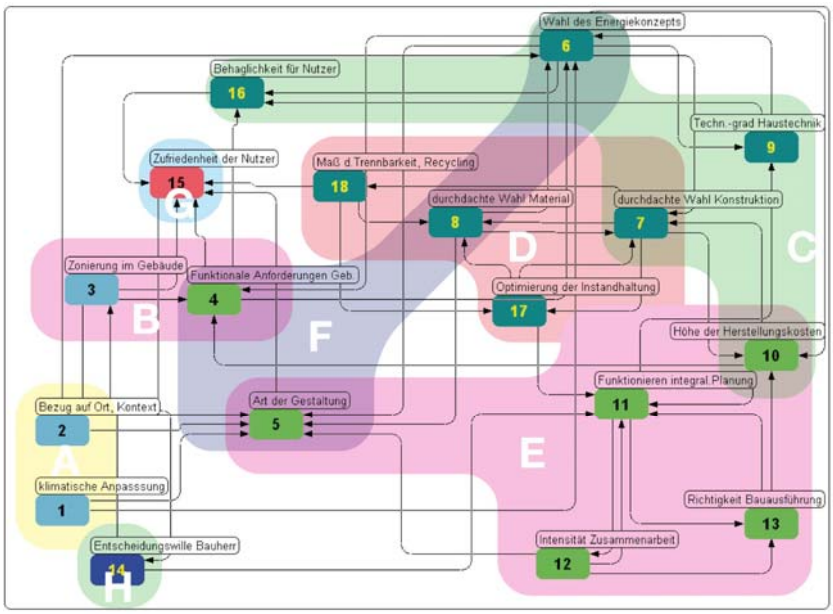


Fig. 7: effect system of interactions between sustainability and quality in buildings on case studies

In addition to important indicators in figure 5 results showed that the site and site specific issues model a different framework for each project. Complex interactions between the issues of energy concept, materiality and quality assurance, but also between design, client, integral planning are visualized.

4. Results

Theoretical effect system and effect system according to case studies were combined to an effect system for the creation of sustainable buildings was developed as a cybernetic model. The cybernetic model indicated which prerequisites are required to develop sustainable buildings.
Certain aspects, which generate high impact for the whole system, can be highlighted and starting points for improvements elaborated.
In figure 8 the interactions of the individual variables are shown. The main issues, which have a major effect on the system of interactions of sustainability and quality in buildings can be outlined. Keeping these in mind helps to strengthen results for sustainable building.
Main issues are:

Client:
The client has an important role to play at the beginning of the project with the definition of the goals for the different aspects and keeps to them throughout the whole project. Clients need to realise about the consequences of changes in goals during the planning process. Also it is important to evaluate quality on site continually in the construction phase, with consistent reparation of mistakes.

integral planning:
An integral planning team at the early stages of the project means an inclusion of all necessary specialist input right from the beginning. Questions which might arise on specialist issues (e.g. fire safety, energetic standard, use of renewable energies) can be properly integrated considering its interactions on other parts. The project coordinator needs to be able to integrate all aspects and has to be mindful of the independence of each other.

construction quality:
Improving the quality of construction can be influenced by precise communication and good motivation of employees on all levels. Constructive cooperation on site has a positive influence on the building. Extensive quality assurance on site produces extra costs but helps to integrate a level

of quality for the building. Therefore the extra cost for an external quality control is invested wisely, as it reduces damage to the building in the life cycle. Not only the actual construction costs should be given attention to in tendering. Also later maintenance and replacement should be included.

life cycle cost:
Introducing life cycle analysis on ecological and economic issues in an early planning stage helps to reach the most sustainable and economically useful solution. The earlier this happens the more interdependencies can be tackled and the fewer extra costs have to be invested in later.

design:
Design is highly dependent on the integration and performance of the interactions between the different variables. In all examined case studies, sustainable architecture is interwoven with a specific site and realised through the integration of an energy concept from design phase to detailing and material choices.

communication:
Knowledge about interactions and close relationships are the basis for explicit communication. Besides this, all parties need to be eagerly motivated in order to achieve the best results to implement sustainable buildings. Sustainability certification can help to integrate the different aspects although design is not clearly quantifiable and sustainable design is not dependent on certification.

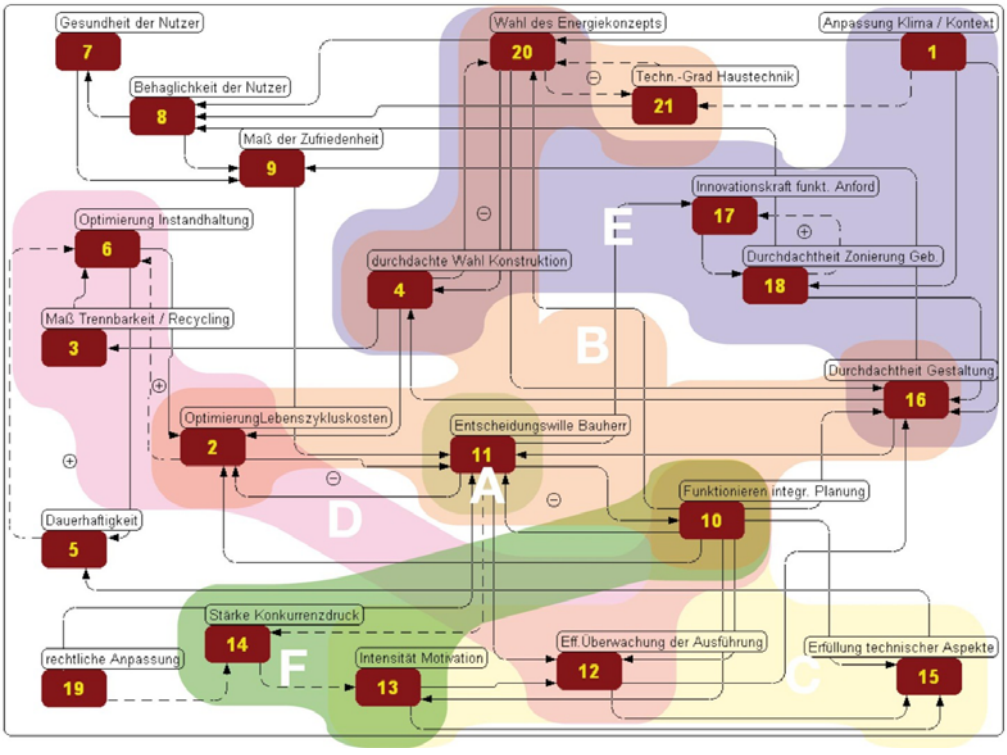


Fig. 8: cybernetic model of interactions – main focus areas

5. Conclusion

Through the cybernetic model many interactions between sustainability and quality in buildings were shown. True sustainable buildings can only evolve from stronger interactions between the separate disciplines. The first step is to understand the interdependencies and interactions between the variables and then to develop the main factors so that the system changes with the lowest input. In order to achieve sustainable buildings, design with its complex dependencies has to regain a central position in planning. The importance of client behaviour as well as quality of

construction work on site needs to come back into focus. Motivation of planners and builders and their communication is highly important.
More training for all parts of the building sector in these issues is necessary. A honest culture of teamwork for the best result rather than only the economic success is fundamental. All the shown issues help to achieve sustainable buildings through manageable processes.

Acknowledgement: This paper contains parts of the PhD thesis [7] from the author.

6. References

[1] DIN ISO EN 9001:2008. Quality management systems – requirements.
[2] TROST M., "*Leistungswettbewerb in der Bauwirtschaft – Die Dimensionen einer Strategie des nicht preisbasierten Wettbewerbs*." Dissertation, Bauhausuniversität Weimar, Weimar, 2006.
[3] BUNDESAMT FÜR BAUWESEN UND RAUMORDNUNG (Hrsg.), *„Dialog Bauqualität – Endbericht*", Institut für Erhaltung und Modernisierung von Bauwerken e.V., Berlin, 2002.
[4] KOCHENDÖRFER B., LIEBCHEN J. et al, „*Bau-Projekt-Management, Grundlagen und Vorgehensweise, 3. aktualisierte Auflage 2007*". B.G. Teubner Verlag / GWV Fachverlag GmbH, Wiesbaden, 2007.
[5] BNB.www.nachhaltigesbauen.de/sustainable-building-english-speaking-information/sustainable-building.html; DGNB. www.dgnb.de
[6] VESTER F., „*Die Kunst vernetzt zu denken. Ideen und Werkzeuge für einen neuen Umgang mit Komplexität"*. Deutscher Taschenbuchverlag, München, 2008.
[7] HAFNER A., *"Wechselwirkung Nachhaltigkeit und (Bau-)Qualität*", Dissertation, Technische Universität München, Munich, 2012.

The impact of sustainability issues on real estate project development processes



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Short Summary

The object of this paper is to present a method to include aspects of sustainability in the various stages of project development and in the processes involved in real estate development. To that end, the criteria for the certification of office and administrative buildings according to the Austrian Society for Sustainable Real Estate (ÖGNI) are analyzed and their influence is examined. Then an analysis of an ideal development process is carried out to see whether sustainability criteria can be implemented, and the temporal and causal correlation between sustainability certification and project development processes are described using a matrix. As a result the authors have adapted the project development process to include all aspects necessary in their opinion for the sustainability certification of office and administrative buildings according to ÖGNI / DGNB standards.

Keywords: Project development, project development process, sustainability, ÖGNI / DGNB, certification systems, real estate industry

1. Introduction

The concept of sustainability and the challenges it involves for us and future generations has become more and more important in recent years. As a result, "sustainability" has become a megatrend. Megatrends can be defined as tendencies in society and business that have an impact on the lives and the economy of future generations. Therefore it is logical that aspects of sustainability have become a big influence in the real estate industry as well. A survey by Jones Lang La Salle has revealed that sustainability will have the highest strategic priority for 83% of real estates professionals in the next ten years. The reason for this is that the real estate industry is one of the largest sectors of the economy as such and is considered one of the major agents when it comes to improving the current situation, in particular because resource consumption is considerable when constructing or running a building. Therefore the potential of the real estate industry for contributing to a sustainable economy is enormous. cf. [1, p.4]

In the opinion of the authors, aspects of sustainability can only be implemented if companies become fully aware of the concept and consider the need for sustainable buildings in an early stage of the development process.

2. Basic concepts

2.1 Project development

As we do not yet have a uniform approach to implementing aspects of sustainability when developing a real estate project, the building and real estate industry interprets the concept and the role of project development in many different ways.

Therefore it is not possible to identify or define the boundaries separating it from other professional fields cf. [2, p. 5]. As a term "project development" is used to signify different phases of time and stages of a project's implementation. According to Brauer three main periods can be identified:

- Development of a real estate project in a narrow sense
  (The period considered lasts from the idea for a project to the design phase)
- Development of a real estate project in an intermediate sense
  (The period considered lasts from the idea for a project until the end of the construction phase)
- Development of a real estate project in a broad sense
  (The period considered lasts from the idea for a project until the end of the demolition or the overall renovation or adaptation of a building) cf. [3, p. 585]

Diederich's definition of project development in general is:

"Project development (in a broad sense) has to combine the factors 'location, project idea and capital' in such a way as to create real estate projects that are competitive in micro-economic terms, that create and secure jobs, that are socially and environmentally sustainable in macro-economic terms and that are cost-efficient in their long-term use." [2, p.5]

From this we can conclude that a building resulting from a project development process has to be motivated not only by the individual requirements of the customer (owners of buildings, investors), but has to take the needs of the public affected by it into account as well cf. [2, p. 5].

2.2 Project development process

Basically there are three relevant models to describe the contents and the conceptualisation of the project development process:

- Equilibrium models: based on political economics
- Agency models: based on behavioristic concepts and administrative economics
- Event-sequence models: focusing mainly on the business-related aspects of managing the project development process as such. To this end, the project development process is subdivided into individual stages cf. [4, p.30]

In this study we have employed the event-sequence model because it is based on the processes taking place in the real world of real estate development. It uses traditional event sequences or schemes that result from the various coordinated and consecutive steps characterizing the processes involved in the production of goods and services. Furthermore, this model captures the complexity of the project development process and the dynamics necessary and allows for overlaps, parallel events and feedback effects cf. [4, p. 35].

The event-sequence model of a project development process according to Schulte / Bone-Winkel in figure 2-1 is used as a basis for creating a new, ideal development process which includes aspects of sustainability.

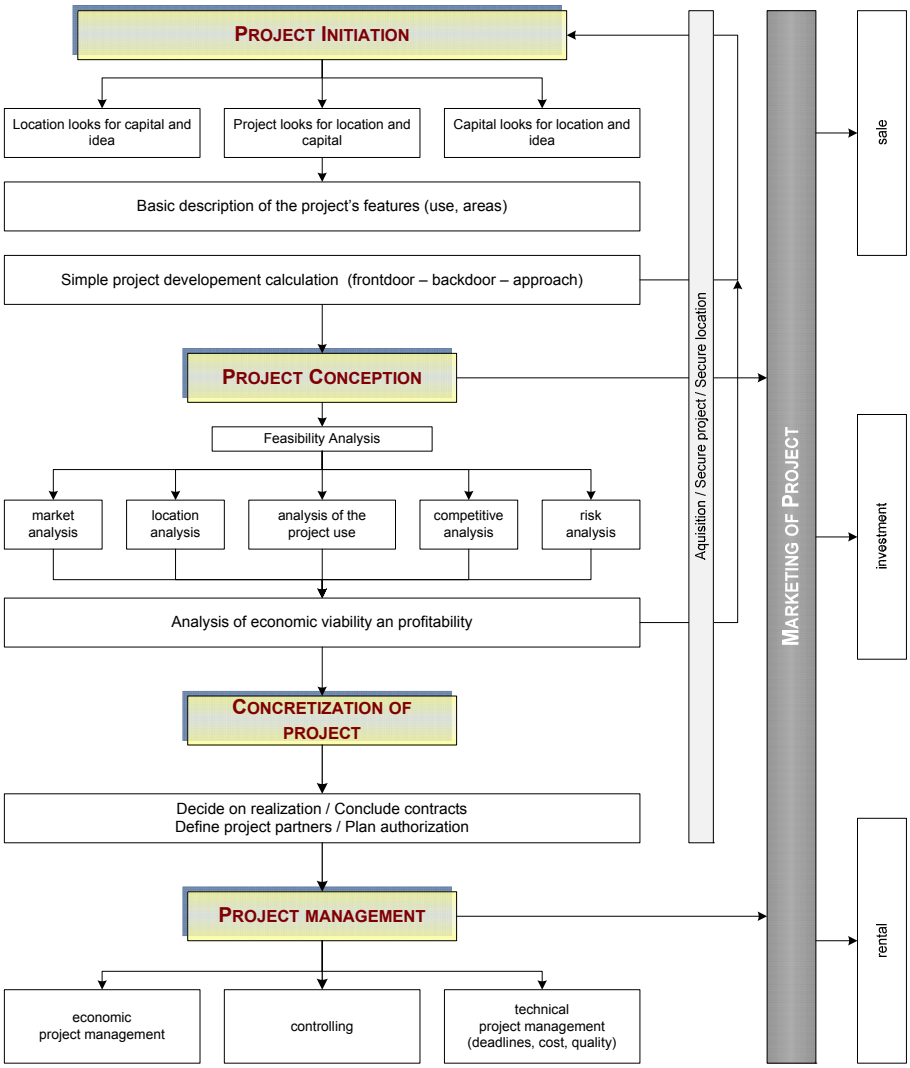


Figure 2-1: Event-sequence model of the project development process [4, p.36]

2.3 Sustainability

As a megatrend, sustainability has an influence on all aspects of our future actions. This is to say that the concept of "sustainability", which scientists started to examine only 40 years ago, is no longer just discussed in the exclusive circle of experts, but has arrived in the centre of society and in the real estate industry as well cf. [1, p.4]

The World Commission on Environment and Development (WCED), the Brundtland-Commission as it is called, contributed significantly to defining the concept and to our current understanding of the term cf. [5, p. 20]. In its report "Our Common Future (1987) sustainability was defined as follows:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [6]

However, the concept of sustainability was not invented by our society. The idea was first developed in forestry and can be traced back to Hans Carl von Carlowitz, who invented the term in the 18th century cf. [5, p.20].

2.4 Sustainability certificates

The various sustainability certificates in existence play a central role when it comes to implementing sustainability aspects. The reason is that only a building that has obtained a certificate or quality label will be considered a sustainable building by the wider public.

Internationally there are numerous certificates and quality labels that have been adapted to meet the needs of the countries concerned. The following list of the most important sustainability certificates can serve as an example:

- Austria ÖGNI / DGNB
- Germany DGNB
- United Kingdom BREEAM
- USA LEED
- Australia Green Star
- Japan CASBEE
- Switzerland Minergie
- France HQE

to name just a few. cf. [7, pp. 90]

The following study uses the ÖGNI / DGNB certification system, because it constitutes a transparent and coherent real estate certification method suitable for the Austrian market.

2.5 ÖGNI / DGNB specifications

Basically, the ÖGNI / DGNB system is divided into six main criteria. The main criteria are composed of groups of criteria that again are made up of the individual criteria described in the specifications. Figure 2-2 shows a diagram of all main criteria groups employed by ÖGNI /DGNB. cf. [7, pp. 96]

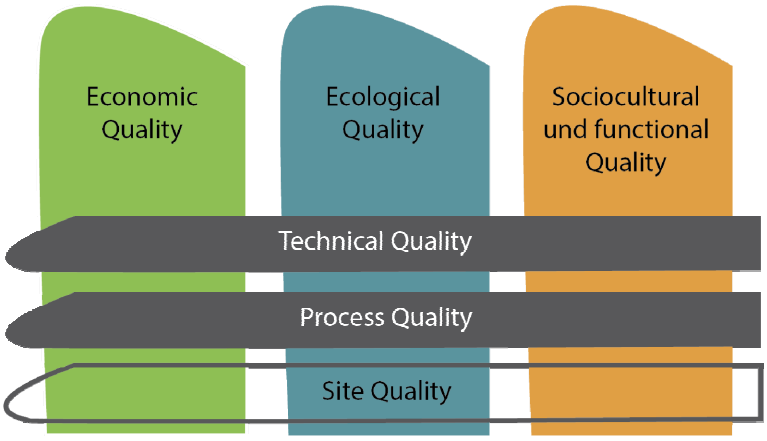


Figure 2 2: System components of ÖGNI certification [7, p.97]

In this context we have to mention that the quality of the location is currently not considered in the final assessment or certification of a building.[1]

The smallest unit in the certification process is the individual specifications containing the descriptions needed for the assessment by allocating points for each criterion. The number of specifications listed depends on the purpose of the building. For this study we have used the specifications for "new office and administrative buildings" comprising 49 individual criteria.

[1] This differs from the "certification of urban districts" according to the DGNB which attributes vital importance to the site of a project.

2.6 Impact of sustainability issues on project development

Sustainability and the certificates connected to it are becoming a significant economic factor in the real estate industry. Jones Lang LaSalle, for instance, published a survey in March 2011, showing that about 75% of all executives responsible for corporate real estate would be prepared to pay higher rents for sustainable buildings cf. [7, p. 3]. We can call real estate development sustainable when the following prerequisites are met:

- cost-efficient
- ecofriendly
- resource saving and
- optimum integration in the socio-cultural environment. cf. [1, p. 16]

Taking its entire life-cycle into account, this should guarantee that a sustainable building is of higher long-term value to communities, investors, owners and users. cf. [1, p. 16]

Figure 2-3 illustrates the main advantages of sustainable development related to the three basic principles of sustainability.

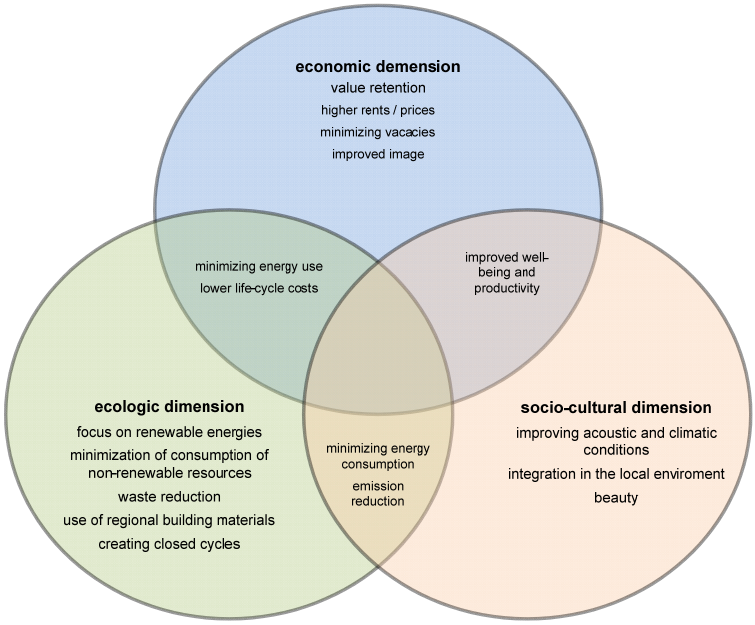


Figure 2-3: The three dimensions of sustainability [1, p. 17]

Due to the interdependence of these aspects, they must not be viewed and worked on in isolation, but have to be combined in a holistic, integrative approach to achieve the best results when developing a real estate project.
In spite of this, cost-efficiency will always be at the centre of investors' attention; ideally, however, sustainable development will lead to more cost-efficiency. cf. [7, p. 81]

3. Adapted project development stages and processes

The steps to be taken to adapt or re-write project development processes are illustrated below:

3.1 Analysis of existing project development processes

Our analysis of project development processes goes to show that they do not include the implementation of sustainability criteria in the individual stages of the process or only deal with them cursorily. Therefore it is easily possible that real estate projects fail to meet sustainability objectives.

According to 2.2 it is necessary to formulate a new, ideal project development process on the basis of Schulte / Bone-Winkel's project development process which includes and guarantees the criteria the authors believe to be necessary to obtain a sustainability certificate.

Figure 3-1 shows a new process resulting from the considerations above, the "accompanying process of sustainability management" for all stages of project development in an intermediate sense. The important element here is that "information" is condensed during the individual stages, which then has to be analyzed and assessed several times with regard to sustainability to obtain a certificate.

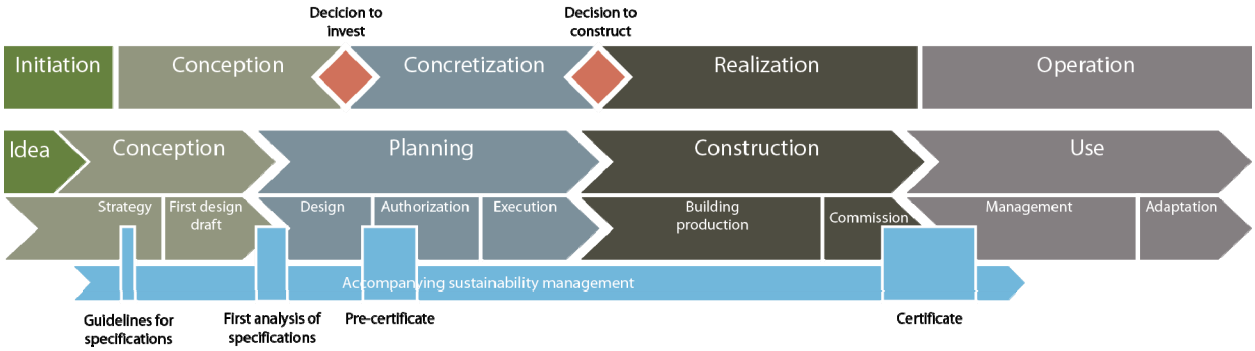


Figure 3-1: Accompanying process of sustainability management during the stages of project development cf. [7, p. 106]

3.2 Analysis of ÖGNI / DGNB specifications:

Our analysis of ÖGNI / DGNB specifications has shown that it is necessary to establish target parameters (e.g. the main ecological and economic criteria groups) and quality requirements (e.g. process quality) at an early stage of the process to obtain the desired ÖGNI /DGNB label cost-efficiently.

3.3 Generating a process matrix focussing on the project development stages as defined in the ÖGNI / DGNB specifications

We have created a matrix illustrating the interdependence and correlation between the specifications and the individual modules of the process. It shows which specifications are needed in which steps of the process to develop an office or administrative building.

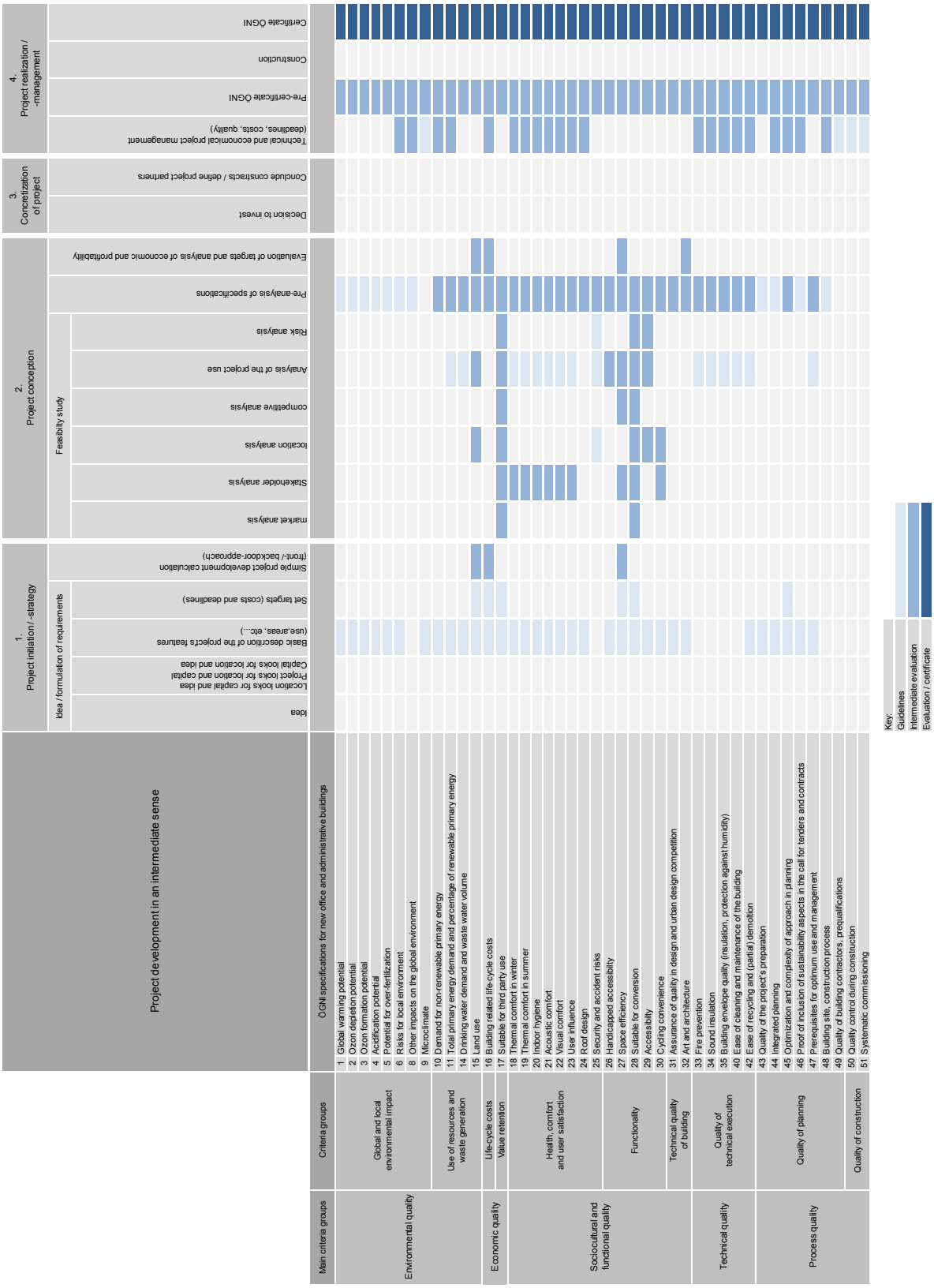


Figure 3-2: Dependence matrix for the ÖGNI /DGNB specifications and the project development process

The matrix in figure 3-2 shows how information and data are condensed during the development of the project by identifying target parameters and quality criteria. In doing so the information given is evaluated several times during the individual stages.

By considering the criteria of sustainability early on during the conception stage, a goal-oriented approach to real estate project development becomes possible. In this way the needs of customers concerning deadlines, cost and public perception can be influenced.

3.4 Implementing the results in a real estate development process

Figure 3-3 shows an adapted real estate development process based on the event-sequence model by Schulte / Bone-Winkel which utilizes the matrix created in point 3.3.

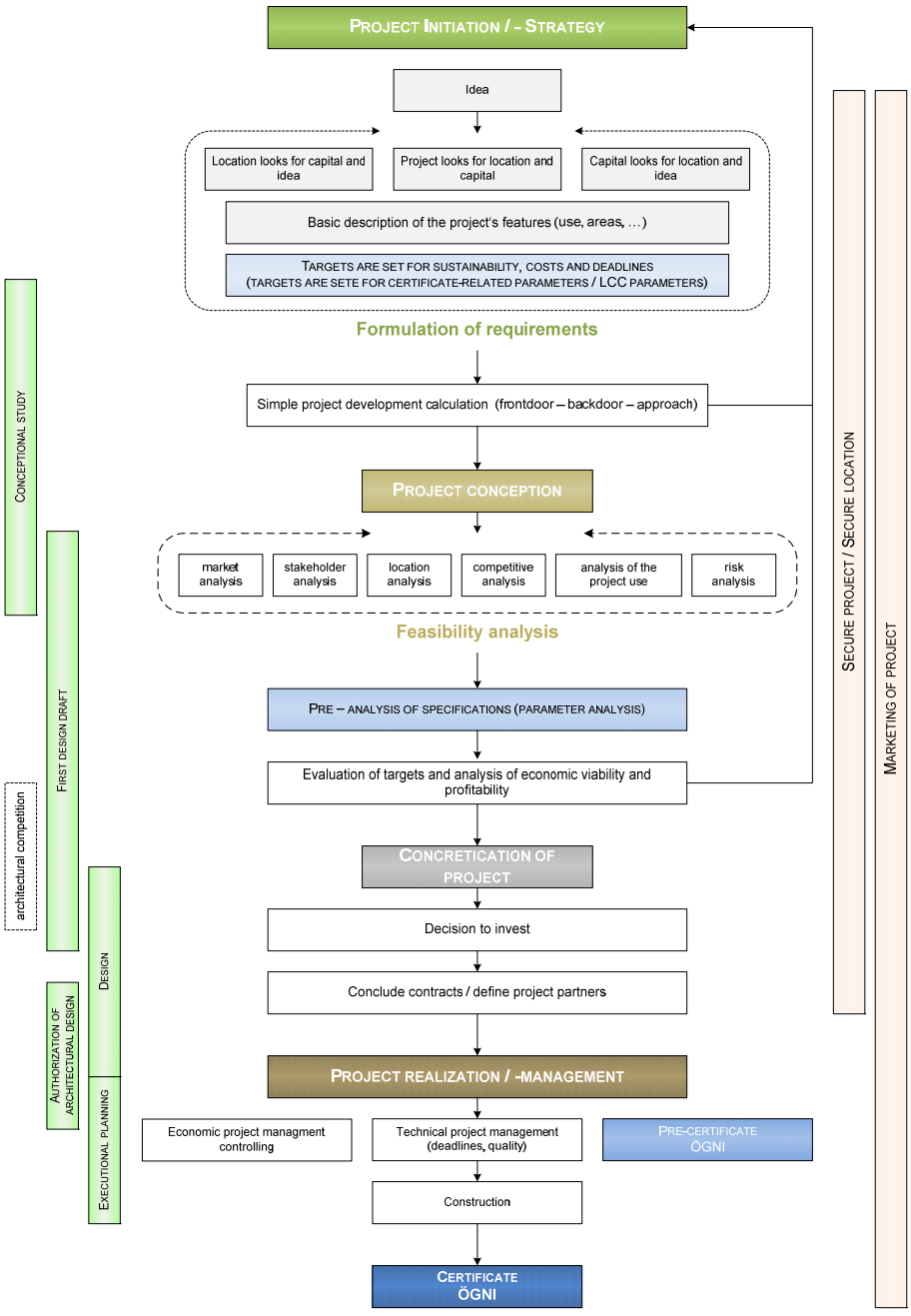


Figure 3-3: Adapted project development process cf. [4, p. 36]

It is essential here that a first set of guidelines for the desired ÖGNI / DGNB label is established when the need for the project is formulated or when the project is initiated and the strategy is developed; the corresponding target parameters and quality objectives have to be set at this early stage.

During the stage of a project's conception a first intermediate evaluation of the target parameters must follow the feasibility study to recognize potential deficiencies at an early stage, so that measures can be taken to control them.

In the end an ÖGNI / DGNB pre-certificate is obtained during the stage of the project's realization and management, which then serves as a basis for the sustainable realization of the project and the final ÖGNI / DGNB certification with the desired ÖGNI / DGNB label.

4. Future perspectives in research

The authors have no doubts that sustainability certification influences real estate development processes. The effects our adapted process has on the structure and operational organization of real estate companies will now be the object of further scientific research employing empirical methods in order to guarantee that the project development process formulated can be managed in the best way possible. Therefore idealtypical forms of organizations are formulated. Further, the results regarding optimum operational or structural organization, including all impacts of sustainability, should be verified on sample projects.

The prerequisites for the accompanying sustainability management as shown in figure 3-1 should be worked out as soon as possible and should be widely discussed with potential project partners and public officials.

5. Conclusions

Studies about implementing ÖGNI / DGNB specifications and criteria in the real estate development process have made it clear that it is easy to consider them at an early stage. This is necessary if projects are to be developed continually and functional and economic targets are to be met. To this purpose, the authors have defined a new process, the accompanying process of sustainability management, which needs organizational support when implementing it.
A detailed dependence matrix was created to show the correlation between ÖGNI / DGNB specifications and the project development process.

This approach contributes to implementing a holistic view of project development to prevent that the sustainability requirements of a building are not only considered in the limited fields of planning, construction and operation.

6. Bibliography

[1] DEUTSCHE HYPOBANK AG „Deutsche Hypo Markt Analyse“, Eigenverlag, 2011
[2] DIEDERICHS C. J. „Immobilienmanagement im Lebenszyklus“, Springerverlag, Berlin – Heidelberg 2006
[3] BRAUER K.-U., „Grundlagen der Immobilienwirtschaft“, Springerverlag, Wiesbaden 2011
[4] SCHULTE K.-W., BONE-WINKEL S. „Handbuch Immobilien-Projektentwicklung“, Immobilien Managerverlag, Köln 2008
[5] EBERT TH., ESSIG N., HAUSER G., „Zertifizierungssysteme für Gebäude“, DETAIL, München 2010
[6] http://bne-portal.de/coremedia/generator/unesco/de/02__UN-Dekade_20BNE/01__Was_20ist_20BNE/Was_20ist_20Nachhaltigkeit_3F.html (12.05.2013)
[7] FRÖCH G., „Probabilistische Bewertung und systematische Optimierung von Projektentwicklungen unter Berücksichtigung von Nachhaltigkeitskriterien“, Dissertation Universität Innsbruck, Eigenverlag 2012

Nearly zero energy target integration in public design tenders



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Short Summary

The paper in the beginning clarifies what the nearly Zero Energy Building (nZEB) means and what the advantages of an Integration Energy Design (IED) process are. Afterwards, it shows two local experiences about nearly zero energy target integration in two different public design tenders procedures. The first experience regards a restricted design competition which aims at finding the best design proposal within a restricted number of projects. While the second experience regards a negotiated design tender which just aims at selecting the design team will design the new public building. Results show how to integrate, require and evaluate the results of different tender procedures, advantages to use IED process.

Keywords: nZEB, IED, public design tender.

1. Introduction

The Directive 2010/31/EU [1] invited public authorities to develop plans to increase the number of nearly Zero Energy Buildings (nZEBs). This paper proposes a way to increase the number of nZEBs including the zero energy balance target within the public design tender for new buildings (or for building renovation) and to push the design teams to follow an Integrated Energy Design (IED) process. The goal was to define the most effective rules and points of attention that municipalities or public administrations must consider in the tender elaboration phase. The paper shows the approach applied to two real experiences with two different public administrations. In both cases close collaborations between EURAC team and municipalities were necessary to fix energy performance indicators, establish a method to calculate the energy balance, the award score criteria and the evaluation commission members.

2. Integrated Energy Design process (IED)

The project Affirmative Integrated Design Action (AIDA), supported by the Intelligent Energy Europe (IEE) programme, aims at setting up strategies to support local authorities in pursuing nZEB target for new buildings and building renovations. One of the key approaches suggested is to enhance the decision making process through an Integrated Energy Design. The IED is a multidisciplinary, collaborative process that analyses the whole building process and integrates different aspects and knowledge during all phases of development of the

building.
The ultimate goal is the achievement of the performance targets defined by the customer (e.g. null energy balance, high internal comfort, economy, functionality, aesthetic impact, etc.) through a collaborative process for determining the most advantageous solution [2]. The IED work team consists of individual figures (i.e. contractor, architect, engineer, constructor, sponsor and users), whose specific expertise, if effectively integrated allows to define, analyse and evaluate different design solutions and their possible interactions. The choices are taken from a work team through a participatory decision making process. Thanks to the IED process qualitative, economic, functional and aesthetical aspects of a wide range of design solutions can be taken into consideration to find the optimal solution [3]. Generally, IED is an iterative process with a feedback loops mechanism [4].

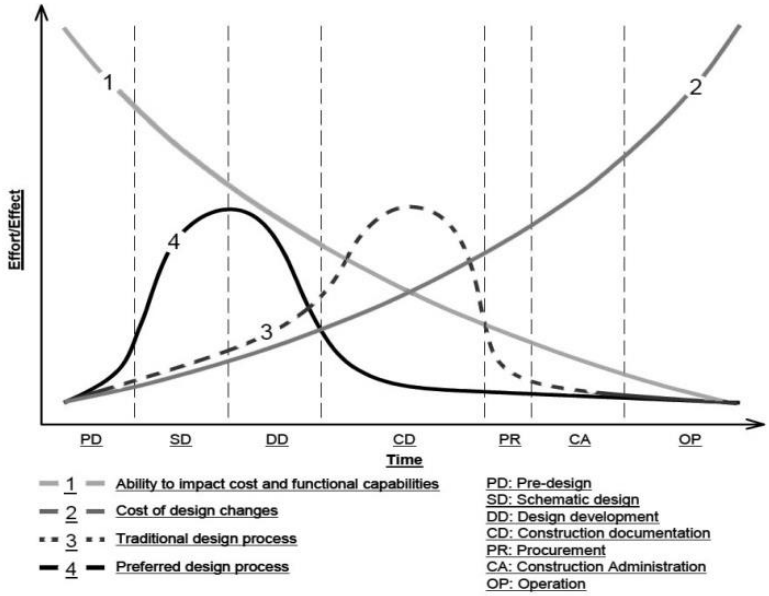


Figure 1: Difference between traditional design process and integrated design process. [14]

Figure 1 shows the difference between a traditional approach and an integrated design process. The main advantage of the IED is, that design decisions are taken at a time, when the cost does influence only design changes and not the overall construction cost. Therefore the design effort is higher during the early design phases than in the construction phase.
For this reason a close collaboration between public administrative figures, engaged to draw up public tenders and to untangle legislative procedures, and nZEB expert figures, is a key to success, which should be included into the rules of design competition procedures.

3. Nearly Zero Energy Buildings

The EPBD recast 2010 introduced the concept of nearly zero energy buildings stating that "*nearly zero energy building means a building that has a very high energy performance*" and that "*the nearly zero or very low amount of energy required should to a very significant extent be covered by energy from renewable sources, including renewable energy produced on-site or nearby*". Member States should ensure that by December 2018 all new buildings owned or occupied by public authorities are nearly ZEBs; public authorities are in charge of promoting and setting up strategies to pursue the nearly ZEB target.
The lack of a precise definition of nZEB [5], has led several member countries of the International Energy Agency to launch the research project "IEA SHC Task 40 – ECBCS Annex 52: Towards Net Zero Energy Solar Buildings". The project aims at clarifying the precise meaning of Net ZEB, translating it in calculation methodologies, and showing the implications of the latter on design solution sets. EURAC is participating in the project and is collaborating, with the Province of Bolzano to transfer the gained knowledge at local level.
The nZEB requirements part included in design tenders are the results of Task 40 project, and consists of energy performance indicators (energy balance, heating/cooling/electric demand, IEQ level, etc.), energy calculation methods (tools and methods) and evaluation

methods (ranking procedures through assignment of points and weighted sum).
In addition to this guide lines, in the tenders should be reported the national/local laws that fixes the energy performance indexes. In the Province of Bolzano, CasaClima Agency is the public authority in charge of establishing the energy performance requirements, and verifying them, for new and existing buildings through an energy certification performance (ECP) procedure. The CasaClima certification defines energy performance classes based on envelope performance during the heating season.
The new legislative decree DP 362/2013, in force from the 4th March 2013, introduces other energy performance requirements such as CO_2 emission, heating load and minimum energy production by renewable energy (see Table 1).

Table 1: Energy requirements for new buildings. Source: DP 362 of 4th March 2013.

Measures	Energy efficiency	RES
New buildings	CasaClima B (Heating Load<50kWh/(m²year))	40% of the total primary energy produced by RES
	CO_2 emission < 20kg/(m²year) (for non residential buildings CO_2<100kg/(m2year))	60% of the DHW load covered by RES
	minimum periodic thermal transmittance (Y_{ie}) for summer season	minimum of 20W (of for each square meter covered) of electric production system from RES

The following sections describe the nZEB definition applied to the two case studies in terms of metrics and calculation boundaries.

4. Alpine huts design competition

In November 2011 the Bolzano Provincial Committee has announced a design tender restricted to 8 selected design teams. The tender concerns the design of three alpine huts located at an altitude of 2000 - 3000 m [6].
The new alpine huts would serve two important purposes: to provide alpinists and hikers protection from the elements and a comfortable place to rest, to be an arrival point for families. The activity period is from July to September, except for a small part of the huts used as winter bivouacs. The huts are not connected to the public power and water supply grids and cannot be reached by vehicles. Actually victuals and supplies are delivered by helicopter or by walk. The construction process cannot be accomplished with traditional methods. So the designers had to contend with the challenge of building the new huts in isolated sites.
The Provincial Committee challenged further the designers by requiring the nZEB target and involved EURAC as energy consultant to support the energy concept design. The first version of the tender just mentioned some general requirements as energy production from renewable energy and sustainable construction mode. EURAC worked with the Provincial Committee to include energy guidelines in the second version of the tender and provided two simplified tools to estimate the energy performance indicators.
As this tender is a first attempt of IED introduction in the common procedures, the Provincial Committee did not include the energy concept in the ranking list and the nZEB target was not mandatory.
EURAC, according to the Provincial Committee and the hut manager's needs, established the following energy targets:

- energy efficiency of the building envelope with heating load ≤ 50 kWh/m²y (CasaClima B);
- 50% of domestic hot water consumption and 20% of the sum of heating and domestic hot water consumption have to be produced by thermal systems driven by renewable energy sources;
- 20% of electric energy demand has to be covered by electric energy produced by renewable supply systems.

The energy autarchy would require a wide area of solar collectors and PV panels with

resulting big storage volumes. Besides the lack of space, we also considered the plant transportation costs both in economic and environmental terms and the fuel transportation which would occur if we do not rely exclusively on renewable plants. We also considered that helicopter flights needed to deliver victuals could also be exploited for fuel transportation.
Another important requirement fixed by the huts manager is the low maintenance need of the systems. High reliability has the priority on high efficiency.

4.1 Simplified tools to assess energy performance

EURAC provided two simplified tools to prove the accomplishment of the fixed target. We modified the existing energy performance calculation tool (CasaClima version 2.3) adding weather data measured by local weather station, adjusting the load profiles according to huts manager descriptions and changing the heating period from winter to summer.
The resulting heating load is needed to calculate the share of energy consumption covered by renewable energy production. We developed an excel tool that enables designers to verify these energy targets accomplishments (Figure 2).

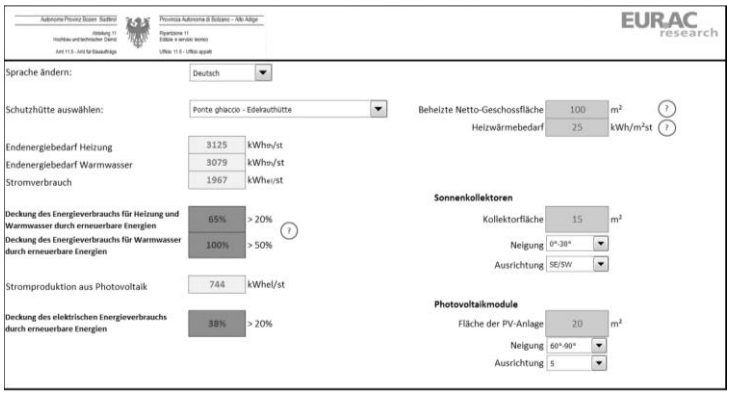


Figure 2: Excel tool to verify target accomplishment.

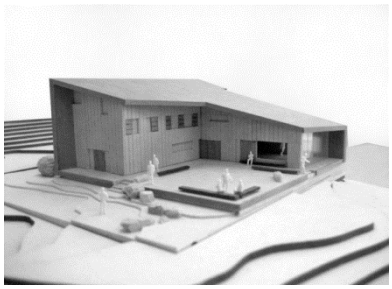
The tool requires as input the following data: net conditioned area, heating load during the activity period, total area, tilt angle and orientation of solar thermal collectors and PV panels.
We estimated Domestic Hot Water (DHW) consumption on the base of the total overnights during the hut opening season and by referring to the standard UNI TS 11300-2. Hut managers gave us indication about the kitchen electric energy consumption. Regarding lighting, we considered a power of 8 W/m² per 5 hours per day. We estimated the auxiliaries' consumption as 2% of the final energy demand of heating and DHW system.
We calculated the solar fraction of the solar thermal system by the f-chart method [7]. Solar thermal collector efficiency and losses are referred to a standard flat plate collector. We advised against evacuated tube solar collector application at high altitudes because they are more frail and need more maintenance compared to the flat plate ones.
We assessed the electric energy production of a standard mono-crystalline PV panel with 14% efficiency in the three location by means of the software PVsol [8] and using the global radiation on surfaces with different inclination and orientation calculated by Meteonorm [9]. We advise against thin film technology at high altitude applications because it is more subject to wear compared to the crystalline technology.
The energy concept guidelines recommend a combination of the following thermal system: gas micro-turbine for cogeneration, wooden boiler or solar thermal collectors with storage.
Gas micro-turbine are recommended for a decentralized use because of their almost constant efficiency in a wide range of load. Considering that the system requires fuel transportation by helicopter and produces exhaust gas emission, the turbine has to be activated only as backup.
For the electric energy production the guidelines recommend a combination of the following electric system: photovoltaic system, wind turbine, hydro turbine or cogeneration.
Due to the lack of wind data collected on site, the wind turbine feasibility and production cannot be assessed at this stage of the project.
The tender also suggests the area needed for storage tanks and batteries.

4.2 Evaluation criteria

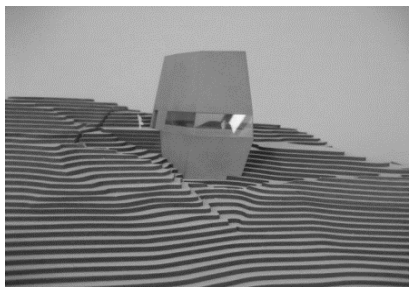
Besides the accomplishment of the tender requirements, the evaluation criteria consists of architectural quality and landscape integration (50 points), functional quality and general standard and law accomplishment (35 points), construction, maintenance and operating costs (15 points).
Even though the ranking list does not include criteria to assign points to the energy concept, EURAC evaluated each project from the energy point of view and presented the results to the Provincial Committee.
Besides the accomplishment of energy target, we evaluated the building shape and the facade layout. Big roof surfaces and solar optimized orientation are preferred. Due to the low outdoor temperature even during the summer season, compact volumes can reduce heat losses.
The position of technical services should be advantageous in order to have a good energy savings potential. The restaurant zone has the higher internal loads due to large window surfaces, the presence of visitors and the kitchen. This zone could be exploited to heat passively the night zones, if the heat losses are limited.

4.3 Results

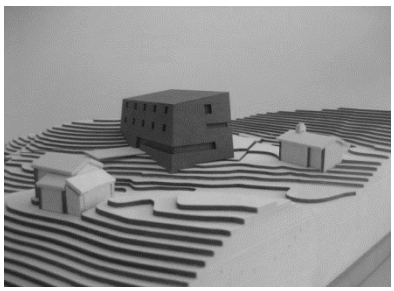
Since the design concept phase the design teams have considered energy efficiency issues. Most of the projects had a compact building shape to reduce heat losses. The design teams defined the thermal and electric energy generation systems and size the technical rooms properly in order to contain storage, batteries and system equipment.
As the huts are located at high altitudes, the landscape integration plays an essential role. Solar optimized orientation of envelope surfaces and high integration of solar systems are important design characteristics to be evaluated. Figure 3 reports the winner project models.



Ponte ghiaccio / Edelrauthütte
Arch. M.Scagnol, Arch. S, Attia



Vittorio Veneto/Schwarzensteinhütte
Arch. H. Stifter, Arch. A. Bachmann



Pio XI / Weisskugelhütte
Arch. Höller & Klotzner

Figure 3: Winner project models.

Main mistakes found from the energy point of view concern the building orientation and the compact shape. Some designers separated into two or more volumes the building isolating the restaurant zone from the rest of the spaces.
The energy concept development was no mandatory and there were no award criteria for energy requirements achieved. Therefore some design proposals had no energy concept description.
In some cases the energy requirements seemed to influence the architectural project in a not advantageous way. In some projects the restaurant zone is oriented towards the afternoon sun to have high solar loads, neglecting that a panoramic view is a high priority requirement too.

5. Negotiated tender to design a new elementary school

The municipality of Merano accepted to join the AIDA project and EURAC supported them in setting up the public design tender for a new elementary school. When the collaboration started, the public administration had already determined which kind of administrative

procedure to adopt for the design tender. The municipality decided to select the design team through a public tender for design service, also called “Negotiated tender”.
This kind of tendering process was chosen to reduce tender time and costs.
The negotiated tender rules the relation between public authorities and private companies as regard design and/or construction services and supply costs. The winner is determined by the most economically advantageous offer and by its experience (curriculum). Design teams participate at the tender without any design proposals. The winning team will deal with the preliminary, definitive and executive project and will direct the construction phase too.
Despite the tender does not demand for a design proposal, the development of an energy strategy was set as obligatory requirement. To support the design teams in this task, energy guidelines were included into the tender documents.
Therefore, the public tender is based on:

- a ‘Preliminary document for design phases’, including national and local laws (fire, acoustic, energy and structural regulation laws...), functional and dimensional requirements, energy performance targets (fixed to nZEB), budget and technical rules (for design teams) to participate in the design competition;
- energy concept guidelines to support design teams in developing energy strategies;
- evaluation criteria.

5.1 Energy concept guidelines

The energy concept guidelines consist of two parts.
The first part fixes the energy design targets and the energy performance requirements. This part explains what nZEB is meant to be, by defining the energy balance calculation method, the balance metric and weighting factors and the physical boundaries of building system [10].
The second part of the guidelines defines the rules of participation and gives instructions about the implementation mode of the required energy strategy. The tender requires an IED process and introduces the design team to this design approach.
The target, for the new elementary school of Sinigo, is the nearly zero energy one. The tender constrains the design team to follow an IED process during the design development.
The Municipality of Merano requires more restrictive energy performance requirements than the local law DP 362/2013 (see Table 1), which adopts the EPBD recast:

- energy efficiency of the building envelope with heating load lower than 30kWh/m²y (CasaClima A);
- nearly zero energy balance, using the calculation method developed within IEA SHC Task 40 project, and described in the energy guidelines of the tender.

The CasaClima certification protocol requires the proof of building envelope air tightness through a Blower Door Test and the on-site inspection of the building site by a CasaClima Agent to prove the correct realization of the execution, the absence of thermal bridges and the thickness of insulation layers. For these reasons, these actions are not mentioned in the energy section of the public design tender.
We define the nearly Zero Energy Building as a building, fulfilling CasaClima A requirements of the local EPC system and any national (DPR59/09 e s.m.i., DLgs 28/2011 e s.m.i.)/local (DP 362/2013) energy efficiency requirements, which offsets the yearly balance between generation and load (Equation 1), weighted in terms of equivalent carbon emissions. [10]
The balance has to be checked in the design phase by means of dynamic simulations.
All the energy uses of the building are considered as negative balance items: heating, domestic hot water, cooling, lighting, auxiliaries, ventilation and every kind of plug loads.
As positive balance item, only the on-site generation from on- or off-site sources can be considered, as long as the generation systems are architecturally and/or urban integrated inside the physical boundary. The physical boundary identifies so called ‘on-site’ generation systems and energy use. If a system is within the boundary it is considered ‘on-site’, otherwise it is ‘off-site’. If an energy use is within the boundary, it is included in the balance, otherwise it is not considered. The physical boundary in this case is defined as the perimeter of the urban lot, also delimited by the point of connection to the energy grid.

In order to guarantee a high aesthetic building value, the integration of energy generation systems is an important aspect which has to be taken into account from the beginning of the project. These systems can be integrated into the architectural elements of the building or in others elements located within the boundary system limits (e.g. integrated into the bus shelter of the parking area).
Weighting factors to translate final energy in equivalent carbon emissions are defined by DP 362 of 4th March 2013.

$$\sum_i g_i * w_{e,i} - \sum_i l_i * w_{d,i} = G - L \geq 0 \quad (1)$$

where:
i = energy carrier
g_i = generation of the i-th energy carrier
l_i = load of the i-th energy carrier
$w_{e,i}$ = weighting factor for exported i-th energy carrier
$w_{d,i}$ = weighting factor for delivered i-th energy carrier
G = weighted generation
L = weighted load

The design team is also committed to follow an integrated energy design (IED) process.
Thanks to the AIDA project EURAC team will support the design team during the preliminary and definitive design phases. Specific meetings and workshops will be organized to actively support the evaluation of energy performance and indoor comfort through energy simulations.
Design teams have to present the energy concept in a report, their experiences and abilities in applying energy efficient solutions through a list of references. The school contains spaces with different functions, use patterns and comfort requirements: classrooms, gym and library. Therefore the energy concept can consider more than one conditioning system typology and/or different management systems. For this reason the tender requires the presence of an Energy Adviser/Certifier in the design team, with experience in energy efficient planning..

5.2 Evaluation criteria

The evaluation criteria consist of design architectural proposal, dimension, cost, urban integration, innovation, quality, functional aspects and daylight of connections areas (30 points), and law accomplishment construction, maintenance and operating costs, criteria to achieve nZEB target, experience of the Energy Adviser/Certifier and design team curriculums (30 points). The design team has to deliver a description of the energy strategy (passive and active solution), planned to reach the fixed energy targets through a technical report (6 points).
The tender deadline is the 22nd of May 2013. Thanks to AIDA project, we will join the jury to evaluate the energy strategy reports.

6. Conclusions

The paper shows two local experiences about energy performance requirements integration into public tenders. The legislative procedures of the tenders are totally different. The first experience (mountain huts) regards a restricted design tender which aims at finding the best design proposal within a restricted number of projects. While the second experience regards a negotiated tender (elementary school) which only aims at selecting the design team. This difference has influenced the way energy performance requirements are included into the tender. In the first case (mountain huts) energy guidelines and supporting tools are integrated in the tender and the design team has to demonstrate that the fixed targets are

reached. In the second case the energy guidelines are part of the tender to define the method that the winning design team has to use to reach the fixed targets.
In both cases the IED process is considered a necessary approach to increase the quality of the design proposal, from aesthetic, functional, energy efficiency and economic point of view. The IED main advantage is the achievement of the performance targets defined in the tender (e.g. nearly zero or zero energy balance, high level of indoor comfort, economy, functionality, aesthetic impact, etc.). The management of an IED is not always easy, because it involves different professionals that have to communicate with each other. For this reason it is necessary to identify a figure able to manage the design process and facilitate the design team meetings.
Results of the mountain huts case, show how the buildings have been shaped to allow the climate potential exploitation and to optimise renewable energy production. The design support activities and the collaboration with municipalities are still ongoing to follow the whole Integrated Energy Design Process.

7. Acknowledgements

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8. References

[1] EUROPEAN PARLIAMENT “*Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)”.* Official Journal of the European Union, 2010, 19 May 2010.

[2] N. LARSSON,. B. POEL, *“Solar Low Energy Buildings and the Integrated Design Process – An Introduction”*. IEA-International Energy Agency, 2003.

[3] “*The Integrated Design Process in practice - Demostration Projects Evaluated,”* June 2003.

[4] J. COLE, M. HATTEN, *“Integrated Energy engineering & performance modeling into the design process*”. Betterbricks: http://www.betterbricks.com.

[5] J. KURNITSKI, F. ALLARD, D. BRAHAM, G. GOEDERS, P. HEISELBERG, L. JAGEMAR, R. KOSONEN , J. LEBRUN, L. MAZZARELLA, J. RAILIO, O. SEPPÄNEN, M. SCHMIDT, M. VIRTA, *“How to define nearly net zero energy buildings nZEB,”* REHVA European HVAC Journal, vol. 48, May 2011.

[6] “*Schützhüttenwettbewerbe,”* Turrisbabel, vol. 91, 10-2012.

[7] B. W. DUFFIE J.A., *Solar Engineering of Thermal Processes*, John Wiley and Sons, 1991. ISBN-13: 978-0471698678.

[8] PV*SOL, “*Valentin Software - Solar Design software,”* 2012. [Online]. Available: http://www.valentin.de/en.

[9] Meteonorm software, Meteotest, 2012. [Online]. Available: http://meteonorm.com/.

[10] I. SARTORI, A. NAPOLITANO, K. VOSS, *“Net zero energy buildings: A consistent definition framework”.* Energy and Buildings, vol. 48, p. 220–232, January 2012.

[11] B. PERKINS, WILL STANTEC CONSULTING, *“Roadmap for the integrated design process”* in Part one: summary guide, BC Greenbuilding Roundtable.

[12] *“Collaboration, Integrated Information, and the Project Lifecycle in Building Design, Construction and Operation”*. CURT. 2004.

[13] K. Voss, I. Sartori, R. Lollini *“Nearly-zero, Net zero and Plus Energy Buildings - How definitions & regulations affect the solutions”*.REHVA Journal, pp. 23-27, December 2012.

[14] “Collaboration, Integrated Information, and the Project Lifecycle in Building Design, Construction and Operation,” CURT, Construction Users Roundtable, 2004

D4

Sustainable Assessment

Chair: Rolf Bohné
Norwegian University of Science and Technology, Norway

Realising Blue Buildings?- Life Cycle Management as an integrated management philosophy for blue building projects



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1. A new focus for Blue Buildings

The core question to be discussed seems to be rather basic but difficult: What is a sustainable success of a building? Green buildings reached already a high standard of ecological and technical know-how integrated. Blue buildings suffer from a missing common understanding. They are assimilated with the optimized life cycle costs. Every company would not be satisfied if its economic success was only measured at the expenditure. You have to take the earnings into account too. In future a holistic statement on the long-term success of a building needs to integrate life cycle costing on the one hand which covers the total investments and earnings out of rental income and sale proceeds over the life cycle on the other hand. Sustainable success can then be defined as the optimized mix of minimizing the (life cycle) costs and maximizing the value of the building.

Keywords: Life Cycle Management; integrated design; Blue buildings; value and earnings, controlling of sustainablity.

2. Requirements of Blue Buildings

In construction project management the main goal was to realize the project in the shortest time, at minimum (investment) costs and in the best quality. Today buildings demand to be “green” and “blue” what means to be ecological and economical sustainable. Already the project development faces these new challenges and the change of behaviour of investors and users which occur out of a rising consciousness on the relevance of the operation phase and its costs.

The main question is how to realise the ideas of blue building. What are the main aspects and criteria of blue buildings and what management issues do we have to focus on?
The management philosophy Life Cycle Management in construction is the sustainable way to cope with these new requirements. The core skills of professional construction project management have to be extended with expert knowledge of life cycle oriented design and build.

3. Efficient ways to Blue Buildings

Out of the practical experience there are five main Life Cycle Management aspects which lead to blue buildings and which are presented in more detail:

(1) Focus on life cycle costs instead of investment costs and additionally have the value and the earnings in mind as basis for all relevant decisions

(2) Use systematically experiences out of the operation phase during project development and design and integrate the learnings in the organisation and in design & construction contracts.

(3) Develop a maintenance program for the 2nd and 3rd life cycle in early project phases to enlarge the lifespan and integrate the requirements in the building concept and design.

(4) Apply (long-term) Opportunity and Risk Management in the whole project development process for a continuous project optimization.

(5) Controlling Systems for sustainability to ensure, that the concept of blue building is realized effectively

3.1 Focus on life cycle costs instead of investment costs and additionally have the value and the earnings/income in mind as basis for all relevant decisions

A deeper view on the economic approach of sustainability shows that with the determination of life cycle costs already the impact of the whole life cycle is taken into account. That seems to be sufficient. But sustainability should lead us further to a holistic approach which includes the perspective of investment and earning out of the recovery of the property. There might be economic advantages, if an investor invests more investment costs and even more life cycle costs, if the earnings increase bigger. It will be discussed which investments make sense in a long term examination.

The ISO 15686-5 [1] defines the whole-life cost. They cover the life-cycle cost (LCC) as well as externalities and income. The LCC are divided into the main cost groups construction, operation, maintenance and end-of-life. A sharp demarcation between externalities and environment cost is hard to line in practise. (Find out more at [2])

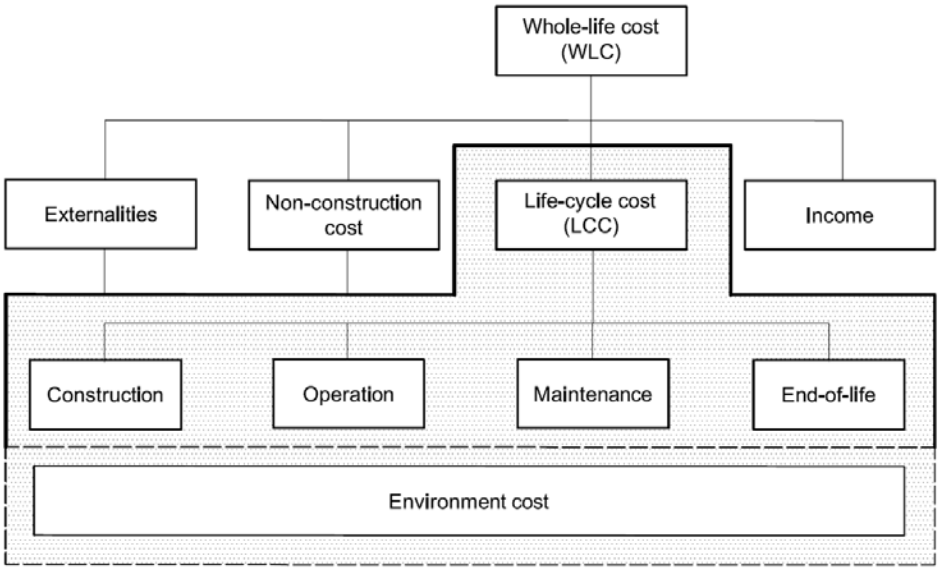


Fig. 1 Whole-life cost - ISO 15686-5 [1]

Focus on life cycle costs

An essentiell decision indicator for realising building projects remains the question of the real arising costs. The consideration only of the investment cost represents just a short-term truth of cost. An actual truth of costs over the entire life cycle can only be reached under the consideration of follow-up costs.

Various analysis of life cycle costs show that investment costs make up only a small proportion of the total life cycle costs (around 15 to 50 per cent depending on the type of object, use and estimated lifetime regarded). Therefore, the total cost planning needs a specific focus on the follow-up costs. The structure of the follow-up costs is detailled in the new Austrian Standard B 1801-2 [3] and can be used as the default for all life cycle cost determinations.

1 administration	administration and management / fees and taxes / space management
2 technical operation	technical building management / inspections, maintenance / small repairs / commissioning, decommissioning
3 supply and disposal	energy (heat, cooling, electricity) / water and sewage / waste disposal
4 cleaning and care	maintenance cleaning / window and glass surface cleaning / facade cleaning / special cleaning / winter service / cleaning public spaces / gardener service
5 security	security services / fire protection services
6 building services	house post / communications and information technology / removals / reception, internal office services / catering
7 repair, modification	major repair / improve, conversion
8 other	other
9 object removal / demolition	planning and organization / demolition and disposal, building the contract state (construction law, easement)

Fig. 2 structure of follow-up costs [3]

Due to the authors' point of view this overview has to be expanded towards financing costs, if the LCC-calculation is meant to determine e.g. the requirement of finances, a liquidity plan or an economic (respectively for tax purposes) result over a specific period.

For an effective cost steering using the life cycle costs it is absolutely necessary to identify the real cost drivers early. Only with this consciousness an ongoing project optimization can start from the very beginning.

A central influence on the determined life cycle costs is the assumed lifetime of the building. The following picture shows an example that makes this influence on the magnitude of the different cost groups pretty obvious.

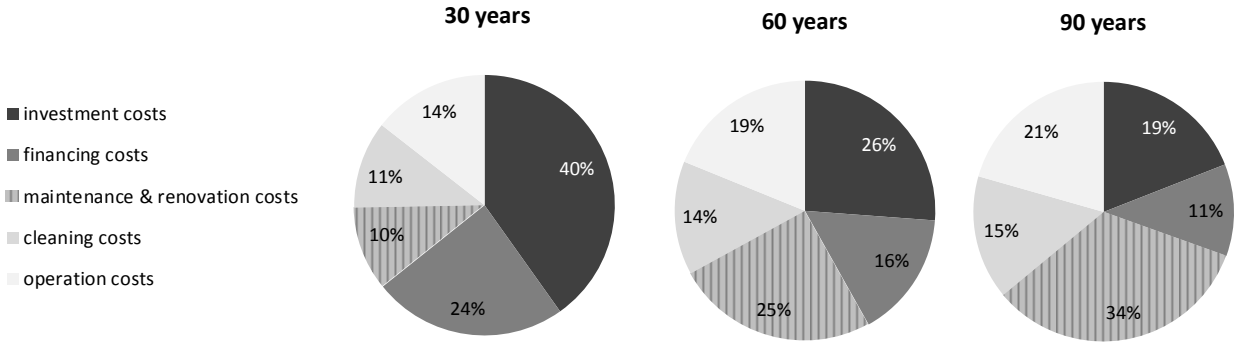


Fig. 33 Makeup of the essential cost parts of the LCC depending on the assumed lifetime [6]

The longer the lifetime is assumed for the cost planning, the higher the time-dependent cost parts like operation and cleaning carry weight. The repair and modification costs rise proportional to the number of operation phases. While in the 30 years consideration virtually maintenance costs are minimal and no modification costs arise, there are extensive repair and renovation / alteration costs for one modification in the 60 years consideration and for two modifications in the 90 years consideration.

So it is simply apparent, which cost components are crucial for a sustainable project success. One of the logical consequences is the focus of all project planning at this cost factors, with the following questions toanswer:

- How can the object be cleaned with minimal effort? (e.g. surfaces inside, facade)
- How can the object be adapted with minimal effort to new user requirements? (eg flexible structures, interchangeable surfaces, upgrading your building services and electric)
- How can the individual components are repaired with minimal effort, bearing in mind that repair work must be carried out at the same time? (Exchange of detailed planning account)
- How can the costs for the technical operation of the building are minimized, especially the staff costs for maintenance and repairs? (Low tech building, simple controls, flexible interfaces)

Consideration of value and earnings / income of the building

The economic success of buildings usually doesn't depend only on the life cycle costs, but also on the earnings from rent, a possible sale or the value of a property. Especially if real estate should be used economically by the owner, the mere consideration of the cost perspective is not enough.

Therefore, the total cost planning should involve the earnings as well including the estimation of possible income or sales proceeds (at different times). Because it can bring quite an economic benefit to invest more in certain parts of the life cycle costs when the earnings can be raised. Successful project developer and operator know exactly which investment in operating affects an increased income and which one will only increase the cost side.

An example will make this theory obvious. The economic lifetime of the surfaces in hotels is getting shorter and shorter; the level of quality is not a warranty for very much longer lifetimes. The best way seems to be to plan simple and cheap measures with a long-term focus, realize them with only a short interruption of the operation and reach the illusion of a true renewal. Than the demand can be increased again which improves the economic results.

In conclusion the author recommends a long-term prognosis that goes over several operation phases and at least 60 years. It compares the life cycle costs including the financing costs to all

possible earnings (taking into account the tax aspects). On this database solid decisions with a holistic life cycle aspect can be made.

3.2 Use systematically experiences out of the operation phase during project development and design and integrate the learnings in the organisation and in design & construction contracts.

While construction project management concentrates mainly on the phases project development, design and build, Life Cycle Management means focusing on all project phases. The whole life cycle of a building - from the start of project development to construction and operation, if necessary alteration and finally demolition respectively recycling of the building - is taken into account. Furthermore a first operating phase (lifetime e.g. 20-30 years) is followed by a second one (till the end of the life cycle) after alteration or altered utilization. Therefore the experiences and knowledge from these phases (operating, alteration and subsequent use) should be used in early project phases.

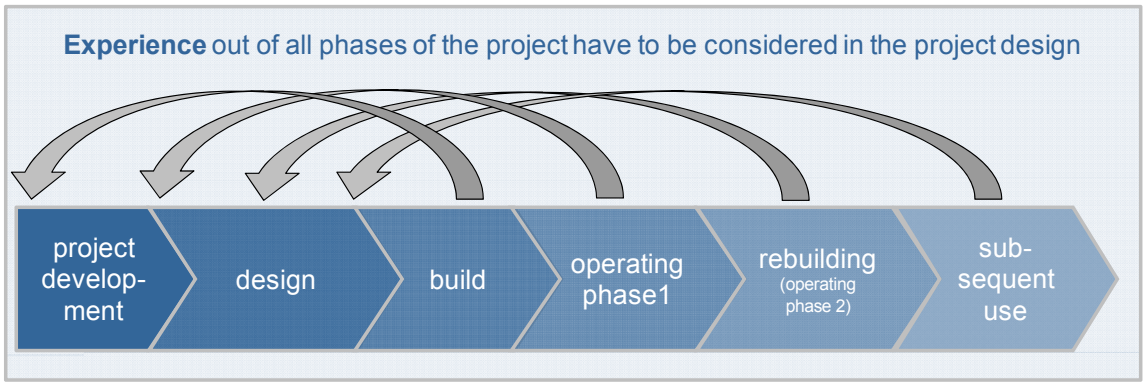


Fig. 4 Experience out of all project phases have to be considered in the early project design [10]

The basically clear demand for optimal use of experience from later phases turns out to be a real organizational challenge in regard to its actual implementation. Depending on the respective form of organization, in many cases the specific operator of the construction project may not be known at the planning phase. Therefore most often an architect whose draft has already set the relevant course is entrusted with the design and further planning process. Subsequent designers and consultants of different special fields can only develop a suitable solution according to these basic conditions.

The Integrated planning team offers a solution-oriented approach. There at a very early stage (project development, pre-draft phase) the entire planning (design) is carried out by a team that involves not only an architect and a structural engineer, but in particular also consultants in the areas of building services engineering, electrical engineering, energy technology, building physics, acoustics, façade construction and depending on the type of project further specialists (e.g. company organization, kitchen designer,).

A key role is transferred to the Facility Management Consultant who provides the experience from the building operation and within the range of facility planning can ensure that the building functions are economically in operation.

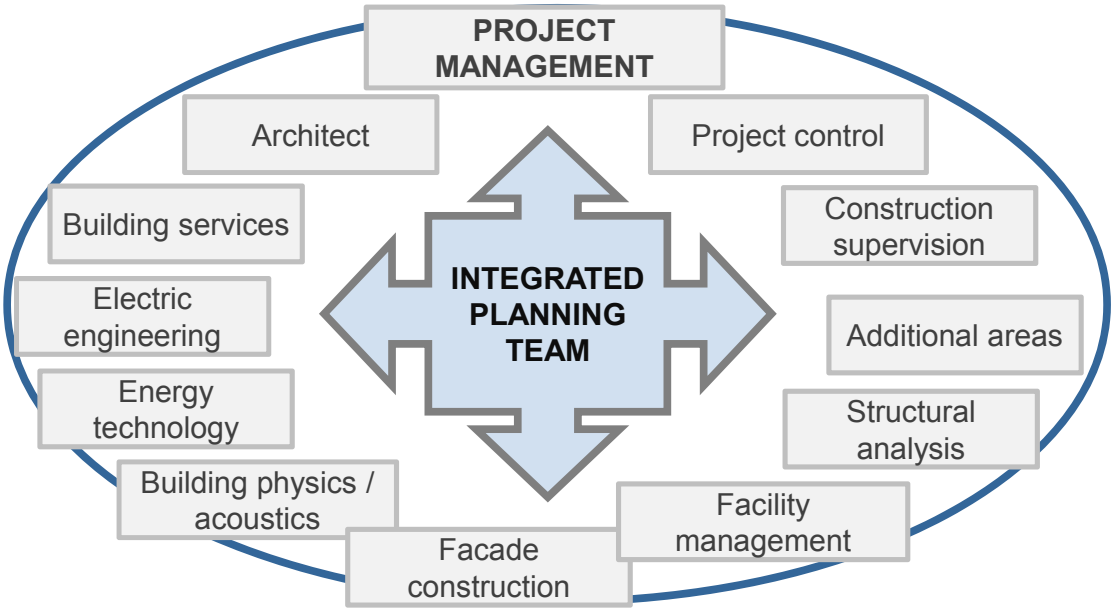


Fig. 5 Integrated planning team [4]

In order to be able to consider relevant experience from the construction phase during the planning phase, in particular concerning the realization of building contracts (e.g. accounting or deviations from specifications), the construction supervision should take an active part already in the phase of preparation, when the specifications and the bill of quantities get established.

An optimal involvement requires the development of a structured process for the progressive introduction of the individual specialists. “At the earliest stage possible” does not necessarily mean that all participants have to meet immediately. Since some specialists need first drafts or the preliminary design before being able to evaluate functionality and profitability, they have to get integrated step by step.

Furthermore, an intensive coordination among consultants and any additional tasks in the course of the joint project optimization have to be taken into account in the scope of work and determination of fees of service agreements.

Another challenge is the development of contracts for all participants, which support the ideas of Life Cycle Management and motivates all participants for project optimization during the whole planning process.

3.3 Develop a maintenance program for the 2nd and 3rd life cycle in early project phases to enlarge the lifespan and integrate the requirements in the building concept and design.

A maintenance program is an important tool to optimize the investments for maintenance, repair, overhauling and services. If the focus is on a 2nd and 3rd life Cycle (that means 60-90 years) and not only on 20-30 years, the importance of maintenance - including alteration - is evident. The experience shows that with this new view the design process and the questions to be answered have to be modified.

Maintenance Program

A Maintenance Program summarizes all measures in a long-term activity plan which are essentiell for the building conservation. In particular, the regular servicing and scheduled maintenance can

significantly affect the life cycle cost. Regular servicing can prevent minor defects to become larger (and thus more expensive to remedy) ones. Out of this thinking it can be derived that a higher investment in the servicing reduces the maintenance costs allocated over the lifetime of the induvidual elements. However, attention should be paid to the interaction between cost and lifespan. Higher servicing costs can extend the maintenance cycles, higher repair investments can prolong the lifetime. The requirement for this is to consider the conditions (market, use options) for the economic lifetime.

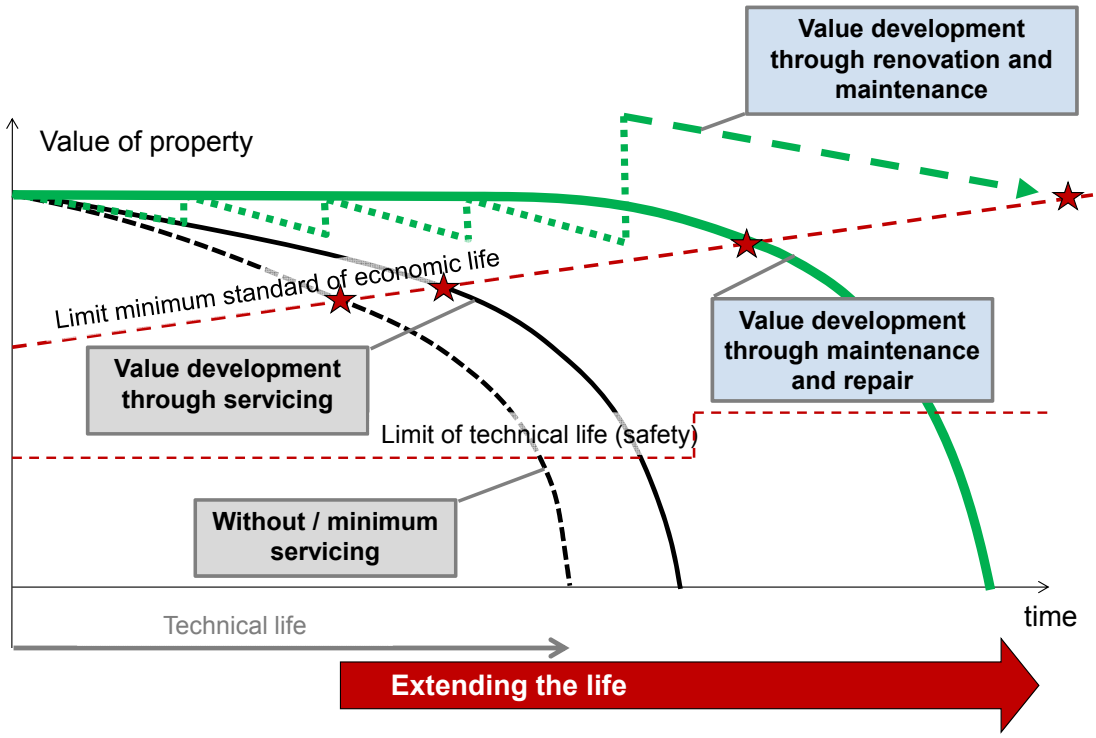


Fig. 6 Dependences between servicing, maintenance and lifetime [11]

The figure 6 shows very clearly that the economic success of a property depends heavily on the extent, kind and timing of appropriate maintenance and repair measures. The best property is always the one that enables the existing substance, the maximum useful service life.

As discussed in chapter 3.1 the maintenance costs are the biggest cost part when based on a long lifetime of the property. In future designers also has to answer these critical questions:

- How can measures for maintenance and repair be implemented?
- How could the building services & electrical engineering be extended and adapted to new user requirements?
- How can the cleaning be done effectively?
- How simple could building functions be adapted to new user requirements?
- What are the options for a conversion?
- How would certain reconstruction scenarios implementable?
- How could a deconstruction of individual components take place?

3.4 Apply (long-term) Opportunity and Risk Management in the whole project development process for a continuous project optimization.

Active Risk Management allows identifying risks early and ensures in the implementation of measures to avoid and reduce risks in sufficient time. Life Cycle Management considers not only risks during design and construction but also during operation and alteration.
Active Opportunity Management ensures that optimization and cost-reducing potentials are efficiently utilized.

Risk Management is a substantial tool of Life Cycle Management. Risk Management meets the demands and copes with the challenges of Life Cycle Management by means of suitable models, methods and responses. In order to cover an overall perspective for the statements, Risk Management simultaneously uses Opportunity Management. It works at all levels from objectives to operative implementation of building projects and integrates the results into all levels in turn. In order to achieve an application quality as high as possible, there is a need for a thorough awareness of risk philosophy and a high understanding for influences, ability to influence, sensitivity, quality of information (statements), dynamics and strategic range of the results.

Risk Management integrates practical experience, scientific research and trend analysis for the forecast to build scenarios out of different perspectives.

- It is not only about finding a right figure – for example the total investment or life cycle costs,
- it identifies the main issues,
- it shows the main aspects which have to be managed,
- it specifies measures that have to be taken,
- it creates a system for dependences and sensitivity,
- it detects time risks and uncertainties of the schedules,
- it implements opportunities and optimization potentials and
- it evaluates the knowledge from other projects.

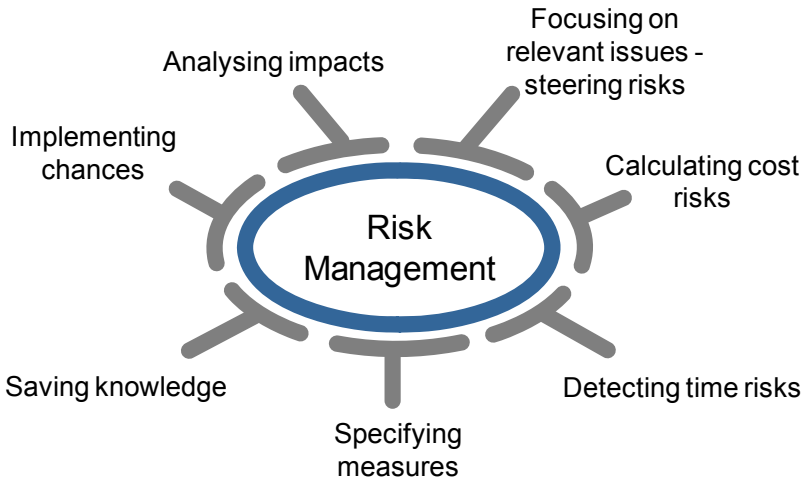


Fig. 7 Elements of Risk Management [11]

The main achievement of Risk Management is the increased reliability in design, costs and schedules. For Life Cycle Management it means an improvement of the whole design process and the output. Risk Management is the main tool to animate Life Cycle Management.

3.5 Controlling Systems for sustainability to ensure, that the concept of blue building is realized effectively

Sustainability and the blue building philosophy is part of the objectives of most real estate projects nowadays. To ensure that this is not just an add-on in the marketing brochure controlling tools are necessary. To achieve sustainable buildings the implementation of controlling tools in all project phase from the preliminary phase to the operation is essential.

Quality control from the project definition to the use

The ability to define quality is easier at the project start. It decreases from phase to phase. For a building project this quality definition should not begin with the building process but at the rather project start like all definitions of aims. In contrast, the control activity increases from phase to phase until it finds the peak of control at the project completion. Afterwards the control activities focus on the use and operation.

Integrated building certification systems represent an ideal system to develop the quality of a building in terms of sustainability (ecological, economic, social) and to examine the requirements for implementation. On one hand the comfort of the user and on the other hand the resource efficiency of the building are assessed in the life cycle. Building Passes serve clients as quality assurance and marketing tool as well as economic and ecological optimization tool. The customers get an objective assessment of housing and building quality. The application of such a principle is more relevant than the decision on a specific type of such a system. The major advantage arises only through the comprehensible definition from quality so it gets controllable and also comparable.

Practical experience from the application of certification systems as quality controlling tools

Public buildings of the province of Vorarlberg provided the analysing base for the development of a quality control system which is built up on the “Kommunalgebäudeausweis” (municipal building ID), a building certification system for sustainable properties. The quality control system deploys the options of an ongoing control and a control in particular after each project phase to compare the definitions of sustainable objectives with the implementation in real. If there are deviations countermeasures can be set in time. The documented results deliver a confirmation of the order and its specifications. The client gets more reliability of the defined quality standards. [13]

With the implementation of a quality control system for sustainability following aspects may be considered:

- Ensuring the implementation of the company's philosophy in terms of sustainability in all building projects
- Specifying the quality objectives more detailed by the definitions in the context of the certification system
- Ensuring the achievement of the quality objectives by the ongoing evaluation and early identifying deviations
- Possibly using the results for the marketing

4. Conclusions

The authors’ experience, e.g. from successfully implementing various project management and Life Cycle Management systems, provide the following success factors for developing and constructing sustainable building projects:

(1) Focus on life cycle costs instead of investment costs and additionally have the value and the earnings in mind as basis for all relevant decisions
(2) Use systematically experiences out of the operation phase during project development and design and integrate the learnings in the organisation and in design & construction contracts.
(3) Develop a maintenance program for the 2nd and 3rd life cycle in early project phases to enlarge the lifespan and integrate the requirements in the building concept and design.
(4) Apply (long-term) Opportunity and Risk Management in the whole project development process for a continuous project optimization.
(5) Controlling Systems for sustainability to ensure, that the concept of blue building is realized effectively

One does professional Life Cycle Management, if all above mentioned demands are met in a satisfactory manner.

5. References

[1] ISO 15686-5 2008 Building and constructed assets – Service Life planning, part 5 Life cycle

costing
[2] DZUBAN P.: *„Ganzheitliche Kostenplanung im Bauwesen unter Berücksichtigung der Externen Kosten“*, Diplomarbeit, FH JOANNEUM Graz, 2011
[3] Austrian Standards Institute / Österreichisches Normungsinstitut (ÖN): ÖNORM B 1801-2 Bauprojekt- und Objektmanagement, Teil 2 Objekt-Folgekosten, 04/2011, Wien
[4] STEMPKOWSKI R.: *„Life Cycle Management, Modul 01, LCM-Bau – Nachhaltiges Bauprojektmanagement“*, Danube University Krems, 2012
[5] STEMPKOWSKI R.: *„Lebenszykluskosten“*, lecture, FH Campus Wien, 2012
[6] STEMPKOWSKI R.: *„Strategie und Umsetzung von Life Cycle Costing“*, Netzwerk Bau Nr. 18, 2013
[7] STEMPKOWSKI R.: *„Life Cycle Management – ganzheitlicher Management-Ansatz für die Baubranche“*, Netzwerk Bau 09, 2008
[8] STEMPKOWSKI R.: *„Life Cycle Management - erfolgreiche Umsetzung“*, Netzwerk Bau 14, 2011.
[9] STEMPKOWSKI R., STURM P.: *„Due Diligence für Bauprojekte unter Berücksichtigung ganzheitlicher Bewertungsaspekte*“, WINGbusiness, Volume 04, 2011
[10] STEMPKOWSKI R., WALLNER-KLEINDIENST M.: *“LCM - Life Cycle Management, Integrated management philosophy for building projects”*, Proceedings IALCCE 2012 – International Symposium on Life-Cycle Civil Engineering, Vienna 2012
[11] STEMPKOWSKI R., WALDAUER E.: Risikomanagement Bau, Netzwerk-Der Verlag, 2013
[12] STEMPKOWSKI R.: *„Ganzheitliches Life Cycle Management in der Praxis – und zahlen sich Blue Buildings überhaupt aus?“*, Lecture, Immobilien Forum West, 2012
[13] Schatzmann M.: *„Qualitätsmanagement für Nachhaltigkeit - Baumanagement für nachhaltige Gebäude des „Landes Vorarlberg““*, Fachzeitschrift Netzwerk Bau, Nr. 18, 2013

Benchmarking of DGNB-Certified Buildings in Austria



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Short Summary

Since 2010 the Sustainable building certification system DGNB is in use In Austria. The Austrian Sustainable Building Council (ÖGNI) was founded in 2009, cooperates with DGNB-Gemany and adapted the German certification system for sustainable buildings to Austrian conditions [1]. This paper focuses on the results of sustainable building certifications in Austria in order to obtain benchmarks for the future development of the assessment system. The certification body of ÖGNI controls the quality of the submitted building audits. The plausibility and the conformity with the documentation guidelines and the evaluation system are verified. Meanwhile, about 50 buildings were certified by ÖGNI.

This paper presents the results of the first building certifications. Several outstanding office buildings are presented. A statistical analysis of the results of all evaluation criteria was performed and evaluated anonymously. The results show, which criteria were easy to fulfil and which were hard to meet. Conclusions concerning further development of the evaluation system are derived. Special emphasis is laid on benchmarks for ecological and technical criteria. Furthermore recommendations for a higher transparency of the results are made.

Keywords: ÖGNI; DGNB; Sustainable building certification; Benchmarking

1. Introduction

The DGNB/ÖGNI Certificate is a transparent and comprehensible rating system, which is based on the CEN/TC350 approach. It defines the performance of buildings in a comprehensive way – with 5 plus 1 topics, and enables auditors to conduct an evaluation systematically and independently. The building's performance, by reaching a defined degree of performance, is assigned a bronze, silver or gold award. Furthermore, grades are given for the total performance of the building as well as for the individual topics.

The DGNB/ÖGNI certification scheme criteria-set includes five weighted topics (main criteria groups): Ecological Quality (22.5%), Economic Quality (22.5%), Socio-functional Quality (22.5%), Technical Quality (22.5%), Quality of Process (10%) and one additionally not weighted, separately evaluated topic – Quality of the Location [2].

Each of these topics is divided into several assessment criteria. For instance, the Global Warming Potential, Total Primary Energy Demands and Proportion of Renewable Primary Energy, Thermal Comfort in Winter and Summer or Energetic and Moisture Proofing Quality of the Building's Shell are considered for the evaluation of a building. For each criterion, measurable target values are defined, and a maximum of 10 points can be assigned. The measuring methods for each criterion are clearly defined.

2. Methodology

The objective of this investigation was to learn from the first certified buildings for the development of the assessment system. Meanwhile, about 50 buildings were certified by ÖGNI and an update of the assessment system is developed currently. Therefore the results of DGNB/ÖGNI certificated buildings have been analysed in order to derive conclusions for a fine-tuning of the criteria set and the benchmarks.

The investigation includes 18 certified offices buildings that had been certified between 2010 and 2013. Data has been derived from ÖGNI and the results are presented anonymously. For each criterion the results are presented in ascending order and additionally the arithmetical mean value of all 18 buildings is shown.

3. Results

Six office buildings achieved a Gold-Certificate, eleven buildings a Silver-Certificate and one building a Bronze-Certificate.

The results (figure 1) show the percentage of the performance value. With an overall performance of more than 80 % a Gold-Certificate is achieved and with an overall performance of more than 65 % a Silver-Certificate is achieved.

The highest results in average were achieved for economical quality (89 %). The lowest results in average were achieved for process quality (65 %) which is due to the introductory phase of DGNB-Certification in Austria. For the first certified buildings the decision for certification was made in a relatively late project stage and therefore the criteria concerning earlier project stages couldn’t be influenced or improved.

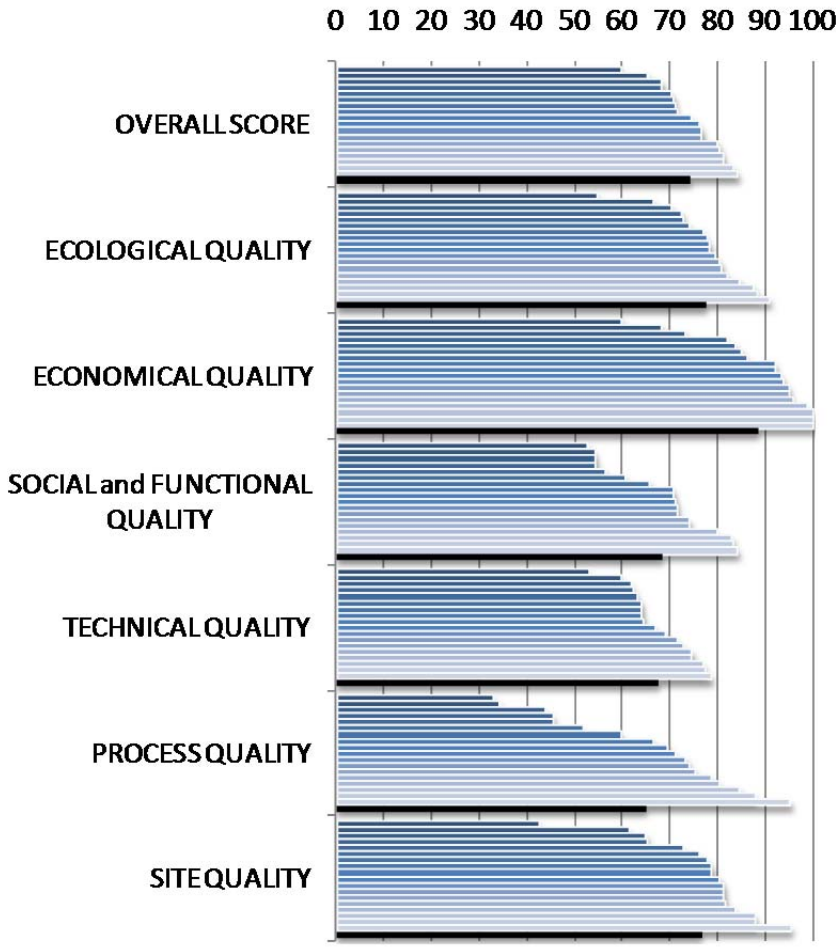


Fig 1: Overall Score and partial results of 18 selected office buildings. Single results and mean value (black bar)

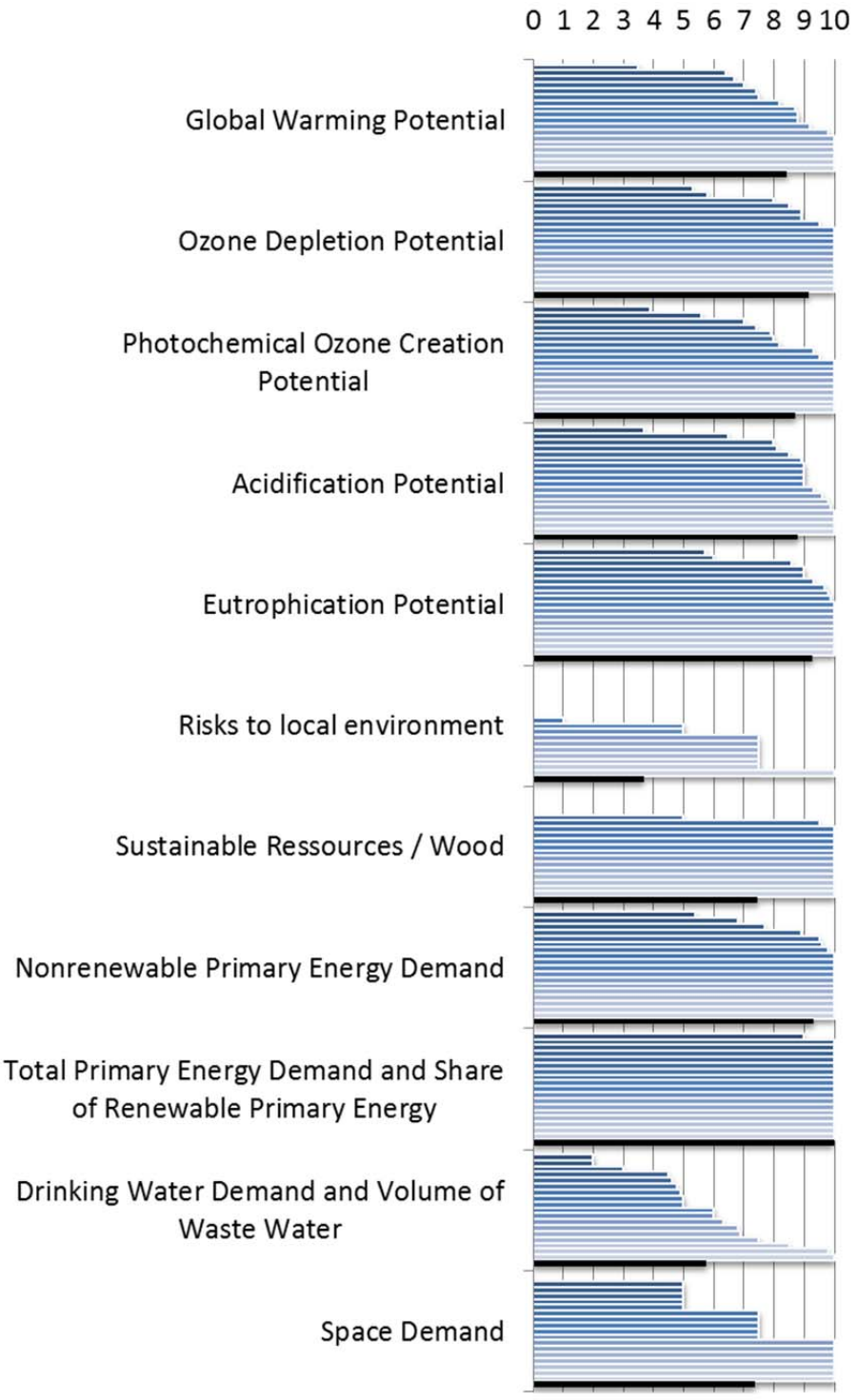


Fig 2: Results for ecological quality. Single results and mean value (black bar)

For ecological quality the highest results in average were achieved for the combined criterion “Total Primary Energy Demand and Share of Renewable Primary Energy” (9.9 assessment points of 10 possible points). The lowest results in average were achieved for “Risks to local environment” (3.7 points).

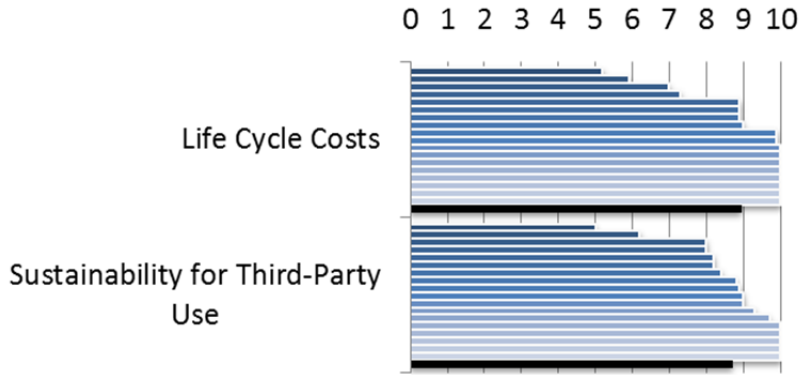


Fig 3: Results for economical quality. Single results and mean value (black bar)

For economical quality very high results in average were achieved for “Life Cycle Costs” (8.9 points).

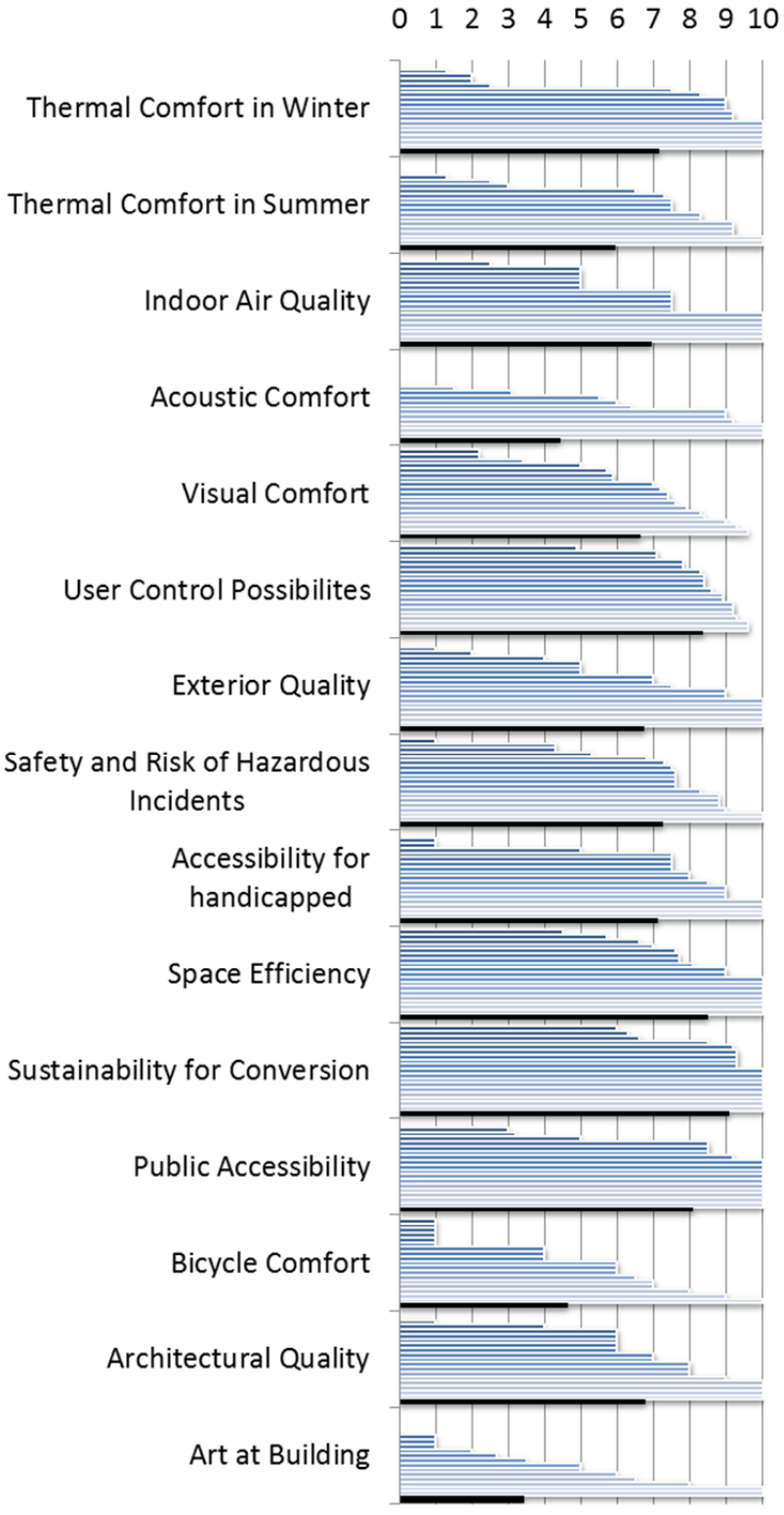


Fig 4: Results for socio-functional quality. Single results and mean value (black bar)

For socio-functional quality the highest results in average were achieved for “Sustainability for Conversion” (9.1 points), “Space Efficiency” (8.5 points) and “User Control Possibilites” (8.4 points). The lowest results in average were achieved for “Art at Building” (3.4 points), “Acoustic comfort” (4.4 points), “Bicycle comfort” (4.6 points) and “Thermal Comfort in Summer” (6.0 points).

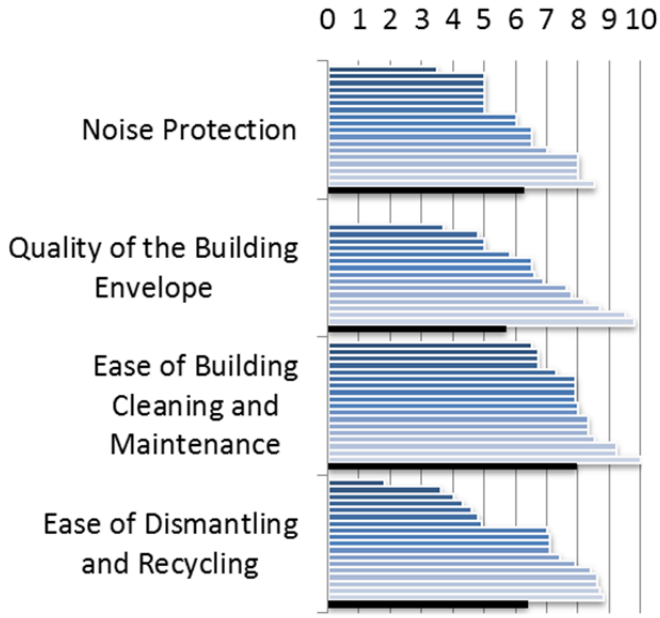


Fig 5: Results for technical quality. Single results and mean value (black bar)

For technical quality the highest results in average were achieved for “Ease of Building Cleaning and Maintenance” (8.0 points). The lowest results in average were achieved for “Quality of the Building Envelope” (5.7 points). The criterion “Fire Protection” was not investigated because it was not mandatory in the introductory phase of DGNB-Certification in Austria.

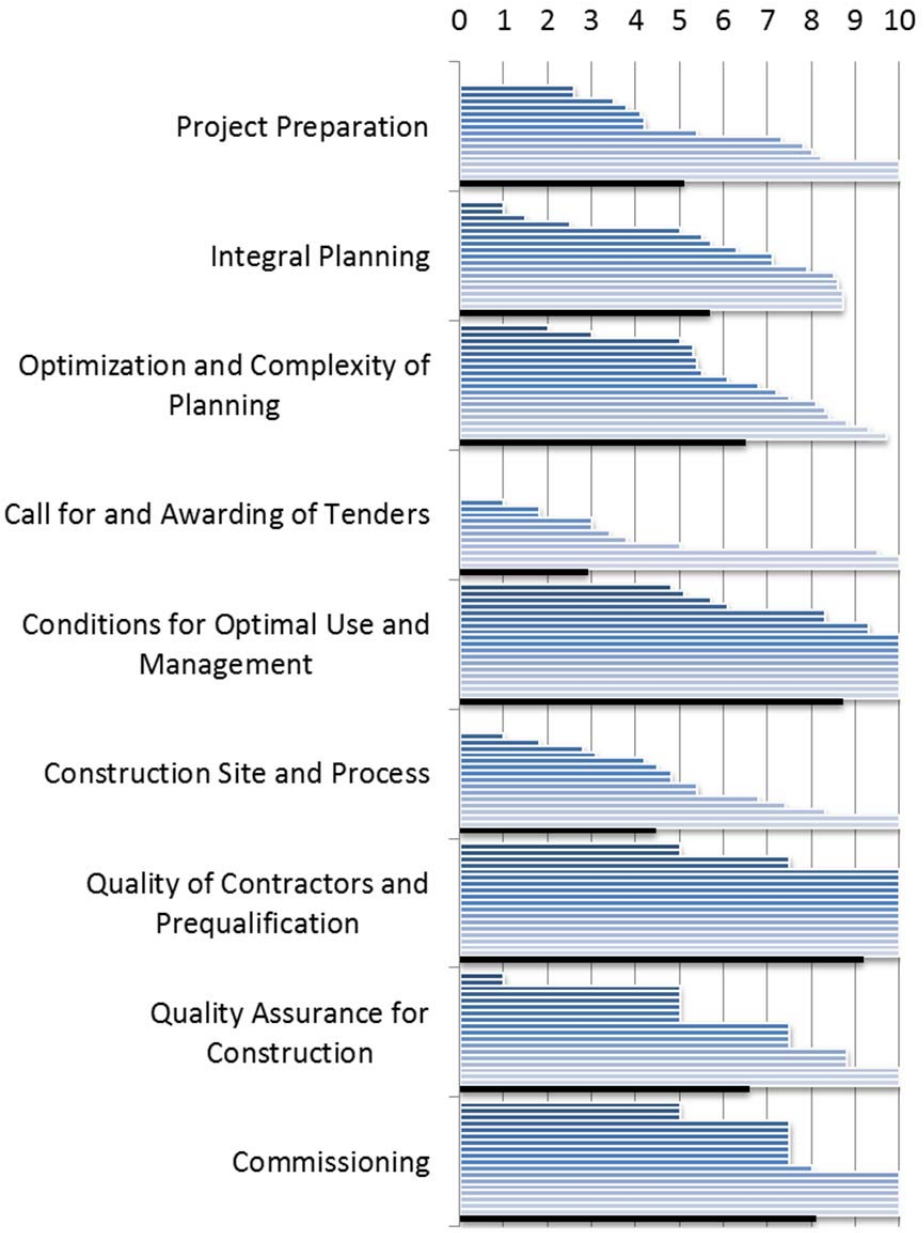


Fig 6: Results for process quality. Single results and mean value (black bar)

For process quality the highest results in average were achieved for “Quality of Contractors and Prequalification” (9.2 points) and “Conditions for Optimal Use and Management” (8.7 points). The lowest results in average were achieved for “Call for and Awarding of Tenders” (2.9 points), “Construction Site and Process” (4.5 points) and “Project Preparation” (5.1 points).

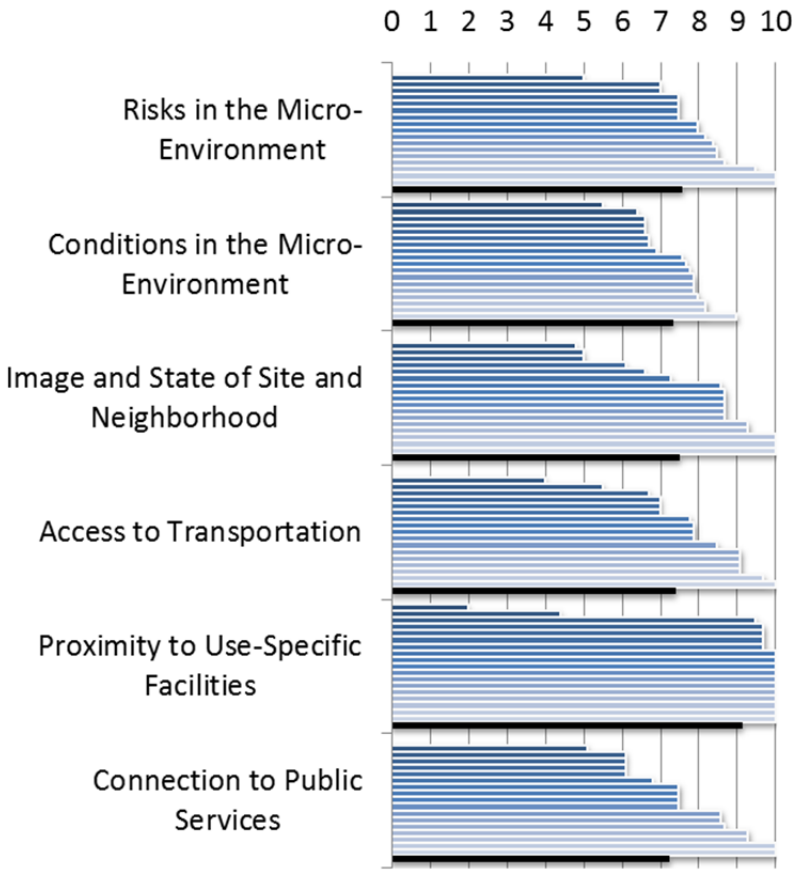


Fig 7: Results for site quality. Single results and mean value (black bar)

For site quality the highest results in average were achieved for “Proximity to Use-Specific Facilities” (9.2 points). The other criteria also achieved relatively high values in average (7.3 to 7.6 points).

4. Conclusions

In average relatively high results were achieved for most of all criteria groups and many criteria. Single results generally vary a lot for nearly all criteria and that proves that the assessment methodology is generally very suitable.

For many buildings in the introductory phase of DGNB-Certification in Austria the decision for a Certification was made relatively late in the project stage. Therefore some criteria of process quality couldn’t be influenced or improved. The results for process quality showed the biggest variations. It is assumed, that future certifications together with early decisions should show higher values for process quality.

Most of the buildings achieved relatively high results for the criteria concerning environmental life cycle assessment (LCA), especially concerning for the combined criterion “Total Primary Energy Demand and Share of Renewable Primary Energy”. Meanwhile, in the updated German DGNB system, this combined criterion is split into two separate assessments. The new structure of the German DGNB system will be adopted in Austria as well and the benchmarks for “Share of Renewable Primary Energy” will be adjusted to Austrian objectives considering the high share of renewables in the Austrian electricity mix.

For the update of the Austrian system the results of the LCA are currently analysed more in detail in order to adjust the benchmarks. Many buildings achieved better LCA results than the target

values, but the amount of this overshooting has no influences on the results. It is recommended to improve the target values or to introduce bonus points for overshooting the target values. This also concerns the criterion “Life Cycle Costs”.

Further adjustments should be investigated concerning the criteria “Quality of Contractors and Prequalification” and “Conditions for Optimal Use and Management” because these criteria of process quality showed very high results and small variations.

Overall the analysis showed that the DGNB-methodology is very suitable to point out individual properties of buildings that are significant for sustainable development. Therefore it is a very powerful tool to quantify and illustrate building characteristics. It is recommended to show the results of all criteria in order to increase the transparency and information content of the DGNB-certificate.

5. Acknowledgments

We would like to express our sincere thanks to The Austrian Sustainable Building Council (ÖGNI) for providing the necessary data and to DI Albrecht Kemmann for his contributions to the working group.

6. References

[1] PASSER A, KREINER H, SMUTNY R, KAUFMANN P. *“Adaptation of DGNB-Methodology to Austria - Lessons Learned from the first Certificates”.* Proceedings of the Sustainable Building Conference in Helsinki, 2011

[2] ÖGNI “DGNB Systembroschüre“, Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft, Austrian Sustainable Building Council, Linz 2013.

Achieve Sustainability in Laboratory Buildings on different Ways – Building, Equipment and User Behavior

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Short Summary

Sustainability is in the focus of many global entities and organizations. Pushed by architectural influence the majority focus on the design of buildings. In terms of life cycle, impact of laboratory process and user behavior, as well as technical equipment such as plug-in-units, seem not to be considered seriously.1

Certification systems for laboratory buildings barely are covered by design criteria usually used for office or industrial buildings. They are dominated by an outstanding use of energy no matter if electricity, gases, demineralized water or any other services. A laboratory may have inline pipe network of more than fifteen media.

The presentation will clearly show that a mix of topics only can achieve sustainability. Laboratory apparatus have a major influence and enable users to achieve sustainability on a high scale, provided it offers energy saving, safety and other sustainable design features. No matter how sustainable the building might be, energy consumption, work flow and influence by the laboratory process impressively dominate the impact in regard to sustainable aspects. Increasing number of plug-ins either multiply those effects.

The major doctrine must be furthermore: Safety beats any other category in the sustainability evaluating system, e.g. reduction of air exchange rates shall only be achieved after a proper risk assessment. The humans and their needs and wellbeing are much important for efficiency and research output. By those means lab designers have to keep an eye on comfort, communication options and individual situations of the users. Therefore lab planners need to be educated in safety strategies either. The general and major use of supply air in a lab building for dilution and evacuation of hazardous substances and gases is changing the character of the purpose of air ventilation. On the other side limitations in regard to air velocity because of comfort aspects are to be considered as well.

For sure sustainability hardly can be achieved in a non sustainable building with non sustainable equipment and instruments, but it is easy to operate a building with a high sustainability assessment in a not sustainable way. Users have the key to operate the building in accordance with the sustainable design criteria.

Once the building is occupied, daily monitoring of the bench marks by submetering, permanent control if the goal is still on the screen and sustainability strategies are aligned to short term change of the lab processes, will help to operate for long term the unity building-lab process-user on a level that is verified with a certification system.

Life cycle cost and assessment of the building is important but operators shall know that it makes sense only if the process and its LCC caused by inevitable equipment and plug-in-units are considered also. Impact of the plug-in-units must cause an own sustainability certification system in order to succeed with the paradigm shift towards more sustainability.

[1] 1 EGBERT DITTRICH “Handbuch für nachhaltige Laboratorien”. Berlin 2012,ISBN 978 3 503 13053 5

Presenter will give an overview upon the EGNATON CERT initiative including PCRs and EPDs – a certification system for laboratory apparatus and equipment.
The learning lesson is to bring the different categories of sustainability in a balance which follows a global standard in order to provide transparency and acceptance. If entities, public bodies and authorities will not agree upon consensual assessments and the meaning of sustainability differs there is no option to penetrate sustainability to private and public life. By those means sustainability must be defined in a new way for laboratory buildings and shall be understood in a holistic view. Some important issue is: Our modern society expects that the industry in general provides sustainable products, substances and processes for the future. By those means research has a clear order which can be achieved only in sustainable buildings and work environment. As a surgeon will not succeed a surgery in a grubby operation theatre, researchers need a sustainable environment to develop sustainable results.

Keywords: Certification; Laboratories; LCC; Plug-in-Units; Sustainability; User Behavior; Ventilation; Safety

Time Valued Life Cycle Greenhouse Gas Emissions from Buildings



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Short Summary

The UK has adopted legally binding carbon reduction targets of 34% by 2020 and 80% by 2050 (measured against the 1990 baseline). Buildings are estimated to be responsible for more than 50% of greenhouse gas (GHG) emissions in the UK. These consist of both operational, produced during use, and embodied, produced during manufacture of materials and components, and during construction, refurbishments and demolition. A brief assessment suggests that it is unlikely that UK emission reduction targets can be met without substantial reductions in both Oc and Ec. Oc occurs over the lifetime of a building whereas the bulk of Ec occurs at the start of a building's life. A time value for emissions could influence the decision making process when it comes to comparing mitigation measures which have benefits that occur at different times. An example might be the choice between building construction using low Ec construction materials versus building construction using high Ec construction materials but with lower Oc, although the use of high Ec materials does not necessarily imply a lower Oc.
Particular time related issues examined here are: the urgency of the need to achieve large emissions reductions during the next 10 to 20 years; the earlier effective action is taken, the less costly it will be; future reduction in carbon intensity of energy supply; the carbon cycle and relationship between the release of GHG's and their subsequent concentrations in the atmosphere. An equation is proposed, which weights emissions according to when they occur during the building life cycle, and which effectively increases Ec as a proportion of the total, suggesting that reducing Ec is likely to be more beneficial, in terms of climate change, for most new buildings. Thus, giving higher priority to Ec reductions is likely to result in a bigger positive impact on climate change and mitigation costs.

Keywords: Carbon, CO_2, emissions, time value, embodied, operational, discount, life cycle, weighting.

1. Introduction

Global temperatures are expected to rise by between 1.1 and 6.4^{o}C by the end of this century, depending, to a large extent, on the quantity of man-made (anthropogenic) greenhouse gases (GHG) emitted in to the atmosphere from now onwards. This warming is expected to have very negative effects on many peoples and ecosystems and, therefore, minimising our greenhouse gas emissions is a priority and is a long-term, large-scale challenge.

The UK, along with many other countries, has adopted a target limit of 2°C of warming relative to pre-industrial temperatures, which requires global greenhouse gas emissions to peak by 2020, be

cut by 50% by 2050 and approach zero before 2100. For equal worldwide per capita emissions to be achieved by 2050 (in developed and developing nations), per capita cuts in the UK of more than 80% below 1990 levels are required before 2050.

The UK has therefore adopted legally binding carbon reduction targets of 34% by 2020 and 80% by 2050 (measured against the 1990 baseline) [1], [2].

Buildings are estimated to be responsible for more than 50% of GHG emissions in the UK [3]. These consist of both operational emissions (Oc), produced during use, and embodied, emissions produced during manufacture of materials and components, and during construction, refurbishments and demolition (Ec).

To date the major effort has focused, quite rightly, on reducing operational emissions but can we reach our reduction targets by just reducing Oc without reducing Ec?

To get an indication we can assume that buildings have to contribute their share of the targets (34% and 80% of the 1990 building emissions) and that the Ec:Oc ratio is 30%:70% over a 60 year service life. Generally different building types exhibit different Ec:Oc ratios but for this purpose a fairly representative 30%:70% ratio is used [4], [5].

Figure 1 shows typical building Ec and Oc profiles for a new building constructed in 2013 and with a service life of 60 years, up to 2073, together with the UK emissions profile from the 1990 baseline through to 2100 using actual emissions up to 2012 and targets up to 2100 [6], [7]. The building emissions are based on the premise that building emissions have already reduced towards their target by 26% in line with the overall UK reduction [6].

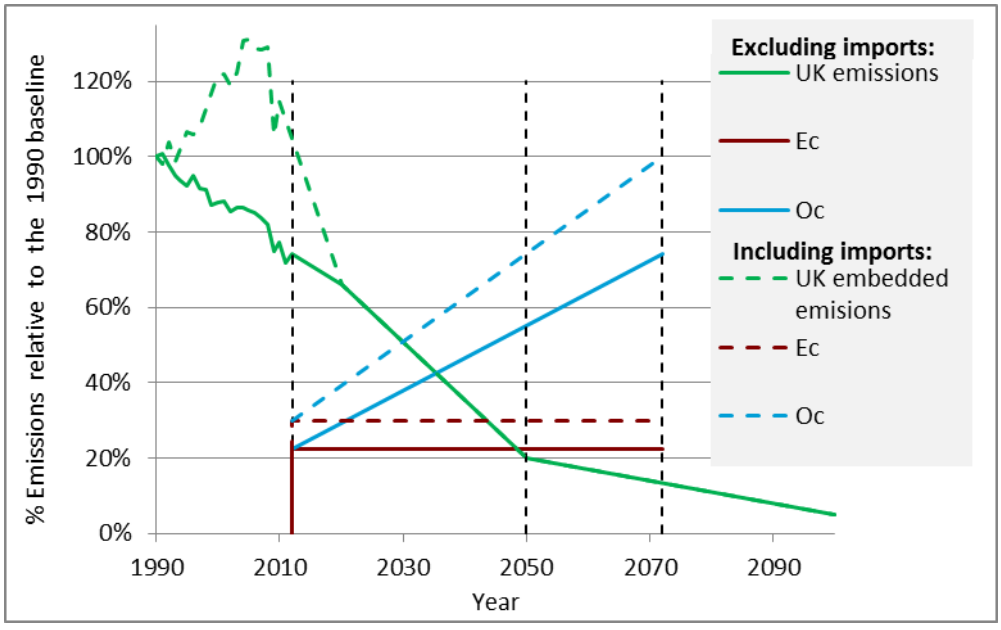


Fig.1: Typical building Ec and Oc profiles with UK emissions

The figure suggests that even if Oc is reduced to zero, Ec would need to be reduced by 10% to reach the 2050 80% target.

If we consider the current thinking for Oc reduction in terms of the 'zero carbon' definition for new homes, which applies to 'regulated' emissions only (space heating, hot water, fixed lighting and building services), and is estimated to be between half and two thirds of Oc, the required reduction in Ec rises to more than 85%. This ignores the issue of 'allowable solutions' which can effectively reduce the amount of regulated emissions which need to be included [8].

To make things worse, a recent report by the UK Committee on Climate Change [8] shows that actually, far from reducing GHG emissions since 1990, the UK has increased its emissions by more than 10% if 'embedded emissions' are considered, including imported materials and goods, with building emissions increasing by 2% over this period. This scenario is shown in dotted lines in Figure 1. If we assume that the 1990 and 2012 emissions are the same (an approximation) and we have made no effective reductions over this period, then if Oc is reduced to zero Ec would need to be reduced by around 30% to reach the 2050 80% target, or reduced to less than zero to meet the target implied by the 'zero carbon' definition.

The exact numbers used above can be debated, however, the example is sufficient to suggest that it is unlikely that emission targets can be met without substantial reductions in both Oc and Ec.

One of the main differences between the two is that Oc occurs over the lifetime of a building, for example 60years and 100years, which are commonly used metrics for the service life of buildings, whereas the bulk of Ec occurs at the start of a building's life during the production of materials and components and building construction. So the timing of building emissions, and in some cases removals as with sequestered carbon during the production of biogenic materials such as wood, varies across the building life cycle.

Therefore, an important issue that needs to be addressed is the time value of these emissions, in other words do emissions that occur now have the same impact as emissions that occur in the future. Or conversely, are emissions avoided now more beneficial than emissions avoided in the future.

A time value for emissions could influence the decision making process when it comes to comparing mitigation measures which have benefits that occur at different times. An example might be the choice between building construction using low impact construction materials but with high operational impact versus building construction using high impact construction materials but with low operational impact.

As operational emissions reduce and further reductions become more difficult and costly, consideration of early embodied GHG reductions, rather than just future operational reductions may be more beneficial, particularly in view of the short 2020 and 2050 timeframes for GHG reductions in the UK.

2. Issues affecting time value

There are a number of time related issues which lead to the idea that emissions occurring at different times during the building life cycle should perhaps be valued differently. The issues considered in this paper are:

- the urgency of the need to achieve large emissions reductions over the next 7 to 37 years (by 2020 and 2050)
- the findings of the Stern Review [9] that the earlier effective action is taken, the less costly it will be
- future decarbonisation of energy supply and more energy efficient building equipment
- the reduced time that delayed emissions are present in the atmosphere during the assessment period
- the carbon cycle and the relationship between the release of GHG's and their subsequent concentrations in the atmosphere over time

2.1 The urgency and cost savings by early effective action.

We need to achieve large emissions reductions over the next 7 to 37 years (by 2020 and 2050). If we don't achieve these reductions we will probably have missed the chance of keeping global temperature below the 2^{o}C target (with the likely extremely serious global impacts) and, because of the way emissions persist in the atmosphere and are only gradually re-absorbed, emission reductions after this date will not help to keep temperatures below this threshold. So it can be

argued that the emission savings during the early life (the earlier the better) of buildings built today should be our first priority, and are therefore more valuable.

The Stern Review [10] demonstrated in economic terms, the need for early effective action. The Review estimates that if no action is taken the costs and risks of climate change will be equivalent to losing between 5% and 20% of global GDP each year from now and into the future. However, with effective action to reduce GHG emissions over the next 10-20 years this can be limited to around 1% of global GDP per year. Although the review findings were not universally accepted at the time (2006), they have been strongly defended [11] and more recent climate data indicates that the review, if anything, underestimated the risks, and the threats to economies [12].

Due to the time lag between taking actions and the effects, the costs of climate change mitigation measures taken now are borne by the present generation but future generations get the benefits and, because of the complexity, many of the effects and consequences are uncertain. So the issue is how to evaluate the costs and the benefits occurring at different times and by different generations.

In terms of economic appraisal, discounting is the generally accepted method of dealing with time, which involves discounting a unit of cost or benefit in the future relative to that unit now. This enables costs and benefits occurring at different times to be converted into a single 'net present value' (NPV) number for decision making. In this context, Stern has suggested that discounting is a slightly misleading term as it implies disregarding benefits in the future and has suggested it may be more helpful to describe the process as 'intertemporal values and valuations' rather than discounting.

Its application in the field of climate change appears to be very controversial with much debate over whether the use of a simplistic system of discounting is appropriate for the complex issue of climate change and what might be an appropriate discount rate to use [11], [12], [13]. Nevertheless, the consensus appears to be that discounting can be a useful tool to provide guidance in the appraisal of options for mitigating climate change.

The formula for net present value can be expressed as:

$$NPV = \sum_{1}^{n} C(1+i)^{-n} \qquad (1)$$

Where C is the cost or benefit in year n at a discount rate of i.

Generally, a positive discount rate is assumed, which reduces the value of a unit of cost or a unit of benefit spent or received in the future in relation to the value of that unit today. The value reduces the further you go into the future and the level of the discount rate considered (generally between 3% and 8%) makes a big difference in assessing options with long-term effects, and therefore finding the correct discount rate for the benefits of reducing GHGs is crucial and is a complex subject giving rise to much disagreement even amongst economic experts.

It is useful to briefly consider the main justifications for discounting. These have been described as [12]:

- Future generations may be wealthier and as you get wealthier the same unit of cost becomes less significant. This leads to the difficulty of forecasting how much wealthier. The problem of climate change could be considered fairly unique in this sense, as it is partly the mitigation actions taken today which will determine the wealth of future generations, and it is by no means certain that they will be wealthier, particularly if only weak mitigation actions are taken.

- 'Pure time' discounting based on the idea that it is a natural preference to have a unit of income or benefit now rather than at some time in the future. The argument goes that we are in fact discounting the benefits to future generations just because they are in the future, which seems difficult to justify ethically. One seemingly justifiable reason for 'pure time' discounting is risk

and uncertainty about whether future generations will continue to exist due to some catastrophic global event unrelated to anthropogenic climate change such as a nuclear war or a meteorite strike. It would seem reasonable to attach slightly less value to benefits occurring in the future over say the next one hundred years to account for the probability (although very low) of such an event happening.

- The 'opportunity cost' basis for discounting looks at future costs and benefits in relation to the level of return from other investment alternatives. On this basis, the discount rate for benefits and costs of a project would be at least as high as the expected market rate of return from the best alternative.

The choice of discount rate appears to be fairly subjective and is generally based on a combination of the above. The so called 'Social discount rate' (SDR) has been described as the measure used to help guide choices about the value of social projects. It is defined as 'the appropriate discount rate to use in computing present discounted value for social investments.' [14], [15], for example to estimate the value of infrastructure projects, schools, or environmental protection schemes. The SDR is used to put a value on both future costs such as maintenance or on future benefits such as reduced pollution emissions, and places less of an emphasis on the market 'opportunity cost'.

Stern arrived at the relatively low overall value of +1.4%, which includes 0.1% 'pure time' discount rate, effectively valuing future generations equally with the current generation but assuming approximately a one in ten chance of the planet being destroyed by the end of this century.

Figure 2 shows discount factors, which can be applied to emissions occurring at different times during a building's service life. A range of discount rates are shown to demonstrate how they influence the results. Using a discount rate of +1.4%, emissions at year 0 are roughly 2.3 times as 'damaging' as emissions at year 60 and 4 times as 'damaging as emissions at year 100. Or putting it another way, emission savings in year zero are 2.3 times as 'beneficial' as those at year 60 and 4 times as 'beneficial' as those at year 100.

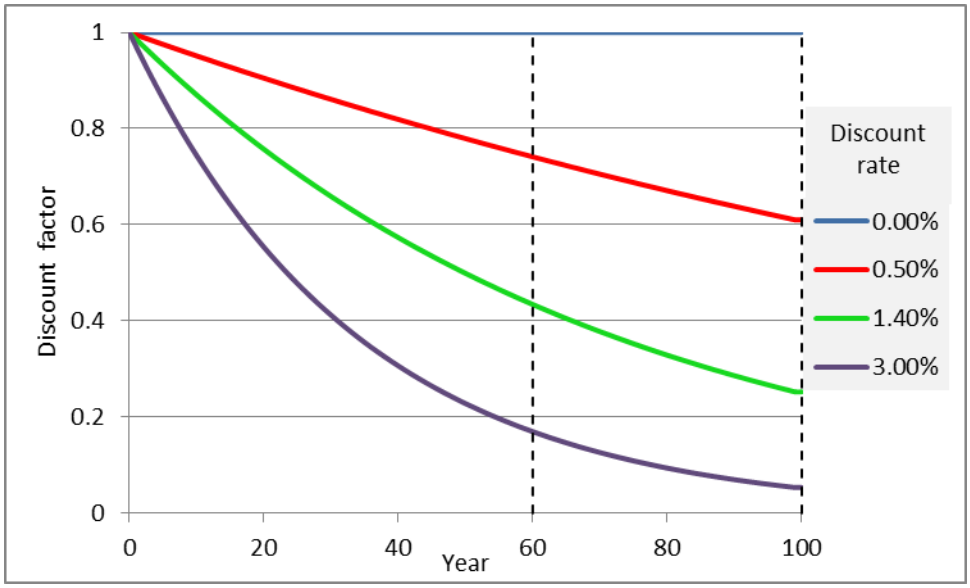


Fig.2: Discount factors for emissions occurring in the future

Assuming equal emissions per year, the NPV of all emissions for a given period is the area under the curve for that period multiplied by the annual emission. In the case of a discount rate of +1.4% and periods 0 to 60 years and 0 to 100 years, the NPVs are 68% and 54% of the non-discounted emissions.

The appropriate discount rate in relation to climate change is still a hotly debated topic amongst economists but the principle of discounting at some level appears to be generally accepted. For the purposes of this paper the methodology and rate put forward by Stern [10] are adopted which

results in a discount rate at the low end of the range discussed in the literature. Adoption of a higher rate would give an even higher value to early embodied emission savings.

2.2 Future decarbonisation of energy supply and more energy efficient building equipment

Decarbonising the electricity supply is a key part of the UK's low carbon transition plan. The ambition is to reduce carbon intensity in line with the Markal scenarios [16], all with reductions of around 90% of the 2010 intensity by 2050, albeit at different rates. The 'mean' scenario is shown in Figure 3.

In 2011 electricity comprised approximately 33% of energy consumption in UK buildings resulting in 55% of emissions [6], [17]. Carbon intensity has already reduced by 35% (2011 figures) against a 1990 baseline. However, electricity use increased resulting in a net reduction in emissions of 16%.

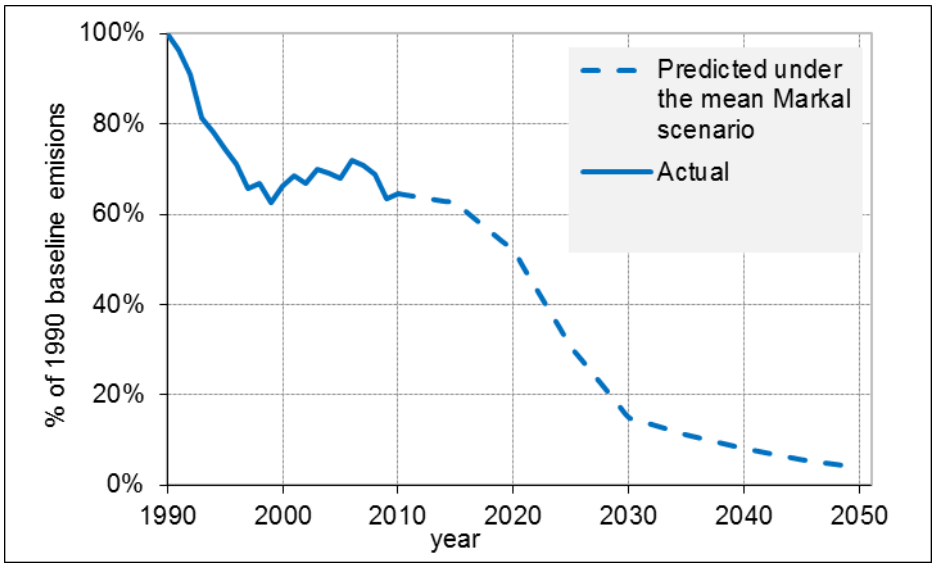


Fig.3: Carbon intensity of grid electricity – rate of reduction based on the mean of Markal scenarios

Gas comprised approximately 57% of energy consumption in UK buildings, resulting in 37% of emissions. There was particularly low gas consumption in 2011 due to a mild winter and more normal percentage emissions would perhaps be 50% from gas and 40% from electricity consumption.

Emissions from oil and solid fuel use were around 8%.

So the question is how will these emissions change in the future? Figure 4 shows emissions from the four main energy sources and the combined total from 1990 to 2011.

Crude linear trend lines have been added, together with the mean Markal profile for reduction of carbon intensity of grid electricity. The trend lines suggest that the UK will not even meet the overall 80% reduction target for all emissions by 2050, whereas, in actual fact the reduction in emissions from new buildings is required to be greater than 80% to make up for the existing building stock, of which a large proportion will still be in use in 2050, and other sectors of the economy, which will be unable to make the same level of reduction [15].

Any future increase in exploitation of shale gas is predicted to increase the carbon intensity of gas supply due to increased fugitive emissions, although the recent report from the Committee on Climate Change [9] has stated that improvements in extraction techniques could possibly maintain the current level of intensity. Overall, it seems unlikely that the carbon intensity of gas supply can be improved significantly and therefore reducing the reliance on fossil gas seems unavoidable.

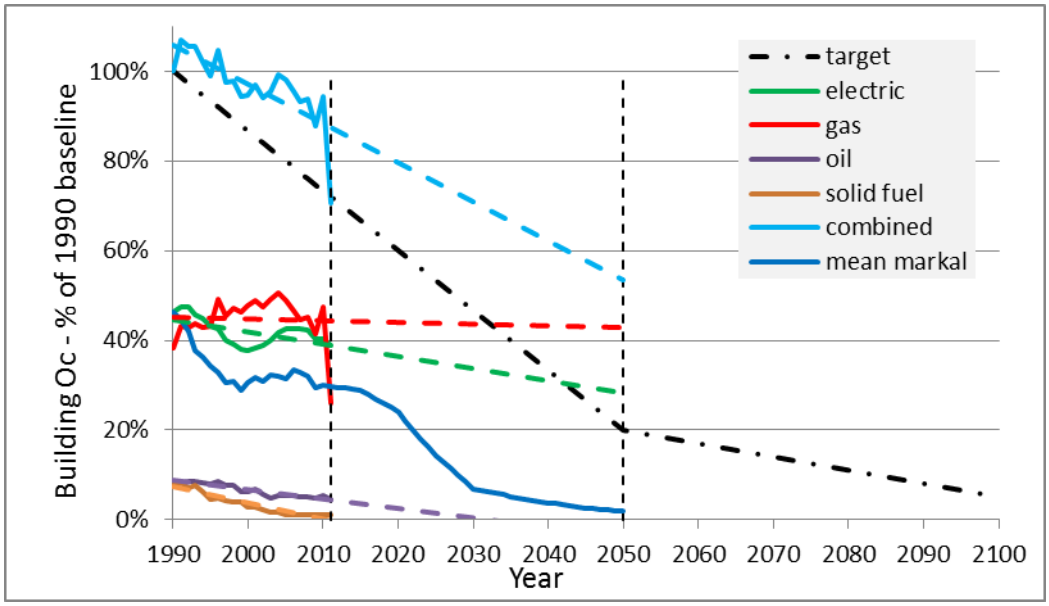


Fig.4: Building Oc- target, emissions from different energy sources, trends based on 1990-2011 emissions and mean Markal scenario for decarbonisation of grid electricity

Substantial changes in energy supply and energy use will be needed to achieve the sort of emission reductions required. These are likely to include: accelerating the reduction of carbon intensity of grid electricity in line with the Markal scenarios; reduced use of fossil gas and oil; more energy efficient replacement equipment in building upgrades and refits, increased use of biogenic fuel sources and consumer behaviour change.

For the purposes of this paper it is assumed, and some would argue we have little option, that the reduction of emissions from buildings built today will generally follow the path of the overall UK emissions, reducing by 80% from 1990 to 2050 and by 95% by 2100 [7], although predicting what reductions may be required at the end of the century can at best be described as somewhat speculative.

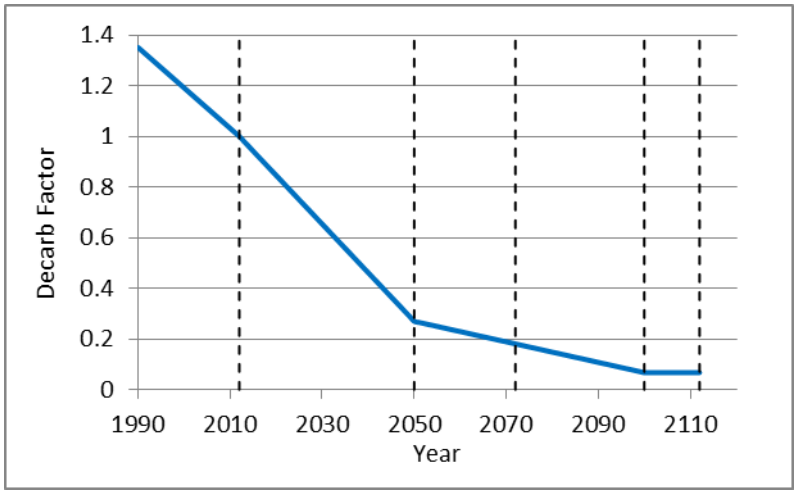


Fig.5: Factors to account for decarbonisation of energy supply

Figure 5 shows the resulting factors, adjusted in accordance with the previously stated premise that building emissions have already reduced towards their target by 26% in line with the overall UK reduction, giving a factor of 1 at the starting point of 2012/13. (1990 was the 100% level, 2012 the 74% 2050 needs to be the 20% level; this effectively means a reduction of 73% of the 2012 level by 2050).

Assuming equal emissions per year, the NPV of all emissions for a given period is again the area under the curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years from 2012/13, the NPVs are 49% and 34% of the unfactored emissions.

2.3 Delayed emissions and the carbon cycle

British Standards Institute publication 'Publicly available specification, PAS 2050, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services' [19] states 'Emissions that are released over time through long use (e.g. light bulbs) or final disposal phases cannot be treated as a single release of emissions at the start of the 100-year assessment period. Therefore, these emissions must be calculated to represent the weighted average time in the atmosphere during the assessment period.'

In addition, all carbon, including anthropogenic carbon, released into the atmosphere is redistributed during the following decades and centuries between the three main reservoirs: atmosphere, ocean, and land biosphere. It is the increase in concentrations of carbon dioxide and other GHGs in the atmosphere, which leads to a rise in global temperature. Some of the anthropogenic carbon released into the atmosphere therefore, effectively 'decays' as it is gradually re- absorbed into the other two reservoirs.

The relationship between anthropogenic carbon emissions and atmospheric CO2 concentrations over time is described by 'the revised version of the Bern Carbon cycle model' [18], which is the basis for calculations of global warming potentials by the Intergovernmental Panel on Climate Change (IPCC).

A weighting factor to account for delayed emissions and 'decay' of atmospheric carbon can be described by Equation 2.

$$Weighting\ factor = \sum_{n=1}^{100} x_n (1 - 0.0068n - (3 \times 10^{-5})n^2) \quad (2)$$

Where n is each year in which emissions occur and x is the proportion of total emissions occurring in any year n.

A simplified version is used in PAS 2050 given by Equation 3.

$$Weighting\ factor = (\sum_{n=1}^{100} x_n (100 - n))/100 \quad (3)$$

The emissions from a building are analogous with the light bulb example and therefore it appears entirely consistent to consider emissions from buildings in the same way.

Plots of the IPCC equation and the simplified PAS 2050 version are shown in Figure 6. The areas under the two curves are approximately equal and therefore for annual emissions over a 100 year assessment period both equations give approximately equal total emissions but can differ for emissions not occurring over the full period.

A limitation with both equations is that they apply only to CO_2 emissions and GHG's with different decay characteristics may not be well represented, although the consideration of CO_2 equivalence for other GHG's goes some way to addressing this issue.

Assuming equal emissions per year, the NPV of all emissions for a given period is again the area under the curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years the NPVs are 76% and 56% of the unfactored emissions using the IPCC equation and 70% and 50% using the PAS 2050 equation.

For the purposes of this paper the IPCC equation is used.

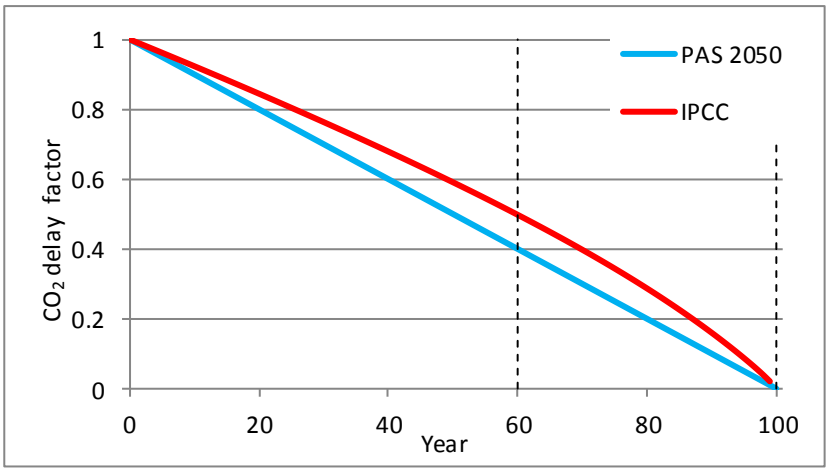


Fig.6: CO_2 delay factors

3. An overall time value of emissions

The overall time value of emissions can be calculated by first applying the decarb factor for the anticipated reductions in energy carbon intensity and energy demand due to energy efficiencies and behaviour change, followed by the decay factor allowing for the atmospheric decay of the resulting emissions, followed by the economic discount factor.

Figure 7 shows these three factors, together with the resulting combined factor and a proposed close fit curve.

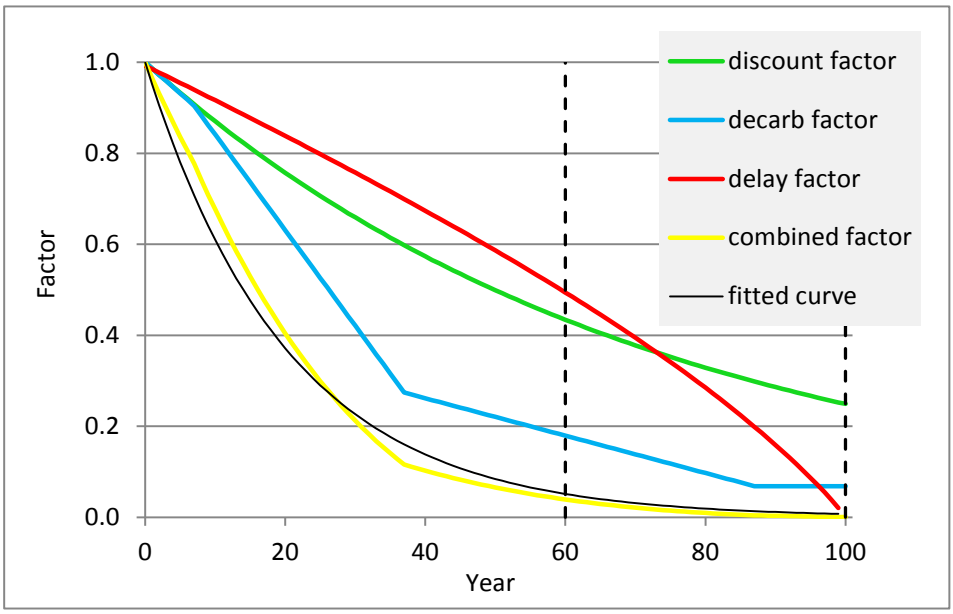


Fig.7: Combined factors for emissions occurring in the future

The close fit curve proposed here is represented by Equation 4

$$Weighting\ factor = \sum_{n=1}^{n} x_n e^{-0.0495n} \quad (4)$$

Where n is each year in which emissions occur and x is the proportion of total emissions occurring in any year n.

Assuming equal emissions per year, the overall NPV of all emissions for a given period is again the area under the combined fitted curve for that period multiplied by the annual emission. For periods 0 to 60 years and 0 to 100 years the overall NPVs are approximately 32% and 20% of the unfactored emissions.

4. Discussion

There seems a strong case for putting a time value on emissions from buildings. Reduction of carbon intensity of energy supply is a reality and there is already a precedent for the principle of delayed emissions in PAS 2050. The likely economic benefits of early reductions have been clearly stated [10], and the urgent need to make substantial early emissions cuts over the next two or three decades is now the mainstream view.

The proposed time value put forward for discussion and comment in this paper is described by Equation 4. It is suggested that a time value factor (TVF) of this type could be a useful tool for assessing and prioritising building options to achieve the most beneficial overall GHG emissions outcome to minimise climate change impacts.

Figure 8 shows a simplified building emission profile (cumulative) with and without time value factors. This is based on a 30%:70% life cycle emission ratio between unfactored Ec and Oc. Applying the combined TVF changes the ratio to 64%:36%, an almost complete reversal.

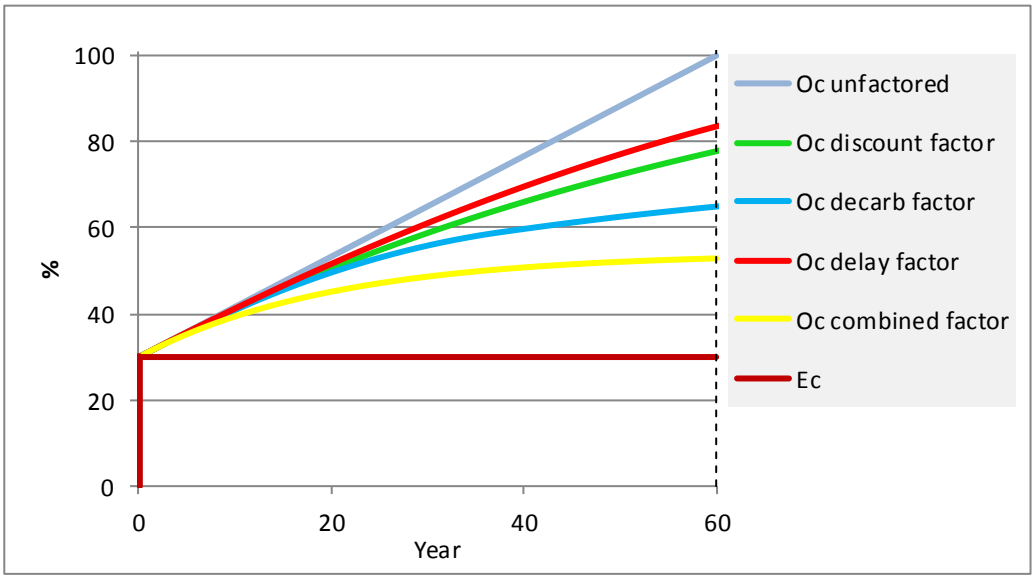


Fig.8: Typical building Ec and Oc unfactored and factored emission profiles over a 60 year service life

Table 1 shows the changes to the Ec:Oc ratio applying the separate TVFs and the final combined TVF for different unfactored ratios ranging from 10%:90% to 80%:20%.

Both the CO_2 and Decarb factors are themselves time dependant and would need to be updated over time.

The CO_2 factor is based on an atmospheric concentration of 378ppm, current at the time the Bern model was developed, but as atmospheric concentrations increase (the 400ppm level has recently been reached) up to the target maximum of 550ppm, the rate of decay may change.

The Decarb factor will need to be updated as the UK progresses down the carbon intensity curve.

Table 1: Unfactored and factored Ec:Oc ratios

Unfactored		Discount factor only		Delay factor only		Decarb factor only		Combined factor	
Ratio (%)		Ratio (%)		Ratio (%)		Ratio (%)		Ratio (%)	
Ec	Oc	Ec	Oc	*Ec*	Oc	Ec	Oc	Ec	Oc
10	90	14	86	13	87	19	81	26	74
20	80	27	73	25	75	34	66	44	56
30	70	39	61	36	64	47	53	57	43
40	60	50	50	47	53	58	42	68	32
50	50	60	40	57	43	67	33	76	24
60	40	69	31	66	34	76	24	82	18
70	30	77	23	75	25	83	17	88	12
80	20	86	14	84	16	89	11	93	7

5. Conclusions

It seems likely that substantial reductions in both Oc and Ec from new buildings will be required to meet the UK emissions targets.

The proposed time value equation could provide a useful tool for comparing different mitigation options giving benefits at different times during the building life cycle, for example when making comparisons between embodied and operational emissions.

A time value for emissions has implications for life cycle assessment methods used for evaluating embodied emissions for materials, products and complete buildings. Factored 'end of life' emissions have a much reduced influence and this suggests that 'cradle to grave' or 'cradle to cradle' assessments may give very similar results to 'cradle to site' assessments. If this is the case, embodied carbon calculations using very much simpler 'cradle to site' assessments could be justified.

When taken at face value, Oc usually appears to dominate and is the focus of reduction strategies. However, when appropriate allowances are made for future scenarios, reducing Ec is likely to be more beneficial, in terms of climate change, for most new buildings. Thus, giving higher priority to Ec reductions is likely to result in a bigger positive impact on climate change and mitigation costs.

6. References

[1] DECC (Department of Energy and Climate Change), "*The UK Low Carbon Transition Plan*, DECC, London, UK, 2009.

[2] DECC (Department of Energy and Climate Change), "*Carbon Plan"*, DECC, London, UK 2011.

[3] BIS (Department for Business, Innovation and Skills), "*Low Carbon Construction, Innovation and growth team: Emerging Findings (report)*", BIS, London, UK, 2010.

[4] RICS (Royal Institution of Chartered Surveyors), "*Methodology to calculate embodied carbon of materials*", RICS information paper IP 32/2012, RICS, Coventry, UK, 2012.

[5] NHBC FOUNDATION, "*Operational and embodied carbon in new build housing: A reappraisal*", NHBC Foundation, Milton Keynes, UK, 2011.

[6] DECC (Department of Energy and Climate Change), "Energy Consumption in the UK: All data tables, Terawatt hours, 2012 update", DECC, London, UK, 2012.

[7] LOWE J, GOHAR L, HUNTINGFORD C, GOOD P, BERNIE D, PARDAENS A, WARREN R, RAPER S, "*Are the emission pledges in the Copenhagen Accord compatible with a global aspiration to avoid more than 2°C of global warming? - A technical note from the AVOID programme*", Met Office Hadley Centre, Exeter, U.K., 2010.

[8] ZERO CARBON HUB. "Zero carbon strategies for tomorrow's new homes", NHBC

Foundation, Milton Keynes, UK, 2013.
[9] COMMITTEE ON CLIMATE CHANGE, "*Reducing the UK's carbon footprint and managing competitiveness risks*", Committee on Climate Change, London, UK. 2013.
[10] www.hm-treasury.gov.uk/stern_review_report.htm, "*Stern Review: the Economics of Climate Change*", 2006 (consulted 10/04/13).
[11] STERN N, "*The Economics of Climate Change",* American Economic Review, 2008. 98(2): p. 1-37.
[12] STERN N, "Ethics, equity and the economics of climate change", Centre for Climate Change Economics and Policy Working Paper No. 97 and Grantham Research Institute on Climate Change and the Environment Working Paper No. 84, 2012.
[13] HEAL G, "Climate economics: a meta-review and some suggestions" Working Paper 13927 National Bureau of Economic Research, Cambridge, MA, USA, 2008.
[14] JALI M. "*Approaches to Measuring Social Discount Rate: A Bangladesh Perspective".* BIISS JOURNAL, Bangladesh Institute of International and Strategic Studies (BIISS) Journal, 2012. VOL. 33(No 4): p. 28.
[15] GRUBER J. "*Chapter 8: Cost-Benefit Analysis*" Public Finance and Public Policy, 2007, pp201-223.
[16] DECC (Department of Energy and Climate Change), *"Analytical Annex to The UK Low Carbon Transition Plan"*, DECC, London, 2009.
[17] DECC (Department of Energy and Climate Change), "*Guidelines to Defra / DECC's Greenhouse Gas Conversion Factors for Company Reporting",* Decc, London, 2012.
[18] FORSTER P, RAMASWAMY V, ARTAXO P, BERNTSEN T, BETTS R, FAHEY D, HAYWOOD J, LEAN J, LOWE D, MYHRE G,. NGANGA J, PRINN R, RAGA G, SCHULZ M. VAN DORLAND R. *"Chapter 2: Changes in Atmospheric Constituents and in Radiative Forcing*", in: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K, Tignor M, Miller H (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007, C2Table 2.14, p.213.
[19] BSI, "Publicly available specification, PAS 2050, Specification for the assessment of the life cycle greenhouse gas emissions of goods and services", BSI, 2011, London.

The influence of structural design on the sustainability assessment of building constructions



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Short Summary

The comparison of commonly used certification systems in Europe and the associated literature displays that an advanced consideration of structural design doesn't happen. Thereof the approach of implementing structural design in the assessment was defined as a main topic of this paper.

An evaluation tool was developed that is based on the structure of DGNB/ÖGNI and this allows evaluating construction details including building materials and fasteners. Content and system boundaries focus only on the technical quality of a construction. Essentially for the development of the assessment model was to ensure the applicability on a component level and to facilitate the evaluation of component layers and joining techniques. As part of the valuation of the model in practice three buildings of the Graz University of Technology have been analysed, evaluated and compared with each other. focus of the assessment have been aspects of maintenance, disassembly, separation and recycling.

The test revealed that the model allows both a detailed and a quick review. The weighting can be adjusted individually so that single component layers can be highlighted in view of their importance. The evaluation matrix can be used both as a decision support system for planers (designers), product manufactures and producers as well as implemented into the DGNB/ÖGNI certification system. For this purpose further development is still needed.

Keywords: sustainability, building evaluation, building certification, building construction, structural design

1. Introduction and background information

Recent discussions about the pros and cons of various methods of constructions are influenced by general principals of sustainable development – sustainable building. To harmonise the assessment of buildings in Europe, in 2004 the European Commission has placed an order with the mandate M350 to CEN to the "Development of horizontal standardised methods for the assessment of the integrated environmental performance of buildings". This European regulation will significantly influence the future planning, construction and operation of a building as well as its demolition. The basis for this is next to the environmental, economic and socio-cultural dimensions the consideration of technical and process-oriented levels of the entire life cycle of a building.

Political intensions led to the development of European standards and regulations regarding sustainability in the building and building material sector. At the same time certification systems all over the world were developed to react to the upcoming trend of building certifications. These systems treat different aspects and topics that make it difficult to compare them with each other. The technical evaluation of a building and/or the evaluation of the building construction are considered in none of the systems. This demand of action is responsible for the aim of this paper – the implementation of constructive design in an evaluation.

2. Objective of the project

In the last few years certification systems were developed that offer the possibility to compare buildings due to their sustainability. These systems provide however no guidance how to use them at an early stage of the planning and during planning.

The literature shows that a lot of research projects have dealt with the optimisation and the development of certification systems. The implementation of structural design is an aspect that has been avoided in the literature up to now. This is the main reason why this, especially for planning decisions, important topic is the focus of this paper.
Expected results are:

- evaluation tool that indicates and evaluates structural design due to sustainable aspects
- guidance for practical use
- to identify the need of addition of the chosen certification system
- evaluation of the assessment tool
- to identify opportunities for improvement and implementation

3. Certification systems

Since a few years a growing interest in “green buildings” and “certifications” has been existing. Nearly all member states of the European Union encourage the public to build “green”, environmentally acceptable and resource efficient buildings like passive houses or low energy houses.

Because of the recent demand a significant number of certification systems came up. These programs assess a building’s sustainability whereas certain topics like the quality of the construction are not considered. Most certification systems deal with energy consumption, emissions, life cycle costs, health and comfort. A missing transparency discourages owners and enterprises to order a certification. Common preconceptions associated with building certifications are that it is too ecological and that the effort is not related to the needs of the certification demanders.

The individual certification schemes are tailored to national standards and conditions. They differ in their complexity, their criteria for evaluation and the valuation methods used. Depending on whether it is an administrative building, a residential or industrial building, specially for different types of use developed system variants of the certification systems have to be considered. In recent years three certification systems have been established on the German real estate market (Austria, Germany, Switzerland):

- LEED
- BREEAM
- DGNB (Austria: ÖGNI)
-

The results out of a certification can be the base for future investment decisions. Following aspects determine which label is the most suitable evaluation system:

- availability and suitability of the evaluation tool
- considered criteria
- accordance of system contents with the wishes and objectives of the client
- establishment of the system on the market
- system’s adaptability
- cost for certification

If you evaluate the 3 most common certification systems, you can see that these systems differ not only in the number of their system variants but also feature different evaluation aspects. A detailed comparison of these three labels shows, that the rating categories and the assignment of criteria for each category are difficult to compare. BREEAM and LEED f.e dispose (distribute) ecological aspects to different rating categories whereas the DGNB/ÖGNI system deals with just one ecological category. Only a few aspects of the certification schemes are comparable to a certain

degree. This is another reason why it is nearly impossible to compare results of different certification systems with one another.

Table 1: Weighting of evaluation criteria for administrative and office buildings (own illustration based on [4])

evaluation aspects	BREEAM	LEED	DGNB
ecological aspects	58,5%	64,0%	22,5%
economic aspects	-	-	22,5%
social aspects	14,0%	14,5%	16,0%
functional aspects	5,0%	0,5%	6,5%
technical aspects	5,0%	-	22,5%
aspects of planning process	1,0%	2,0%	5,0%
aspects of construction process	7,0%	8,0%	3,0%
aspects of business procedures	4,0%	1,5%	2,0%
aspects of location	5,5%	9,5%	separate

The main topic in LEED deals with ecological aspects (64%), nearly the same can be seen in BREEAM (appr. 60% ecological aspects). DGNB has however a uniform weighting of evaluation criteria and considers technical aspects as well. One aspect they all have in common is their aim to develop tools to measure and evaluate the ecological quality of buildings.

Sustainability has to be evaluated but ecological aspects are not the only topic to look at, although the main focus is apparently on this aspect. Sociocultural and functional aspects are taken into consideration, but with less intense. But there is an essential distinction between the DGNB system and other certification systems: the analyse of economic quality which is defined by the study of life cycle costs and conversion feasability. The associated conversion of value is not covered by standards yet.

Furthermore the analyse showed that the certification system DGNB is the only one out of the three considered systems which corresponds to the structure of the CEN/TC 350 and is compatible. It is a fact that – after closer examination of the 3 analysed systems LEED, BREEAM and DGNB – only the German system takes the technical features into account. Criteria such as sound insulation, fire protection and moisture are covered. The topics of maintenance, dismantling and recycling are discussed but regarding the building construction only on a superficial level. Certain indicators are only applicable to the building level, on component level other aspects have to be taken into consideration accordingly.

4. Model development

Before developing an evaluation model the most important decision was to choose a certification system that has to function as the base for the upcoming assessment tool. After the analysis of the most common certification systems on the German speaking market the German certification system DGNB was selected. On the one hand this system is the only one with an allusion to the European standard and the work of CEN/TC 350. On the other hand the chosen system deals not only with the triple bottom line, it covers also aspects regarding the technical and the process oriented quality. Furthermore there is no special emphasis on a certain topic, all categories are treated equally, with the exception of the process quality.

The development of the evaluation model needed a structured approach and started with the analysis of all 49 criteria (stand 2009), followed by the analysis of the 49 criteria regarding their relevance for building constructions. This means that their applicability on the construction itself was evaluated based on a simple yes/no-analysis. Additionally it was tried to find a definition for “relevance for building construction”, with the aim to identify new criteria for the evaluation of building constructions.

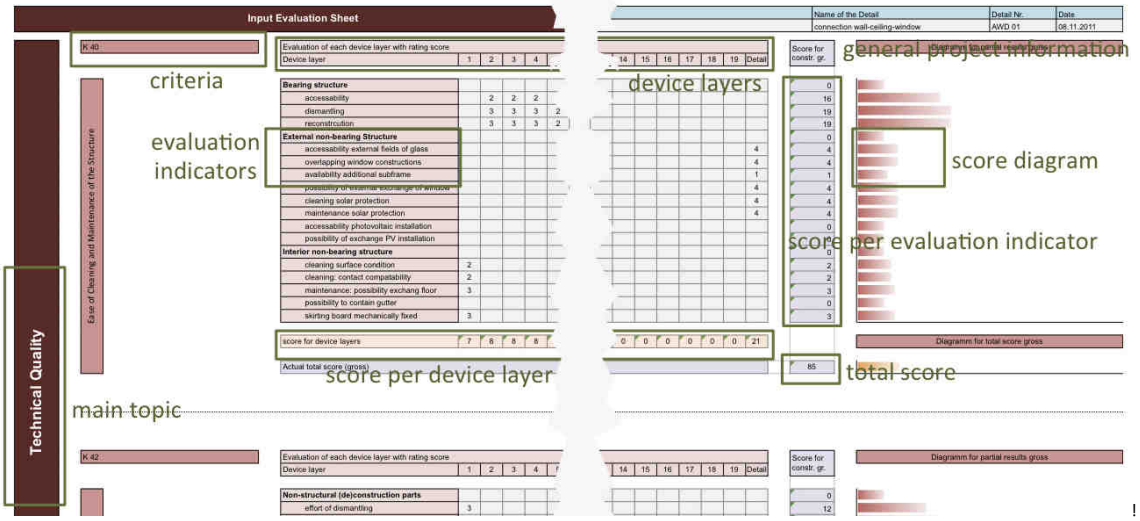
It became apparent, that it would be necessary to limit (qualify) the number of assessed criteria. During the selection of the evaluation criteria the idea was to avoid double evaluation. The attempt was to filter those criteria that are applicable on both, the component and the building level. Because they are mentioned in the general DGNB evaluation they are not taken into consideration for the upcoming evaluation matrix.

The aim of the dissertation was to evaluate building constructions on a technical level, a limitation of DGNB criteria K40 “Ease of Cleaning and Maintenance of the Structure“ and K42 “Ease of Deconstruction, Recycling, and Dismantling“ occurred. They were selected because they exhibit the closest reference to building constructions.

The try to define “relevance for building construction” generated new aspects that have not been considered in the actual DGNB system yet. On the one hand two new criteria emerged out of these, criterion K41a “design features” and K 41b “durability and robustness”. On the other hand the “old” criteria 40 and 42 were expanded and adapted with new evaluation indicators.

Right after the definition of the evaluation criteria the development of the evaluation matrix started. During this process it was decided to select a scoring system. The assessment and the scoring should be as simple as possible, that’s the reason for a scoring rate from 1 to 5 points. The next step was to develop the structure of the matrix, which should be as simple and clear as possible. For one criterion the matrix is exemplarily shown in table 2.

Table 2: Overview evaluation matrix criterion K40



As shown in the picture above the scoring scale varies between 1 to 5 points per evaluation indicator. The assessment is made – if possible – per each single device layer and is itemised for each layer. The weighting depends initially on the existing component layers (f.e. the construction consists of 5 device layers, therefore the criteria indicator get a weighting of 1/5). Basically there is the possibility to distinguish and weight individual component layers additionally in consideration of their importance. Using this assessment model to extend a certification system the weighting normally has to be predefined.

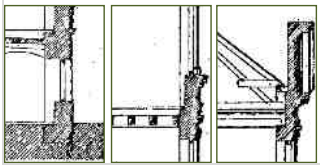
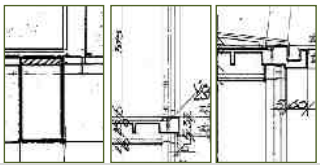
After the formal description of the model some starting points have to be described. Initially considerations about different maintenance scenarios regarding building constructions have been made. Certain reconstruction measures cannot be prevented and have to be scheduled and budgeted during the life cycle of a building. Thereby the existing joining technology in the construction has an enormous influence on the maintenance and is responsible for possible maintenance scenarios. Reacting to the entire life cycle of a building means not only considering the construction- and utilisation phase but to take a gander at the demolition (removal) and dismantling.

In the course of work the influence of structural design and class of age was reflected on the recycling management. For the pilot phase of the evaluation model it made sense to select demonstration buildings from different time periods. Additional considerations regarded following aspects: type of use of the building, building age, comparison and criteria and the needed documentation

5. Practical application

The developed evaluation system was tested due to its practicability on three existing buildings of the Graz University of Technology (see table 3). The three objects should be from different building periods and differ in their way of construction and their building materials. The thing they had to have in common was their utilisation: they are all administrative buildings mainly with office use. With relation to the DGNB system “office and administration buildings” it seemed useful to choose administrative alike buildings.

Table 3: Overview evaluated buildings of the Graz University of Technology

Main Building (AT)	Hydraulic Engineering Lab	Frank Stronach Institute
		
year of construction: 1884-1888 materials: bricks, natural stone, timber Building in Wilhelminian style typical: high ceilings, stukko	year of construction: 1960 materials: many different materials, prefabricated concrete elements typical: skeleton structure, flat roof, sandwich construction	year of construction: 2006 materials: reinforced concrete, steel, dry walls, many different materials, new technologies typical: open coverage type, glass facades
		

5.1 Building analysis

Before starting the evaluation with the developed assessment matrix certain preinvestigations on the buildings had to be done:

- Bill of quantities: a separation between the construction elements wall, ceiling, windows, doors and stairs and landing occurred. For each single device layer the mass was indicated and allocated to the shell construction or the fitout, whereby the relation is stated in %. This proportion should give information on the influence of a building period or construction design on the relation shell-construction and fitout.
- Detailed analysis: for each building three details were chosen for an detailed analysis: foundation and/or base, connection between exterior wall and ceiling including an existing window and roof
- detailed analysis I: each construction detail was analysed due to the building devices’ classification into a substance group (mineral, inorganic and metallic)
- detailed analysis II: the component layers of each construction detail were assessed due to their separability and recyclability. Additionally the disposal costs incurred were mentioned.

5.2 Evaluation of the model

The selected details mentioned before were evaluated and analysed based on the developed evaluation matrix. Therefore each detail with its component layers was recorded in the evaluation tool. After that it was possible to evaluate and assess each layer regarding the determined criteria, whereby the award of points took place on the basis of the new and reworked criteria lists with the defined scoring rate. Likewise the weighting was filled in, so that a sum of points is the result of the evaluation. For a better comparison and understanding a final summary of the results with the help of color-coded list was prepared for each detail. Afterwards the comparison of the buildings and their details occurred.

5.3 Comparison of the buildings

The three rated buildings were compared regarding the results obtained from the evaluation model. Besides a detailed analysis of the buildings a critical evaluation of the model should take place, in which the pros and cons are exposed and further development needs are determined.

The assessment of individual structures should show that sustainability should not be limited to the building itself but must be considered in the construction details as well. Sustainability on a component level does not mean considering the building material is the only aspect, it requires the consideration of technical aspects in the same way. Recyclability and life cycle analysis is not only valid on the building level, but should also be at a detailed level.

Sustainability in the construction detail is in interaction with the sustainability of a building. Often detailed designs have to have certain aspects of sustainability so that the building itself can be classified as sustainable.
The evaluation was made due to two different aspects:

- comparison of the details
- comparison of the costs

5.3.1 Comparison of the details

The evaluation model was tested on three buildings by analysing three different detailed constructions with the assessment matrix. The comparison of the structural designs for each building is constituted by comparing the individual details for each building. This automatically leads to an assessment of the practicability of the evaluation model.

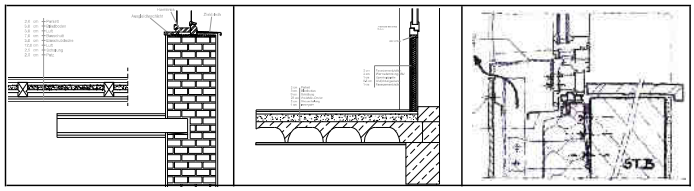
Possible fields of application are:

- useful addition to the German system DGNB
- comparison of alternatives for planning
- comparison of alternatives for system manufacturer

Table 4 shows exemplarily the comparison of the detail “connection exterior wall with the ceiling including a window”. The comparison is illustrated with a simplified color-code rating that shows the weakness in a construction.

In the present detail the accessibility f.e.– regarding the criteria – is not always possible. The disassembly of the construction requires in the detail of the AT less effort than the other constructions. One reason for this is the floor structure. The AT has a wooden beam ceiling where the component layers have been installed either by nails, plugs or loose connections. The solubility of the compounds makes the disassembly easy to perform. In the hydraulic engineering laboratory are even mainly nail joints, but less loosely installed component layers, which is responsible for the different scaling. The FSI however shows not releasable compounds whose removal is only possible through the destruction of the device layer.

Table 4: Comparison of the 3 buildings for a detail (connection ceiling-wall-window)

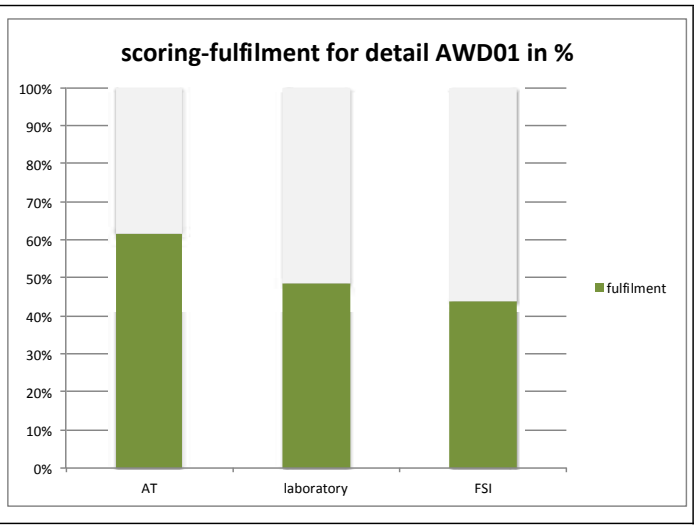
	Project: AT - laboratory - FSI	Detail: AWD01	Datum: 8.7.2012
Plan			

			possible score	average score	AT	average score	laboratory	average score	FSI
simplified criteria	entire construction - bearing structure and non-structural construction parts	accessability	1 - 3	2		2		2	
		dismantling	1 - 5	4		2		2	
		effort of separation	1 - 5	5		5		3	
		recyclability	2 - 5	4		4		4	
		dismantling of joints	1 - 3	2		3		2	
		material variety	1 - 3	3		2		2	
		durability							
		robustness							
		total score		20		18		15	

legende:
- very good condition
- good condition
- bad condition
- very bad condition

explanation total score

	24 - 19	points
	18 - 13	points
	12 - 7	points
	6 - 0	points



This comparison was done for all details, where the individual details of the “detail group” were compared to each other.

5.3.2 Comparison of costs

A holistic contemplation over the entire life cycle of a building means to cover also aspects about the recyclability and dismantling. Because of the fact, that a calculation for a demolition is quite difficult to undertake and mostly a cost estimation, it was decided not look at the whole demolition cost but to have a look at the disposal costs. Unfortunately there are no specific costs for simple dismantling steps available.

Therefore the disposal costs after the demolition were determined for each building. Already done measures regarding the mass and the individual component layers of each building simplified the listing of all existing building materials with their cubature and mass. That made it possible to calculate the disposal costs per m^3.

As assumed in the run-up the joining techniques, material diversity and building material selection have major influence on the disposal costs.

6. Critical evaluation of the model

The comparison of the buildings was not only meant as a comparative analysis, but also as a practical trial of the model. Pros and cons should get visible to think about further development.

A full and independent assessment regarding all aspects of sustainability is not possible with the developed model. It is considered as an additional tool to the German DGNB system. The focus in this work was the consideration of the technical quality on the component level, especially building constructions. Criteria that are part of the DGNB system and are relevant for a building construction were not considered, because a double evaluation of certain criteria should be avoided. But the tool was programmed in a way that the other qualities are linked and just have to be activated.

Following aspects can be pointed out as strengths:

- a deepened and detailed analysis is possible: all existing criteria, if relevant for the construction, can be evaluated
- rapid evaluation: it is possible, but not obligatory to assess all criteria, because
- no fixed maximum of points exists
- weighting is adaptable individually
- division in gross (without weighting) and netto points (with weighting)
- because of the programming in Excel a graphical display of the points is visible
- decision guidance for planers
- decision guidance for system manufacturer
- implementation into the DGNB system is basically possible, because it was the foundation of the evaluation model

In the course of evaluation it was possible to recognise concurrently some weaknesses:

- because of the programming in Excel a submission of criteria, points and weighting by hand is necessary
- the points to be awarded are not implemented in the tool, therefore the list with the criteria and their points is needed during the submission
- the submission by hand seems to afford a lot of effort at the first sight
- amount of sheets when printing the file
- bad definition for the German terminus “Tragkonstruktion” (supporting structure) in criteria K40

For a safe and more objective evaluation following points would need further development:

- eventually a new rating scale
- more specific explanations for the award for points for each criteria and
- eventually adding more criteria
- eventually adding the aspect “fitout” to criterion K40 with the same evaluation indicators as the aspect “supporting elements” in the same criterion
- implementation of criterion K41b “durability and robustness” into the tool
- implementation into the DGNB system

7. Conclusion

Out of the summarised view following conclusions regarding both the evaluation model as well as general aspects came up.

Use of the tool: the main field of application are these:

- additional tool for the German DGNB system
- decision aid for planers
- decision aid for system manufacturer

Basically the model can be used parallel to the planning stage for new buildings as well as during the renovation of existing buildings like f.e. for the comparison of alternatives. An advantage of the model is its flexibility – both a detailed and a rapid evaluation can be done. Now it is important to

develop tools for planers to implement sustainability in the building construction.

Content of the evaluation tool: device layers have different life spans – that is the reason why it is important to consider the different life ties in future planning and maintenance projects.

Dismantling: the demolition of a building is very difficult to calculate and often the announced costs are just estimation. In the future dismantling friendly constructions should make it possible to dismantle building components disposal-oriented and separate them varietal, whereby a dramatically increased added value out of the construction waste disposal can be earned. Basic requirement 7 of the upcoming Construction Product Regulation, after the transposition into national law, will force planers to consider the demolition and material disposal during the design. It has to be part of future planning.

Finally, it should be noted that the ultimate goal of sustainable building despite the highest demands on the assessment procedures should not be lost of sight: to leave a liveable built environment that can be returned to its original state at any time or that can be adapted to future requirement with the help of new technologies.

8. References

[1] Maydl P.; Sustainable Engineering: State of the Art and Prospects, in: Structural Engineering International, 3/2004, p 176-180
[2] Kommission der Europäischen Gemeinschaft: Mandat M/350 DE – Entwicklung horizontaler standardisierter Methoden für die Beurteilung der integrierten Umweltleistung von Gebäuden, 2004-03-29
[3] DGNB: Deutsches Gütesiegel Nachhaltiges Bauen – Handbuch, 2.Auflage. 03/2009
[4] Graubner C.-A., Lützkendorf T., et.al.; Umwelt und Nachhaltigkeitszertifizierungs-systeme für Gebäude im Vergleich, in: Bauingenieur, Band 84, Juli/August 2009, p. 320-329
[5] Lechner R. et.al.; TQB-Leitfaden für die TQB-Bewertung
[6] Maydl J.; Zum Einfluss der konstruktiven Durchbildung auf die Nachhaltigkeits-bewertung von Hochbauten, Dissertation TU Graz, November 2012

D5

Blue Buildings

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Development of LCA Tool for Use in Initial Stage of Housing Design Based on Endpoint Modeling of Residents

Part. 1 Examination of Assessment Framework

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Short Summary

In this study, we develop an integrated endpoint-type LCA tool for the initial stage of housing design. In this part of the study, we adopt the Japanese version of Life-cycle Impact assessment based on Endpoint modeling (LIME2) and examine the associated assessment framework for the case of a detached house.

Keywords: life-cycle assessment; based on endpoint modeling; housing; initial stage of design; human health

1. Introduction

Life-cycle assessment (LCA) tools for buildings can be classified into two categories. In the first, the potential effects on a specific region of the global environment and on human health are assessed. For example, CO_2 emissions or NO_2/SO_2 emissions can be assessed through a life-cycle assessment. We define this as a characterization LCA tool. Characterization method was proposed in the early 1990's by a publication of Code of Practice (Consoli et al. 1993) by SETAC (The Society of Environmental Toxicology and Chemistry) and etc. There are previous characterization LCA tools for detached house in Japan which are "LCA tool for building that added assessment of resource circulation" by Architectural Institute of Japan and "Building Environment Assessment Tool (BEAT)-house" by Building Research Institute Incorporated Administrative Agency.

The other type combines the effects on a number of regions and yields a single overall index. We define this as an integrated LCA tool. The integrated LCA tool can be further classified into two categories: the problem comparison type, in which the importance of each region is represented by a weighting factor; and the endpoint type, in which the assessments of each region are consolidated at the endpoint level. Integrated method was proposed in the early 1990's by Eco-scarcity (Ahbe et al. 1990) in Switzerland and etc. The endpoint type was adopted by improved version of Eco-indicator (Goedkoop et al. 1999) in the late 1990s. Previous integrated problem-comparison-type LCA tool is "Comprehensive Assessment System for built Environment Efficiency (CASBEE)" developed by Japan Sustainable Building Consortium. However, there is no previous integrated endpoint-type LCA tool in Japan.

Characterization and integrated LCA tools have been previously developed for detached houses in Japan; however, there is a need for an integrated endpoint -type LCA tool , that could comprehensively assess the direct influence of building safety and comfort on residents, as well as the cost-effectiveness of buildings at a local or personal level. Such a tool has the potential to be used as a communication tool for architects and their clients to determine the direction of housing design in the initial stages. In this study, we develop an integrated endpoint-type LCA tool for the initial stage of housing design. In this part of the study, we adopt the Japanese version of Life-cycle Impact assessment based on Endpoint modeling (LIME2) and examine the associated assessment framework for a detached house.

2. Assessment framework

2.1 Protected objects

LIME2 is designed to reflect environmental ethics, and as such “Human Health,” “Biodiversity,” “Social Assets,” and “Primary Production” are defined as protected objects. Human Health and Biodi-versity are defined as the rights of human society and ecosystems to exist. Social Assets and Pri-mary Production are defined as essential items needed to maintain human society and ecosystems. Since users of this tool are residents, Primary Production is excluded as a protected object because it is considered to have a negligible influence on decision-making in housing specification. Since the required cost of housing (internal cost) is considered to have the greatest influence on decision-making in housing specification, “Intraregional Residual Cost,” which is the contribution to the local economy from the cost of the project, is defined as a protected object. Based on LIME2, the assessment elements for Human Health are death or non-lethal handicap and disease. Similarly, the assessment element for Biodiversity is extinction of a species. The assessment elements for Social Assets are limited elements that might have a direct influence on the housing site, ambient environment, and local society.

This proposed LCA tool considers existing earthquake risk management and human health risk assessment methods, such as disability-adjusted life years (DALY) proposed by the World Health Organization (WHO), and a function to estimate this is embedded in the method. DALY can estimate the decrease in lifespan resulting from harm to human health. However, it cannot estimate the increase in lifespan caused by improvements in human health. Incorporating improvements in human health into this tool will remain a challenge for the future.

2.2 Category endpoint

In this tool, it was assumed that the house and surrounding environment fulfils the Building Standards Act and other environmental standards. Thus, category endpoints are set for each protected object. The category endpoint for Biodiversity is terrestrial species because they are considered to be relatively strongly influenced by housing.

In accordance with the reasoning described in 2.1, the category endpoints for Social Assets are crops and marine products, as well as user cost and the carbon offset from CO_2 emissions trading. The user cost reflects that resources cannot be extracted in the future because they have already been used. The category endpoint for Intraregional Residual Cost is the rate of local production for local consumption. This evaluation method will be addressed in future studies and would analyze characteristics of the region, such as population size and the distribution of different industries, to yield the correct internal cost.

Among the many environmental elements and agents, the elements that influence buildings are sound, noise, vibration, sunshine, daylight, color, heat, air, humidity, water, radiation, fire, and force. Noise, sunshine, daylight, and fire are not included because of the assumptions made about the usage of housing in this tool. At this time, vibration, humidity, and water are also not included owing to insufficient evidence about their influence. Radiation is not included because it represents a highly special case. In regard to sound and color, there are established solutions and these fac-

tors are routinely considered by almost every architect in the initial stage of housing design. For these reasons, heat, air, and force are the selected elements considered in the initial design stage that affect human health and cost in the long term. The category endpoint for Human Health are symptoms and events related to these elements. In the future, evaluation of symptoms and events caused by the other elements will be added to the assessment framework.

2.3 Influence region

The influence region is set based on the category endpoint. Damage to Biodiversity is divided into chemical effects and physical effects: chemical effects are caused by exposure to harmful substances; physical effects are caused by physical changes to the habitat, which affect the ecosystem. In this tool, the influence regions considered for Biodiversity are land use, fossil-fuel consumption, consumption of forest resources, and waste, because they correspond to physical effects that directly arise from buildings.

The influence regions for Social Assets are additional fossil-fuel consumption and consumption of forest resources. Also, acidification is considered, which represents the deposition of acidifying materials that can affect forest and marine resources, and photochemical oxidants affecting the production of crops. Based on LIME2, the loss of social assets caused by landfill of waste is also included. Since CO_2 emissions trading is currently being practiced, financial profits and losses are also taken into consideration.

The influence regions for Human Health are thermal stress, heat shock, urban air pollution, photochemical oxidants, indoor air contamination, building movements, and domestic accidents. The assessment framework is shown in figure 1.

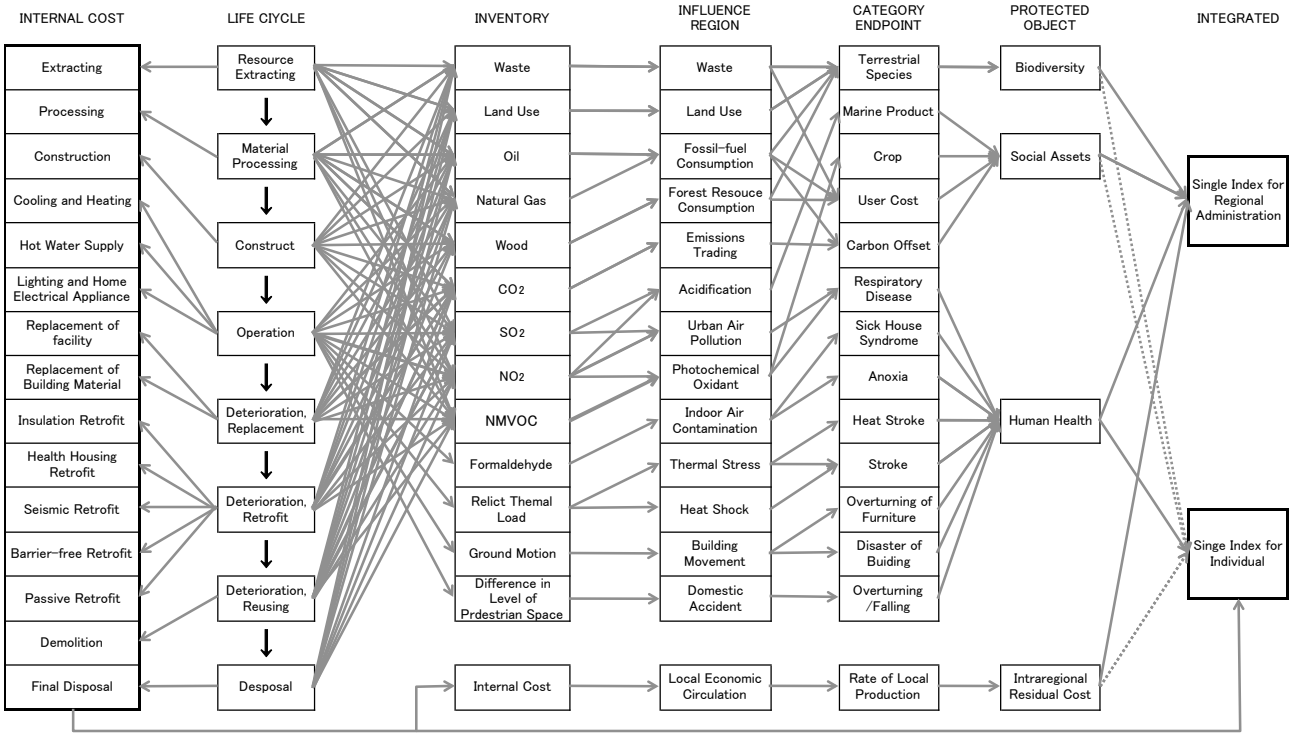


Figure 1: Assessment framework used in this study

3. Evaluation of assessment framework by case study

The cost was calculated for a case study using the assessment framework of LIME2 and the results were analyzed to examine the efficacy of the assessment framework.

3.1 Calculation model

The subject land is Akita city, Akita prefecture. With respect to land use, it was assumed that rice fields are transformed to land for buildings. The target families are a family of four with a husband, wife, and their daughter and their son (H1), and a family of two with an elderly husband and wife (H2). Both wives are full-time housewives. The average male and female life expectancies used were 79.59 years and 86.44 years, respectively. The assessment period was thirty years. The changes in household composition over thirty years are shown in table 1. The household incomes of the two families are taken from previous research and are based on the age of the husband (Ministry of Health, Labour and Welfare, 2010). The simulated housing types were C1, referred to as "Standard problem for house" (Utagawa, 1985), C2, which has thicker insulation than C1, and C3, which is an entirely air-conditioned house. The insulation efficiencies of C2 and C3 are the same. Specifications for each case and heights of furniture are shown in table 2. The heat source was heating oil and the heat source for hot water was city gas.

Table 1: Resident information

	H1	H2
Number of baths and showers	7 times/ person・week	7 times/ person・week
First year of assessment	Husband: 25 years old, Wife: 23 years old	Husband : 55 years old, Wife: 53 years old
Changes in household composition	A girl is born in the sixth year. A boy is born in the eighth year. The girl leaves the house in tthe 24th year. The boy leaves the house in tthe 26th year	Husband dies In the 26th year.

Table 2: Housing information for type of house

		C1	C2	C3
Insulation (thickness)	Ceiling	Glass wool 10K (65mm)	Glass wool 10K (200mm)	Glass wool 10K (200mm)
	Wall	Glass wool 10K (45mm)	Glass wool 16K (100mm)	Glass wool 16K (100mm)
	Floor	Glass wool 10K (40mm)	Glass wool 16K (100mm)	Glass wool 16K (100mm)
Air change rate (time/h)		1.0	0.5	0.5
Heat transmission coefficient ($W/m^2 K$)		5.8	2.8	2.8
Q valie ($W/m^2 K$)		4.14	1.87	1.87
Energy saving standerd		Old generation energy saving standard	Future generation energy saving standard	Future generation energy saving standard
Air conditioner location		Parlor only	Parlor only	All rooms
Furniture (height)		High chest (138cm), Microwave oven (35cm), Book shelf (197cm), Shelf (120cm), Kitchen cabinet (192cm), Range stand (120cm), Television (66cm)		

3.2 Assessments of ecosystem and social assets

3.2.1 Calculation method

Using LIME2, the amount of damage to the influence regions of the ecosystem and social assets were calculated. Each influence region and inventory is shown in table 2. With respect to mineral resource consumption, eco-toxicity, and eutrophication, it was difficult to acquire data on benzene, dioxin, copper, lead, nitrogen, and phosphorus, and it was decided that these could be safely ignored for normal housing. Therefore, mineral resource consumption, eco-toxicity, and eutrophication were not calculated in this study.

Table 3: Assessment framework of ecosystem and social assets

Influence region	Waste, Land Use, Forest Resouce Consumption, Fossil-fuel Consumption, Ozone Depletion, Global Warming, Acidification
Inventory	Waste, Land Use, Wood, Oil, Natural Gas, CFC, CO_2, SO_2, NO_2

1) Damage to ecosystem and social assets

Oil consumption was calculated from the heating load using a transient systems simulation program (TRNSYS). Schedules of cooling and heating were set using an automatic program for lifestyle scheduling (SCHEDULE). Natural gas consumption was estimated from the consumption of hot water using a previously reported formula (Sawachi, 1994). All natural gas was assumed to be composed of city gas, and the unit calorific value of city gas was taken as54.5MJ/kg. The unit calorific value of heating oil was45.9MJ/kg. The correspondence of heating oil to crude oil was 0.9L/L. The inventory quantities for waste (CFC, CO_2, NO_2, and $SO_{2)}$ were calculated using the detached house version of the LCA tool for buildings from the Architectural Institute of Japan. The quantities of material used for the foundations and building frame were calculated using a regression formula (Takayama, 2010); material quantities were estimated based on the "JUTAKUTOKUSYU" architectural magazine, and the regression formulae were derived based on this. The regression formulae are shown below.

Concrete: $y_c = 0.2073x_1 + 2.6164$ (1)
Reinforcing bar: $y_r = 6.5011\ x_1 - 153.47$ (2)
Lumber: $y_w = 0.0464x_2 - 0.1596$ (3)
y_c is concrete quantity, $y_{r\ i}$s reinforcing bar quantity, y_w is lumber quantity, x_1 is the ground floor space, x_2 is total floor space.

In LIME2, the inventory of land use is the product of the occupation time and occupation space. The occupation space was taken to be160.4 m^2,which is the average area of a detached house in Akita (Statistics Bureau, 2010). A formula for the amount of damage is shown below. The values of the damage coefficients were those from LIME2.

(Damage quantity) = (Damage coefficient) × (Inventory quantity) (4)

2) Internal cost

Costs of cooling and heating were converted from the cooling load and heating load calculated using TRNSYS. To determine the costs of hot-water supply and lighting, the energy consumption was calculated using a previously reported formula (Sawachi, 1994), and these were converted to costs. The costs of city gas and heating oil were three yen/MJ and 22 yen/kWh for electrical power. The costs associated with materials manufacturing, construction, and disposal were calculated using the detached house version of the LCA tool for buildings from the Architectural Institute of Japan.

3.2.2 Results and discussion

Figure 2 shows that the costs of ozone depletion and global warming were small in the ecosystem and social assets. Since the costs of acidification waste, land use, fossil-fuel consumption, and consumption of forest resources are measurable values, it is important that they be included in the assessment framework.

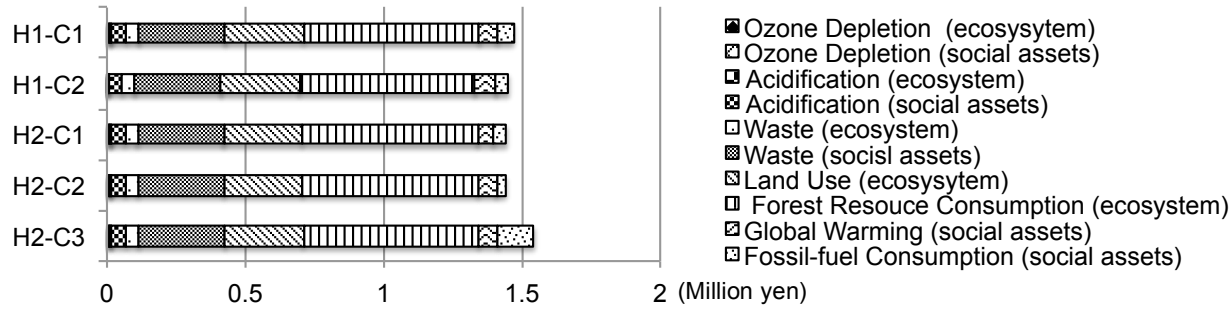


Figure 2: Cost of damage to ecosystem and social assets

3.3 Assessments of human health

3.3.1 Calculation method

Based on LIME2, the amount of damage to the influence regions of human health were calculated. Each influence region and each inventory is shown in table 3. As it is difficult to calculate the damage associated with heat shock, it was not calculated in this study. Similarly, it is difficult to calculate the amount of damage caused by heat stroke and stroke. In this study, these were replaced with heat stress and cold stress, and the amount of damage associated with these was calculated. The calculation of damage arising from heat stroke and stroke will be addressed in the future. With regard to damage caused by building moving, this is calculated as the amount of human suffering caused by toppling furniture. The methods for calculating damage caused by disasters and domestic accidents is discussed, but these damages were not calculated in this study.

Table 4: Assessment framework of human health

Influence region	Ozone Depleting, Global Warming,Urban Air Pollution, Indoor Air Contamination, Thermal Stress, Building Movement
Inventory	CO_2, CFC, NO_2, SO_2, Formaldehyde, Relict Themal Load, Ground Motion

As in LIME2, the conversion of DALY to yen was 14.7 million yen/DALY, which represents the cost of a reduction in life expectancy. This value does not include medical costs, and this will be addressed in future studies.

1) Damage quantities caused by indoor air contamination and thermal stress

The cost of sick house syndrome was calculated using a previously reported formula (Narita, et al., 2005). The release rate of formaldehyde from floors is 20 $\mu g/m^2h$ and from walls/ceilings is 5 $\mu g/m^2h$. The thermal load was calculated using TRNSYS. The annual indoor temperature was calculated, and the DALY resulting from heat stress and cold stress was calculated using a previously reported formula (Honda, et al., 1998), in which the dependent variable is outdoor temperature. The indoor temperature was modified to reflect improvements in the indoor temperature; the modified formula is shown below.

(Modified daily maximum temperature) =
(Daily maximum temperature) × (Mean indoor temperature of measured house) / (Mean indoor temperature of standard house) (5)

2) Damage caused by building moving

This damage was estimated by earthquake intensity and indoor condition. DALY was calculated according to the damage level, as shown below.

DALY = YLL + YDL (6)
YLL = N × L (7)
YDL = I × DW × L' (8)

YLL is the number of years lost by premature death, YDL is the number of healthy years lost by disability, N is the number of deaths, L is the average life expectancy at the age of death, I is the number of accidents, DW is the injury weight, L' is the average number of years until being cured or until death.
In this study, the formula for calculating the damage caused by toppling furniture is shown below.

YLL' = N × L ×(Mortality rate) × (Earthquake occurrence probability) (9)
YDL' = I × DW × L' × (Injury rate) × (Earthquake occurrence probability) (10)

YLL' is the number of years lost by premature death caused by toppling furniture, YDL' is the number of healthy years lost by disability caused by toppling furniture.

The mortality rate and injury rate were calculated using previously reported formulae (Midorikawa, et al., 1995;Okada, et al., 2003). The injury weight of DALY is taken from the Abbreviated Injury Scale (AIS). Median values of injury weights were used as representative values.

A long-term assessment published by the Headquarters for Earthquake Research Promotion was consulted to estimate the probability of furniture toppling. The potential earthquake is off the coast of Akita prefecture (magnitude of 7.5) on the eastern margin of the Japan Sea. It was assumed that the earthquake occurrence probability is the Poisson distribution for which the average occurrence interval is over a thousand years. The expected earthquake intensity is a seismic intensity of six or lower (Akita prefecture disaster prevention council, 2011). The annual earthquake occurrence probability is 0.1%, and accumulates annually. The amount of damage accounts for the household composition in the year it is calculated The most damage is the result of toppling furniture.

3.3.2 Results and discussion

Figure 3 shows that the amount of damage associated with toppling furniture is highest in the case of H1. A high probability of deadly wounding and a 100% toppling rate of furniture was used. In the future, this method must be reviewed. Since the damage associated with ozone depletion and global warning were small, we believe that the assessment framework for human health in this tool is effective.

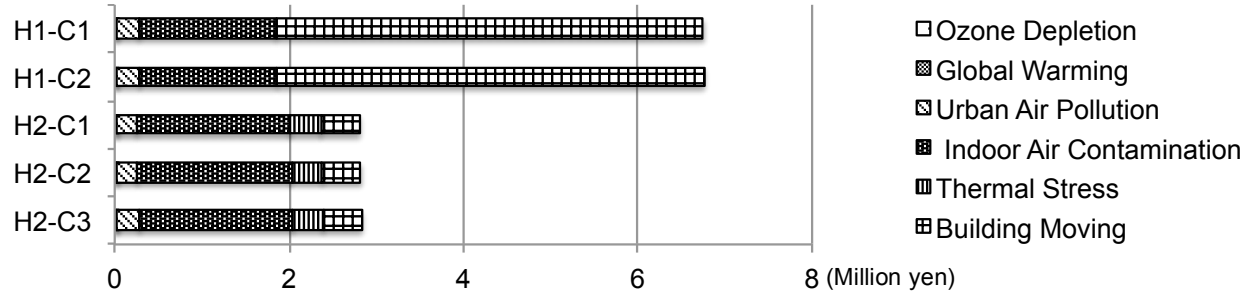


Figure 3: Cost of damage to human health

3.4 Full-cost assessment

A result of the full-cost assessment is shown in figure 4. Before the basic design, multiple housing types can be considered to decide on the best option. This figure shows that operational costs are highest. It is thought that a full-cost assessment would encourage the client to choose housing using the cost-effectiveness estimate from the LCA.

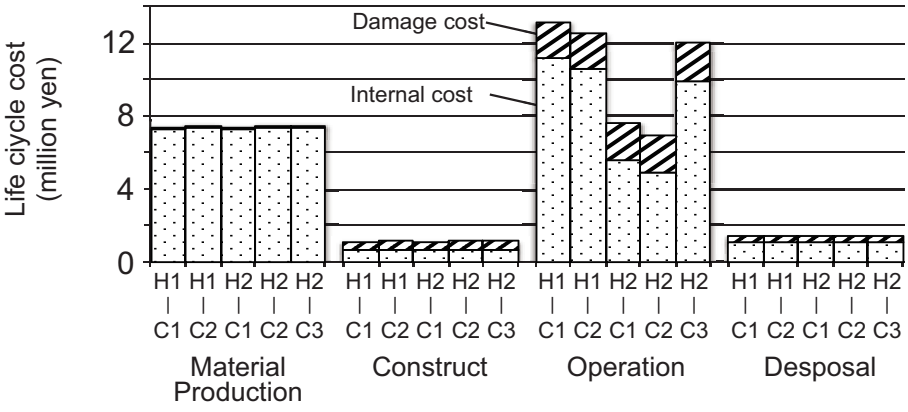


Figure 4: Full-cost assessment

4. Conclusion

In this part of the study, we have proposed a new housing LCA tool that can comprehensively assess potential damage to residents, and we have tested the assessment framework in this tool. We carried out a case study to confirm the utility of this tool. According to the case study, the overall trend of the results showed that operational costs were the highest costs.

Aspects of the study that should be improved further include the methods used to calculate toppling furniture and medical costs. Based on the results presented here, we will develop a prototype of this tool and assess its applicability.

5. References

[1] Consoli, et al. Guideline for Life – Cycle Assessment: A Code of Practice, SETAC-Europe, Brussels, 1993

[2] Ahbe, et at. Method for Ecobalancing based on ecological optimisation, BUWAL 133, 1990

[3] Goedkoop, et al. The Eco-indicator 99, A damage oriented method for life cycle impact assessment, Pre Consultants, Amersfoort, 1999

[4] Architectural Institute of Japan. “The publication of LCA tool for building that added assessment of resource circulation”. http://news-sv.aij.or.jp/tkankyo/s0/site/arc08.html

[5] Building Research Institute Incorporated Administrative Agency, Japan et al. “Design guideline for Autonomous Housing”. Institute for Building Environment and Energy Conservation, Japan, 2005

[6] Japan Sustainable Building Consortium. Comprehensive Assessment System for built Environment Efficiency (CASBEE), “CASBEE for House (Detached Houses) assessment manual”. Institute for Building Environment and Energy Conservation, Japan, 2010

[7] ISaka, et al. “LIME2”. Japan Environmental Management Association for Industry, 2010

[8] Earthquake risk management group. “Practical use of earthquake risk management method aimed at promoting earthquake countermeasure”. Architectural research, No.103, 2005

[9] Architectural Institute of Japan. Architectural Design Data Corpus, Environment 1”. Maruzen, 1978

[10] Ministry of Health, Labour and Welfare, Japan. “Abridged life table”. 2010

[11] National Tax Agency JAPAN. “Statistical survey about private salary”. 2012

[12] Utagawa. “Proposal of standard problem, standard problem for housing”. Architectural Institute of Japan, environment engineering committee 15th thermal symposium, 1985

[13] University of Wisconsin. “TRNSYS User’s manual”. 2012

[14] The Society of Heating, Air-conditioning and Sanitary Engineering in Japan. “SCHEDULE ver.2.0 manual”.

[15] Sawachi, et al. “Energy consumption for different uses in dwelling and Its estimation formulas: Study of energy consumption in residential buildings from the viewpoint of life style on the basis of national scale surveys part 1”. J. Archit. Plann. Eng. AIJ, No.462, 41-48, 1994

[16] Takayama, et al. “A study on designing support of roadmaps for low carbon societies by an evaluation of $LCCO_2$ using GIS of the local government : Part 1 an evaluation of $LCCO_2$ from detached houses using local government information”. Architectural Institute of Japan, Tohoku branch study report collection, No.73, 115-118, 2010

[17] The Statistics Bureau and the Director-General for Policy Planning of Japan. “Statistical survey about housing and land”. 2010

[18] Honda, et al. “Shift of the short-term temperature mortality relationship by a climate factor - some evidence necessary to take account of in estimating the health effect of global warming”. Journal of Risk Research, Vol. 1, No. 3, 209-22, 1998

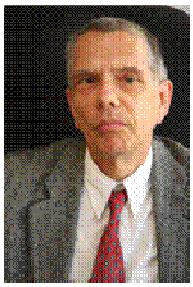
[19] Narita, et al. “Development of life cycle impact assessment methods for the indoor air pollution: Study on health damage caused by indoor air pollution (Part 1)”. J. Environ. Eng., AIJ, No.592, 83-88, 2005

[20] Midorikawa, et al. “Evaluation of earthquake injuries in office buildings”. J. Struct. Constr. Eng., AIJ, No.476, 49-56, 1995

[21] Okada, et al. “Estimation for human casualty due to furniture overturned in earthquakes”. Architectural Institute of Japan, synopsis collection of convention, B-2, 63-64, 2003

[22] Akita Prefecture Disaster Prevention Council. “Akita prefecture regional disaster prevention plan”. 2011

Contribution of plastics to the sustainability of buildings



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Summary

The contribution of plastic materials and plastic products towards more sustainable buildings is covered from a full life cycle perspective, taking into account the three pillars of sustainable development.

Environmental impacts of plastics manufacturing are weighed against contributions of plastic products in saving scarce resources (energy, water, etc.). Economic aspects are discussed in terms of cost effectiveness, based on the “Total Cost of Ownership”, i.e. life cycle costs borne by the owner/user. Last but not least, a few social considerations are developed, such as health and safety of workers and users, convenience afforded to the user, and the possibilities of creating innovative products.

Keywords: Plastic; life-cycle; eco-profile; insulation; windows; piping

1. Introduction

Buildings are responsible for roughly 40% of the EU’s energy consumption and greenhouse gas emissions [1]. Improving the energy efficiency of new and old buildings is therefore one of the keys to tackling climate change and saving resources. Around 70% of the energy used in buildings is due to space heating and cooling. With new legislation on the energy performance of buildings adopted in 2010, the European Union has set targets for all new buildings to be “nearly zero energy” by 2021 (2019 for new public buildings). However, even in 2050 most buildings will have been built before 2010. An ambitious programme of energy-efficient renovation of existing buildings is therefore needed as well. This will require a huge effort, in which all construction materials and products will have a role to play.

Energy is only one aspect of sustainability, albeit a paramount one. Both the construction of new buildings and the renovation and operation of existing ones must take into account all aspects of sustainability, i.e. energy and raw materials consumption or savings during all phases of the life cycle of the building, as well as other environmental impacts; cost effectiveness; health and safety of the workers involved throughout the value chain and of the users; the convenience afforded to the user, to name only a few.

This paper will present the contribution plastic products can bring to this array of goals.

2. Applications of plastics in buildings

Building and construction is the second largest market for plastic products in the EU, after packaging. More than 20 % of the plastics raw materials go into these long life applications, a yearly amount close to 10 million tonnes. The average working life of all plastics applications in construction is 35 years [2]. Use of plastics in construction has been growing rapidly: in 2002, it represented less than 7 million tonnes. Compared to other materials the total weight of plastics used is still small, but they make a significant contribution to a large variety of applications.

Plastics are widely used in thermal insulation products, window frames, shutters, piping systems, electric and telecommunication cables and cable ducts, roofing membranes, floor coverings, interior decoration, fitted furniture, fencing and decking. Photovoltaic cells and solar panels also rely on plastics.



Fig. 1: PVC window frame



Fig. 2: PS insulation board

3. Environmental benefits and impacts

3.1 Life cycle perspective and data availability

PlasticsEurope was the first industry organisation publishing detailed environmental data, and Life Cycle Thinking (LCT) remains a guiding principle of advocacy. By means of a comprehensive view on production systems and product life cycles, the LCT approach enhances the understanding of product benefits and burdens. Under its former APME name, PlasticsEurope first launched the Eco-profile Programme almost 20 years ago. Today, there are more than 70 Eco-profile reports available for free, covering all major plastic materials as well as monomers. Eco-profiles are detailed reports on product or material specific environmental impacts. Based on European industry averages of the respective polymer production technologies, those published by PlasticsEurope include detailed environmental datasets – the so-called life cycle inventory (LCI) – and environmental key performance indicators. Their scope is from cradle (extraction of raw materials) to gate (un-compounded precursors or resins) [3]

By providing publicly available data about the environmental performance of plastics production, the Eco-profile programme not only responds to stakeholder needs but also fosters continuous improvement, innovation and competitiveness among plastic manufacturers. Downstream users, such as plastics converters and brand owners, employ eco-profiles as an invaluable data resource

because they are reliable building blocks for LCA studies. In line with current trends and the standards developed by CEN TC 350, Environmental Product Declarations are now being derived from these eco-profiles, and are also made freely available.

3.2 Energy

Efficient heat insulation of roofs, walls, cellars and windows is a key element for reducing energy consumption. In addition, solar panels and cells further reduce energy use. Plastic products contribute to the solutions in all these applications. Combining thermal insulation with triple glazed windows can for example reduce energy consumption by up to 80%. Each year over 80 million new windows are needed in Europe. If high standard window frames were installed all over Europe tomorrow, this would eliminate the need for five large power stations [4]

All insulation materials, including plastics, have strong and weaker features; no material is best in all building applications and hence one should always choose the one best adapted to a specific need. Any insulation level can be achieved with the appropriate product thickness; it is therefore more useful to assess the respective merits of various materials on their other properties, some of which described later. At this stage, the discussion can focus merely on the energy saved over the life time of a product compared to the energy used for its production. In the case of plastic insulation, the ratio exceeds 200:1 [5].

3.3 Efficiency in the use of other resources

Raw materials, water and land use have to be considered. The plastic materials used to produce insulation products and windows are still to a very large extent based on non-renewable raw materials. Ethylene, the chemical feedstock most plastics derive from, can however be produced from natural sources. This route is not developed yet for economic reasons as well as because doing so with the current technology would hugely strain land resources. It will benefit from technology progress as production of bio-fuels and chemical building blocks is shifting to natural sources which do not compete with food production.

The current production route of plastic insulation already uses 83 % less water and 99 % less land than the production of stone wool, for example. [6]

Many plastics are very good insulators, affording the desired insulation performance with thinner products than most competing materials (fig. 3). This allows optimum use of space, an essential feature especially when renovating existing buildings.

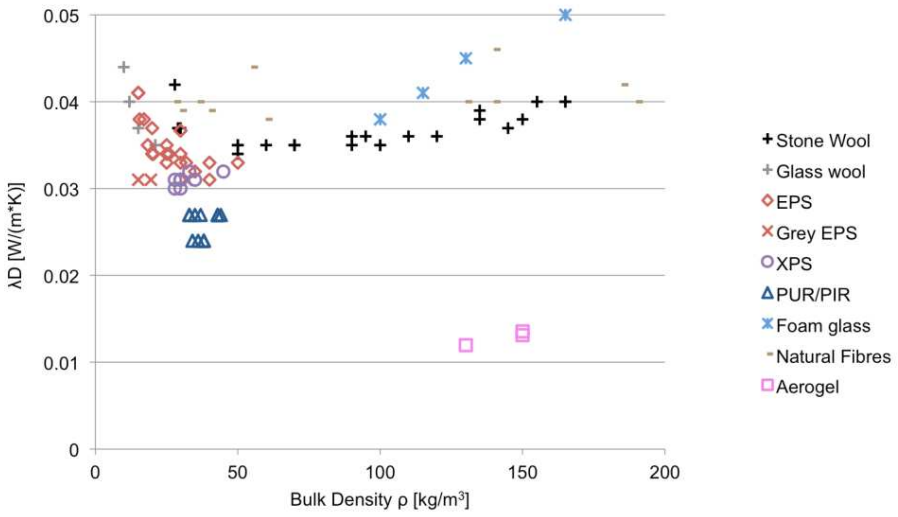


Fig. 3: Thermal conductivity versus density of products on the European market 2011, courtesy Büro für Umweltchemie, Zürich

Plastic insulation materials are also highly durable, require no maintenance and perform at the same high level over the whole life of the building. Needless to say, durability is the most effective way to save resources. Plastic pipes are durable, corrosion-free and smooth, thereby reducing water losses and deposits. The latter in turn decreases pumping energy or, in the case of sewers, avoids over-designing. Typically a 300 mm ID PVC slimed sewer pipe laid at 1:200 running full bore will achieve 90 l/s compared to 69 l/s for a 300mm ID concrete pipe [7].

3.4 End of life

Plastic waste is a minor component of B&C waste. A recent report estimated it ranges between 0.1 % and 2% of construction and demolition waste arising in the EU [8]. An earlier report estimated it at 0.7 % [2]. This is because a large proportion of plastics used in the construction industry have an intended life of many decades, and because use of plastics is a relatively recent phenomenon. Hence the amounts and proportion of plastic waste will obviously be growing in future, requiring careful consideration of the various options.

As construction products are usually tailored to a specific building, re-use of discarded products is in general not an option. Recycling is then the next preferred solution in the waste hierarchy of the EU Waste Framework Directive. However recycling of plastics from C&D waste is facing a series of obstacles [9]:

- Cost, time and space needed for dismantling and separation, especially in urban areas
- Lack of synergy between local/regional authorities and the private sector
- Low cost and/or poor control of landfilling
- Lack of sorting/crushing plants
- Cross-contamination and general mixing of materials

For example, most insulation products, either plastic or from other materials, are difficult to recycle, as these products are often contaminated by other materials, rendering recycling costly or impractical. On the other hand, plastic profiles and pipes are easier to collect and recycle. Almost 105,000t of window profiles and other profiles, as well as 24,000 t of pipes were recycled in 2011 as a part of the schemes funded by the PVC industry [10].

Across the EU-27 plus Norway and Switzerland, more than half of plastics building and construction waste is now being diverted from landfill through a combination of recycling and energy recovery. It is interesting to mention that trends show strong disparities in recovery rates from country to country. Germany provides an example of what can be achieved with the right infrastructure and regulations in place, recovering nearly all of its plastic building and construction waste while Southern Mediterranean countries send most of it to landfill. The overall recovery of plastic waste in the building and construction sector shows a positive trend, improving from 56.2% in 2010 to 57.6% in 2011.



Fig. 4: Treatment of building/construction plastic waste

4. Economic efficiency

4.1 Total Cost of Ownership (TCO) methodology

The TCO methodology is an economic analysis focused on the customer of a product. It adds up the costs borne by the owner or user over the entire life of the product: purchase, transport, installation, use, maintenance, dismounting and end-of-life management. All data are adjusted to net present value, thereby allowing a comparison of different products.

4.2 Application to some construction products

The TCO methodology has been applied to window profiles, water mains and sewage pipes, as well as flooring, as available and used in Germany and in Italy [11]. Compared to wood and aluminium windows, PVC plastic has the higher net present value over a 30 years lifecycle. The TCO of plastic pipes is the lowest among the materials commonly used, i.e. ductile iron for water mains, clay or concrete for sewage pipes. The TCO differences range between 19 and 52 %. Installation cost is the main cause of such differences for sewage pipes. In the case of water mains, the difference is due to purchase and use costs, the latter being related to a lower pumping energy required by plastic pipes as deposit formation is much less prevalent.

5. Social aspects

5.1 Safety

5.1.1 Reaction to fire

The European classification for reaction to fire is harmonized at EU level and is described in EN 13501-1. On the other hand, national fire regulations specify the allowed product classes for any given category of building (e.g. hospital, public building, high- or low-rise residential). All construction products placed on the market have to comply with these regulations. To achieve the intended level of safety, the application and the whole concept of a building are taken into account. Concerning the application of insulation materials for example, requirements are not only focusing on the classification of the products but also where they are used and how they are applied.

Plastics are combustible, like many natural construction products such as wood, and hence in some specific conditions it is necessary to add flame retardants in plastic products in order to achieve the required level of fire safety. The plastic industry is fully confident that EU legislations (e.g. REACH), as well as the institutions in charge of implementing these legislations, ensure the appropriate levels of consumer and environmental protection. Appropriately designed plastic products can reach fire classifications up to B.

5.1.2 Safety of workers during production and installation

Plastic raw materials are produced by large chemical companies in highly regulated conditions. The safety record of the European petrochemical industry is one of the best among all industry sectors. The weight of the products per functional unit is an important factor determining the level of occupational health risk further down the chain. Heavier products put a higher stress on the body of the worker. For example the insulation of a flat roof with 25 cm of stone wool weighs about 45 kg/m^2. An equivalent insulation with XPS or EPS is about 10 times lighter. Handling safety also relates to certain physical properties of the materials that affect the degree of care that has to be taken during installation in order to assure the durability of the materials or in order to prevent damages. Rigid insulation materials for instance are more difficult to handle than flexible ones since they require more attention in order to prevent gaps between the insulation boards and the building structure. Rigid materials are also more prone to deformation due to differences in temperatures and humidity, which requires also special care during installation. The flexibility of plastic products renders installation easier and safer than many traditional solutions.

5.2 Health/hygiene

5.2.1 Indoor air quality

Indoor air quality (IAQ) is the focus of increased attention, as natural air flows are more and more restricted in order to save energy. Appropriate ventilation is necessary to preserve health and comfort. IAQ related burden of disease (BoD) was analysed in a recent report from the European Commission. The main causes of BoD are combustion particles, building dampness, volatile organic compounds (VOC), radon and carbon monoxide. VOCs account for about 8 % of the total BoD. The main contributors of VOCs are paints and furniture. An assessment of the key sources of exposure concluded that building materials account for about 0.2 % of the total burden [12].

Most plastic construction products do not contain VOCs, and/or are shielded by a layer of e.g. plaster. The few that may emit VOCs into indoor air include flooring, decorative ceiling or wall covering products. These products are tested for emissions, for instance under the German AgBB scheme.

5.2.2 Maintenance and housekeeping

Plastic products have generally smooth surfaces which are easy to clean. They require neither painting/varnishing, nor chemical cleaning. This contributes to lowering the exposure of workers and occupants to potentially hazardous chemicals, as well as emissions to the environment. Easy cleaning also helps maintaining a high level of hygiene at home and, even more relevant, in health care facilities, schools and buildings open to the public.

5.3 Convenience, choice and innovation

Durability, minimum maintenance needs and easy cleaning as mentioned above are major contributors to the convenience of users.

The large variety of plastic materials affords a wide choice of solutions for many uses. They also give much playing room to architects and designers.

Plastics are still a young material and one can be confident that future developments will continue. The future is difficult to predict, but some possibilities might include:

- Transparent photovoltaic cells printed onto plastic films as window glazing bringing about high-efficiency, power-generating windows
- The resistance to corrosion, light weight and strength of fibre-reinforced plastics composites will enable the construction of durable load bearing concrete structures.

6. Conclusion

The sustainability criteria discussed in this paper overlap to a large extent with those used by building certification and rating systems such as e.g. BREEAM (UK), LEED (US), HQE (France), and DGNB (Germany). Rating systems based on a broad spectrum of environmental, economic and social criteria, and offering a more holistic view than single criteria systems (such as carbon footprint for example), should be welcomed, provided that they are based on an assessment of the entire life cycle of the building and of its components, and that they follow the principle of risk assessments rather than discriminating substances solely on the basis of hazard. Eco-labels should follow the same principles in order to convey meaningful information to the consumers.

This holistic view may appear complicated, but it is the only one capable of correctly assessing buildings, their components, and the materials they are made of. The diversity and complexity of the building industry requires such a broad perspective. Its environmental, economic and social importance deserves the effort.

7. References

[1] Speech by EU Commissioner Connie Hedegaard “The need for progressive European Agenda” (March 2012)

[2] “Guide Towards Sustainable Construction and Demolition Waste Management in Europe”, APPRICOD project of Life Environment Programme, (2006), pp 12 – 13

[3] http://www.plasticseurope.org/plastics-sustainability/eco-profiles.aspx

[4] Marcus Hermes “Potential to save energy through the use of modern window systems in Europe”, 2006

[5] “*Innovations for Greenhouse Gas Reductions*”, International Council of Chemical Associations - ICCA (July 2009), p.31.

[6] “*Beyond “carbon footprint*”: The contribution of plastic products to various resource savings”, Denkstatt GmbH, Vienna, 2012

[7] http://www.teppfa.org/More-about-Sewer-FAQ-1.asp

[8] “*Management of construction and demolition waste*”, BIO Intelligence Service on behalf of European Commission (DG ENV), February 2011, page 18

[9] Guide Towards Sustainable Construction and Demolition Waste Management in Europe”, APPRICOD project of Life Environment Programme, (2006), page 15

[10] *VinylPlus Progress Report 2012*, page 23 www.vinylplus.eu

[11] Marangoni A. “*PVC products competitiveness*” http://www.pvcconstruct.org/en/p/pvc-tco

[12] Jantunen M., THL, Oliveira Fernandes E., FEUP, Carrer P., “*Promoting actions for healthy indoor air (IAIAQ)*”, on behalf of Directorate-General for health & Consumers, 2011

Relevance of the recycling potential (module D) in building LCA: A case study on the retrofitting of a house in Seraing



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Short Summary

Following EN 15978 [1], the informative module D allows crediting a building for the recycling potential of its materials and the exported energy. Whereas the relevance of this module has largely been associated with the environmental assessment of metals so far, it is not clear to what extent module D is relevant in the life cycle assessment (LCA) of buildings. In this paper a building renovation case study is considered to investigate and discuss the implications of including module D in a building LCA.

The environmental impacts of the building elements and materials are analysed using a cradle-to-grave LCA, including module D. The impacts related to the different life cycle stages are compared to each other and discussed in relation to the input and output materials. The results initiate a discussion on the controversial module D and illustrate the potential effects of this module compared to the rest of the life cycle.

Keywords: Life Cycle Analysis (LCA); Recycling; Module D; Renovation; Environmental Assessment; Building LCA; LCA Methodology; Cradle to Grave; System Boundary

1. Introduction

The consideration of recycling aspects in life cycle assessment (LCA) has been a point of discussion for several years. In general there are two contrasting approaches to account for recycling in LCA: (1) the recycled content approach, which considers the benefits of recycling at the input side of the life cycle and (2) the end of life recycling approach, which accounts for the benefits of recycling at the output side of the life cycle [2].

According to the European standards concerning the sustainability of construction works EN 15804 [3] and EN 15978 [1], a building's life cycle information is organized along three major life cycle stages: (A) the product and construction process stage, (B) the use stage and (C) the end of life stage. The system boundary at the end of the life cycle is set where outputs have reached the "end-of-waste" state, leading to the recycled content approach. However, for the building assessment information, the standard identifies an additional optional life cycle stage (D) describing the benefits and loads beyond the building life cycle. This stage, also called module D, allows crediting a building for the recycling potential of its materials or the exported energy. The calculation of module D thus allows using the end-of-life recycling approach.

The consideration of module D is argued to be important for metals [2], but it is not clear to what

extent this approach impacts the results for building LCA's. Moreover, the consideration of module D appears to be straightforward for certain product LCA's (e.g. metals), but the complexity increases when performing a building LCA. In this paper a building renovation case study is considered to investigate and discuss the implications of including module D in an LCA for buildings.

2. Case study

The renovation of a 4-storey high multi-family house located in Seraing, a city in the Liège agglomeration (Belgium), is analysed for this study. The building includes 3 apartments and a commercial space and has been renovated using industrial products claimed to be suitable for environmental friendly renovation. A deep renovation is pursued in order to meet the current needs and standards in terms of comfort, space and energy requirements.

The existing building was composed of brick walls (without thermal insulation) and a sloped roof with ceramic tiles (see Fig. 1). The main structure of walls and floors are preserved during the renovation. Due to city regulations, external insulation of the façade is not possible. As a result, the external walls are insulated from the inside, using a system wall with a metal structure, filled with mineral wool and covered with gypsum plaster boards. The original street façades are preserved and the façades of the new top floor and south side are covered with metal sheeting. All windows and doors are replaced and new interior walls are assembled using a dry wall system composed of a metal frame structure and gypsum plaster boards. The entire roof structure is removed and replaced with a steel structure and steel roof covering in order to provide a useable living space on the third floor (see Fig. 1). On the south side of the building, a new building annex is constructed to create an additional bedroom for each apartment.

As the renovation project includes quite some materials that are recyclable, the benefits and loads beyond the building life cycle (module D) are calculated in the LCA in order to illustrate the potential effects of this module compared to the rest of the life cycle.



Fig. 1: Case study: Multi-family house in Seraing with renovated steel roof, walls insulated from the inside and annex on south side of the building. Representation of the old situation (left) and the renovated situation (middle and right)

3. Methodological approach

LCA is a technique to assess the environmental impact of a product throughout its life cycle, from raw material extraction, via production and use phases to waste management. It is a scientific approach, broadly applied in practice and used to improve the environmental performance of industrial applications. Following the methodological framework defined in the ISO14040 standard on life cycle assessment [4,5] an LCA approach consists of 4 major steps: (1) the goal and scope definition, (2) the inventory of data, (3) the impact assessment and (4) the interpretation of results. The harmonised European standards EN 15804 [3] and EN 15978 [1] on the sustainability of construction works, describe the methodology and calculation methods to be used for the

environmental assessment of building materials and complete buildings. This study is performed according to the principles of ISO 14040 and the European standards [1,3].

3.1 Goal and system boundaries

The aim of this study is to evaluate the environmental impact related to specific retrofitting actions performed during the renovation of a building in Seraing and to discuss the relevance of including module D in a building LCA. The functional unit is a 4-storey high multi-family house with three living units and a commercial space, a total floor area of 280 m² and a reference service life of 60 years.

The LCA is a *'cradle-to-grave LCA including module D'*, with consideration of the 'product stage', 'construction process stage', 'use stage', 'end of life stage' (EOL) and the 'benefits and loads beyond the system boundary' as defined in *Table 1* and described in EN 15978 [1]. For materials going to recycling, the system boundary between the system under study and the system that will use the waste is set at the gate of the sorting plant. This means that all subsequent processes (transport to recycling facility and recycling process itself) are allocated to the product that will use the secondary material.

Table 1: Overview of life cycle stages considered in the LCA, according to EN15978 [1]

Product stage	A1-3	Production of new materials
Construction process stage	A4	Transport of new materials
	A5	Installation of new materials
Use stage	B4	Replacements: Disposal of materials that need to be replaced and production, transport and installation of the new materials
	B6	Operational energy use of building-integrated technical systems, which are covered by the Energy Performance of Buildings Directive
End of Life stage	C1-4	Demolition process, transport to the treatment facility, impact of EOL treatment and final disposal
Benefits and loads beyond the system boundary	D	Reuse-, Recovery-, Recycling- potential

Following EN 15978 [1], the informative module D declares the potential loads and benefits of secondary material, secondary fuel or recovered energy leaving the product system. This module is primarily intended to describe in a transparent way the potential benefits of avoided future use of primary materials and fuels – and loads associated with the recycling and recovery processes.

In this study, module D reports on the loads and benefits of:

- the recycling potential of materials
- exported energy generated by photovoltaic panels.

Materials for energy recovery (e.g. through incinerations) are not considered because of the lack of data available on the efficiency of waste incineration installations in Belgium. As a result, the impact of materials being incinerated is fully allocated to the building life cycle (within the system boundary).

The disposal of materials and equipment removed as part of the refurbishment is not taken into consideration because the impacts of these existing materials and equipment have already been accounted for in their previous life cycle. Only the structural elements which will last for another life cycle are retained during the renovation process, but these do not generate impacts within the current LCA.

3.2 Life cycle inventory (LCI)

3.2.1 Generic data and use of scenarios

The LCA is modelled using Simapro software. The considered building system can be broken down into a certain number of unit processes related to the production, transportation, construction and EOL of building materials and to the use of energy for heating, ventilation, ... For the collection of inputs and outputs related to these unit processes generic data is used from the ecoinvent database v.2.2 [6], harmonized with the Belgian/European energy mix.
The ecoinvent database contains LCI datasets for the production of various common building materials (cradle to gate LCI data = impacts from material extraction, transport to the production site, production process and infrastructure), and separate datasets for the different disposal options (incineration, landfill or recycling), as well as for various transportation modes (different types of trucks, train, boat,). Transport distances and waste treatment processes are based on specific scenarios, representative for the Belgian situation.

For the transport of the materials to the construction site and the waste treatment processes at the end of life, the study makes use of the scenarios established within the Flemish study OVAM MMG [7]. These scenarios describe the typical transport distances, routes and transportation modes for different product material groups. For the EOL scenarios, it is assumed that all demolition waste is transported to a collection point (e.g. sorting plant, crushing facility first, scrap yard) and is then redistributed amongst the various waste treatment options.

3.2.2 Recycling potential

Potential benefits or avoided loads related to recycling, reuse and energy recovery can be based on a specific scenario which is consistent with any other scenario for “waste” processing and is based on current average technology or practice [3]. The recycling scenarios considered for this study are represented in *Table 2*. For materials recycled in a closed loop (such as steel), any secondary materials used as inputs for the system are subtracted from the secondary material leaving the system at the end of life, in order to avoid double counting and calculate the net impacts for the net output flow. Recycled content is based on average current production technologies. Recycling rates for each product are determined based on the EOL scenarios.

Table 2: Scenarios used to determine the recycling potential at the end-of-waste point (to be declared in informative module D)

Material to be recycled	**Secondary material**
Steel	Secondary steel (closed loop)
Concrete, screed,	Secondary granulates for roadwork (open loop)
Concrete blocks, bricks, facing tiles,	Secondary granulates for roadwork (open loop)
Untreated sawn timber, wooden boards (MDF, OSB), parquet	Wood chips (open loop)
Interior plaster (crushed together with concrete granulates)	Secondary granulated for roadwork (open loop)
Facing tiles, ceramic wall and floor tiles,	Secondary granulated for roadwork (open loop)
PE-foil, vapour barrier,	Secondary PE granulates (open loop)
Gypsum plaster board	Gypsum plaster (open loop)
Aluminium in window frames	Secondary aluminium (closed loop)
Glass	Glass cullets (closed loop)

3.2.3 Quantification of the building

A material inventory was assembled based on drawings and the actual composition of the renovated building. These quantities represent the net amounts of materials and do not account for the losses that occur during transport, handling, or installation. The inventory considers all new materials used in the building, with the exception of materials for the water drainage and the exterior stairs.
Technical installations for heating and ventilation (boilers, radiators, photovoltaic panels, ducts, fans,), sanitary installations (kitchen and bathroom) and electrical installations (wiring, lighting,) are excluded from the study.

The life cycle of the building renovation is set to 60 years for the analysis. Building elements with a shorter life span (like windows or gypsum plaster boards) are considered to be replaced during this period. Assumptions regarding the probable service life of the materials and components are based on standard values used in the ecoinvent database v2.2 [6] and existing LCA tools, as well as values from literature [e.g. 8,9].

3.3 Life cycle impact assessment (LCIA)

After an analysis of different impact assessment methodologies [10,11], we opted to interpret the LCI results using the ReCiPe method [12]. This method makes use of the state of the art LCIA methodologies and it enables to present the results both at midpoint and endpoint level - thus allowing to quantify various environmental indicators (each with their proper unit) as well as to determine a global environmental score (expressed in points) after a process of normalization, grouping and weighting. The higher the score, the larger the environmental impact. Even though the ISO and EN standards do not recommend the weighting and aggregating of different impact categories it allows for an easier comparison and interpretation of the results.

As recommended by the author of the ReCiPe method, the present study makes use of the version ReCiPe endpoint Hierarchist method (Europe, average), which is based on the most common policy principles with regards to time-frame and other issues [12]. When discussing the “impact” of a material or building element in this paper, this refers to the single score (of aggregated impact indicators) unless when specified otherwise.

4. Results

First, we discuss the environmental impact of the total building over its considered life cycle stages. In the subsequent sections, these results will be broken down according to the different building elements and discussed for the different life cycle stages.

4.1 Total impact per life cycle stage

Fig. 2 shows the results of the full cradle-to-grave analysis, including module D, of the total building renovation case. The impact related to the energy use over the building’s considered service life (60 years) clearly dominates and represents about 80% of the building’s total life cycle impact. Within this energy use, the largest impact is related to the use of energy for heating. The energy gains from energy generated by the photovoltaic cells are reported in module D, but seem to be insignificant.

The impact of the materials introduced for the retrofitting works is organised according to the different life cycle stages: production, transport, construction, replacement, end of life, and recycling potential (Fig. 2). The largest material impacts result from the production stage. Next, the impacts resulting from module D and the replacements are in the same order of magnitude. Finally, the impacts related to transport, construction and end of life are negligible compared to the other life cycle stages.

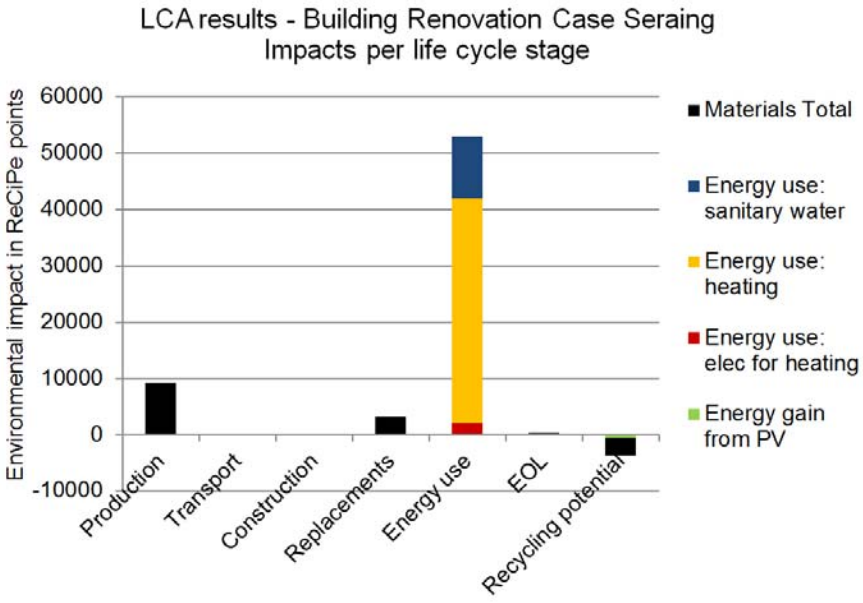


Fig. 2: Impacts of the total building renovation case per life cycle stage, including module D.

4.2 Production, installation and EOL of materials

When excluding the impacts of the energy use during the use phase, the results can be evaluated per building element (Fig. 3). The highest environmental impact among the different building elements is related to the materials for the roof and intermediate floors. Also the exterior walls, interior walls and windows and doors have a considerable impact.

ROOF - The environmental impact of the roof is mainly related to the production of low-alloyed construction steel (66% of the total impact). 10% of the impact for the roof can be allocated to the use of timber and 8% to the use of mineral wool.

INTERMEDIATE FLOORS - About 43% of the environmental impact of the intermediate floors originates from the parquet used for the finishing layer. An investigation of the different environmental indicators shows that the environmental impact of these hardwood floors is mainly linked to the environmental indicator ‘Agricultural Land Use’. It should be noted that no scientific consensus exist concerning this indicator and that these results thus should be considered within the proper context. The other relevant impacts of the intermediate floors can be linked to the oriented strand board (14%), the mineral wool (11%), the gypsum fibre board (9%) and the gypsum plaster board (6%).

EXTERIOR WALLS - The environmental impact of the exterior walls results from a number of different materials: the hollow concrete block walls (19%), the facing bricks (18%), the mineral wool used to insulate the main building (10%), the PUR rigid foam board used to insulate the annex (10%) and the steel used to cover the south façade and the annex (8%).

INTERIOR WALLS - The largest impact of the interior walls is related to the use of ceramic wall tiles in the bathroom (35%). The construction steel used in two new supporting beams determines the impact for 28%. The gypsum plaster board (17%), mineral wool (6%) and galvanised steel used for the supporting structure of the interior walls (metal frame) (5%) represent smaller portions of the impact.

WINDOWS - The impact of the windows can in large (78%) be related to the life cycle of the aluminium frames.

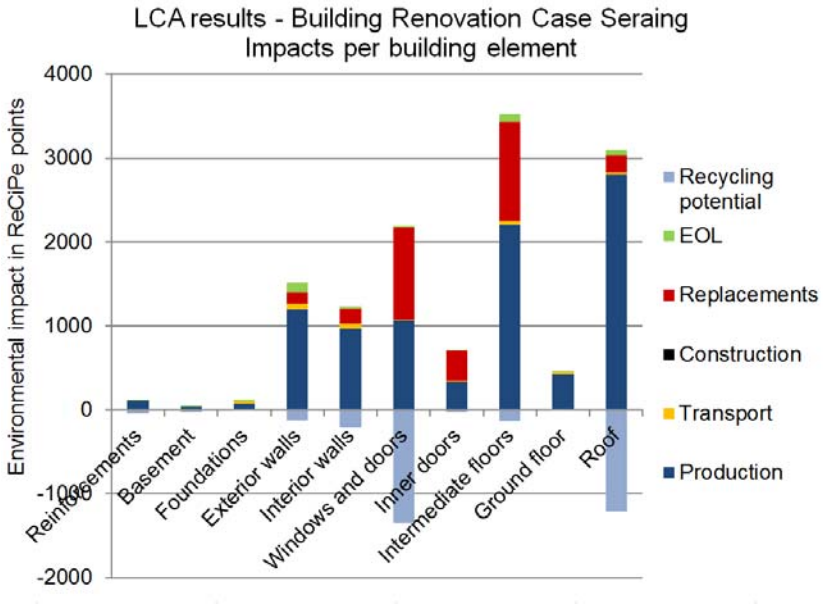


Fig. 3: Environmental impact of the materials over their life cycle, according to the different building elements, with indication of recycling potential (module D).

4.3 Replacements of materials

Fig. 3 shows that the impact of the replacements is significant for the windows and doors, which are replaced once during the considered life cycle. Also the replacements of the wooden floors after 30 years have a substantial impact. The impact of replacements in the interior walls will be limited as the gypsum panels are replaced after 30 years, but the metal studs and insulation are supposed to remain in place.

Most of the materials used for the building envelope (exterior walls and roof) do not have to be replaced during the reference service life. Consequently, the initial impact of the materials dominates the material impact for most building elements. However, we should note that the study does not account for repairs or partial replacements during the life time, which implies that the calculated impact is slightly underestimated.

4.4 Module D

The recycling potential of the materials and their associated environmental loads and benefits were modelled according to the scenarios described in *Table 2*. Materials with a recycling potential used within the current building are mainly: steel (recycled into steel), concrete or bricks (recycled into granulates) and untreated wood (recycled into wood chips).

The environmental impacts related to the recycling potential (module D) are represented in Fig. 3 as negative impacts and can be compared to the impacts related to the other life cycles. This shows that the potential benefits from recycling the materials are considerably high for both the roof and the windows and doors. For the roof, 98% of the avoided impacts are related to the high use of steel, where 95% up to 99% is recycled into new steel (see Fig. 4a for network diagram). Also for the windows, the majority of the avoided impacts can be linked to the high recyclability of aluminium (98% of module D impacts). The high recyclability of the glass panes (with 70% recycling rate) represents only a small part of the module D impact (see Fig. 4b for network diagram).

The impacts reported in module D for the other building elements are rather small (Fig. 3) because of the non or low recyclability of the materials (e.g. mineral wool, gypsum board), or because of the low benefits related to the recycling process (e.g. concrete, bricks). For the exterior and interior

walls, the potential benefits in module D can be linked to the use of steel for structural purposes (supporting beams and metal frame for dry wall system). In the intermediate floorings, the module D impact is related to the recyclability of the hard wood floors into wood chips.

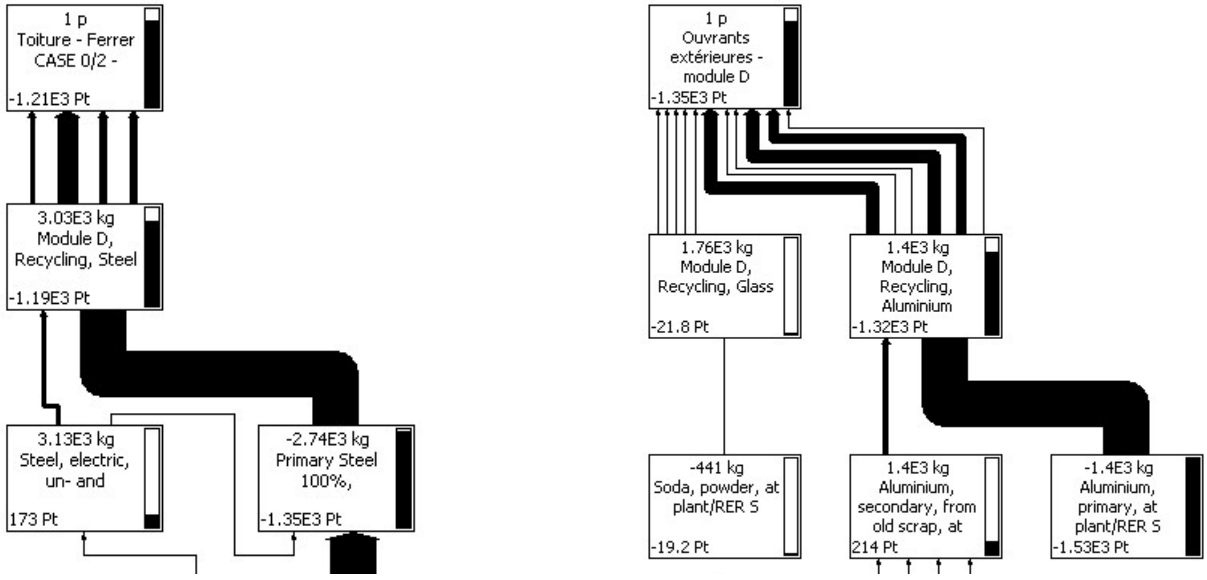


Fig. 4: Network diagram illustrating the materials representing the major impacts in module D for (a) the roof and (b) the windows and doors.

5. Discussion

5.1 Dominance of use phase

Comparing the environmental impacts generated over the different life cycle stages, the LCA results reveal that the highest environmental impacts are related to the energy use during the occupancy phase of the building. This is in line with several other building LCA studies, which illustrate that the building occupation phase is the most important stage in terms of environmental impacts - especially for conventional buildings - and that these impacts can mainly be related to the heating demand [e.g.13-15]. The results of this study confirm that the initiatives to perform better from an environmental point of view, should first be considered from the point of view of reduction of energy during the use phase. Alternative energy production systems, as well as higher insulation levels might lead to a decrease of the building's overall environmental impact.

However, it should be noted that the relatively high importance of the use phase compared to the impact of the materials is also largely related to the fact that it concerns a renovation project: besides the limitations in terms of thermal performance (e.g. thermal bridges, air tightness), only a limited amount of new materials are being added to the renovated building. Consequently, relatively seen, the impact of the energy during the use phase is likely to be higher for a renovation project than for a new construction.

5.2 Relevance of module D

The results of this case study analysis suggest that the consideration of module D at building level can be significant: the module D impacts are of the same order of magnitude as the impacts of the replacements, and are significantly larger that the impacts related to the transport, construction and EOL of the materials. This suggests that, even though module D is stated to be optional, it can provide some relevant additional information concerning the recycling of materials at the end of life.

However, it should be noted that the case considered for this study contains a lot of metals: the roof is composed of steel beams and a steel covering, part of the façade is covered in metal, metal

profiles are used in the dry wall system and the window frames are aluminium. Whereas the large amount of recyclable materials was partially the incentive for calculating module D in this LCA study, the results also reveal that the potential benefits reported in module D are strongly - or even almost strictly - related to the use of metals. This confirms the relevance of considering module D for metals [1] but makes it hard to discuss the relevance for other building materials. It seems obvious that materials with low recycling rates (like PE) do not show in the module D impacts. However, it is surprising that certain materials with high recycling rates (like glass or concrete) are hardly visible in module D.

Typical Belgian buildings usually use large amounts bricks and concrete materials with high recycling rates (around 95%). In the present case only a small amount of these materials is considered for the LCA as the majority of walls is preserved during the renovation. As a consequence it is hard to value the relevance of module D for these materials at the scale of the building based on this study.
Nevertheless, at the material level, the LCA of the bricks and concrete materials used in this study shows a rather small contribution to module D, which appears to be in the same order of magnitude as the impacts of the transport and EOL life cycle stages. The small module D impacts can be explained by the fact that bricks and concrete are considered to be down cycled into secondary granulates to be used for roadwork (common practice in Belgium). As a result, their avoided impacts relate to the mining and crushing of primary granulates. The latter process is far less energy and resource consuming than the production process of the concrete or bricks themselves and therefore will not outweigh the impact related to the production phase. Thus materials with high recycling rates do not necessarily relate to high (avoided) impacts in module D.

In general, one should be conscious of the fact that the impacts reported in module D do not tell the complete story about a material's potential beyond the system boundary. Whereas the module D impact might be relatively small for materials like concrete or bricks, it reveals nothing about issues like avoidance (or production) of waste or market demand for recycled materials. Future research on the specific implications of calculating module D for different material types could provide further insights in the actual relevance of incorporating module D in building LCA's.

6. Conclusions

Comparing the environmental impacts generated over the different life cycle stages, the LCA results reveal that the highest environmental impacts are related to the energy use during the occupancy phase of the building. However, for buildings with a better thermal performance (such as passive houses or nearly zero energy buildings) and for new constructions (with a larger of amount of materials used for the building), the relative importance of the use phase will become smaller and the decisions taken at material level will become more significant.

The present study reveals that the consideration of module D in a building LCA is possible and can be relevant. It provides additional information on the potential of materials beyond the building's life cycle and can represent a significant part of the total building impact. For the presented case, the impacts related to module D are larger than those related to transportation, construction and end of life. However, the case also shows that the impacts being reported in module D are strongly related to the use of metals in the building. Based on this study, we can state that module D will show a considerable impact for buildings containing a large amount of metals, but these results cannot be generalized to other buildings without further investigation. Research on the recycling impacts of different types of materials is desirable to get a more holistic view on the value of module D at building scale.

7. Acknowledgements

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8. References

[1] EN 15978:2011. *"Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method"*. European Committee for Standardization (CEN), 2011.

[2] LEROY C, THOMAS J-S, AVERY N, BOLLEN J, TIKANA L. *"Tackling recycling aspects in EN 15804"*. Proceedings International Symposium on Life Cycle Assessment and Construction, July 10-12, Nantes, France, 2012.

[3] EN15804:2012. *"Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products"*. European Committee for Standardization (CEN), 2012.

[4] ISO 14040:2006. *"Environmental management - Life cycle assessment - Principles and framework"*. International Standardization Organization, Geneva, Swiss, 2006.

[5] ISO 14044:2006. *"Environmental management - Life cycle assessment - Requirements and Guidelines"*. International Standardization Organization, Geneva, Swiss, 2006.

[6] HISCHIER R *"Implementation of Life Cycle Impact Assessment Methods - Final report ecoinvent v2.2"*. Swiss Centre for Life Cycle Inventories, 2010. [Online]. Available: www.ecoinvent.org

[7] DELEM L, VAN DESSEL J, JANSSEN A, DEBACKER W, SPIRINCKX C, ALLACKER K, DE TROYER F. *"Bepalingsmethode Milieugerelateerde Materiaalprestatie van Gebouwelementen (MMG)"* . Openbare Vlaamse Afvalstoffen Maatschappij, 2012.

[8] SBR "Levensduur voor bouwproducten. Methode voor referentiewaarden". SBR, Rotterdam, 2011.

[9] "INIES - Base de données Française de référence sur les characteristiques environnementales et sanitaires des produits de construction". Association HQE, France, 2009.

[10] JRC *"ILCD Handbook - General guide on LCA"*. Joint Research Centre, Institute for Environment and sustainability, European Commission, 2010.

[11] GUINEE J et al. *"Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards"*. Kluwer Academic Publishers, The Netherlands, 2002.

[12] GOEDKOOP M et al. "ReCiPe 2008, A life cycle impact assessment method which comprices harmonised category indicators at the midpoint and the endpoint level, 1st edition, Report I: characterisation". VROM, 2009

[13] VRIJDERS J, WASTIELS L, HERINCKX S. *"Costs, benefits and environmental impact of achieving NZE level in renovation: a case study"*, Proceedings PassiveHouse 2012 Conference Proceedings, Brussels, 2012.

[14] ANNEMANS M, VERHAEGEN M, DEBACKER W. *"Life Cycle Assessment in architecture practice: the impact of materials on a flemish care home"*. Proceedings International Symposium on Life Cycle Assessment and Construction, July 10-12, Nantes, France, 2012.

[15] GUSTAVSSON L, JOELSSON A. *"Life cycle primary energy analysis of residential buildings"*. Energy and Buildings, 2010, Volume 42, pp. 210–220.

Decision making processes in sustainable refurbishment projects for public administration



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Short Summary

Most existing real estate portfolio management systems lay their focus on tangible assessment criteria, leaving the value of a building for a corporation in terms of user satisfaction or support of the core business aside. Therefore M.O.O.CON developed a holistic portfolio management system which enables the user to base portfolio decisions on an analysis of all organizational, technical and economical factors. This leads to feasible allocated resources on refurbishment projects that support achieving an organization's goals. The early planning phases of sustainable refurbishment projects are efficiently supported by assessing life cycle costing parameters for project alternatives. This method was successfully adopted from the federal province of Vorarlberg, which holds more than 120 buildings within their portfolio.

Keywords: Portfolio management, sustainable refurbishment, corporate, life cycle costing

1. Introduction

While enthusiastic self-imposed code of practices as well as EU directives (EPBD – energy performance of buildings directive) demand that Austrian federal states and municipalities apply high modernization standards when refurbishing their existing building stock, public administration faces a wide array of challenges [1][2].
Considering budgetary limits of federal states and governments, a four step methodology was developed that helps public administration to successfully tackle energy efficient retrofitting projects within their existing building portfolio while focusing on a rational and transparent decision making process.
This work presents a method that allows policy makers to first evaluate their existing building stock and identify leverage points before heading into complex and costly refurbishment projects. Stated procedure, which ought to be implemented in accordance with public officials, follows four steps:

1. Developing Criteria for portfolio evaluation
2. Evaluating the existing building stock
3. Compilation of specific strategy for each object
4. Initiating sustainable refurbishment project based on specific object strategy and analysis of project's life cycle costs

2. Methodology

Ever increasing competition and the long-term capital commitment connected to real estate have changed the perspective of which corporate real estate is viewed today. While corporate buildings used to be considered as passive capital, they are nowadays understood as assets which can be enhanced in value [3]. This has led to the question of how a portfolio consisting of various objects which differ in nature can be structured best.
Most existing portfolio management tools were developed for large property funds, thereby focusing on tangible assessment criteria such as earning capacity or technical conditions.

Public administration and municipalities, on the other hand, which also act as tenant, do have great interest in evaluating their building stock with a broader but objective method.
For this reason, M.O.O.CON developed a portfolio management system which takes all organizational, technical and economic criteria into account which suit the client's specifications and needs regarding its building stock.

2.1 Developing Criteria for portfolio evaluation

In a first step the corporate objectives for real estate are levied and documented in structured interviews. Based on these objectives and common systems for object- and service strategies (e.g. certification systems), the assessment criteria which are relevant for the user are determined.
These criteria are then clustered for specific object groups: office buildings, schools, housing et cetera.
Generic criteria for all building clusters sum up the complete set of criteria for evaluation. Figure 1 demonstrates the systematic approach of deriving the object strategy from evaluated buildings and leading to a portfolio strategy.
While developing criteria intangible factors such as user satisfaction or core business enhancement are relevant and need to be considered for these kinds of stakeholders.

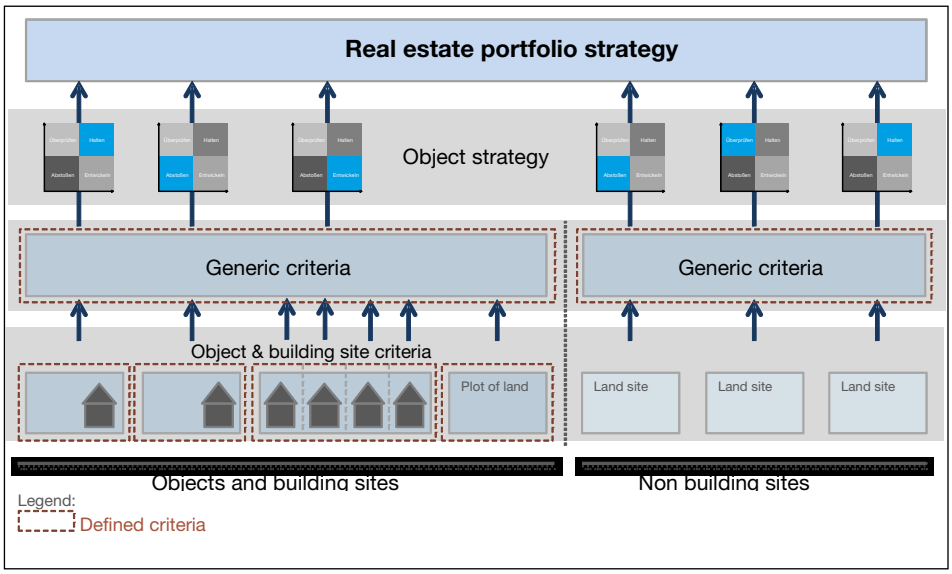


Figure 1 Systematic approach for a heterogeneous portfolio

2.2 Evaluating the existing building stock – Status quo

M.O.O.CONs portfolio management system focuses on the holistic analysis and strategy development of real estate portfolios. The basis of this analysis is represented by the portfolio model which contains assessment criteria that reflect the quality of each particular building. Each of the developed criteria can be assigned an evaluation weight, providing the possibility to

influence how much one criterion contributes to the final result (see figure 2).

Furthermore, each developed criterion will be assigned its weight for the evaluation. Subsequently, the grades will be awarded for each particular building and criterion. The combined weights and grades are then converted into the overall-grades for the building or the sub-categories.
The additional factors which influence strategic decisions (generic criteria) are then determined in a further step.

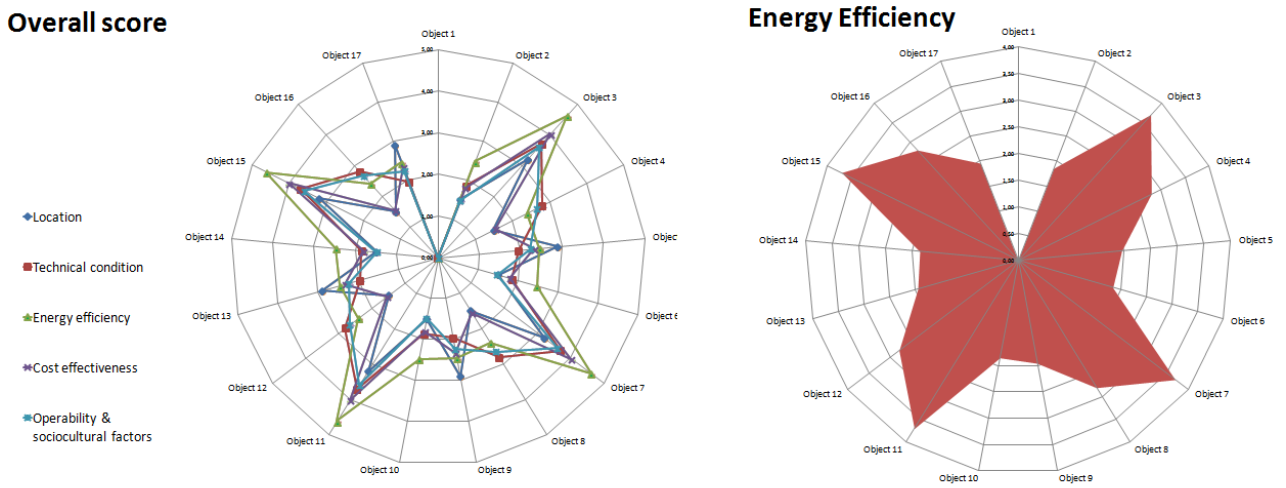


Figure 2 Evaluation of a portfolio with seventeen objects

2.3 Compilation of specific strategy for: each property and object

For the actual assessment of each object, grades are given for each weighted criterion. Based on the grades awarded and the assigned weight, a final grade can be calculated for the total object or the assessed sub-categories:

1. Location
2. Technical quality
3. Energy
4. Economical quality
5. Functional/socio-cultural quality

The visualization of the results for each assessed criterion, the sub-categories and the overall grade for each building in form of graphs enable the system user to identify outliers or pitfalls easily.

In addition to this object evaluation, all factors which influence strategic decisions are determined separately. These extra criteria lead to the strategic decision whether or not a building should be held or divested, regardless of the actual object assessment. The evaluation of both, the building and the strategy influencing factors, enable the system user to objectively decide about the future steps for the portfolio. These steps mainly distinguish between four different scenarios: hold, refurbish, examine or divest. Thereby the user can chose between different levels of detail. An example of an overview of a total portfolio analysis is shown below in figure 3.

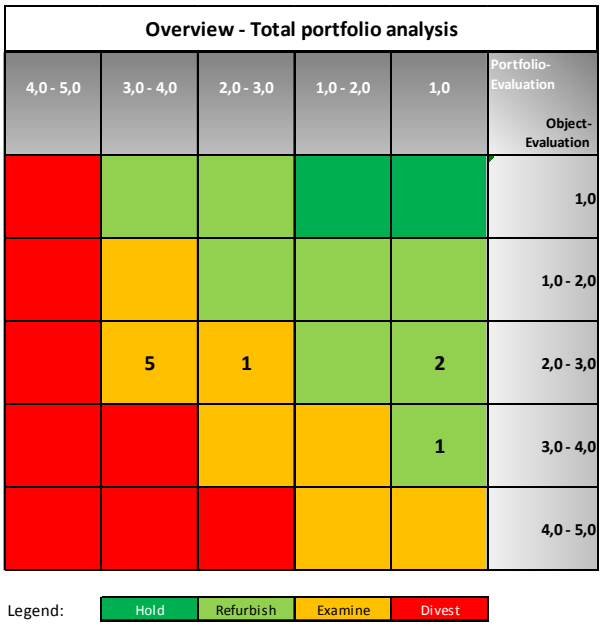


Figure 3: Overview total portfolio analysis

However, the analysis of the portfolio is not a means of itself. It creates a foundation for future scenarios, such as reducing the number of sites or identifying necessary refurbishments.

The described system and method were applied on an Austrian federal state which operates 88 public buildings with a total usable building area of 500.000 m². The paper presents the implementation of the portfolio management system. Based on the developed strategy all buildings categorized as “refurbish” are singled out. The necessary refurbishment scenarios for these buildings are compared by using life cycle costing.

2.4 Initiating sustainable refurbishment project based on specific object strategy

In accordance with the holistic process of evaluating an organization’s real estate portfolio and identifying buildings which call for action (see figure 3) to either:

- Refurbish or
- Examine

an object strategy derived from the client’s demand and requirement supports public officials to allocate resource to objects within its portfolio in a evidence based and controlled manner.
Thus avoiding incomprehensible public spending, while concentrating resources on key assets in a sustainable process.

In this case study for an Austrian federal state the next, logical step was to act upon one analyzed object strategy and investigate possible refurbishment scenarios for this specific building.
Due to the evaluation and preliminary defined goals for building standard and services a possible solution space for the existing building was quickly developed.

The existing building is an administrative building which houses offices, a conference center and ancillary services (e.g. cafeteria, storage, garage, data center). After more than 34 years of operation (built 1979), the office building faces a significant backlog concerning reinstatements and renewals resulting in

a) Depreciation of real estate
b) Questionable legal certainty regarding current norms and regulations (e.g. fire protection)
c) High costs for utilities and operation

d) Energy efficiency does not comply with self imposed sustainability goals

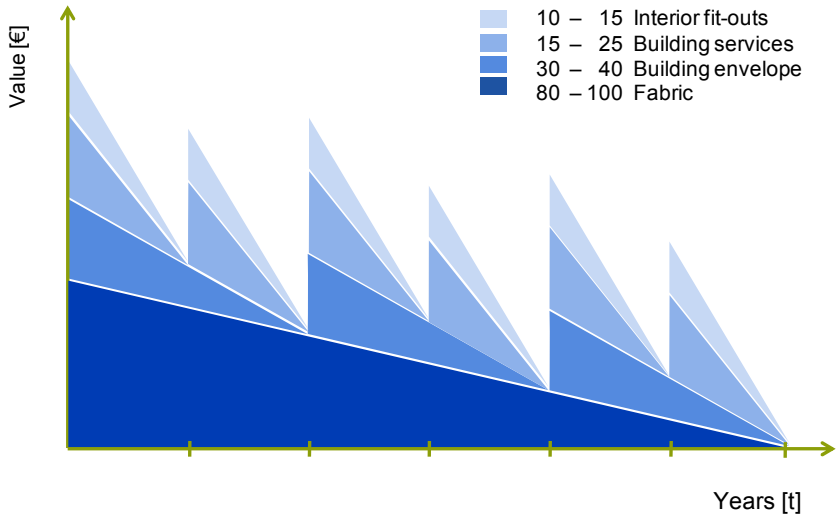


Fig. 4: Interval of renewals according to theoretical service life for different building components.

In a first step the buildings condition was examined from a life cycle point of view: which building components have reached or passed their given service life? Figure 4 shows an idealized model of a building's life cycle and its components while Figure 5a shows the given building's examination. Besides minor technical reinstatements and a modernization procedure along the way, the building's value decreased according to building components' rates of depreciation.

In several workshops consisting of client, users and facility management three basic refurbishment scenarios were developed and characterized using a probabilistic approach [6]:

1. Event driven refurbishment
   The current strategy of only reinstating components and facilities once they do not function anymore will be continued with minor renewals over the upcoming fifteen years. An assumption was taken that due to the delay of fundamental renewals of building envelope and central building services a breakdown of several systems within a short time frame will occur.
2. Fractional refurbishment
   This scenario follows the strategy to split up necessary refurbishment actions into separate tasks that are tackled over the course of several years with the idea of a economically smoothly balanced approach.
3. The third scenario follows the principle that a holistic refurbishment approach that yearns for high standards regarding energy efficiency and sustainability can only be achieved when necessary renewals are integrative tackled. Thus bundling the modernization of building elements and components that are functionally linked (e.g. modernizing the building envelope as well as the HVAC).

Figure 5b displays the results of the first life cycle cost analysis of roughly described scenarios above. The calculations also features a energy calculation based on EN ISO 13790 combined with significant improvements including a monthly balancing method. Thus making it possible to rate the refurbishments scenarios' energy demand and costs. Furthermore, costs for maintenance and cleaning are calculated for each scenario based on chosen building components (see Pongratz et al. [4]). The graphs in figure 5b shows cummulated costs for refurbishment and follow up costs along the scenario's life cycle.
When looking at the given refurbishment scenarios (Figure 5b), alternatives not only differ in the timing and execution of refurbishment, but also in varying strategies concerning the building's

energy system.
Supposedly efficient energy concepts may finally end up raising the building's life cycle costs due to complex building services equipment, which on the one hand achieve a certain decrease of the annual energy consumption level but that –on the other hand- leads to overwhelming maintenance requirements and operations costs outweighing the benefits.

The LCC analysis shows that comparing refurbishment scenarios with an established life cycle costing method (for further details on LCC-Tool and its methodology see: Pongratz et al. [4]) allows a timely review a project's framework as well as economically and energetically tangible impacts.

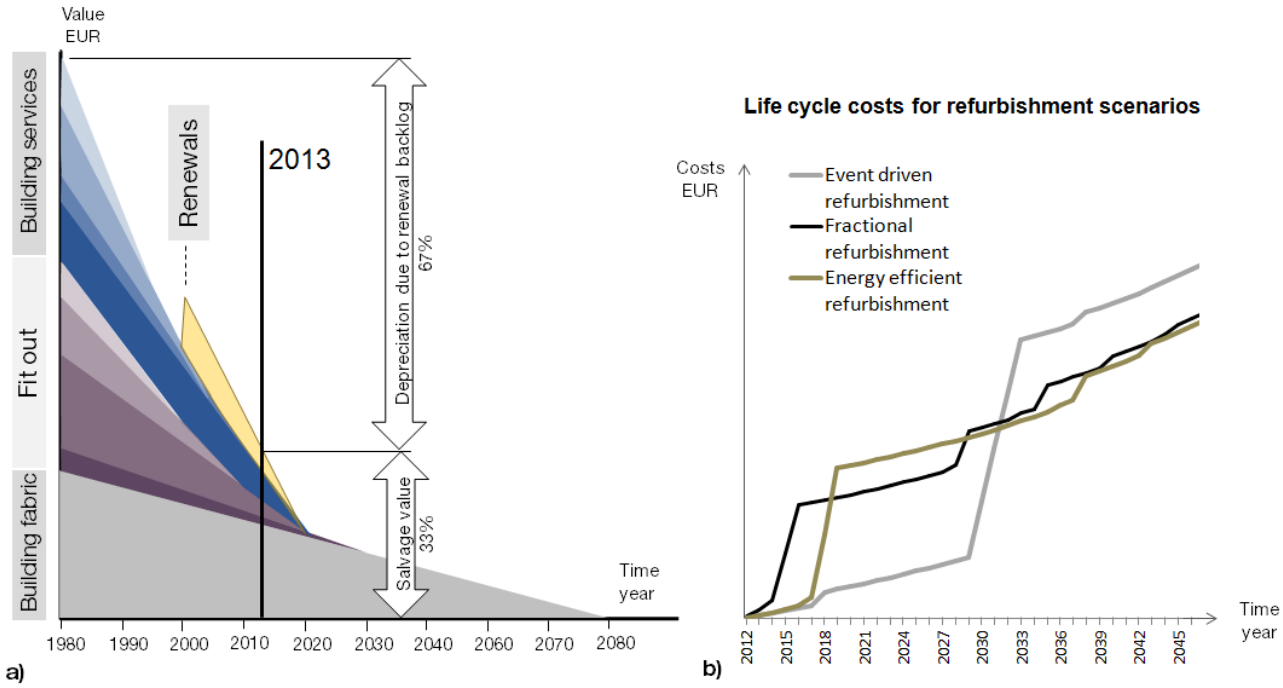


Fig. 5: Life cycle analysis for three refurbishment scenarios

3. Conclusion

Before concentrating on certain refurbishment projects within a given building stock, first an evaluation of the entire building portfolio allows the efficient allocation of resources. Most existing real estate portfolio management systems lay their focus on tangible assessment criteria, leaving the value of a building for a corporation in terms of user satisfaction or support of the core business aside. Therefore new portfolio management tools and methods need to be fully customized for public administration that manages buildings for own usage.
This allows a holistic and evidence based approach that support an informed decision making process. When an object strategy is derived, life cycle costing guarantees the continuous controlling of initially set goals of a developed portfolio strategy.

Although life cycle costing for buildings has been implemented in many national norms and building certifications, during early refurbishment project phases, i.e. during the phases when the project's fundamental structural parameters of environmental footprint and resulting costs are created and decided, LCC-tools have not yet found their way into general project management procedures [5].

LCC tools and their early involvement in the planning phases of refurbishment projects undoubtedly support the planning and decision making process underline procedures that account for more than only investment costs: building operation costs for e.g. energy, maintenance and cleaning need to be considered when evaluating possible refurbishment scenarios. Life cycle costing offers true costs for project alternatives and distinguishes between supposedly efficient looking scenarios and ones that do offer real benefits and advantages for the user, the organization and the environment over a building's entire life cycle.

4. References

[1] VORALBERGER LANDESREGIERUNG "Planungsleitfaden für nachhaltige Landesgebäude", Bregenz, 2012

[2] KESSLER S, SIEBER W, GROSS A, SCHEDLER B, et al. "Schritt für Schritt zur Energieautonomie in Vorarlberg – Maßnahmenplan bis 2020 Schlussbericht", Amt der Vorarlberger Landesregierung, Bregenz, 2011

[3] PREUß N, SCHÖNE L.B. "*Real Estate und Facility Management: Aus Sicht der Consultingpraxis*", Springer Heidelberg, 2010, ISBN 978-3-540-88998-4

[4] PONGRATZ M., HOFER G., The positive impact of Life Cycle Cost Calculations in the early design phase on energy efficient and sustainable buildings, Proceedings of the 7th International Conference on Improving Energy Efficiency in Commercial Buildings, Frankfurt, 2012

[5] WALTENBERGER L., HERZOG B., PONGRATZ M., The Potential of Life Cycle Costing for Plus-energy Buildings in Architectural Competition and Early Design Phases - A Case Study, EnviBuild Brno, 2012

[6] ELLINGHAM I., FAWCETT W., New Generation of Whole Life Costing, Taylor and Francis, New York, USA, 2006

D6

Life Cycle Assessment

Chair: Viola John
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The need for a comprehensive and consistent approach in sustainability assessment of buildings - the EC Product Environmental Footprint



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Short Summary

To date a proliferation of sustainability claims in architecture is noticed. The major focus is on energy and related CO_2 and on the use stage of buildings. Although energy during the building use stage is highly relevant, a more comprehensive life cycle approach is needed to support decision making in order not to overlook relevant environmental burdens such as respiratory effects and land use. This proliferation of sustainability claims is not only noticed in the building sector. Also in other sectors confusion in the market on how to measure the environmental performance has appeared due to this proliferation of claims. This can lead to unfair commercial practices and greenwashing. As a base for addressing the current confusion in the market, the Environmental Footprint was developed and has recently been adopted by the European Commission. This method provides specific guidance for comprehensive, robust and consistent environmental assessment of products and organisations. It is based on four main principles: (1) multi-criteria, (2) life cycle thinking, (3) consistency and (4) ensuring maximally physically representative modeling. This paper presents the Product Environmental Footprint in the specific context of buildings.

Keywords: Labelling, Life Cycle Assessment, Multi-criteria approach, Product Environmental Footprint, Sustainable Buildings.

1. Introduction

Although the construction sector contributes to socioeconomic development, it also induces important environmental impacts due to its energy consumption, solid waste generation, global greenhouse gas emissions, adverse health effects, environmental damage, resource depletion and land use [1], [2]. It is therefore a relevant sector in terms of reducing the environmental impact. Sustainability and environmental impact of buildings have hence received a high interest in the last decades. In this context, a proliferation of sustainability claims of buildings is noticed to date, such as 'Passive House', 'Ecological Passive House', 'Net Zero Energy Building', 'CO_2 neutral building', 'Solar Self Sufficient Building', 'Autonomous object', 'Energy Autonomous City', 'Mixed-use Carbon Neutral development', 'Eco-village', '2000 Watt City' and many more [3], [4], [5], [6], [7], [8]. The major focus is clearly on energy and related CO_2 and on the use stage of buildings. By limiting the focus to a single environmental impact category and/or a single life cycle stage there is however a potential risk of burden shifting to other impact categories and/or other life cycle stages [1], [9].

In a response to that, more holistic evaluation methods (and related labels) have appeared such as the Leadership in Energy and Environmental Design (LEED) rating system ([10], [11]), the BRE

Environmental Assessment Method (BREEAM) ([12], [13]) and the German Sustainable Building Council (DGNB) [14] system. These are more holistic as these include other life cycle stages than the use stage and consider other impacts in addition to global warming (multi-criteria). As the different systems lead to different recommendations and labels [15], the confusion in the market however remains. Moreover, although these holistic evaluation methods are more comprehensive, they show some important drawbacks. This is elaborated in section 2 of this paper. To overcome the drawbacks a detailed and rather prescriptive Life Cycle Assessment (LCA) method is recommended and has been adopted by the European Commission (EC), the Product Environmental Footprint (PEF) [17]. This method is presented in section 3. The scope of the PEF method is however not limited to the construction sector. More specific PEF category rules for construction products and buildings are needed to define even more clear, relevant and actionable guidelines in order to guarantee consistency and comparability of PEF studies. Another European initiative is the development of the standards of the CEN TC350 which provide such more specific guidelines (Product Category Rules). The two most relevant ones in the context of this paper are the EN15804 [18] and EN15978 [19]. The development of future PEFCRs for construction products and the harmonization with the CEN TC350 standards are further discussed in section 4. Some conclusions and steps forward are summarized in the final section.

2. Existing comprehensive assessment methods for buildings

This section provides an overview of three widely used comprehensive sustainability assessment methods for buildings, i.e. LEED, BREEAM and DGNB system. The methods are here briefly presented in order to illustrate their scope and importance. We refer to literature for a more comprehensive description and analysis, including implementation to case studies [20], [21], [22], [23], [24]. Some issues for improvements and the related recommendation for a multi-criteria LCA based approach are moreover discussed. The description mainly focuses on the environmental issues, as this serves as background for the subsequent section which presents the EC PEF method and indicates how the EC PEF method can contribute to an improvement of the environmental impact assessment of the existing methods.

2.1 Overview of existing methods

2.1.1 Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM was developed in 1990 and as such is the oldest certification system for sustainable building. It has become one of the most widely recognised systems with more than 250.000 buildings certified [12]. It assesses the environmental performance of buildings and includes aspects related to energy, water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes.

BREEAM considers nine categories (*Table 1a*). There are a number of aspects that determine the BREEAM rating: rating benchmarks (*Table 1b*), environmental weightings (*Table 1a*), minimum standards (i.e. minimum number of credits achieved within the sub-criteria of the nine categories), credits achieved and additional credits achieved for innovation (maximum 10 additional credits, which equals a maximum of 10% to be added to the rating score) [25]. The certification levels range from pass to outstanding.

Life cycle environmental impact assessment is mainly addressed in the category ‘materials’ by providing a link with the *Green Guide to Specification* ratings [26]. This *Green Guide to Specification* provides environmental rankings (i.e. from A+ to E) of materials and components for different building elements used in different buildings. It is based on LCA using BRE's Environmental Profiles Methodology 2007 [27]. This methodology comprises 13 environmental impact categories, including amongst others climate change, human toxicity, water extraction, fossil fuel depletion and acidification. The characterisation factors are mainly taken from the CML 2000 method combined with characterisation factors developed by BRE for any gaps [27]. For the total BREEAM rating, maximum six credits can be obtained by following the Green Guide to Specification within the category ‘Materials’. As in total 12 credits can be obtained in this Category

and the weight of this category is 12.5%, only 6.25% of the total BREEAM rating score is based on LCA of the building materials used.

Table 1: $BREEAM_{2008}$: weighting scheme for new builds, extensions and major refurbishments (table 1a) and certification level (table 1b), ([25], page 3).

Table 1a

Category	$BREEAM_{2008}$
Management	12%
Health and wellbeing	15%
Energy	19%
Transport	8%
Water	6%
Materials	12.5%
Waste	7.5%
Land use and ecology	10%
Pollution	10%

Table 1b

$BREEAM_{2008}$ rating	% score
Unclassified	<30
Pass	≥30
Good	≥45
Very good	≥55
Excellent	≥70
Outstanding*	≥85

*Additional requirements for achieving a BREEAM Outstanding rating.

2.1.2 Leadership in Energy and Environmental Design (LEED)

LEED is developed in 1998 by the U.S. Green Building Council. LEED is a voluntary, consensus based national rating system for buildings designed, constructed and operated for improved environmental and human health performance. It evaluates the environmental performance of a building over its entire life cycle. In 2013 over 10.000 buildings have been certified [11].

A project must satisfy all LEED prerequisites and earn a minimum number of points on a LEED rating system scale. Homes for example must earn a minimum of 45 points on a 136-point scale (*Table 2b*). The certification levels range from certified to platinum. The points to be gained are subdivided in eight categories (*Table 2a*). These consist of a number of measures which are prerequisites and/or a number of measures resulting in credits of one or more points. As the number of measures differs between the different categories and the number of points for the measures differs, weighting factors are implicitly assigned (*Table 2a*). It is however not clear how the measures within each category were selected and how the number of points was assigned to each measure.

Table 2: LEED for Homes (v. 2008): Weighting scheme (Table 2a, [11]) and certification level (Table 2b, [10]).

Table 2a

Category	$LEED_{2008}$
Innovation and Design Process	8%
Location and Linkages	7%
Sustainable Sites	16%
Water efficiency	11%
Energy and Atmosphere	28%
Materials and Resources	12%
Indoor Environmental Quality	15%
Awareness and Education	2%

Table 2b

$LEED_{2008}$ certification levels	Number of points required
Certified	45-59
Silver	60-74
Gold	75-89
Platinum	90-136
Total Available points	136

2.1.3 German Sustainable Building Council (DGNB) system

In 2009 the DGNB introduced a new system that can be seen as a second-generation scheme as it built on the experiences of the existing schemes at that time such as BREEAM and LEED. In 2012 over 200 buildings have been certified in Germany and abroad [22]. It is more holistic than the previously discussed systems as it is not limited to environmental and health issues.

The DGNB system gives equal weight (22.5%) to the widely accepted three pillars of sustainability: environmental, economic and social pillars. It moreover considers the technical quality (22.5%), the process quality (10%) and the location quality (0%, which actually means it is not considered). The total score of the building is calculated based on the weighted individual scores on each criterion (about 50 in total). Based on this total score, a bronze, silver or gold certificate can be obtained (*Table 3b*). The gold certificate is reached when 80% of the possible maximum score is reached. As described by Schuster et al. "*this can only be achieved with a performance far better than required by law, e.g. with extremely high energy performance and/or low emission material selection"* [22].

In *Table 3a,* the indicators in the environmental pillar are summarised together with their weighting factors (in relation to the overall DGNB score). The environmental impact assessment is based on the CML 2001 characterization model and represents 13.5% of the total DGNB score [28].

Table 3: DGNB system: weighting scheme for ecological quality issues of overall certification (Table 3a) and certification level (Table 3b) [20].

Table 3a

Indicator	Weight
Global Warming Potential (GWP, kg CO_2 eq.)*	3.46%
Ozone Depletion Potential (ODP, kg CFC_{11} eq.)*	0.58%
Photochemical Ozone Creation Potential (POCP, kg C_2H_4 eq.))*	0.58%
Acidification Potential (AP, kg SO_2 eq.)*	1.15%
Eutrophication Potential (EP, kg PO_4 eq.)*	1.15%
Risks to the regional environment	3.46%
Other impacts on the global environment	1.15%
Microclimate	0.58%
Non-renewable primary energy demand* (MJ)	3.46%
Total primary energy demand and proportion of renewable primary energy* (MJ)	2.31%
Potable water demand and sewage generation	2.31%
Land use	2.31%

* Based on LCA.

Table 3b

Total Performance Index	Awards
From 50%	Bronze
From 65%	Silver
From 80%	Gold

2.2 Need for improvement

Although assessment methods such as LEED, BREEAM and the DGNB system have clearly their strengths in terms of comprehensiveness and awareness raising, they also show some weaknesses. The most important need for improvement is the consistency and rigidness of the methods for the determination of the environmental benefits assigned to each building measure and the relative importance of each of the measures. Based on an LCA of the measures in the LEED method, Humbert et al. concluded that actually not all measures are environmentally beneficial but some result in an environmental burden instead [29]. This was for example the case for the measure '*provide alternative fuel vehicles or install alternative refuelling stations for 3% vehicle parking capacity*' within the category '*sustainable sites*'. This measure was translated into "*3% of the cars driven with bioethanol instead of gasoline*" by Humbert et al. and proved to lead to a positive impact on depletion of resources but to a damage to human health and ecosystems based on their LCA study [29]. Similar critics can be formulated for the BREEAM method as it was identified that it does not use an LCA approach consistently throughout the assessment. The environmental assessment of the DGNB method only comprises a limited number of impact categories and the impact assessment models used date from 2001. It therefore shows room for improvement.

A comprehensive LCA of the environmental impacts is hence recommended to improve the existing methods. Consistency over the different building types, but also over the different EU

Member States would be beneficial in terms of transparency and comparability. It would moreover be advantageous for the assessors to have a consistent method in different building locations in terms of time and money. The EC PEF method exactly aims at providing consistent, LCA based, clear and actionable guidance and is further elaborated in the subsequent section. Besides the EC PEF method, the CEN TC350 developed LCA standards for construction products and buildings, i.e. the EN15804 and EN15978 standards respectively [18], [19]. These are further discussed in the subsequent section related to more specific PEF category rules for the construction products.

3. The EC Product Environmental Footprint (PEF)

3.1 Background

The EC PEF method has been developed by the Joint Research Centre (JRC) of the EC in close cooperation with the Directorate General for the Environment (DG ENV). It was recently published as an annex of the recommendation linked to the Communication "*Building the Single Market for Green Products - Facilitating better information on the environmental performance of products and organisations*" [16], [17], [30]. The aim of the PEF is to bring comparable and reliable environmental information in order to build confidence for consumers, business partners, investors and other stakeholders. It should provide the basis for addressing the current confusion of sustainability claims which is not only noticed in the building sector.

The EC PEF method is an LCA based method to calculate the environmental performance of a product (i.e. good or service). PEF information is produced for the overarching purpose of seeking to reduce the environmental impacts of products taking into account supply chain activities (from extraction of raw materials, through production and use, to final waste management). The EC PEF method provides guidance for modelling the environmental impact of the flows of material, energy and the emissions and waste streams associated with a product throughout its life cycle. It builds upon the ISO 14040 and ISO 14044 standards [31], [32] and the International Reference Life Cycle Data System (ILCD) Handbook [33]. The EC PEF method is however more prescriptive than any of these documents in order to increase consistency and reproducibility. The relation with the ISO standards and the ILCD handbook are schematically presented in *Fig. 1*. Besides these reference documents, existing footprinting methods were consulted at the start of the development process of the EC PEF method such as PAS 2050 [34], Greenhouse Gas Protocol [35], [36] and BPX 30-323-0 [37]. Briefly summarised it can be concluded that existing methods are not prescriptive enough (to guarantee consistent and comparable outcomes) and not comprehensive enough (i.e. limited to a single issue instead of multi-criteria) to fulfil the goals set for the EC PEF method. A detailed description of the analysis of existing footprinting methods can be found in [38].

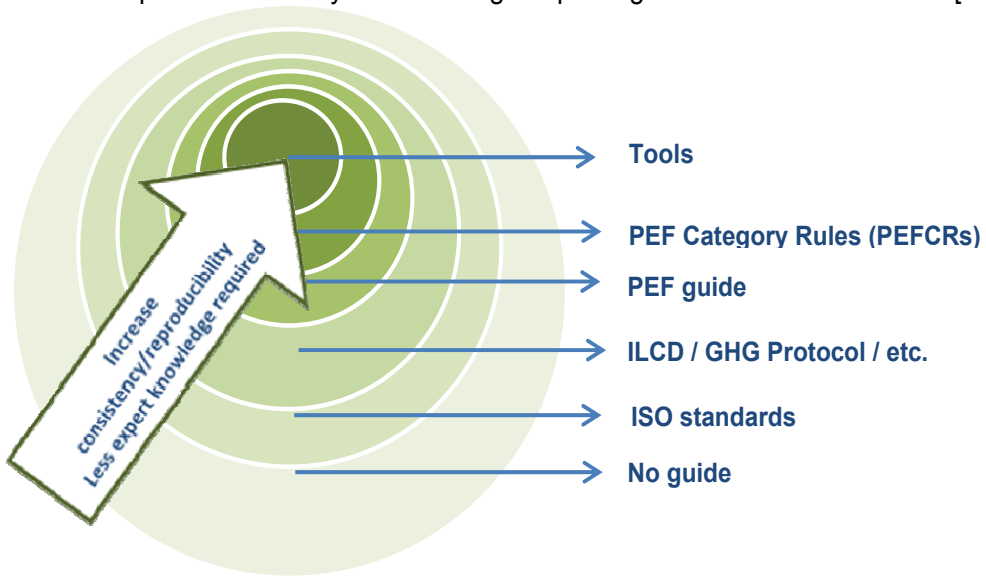


Fig. 1 Situating standards and methods for product environmental footprinting along the continuum from flexibility to prescriptiveness/reproducibility

3.2 Scope

The EC PEF method can be applied to all products including construction products. The system boundary includes all life cycle stages from raw material extraction through processing, production, distribution, storage, use and End-of-Life (EoL) treatment of the product (i.e. cradle-to-grave), as appropriate to the intended application of the study. As the EC PEF method has a wider scope than only building products, additional, even more specific, requirements for the building sector will be necessary to increase reproducibility, consistency and relevance of PEF studies of construction products. These additional guidelines are referred to as Product Environmental Footprint Category Rules (PEFCRs) and are further discussed in section 4.

3.3 Prescriptiveness

The EC PEF Guide has a high level of prescriptiveness and hence a low level of flexibility. This was seen as essential in order to obtain more consistent and comparable results. The EC PEF Guide provides for example strict guidelines regarding the data quality, allocation, EoL allocation, cut-off, impact assessment, biogenic carbon removals and emissions, temporary carbon storage and nomenclature. This is in contrast with many other currently available methods which in general allow the user to choose out of a range of possibilities. The data quality requirements and environmental impact assessment are described in more detail in the subsequent sections as these are important issues for all environmental assessments, including buildings.

3.4 Data quality requirements

Strict data quality requirements are included in the EC PEF Guide in order to ensure good quality results. A semi-quantitative assessment is required addressing six criteria: technological representativeness, geographical representativeness, time-related representativeness, completeness, parameter uncertainty and methodological appropriateness and consistency. The single scores are combined giving equal weight to each criterion in order to obtain the overall data quality rating. The overall rating ranges from poor to excellent. For the processes accounting for at least 70% of contributions to each impact category, data shall achieve at least an overall “good quality” level, for at least 20% of the remaining impact “fair quality” data shall be used, and for the remaining processes (maximum 10% of the impact) at least best available data shall be used (*Fig. 2*). The European reference Life Cycle Database (ELCD) and the International Reference Life Cycle Data System Data Network (ILCD DN) will play a crucial role in achieving this fundamental goal of coherent and quality assured data [39].

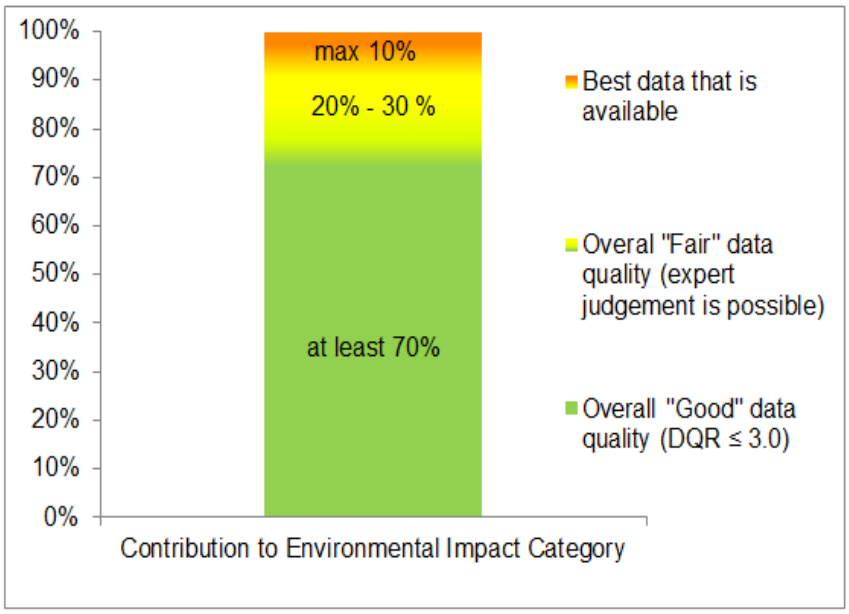


Fig. 2 Data quality requirements according to the PEF Guide.

3.5 Environmental impact assessment

The EC PEF method includes a comprehensive list of 14 impact categories and prescribes the midpoint models, related indicators and characterisation factors to be used (*Table 4*). This is based on the ILCD recommendations [33] agreed upon internationally and is therefore widely supported.

Table 4: Product Environmental Footprint: impact categories, assessment models and indicators.

Impact Category	Assessment Model	Indicators
Climate Change	Bern model - Global Warming Potential over a 100 year time horizon.	kg CO_2 eq.
Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon.	kg CFC-11 eq.*
Ecotoxicity for aquatic fresh water	USEtox model	CTUe **
Human Toxicity - cancer effects	USEtox model	CTUh ***
Human Toxicity – non-cancer effects	USEtox model	CTUh ***
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2.5 eq. ****
Ionising Radiation – human health effects	Human Health effect model	kg U^{235} eq. (to air)
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC eq. *****
Acidification	Accumulated Exceedance model	mol H+ eq
Eutrophication – terrestrial	Accumulated Exceedance model	mol N eq
Eutrophication – aquatic	EUTREND model	fresh water: kg P eq. marine: kg N eq.
Resource Depletion – water	Swiss Ecoscarcity model	m^3 water use related to local scarcity of water
Resource Depletion – mineral, fossil	CML2002 model	kg Sb eq. ******
Land Use	Soil Organic Matter (SOM) model	kg (deficit)

* CFC-11 = Trichlorofluoromethane, also called freon-11 or R-11, is a chlorofluorocarbon.
** CTUe = Comparative Toxic Unit for ecosystems
*** CTUh = Comparative Toxic Unit for humans
**** PM2.5 = Particulate Matter with a diameter of 2.5 µm or less.
***** NMVOC = Non-Methane Volatile Organic Compounds
****** Sb = Antimony

4. Product Environmental Footprint Category Rules (PEFCRs)

As mentioned in section 3.2, PEFCRs for the construction products will need to be developed in future in order to further increase consistency, reproducibility and relevance for the construction sector and to enable comparisons and comparative assertions. The PEFCRs should moreover reduce the time and efforts needed to conduct a PEF study by limiting the scope in terms of relevant processes/life cycle stages and impact assessment categories. Coherence of PEFCRs will be ensured trough the foreseen sectorial level guidance for their development. Existing product category rules (PCRs) for construction products should be consulted when creating the PEFCRs for construction products and buildings, especially the widely used EN15804 and EN15978 should be carefully considered. In addition, other existing PCRs of construction products should be taken into account as well, such as the BREEAM PCR [27]. Their requirements and assumptions regarding for example the reference service life of buildings and components, the technological, geographical and time-related representativeness of processes should be carefully considered.

5. Conclusions and steps forward

The current proliferation of methods for assessing the sustainability of buildings leads to inconsistency and hence confusion. Although comprehensive methods exist taking into account several sustainability issues and life cycle stages, the methods to date are mainly rating-based methods, also referred to as qualitative systems. They consist of a subjective weighting of credits assigned to a list of measures, covering different issues such as energy use, material choice and water efficiency. The need for a more consistent and comprehensive Life Cycle Assessment (LCA)

based (quantitative) method is highlighted. The presented Product Environmental Footprint (PEF) method, recently adopted by the European Commission, gives an answer in terms of environmental impact assessment to the needs identified. The next step forward consists of developing Product Environmental Footprint Category Rules (PEFCRs) for construction products in order to increase consistency, reproducibility, relevance and comparability of building and building product assessments. In order to move towards a harmonised European method for construction products and buildings it will be important to envisage an alignment between the PEFCRs for construction products and the CEN standard EN15804.

6. Acknowledgement

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7. References

[1] ORTIZ O, CASTELLS F, SONNEMANN G. "*Sustainability in the construction sector: A review of recent developments based on LCA*". Construction and Building Materials; 2009, Volume 23, pp. 28-39.

[2] ALLACKER K. "*Sustainable Building: The development of an evaluation method*". PhD dissertation, KU Leuven, September 2010, ISBN 978-94-6018-231-0, 464 pages.

[3] Passivehouse Database; http://www.passivehousedatabase.eu/ [accessed April 2013]

[4] EnOB "*Research for Energy Optimized Building; Net zero-energy buildings – Map of international projects*"; http://www.enob.info/en/net-zero-energy-buildings/map/ [accessed April 2013]

[5] THE INDEPENDENT. "*Feldheim: A hamlet swept by the winds of change*"; The Independent, 11 April 2012. From: http://www.independent.co.uk/environment/green-living/feldheim-a-hamlet-swept-by-the-winds-of-change-7631152.html [accessed April 2013]

[6] http://www.wellspent.eu/#feldheim [accessed April 2013]

[7] "*Økosamfundet Dyssekilde*". From: http://www.dyssekilde.dk/uk [accessed April 2013]

[8] CITY OF ZURICH. "*On the way to the 2000 Watt society – Zurich's path to sustainable energy use*"; 2011. From: http://www.stadt-zuerich.ch/2000-watt-society [accessed April 2013]

[9] ALLACKER K, DE TROYER F. "*Moving towards a more sustainable Belgian dwelling stock: the passive standard as the next step?*" Journal of Green Building; 2013, Volume 8/2 (in press).

[10] USGBC. "*LEED for Homes – Rating System version 2008*". USGBC; 2007.

[11] USGBC. "*LEED (Leadership in Energy and Environmental Design*". From: http://www.usgbc.org/leed (accessed April 2013)

[12] BRE. "*BREEAM - The world's leading design and assessment method for sustainable buildings*". http://www.breeam.org/ (accessed April 2013)

[13] DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT. "*Code for Sustainable Homes – Technical Guide, November 2010*". Crown, 2010.

[14] DGNB GmBH. "*The DGNB system*". 2013. http://www.dgnb-system.de/ [accessed April 2013]

[15] SAUNDERS T. "*A discussion document comparing international environmental assessment methods for buildings*". 2008

[16] EUROPEAN COMMISSION. *COM(2013) 196 Final: Communication from the Commission to the European Parliament and The Council: "Building the Single Market for Green Products - Facilitating better information on the environmental performance of products and organisations"*. Brussels, 2013a.

[17] EUROPEAN COMMISSION. "*Annex II: Product Environmental Footprint (PEF) Guide to the COMMISSION RECOMMENDATION on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*". European Commission; 2013b.

[18] EN:15804 "*Sustainability of construction works - Environmental product declarations - Communication format business-to-business*". European Committee for Standardisation; 2012.

[19] EN:15978 "*Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method*". European Committee for Standardisation; 2011.

[20] BOSCH P, LAVALAYE K. "*Afstudeeronderzoek DGNB*" (translated: Undergraduate thesis DGNB). Hogeschool Arnhem en Nijmegen; 2011.
[21] DIRLICH S. "*A Comparison of Assessment and Certification Schemes for Sustainable Building and Suggestions for an International Standard System*". The IMRE Journal; 2011, Volume 5/1, p. 1-12.
[22] SCHUSTER H, PERETTI G, THUMMLER T. "*Building Certification 2.0 – The German Sustainable Building Certification System in Practice*". Proceedings: PLEA conference; 2012.
[23] OSORIO-PETERS S, DURAO V, SILVA C. "*ZeroWIN – deliverable 3.4: Paper on the certification practices in different countries*". FP7 project, 2010. www.zeroWIN.eu [accessed April 2013].
[24] KAJIKAWA Y, INOUE T, GOH TN. "*Analysis of building environment assessment frameworks and their implications for sustainability indicators*". Sustainability Science; 2011, Volume 6, pp. 233-246.
[25] BRE. "*BREEAM – BRE Environmental and Sustainability Standard: BREEAM Offices 2008 Assessor Manual*". BRE, 2008.
[26] BRE. "*Green Guide To Specification*". http://www.bre.co.uk/greenguide [accessed April 2013].
[27] BRE. "*Methodology for environmental profiles of construction products - Product Category Rules for Type III environmental product declaration of construction products: DRAFT August 2007*". BRE, 2007.
[28] WITTSTOCK B, LOWE K, FISCHER M, BRAUNE A, KREIßIG J. "*What is green? Benchmarking the environmental performance of sustainable buildings*". Proceedings: CESB10 Prague; 2010.
[29] HUMBERT S, ABECK H, BALI N, HORVATH A. "*Leadership in Energy and Environmental Design (LEED) – A critical evaluation by LCA and recommendations for improvement"*. Int. J. of LCA; 2007, Volume 12 (special issue 1), pp. 46-57.
[30] EUROPEAN COMMISSION. "*Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: Building the Single Market for Green Products Facilitating better information on the environmental performance of products and organisations*". EC, 2013.
[31] ISO 14040. "*Environmental management - Life cycle assessment - Principles and framework*". International Organisation for Standardisation; 2006, Geneva.
[32] ISO 14044. "*Environmental management – Life cycle assessment – Requirements and guidelines*". International Organisation for Standardisation; 2006, Geneva.
[33] EC-JRC. "International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context". European Commission – Joint Research Centre; 2011. http://lct.jrc.ec.europa.eu/assessment/projects [accessed May 2013]
[34] PAS 2050. "*Specifications for the assessment of the life cycle greenhouse gas emissions of goods and services*". 2011. http://www.bsigroup.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/ [accessed April 2013]
[35] WRI & WBCSD. "*Product Life Cycle Accounting and Reporting Standard. Greenhouse Gas Protocol*". 2011a
[36] WRI & WBCSD. "*Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard".* 2011b
[37] ADEME. "*General principles for an environmental communication on mass market products 2011 BPX 30-323-0*". 2011. http://www2.ademe.fr/servlet/getDoc?id=38480&m=3&cid=96 [accessed April 2013]
[38] JRC – IES. "*Analysis of existing Environmental Footprint Methodologies for Products and Organizations: Recommendations, Rationale and Alignment*". 2010.http://ec.europa.eu/environment/eussd/smgp/dev_pef.htm [accessed April 2013]
[39] JRC – IES. JRC – Technical reports. ILCD Data Network and ELCD Database: current use and further needs for supporting Environmental Footprint and Life Cycle Indicator Projects, Report EUR 25744 EN, doi: 10.2788/786782012.

A modular LCA database adapted to different user needs during the building design process



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Abstract
LCA is widely recognized as the most relevant tool to evaluate building environmental impacts [1]. However, its use is still facing limitations which make it restricted to experts and researchers. Over the last few years, many works and initiatives have focused on methodologies and user-friendly tools to spread building LCA practice and ease its understanding [2],[3],[4],[5], encouraged by the growing interest for this method as a tool to achieve a more sustainable development [6]. However, few works have tried to adapt the tools to the specific needs of the different building stakeholders.

The objective of our work is to make LCA more accessible to non-experts willing to assess their building projects at different stages. Depending on the goal and scope of the study, data, methods, calculation rules, etc. within LCA tools have to be adjusted. All these adjustments require advanced knowledge in order to ensure proper representativeness, respects of certification schemes requirements, etc. Such adaptations have been formalized in a recent European project [9] by defining different study types (screening, simplified and complete) and providing a series of guidance for each type. We propose a first implementation and assessment of this approach for the building products and equipment aspects of a full building LCA. Modular approach has been identified as a possible answer to data adaptation problem [11]. This includes a modular description of components, products and materials but also different types of LCA data (e.g. generic data or specific EPDs) that are able to support different goals and scopes, from early design to detailed assessment.

Our work focused on developing such a database based on the modular principle, implementing it on an existing LCA tool (ELODIE), and validating its use for different types of studies. This paper provides an overview of the approach at different scales, supported by

case studies that show its relevance and consistency depending on the considered goal and scope. Examples will provide an overview of the methodology and demonstrate its usefulness. They will illustrate the distances between results from LCA of early design eco-conception and final certification results or existing building models. The investigated approach is dedicated to further facilitate the deployment of LCA amongst non-expert users. Integration of such an approach in building LCA tools could facilitate the decision making at the first steps of a building project, when the potential influence of design on costs and environmental impacts is the highest.

Keywords
Sustainable building; LCA; Environmental impacts; Macro-component; Generic data.

1. Introduction

Worldwide statistics show that the building sector generates the highest energy consumption. For this reason, many regulation rules and technological improvements emerged since last mid-century, aiming a drastic drop of this consumption. Nowadays, buildings are still responsible for at least 40 % of energy use in most countries. Parallel and often correlated to this energy consumption, buildings are also emitting about 30 % of greenhouse gases (GHG). Then, efforts are maintained by politics, industrials and personal initiatives to amplify this decrease. Emerging from the statement that all pollution sources are linked and interacting, multicriteria study forces itself on the scientific community as a way to perform a complete environmental assessment can be perform avoiding transfers of pollution. These transfers could occur from a source to another or from one phase of the life cycle to another. Then, the multicriteria approach allows to consider these transfers and to make a real systemic optimization.

Over past few years, multicriteria assessment tools have been developed and so building LCA tool emerged [1]. In that way, it is now possible to perform a global optimization of different aspects without pollution transfer. These tools offer new design perspectives by taking environmental aspect into account in a global sustainable process. For instance, thanks to such method [2],[3],[4],[5], one can explore both energy consumption and waste production at the same time. Additionally, it also allows evaluating physical resource uses and other environmental impacts (water pollution and consumption, air pollution, greenhouse gases emissions…). The use of mineral resources is also of high concern in the construction sector. For example, the production of gravels in France in 2010 was about 365 millions of tons according to [7]. Also, the building lifetime, often about 80-100 years, justifies the position of the construction sector to significantly contribute to a more sustainable development [6].

A complete building LCA is not a simple aggregation of LCA of component and construction materials. Buildings have a very long service life. A building LCA has also to take into account the impacts related to the energy consumption (values to be taken from thermanl anlysios software). The other contributors of a building are also the operational water consumption, the transportation of the users of the buildings, the construction site processes. However, the assessment of the impacts related to the building products and technical equipment is still the most time consuming aspect during a building LCA. Generally speaking, a bill of quantities of materials can have plenty of materials and products often presented in units, kilograms, m² or m^3. Inventorying all the materials and linking them to an environmental data is thus time consuming. Also, building LCA tools are usually more specifically oriented towards one objective and then one construction project phase [8].
Because of this time consumption and this tool specialization, the evolution from eco-design to performance evaluation of building environmental quality is still limited. To promote the holistic approach, tools must provide a real continuum all along the building project stages. This is particularly important since early design stages are not only used for alternatives

comparisons but also as a first assessment to reach a required performance level. In that way, the continuum needs to be assured and so, create a higher synergy between all the stakeholders.

To ensure this continuum, the use of different study types as described in the European project, EeBGuide [9] will likely present a growing interest in the future. To summarize, the three study types, screening, simplified and complete, are proposed with an appropriate level of completeness and data requirements in the description [10]. To do so, scalable description systems are foreseen as one solution to be embedded within building LCA tools. A scalable description system, historically implemented in building LCA software like LEGEP [11] will offer a way to consider smaller entities within a whole assembly, avoiding getting into the detail when it is not part of the goal and scope of the study. For instance, a generic data representing an average external wall could be implemented in a LCA database so that the user could directly select it without selecting each materials and products implemented in it. Such an assembly is then considered as a "macro-component". Linked to the scalability approach, the selection between both generic data (representing a whole set of products, by a weighted average for example) and specific data (representing a particular commercial reference) allows the users to set his level of accuracy: from aggregated and generic building parts with uncertainties to more specific and more accurate compound by compound description.

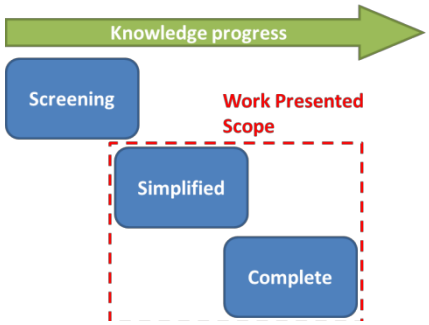


Figure 1: Positioning of this study within the three study types as exposed in the EeBGuide project *vs.* the project knowledge progress

Figure 1 presents the scope of this paper according to the three study types presented in the EeBGuide project. More particularly, this whole study is focused on the building products and technical equipment contributor. Also, the presented approach is restricted to the "simplified" and "complete" types, as approach to deal with a screening LCA, consisting on using aggregated ratio of parts of the building is already documented in previous papers [12].

The work exposed below describes the methodology developed to obtain scalable datasets. The methodology is based on the general guidance and standards on LCA [13],[14][15]. The discussions all along this paper will expose the potential implementation of the approach in building LCA tools as well as limitations and prospects.

2. Overview of datasets included in building LCA tools

Most of existing tools are mainly oriented towards one construction project phase. In fact, these tools are often developed under a specific context considering a pre-defined goal. A complete modularity of database would potentially be needed in order to offer the right information on the whole construction project.

Name	Developer	Country of development	Mostly oriented towards	Type of data (number)	Import new data	Scalable data
COCON	Luc Floissac	FR	Eco-design	Generic and specific	✓	✓

Impact Estimator for Buildings	Athena Sustainable Materials Institute	US	Eco-design	Regionally customized generic		✓
IMPACT	BRE	UK	Eco-design, Certification	Specific		
eco-bat	HEIG-VD	CH	Eco-design, Pre-sizing	Generic		
ECOSOFT	IBO	AT	Eco-design, Operation management	Generic	✓	
ELODIE	CSTB	FR	Research, Eco-design, Pre-sizing, Certification	Generic and specific	✓	✓
EQUER	Armines/Izuba Energie	FR	Research, Eco-design	Nationally customized generic		
GaBi Built IT	PE International	DE	Certification	Generic		
LEGEP	LEGEP Software GmbH	DE	Eco-design, Pre-sizing, Certification	Generic materials and generic building product	✓	✓
SBS	Fraunhofer	DE	Research, Certification	Generic and specific		

Table 1: Brief summary of some building LCA tools and their objective

Table 1 gives a listing of some building LCA tools as examples of solutions offered to construction stakeholders. This listing is not to make any comparisons and does not pretend to be exhaustive. It has been filled according to information given on websites or user guides. Also, the "mostly oriented towards" column gives the information as exposed and highlighted by the developers; it is not exclusive and all these tools can be used differently depending on user's expertise. As shown on Table 1, only few tools are offering a fully scalable data even if many of them are oriented towards both early phases of planning and operation phase. Since we are mainly interested in the scalability and modularity, the type of data will not be considered further than the difference between generic (i.e. a data roughly describing the impact of a product or component mainly based on industry data averaging or use of European generic data e.g. based on previous studies [16]) and specific data (industry data provided by companies and representing a commercial reference of a product).

3. Modular description scale methodology

The goal of this section is to give some explanations about the approach by presenting the building LCA tool used for this work as well as the methodology to determine and calculate the macro-component values. We would like to insist on the validation aspect of this work which should in the end help stakeholders to clearly position their early phase results to a targeted performance value.

3.1 Presentation of the building LCA tool ELODIE

ELODIE is a French building LCA software assessing the environmental impacts due to construction materials and products, the operational energy and water use, the construction site processes and the transportation of users. ELODIE provides an environmental multicriteria profile of building considering 15 indicators based on CML, 2001 and French standard (NF P01-010 and XP P01-020-3, evolving towards NF EN 15804 [17] and NF EN 15978 [18]). However, the set of indicators discussed here will be restricted to some of the most commonly used:

- Total primary energy
- Non-renewable energy
- Abiotic depletion potential (ADP)
- Water consumption
- Global warming potential (GWP)

The software uses Environmental Product Declarations (EPD) provided by manufacturers and available in the INIES database [19] as well as homemade generic data. INIES is the French free access reference database of Environmental Declarations of Building Products (EPDs). The INIES database hosts two types of data:

- Single manufacturer's EPD
- Group of manufacturer's EPD

In the present study, generic data are used as far as possible either on the form of industry average (e.g. large group of manufacturer's EPD or existing generic data). Thus, using group of manufacturer's EPD seem consistent in early design as we may not know the exact producer of the component or the product.

The work is divided in two parts. First, environmental profiles at different scales are manually calculated (except for materials and products already having an EPD). Secondly, a modular description scale configurator can be developed to have automation in macro-component description and impact calculation.
In the next section, only the first stage is presented as it is a required step to validate the methodology.

3.2 Methodology

This section is dedicated to the description of the vocabulary and calculation rules applied to the modular system configuration.

3.2.1 Classification and nomenclature

In order to efficiently use the aggregated data, a clear and understandable classification and nomenclature has to be adopted. The main objective of this nomenclature is to match stakeholders' needs and vocabulary. For this reason, it is mainly based on the classification given in the French project HQE Performance, looking at the determination of reference values for different types of low-energy buildings [12]. Obviously, this classification was defined with the help of French construction stakeholders and may differ from other classification in other countries.

Main parts	Sections	Macro-component families
External works	1. External works	1.1 Distribution network (on parcel)
		1.2 Storage
		1.3 Roadworks, flooring, fencing
Shell and loadbearing structure	2. Foundations and substructures	2.1 Foundations
		2.2 Underground walls and structure (stairs, parking area…)
	3. Superstructure - Masonry	3.1 Horizontal elements - Slab floors
		3.2 Horizontal elements - Floors
		3.3 Horizontal elements - Beams
		3.4 Balconies
		3.5 Vertical elements - External walls
		3.6 Vertical elements – Cross walls
		3.7 Vertical elements - Posts
		3.8 Stairs and slopes
	4. Roofing - Proofness - Framework	4.1 Flat roof
		4.2 Roof and framework
		4.3 Roof technical elements
Architectural trades	5. Partitions - Doublings - Suspended ceilings - Interior woodworks	5.1 Interior doors and partitions
		5.2 Doubling partitions
		5.3 Suspended ceilings
		5.4 Woodworks, metal works and ironmongery
	6. External walls and woodworks	6.1 External painting and external doubling
		6.2 Doors, windows, shutters
	7. Floor, wall and ceiling coverings - Screed - Paintings - Decoration	7.1 Floor coverings
		7.2 Wall and ceiling coverings
		7.3 Decoration and woodwork coverings
Technical	8. HVAC	8.1 Heating/cooling systems, emitting systems and network

trades		8.2 Air treatement
		8.3 Chimney blocks and pipes
	9. Plumbing - sanitary facilities	9.1 Sanitary network and plumbing fixtures
		9.2 Storage and treatment
	10. Electrical, lighting and communication networks	10.1 High voltage network and facilities
		10.2 Low voltage network and facilities
		10.3 Special equipments
	11. Persons and buildings safety	11. Security systems
	12. Lifting systems	12. Lifting systems
	13. Local electricity generation equipments	13. Local electricity generation equipments

Table 2: Description of the different scales nomenclature and links between them

Table 2 shows the selected nomenclature with the different scales of description. Each macro-component family can contain different solutions. For example, the "3.5 Vertical elements - External walls" could include the different construction systems. This study only focuses on bright cells in Table 2. "External works" and "Technical trades" will not be addressed, mainly due to missing data for these categories of products. One can easily figure out that some "Shell and loadbearing structure" sections can integrate materials/products or even macro-components from "Architectural trades". In fact, suspended ceilings will be taken into account in "3.2 Horizontal elements – Floors". This could be judged both a problem and a solution; a problem since it does not encapsulate clearly certain elements but a solution since it is the way to get sufficiently aggregated solutions to drop the description time.

3.2.2 Calculation rules

It is reminded that we are only considering the construction materials and products contributor to the LCA. Even if the scope appears limited, it is justified by:

- The time consuming aspect of this contributor
- The potential increasing contribution of this contributor due to decreasing of the others (higher energy efficiency, better water management…)
- The high level of complexity in translating exhaustive lists of materials into LCA tools

We consider a macro-component (MC) made of *n* different layers.

The selection of the Reference Service Life (RSL) is performed assuming that the highest RSL among the layers is the baseline to calculate replacements of other layers.

$$RSL_{MC} = \max_{1 \le i \le n} \{RSL\}$$

Equation 1: Reference Service Life identification formula within the components set

Equation 1 mathematically translates the macro-component RSL definition. For all other components, the replacement rate is obtained by dividing the RSL_{MC} by the considered component RSL.

$$I_{MC} = \sum_{1}^{n} q_n \times I_n \times \left\lceil \frac{RSL_{MC}}{RSL_n} \right\rceil \times \tau_n$$

Equation 2: Calculation of the macro-component environmental impacts

$Wherein$:

q_n: $material\ n\ quantity$

I_n: $material\ n\ environmental\ impact\ on\ the\ whole\ life\ cycle$

$\left\lceil \frac{RSL_{MC}}{RSL_n} \right\rceil \in \mathbb{N}$: $material\ n\ replacement\ rate$

τ_n: $material\ n\ conversion\ coefficient\ to\ adapt\ the\ functional\ unit$

Equation 2 gives the aggregation formula to calculate the equivalent macro-component scale environmental impact from the material/product scale, taking into account the replacement rate of each layer.

The as-calculated I_{MC} and RSL_{MC} can at the time be considered as the environmental declaration of the macro-component to be used in LCA software.

One can see that the systemic information obtained thanks to this macro-component approach could lead to major improvement of the calculation rules. In fact, we consider an aggregation of materials/products ensuring some functionality in the building but this aggregation can also give information about:

- Accessibility
- Position of the macro-component in the building and/or the project in a territory
- Stack order

As an example, the accessibility of one material in the macro-component could help defining new replacement rate closer from practices in the field. In the same way, the position of the project in a territory could lead to a better description of some macro-components such as foundations according to the seismic area.

3.3 Illustration of a macro-component description

This part highlights the potential interest of a comparing tool of macro-component by illustrating it with a simple example.

Name	**Glass wool insulated concrete block masonry external wall**			
Functional Unit	Provide a concrete block masonry external wall functionality with a minimum thermal resistance of 3,1 m²,K/W on 1 m² including replacement for a 100-year reference service life			
Description	Arrangement	quantity	FU	RSL (year)
	External painting	1	m²	50
	Concrete block masonry	1	m²	100
	Stainless steal	1	kg	100
	Glass wool	1	m²	50
	Plasterboard	1	m²	50
	Interior painting	1	m²	30
Name	**Glass wool insulated burnt clay brick masonry external wall**			
Functional Unit	Provide a burnt clay brick masonry external wall functionality with a minimum thermal resistance of 3,1 m²,K/W on 1 m² including replacement for a 100-year reference service life			
Description	Arrangement	quantity	FU	RSL (year)
	External painting	1	m²	50
	Burnt clay brick masonry	1	m²	100
	Stainless steal	1	kg	100
	Glass wool	1	m²	50
	Plasterboard	1	m²	50
	Interior painting	1	m²	30

Table 3: Description of both studied systems

As shown in Table 3, describing the two considered systems, only one layer distinguishes them. In fact, only the masonry is different in these cases, one with concrete block and the other with burnt clay brick.

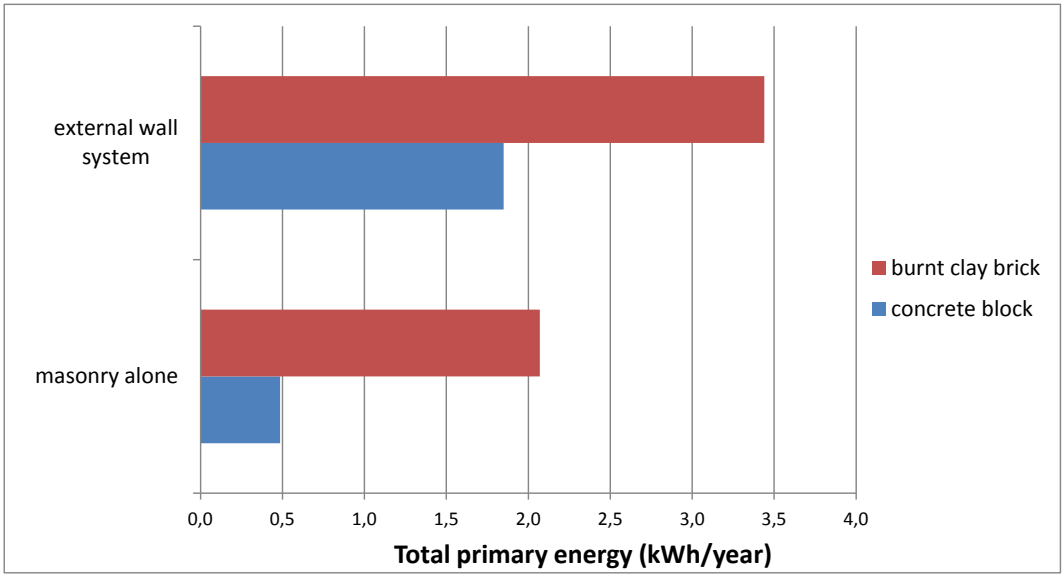


Figure 2: Relative comparison of concrete block (blue) and burnt clay brick (red) masonries in two cases: alone; in an external wall system

Figure 2 shows the total primary energy indicators obtained with two masonry systems in both cases:

- The masonry alone: this makes visible a concrete block impact representing less than 25 % of the burnt clay brick impact.
- The masonry integrated in an external wall: the classification is still the same with the burnt clay brisk system implicating a higher impact. However, the concrete block system now represents more than 50 % of the burnt clay brick one.

So, at first sight, the conclusion could be the same. Yet, a further interpretation could lead to a totally new thinking: "*since the discrepancy is not as important when considering the system, why could I not think about finding another macro-component, assuming another function in the building to counterbalance this smaller difference?"*

Finally, the modular scale is firstly a way to retain the systemic approach and helps considering an element as part of a whole.

4. Results and discussion

The results below are examples to illustrate the process and give first highlights and enhancement ways. They are a first brick in the wall that will have to be further explored and studied to build the entire work.

A set of 80 generic macro-component data has been calculated on the basis of the previously exposed methodology. A key point of the study is that we only took into account of the most commonly used constructive systems in France (for single and community housing). Large-scale case studies have been conducted by volunteers and construction stakeholders on both single housing (9 samples) and community housing (14 samples) described with macro-components. The results have been compared to the detailed description of the same works performed in the framework of the ongoing HQE Performance experimentation.

The objective is mainly focused on the qualification and much more essential the quantification of discrepancies between a detailed description with specific data of the building and a simplified one, using predefined macro-components. As it is a main fact to put things into perspective, we would like to remind that the macro-components implemented in this demonstration tool are not customizable. One can easily figure out that this strong hypothesis may lead to substantial differences in results. Indeed, the more the building will be close to the reference (here a building using the commonly used techniques), the less deviation we will have in the results.

4.1 Reproducibility

This point is of prime importance to increase the confidence in tools for the different stakeholders. The building LCA non-reproducibility causes are mainly due to:

- Metrics interpretation and typing errors
- Data choice
- Description perimeter = boundaries of the system

The macro-component description method becomes a solution to decrease the margin due to the two first points highlighted above in this way:

- Metrics interpretation and typing errors: since the number of inputs to perform a macro-component description is drastically decreased compared to a fully detailed description.
- Data choice: thanks to the use of pre-selected generic data that can confidently be used for eco-designing.

The description perimeter still faces the subjective interpretation problem to fix it. However, the macro-components can act positively by including complementary products that could easily be missed out when performing a detailed description.
Two examples within the single housing set have been calculated by two different experimenters to check the reproducibility capacity.

			User 1			User 2		
			Detailed description	Macro-component description	Relative gap (%)	Detailed description	Macro-component description	Relative gap (%)
Energy consumption	Total primary energy	(kWh / m² NFA / year)	36,4	42,9	17,9	36,4	40,9	12,4
	Nonrenewable energy	(kWh / m² NFA / year)	29,3	33,9	15,7	29,3	32,3	10,2
Abiotic depletion potential		(kg Sb_{eq} / m² NFA / year)	4,04E-02	5,31E-02	31,4	4,04E-02	5,15E-02	27,5
Water consumption		(L / m² NFA / year)	69,5	62,4	-10,2	69,5	56,7	-18,4
Global warming potential		(kg $CO2_{eq}$ / m² NFA / year)	7,24	8,08	11,6	7,24	7,56	4,4

Table 4: LCA results in detailed description for a single house and macro-component descriptions performed by two different users; green highlighted values for smaller than 20 % (arbitrarily determined)

Table 4 shows the results obtained by two users in a macro-component description and the comparison with one detailed description (obtained in HQE Performance). One can see the quite close results between the two users.

			User 1			User 2		
			Detailed description	Macro-component description	Relative gap (%)	Detailed description	Macro-component description	Relative gap (%)
Energy consumption	Total primary energy	(kWh / m² NFA / year)	46,6	64,8	39,1	46,6	66,3	42,3
	Nonrenewable energy	(kWh / m² NFA / year)	36,8	49,9	35,6	36,8	51,8	40,8
Abiotic depletion potential		(kg Sb_{eq} / m² NFA / year)	5,41E-02	7,43E-02	37,3	5,41E-02	7,76E-02	43,4
Water consumption		(L / m² NFA / year)	119,6	80,2	-32,9	119,6	85,5	-28,5
Global warming potential		(kg $CO2_{eq}$ / m² NFA / year)	10,3	12,3	19,4	10,3	12,9	25,2

Table 5: LCA results in detailed description for a single house and macro-component descriptions performed by two different users; green highlighted values for smaller than 20 % (arbitrarily determined)

Table 5 is a second example on which similar results between the two users can be observed even if the gap with the detailed description is higher.

Both exposed examples give a good reproducibility (highest gap of 8 points between both relative gap) even when the discrepancy with the detailed description is high.

4.2 Accuracy

Here is a brief summary of the statistical study carried out with 14 projects of community housing. Despite, a reduced number of projects to conduct a consolidated statistical analysis, this work furnishes a first oversight to highlight the interest of the approach.

		Minimum relative gap (%) (1)	Maximum relative gap (%) (1)	Average relative gap (%) (2)
Energy consumption	Total primary energy	5,4	67,1	6,6
	Nonrenewable energy	1,7	88,4	**7,8**
Abiotic depletion potential		0,5	94,4	**-4,7**
Water consumption		1,6	77,4	**-36,5**
Global warming potential		6,8	53,3	**-14,4**

Table 6: Recap chart of minimum and maximum relative gaps observed among the 14 projects and the calculated average relative gap; (1) for absolute value and (2) for real number; ; green highlighted values for smaller than 20 % and red highlighted values for higher than 50 %

Table 6 gives, on both first columns, a summary of the observed minimum and maximum relative gaps between the detailed and the macro-component simplified description among the 14 projects. These relative gaps are in absolute value to correctly take into account both negative and positive values. This demonstrates that some projects can be accurately described with macro-components and others less precisely. This can easily be understood by considering the data. In fact, the macro-components are described with generic data while the detailed description is performed with specific data. If the specific data is close enough from the generic one, the relative gap is low and in return, if the specific data differs widely from the generic one, the relative gap is high. This also highlights the limitation of generic data widely preferred to specific ones in eco-designing process. From then on, it appears that a clear representation of the statistical distribution considered for the

calculation of the generic data as well as an evident positioning of this value within the distribution is the only way to give people all the keys to interpret the results.
Table 6 also shows the average relative gap calculated from the 14 projects and helps to put into perspective the maximum relative gaps.



Figure 3: Schematic illustration of a statistical distribution by a boxplot and the positioning of obtained results within this distribution; black circle = mean value; red stars = outside 1st and 3rd quartile values; green stars = inside 1st and 3rd quartile values

Figure 3 gives an illustration to summarize the previous observations. One can see the boxplot representing the statistical distribution of the 14 samples. The calculated generic macro-components, chosen according the representativeness and the use frequency at the territorial scale, lead to a generic building represented by the black circle. Then, the relative positioning of the sample values compared to this mean is given by stars, green ones for *close to the mean* values and red ones for *not so close to the mean* values.

This trend is confirmed by the statistical analyses on 9 individual housing projects (results not shown) leading to similar conclusions.

Finally, this condensed summary helps to understand the interest of the approach and also highlights some enhancement possibilities as well as limitations that would have to be considered but unlikely avoided.

4.3 Time saving

Last but not least, few words about the time saving coming out the use of macro-components. The average time is 1 hour and 45 minutes to describe the shell and loadbearing structure and the architectural trades. Then, by emphasizing the simplification and adaptation approach in the broad sense to all other contributors, one can comfortably figure out the potential to conduct a complete building LCA in a half-day. This has to be compared to the four/five days spent in the framework of the HQE Performance to perform the detailed description. These are informal information given by the users but not exactly timed. However, the gap is so important that we can still get a good idea of the approach potential.

5. Conclusion

This work as a whole leads to first validation results and potential enhancement possibilities for a clear positioning of simplified building LCA results. Even if some observations seems to state the obvious, it is of prime interest to clarify this positioning and allow people to eco-design not only to compare variations but also to aim for and assure performances.

The approach can now correctly be recognized as an adaptation method to offer time saving with a potentially good accuracy. Some limitations can already be identified and we can easily foresee that some of them will not be avoided. However, these limitations could likely be circumvented by providing interpretation tools in a total transparency. As an example, ways to read into generic data as well as uncertainty displaying would facilitate result analyses and decision making. The interest of the approach is even more justified by the possible reproducibility increase that would lead to a great confidence in tools and an easier continuity and result exchanges between stakeholders.

This study will be continued to consolidate these first results and improve the robustness of the approach. A statistical analysis being performed at a national scale, the ongoing HQE Performance project, will also help the validation and make the conclusions clearer. The as-obtained results will also lead to improvements in order to ensure the modularity from the "screening" to the "complete" studies. All this work is a validation of the specifications and the tool is under development to offer scalability to the ELODIE database. This feature has to allow the creation of macro-component from the building products with flexibility to match user needs.

References

[1] KELLENBERGER D, ALTHAUS HJ. *"Relevance of simplifications in LCA of building components"*. Building and Environment 44 (2009) 818–825.

[2] CHEVALIER JL, LE TENO JF. *"Requirements for an LCA-based Model for the Evaluation of the Environmental Quality of Building Products"*. Building and Environment 31 (1996) 487-491.

[3] ORTIZ O, CASTELLS F, SONNEMANN G. *"Sustainability in the construction industry: A review of recent developments based on LCA"*. Construction and Building Materials 23 (2009) 28–39.

[4] ERLANDSSON M, BORG M. "Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs". Building and Environment 38 (2003) 919 – 938.

[5] BRIBIAN IZ, USON AA, SCARPELLINI S. *"Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification"*. Building and Environment 44 (2009) 2510–2520.

[6] HEIJUNGS R, HUPPES G, GUINEE J. *"Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis"*. Polymer Degradation and Stability 95 (2010) 422-428.

[7] MEDDE (2010) INDICATEURS DE DÉVELOPPEMENT DURABLE TERRITORIAUX - Ministère de l'Écologie, du Développement Durable et de l'Énergie – accessed on 15/05/2013 http://www.statistiques.developpement-durable.gouv.fr/indicateurs-indices/f/498/1346/production-granulats.html

[8] HAAPIO A, VIITANIEMI P. "*A critical review of building environmental assessment tools".* Environmental Impact Assessment Review 28 (2008) 469-482

[9] EeBGuide Project *"Operational Guidance for Life Cycle Assessment Studies of Energy Efficient Buildings Initiative"* InfoHub available online: www.eebguide.eu

[10] LASVAUX L, GANTNER J, SCHIOPU N, NIBEL S, BAZZANA M, BOSDEVIGIE B, SIBIUDE G. *"Towards a new generation of building LCA tools adapted to the building design process and to the user needs?"*. Submitted to SB13 Graz, 25-28 September 2013.

[11] KÖNIG H, Handbuch LEGEP, Version 1.3, October 2009, Weka Media, 128 p.

[12] Association HQE. "HQE Performance: *First trends for new buildings"*. Report from the HQE Performance Test 2011. Available online: www.assohqe.org/hqe/IMG/pdf/HQEPerf-BDPPP.pdf

[13] ISO 14040 *Environmental management – Life Cycle Assessment – Principles and framework.*

[14] ISO 14044 *Environmental management – Life Cycle Assessment – Requirements and guidelines.*

[15] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): ILCD Handbook. *General guide for life cycle assessment: detailed guidance. First edition.* Luxembourg: Publications Office oft he European Union 2010. ISBN: 978-92-79-19092-6.

[16] HODKOVA J, LASVAUX S. *"Guidelines for the use of existing LCA data on building materials to be used as generic data for a national context".* Proceedings of the International Symposium on Life Cycle Assessment and Construction – Civil Engineering and Buildings, 10–12 July 2012, Nantes, France, 9p.

[17] EN 15804: *Sustainability of construction works – Environmental product declarations – Core rules for the product category of building products.* CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2011.

[18] EN 15978: *Sustainability of construction works – Sustainability assessment of buildings – Calculation method.* CEN – European Committee for Standardization. Brussels: CEN – CENELEC 2011.

[19] INIES, The French EPD Database for building products, retrieved on 10/05/2013 from: www.inies.fr

System and scenario choices in the life cycle assessment of a building – changing impacts of the environmental profile

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Short Summary

This paper presents a life cycle assessment (LCA) case study of an office building. The case study investigates how the setting of free parameters (adopted from the CEN/TC 350 standards) influences the results of the building's LCA in the DGNB certification scheme for sustainable buildings. The parameters concern the reference study period and the energy supply scenarios. Furthermore, a set of toxicological impact categories are included in the assessment to test whether the toxicological impact potentials follow the same trends as the impact categories already included in the DGNB methodology

Keywords: building LCA, reference study period, energy scenarios, impact categories, DGNB

1. Introduction

Increased focus on sustainable production and consumption has led to numerous mappings of energy use and environmental impacts from different sectors of today's society. This mapping serves two main purposes: to quantify the potential environmental impacts of a sector and to assess where impact improvements of a sector can be made. The building and construction sector operations, associated with housing and office- and industrial services, make up as much as 40 % of society's final energy consumption [1]. Furthermore, building occupancy and structure account for up to 20-35 % of most other environmental impact categories associated with buildings such as greenhouse effect, acidification, smog formation, eutrophication, land-, resource- and water use and waste generation [2].

In a Danish context, the founding of the Green Building Council Denmark in 2010 marked the beginning of a collective effort from a range of stakeholders in the Danish building industry to develop a nationally tailored sustainability assessment framework for buildings. The German developed DGNB International certification was chosen as the role model scheme on which to base a Danish certification scheme. Since then, the parties involved have worked on the adaptation of the system to meet Danish regulations and conditions [3]. In the meantime, on a European level, the finishing of the European CEN/TC 350 standard series on Sustainability of Construction Works is approaching [4]. It is the explicit goal of the DGNB International to have the certification scheme complying with these European standards, and the Danish version of the DGNB scheme must therefore also take this framework into account in the adaptation process.

Both the CEN/TC 350 standards and the DGNB International certification scheme make use of the LCA methodology to evaluate the environmental sustainability of buildings, but whereas the CEN/TC 350 standards present a broad framework for the evaluation of sustainability, the DGNB International is a concise recipe for the evaluation process, complete with system boundary settings and benchmark values. In this sense, the DGNB International scheme serves as (one of

many possible) translations of the CEN/TC 350 standards into an applicable scheme for sustainability evaluation.

Important system and scenario settings for the LCA in the DGNB International are:

1. The choice of reference study period, i.e. the period in which the environmental effects of the building's life cycle are accounted for and distributed over. For office buildings the study period is defined as 50 years
2. The choice of energy supply for the building's use stage, i.e. the data input concerning the technologies producing energy for the building's consumption of heat and electricity. For office buildings the input of electricity is specified to be the European grid mix and the reference input of district heating to be a mix of 65 % thermal energy from natural gas and 35 % thermal energy from hard coal
3. The choice of impact categories, i.e. the environmental damage categories assessed in the study. In the DGNB International scheme two resource use categories are assessed (concerning the non-renewable and the renewable primary energy use) and five environmental impact categories (global warming, eutrophication, acidification, smog-formation and ozone depletion potentials)

These system and scenario choices defined by the DGNB scheme were questioned in the Danish adaptation process of the certification scheme. This paper presents the case study that was performed to explore the environmental impacts and hence the quantitative environmental sustainability implications of the system and scenario choices.

2. Method and study design

The case building was assessed using the DGNB simplified LCA methodology [5], which include the life cycle stages and processes shown in table 1. The life cycle stages covered by the DGNB simplified approach is a simplified version of the life cycle stages included according to the CEN/TC 350 standards.

Table 1: Life cycle stages and processes included in the case study

Product stage	**Use stage**	**EoL stage** (End-of-life and benefits and loads for the next product system)
• Raw material supply • Transport to manufacturer • Manufacturing	• Operational energy use (heat and electricity for building operation only) • Replacements of materials and components	• Waste processing • Disposal • Reuse, recycling, recovery potential

The life cycle impact assessment was carried out applying the CML 2001 methodology [6]. Since one purpose of the case study was to investigate how a broadening expansion of the included impact categories could potentially change the environmental impact profile of the building, four toxicological categories (presented in *italic* in the list below) supplement the other seven categories assessed in accordance with the DGNB scheme:

- Acidification potential (AP) in [kg SO_2-equivalents]
- Eutrophication potential (EP) in [kg PO_4-equivalents]
- Global warming potential (GWP) in [kg CO_2-equivalents]
- Ozone depletion potential (ODP) in [kg R11-equivalents]
- Photochemical ozone creation potential (POCP) in [kg ethene-equivalents]
- Primary energy use, non-renewable (PEn.ren) in [MJ]
- Primary energy use, renewable (PEren) in [MJ]

- *Freshwater aquatic ecotoxicity potential (FAETP) in [kg DCB-equivalents]*
- *Human toxicity potential (HTP) in [kg DCB-equivalents]*
- *Marine aquatic ecotoxicity potential (MAETP) in [kg DCB-equivalents]*
- *Terrestrial ecotoxicity potential (TETP) in [kg DCB-equivalents]*

For the study we set up and analyzed different product system scenarios for the case building. Table 2 lists the free parameters and the setting of these across the four scenarios assessed. Inclusion of toxicological impact categories in the LCIA step is carried out only on the reference scenario 1.

Table 2. Scenarios and parameters assessed in case study

	Scenario 1 Reference	**Scenario 2 Long reference study period**	**Scenario 3 Danish energy supply**	**Scenario 4 Forecast energy supply**
Study period in years	50	100	50	50
Electricity supply	EU-25 grid mix [7]	EU-25 grid mix [7]	Danish grid mix, 2010 [8][9]	Danish grid mix, average 2010-2060 [10]
Heating supply	District heating (100 % natural gas) [11]	District heating (100 % natural gas) [11]	Danish district heating mix, 2010 [10][12]	Danish district heating mix, average 2010-2060 [13]

2.1 The case study

The case study office building is the headquarters of a larger Danish company. Main characteristics of the building are presented in table 3.

Table 3. Case building main characteristics

Building type	Office
Location	Bagsværd, Denmark
Expected use	45 h/week
Gross floor area (GFA)	31,135 m2 distributed on 8 storeys (2 of these are underground, partly serving as parking space)
Building structure	Concrete, steel
Building envelope	Flat roof, ¼ of roof area made up by steel framed glass dome, façade of glass, white glazed tile, aluminium lamellas
Expected energy consumption (building operation only)	13.8 kWh/m2/year district heating 12.3 kWh/m2/year electricity from grid

2.1.1 Product stage.

The product stage modules accounted for cover the materials used in the following 8 building component categories: foundations/floor slabs, structural parts/columns, staircases, roofs, ceilings/floors, external walls/facade, internal walls/doors, and central heating/cooling. In accordance with the DGNB International simplified methodology the inventory does not include connecting parts (e.g. screws, bolts, concrete anchors), exterior activities (e.g. landscaping), nor user specific electronic equipment (e.g. personal computers, refrigerators, desktop lamps).

Around 50 different building materials were identified in the case building. Table 4 lists the mass of the building materials distributed on 11 main material categories.

Table 4. Mass of building materials in main categories

Building material category	Concrete, screed and mortar	Gravel and natural stone	Steel	Gypsum based materials	Glass	Insulation materials	Tiles and ceramics	Paints and primers	Wood based materials	Plastics	Aluminium
Total mass [1000 kg]	38,660	6,280	3,950	675	340	290	210	105	85	75	70

2.1.2 Use stage.
The use stage modules of the product system model cover the expected use of energy (i.e. heat and electricity for building operation) and the expected consumption of building materials for replacements across the entire reference study period, here set as 50 years in accordance with DGNB International.

Data on the energy demand of the case building originate from the mandatory energy simulation of new buildings in accordance with the Danish building regulations [14]. The expected energy use for building operation complies with the requirement for the Danish low energy building class 2015.

Building materials are modelled to be replaced at the end of the required service lives respectively [15].

2.1.3 EoL stage and benefits and loads beyond the system boundary
Mineral waste (e.g. concrete, screed) is assumed to be recycled as road filling material, wood and plastics are assumed incinerated with energy recovery and insulation materials are assumed landfilled. Metals are assumed recycled and central heating and cooling appliances are directed according to the information given in their respective datasets.

2.2 Modelling of energy mixes

The case study further tested how a change from regional energy supply (EU-25) to national energy supply (Danish) influenced the results of the environmental profile. In conventional building LCAs, a status quo input of energy in the building's operation stage is used, i.e. the energy technologies used for the supply is assumed the same over the full 50 years of study period. In this study we tested the influence on results of using a projected future energy scenario with a higher share of renewable technologies in the years to come. The future energy scenarios were modelled partly as linear projections from the 2010 statistics. Endpoints in the projections are "expert projections of year 2050 scenarios" for both heat [13] and electricity [10].

The specific compositions of the energy mixes used in the modelling of scenario 3 and 4 are presented in figures 1a-b.

It was necessary to project the future energy scenarios further than the 2050 scenarios in order to reflect the full 50 years of reference study period. The period 2050-2060 is projected as a 2050 status quo. The dynamics of the energy supply composition in the full period 2010-2060 is reflected in the system modelling by applying average contribution shares from each technology within the 50-year reference study period.

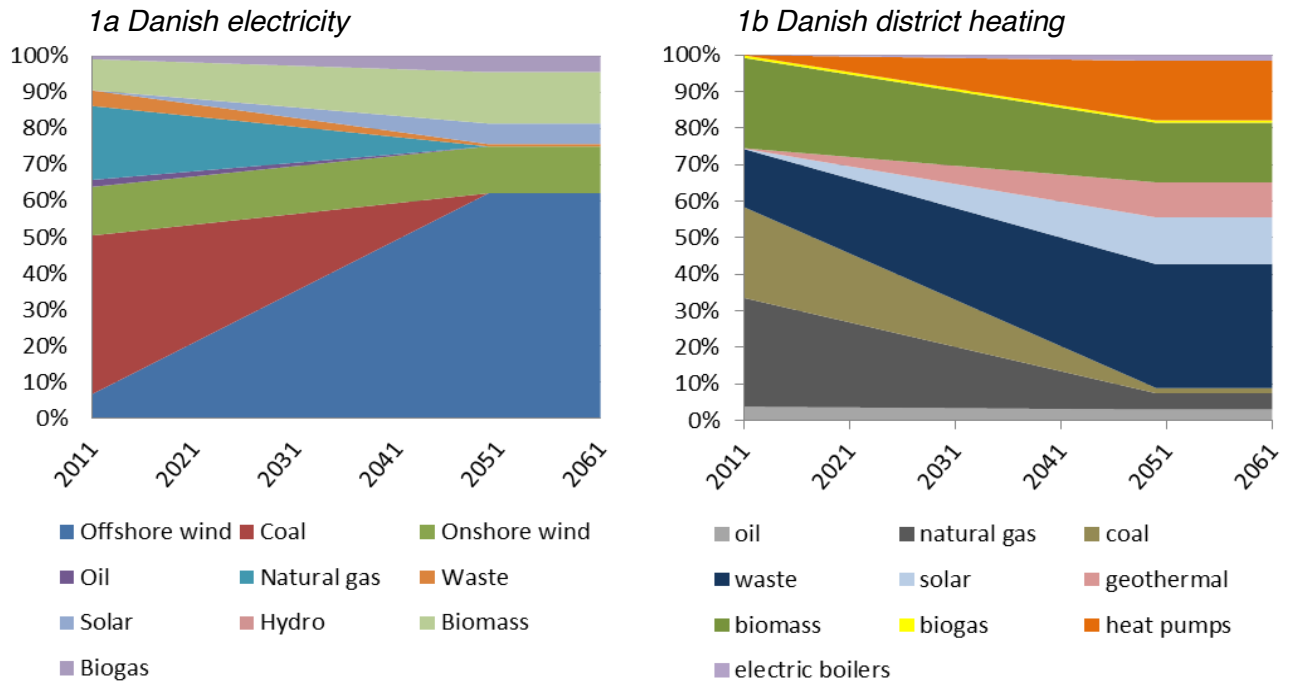


Fig 1a. Scenario of fuel/technology shares in the Danish electricity production 2011-2061 [16]

Fig 1b. Scenario of fuel/technology shares in the Danish district heating production 2011-2061 [16]

3. Results

Results obtained from the reference scenario 1 for the life cycle stages covered are presented in figure 2a. For all environmental impact and resource use categories, the use stage modules (heat and electricity consumption, replacements) have the largest impact contribution to the total impacts. Material-related impacts (production and replacements) are contributing with more than 50 % of the total impacts within the impact categories EP and POCP and 35-40 % of the embodied energy demand (renewable and non-renewable).

The results from scenario 2 highlight how the contributions to the total change when the reference study period is prolonged to 100 years. The total differences from the reference scenario's impact results are presented in figure 3. The 10-20 % lower impacts/m^2/year in the impact categories are caused by the decreased impact contributions from the building materials used in the completed building prior to the use stage. Since the impacts are given per m^2 per year, the impact contributions from building materials are distributed over twice the number of years (i.e. 100 years) as in the reference scenario. Thus, the contributions from building materials to the impact categories, presented in figure 2b, decrease from 20-50 % of the total impact in the reference scenario to 10-35 % of the total impact in scenario 2.

The use of the Danish electricity and district heating mixes in the modelling of the use stage yields impact results in scenario 3 that vary considerably from the reference scenario applying European energy mixes. Figure 3 reveals how the impact from the building increases with up to 5 % within the impact categories EP and GWP. For other impact categories, the total impact results are lower than the reference, up to 33 % lower within AP and 56 % lower within ODP. The impacts from PEren are app. 175 % higher in scenario 3 than in the reference scenario 1. Looking at figure 2c and the contribution from the different life cycle stages to the total results, scenario 3 also shows large changes in the share contributed from the building's energy demand (electricity and heat). In the impact categories AP, ODP, POCP and PEn.ren the contribution from the energy demand decreases by 10-20 percentage. In the EP and GWP impact categories the contribution from the energy demand increases by a few percentages from the reference scenario 1 to scenario 3. For the PEren category the contribution from the energy demand increases by 25 percentage points.

In scenario 4 the energy mixes were modelled in order to reflect a projected development of the technology composition of the energy production. Figure 3 illustrates how the impact from the case building increases considerably in the PEren category with a more than 300 % increase in scenario 4 relative to the reference scenario. In all other categories impact results are lower than the reference scenario results, ranging from 2 % lower impact in the EP category and to 53 % lower impact in the ODP category. Figure 2d illuminates how the contribution from the energy demand to the total impacts is dramatically reduced compared with the reference scenario. The contribution from the building materials (original building and replacements) is noticeable within each impact category with PEren as the only exception.

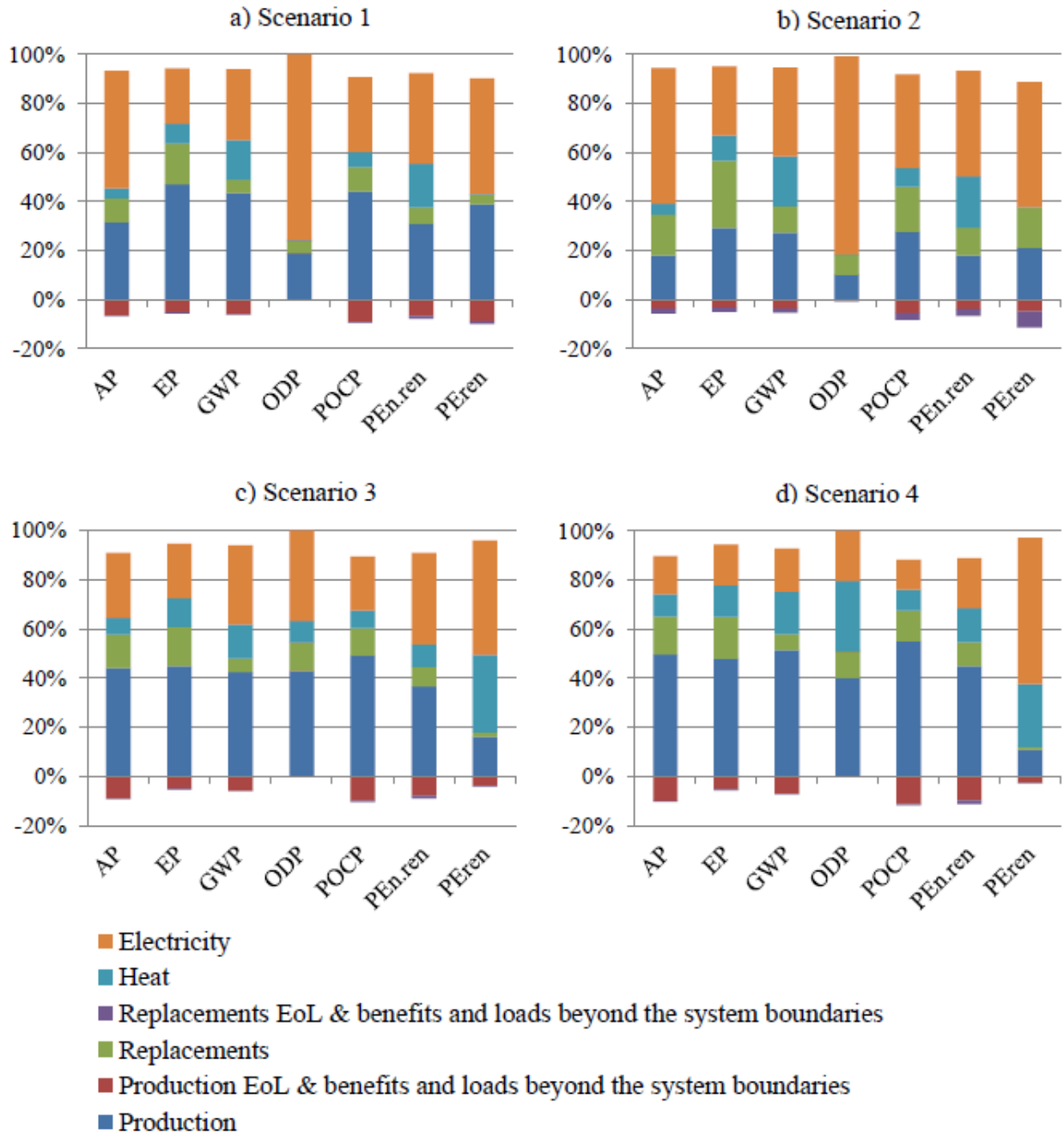


Fig 2a-d. Environmental impact results and resource use contributions from the individual life cycle stages of the different scenarios

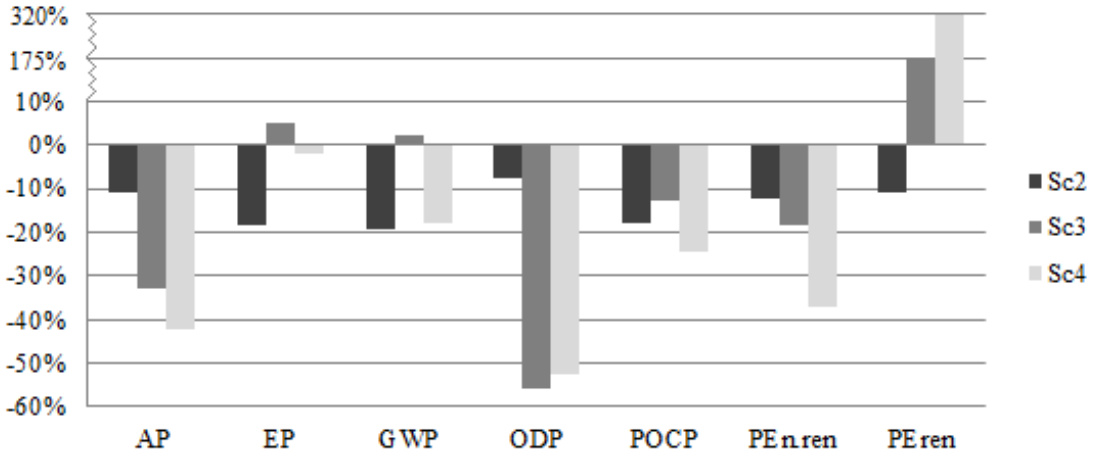


Fig 3. Differences in impacts potentials per m^2/year for scenario 2, 3 and 4 relative to scenario 1

The toxicological impact potentials from scenario 1 are given relative to the contributing life cycle stages in figure 4. Building material related impacts from the original construction and replaced materials are dominating the total impacts across all four toxicological impact categories with contributions amounting to 60-80 % of the total impact. In the FAETP category the impact from replacements is contributing with the same share of the total impact as the production of all the originally installed building materials.

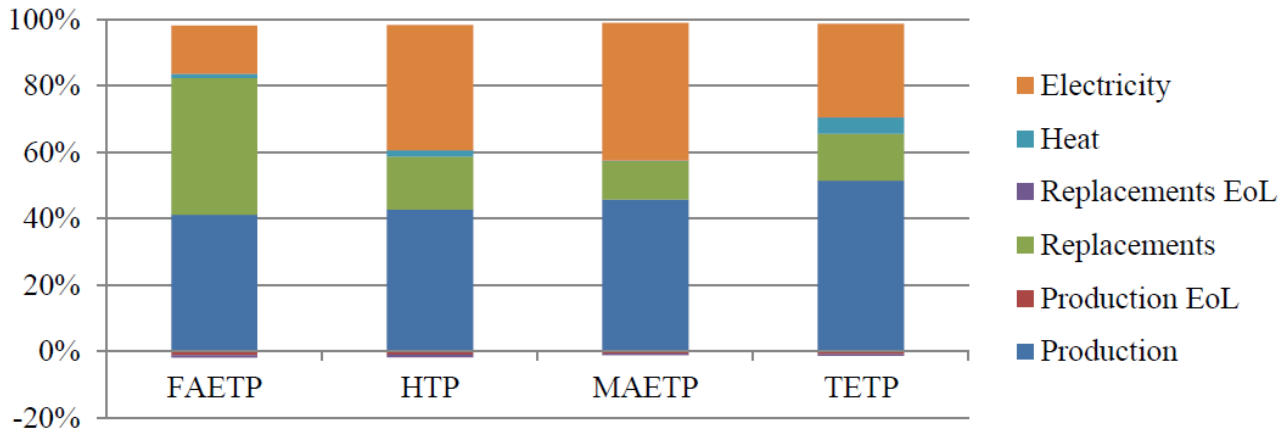


Fig 4. Toxicological impact contributions from different life cycle stages – Scenario 1

4. Discussion

As the results from this case study illustrates, the environmental burden of a building can vary as much as 20 % in some impact categories depending on whether a study period of 50 or 100 years is used (cf. figure 3). Other studies have similarly shown considerable changes in impact results for one or more impact categories [17, 18, 19, 20, 21] depending on the reference study period.

Traditional structural elements, concrete and steel, have expected service lives in the range 80-100 [15] and a required service life of a building containing these structural elements could thus easily be defined as 100 years. The use of a shorter reference study period does not justify the use of long lasting/high quality building materials. Such assumptions could possibly lead building designers to choose materials that are not necessarily environmentally beneficial. However, an expected life span and reference study period of 100 years is a long time span when scenarios are founded on current data, energy consumptions and EoL technologies. The uncertainties connected with this kind of long study periods, would hence make the results more unreliable as a whole.

Environmental impacts from energy consumption in a building's use stage have generally proven a major contributor to impact potentials of buildings [17, 22, 23, 24, 25], and the type of energy input does therefore have a potential strong effect on the environmental results. The impact results from scenario 1 to scenario 3 confirm this picture with substantial changes within some impact categories. The use of national energy mixes in the LCA modelling is hence necessary to obtain more exact results. Furthermore this way of modelling the energy supply complies with recommendations on defining energy supply system boundaries in LCA where local data should be preferred, i.e. the local district heating grid and the national electricity grid mix [26].

The focus of LCAs on energy consumption in buildings is generally on the influence of changes in the building's energy demand [27, 28, 29]. Scenario 4 explores the relevance of changes in the energy supply mix for the building. The results from scenario 4 revealed considerable changes in all impact categories, reductions in all (e.g. a 20 % reduction in the GWP and a 40 % reduction in the PEn.ren categories) but one case (PEn.ren, cf. figure 3). The energy system will in reality develop, and most likely to a composition with more input from renewable energy sources [10]. Results like those obtained from scenario 4 may hence come closer to the actual impacts of the building. However, the energy supply development could take place in a number of ways; new technologies are introduced, known technologies are improved, and a simple model of the future energy scenario will not be able to take all of these aspects into account. For the sake of comparison possibilities of building LCAs at early stages of the building's life span the status quo future scenarios (i.e. no energy supply mix dynamics) serves adequately.

The most commonly included impact categories in building LCAs are GWP, AP, EP, ODP and primary energy consumption. Toxicological impact potentials however, are rarely included in the LCA of buildings [30, 31]. Results from our study show how the toxicological impact profiles of the building do not follow the same trends as the other impact categories. Building materials, originally installed and replaced, contribute more than energy consumption to all toxicological impact categories assessed. This is opposing the general trends in the other assessed impact categories where the energy consumption, with a few exceptions, accounts for the largest impact share. The inclusion of toxicological impact categories can thus be seen as an important broadening of perspective. However, the toxicological impact categories would be difficult to include in the DGNB scheme because the background data on toxicological impacts is not included in the European standards on environmental product declarations of building materials, the EN 15804 [32].

5. Conclusion

This case study investigated some of the free parameters of the CEN/TC 350 standards on sustainable construction work. The free parameters investigated; the reference study period and the choice of energy data have been set in the practical application of the standards in the DGNB certification scheme for sustainable buildings. In the adaptation of the DGNB scheme to Danish conditions it has been desirable to know how the parameters affected the results of the environmental profile of the building.

The results of the case study illustrate how a 50-year study period cannot justify the use of long-lasting materials. On the other hand, a study period of 100 years increases the uncertainty of the scenarios on energy input and replacement.

National or local data on energy production should be preferred to regional data, so as to give a more correct picture of the actual environmental effects of the building. This approach is already being followed in the Danish DGNB adaptation process. The use of dynamic energy scenario modelling may prove to provide results which come closer to the actual situation of the building. However, the uncertainties connected with this kind of projections can be considerable.

The contributions from the life cycle stages to the toxicological impact categories do not follow the trends found in the other impact categories. The inclusion of toxicological impact categories thus widens the perspective of the environmental profile of the building. In practice however, it will be difficult to include the toxicological impact potentials as part of the certifications scheme, because the background data is not readily available in the standardized environmental product declarations.

6. References

[1] UNEP, 2003, *"Sustainable building and construction - Facts and figures"*, UNEP Industry and Environment, (April - September 2003), pp. 5-8

[2] EUROPEAN COMMISSION JRC, 2006, *"Environmental Impact of Products (EIPRO) - Analysis of the environmental impacts related to the final consumption by the EU-25*", EUR 22284 EN, Spain, European Commission

[3] DK-GBC, 2012, *"Green Building Council Denmark"*, (available at www.dk-gbc.dk, accessed May 12 2013)

[4] EUROPEAN COMMITTEE FOR STANDARDIZATION, 2010, *"CEN/TC 350 - Sustainability of construction works – Sustainability assessment of buildings – Part 1: General framework*", European Committee for Standardization, Brussels

[5] DGNB INTERNATIONAL, 2010, *"Ecological quality – Criteria 01-05 Ecological Footprint"* [draft version], DGNB International

[6] GUINÈE J, GORRÈE M, HEIJUNGS R et al. 2002, *"Handbook on life cycle assessment: operational guide to the ISO standards"*, Dordrecht: Kluwer Academic Publishers

[7] PE INTERNATIONAL, 2006, *"EU:25 Power grid mix PE [Power grid mix]*", Stuttgart, Germany

[8] ENERGINET.DK, 2011, *"Retningslinjer for udarbejdelsen af miljødeklarationer for el, Fredericia*", Energinet.dk

[9] DANISH ENERGY AGENCY, 2011, *"Energistatistik 2010*", Copenhagen, Denmark, Danish Energy Agency

[10] ENERGINET.DK, 2010, *"Energi 2050 – Udviklingsspor for energisystemet*", Fredericia, Energinet.dk

[11] PE INTERNATIONAL, 2006, *"EU:25 Thermal energy from natural gas ELCD/PE-GaBi [Thermal energy from natural gas]*", Stuttgart, Germany

[12] DANISH ENERGY AGENCY, 2010, *"Forudsætninger for samfundsøkonomiske analyser på energiområdet*", Copenhagen, Danish Energy Agency

[13] DANISH DISTRICT HEATING ASSOCIATION, 2010, *"Varmeplan Danmark 2010 – Hovedrapport*". Copenhagen, Danish District Heating Association

[14] DANISH ENERGY AGENCY, 2010, *"Bygningsreglementet"*, (available at http://www.bygningsreglementet.dk/forside/0/2, accessed 29 January 2013)

[15] BUNDESAMT FÜR BAUWESEN UND RAUMORDNUNG IM AUFTRAG DES BUNDESMINISTERIUMS FÜR VERKEHR, BAU- UND WOHNUNGSWESEN, 2001, *"Leitfaden Nachhaltiges Bauen – Anlage 6 - Bewertung der Nachhaltigkeit von Gebäuden und Liegenschaften"* (available at http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/nutzungsdauern-von-bauteilen.html, accessed 29 January 2012)

[16] RASMUSSEN F, 2012, *"Certification of sustainable buildings in a life cycle assessment perspective"*, M.Sc. thesis Environmental Engineering, Technical University of Denmark

[17] COLE R, KERNAN P, 1996, *"Life-Cycle Energy Use in Office Buildings*", Building and Environment, 31(4), pp. 307-317

[18] ITARD L, KLUNDER G, 2007, *"Comparing environmental impacts of renovated housing stock with new construction*", Building Research & Information, 35(3), pp. 252-267

[19] WALLHAGEN M, GLAUMANN M, MALMQVIST T, 2011, *"Basic building life cycle calculations to decrease contribution to climate change – Case study on an office building in Sweden*", Building and Environment, 46, pp. 1863-1871

[20] HAAPIO A, VIITANIEMI P, 2008, *"Environmental effect of structural solutions and building materials to a building*", Environmental Impact Assessment Review, 28, pp. 587-600

[21] AKTAS C, BILEC M, 2012, *"Impact of lifetime on US residential building LCA results*", Int J Life Cycle Assess ,17, pp. 337–349

[22] BRIBIÁN I, ARANDA A, SCARPELLINI, S; 2009, *"Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification"*. Building and Environment, 44(12), pp. 2510-2520

[23] MITHRARATNE N, VALE B, 2004, *"Life cycle analysis model for New Zealand houses*", Building and Environment, 39, pp. 483 – 492

[24] JUNNILA S, HORVATH A, 2003, *"Life-cycle environmental effects of an office building*", Journal of Infrastructure Systems, 9(4), pp. 157-166

[25] MARSH R, LAURING M, PETERSEN E, 2000, *"Arkitektur og miljø: form, konstruktion, materialer - og miljøpåvirkning*", Århus, Arkitektskolen
[26] VON MALMBORG F, FORSBERG A, 2003, *"Choice of energy data in environmental assessment of the built environment*", Journal of Environmental Assessment Policy and Management, 5, pp. 83–97
[27] KEOLEIAN G, BLANCHARD S, REPPE P, 2001, *"Life-cycle energy, costs, and strategies for improving a single-family house*", J Ind Ecol 4 (2), pp. 135–156
[28] KNEIFEL J, 2010, *"Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings*", Energy and Buildings, 42, pp. 333–340
[29] HERNANDEZ P, KENNY P, 2011, *"Development of a methodology for life cycle building energy ratings*", Energy Policy, 39, pp. 3779–3788
[30] KHASREEN M, BANFILL P, MENZIES G, 2009, *"Life-Cycle Assessment and the Environmental Impact of Buildings: A Review*", Sustainability, 1, pp. 674-701.
[31] ORTIZ O, CASTELLS F, SONNEMANN G, 2009, *"Sustainability in the construction industry: A review of recent developments based on LCA*", Construction and Building Materials, 23(1), pp. 28-39
[32] EUROPEAN COMMITTEE FOR STANDARDIZATION, 2012, *"EN 15804 - Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products"*, European Committee for Standardization, Brussels

Trends in Building & Construction Life Cycle Assessment



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Summary

Life Cycle Assessment (LCA) based Environmental Product Declarations increasingly become a default communication format for construction product manufacturers – e.g. based on the new EN 15804 standard [1]. In sustainable building certification schemes, particularly in those of the DGNB and its partner organizations across Europe, e.g. ÖGNI in Austria, LCA of buildings is well established as default mechanism [2, 3]. In both areas – product LCA for EPDs and building LCA for certification – the method has matured from research into daily application and planners increasingly use LCA for decision support during the planning process.
This in turn raises the question: What future developments can we expect for LCA in the construction sector?
This article indicates different upcoming developments in LCA that are either already under way – yet not necessarily generally visible – or that are likely to come. Some developments indicate increasing harmonization of calculation methods, e.g. across Europe. The European research project “EeBGuide”, for instance, yielded a comprehensive set of guidelines and provisions to uniformly conduct LCA studies in the construction sector [4].
Other developments include the assessment of new environmental aspects such as scarcity of abiotic resources, water consumption, land use, biodiversity or toxicity, always covering a product’s or building’s life cycle.
Also the improvement of LCA for use in the planner’s daily work reflects a visible trend in the field of LCA. This includes simplified methods for building LCA and automatic connections of LCA models and software to planning tools. The link of LCA to decision support in building planning – e.g. by identifying major drivers for environmental impacts of building, reported through LCA – forms another basis for future LCA-developments.
The article outlines which trends are in sight and the need for research activities in the different fields is mentioned. Focus of those discussions hereby lies on the need for pragmatic implementations of new developments into the practical use of LCA.

Keywords: Life Cycle Assessment; Environmental Product Declarations (EPD); Building Certification; EeBGuide; Future Developments.

1. Introduction – LCA in the building and construction sector

Life Cycle Assessment is a method used to assess the environmental performance of product life cycles. It is used in the building & construction sector to assess several environmental indicators that are part of building certification systems. It is also used to declare the environmental performance of construction products within Environmental Product Declarations. In addition to that, LCA is used e.g. in research projects to investigate the environmental preference of new technologies against existing technical systems.
LCA has matured from a method used solely for research purposes to an instrument that is regularly used and that currently finds its way e.g. into architects' workflows. It is well established as a method, and for specific purposes, it is readily available for use by non-LCA-experts. In order to make LCA available for no-LCA experts, methodological choices and calculation rules have been defined and consistent LCA databases have been implemented as a basis for consistent and transparent LCA studies. For the specific application of LCA, some tools are available for use [5].
Two major fields, where LCA is used on a regular basis are laid out below. These fields outline the basis for upcoming developments in the field of LCA that are detailed afterwards.

1.1 LCA in building certification

Within the German building certification systems of the German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen, DGNB) and of the German federal ministry for building & construction (Bundesministerium für Verkehr, Bau und Stadtentwicklung, BMVBS), LCA plays a core role for the assessment of buildings [3, 6]. Both systems are closely related and define LCA as a mandatory assessment method for sustainable buildings. The German federal government also defined the assessment of the sustainability of buildings – and hence LCA – to be a mandatory element of the planning of certain public buildings [9].
The certification systems contain detailed calculation methods for building LCAs, the federal ministry for construction released a publicly available database for LCA data of construction products, called 'Ökobau.dat' [10] and benchmarks are defined for the environmental performance of building life cycles.
The British building certification system BREEAM ('BRE Environmental Assessment Method') also has a long history of incorporating LCA into the certification system. The consideration of LCA, however, is done on the basis of standardized assessments of building elements and LCA-based ratings of these elements. These elements are listed in the 'green guide to specification' [11] which serves as the basis for building assessments.
The certification system LEED ('Leadership in Energy and Environmental Design', U.S.A.) allows a full building LCA to be conducted for obtaining an optional credit. Several impact categories are defined and the LCA is required to demonstrate a certain reduction of impacts against a reference building. [7]
All in all, LCA has already found its way into several building labelling schemes where it is applied on a regular basis.. However, an increasing use of LCAs is expected, partly along with an increasing use of building certification, partly due to the efforts to adopt LCA into existing schemes.

1.2 LCA for Environmental Product Declarations

Besides applying LCA on entire buildings, construction products are the second large subject for LCA in the building & construction sector. Product LCAs describe the environmental impacts over a product's life cycle, using specific assumptions on how the product will be utilized and later recycled.
Product LCAs form the basis for Environmental Product Declarations (EPD) of construction products. Such declarations – type III declarations as defined in ISO 14025 [12] and for construction products specifically described in EN 15804 [1] – declare the environmental profile of

a manufacturer-specific construction product.
EPDs are registered within an EPD programme, which organizes the development of calculation rules – Product Category Rules (PCR) – the independent verification of the EPDs and the dissemination of the EPDs.
The advantages of EPDs are primarily that LCA practitioners have a sound data source for product-specific LCA profiles at-hand. This improves the quality of building LCAs and permits the reflection of the specifically built building, using the product LCAs for the construction products used. For manufacturers, in turn, the dissemination of environmental profiles of their products enables prospective customers to decide on the product use on the basis of also environmental data. This also means that in construction projects, where LCAs are to be conducted, e.g. because a building certification is intended, the mere availability of an EPD may lead to the decision for the respective product, as the availability of LCA data is of major importance.

1.3 LCA in research

LCA as such is subject to research, yielding a continued evolution of LCA. These directions include the development of indicators e.g. for water consumption [19], for land use [20]. Developments also are directed towards better availability of inventory data ('LCA datasets') to address the practitioners' needs for regionally (e.g. nationally) specific data and for a wide range of e.g. building material data.
In general, however, a strong focus lies in the use of LCA for practitioners, rather than in the continuation of methods development for LCA.
LCA is also frequently used in research projects to discuss the environmental advantages of one technology against another (e.g. European FP7 research projects Cost-Effective [13]).

2. Upcoming developments

While LCA is well established in the building & construction sector in the named ways, a number of new developments concerning LCA in the construction sector are well under way or are emerging. They include an increasing relevance of LCA for political activities and legislation, harmonization activities on different levels and by various methods, as well as the introduction of new indicators. On the back of such developments, real trends may come along. Following the description of developments in sight, an interpretation concerning those trends is given.

2.1 LCA in legislation and on political agendas

The new European Construction Products Regulation (CPR) [14], replacing the Constructions Products Directive, calls "sustainable use of natural resources" as one of seven basic work requirements for the marketing of construction products across Europe. So far, no specific guidance is given on how to address this novel basic work requirement. The European Parliament, however, identified Environmental Product Declarations as a feasible means meet the respective requirements of the CPR. As a consequence, LCA of construction products may contribute to meet the legal requirements for trading construction products in Europe.
In addition to the call for EPDs of construction products, the EPD-rules of the EN 15804 standard are currently implemented in some of the harmonized standards of construction products. Such standards define the technical specifics for construction products and their testing to be compliant with European legislation. The inclusion of LCA-based assessments into European Technical Assessments (ETA, formerly known as European Technical Approvals) and national approval routines in one way or another may also well be expected.
This yields a situation, where LCA-based product information as part of EPDs is conceivable to be mandatory for all building products within the European market. The current on-going developments in France regarding the environmental labelling of products can be seen as a first step in this direction [21]. This could have a major impact on the use and distribution of LCA in

Europe. A significant pressure on simplification, harmonization and appropriate tools for LCA would be the consequence, in order to enable non-LCA experts to perform product LCA studies.
In addition to EPDs based on EN 15804, the European Commission's Joint Research Centre developed an LCA-based Product Environmental Footprint (PEF) [16]. This method is intended to promote the use of life cycle based environmental assessment by simplifying LCA and is not limited to the category of building products. The method has been established too recently to be able to comprehensively discuss its' relation to EN 15804 based assessments or its' practical applicability

2.2 Harmonization for wider acceptance

The first step for harmonization of methods is obviously the development of standards that define LCA as a method to assess the environmental performance of buildings, construction products and services. This is the case for the European standards EN 15804 – assessment of the environmental performance of construction products [1] – and EN 19578 – assessment of the environmental performance of buildings [15]. The standards, along with corresponding ISO standards under development (ISO TC 59 / SC 17), represent a basic level of harmonization of LCA calculation rules with a broad consensus. Additionally the ILCD handbook [22] is giving general guidance and provision on how to conduct LCA studies. Further harmonization activities are for instance initiated by the Sustainable Buildings Alliance (SBA). The SBA, being a forum of international building certification institutions, developed a set of core metrics for building certification, which includes LCA based "common carbon metrics" [17].
A European project that was explicitly dedicated to providing consistent calculation rules for LCAs in the construction sector was the EeBGuide project (www.eebguide.eu). The project duration was from Nov. 2011 to Oct. 2012 and yielded a comprehensive guidance document for LCA studies of buildings and building products [4]. While the project's core objective was to provide LCA-guidance for European research projects, a clear focus of the guidance document also lies on harmonizing existing LCA approaches and providing rules that can be used for various purposes and still are capable of yielding consistent results. In addition to that, the work conducted also had a strong focus on practical applicability and robustness of the results [23].

2.3 New indicators

LCA is used to assess the environmental performance of a technical system with regard to various fields of environmental concern. 'Typical' indicators – indicators that have been frequently used in the past – include Global Warming Potential (GWP), Eutrophication Potential (EP) or Photochemical Ozone Creation Potential (POCP). As a consequence of the discussions of the different standardization bodies, indicators found their way into standardization that have not been frequently used by all LCA practitioners. Such indicators include Abiotic Depletion Potential for non-energetic material resources and for material resources with heating value. Other indicators cover fresh water consumption or Life Cycle Inventory information such as use of secondary material as material or as energy source. In addition to that, the recommended Life Cycle Impact Assessment Methods (LCIA) of the ILCD include indicators that are similar, yet technically different to CML-indicators [4]. Indicators such as water consumption or land use, are subject to LCA research, yet have not been brought to a level where they may be used in daily operations by non-LCA-experts. All in all there is a tendency within the LCA community to try to quantify environmental consequences that have not been assessed quantitatively in the past, such as land use or impacts on biodiversity.

2.4 Conclusions: Trends

While trends are difficult to be proven by means of rock-solid evidence, this is an attempt to identify trends derived from the above given developments. Hence, this should not be seen as a 'final' list,

but rather as an invitation for discussion. One major trend is surely the wide recognition of LCA beyond scientific application. LCA is already in use for planning and financing decisions in the sustainable building sector and is increasingly coming into the focus of building product manufacturers. This trend may lead to tremendous movements and changes in the LCA field, more so, if it really ever happens to become a legally mandatory assessment method. (In fact, it should be noted that for very specific purposes, it already is legally mandatory – e.g. as part of the mandatory sustainability assessment of the new construction of public federal buildings in Germany [5].)
The second large trend that is believed to be visible is derived from the developments of harmonization, standardization and indicator development: while LCA moves into the public focus, demands grow towards the method that it should be able to reflect the environmental consequences of human interventions more comprehensively and more comparatively. This trend may and quite likely will initiate increasing research activites towards both of these two demands: harmonization and indicator development.
Based on the presented developments and the concluded trends, research fields open up. The following section attempts to outline the areas where specific research on LCA-related topics is needed.

3. Need for dedicated research

LCA has reached a state where it is well used by practitioners of various professions. LCA experts provide support for building planning, product manufacturers start to incorporate EPD-generation functionality into their ordering and planning tools and architects start to use LCA as planning tool on a daily basis.
Nonetheless, on the level of research and scientific advancement, it should not be forgotten that a method like LCA needs constant adjustments to be able to address new aspects. It is crucial, however, to direct research to dedicated fields of interest. Some of these fields are given below. They may also be understood ideas to develop research activities in these fields. Yet, it should be noted that the mentioned fields are mere examples and other fields exist additionally and may be equally relevant.

3.1 Benchmarking building performance

Benchmarks and LCA benchmarks in particular are very important not only to rate a building, product or service but also to get a general understanding for the environmental impact of any human intervention. Thus, in building certification schemes, a comparison of the results of one building with a given benchmark should be performed, rather than just conducting an LCA study without benchmarking [18]. The understanding of such benchmarks, their technical justification and possibilities for future developments of benchmarks is an important, yet somewhat neglected aspect. Existing benchmarks may be based on a limited number of data and assumptions. A cross-examination against large statistical samples may confirm the original assumptions for benchmark generation or may yield to partial revisions. All of the currently available building labelling schemes so far lack these scientifically sound benchmarks, both on a broader European level and on a national level. The European research project OPEN HOUSE [24] gave an initial outlook on LCA benchmarks for buildings on an European level, but so far, the number of case studies is not sufficient for statistically robust benchmarks.
Also, having the general aim of building certification – being the transformation of the built environment into a more sustainable state – in view, benchmarks should be defined in a way that a long-term market transformation may be initiated. For some indicators, political goals may define long-term emission reduction targets which could be supported by adequate benchmarks, if the scientific link between building benchmarks and political targets can be given.

3.2 Understanding the relevance of planning decisions

In the past, LCAs of buildings have mostly been isolated case studies of individual buildings, new constructions or retrofit measures. Some common rules have been identified in the past, such as that insulation in typically used ranges is always preferable for the life cycle impacts of a building.

Yet, beyond such very basic conclusions, it is extremely difficult or impossible to draw general and valid conclusions from different case studies that have different scopes, system boundaries, assumptions, etc. In order to better understand the environmental performance of buildings and the relevant drivers, such conclusions concerning the relevant decisions of planners are of major importance. Certification systems utilizing LCA provide the grounds to investigate LCA studies with regard to finding the drivers for environmental impacts. These LCAs are based on common databases, pre-defined calculation rules, etc. Statistical and empirical analyses of these LCAs may lead to a better understanding of the environmental performance of buildings.

3.3 Simplifying LCA

As LCA increasingly becomes available to planners and architects, the method evolves to an instrument actively used in planning processes. This, however, also means that LCA cannot remain an expert instrument available only to those who have in-depth knowledge on LCA as a method, but it must also become available to practitioners on a more applied level. For this, the LCA methods urgently require simplification. Simplifying LCA, could be done by merely cutting off some aspects rather randomly. Yet, this would greatly increase uncertainty, whether the LCA covers the major environmental impacts reliably.
For simplifying LCA, a sound understanding of generally less relevant aspects is necessary. With such knowledge, the method could well be brought to a level, where planners could easily apply LCA in their daily work with less intense training than today.
Hence, simplification and harmonization of LCA in terms of methodology and relevance is important.. There is a great need for professional LCA software for non-LCA experts. Within such software, specific calculation and methodological rules, standardized reporting templates and a simply user interface need to be implemented [25].

3.4 Indicators to assess current environmental issues

LCA is typically used with a set of well-known environmental impact categories. In the construction sector, a number of aspects, however, is also of importance. Some of these aspects are available in principle to be assessed within an LCA. These indicators include for instance the consumption of potable water, the use of land as a resource, impacts on biodiversity, but also the emission of hazardous substances from construction products, the management of waste (during construction and during use).
Three core challenges exist with new indicators in LCA:

- they need to be supported by the relevant LCI data, hence, LCA databases must provide these LCI data adequately, without asking the practitioner for extensive additional data collection,
- they need to be aggregated over the entire life cycle of a product into single values without losing their core information, and
- they need to be accurate enough to reflect the decision options that are available, as LCA is generally used for decision support.

Yet, providing indicators that are of interest to those who apply LCA for their purpose, will improve the acceptance of LCA and will hence generally improve the consistent assessment of the environmental performance of products and buildings.

4. Conclusions

Life Cycle Assessment as a method to investigate the environmental performance of products and technical systems is well established in the building and construction sector. LCA already serves to assess buildings and construction products in building certification systems and for Environmental Product Categories.
Upcoming developments include, among others, increasing efforts to harmonize the method and the integration of the method into political agendas and legislation. However, the continued development of the method of LCA should hereby not be forgotten. A number of subjects for further development can be identified and should be pursued. These fields leave wide open spaces for research activities, which are often tasks for consortia of several involved stakeholders.
Some of the research fields are described: understanding benchmarks for buildings and the relevance of certain planning decisions is necessary to improve the use of LCA as planning tool and for certification. In that context, the development of justified simplification approaches is also essential to improve the method's use for planners. And finally, the development of indicators to address the information demand is necessary work.
For all new developments, two things should also be kept in mind: LCA is a method to support decisions of one kind or another; it is never an end in itself. As LCA is relevant for decision making in numerous situations, it is a method that must provide meaningful answers and if the intention is – as it is the case in the construction sector – to have planners and building practitioners to work with LCA, then the method must be provided in a way that is useful for those who should use LCA. Researchers working to improve and advance LCA should always keep this in mind and should always assure that their work is not only scientifically sound and innovative, but also helpful for those, who are intended to use LCA.
Typically, scientific papers should conclude with an outlook on upcoming developments in the field that the article addresses. If the article's subject is an overview on upcoming developments, any further outlook would not make much sense. Instead, the reader should be encouraged to take up the hints given in this article to find research topics that have been identified as in need for further research and he could match those research topics with his own fields of interest and research in order to supply the LCA community with new developments. Such developments then yield any further and very much wanted outlook.

5. References

[1] EN 15804. *"Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products".* European Committee for Standardization (CEN), 2012.

[2] WITTSTOCK B, FISCHER M, KREISSIG J, BRAUNE A, LÖWE K. *"The Role of LCA in the German Sustainable Building Certification".* In: HONDO H (Ed.): *"EcoBalance 2010. The 9th International Conference on EcoBalance. Towards & Beyond 2020".* Manuscripts. November 9-12, 2010. Tokyo: ILCAJ, S. 81–82.

[3] DGNB (Ed.). *"Neubau Büro- und Verwaltungsgebäude. DGNB Handbuch für nachhaltiges Bauen".* Stuttgart: Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council), 2012, ISBN 978-3-942132-11-4.

[4] WITTSTOCK B, et al. *"EeBGuide Guidance Document. Operational guidance for life cycle assessment studies of the Energy-Efficient Buildings Initiative".* Project report, 2012. Online: www.eebguide.eu.

[5] BBSR (Ed.): *Nachhaltiges Bauen. Strategien - Methodik - Praxis.* (BBSR-Berichte KOMPAKT 14/2010). Bonn: Bundesamt für Bauwesen und Raumordnung 2011. ISBN: 978-3-87994-609-9.

[6] TRITTHART W. et al.: *LoRe-LCA State of the art report – Use of Life cycle assessment Methods and tools.* Project report, 2010. Online: http://www.sintef.no/Projectweb/LoRe-LCA/Training/

[7] U.S. Green Building Council (Ed.). *"Whole Building LCA req- pc. LEED. REQPC63r1, possible point"*. Online: http://www.usgbc.org/credits/reqpc63r1, last checked: 2013-05-02.
[8] BMVBS (Ed.). *"Leitfaden Nachhaltiges Bauen".* Berlin: Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013. Online: www.nachhaltigesbauen.de.
[9] BMVg (Ed.). *"Nachhaltige Entwicklung in der Bundeswehr. Nachhaltigkeitsbericht des Bundesministeriums der Verteidigung".* Bundesministerium der Verteidigung, 2012. Online: http://www.bundesregierung.de/Content/DE/_Anlagen/Nachhaltigkeit-wiederhergestellt/2012-04-27-nachhaltigkeit-in-der-bundeswehr.pdf?__blob=publicationFile, last checked 2.4.2013.
[10] BMVBS (Ed.). *"Ökobau.dat. Baustoff- und Gebäudedaten im Internetportal 'Nachhaltiges Bauen'"*. Website: Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2010. Online: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html, last checked: 06 Sep 2011.
[11] ANDERSON J; SHIERS D; STEELE K: *"The green guide to specification. An environmental profiling system for building materials and components"*. 4th Edition. Bracknell, Berkshire: (IHS BRE Press), 2009. ISBN: 1848060718.
[12] ISO 14025: 2006. *"Environmental Labels and Declarations – Type III Environmental Labeling – Principles and Procedures"*. International Organization for Standardization, 2006.
[13] LENZ K, HELD M, SCHNEIDER S, SEDLBAUER K. *"Determining the environmental influence of energy generating components for facade integration within existing high-rise buildings"*. Conference presentation: LCM2011, Berlin, 2011.
[14] *"Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC"*. OJ L 88 of 4 April 2011.
[15] EN 15978:2011. *"Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method".* European Committee for Standardization (CEN), 2011.
[16] Official Journal of the European Union (Ed.): *Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (2013/179/EU) 2013.* Online: doi:10.3000/19770677.L_2013.124.eng.
[17] SBA, UNEP-SBCI (Ed.). *"Common Carbon Metric for Measuring Energy Use & Reporting Greenhouse Gas Emissions from Building Operations".* United Nations Environmental Programme & Sustainable Buildings Alliance, 2009. Online: http://sballiance.org/wp-content/uploads/2011/11/Common-Carbon-Metric-20091.pdf.
[18] WITTSTOCK B, et al. *"What is green? Benchmarking the environmental performance of sustainable buildings"*. Prague, Czech Republic: CESB10, 2010.
[19] RIDOUTT B. et al.: *A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone weighted indicator.* The International Journal of Life Cycle Assessment 18 (1), pp 204-207.
[20] BECK T. et al.: LANCA®: *Land Use Indicator Value Calculation in Life Cycle Assessment*. Stuttgart: Fraunhofer Verlag, 2010. ISBN: 978-3-8396-0170-9.
[21] ELALOUF Z: *Environmental declaration for construction, decoration, electrical equipment, electronics and climatic engineering used in buildings*. Oral communication presented at the International Conference LCA Construction 2012 – Civil Engineering and Buildings, 10-12 July 2012, Nantes, France.
[22] European Commission – Joint Research Centre – Institute for Environment and Sustainability (Ed.): *ILCD Handbook. General guide for life cycle assessment: detailed guidance.* First edition. Luxembourg: Publications Office of the European Union 2010. ISBN: 978-92-79-19092-6.
[23] BAITZ et. al.: *LCA's theory and practice: like ebony and ivory living in perfect harmony?*, International Journal of Life cycle assessment 18 (1), pp 5- 13.
[24] ESSIG N, et al: *OPEN HOUSE. D1.2.2 First set of recommendations for standardisation for the baseline.* Project report. Online available: http://www.openhouse-fp7.eu/
[25] GANTNER J, et al: *EeBGuide D4.3 Requirements for building LCA tool designer*. Project report, 2012. Online: www.eebguide.eu

Life Cycle Assessments and the Austrian Construction Sector

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Short Summary
Sustainability assessments quantify impacts and aspects in order to analyse the environmental, economic and social performance of products and services.

EN 15643 states the methodology of Life Cycle Assessment (LCA) as one of the most efficient possibilities to determine environmental impacts and aspects based on transparent data and an extensive life cycle analysis.

In recent years the application of the LCA methodology increased intensively within the construction sector. On the level of construction products LCA established as an effective option to demonstrate environmental impacts of single products with a tendency to Environmental Product Declarations (EPD), which offer a high credibility due to their independent verification. The rising number of building certification systems increases the need of LCAs for the building construction. In contrast regarding built infrastructure the LCA methodology was applied marginal so far and mainly on research level.

This paper analyses and compares the application of LCAs within the Austrian and international construction sector. It is shown, which potentials exist on national and international level, and which gaps need to be filled in the upcoming years especially with regard to built infrastructure. Finally suggestions for further LCA-based research and development projects, which should focus on the applicability and the future profit for the Austrian construction sector, are made.

Keywords: Life Cycle Assessment, Environmental Product Declaration, buildings, built infrastructure

1. LCA - State of the Art

1.1 Sustainability

The Brundtland Report released by the World Commission on Environment and Development (WCED) in 1987 defines sustainable development as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs and to choose their own lifestyle” [1].

In 1992, the definition of sustainable development was further concretized during the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. At this conference Agenda 21 [2], a developmental and environmental action program for the 21st century, was created. In total 172 countries agreed on this document as a guide for sustainable development at the UNCED. Agenda 21 has become the guideline of public action in many countries and is considered to be a common basis for the future development of the world. Through this guiding document, the concept of sustainability was developed, founded on its three target dimensions: social solidarity, economic efficiency and environmental protection. These three dimensions can be defined as columns carrying the concept of sustainability with equal loads. In other words, sustainable development can only be achieved by simultaneous and equitable implementation of environmental, economic and social goals.

1.2 Life Cycle Assessment (LCA)

The methodology of Life Cycle Assessment (LCA) analyses and observes a product regarding its environmental impacts over its entire life cycle or over specific analysis periods [3]. An LCA is generally executed in four steps:

a. Definition of Goal and Scope
b. Life Cycle Inventory Analysis (LCI)
c. Life Cycle Impact Assessment (LCIA)
d. Interpretation

The goal of an LCA study can be defined by answering simple but essential questions [4]

- What is analysed?
- Why is the LCA carried out?
- For whom is it carried out?
- Will the LCA compare results of different products?

The goal of the Life Cycle Assessment has a great influence on the depth and accuracy of the analysis and therefore on the scope of the study. The scope of an LCA is described by the product system and the functional unit.
The product system is defined by setting the system boundaries and defining all process within the boundaries, i.e. all processes analysed in the LCA.
The environmental impacts stemming from the processes analysed relate to the so-called functional unit, i.e. the product systems analysed have to fulfil a specific function and therefore generate a certain benefit. This benefit should be the basis for the choice of the functional unit [5].

The Life Cycle Inventory (LCI) quantifies relevant inputs and outputs of the analysed product systems, e.g. materials and fuels applied as well as emissions and waste products.

The LCIA sorts, characterizes, weights and aggregates the inputs and outputs quantified in the LCI (energy, materials, emissions, etc.) according to the selected environmental indicators and their characterization and weighting factors. ISO 14040 states that the weighting and aggregating to “weighted indicator results” (e.g. ReCiPe Endpoint) is not allowed for public LCA studies comparing product options.

The LCA model analysing a product over its entire life cycle, including all processes from raw material extraction until waste treatment after the product is no longer useable, is called the “cradle-to-grave” model [3]. This model is mainly utilized to determine the environmental relevance of decision options, in other words, to compare the environmental impacts occurring over the whole lifetime of products fulfilling the same function and offering the same benefit [6].
The “cradle-to-gate” model analyses all processes until the finished product leaves the production plant. This model is applied for example to determine the environmental potentials of alternative production processes of a product, whereby it is essential that the optimized production conditions do not influence the environmental impacts of the use and end-of-life phase of the product [4, 5].
The “cradle-to-cradle” model can be used for the analysis of products that are recyclable for the most part. Thus, the cycle from the end-of-life phase to the production phase can be closed. This model is applied to demonstrate the environmental performance of products that are utilized with the same function after a recycling process [4].

1.3 Progress of standardisation

In Austria, the technical and functional performance in the context of sustainability assessments of buildings has not been specified yet. In contrast, the technical and functional requirements are defined in the Austrian OIB-guidelines 1-6 [7], which are largely in line with the essential requirements of the construction product directive [8, 9]. A first definition of technical and functional per-

formance is given below. Thus functional requirements are qualitative requirements used to describe a defined goal (e .g. demand on energy efficiency construction methods). The fulfillment of functional requirements is determined by the following different performance requirements (or technical requirements):

- Quantitative performance requirements (product-specific, construction-specific and building-specific) and descriptive/defining performance requirements
- The aggregation of the fulfillment of all described functional requirements as well as quantitative performance requirements and/or descriptive performance requirements leads to functional qualities and technical performance characteristics of a building, in accordance with the technical regulations e.g. [10].
- In other words, "functional quality" depicts the aggregation of the degree of fulfillment of the functional requirements. "Technical quality" reflects the degree of fulfillment of the aggregation of the individual technical requirements.

2. LCA in the construction sector

2.1 Construction Products – EPD

Taking into account the meaning of sustainability it is an important issue in the new Construction Product Regulation (CPR) of the European Union [11], which became completely and directly in to effect on 1 July 2013 in all member states of the European Union. In addition to the previous valid Construction Product Directive (CPD) [12] the sustainable use of natural resources is now implemented as a new basic requirement for construction works, which means that idea of sustainability has to be considered in all phases of construction works.

As a result the ecological assessment of buildings will gain a higher importance. But due to the high individuality of construction works (generally no mass production of buildings) assessments of the end products are a higher effort compared to other sectors of industry. As a consequence the ecological assessment of buildings must be reasonably based on a several-stage-assessment.

The foundation for the assessment of buildings is the assessment of single construction products, so called EPDs (Environmental Product Declarations). EPDs are executed as Type III environmental declarations according to ISO 14025 [13] and EN 15804 [14]. Evaluations are based on databases (e.g. “GABI” [15], “ecoinvent” [16]) certified by platform operators (e.g. Germany: IBU [17]) and verified by an independent board of experts. The ecological assessment is often completed by additional information concerning handling, application, health and safety.

By now EPDs for single products are available for almost all kinds of constructions products starting with the beginning of the product chain (e.g. cement, aggregates) ranging to pre-fabricated elements (e.g. pre-fabricated concrete elements). Assessments are carried out for single products of single producers as well as for product types for a whole industry sector of a product type.

Environmental product declarations (EPD) are important components for the assessment of structures and buildings. Nevertheless the effect of one product on the sustainability of the whole building is often low. Calculations of the Association of the German Cement Industry show the impact of construction materials on the ecological assessment for sustainable buildings by the example of cement [18]. The ecological impact of cement on the product concrete is calculated at significant 77 percent. For the construction phase of a typical building it is already down at 37 percent and considering all parts of a sustainable building certificate (e.g. maintenance, energy demand for use, social assessment) the impact of the cement production is only at about 1 percent.

The producers’ competition will probably force more and more companies to ecological assess their products. But due to differences of background databases, assumptions, allocations and simply due to the time factor of elaboration (e.g. rapid changes in the energy mix of electricity)

comparisons within the same product group will always be imprecisely and hardly useful. Moreover this area of application for EPDs would assume the knowledge of the exactly used product already in the planning process of a construction. That is – considering the present process of planning and building – not realistic.

The more promising application of EPDs will probably not primarily be the comparison of single products, but the as input data for the comparison of building systems. Taking into account the impact of construction products to the sustainable assessment of a building it should be precisely enough to work with EPDs of product groups. This approach allows the evaluation of construction systems in the first planning phase. If data is available for all product groups, a further improvement in the level of detail by the elaboration single product EPDs could be contemplated.

2.2 Buildings

In the past few years, an increasing number of building certification systems have been placed on the market [19]. Due to multi-characteristic influences in the context of sustainability assessments of buildings a complete evaluation criteria-structure is essential. A very large number of international building certification systems have existed since the 1990s. In the following, the two most common, LEED and BREAM, will be briefly described. In Austria, three national certification systems currently exist, DGNB/ÖGNI, klima:aktiv and ÖGNB (TQ-B). As regards assessment of buildings, these certification systems implement different approaches to environmental performance, e.g. completely or partly using LCA methodology. The differences between the three certification systems used in Austria are described below taking into account certifications on "new construction dwellings". Apart from already existing building certification system, reference is also made to the ongoing R&D European projects developed under the FP7 framework European as OPEN HOUSE[1] or SuPerBuilding[2].

2.3 International building certification systems

2.3.1 LEED

The Leadership in Energy and Environmental Design (LEED™) Green Building Rating System is a third-party certification program developed by the U.S. Green Building Council (USGBC) in 2000. Its latest version is LEED v2009. LEED is a point-based system for buildings of all types and sizes where building projects earn LEED points for satisfying specific green building criteria. The five categories include sustainable sites (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR) and indoor environmental quality (IEQ) and an additional category, innovation in design (ID) which addresses sustainable building expertise as well as design measures not covered under the five environmental categories.
According to [20], the USGBC is moving in a careful way to integrate life cycle information into the LEED framework. This means that LEED's implementation of LCA is partial in many ways (implicit). Each credit was evaluated against a list of 13 environmental impact categories, including climate change, indoor environmental quality, resource depletion and water intake, among many others [21].
Comparing it to other building certification systems, LCA aspects are not assessed in an explicit (transparent) way, i.e. an explicit LEED credit, to compare buildings using LCA benchmarks. As stated in [16] the LEED credits actually implemented are not always the most beneficial for the environment.

2.3.2 BREEAM

[1] OPEN HOUSE - Benchmarking and mainstreaming building sustainability in the EU based on transparency and openness (open source and availability) from model to implementation. http://www.openhouse-fp7.eu/

[2] SuPerBuilding - Sustainability and Performance assessment and Benchmarking of Buildings . http://cic.vtt.fi/superbuildings/node/2

BRE Environmental Assessment Method (BREEAM) [22] is a voluntary design and assessment method for sustainable buildings that was established in the UK by the Building Research Establishment (BRE). It can be used to assess the environmental performance of any type of building. BREEAM uses an explicit weighting system derived from a combination of consensus-based weightings and ranking by a panel of experts within the categories: management, health & wellbeing, energy, transport, water, materials, waste, land use & ecology, pollution and innovation (additional).
In the materials group, the number of credits achieved for this BREEAM issue is based on a spreadsheet-based calculator for each applicable element's Green Guide rating using the Ecopoint method. The Ecopoint used is a single score that measures the total environmental impact of a product or process as a proportion of overall impact occurring in Europe. Green Guide ratings are derived by sub-dividing the range of Ecopoints/m² achieved by all specifications considered within a building element and are based on LCA data generated using the BRE Environmental Profiles Methodology. These can, therefore, not be compared with the indicator values according to CEN or other building certification systems.

2.3.3 DGNB

The German Sustainable Building Council (DGNB) [23] together with the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) developed a voluntary certification system for sustainable buildings in 2007. The building certification system of DGNB is based on the CEN/TC350 approach. The DGNB certification system criteria-set includes five weighted topics (main criteria groups): ecological quality (22.5%), economic quality (22.5%), social quality (22.5%), technical quality (22.5%), quality of process (10%) and one additionally not weighted, separately evaluated topic (main criteria group) quality of the location.
The assessment is based on a holistic life cycle approach considering the before-use phase, use phase and end-of-life phase with a reference study period of 50 years.
DGNB implemented an explicit LCA method [24]. The goal of the assessment is to quantify and document the environmental performance of the building under consideration (office building, retail, hospital, school, etc.) by means of applying LCA methodology and to compare the results with a defined benchmark.

2.3.4 SBTool

The SBTool[3] is based on the philosophy that a rating system must be adapted to local conditions before its results can become meaningful. The system is therefore designed as a generic framework, with local non-commercial organizations being expected to define local context conditions and to develop appropriate weights and benchmarks. The system has been designed to facilitate such a regional calibration; in fact, the system requires the insertion of regionally meaningful benchmarks.
SBTool covers a wide range of sustainable building issues, not just green building concerns, but the scope of the system can be modified to be as narrow or as broad as desired, ranging from 120 criteria to half a dozen;
The system allows third parties to establish parameter weights that reflect the varying importance of issues in the region, and to establish relevant benchmarks by occupancy type, in local languages. Thus, many versions can be developed in different regions that look quite different, while sharing a common methodology and set of terms. The main advantage, however, is that an SBTool version developed with local knowledge is likely to be much more relevant to local needs and values than other systems;
The system provides separate modules for Site and Building assessments, with Site assessments carried out in the Pre-design phase and Building assessments carried out in Design, Construction or Operations phases;

[3] Overview of the SBTool assessment framework, Nils Larsson, iiSBE and Manuel Macias, UPM Spain, April 2012

SBTool takes into account region-specific and site-specific context factors, and these are used to switch off or reduce certain weights, as well as providing background information for all parties. Weights for criteria that remain active are re-distributed, so that the total always remains 100%.
There is a capacity to carry out assessments at four distinct stages of the life-cycle and the system provides default benchmarks suited to each phase.

2.4 National building certification systems in Austria

2.4.1 Klima:aktiv (building and refurbishment)

The klima:aktiv building and refurbishment certification system for New Construction Office [25] is divided into four assessment categories according to a system of 1000 points. The categories are design and construction (Category A maximum 120 points), energy (Category B, maximum 600 points), building materials and construction (Category C, maximum 160 points) and comfort and indoor air quality (Category D, maximum 120 points).
Klima:aktiv assessment allows LCA to be carried out in two different ways: on the one hand, category C 2.1a (ecological benchmark of the whole building) and alternative category C 2.1b (ecological benchmark of building envelope). The assessment considers three environmental impact categories GWP, AP and PEI.n.e. (or CEDnr). For the final assessment these three environmental impact categories are aggregated into one ecological benchmark (OI 3).
In the first case, the assessment goes only partly in line with the CEN/TC 350 approach. The Use phase only focuses on environmental impacts. Due to the fact that the construction and maintenance processes are considered by the assessment, environmental impacts caused by energy demand during use phase are not included in the aggregated results. Environmental impacts are partly embedded in category B 2.2 (CO_2 emissions) and B 2.3 (cumulative energy demand).
In the second case, due to time-related focus of the before use phase and the spatial-related focus of the building envelope as well as the declaration of environmental impacts in CO_2-emissions, the environmental assessment concept does not correspond to the CEN/TC 350 concept, which is based on a holistic approach. The influence of neglecting spatial and/or time related aspects is shown in detail in.
At most, 100 points (or 10%) can be achieved by using case one, and 75 points can be reached by accomplishing LCA in case two. Taking into account the previously mentioned categories B 2.2 (125 points) and B 2.3 (125 points), a total of 350 points using case one, and 325 points using case two, can be achieved.

2.4.2 ÖGNB (TQB)

The ÖGNB (Austrian Association of Sustainable Building) [26] certification system (also named TQB) is separated into five main categories behind a 1000 point system as in the klima:aktiv certification system. The main categories are quality of the location and infrastructure (Category A, maximum 200 points), economic and technical object quality (Category B, maximum 200 points), energy (Category C, maximum 200 points), health and comfort (Category D, maximum 200 points), materials and construction (Category E, maximum 200 points).
LCA is embedded in category E.3.1 ecology of materials and construction. In contrast to klima:aktiv, the environmental assessment is based on the new assessment concept which was developed during a national research project named "Nachhaltigkeit Massiv" [27] which allows focusing on the spatially related system boundaries of flexible assessment. The time-related system boundary chosen for ÖGNB-assessments for dwelling-types considers before-use, use and end-of-life-phase. Compared to case two assessments in klima:aktiv, the spatially related system boundaries have been enlarged. Next to the building envelope, finishes are also included, but the technical equipment is not included due to missing data-sets. Environmental impacts are assessed in a similar way to the klima:aktiv assessment system, thus it is also not in line with CEN/TC350. The reference study period is stated to be 100 years. At most, 60 points (or 6%) can be achieved with LCA within the sustainability assessment by ÖGNB certification system.

2.4.3 ÖGNI

The Austrian Green Building Council (ÖGNI) [28] was founded in 2009. Due to a cooperation agreement with the DGNB, signed in June 2009, a substantial basis for the operation of the council was established, and thus the German certification system for sustainable buildings (DGNB) has been successfully adapted to Austria. The DGNB/ÖGNI certification scheme criteria-set includes the same criteria as DGNB. Each of the main topics is divided into several assessment criteria. For instance, the Global Warming Potential, Total Primary Energy Demands and Proportion of Renewable Primary Energy, Thermal Comfort in Winter and Summer or Energetic and Moisture Proofing Quality of the Building's Shell are considered for the evaluation of a building. For each criterion, measurable target values are defined, and a maximum of 10 points can be assigned. The measuring methods for each criterion are clearly defined. The certificate follows the concept of integral planning that defines the aims of sustainable construction with the related building performances at an early design stage. This means sustainable buildings can be designed which are based on the latest state of technology, and their performance can be communicated with the relevant criteria in the pre-certificate at the planning stage and in the certificate after completion. The consulting auditor accompanies the owners during the certification process and prepares an accompanying planning and construction documentation in accordance with the specifications of the documentation guidelines. Having completed the building, the auditor compares and checks the building specifications with the realized project.
Finally, DGNB/ÖGNI reviews the entire certification process and performs a conformity inspection based on the documentation guidelines, makes plausibility checks and takes control samples, and checks whether everything was executed properly according to the documentation. If all requirements are fulfilled, the owner receives a certificate [29].

2.5 Infrastructure

2.5.1 Characteristics of infrastructure construction

The infrastructure construction section is dominated by public contracting authorities, which do not mainly focus on environmental assessment as criteria for their decisions by now. Nowadays their emphases are basically placed on construction costs, availability and safety concerns. Thus, contrary to the structural surface engineering (industrial, office and residential buildings) tools of sustainability assessment are far less in use for civil engineering underground and for infrastructure constructions.

Furthermore, infrastructure buildings often have significantly different characteristics in comparison to the other construction sectors in which sustainable building certificates are already in general use and at least partly established. Main construction characteristics of infrastructure buildings are for example their high life expectancy and high consumption of raw materials. All these peculiarities are different to the assessment with conventional methods and must be considered in the life cycle assessment model. Hence, for instance a characteristic for the use of natural raw materials (e.g. gravel) must be implemented. Besides, the thigh environmental impact of transport distances as a consequence of raw material consumption is shown in research projects [30].

But the biggest challenge is the evaluation and consideration of general public interest. The question is how the construction itself and its public availability can be set in equation with an ecological impact. Moreover not only the building period must be evaluated but also the utilisation phase. High maintenance efforts and short service periods due to a wrong construction system do not only cause costs for the building owner but also affect the public. Besides, generally also the impact on the environment (e.g. by emissions caused by congestion due to repair works) is bigger compared to buildings of other construction sectors.

This complex environment might be the reason why ecological assessment of infrastructure construction was only rarely part of research programs and hardly ever executed in construction projects. On the other hand exactly due to this complexity research on this topic should be forced more intensively in the future.

2.5.2 Road Infrastructure

Generally the lifetime of buildings can be separated into three main parts: the construction phase, the use phase (including maintenance, reconstruction and the real use) and the end of life phase (demolition).

Existing studies show that the environmental impact of an infrastructure in the construction phase could be reduced by optimization of the raw materials and production of the construction materials [31, 32]. For the two main construction materials for road surfaces examples for the reduction potential are reduced clinker content in concrete and the use of secondary fuels and reclaimed materials for asphalt production. Transport distances of raw materials are another factor, which influence the environmental impact of the use phase [33].

But these potentials must always be compared with the impact of the whole lifetime construction. Maintenance strategies and their environmental potential (reduction up to 60% depending on the quality of execution [32, 34, 35]) have also to be taken into account.
Moreover it is known that the environmental impact of traffic during the life time is about 100 times higher than all the effects of construction and maintenance.
Thus, the most important question in the assessment of a construction technique is their costs over the whole lifetime. This does not apply only to the economical costs, but also to the social and environmental impact of the construction.

There are still a lot of side effects of the material selection, which could have serious environmental impacts but are not considered in the studies so far.

Research projects, dealing with the comparison of different road surfaces and their stiffness properties display the fuel consumption as the main environmental factor for road constructions over the lifetime. These studies show a benefit of the concrete in comparison to asphalt surfaces. The resulting fuel consumption depending on the stiffness of different road constructions shows significant differences in connection with the type of construction. A fuel saving potential up to 3.9 percent [36] depending on the construction type causes an immense impact on the environmental potential over the lifetime.

Another example for a passive environmental impact of the construction is the reflection of material surfaces. On the one hand the albedo of constructions can directly affect the global warming by reflecting light back into the universe, on the other hand this effect could be increased by the heat island effect (increased urban temperatures in large cities caused by solar heat absorption due to dark surfaces) and additional use of energy for air conditioning. The albedo of the surface is also a factor in tunnels. A lighter surface appearance does not only improve the traffic safety but also lower the energy costs for tunnel lighting [37].

In the end of life phase an easy low energy demolition process and the direct reuse of demolition products on the highest possible quality level is essential (avoidance of “down cycling”).

2.5.3 Existing assessment tools for road infrastructure

Assessment systems analysing the sustainability of road infrastructure projects can be found in the US and in Europe. Most of these assessment instruments also use a mixed assessment method utilizing monetized, quantitative and qualitative indicators.

The NISTRA instrument (Switzerland) [38], the NATA Approach from the UK [39], the GreenLITES [40] and the Greenroads [41] assessment approaches, both from the US, are examples of such assessment systems.

In 2001 the Swiss Federal Road Office (ASTRA) decided to develop an instrument that allows the assessment of road infrastructure projects considering the three sustainability target dimensions (“Sustainability Indicators for Road Infrastructure Projects” (Nachhaltigkeits-Indikatoren für

STRAsseninfrastrukturprojekte NISTRA). The revised version of NISTRA published in 2010 utilizes the cost-benefit analysis (CBA) and the utility analysis (UA) methodologies as well as descriptive indicators to assess road infrastructure projects.

The indicator system of the NISTRA instrument can be split up into 39 indicators (8 social, 21 economic, 10 environmental).

The Greenroad approach analyses the planning, the new construction and the use phase (processes related to the use of the road) of road projects with a focus on the enhancement of the environmental performance and possible lifetimes of the road pavement, and requires a Life Cycle Cost Analysis (LCCA) and a detailed Life Cycle Assessment (LCA) for each evaluation carried out. The overall goal of the Greenroad system is not to demonstrate and compare results for different road projects, but to minimize its negative environmental, economic and social impacts, and to give road projects a sustainable certificate according to their assessment results.

3. Conclusions

3.1 General improvement of ecological construction assessments

The ecological assessment of building products and constructions is an important part for proceeding to a sustainable society. By now a large scope of tools, such as standards, are available to state an ecological footprint of products in several stages to the final building. But there are some problems that interfere the wide application of ecological evaluation.

- Lack of comparability and usability due to different systems and parameters in the evaluation of environmental performance. This shows that ideal characteristics are still not found. This gap must be closed in future.

- Uncertainty of background data due to unclear raw data and arbitrarily set system limits. Studies on the same topic often lead to completely different findings. Such contrary results must be avoided by better raw data and a better conformability.

- Significance regarding the whole building must be displayed. The focus must be set on the parts with the highest impact on the environment. Hence the main focus of further research works must be set on the detection of the essential products and processes of constructions.

- Period of validity due to daily changing background data. There is still a special need for a definition of the validity of an ecological evaluation.

If these aspects could be more clearly in the future the acceptance and application of decision makers would probably be higher. In addition also the other constituents of sustainability – beneath ecology - should be kept in mind. The social and macroeconomic benefits of constructions are often not easy to evaluate, but of extreme importance. Thus, the ecological evaluation must always be set into relation of all these parts.

3.2 Austrian EPD program for building products

In the last years a board of Austrian research institutes prepared the start-up of an Austrian EPD platform for building products by developing the basic documents needed for an EPD program:

- Basic document for the preparation of an EPD
- General rules for the LCA part of the EPD
- Analysis guidelines for emissions to air and environment

By the beginning of July the Austrian EPD program will start his operational work, so the first EPDs

can be submitted for verification and publication.

The Austrian EPD program should then build the base for a bottom up approach leading to Life Cycle Assessments of buildings, built infrastructure and building components utilizing datasets representing the Austrian situation. This can be seen as first step towards stable characteristics for ecological assessments within the Austrian building sector.

3.3 Research need for infrastructure buildings

Within the construction industry infrastructure buildings are much less analysed regarding to their ecological impact than other buildings. The high potential for further research in this field is based on the following properties of infrastructure buildings:

- Long lifetimes
- High consumption of materials
- Enormous Impact of utilisation phase
- Influence of maintenance strategies
- Social end macro-economical side effects

The road LCA studies carried out in Germany, Switzerland and The US demonstrated the necessity of an ecological study analysing at least Austrian highway constructions regarding their environmental characteristics in order to build the ecological base for a future sustainability assessment tool such as NISTRA [38] or Greenroads [41].

Furthermore, there should be a focus on LCA studies and sustainability assessments of further civil engineering structures such as railways, tunnels, power plants, etc. where the overall ecological consequences of the situation with and without the project need to be compared.

4. References

1. WCED, *Our common future*, 1987, World Commission on Environment and Development (WCED) - United Nations: New York. p. p.54.
2. UNCED, *Agenda 21: Earth Summit - The United Nations programme of action from Rio*, 1993, United Nations Conference on Environment and Development (UNCED) - United Nations: New York.
3. ISO, *DIN EN ISO 14040 - Umweltmanagement - Ökobilanz - Grundsätze und Rahmenbedingungen*, 2006, International Standard Office: Berlin.
4. Klöpffer, W. and B. Grahl, *Ökobilanz (LCA) - Ein Leitfaden für Ausbildung und Beruf*. 2007, Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA.
5. Baumann, H. and A.-M. Tillman, *The Hitch Hiker's Guide to LCA - An orientation in life cycle assessment methodology and application*. 2004, Lund, Sweden: Studentlitteratur AB.
6. Guinée, J.B., et al. *Life cycle assessment - An operational guide to the ISO standards - Parts 1 and 2*. 2001 15.09.2010]; Available from: http://www.leidenuniv.nl/cml/ssp/projects/lca2/lca2.html.
7. Österreichisches Institut für Bautechnik. 2011 15.03.2011]; Available from: http://www.oib.or.at.
8. Maydl, P., E. Eustacchio, and A. Passer, *Die Umsetzung der Grundanforderung Nr. 7 in der künftigen Bauprodukteverordnung.* OIB aktuell, 2010. **2010**(4): p. 10-15.
9. Mikulits, R., *Die neue EU-Bauprodukteverordnung.* OIB aktuell, 2011. **2011**(4): p. 10-15.
10. Mikulits, R., *The legal two-tier approach in the new Austrian Building Codes*, in *CIB Commission Meeting on Law and Dispute Resolution*2008: London.
11. 89/106/EEC, C.D., *REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing*, 2011, European Parlament: Brussels.

12. 89/106/EEC, C.D., *COUNCIL DIRECTIVE of December 1988 on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products* 1988, European Parlament: Brussels.
13. ISO, *EN ISO 14025: 2006, Environmental labels and declarations – Type III environmental declarations – Principles and procedures*, 2006: Brussels.
14. ÖNORM, *ÖNORM EN 15804: 2012, Nachhaltigkeit von Bauwerken – Umweltproduktdeklarationen – Grundregeln für die Produktkategorie Bauprodukte*, 2012: Wien.
15. http://www.gabi-software.com/deutsch/databases/.
16. http://www.ecoinvent.org/database/.
17. http://bau-umwelt.de/hp1/Startseite.html.
18. Müller, C., *Stellung von Zement in der Nachhaltigkeitsbewertung von Gebäuden*, in *Nachhaltiger Beton – Werkstoff, Konstruktion und Nutzung, 9. Symposium Baustoffe und Bauwerkserhaltung Karlsruher Institut für Technologie (KIT)*2012: Karlsruhe.
19. Passer, A., et al., *Genormte Nachhaltigkeit?* in: Nachhaltige Gebäude - Planung, Betrieb und Bewertung, 2010: p. 25-33.
20. U.S. Green Building Council, *Getting LCA into LEED: a backgrounder on the first lca pilot credit for LEED®*, 2008: Washington.
21. U.S. Green Building Council. *LEED Green Building Rating System, Frequently Asked Questions*. 2008; Available from: http://www.usgbc.org.
22. BRE Environmental Assessment Method. 2013 13.01.2011]; Available from: http://www.breeam.org.
23. Deutsche Gesellschaft für Nachhaltiges Bauen. 15.02.2011]; Available from: http://www.dgnb.de.
24. Deutsche Gesellschaft für Nachhaltiges Bauen and Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft, *Assessment Criterion 1 Treibhauspotential - GWP, NWO2010*, 2011: Berlin.
25. klima:aktiv. *Bauen und Sanieren Kriterienkatalog*. 2011; Available from: http://www.klimaaktiv.at.
26. Österreichische Gesellschaft für Nachhaltiges Bauen. *Total Quality Bauen TQB*. 14.03.2011]; Available from: http://www.oegnb.net.
27. Fachverband der Stein- und keramischen Industrie Österreichs. *Forschungsinitiative „Nachhaltigkeit massiv“*. 2011 16.03.2011]; Available from: http://www.nachhaltigkeit-massiv.at.
28. Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft, 2011.
29. Passer, A., H. Kreiner, and R. Smutny, *Adaption of DGNB-Methodology to Austria - Lessons Learned from the first Certificates*, in *SB11*2011: Helsinki.
30. Bischof, S., *Ökobilanzen rezyklierter Gesteinskörnung für Beton*, H.S. AG and H. Rapperswil, Editors. 2010: Zurich.
31. Gschösser, F., H. Wallbaum, and M. Boesch, *Life Cycle Assessment of the Production of Swiss Road Materials.* Journal of Materials in Civil Engineering, 2012. **24**(2): p. 168-176.
32. Milachowski, C., *Erstellung einer Ökobilanz für die Herstellung und Nutzung eines Autobahnabschnitts*, 2010, TU München, BetonMarketing Deutschland GmbH: München.
33. Gschösser, F., H. Wallbaum, and B.T. Adey, *Environmental analysis of new construction and maintenance processes of road pavements in Switzerland.* Structure and Infrastructure Engineering, 2012: p. 1-24.
34. Gschösser, F., *Ökologische und ökonomische Bewertung von Schweizer Nationalstrassen*, 2012, Holcim Group Support, Holcim Schweiz: Zurich, Switzerland.
35. Santero, N., et al., *Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle*, 2011, Concrete Sustainability Hub of the Massachusetts Institute of Technology (MIT): Cambridge (MA, USA).
36. Taylor, G.W., P. Farrel, and A. Woodside, *Effects of pavement structure on vehicle fuel consumption - Phase III*, 2006, National Research Council of Canada: Ottawa.
37. Gajda, J. and M. Vangeem, *A comparison of six environmental impacts of Portland cement concrete and asphalt cement concrete pavement - PCA Report RN2068*, P.C. Association, Editor 2001.
38. ASTRA, *NISTRA: Nachhaltigkeitsindikatoren für Strasseninfrastrukturprojekte - Ein Instrument zur Beurteilung von Strasseninfrastrukturprojekten unter Berücksichtigung der Nachhaltigkeitsziele*, 2003: Bern.

39. UK Department of Transport, *Understanding the New Approach to Appraisal*, 1998, UK Department of Transport: London.
40. GreenLITES, *Recognizing Leadership in Transportation Environmental Sustainability*, 2011, New York State Department: New York.
41. Greenroads, *Handbook*, 2010, University of Washington: Washington.

Posters

Renovation strategies for ageing society

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Short Summary

The specific building stock of Red Vienna represents 16% of total Viennese housing stock [1]. This stock is of significant cultural value, as a monument of an era, which determined the worldwide unique Viennese housing policy. Moreover, it represents a high social value, still bearing a large ratio in provision of affordable housing. The stock is more than 50 years old and in need of refurbishment and adaptation to the modern housing requirements. These are determined through the trends such as ageing society, increasing of housing areas [2] and of user comfort. On the other hand, the issues such as scarceness of resources and energy and minimisation of emissions must be considered in refurbishment process.
This paper presents a case study carried out on a specific housing block of the Red Vienna period. In the course of research, the economic (life cycle costing and yields), ecologic (CO_2 emissions) and socio-cultural impacts (monument protection, accessibility, assisted living) of several refurbishment variants were evaluated through quantitative and qualitative analysis. The research points out the large potentials in structural refurbishment of building stock for development of assisted living models, which prove to be substantially more cost efficient than the institutional care, providing a better comfort for the inhabitants, and also the necessary social mix through trans-generation housing in the social housing facilities.

Keywords: Life Cycle Costs, Social Housing, Assisted Living, Thermal Refurbishment, Sustainability Criteria

Towards research model

For the evaluation of refurbishment strategies by the means of sustainability criteria, a case study methodology was chosen. As specific reference object a housing estate “Elderschhof” in second Viennese district (erected in the years 1931 to 1932, owned by the federal state Vienna and administered by Wiener Wohnen) was chosen. In the first step, several refurbishment strategies were compiled:

Table 1: Summary reconstruction strategies

Reconstruction strategies	A Thermal refurbishment	B Barrier-free ground floor	C Installation of elevators and stairlifts	D Stairlifts
Starting Position	Existing building 2011	Existing building 2011	Existing building 2011 - without elevators	Existing building 2011- without elevators
Thermal reconstruction	X	X	X	X
Technical modernisation			Elevators, stairlifts	stairlifts
Modification in apartments on ground floor		Furnishing category A and universal accessibility	Furnishing category A and universal accessibility	Furnishing category A and universal accessibility

In further steps, the thermal refurbishment represented through variations of façade-insulation - systems was evaluated for life-cycle costs (LCC) [3] and the life-cycle analysis (LCA) [3].
For the thermal refurbishment of facades following variants were examined:

- Modernisation of the façade without thermal insulation measures (without TIM)
- Exterior thermal insulation composite system EPS (ETICS EPS)
- Exterior thermal insulation system mineral wool (ETICS MW)
- Thermal insulation plaster (TIP)
- Interior insulation (II)
- Vacuum insulation panel (VIP)

Finally, the developed thermal and structural refurbishment measurements were evaluated upon the sustainability criteria: economic (LCC, capital strain of rental income) [3], ecologic (CO_2 emissions) [3] and socio-cultural (monument protection, accessibility, assisted living); through qualitative analysis. The structural refurbishment strategies were compared to the gross expenses of public authorities [4] for various nursing services.

Conclusion

The study implies large potentials of existing stock for care at home, instead of much more cost intensive institutional care; reinforcing the value of stock as social capital. The comparison of the life-cycle costs concerning a structural refurbishment with the gross expenses of the public authorities points out, that nursing expenses are a multiple of the life-cycle costs caused by a structural refurbishment for accessibility in an existing building. In terms of thermal refurbishment, due to the large energy consumption during the operation, the most preferred measure is the holistic refurbishment (complete envelope) through the highest energy and CO_2 saving potential. The façade options with low potential of heating demand reduction have, despite the positive sustainable performance concerning production and maintenance, high economic and ecological life-cycle values (cumulated over 50 years), which cannot be neutralised by the positive monument conservation effects. In terms of lifecycle costs and achieved energy and CO_2 savings the ETICS EPS refurbishment variant shows the best performance over the period of 50 years, however is not compatible in terms of monument protection. As alternative, the interior insulation, causing higher ecological impact and higher skills in application, can be taken in account. The qualitative evaluation of the structural refurbishment and exploration of the potentials for providing the appropriate housing for aging society proves variant D (disclaims the use of existing elevators, but instead installs the stair lifts and enables the barrier-free living of the ground floor) as the optimal variant, both in terms of LCC as in social criteria for affordable housing (low heating costs and rent).

References

[1] STATISTIK AUSTRIA. „*Gebäude- und Wohnungszählung 2001, Hauptergebnisse Wien*“. DOI: http://www.statistik.at/web_de/statistiken/wohnen_und_gebaeude/bestand_an_gebaeuden_und_wohnungen/wohnungen_einschl._nebenwohnsitzen/index.html, last access March 2013.

[2] STATISTIK AUSTRIA. „*Haushalte*“. Last update: 28.03.2013. DOI: //www.statistik.at/web_de/statistiken/bevoelkerung/haushalte_familien_lebensformen/haushalte/index.html, last access April 2013.

[3] WEKA MEDIA. „*LEGEP - die Software für Lebenszyklusplanung*“. DOI: http://www.legep-software.de/, last access December 2012.

[4] FEDERAL MINISTRY OF LABOUR, SOZIAL AFFAIRS AND CONSUMER PROTECTION. „*Österreichischer Pflegevorsorgebericht 2010*“. Federal ministry of labour, social affairs and consumer protection, Vienna, 2011.

Renovation strategies for ageing society

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Short Summary

The specific building stock of Red Vienna represents 16% of total Viennese housing stock. This stock is of significant cultural value, as a monument of an era, which determined the worldwide unique Viennese housing policy. Moreover, it represents a high social value, still bearing a large ratio in provision of affordable housing. The stock is more than 50 years old and in need of refurbishment and adaptation to the modern housing requirements. These are determined through the trends such as ageing society, increasing of housing areas and of user comfort. On the other hand, the issues such as scarceness of resources and energy and minimisation of emissions must be considered in refurbishment process.
This paper presents a case study carried out on a specific housing block of the Red Vienna period. In the course of research, the economic (life cycle costing and yields), ecologic (CO_2 emissions) and socio-cultural impacts (monument protection, accessibility, assisted living) of several refurbishment variants were evaluated through quantitative and qualitative analysis. The research points out the large potentials in structural refurbishment of building stock for development of assisted living models, which prove to be substantially more cost efficient than the institutional care, providing a better comfort for the inhabitants, and also the necessary social mix through trans-generation housing in the social housing facilities.

Keywords: Life Cycle Costs, Social Housing, Assisted Living, Thermal Refurbishment, Sustainability Criteria

1. Current issues: housing stock and the new social requirements

The existing Viennese housing stock consists of 170.000 buildings [1]. 50% of them are already older than 50 years [1]. The buildings built in the era of Red Vienna in particular, represent 16% of the whole building stock of Vienna [1]. These are marked with an insufficient state of repair and a dwelling supply, which does not fit with modern demand considering the size of housing units and facilities. The result is an urgent need of thermal and structural refurbishment. Appropriate renovation, considering the type of building-hull refurbishment with the most sustainable effect over the life-cycle in terms of economy, ecology and monument conservation has to be determined. An aging society with the tendency to two person-households [2] leads to changing of housing requirements. Simultaneously, an aging society causes an increasing demand of care giving institutions. To delay the move into a home for the elderly creates necessity for creation of small affordable and barrier-free housing units, which enable the stay of high-maintenance persons at their beloved home. Therefore, structural renovations in the existing housing stock are necessary. Alternatively the new construction of homes for the elderly can bare the increasing demand of care. Regardless of the individual need affecting the intensity of care the benefits of structural reconstruction in the existing housing stock in combination with institutions for mobile nursing and assisted living should be compared to the new construction of homes for the elderly. Beside the large demand of refurbishment, the Viennese social housing stock has the task to supply inexpensive housing units to create affordable housing for everyone of society. The aspect of affordable living, as well as monument protection of cultural important buildings, such as the building stock of Red Vienna is, and the guidelines of sustainability have to be considered in structural and thermal refurbishment.

2. Towards research model

For the evaluation of refurbishment strategies by the means of sustainability criteria, a case study methodology was applied. As specific reference object a housing estate “Elderschhof” in second Vienese district was chosen. The Elderschhof (11 414 m^2 gross floor area, 7 floors) is a housing block owned by the state Vienna and administered by Wiener Wohnen. It was erected in the years 1931 to 1932 and is an example of the building activity during the era of Red Vienna.

In the first step, several refurbishment strategies were compiled: only thermal refurbishment, thermal refurbishment with: barrier-free ground floor, with elevators and stair lifts, with stair lifts only (Table 1).
In further steps, the thermal refurbishment represented through variations of façade-insulation - systems was evaluated by the means of the life-cycle analysis (LCA), using the software Legep [3] which is based on ökobau.dat data [4], for a) only production and maintenance, and b) production and operation; and life-cycle costs (LCC). For the calculation of the life cycle costs (LCC), the “total cost of ownership” approach was used, considering only the emerging costs over the life-cycle of a building, which have to be carried by the owner [5]. Outpayments are discounted to the present value of the date of investment and are the base for LCC-evaluation of the investigated buildings [6]. The LCC are calculated over the period of 50 years [7].

Finally, the developed thermal and structural refurbishment measurements were evaluated upon the sustainability criteria: economic (LCC, capital strain of rental income [8]), ecologic (CO_2 emissions) and socio-cultural (monument protection, accessibility, assisted living) through qualitative analysis.
The structural refurbishment strategies were compared to the gross expenses of public authorities for various nursing services.

Following reconstruction strategies were developed and evaluated based on ÖNORM B1600 [9]:

Table 2: Summary reconstruction strategies

Reconstruction strategies	A Thermal refurbishment	B Barrier-free ground floor	C Installation of elevators and stair lifts	D Stair lifts
Starting Position	Existing building 2011	Existing building 2011	Existing building 2011 - without elevators	Existing building 2011- without elevators
Thermal reconstruction	X	X	X	X
Technical modernisation			Installation of elevators in all staircases and stair lifts on the groundfloor in staircase 2, 4	Installation of stair lifts on the groundfloor in all staircases
Modification in public space			Modification of the business office to a recreation room/nursing care base	Modification of the business office to a recreation room/nursing care base
Modification in the apartments		Reconstruction of apartments on the ground floor to furnishing category A and universal accessibility	Reconstruction of apartments on the ground floor to furnishing category A and universal accessibility	Reconstruction of the apartments on the ground floor to furnishing category A and universal accessibility

For the economic operation of nursing services like assisted living 10-20 barrier-free apartments are necessary [10, 11]. The existing elevators at the examined housing block cannot be used with a wheelchair because of the insufficient size of the elevator cabin. The elevator is situated on a ground floor landing, which is one stair flight higher than the yard level. As a solution the reconstruction of the apartments on the ground floor was chosen. Stair lifts will be installed at the stairs leading from the level of the yard to the ground floor.

3. Findings

3.1 Evaluation of Strategy A: Thermal Refurbishment

For the thermal refurbishment of facades following variants were developed and examined:

1. Modernisation of the façade without thermal insulation measures (without TIM)
2. Exterior thermal insulation composite system EPS (ETICS EPS)
3. Exterior thermal insulation system mineral wool (ETICS MW)
4. Thermal insulation plaster (TIP)
5. Interior insulation (II)
6. Vacuum insulation panel (VIP)

The life-cycle analysis of the building hull examines following respective versions in the software Legep [3]:

Table 3: Respective variants of facade systems according to OIB-Richtlinie 6 [12]

	λ [W/m · K]	d [cm]	u-value [W/m^2 · K]
Without TIM	-	-	1.694
ETICS EPS	0.035	20	0.159
ETICS MW	0.040	20	0.179
TIP	0.130	7	0.886
II	0.040	6	0.520
VIP	0.008	5	0.179

Façade systems with high insulation properties, like EPS, MW and VIP require high financial input for production, maintenance and replacement and simultaneously generate a high economic impact. Especially the respective version VIP has enormous production costs compared to the other options. The alternative modernisation of the façade without thermal insulation measures and thermal insulation plaster - TIP offer low economic and ecological values concerning production and maintenance.
The evaluation of operational phase - heating energy demand savings potential resulting from façade refurbishment variants compared to the existing state of Elderschhof is determined through calculations of energy certificates along the lines of the OIB-Richtlinie 6 [12].

Table 4: Facade systems, heating demand according to OIB-Richtlinie 6 [12]

	Heating demand [kWh/m^2·a]	Savings potential to stock (171,69 kWh/m^2·a) [%]
Without TIM	123.74	28
ETICS EPS	39.16	77
ETICS MW	40.37	76
TIP	79.18	54
II	59.88	65
VIP	40.36	76

The life-cycle analysis over the period of 50 years of a theoretical extensive thermal modernisation with the variation of the façade system, provides following results concerning the LCC, the primary energy demand (PED), the global warming potential (GWP) and the capital strain of the rental income depending on the availability of subsidy by the federal state of Vienna [8] (Table 4).

Table 5: Variant A, results summary

	Capital strain of rental income incl. subsidy [€/m^2.mth]	Capital strain of rental income excl. subsidy [€/m^2.mth]	LCC (present value) [€]	LC PED [kWH]	LC GWP [kg CO_2-Äq.]
Without TIM	2.88	3.44	15 788 844	153 471 966	29 078 051
ETICS EPS	2.86	4.27	15 002 127	120 005 595	21 822 030
ETICS MW	2.95	4.36	15 079 191	121 388 327	22 168 426
TIP	2.72	3.75	15 121 241	135 337 980	25 175 898
II	2.50	3.95	14 642 429	127 394 235	23 379 028
VIP	4.22	5.81	15 877 376	119 930 005	21 751 520

Façade systems with high insulation properties EPS, MW, II, VIP are more sustainable over the life-cycle of 50 years, than the options without TIM or TIP. The low costs and the global warming potential caused by production and maintenance of the variants without TIM or TIP are neutralised through the high heating demand. The variants´ EPS, MW, II, VIP amount of produced GWP over 50 years is 20-25 % lower than that one of the variants without TIM or TIP.

The economic advantage of façade systems with high thermal insulation properties is reached after 20 years. The LCC regarding increasing energy costs point up the façade´s economic differences over the period of 50 years. Façade systems with high insulation properties EPS, MW, II, VIP cause low LCC, which are the hirers´ economic advantage. Those respective versions require high investment costs, especially variant VIP, a disadvantage for the building´s owner. The capital strain of the rental income over the period of 10 years for the variant without TIM is 15-70 % lower than compared with EPS, MW, II or VIP. That means a high reduction of the rental income yield.
Based on these results the qualitative evaluation of the façade systems concerning sustainability is carried out with the help of following criteria:

- economic
- ecological
- cultural historical / monument conservation

The economic sequence is influenced by the life-cycle costs considering as well the present value as the follow-up costs. The GWP is determining the ecological ranking of the variants. The ranking monument conservation is carried out by the means of the office for federal monument´s guideline “energy efficiency on historic monuments” [13]. The façade systems EPS, MW and VIP are equally weighted concerning monument preservation because of the same impact on structured facades (Table 5).

Table 6: Façade systems, qualitative evaluation through weighing

Qualitative evaluation	Economic	Ecological	Cultural historical
Without TIM	6	6	1
ETICS EPS	1	2	4
ETICS MW	3	3	4
TIP	5	5	3
II	2	4	2
VIP	4	1	4

The evaluation is carried out with the help of a network diagram (1=best, 6=worst result). The results concerning sustainability are pictured as areas. The façade system with the smallest area has to be favoured.

1. ETICS EPS (6.06)
2. II (8.66)
3. VIP (10.39)
4. ETICS MW (14.29)
5. Without TIM (20.78)
6. TIP (23.82)

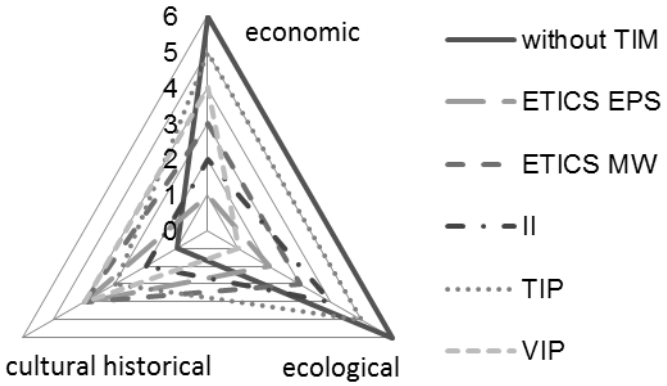


Fig. 1: Façade systems, qualitative evaluation

The evaluation of facade systems in the context of a thermal refurbishment shows that the most sustainable variant is the exterior thermal insulation composite system EPS. Disadvantage is, that it is not compatible with the principles of monument protection. An alternative is the interior insulation, which causes higher ecological impact. The façade options with high heating demand have high economic and ecological values, which in this proposed weighing cannot be neutralised by the evaluation concerning monument conservation.

3.2 Evaluation of Strategies B,C, D : Structural Refurbishment

Due to the results from chapter 3.1 the façade system EPS will be chosen for the evaluation.

3.2.1 Quantitative evaluation

Variant D has the lowest GWP compared to the other refurbishing options because of the abdication of an elevator (Figure 4). The ecological impact of the variants A, B and C equates the extent of the building measures. The difference between the lowest and the highest ecological impact is only 1.65 % of the overall GWP of variant C. The ecological potential connected with the choice concerning the façade system is higher. The subsequent installation of an elevator causes

additional GWP in a range of 1-2 % compared to the GWP of variant A, but a great ease of daily life.

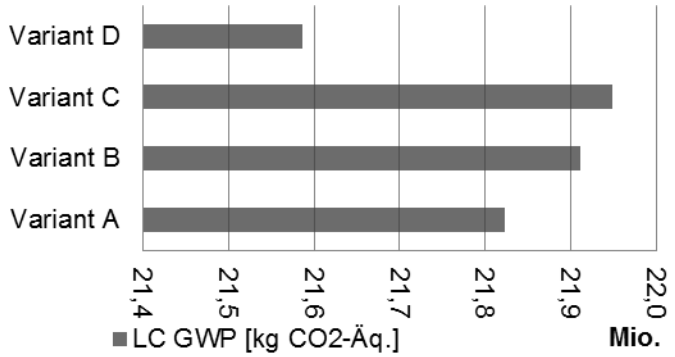


Fig. 2: Variants evaluation, ecological

The investment costs of the refurbishment variant A creates the lowest capital strain of the rental income and the highest yield. Variant D (no elevator) has a lower capital strain of the rental income and the lowest yield of all refurbishment variants. Variant B and C have a higher capital strain of rental income than the variants A and D. The structural refurbishment in variant B, C and D improves the furnishing category of the apartments on the ground floor and increases the associated rent. The strategy of renting determines whether the apartments come up to future housing requirements or the rent stays affordable.

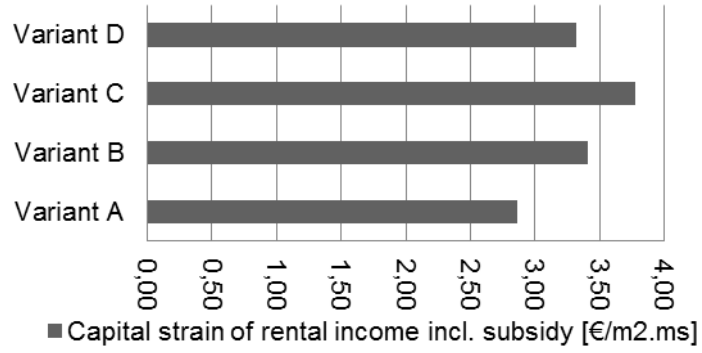


Fig. 3: Variants evaluation, strain of rental income

Variant D has the lowest LCC and is 9 % cheaper than variant C. The main reasons are the high elevator´s costs for service and maintenance. The additional costs caused by building measures in the apartments and the subsequent installation of an elevator are minimal compared to the overall building costs. The structural refurbishment of the variants B, C and D creates barrier-free designed apartments to ensure a self-organised life of people, who are in need of care or disabled, and delays or prevents the move into a nursing home.

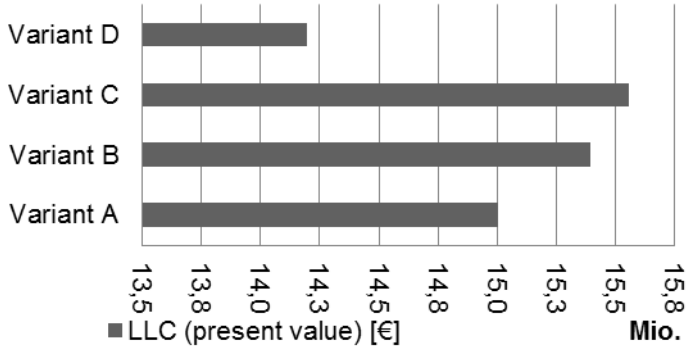


Fig. 4: Variants evaluation, LCC

3.2.2 The qualitative evaluation

The data base for the qualitative evaluation is represented in the Figures 4-6 shown above for each refurbishment variant. The evaluation is carried out with the help of the following criteria (not weighted) in a network diagram (1= best result, 6= worst result):

- economic
- ecological
- social (barrier-free design of the building, recreation room and nursing care base)
- functional (the building´s potential to come up to future housing requirements and the flexibility concerning changing use.)
- cultural historical / monument conservation

Table 7: variants, qualitative evaluation

Qualitative evaluation	A	B	C	D
Economic	2	3	4	1
Ecological	2	3	4	1
Social	3	2	1	4
Functional	3	2	1	4
Cultural historical	2	3	4	1

The results concerning sustainability are pictured as areas. The refurbishment variant with the smallest area has to be favoured.

1. Variant D (12,36)
2. Variant A (13,79)
3. Variant B (16,17)
4. Variant C (19,50)

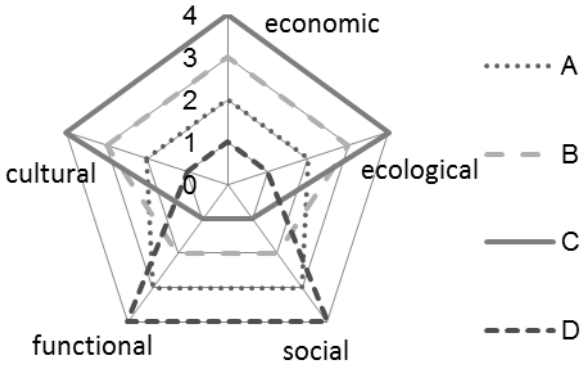


Fig. 5: Variants, qualitative evaluation

Variant D owns the best ecological, economic and cultural historical results. (The abdication of the subsequent elevators´ installation keeps the life-cycle costs including costs for maintenance, service and replacement low and the rent for dwellings affordable cheap. The low investment costs cause a low capital strain of the rental income.) The best cultural historical ranking is based on the abdication of a subsequent installation of an elevator. In each individual case it has to be decided whether the maintenance of the existing building structure is more important than an elevator. In variant A an elevator exists, but no adaptation of the building stock to future housing requirements is realised. If an elevator exits in the existing dwelling, variant A has to be favoured compared to variant B. Variant C with high potential concerning building measures to create barrier-free apartments and a nursing care base owns the largest area in the network diagram. The extensive building measures affect the ecological, economic and cultural historical evaluation negatively. Within the framework of refurbishment, planning decisions concerning the refurbishment variants and the weighting of the evaluation criteria are mainly influenced by the purpose of the decision maker.

3.3 Comparison LCC refurbishment assisted living - gross expenses of the public authorities for various nursing services

Referring to variant B the life-cycle costs caused by a structural refurbishment on the ground floor

of the Elderschhof (13 apartments, inhabited gross floor area of 1 474 m^2) can be determined with a value of € 650 893.
The annual gross expenses of the public authorities for various nursing services [14] are shown in the table 8.

Table 8: Nursing expenses

Nursing services	Gross expenses of public authorities [€]	Looked after persons	Annual costs per person [€]	Accumulated costs over 50 years [€/p]	Costs over 50 years for 13 apartments/ persons [€/p]
Mobile care services	470 133 325	127 891	3 676	183 802	2 389 431
Inpatient care services	2 121 480 105	71 798	29 548	1 477 395	19 206 135
Day care centres	23 091 331	4 564	5 059	252 973	3 288 643
Assisted living	147 485 564	10 806	13 648	682 424	8 871 517

The comparison of the life-cycle costs concerning a structural refurbishment with the gross expenses of the public authorities points out that nursing expenses are a multiple of the life-cycle costs caused by a structural refurbishment for accessibility in an existing building. The nursing costs itself differ widely. In patient nursing homes cause minimum the double costs of assisted living. As a result the installation of assisted living in existing building stocks can save nursing costs and creates a high economic and ecological benefit compared to the new building of nursing homes. According to information of Wiener Wohnen the cost-efficient operation of assisted living requires 10-20 connected apartments [10, 11]. For this aspect assisted living in small buildings is only realisable if the whole building is barrier-free designed. A requirement is an existing elevator or a subsequent installation. Assisted living only in apartments on the ground floor in small residential buildings without an elevator is realisable if the small residential buildings are located near a nursing institution.

4. Conclusion

In the presented research, a case-study of refurbishment strategies for a specific housing block of Red Vienna has been carried out and evaluated according to the criteria of sustainability. The study implies large potentials of existing stock for care at home, instead of much more cost intensive institutional care; reinforcing the value of stock as social capital. In terms of thermal refurbishment, due to the large energy consumption during the operation, the most preferred measure is the holistic refurbishment (complete envelope) through the highest energy and CO_2 saving potential. The façade-variants with low potential of heating demand reduction (without TIM, TIP) have, despite the positive sustainable performance concerning production and maintenance, high economic and ecological life-cycle impact (cumulated over 50 years), which cannot be neutralised by the positive evaluation concerning monument conservation.
In terms of lifecycle costs and achieved energy and CO_2 savings the ETICS EPS refurbishment variant shows the best performance over the period of 50 years, however is not compatible in terms of monument protection. As alternative, the interior insulation, causing higher ecological impact and higher skills in application, can be taken in account. The qualitative evaluation of the structural refurbishment and exploration of the potentials for providing the appropriate housing for aging society proves variant D as the optimal variant, both in terms of LCC as in social criteria for affordable housing (low heating costs and rent). Variant D disclaims the use of existing elevators, but instead installs the stair lifts and enables the barrier-free living of the ground floor and thus significantly lowers the LCC as well as the rents. However this simultaneously means a low owner´s rental income yield; which should not be primary concern for non-profit oriented social housing .associations.

REFERENCES

[5] STATISTIK AUSTRIA. „*Gebäude- und Wohnungszählung 2001, Hauptergebnisse Wien*“. DOI: http://www.statistik.at/web_de/statistiken/wohnen_und_gebaeude/bestand_an_gebaeuden_und_wohnungen/wohnungen_einschl._nebenwohnsitzen/index.html, last access March 2013.

[6] STATISTIK AUSTRIA. „*Haushalte*“. Last update: 28.03.2013. DOI: //www.statistik.at/web_de/statistiken/bevoelkerung/haushalte_familien_lebensformen/haushalte/index.html, last access April 2013.

[7] WEKA MEDIA. „*LEGEP - die Software für Lebenszyklusplanung*“. DOI: http://www.legep-software.de/, last access December 2012.

[8] ÖKOBAU.DAT. „*Ökobau.dat*“. DOI: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html, last access January 2013

[9] KÖNIG H, KOHLER N, KREISSIG J, LÜTZKENDORF T. „*Lebenszyklusanalyse in der Gebäudeplanung. Grundlagen, Berechnungen, Planungswerkzeuge*“. Institute for international architecture-documentation GmbH & Co. KG , Munich, 2009, pp 60.

[10] KÖNIG H, KOHLER N, KREISSIG J, LÜTZKENDORF T. „*Lebenszyklusanalyse in der Gebäudeplanung. Grundlagen, Berechnungen, Planungswerkzeuge*“. Institute for international architecture-documentation GmbH & Co. KG , Munich, 2009, pp 73.

[11] KÖNIG H, KOHLER N, KREISSIG J, LÜTZKENDORF T. „*Lebenszyklusanalyse in der Gebäudeplanung. Grundlagen, Berechnungen, Planungswerkzeuge*“. Institute for international architecture-documentation GmbH & Co. KG , Munich, 2009, pp 63.

[12] WOHNFONS WIEN. „*Wohnhaussanierung. Liegenschaftsmanagement und Projektentwicklung*.“ DOI: http://www.wohnfonds.wien.at/, last access April 2012.

[13] ÖSTERREICHISCHES NORMUNGSINSTITUT. *„ÖNORM B1600 - Barrierefreies Bauen – Planungsgrundlagen“* DOI: http://www.uibk.ac.at/fakultaeten/technische-wissenschaften/pr-team/bauingenieurexkursion/exkursionsziele/101111-barrierefreies-bauen/oenorm-b-1600.pdf, last access April 2013

[14] NOWAK R. „personal interview Höflinger M, Kovacic I, Lorbek M“ Wiener Wohnen 2011.

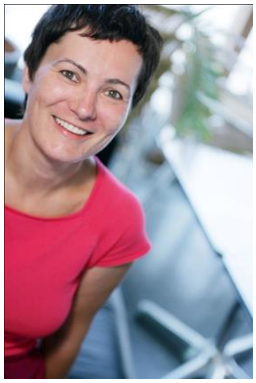
[15] SILVER LIVING. *„Selbstbestimmtes Wohnen im besten Alter*“. DOI: http://silver-living.at/uploads/media/Pressemappe_Silver-Living_4-2011.pdf, last access April 2012

[16] ÖSTERREICHISCHES INSTITUT FÜR BAUTECHNIK (OIB). „*OIB-Richtlinie 6. Energieeinsparung und Wärmeschutz*“. DOI: http://www.oib.or.at/richtlinien11.htm, last access October.2012

[17] NATIONAL HERITAGE AGENCY. „*Richtlinie Energieeffizienz am Baudenkmal*“. DOI: http://www.bda.at/documents/462396673.pdf, last access Mai 2012

[18] FEDERAL MINISTRY OF LABOUR, SOZIAL AFFAIRS AND CONSUMER PROTECTION. „*Österreichischer Pflegevorsorgebericht 2010*“. Federal ministry of labour, social affairs and consumer protection, Vienna, 2011.

GENDER PERSPECTIVES ON THE DESIGN AND OPTIMISATION OF HIGHLY ENERGY EFFICIENT BUILDINGS



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GENDER PERSPECTIVES ON THE DESIGN AND OPTIMISATION OF HIGHLY ENERGY EFFICIENT BUILDINGS

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Summary

This conference contribution presents a study tackling user behaviour and consumer aspects in highly energy efficient buildings taking into account social, ethnical, and especially gender-related aspects, and analyses the building design concept in comparison with the actual energy consumption. The interdisciplinary project team applies new socio-scientific methods to develop innovative solutions for influencing user behaviour, which undergo trial runs in selected buildings. Results will contribute to improving communication measures, design process and product development in order to tap the full potential of energy savings due to user behaviour.

Keywords: Gender mainstreaming; user behavior; planning tools; holistic planning approaches; highly energy efficient buildings

1. Introduction

According to the EU-project „BEHAVE“ (http://www.energy-behave.net/) more than 50% of energy savings are due to changes of energy consumption related user behaviour. The development towards plus-energy-buildings (buildings which produce more energy than what occupants consume) causes a change in the role of consumers: consumers turn to active stakeholders, because their way of using the building will be decisive whether the building actually achieves plus-energy status, or not. It is a precondition to fully understand the motivations and options for actions of consumers, in order to tap the full potential of energy savings related with user behaviour. In this regard, gender-specific aspects have not been considered so far. In order to meet the challenging reductions in greenhouse gas emissions behavioural change will be necessary along with technological innovations. Energy research and building technology in particular, are predominantly technology oriented fields. Gender aspects are so far still largely unresearched in both fields.

The ongoing research project *GINGER – The influence of gender on user behaviour in highly energy efficient buildings* (July 2012 – June 2014) tackles user behaviour and consumer aspects in highly energy efficient buildings taking into account social, ethnical, and especially gender-related aspects. This paper describes first assumptions about gender relevant aspects in energy research and in the concept of highly energy efficient buildings. In addition, the methodological approach applied in GINGER is presented: social, ethnical, and especially gender-related aspects are taken into account to analyse the building design concept in comparison with the actual energy consumption, user behaviour and consumer aspects.

2. Definitions: Gender, Doing Gender, Gender Mainstreaming

Modern science includes a gender perspective. Gender refers to the array of socially constructed roles and relations, personality traits, attitudes, behaviours, values, relative power and influence that society ascribes to women and men. Gender is an acquired identity that is learned, changes over time and varies widely within and across cultures, ethnicity, class and age etc.

"Doing gender" means how people construct and maintain gender through our actions and interactions. While gender can be done in repetitive ways it also can be undone or done differently. As Offenberger and Nentwich stated the research focus on gender and technology has shifted to the following three prepositions 1) from a single perspective on doing gender to a double perspective of doing and undoing, 2) from gender as a binary construction to multiple femininities and masculinities. [1]

3. Gender & Energy

Energy is recognized as a sector with an extremely low proportion of women in all its fields and at all levels. Therefore Gender mainstreaming plays an important role in enhancing the amount of influence afforded to women in energy planning and decision-making in production and in integrating gender expertise into planning as a whole to meet the different needs. Efficiency and effectiveness of energy technology development and energy policy instruments, could be increased by reflecting on gender implications and taking participatory approaches into account. [2]

Regular surveys on environmental awareness among the general public have shown that women are generally more environmentally aware and behave in a more environmentally compatible manner than men, even though they possess less specialist knowledge on the environment. Gender is also relevant in the field of energy. Great efforts must be undertaken to discover gender impacts in technology-orientated research because of lacking data and research. Gender aspects are to be found or can be assumed in access to energy technologies, perception of (risk) technologies, energy needs and use (e.g. energy needs are linked to gendered roles, responsibilities and identities as well. The question whether a new energy technology meets the needs and the interests only of those parts of societies who have power to define problems, design solutions and take decisions can be best solved by analytical approaches involving all stakeholders, including women and gender experts) and in particular in the very small share of women in energy technology-related areas, resulting in an inclusion of their perspectives in research and development. [3]

Different income levels of women and men, gender stereotypes and society's attribution of assignments in the field of energy technologies and energy use, and the low share of women in energy-related fields of work, in particular in technological professions are further reasons for inequalities in this field., but also the difference between countries of the North and countries of the South. Joy Clancy stated in an article on a "northern perspective" that e.g. more women than men are living below the poverty line. Poor women are disproportionately found as heads of households, either in single parent's families or, due to their greater longevity than men, living alone at pensionable age. Northern climates create the need for space heating and/or cooling for significant parts of the year. Young children and older people have special heating requirements to reduce their vulnerability to illness. Many women in the North are (were?) active in renewable energy e.g. running co-operatives like the Windfang women's wind energy cooperative in Germany Women have been leading activists in the anti-nuclear movement. [4]

4. Energy-efficient Building Concepts and User Experiences

A survey carried out with residents of four low energy building projects and four conventional residential buildings in the city of Salzburg showed that energy consumption of an apartment plays

no significant role in the residential choice of Austrians. [6] The main reasons to move into a new apartment are the size and the number of rooms followed by its attractive and quiet surroundings. As energy costs are hidden and hard to compare only a small share of respondents (25%) are aware of the main domestic energy cost factor for room heating and hot water (more than 50%).

When refurbishment projects of buildings are set up as effective measure for energy savings, possible rebound-effects have to be considered. Studies to date indicate that after the refurbishment not only expected energy reductions are hardly achieved but by a worst case scenario even an increased energy consumption for space heating is possible. Peter Biermayr examined measures for minimisation of rebound-effects concerning residential building renovation.[7] Within the framework of economical, structural and technical rebound effects he sees only limited opportunities for the reduction of rebound-effects when on the other hand higher demands on comfort and on living space is to be provided. Nevertheless, Biermayer suggests optimising the heating system or implementing an intelligent regulation system to reduce technical rebound-effects. Further research could be done to explore societal, social, ethnical, and especially gender-related aspects of different demands on comfort and how it could be restricted to a meaningful measure.

Gabriele Rohregger evaluated comfort, health and recreational value of passive houses. [8] Usually passive house concepts are not presented as “comfort houses” but as “highly energy-efficient buildings” or “houses without heating”. As such, potential customers tend to be sceptical about living in a house without a heating system to satisfy individual demands for thermal comfort. Her study stresses that different heating configurations in the buildings (pure heated supplied air, wall heating and pellet stove heating) were equally sensed objectively, via physiological measurements, and subjectively by questionnaires. However, all respondents stated that it would not be possible to heat the passive houses only by the air heating system. The customers’ desire for an additional heating system and individual temperature regulation is so far crucial for a success of the passive house building standard. Gender aspects or differences in the perception of comfort and convenience between men and women remained unobserved.

In most of the sociological studies on users’ acceptance one looks for the word „women” in vain. Men and women are summarized in their statements to „builder-owner” and their different interests are not brought up for discussion. And if attention is paid to gender related aspects, then as a problem making obstacle which has to be considered („space and cityplanning criteria: e.g. bicycle, women, kindergarten, social mixing, generation mixing, civil participation“, Rohracher and Ornetzeder 2008, p. 150) [9] or as „(married) wives“ and as such something which cannot be taken particularly serious („on the part of the wives there is partly a disputing from the belly“, respondent cit. in Rohracher et al. 2001, p. 122) [10].

5. Methods to Investigate Gender Related Aspects of User Behaviour in Energy Efficient Buildings

The research focuses specifically on large-volume multi-storey residential buildings (usable area > 5000m2), office and administration buildings (usable area > 3000m2) as well as larger school buildings and nursery schools which were constructed according to passive / plus-energy house standards or were upgraded to low-energy standards in the last five years. The entire proceedings – from the start of the planning process to the present operations of the building – will be taken into account. To ensure the best possible diversity among the research objects, the ranking of the selected objects was determined firstly by size and energy standards (heating requirement according to Passive House Planning Package PHPP less than 15kWh/m2a), followed by a selection of different locations, new buildings and renovations.

Research questions:

- How much knowledge does exist about the different technologies as well as the topic of energy efficiency
- Which motives and attitudes exist
- How are the technologies being used (operation, application)

- Which requirements and needs do the users have concerning the technologies/ the building/ the functionality?
- How and according to which factors can the users be segmented/ which user groups can be identified
- Do gender aspects have influence on user behaviour
- Are there differences in the perception of comfort/ convenience depending on lifestyle/ living standards/ values system
- Do various user groups have different needs for and behaviour towards obtaining information
- To which extent is the application of technology regarded as reasonable by the users? (affinity to technology)

5.1 Initial survey:

A plain user survey about their behaviour, habits, attitudes, motives and needs would only capture a superficial understanding of those. Many things that have become second nature (automated actions) or happen even unconsciously would therefore not be considered. [11] Therefore, in the first part of the initial survey a mix of methods of qualitative empirical social research is applied. Afterwards in the second part, the yielded results will be quantified by means of larger samples.
Qualitative pilot study: mixed methods, observation, ethnography, in-depth interviews
Quantitative questioning: in different target groups, by means of standardised questionnaire, large sample

It is the aim of this pilot to identify the range of existing attitudes, opinions, motives, behaviours and behavioural routines of the users of the researched buildings and understand their connections.
Especially when dealing with automated behavioural patterns, a lot is unconscious and would not be stated during an interview because it is regarded as obvious or self-evident. [11]
Through observation, these automated behaviours and habits as well as all behavioural routines can be surveyed and documented (e.g. filming, taking photos).
Additionally, ethnographic methods and in-depth interviews are used to add explanations by the users to the observed facts.
In so-called „focus blogs“, a small group of participants will be dealing with the topic for a limited period of time in a staged blog under the guidance a moderator. This method is similar to the conventional group discussion but is handled online. The participants will be asked questions and be given short tasks which will then have to be worked on and discussed in the blog. The advantage of this method is that the participants have an extensive amount of time to deal with the topic. Furthermore, they can upload self-made video and photo material and hence also provide non-verbal information. [12]

Webdiaries are arranged similarly to focus blogs but are more structured. The participants are provided with material they can work on by the moderator. Several rounds of tasks are carried out. The participants can also work on drafts or evaluate ideas and drafts, respectively. They can observe many aspects of their user behavior, illustrate and explain it, and develop new ideas and solutions. [13]

For the steps where social media methods are introduced, only users can be included who have internet access and are internet literate. However in 2010, 75% of Austrians used the internet and in 73% of households, internet access was available, with this figure set to increase in the future. [14] The stated social media methods are being utilized successfully in many areas of market research and innovation research, since they compensate for numerous disadvantages of conventional questioning – like limited time frames or little opportunity for the interviewee to contemplate or purely focusing on conscious verbal content. This contributes to a higher validity of the results. [11] For this purpose, they should render data in addition to the results from the qualitative one-on-one interviews by encouraging the researched users to more closely observe and analyse their behaviour. These additional methods will only be used for part of the participants, depending on their willingness and their possibility to work online. (access, „internet literacy“).

The sample is small, as is common for qualitative samples. It consists of different groups. These

are diversified according to lifestyle and other socio-demographic properties. The “Lebensphasenmodell” (Stage of Life Model), the socio-demographic structure of the Austrian population as well as models of lifestyle research will serve as a basis for this. Gender aspects are regarded separately.

Advantages of this extensive approach: a comprehensive and at the same time detailed image of the existing behaviours can be obtained attitudes and motives are identified and can be put into context from this, the needs of the users can be identified within the overall system to serve as a basis for the measures planned for step 2.

From the information collected in the pilot phase and from already existing studies, a structured questionnaire is developed which forms the basis for representative questioning. A sample consisting of a few hundred people will be recruited out of the users of the selected buildings. These interviews will be rendering representative data on behaviour, attitudes and motives of the users, which will then be assessed for significant differences in gender, diversity aspects, socio-demographic markers, lifestyle, values and many more. This phase allows to quantitatively acertain the acceptance of concepts and ideas developed in the qualitative phase.

As mentioned before, the research focuses on large-volume multi-storey residential buildings (usable area > 5000m2), office and administration buildings (usable area > 3000m2) as well as larger school buildings and nursery schools which were constructed according to passive / plus-energy house standards or were upgraded to low-energy standards in the last five years. Included will be

- 3 passive-house residential buildings,
- 3 passive-house office buildings and
- 3 passive-house school and nursery school buildings.

In the office buildings, the participants will be grouped according to various departments and a cluster sample will be drawn in order to produce a representative sample. In the schools and nursery schools, the entire teaching and childcare staff, the building service providers and technicians and the administrations will be contacted. Individual school classes will be chosen by means of cluster sampling and interviewed.

From the results of the initial survey, exact conclusions about behaviour, knowledge and attitudes of the users can be made, factors which determine user behaviour (ranked according to their intensity) can be identified, user profiles in the researched building types structured according to user groups can be created, differences in user behaviour between various user group according to gender and diversity aspects can be depicted (segmentation of users), the needs of the users can be deduced weighted by importance and degree of satisfaction, the influence of attitudes/ values/ lifestyles on user behaviour can be determined and existing differences of all aspects can be identified according to gender and diversity aspects.

5.2 Developing measures and solution strategies:

Based on the results of part 1, the most important factors to influence user behaviour will be analysed and measures and solution strategies will be conceived, e.g.

- information/ education and feedback measures for utilisation,
- different standards of regulation and supervision,
- „low tech“ solutions or
- incentives for employees (office buildings).

Special focus will be put on differences according to gender and diversity aspects.

5.3 Application in research units:

These measures will subsequently be implemented in a sample. The number of research units may vary according to the complexity of the proposed measures, e.g. the extent to which technology is used. Measures purely for information and education can be applied in larger groups rather than technically complex measures.
To be able to measure the effects of the strategies on user behavior (habit, routine), a time frame

of 4 to 6 months is calculated for this phase.

5.4 Evaluation of measures

For the final evaluation, the questionnaire created in the initial survey (step 1) will be utilised again to make the differences in behavior measurable.
All research units that participated in part 3 will be interviewed again.
This will provide an evaluation of the effects of the developed measures and solution strategies on user behavior by comparing the data before and after the changes were made.

6. Results

At the moment, the first qualitative part of the project has been concluded. The second phase of quantitative interviews in the test buildings are in the planning stages and will commence within the next month. A few aspects from the qualitative research could already be deduced that will be quantified in the subsequent questioning.

6.1 Motivations for moving into a passive house building:

The main motive for the residents that determined moving into the building complex was not so much the energy aspect but rather the good quality of living in the new and renovated apartments as well as the location. In the office and school buildings, the energy aspect is of more importance because the key staff (headmasters and headmistresses, office managers, CEOs) had already communicated about the advantages of a passive house building.

6.2 Level of knowledge and information:

The level of knowledge and information is small for most users in regard to functionality and the implementation of a passive house. Only few users feel sufficiently informed. If information material had been provided by the building owners or property management when the users moved in, the material was regarded as unappealing for the majority of users because it was too technical and incomprehensible.

6.3 Amenities of temperature and air quality:

The temperature regulation does not pose a problem for many users. For part of the interviewees it is problematic, however, to reach a comfortable room temperature. Depending on the seasons, the rooms are too cold during the winter and too hot in the summer. This user group refers to a badly functioning ventilation system. It is hard for this user group to regulate ventilation. It is often unknown how it works or is being used in the wrong way. Subsequently, the ventilation system is sometimes being rendered inoperative, for example by blocking the vent openings. It is considered as another possibility for regulating the room temperature to open the windows, although it is known that the windows should best remain closed.

This course of action is more common in the school and office buildings than in the residential buildings. Especially in the schools, the majority of teachers open the windows on a regular basis because the room appears too stuffy. Additionally, dry air is complained about. The students do not perceive this, however.

The users of the office buildings show similar behaviour. Many of them open the windows to let in better – not so dry – air. Some of the users complain about health problems as a consequence of the ventilation system. It has to be noted that this was solely mentioned by male employees.

6.4 Handling:

The control systems in the rooms are restricted to regulating the ventilation system and raising and lowering of the blinds. A part of the users perceives this as restricting, especially as the logic

behind it cannot be understood, e.g. why blinds are suddenly raised when the sun is shining on that particular side of the building.

6.5 Gender aspects:

Ecological aspects play a more and more important role in social community housing; residents in such buildings have a rather low level of education and small incomes. The role of women is a more traditional one. Therefore, they might spend more time at home and can/should serve as the main contact person for the technical facilities. Women make themselves responsible for many things in the household organization.

Women often consider issues in regard to their children. Social aspects play an important role for this. One starting point is to increasingly see them as addressees for environmental issues. At the same time, men who also fulfill their care responsibilities will be addressed with the same issues. Women should be encouraged where they doubt their technical abilities and understanding. Where they have no doubts, their competences can be further acknowledged.

In the quantitative study which will start shortly, the stated aspects will be transferred into a standardized questionnaire and will be quantified in an extensive sample. Only then can valid predictions about the emphasis of individual aspects be made.

7. References

[1] OFFENBERGER U. and NENTWICH J., „Intertwined practices of gender and technology: The case of home heating“, St. Gallen, *Working Paper No. 11*, 2010, p. 9.

[2] ROEHR U., Gender & Energie. Aus der Sicht des Nordens. Life e.V. – FrauenUmweltNetz, 2001.

[3] EUROPEAN COMMISSION, Ed., „Gender and Energy“, *Toolkit: Gender in EU-funded Research*, Luxembourg: European Commission, 2009, pp. 3.1–3.14.

[4] CLANCY J. and ROEHR U., „Gender and energy: is there a Northern perspective?“, *Energy for Sustainable Development*, Bd. Volume VII No. 3, 2003.

[5] SCHORRER Y., „Schatz die Heizung spinnt…“, *FEMtech-Forschungsprojekt CONvenientBioEnergy*, 2012, (http://www.ecoplus.at/sites/default/files/Artikel%20Convenient%20Bioenergy%2020120215.pdf; 30.01.2013).

[6] KEUL A, „Energiesparprojekte und konventioneller Wohnbau - eine Evaluation. NutzerInnen-Evaluation nach Bezug (Post Occupancy Evaluation) von sieben Energiesparprojekten und konventionellen Wohnbauten in der Stadt Salzburg“, Wien, 2001.

[7] BIERMAYR P., SCHRIEFL E., BAUMANN B. and et al., „Maßnahmen zur Minimierung von Reboundeffekten bei der Sanierung von Wohngebäuden (MARESI)“, Wien, 2005.

[8] ROHREGGER G., „Behagliche Nachhaltigkeit“, Wien, 2004.

[9] ROHRACHER H. and ORNETZEDER M., „Wohnen im ökologischen ‚Haus der Zukunft‘. Eine Bestandsaufnahme sozio-ökonomischer Projekte im Rahmen der Programmlinie ‚Haus der Zukunft‘“, Wien, 2008, p. 150.

[10] ROHRACHER H., KUKOVETZ B. and ORNETZEDER M., „Akzeptanzverbesserung von Niedrigenergiehaus-Komponenten“, Graz, 2001, p. 122.

[11] MARIAMPOLSKY H., "Qualitative Market Research", Thousand Oaks, 2001.

[12] MESSERLI A., "Mittendrin statt nur dabei – Blogs als neues qualitatives Marktforschungstool" in: Jahrbuch des Verbandes der Schweizer Markt- und Sozialforscher, 2008, p .50.

[13] KISCHKAT A., DU PERRON B., "Digital Consumer Connections – An alternative to direct consumer contact" in: ESOMAR Conference papers, Qualitative research in the 21st century, Paris, ESOMAR publication series Volume 324, 2007, pp. 203.

[14] STATISTIK AUSTRIA (online), Computernutzerinnen oder Computernutzer, Internetnutzerinnen oder Internetnutzer 2010, http://www.statistik.at/web_de/statistiken/informationsgesellschaft/ikt-einsatz_in_haushalten/index.html, 4/7/2011 18:26.

Cost optimal levels for envelope components in residential building renovation – Rainha Dona Leonor neighbourhood case study

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Short Summary

Energy Efficiency in Buildings has been gaining increasing relevance in the past decades due to the raise of the energy consumption in the building sector as a consequence of the modern way of living with higher comfort patterns. In Europe, buildings are responsible for 40% of the energy consumption, which turns them into an important target for carbon emissions' reduction [1]. Energy efficiency should be a main concern not only in new buildings, but also in the existing ones, which have poor energy performances. In Portugal most of the building stock was built before 1990, date of entrance into force of the first thermal regulation. Therefore, most of these buildings need intervention to improve not only the living environment, but also their energy performances. To evaluate the best measures, that fulfil the minimum requirements established for the energy needs with the lowest costs, the European Commission released the Commission Delegated Regulation (EU) Nº 244/2012 that establishes a comparative methodology framework for calculating the cost-optimal level for minimum energy performance. In order to verify the renovation potential of these buildings, based on the Delegated Regulation methodology and taking advantage of a renovation process in course, a social housing neighbourhood called Rainha Dona Leonor was analysed. This analysis allowed obtaining the optimal levels for different renovations measures. The results show that it is not possible to establish a direct connection between the optimal level for the building envelope and the building as a whole, without considering the influence of the building systems.

Keywords: Buildings renovation, cost-optimal, energy savings, renovation measures

1. Introduction

Changes in the comfort patterns required by the buildings occupants and the buildings poor energy performance, led to excessive energy consumption in this sector, especially electricity [2].
In order to stop the increase in energy consumption and help the member states to keep up with their commitment towards the 2020 targets, the European Commission released the Directive 2010/31/EU (EPBD recast) to replace the previous one, dating from 16 December 2002. The new Directive states that after 2020 every new EU building must be a nearly zero energy building (nZEB). Besides this, every member state should create a methodology to establish minimum recommended requirements for buildings and building components to be integrated into the national legislation.
The minimum recommended requirements should be established to the buildings cost-optimal levels and also to their components [3].The cost-optimal level is the balance between the best energy performance achieved with the lowest cost during the buildings life cycle [4]. The costs

include initial investment, maintenance costs and energy costs.
Based on primary energy consumption and on the investment in each renovation solution, this methodology allows analysing different solutions. Usually the analysis starts with a basic solution and evolves to more efficient ones. When the analysis includes packages, instead of individual measures, it is possible to observe not only one cost-optimal level but a group of similar packages that form a range of cost-optimal solutions [5].
The combination of several measures can create a synergy that leads to better results compared to individual ones. Therefore, it is possible that despite the increase of the initial investment, the global cost may decrease because there is less energy costs associated to a certain measure or package. However, after a certain point, the increase in the initial investment will not be compensated by the reduction in energy costs [5].
This is an iterative process and the biggest challenge is to assure that the analysis doesn't become unbearable due to the numerous possibilities. Therefore, the analysis should be targeted to the lowest energy consumptions and lowest carbon emissions [5].
The cost-optimal analysis can follow two different perspectives: private perspective (microeconomic) and social perspective (macroeconomic). The social perspective considers the cost of the carbon emissions and excludes investment rates and discounts. The private perspective considers the discount rates and excludes the carbon emissions costs [5].
The methodology also advices choosing a reference building that can be either real or virtual. This building must be representative of the major part of the national building stock in order to have results that do not depend much on the buildings specific characteristics. In countries where the building stock has not been renovated, the age criteria may be very useful [5].
In Portugal the building sector is the second biggest energy consumer [6] after transports.
Despite this fact, there aren't yet many studies in accordance with these recommendations, so it is important to develop knowledge by applying the methodology to case studies.
Therefore, the present work aimed at studying a real building in which this methodology has been applied. The chosen building is part of the social housing Rainha Dona Leonor neighbourhood and it is located in Oporto city, Norwest of Portugal.

2. Methodology

The analysis followed the recommendations of the Delegated Regulation and the selected building is representative of the Portuguese building stock and is currently under a renovation intervention.
The analysis started with the energy characterization of the building. The determination of the energy needs followed the Portuguese regulation for thermal behaviour of the buildings (RCCTE, Decree-Law 80/2006) in accordance with ISO – 13790 [7]. The comfort temperatures considered were 20ºC for winter and 25º for summer.
After this characterization it was necessary to establish renovation measures able to promote energy efficiency in the building. The measures should affect the elements of the building with higher losses in winter and excessive gains in summer.
For this case study, the renovation measures intended to improve the insulation level in walls, roof, floor and windows. There were also some calculations related to the heating/cooling systems. The analysed systems (one for heating and another for cooling) were divided into three groups: first, electric heater and electric cooler; second, gas boiler with radiators for heating and electric air conditioned for cooling, third, a heat pump for both heating and cooling.

To evaluate the impact of the renovation measures it is necessary to calculate the heating and cooling needs and then the energy needs for all other usages. After that it is necessary to calculate the primary energy usage.
After calculating the energy needs for each measure or package it is necessary to calculate the global cost. The solution with the lowest global cost is the cost optimal solution. This global cost depends on the initial investment and on all the costs related to the measure during the life cycle of the building that was considered of 30 years. The costs were calculated according to the private perspective, so the carbon emissions costs weren't considered. The discount rate applied was 6% and it was considered an increase of the energy cost of 3% per year. The initial investment and maintenance costs were based on the Cype® software for generating prices.
With the primary energy consumption and the global cost of each renovation measure, it was

possible to determine the cost optimal measure. For this case, the primary energy included only the heating and cooling needs.
For an easier reading, the results were presented in graphics with the primary energy consumption on the x-axis and the global cost in the y-axis, for every tested measure. This way of presentation usually allows drawing a curve where the lowest point shows the optimal level for the selected building.

3. Case study characterization

The analysed building is part of a social housing neighbourhood built in 1953. It has two apartments with three bedrooms each with a total area of 110.54m² (55.27m² each apartment), divided in two floors. The building no longer comply with the current living patterns, therefore it will be transformed in two apartments, one in each floor and, instead of three small bedrooms, there will be only one bedroom with a bigger area, in each apartment. Besides these changes, the project also includes improvements in the building envelope. Figure 1 shows the building final horizontal plan and figure 2 shows how it looks like after renovation.
The building has single brick walls, light weight slabs, a wooden roof structure covered with fibre cement tiles and wooden windows frames with single glass. There is no insulation and the domestic hot water (DHW) is provided by an electric heater with a storage tank. The building doesn't have any heating or cooling system installed.

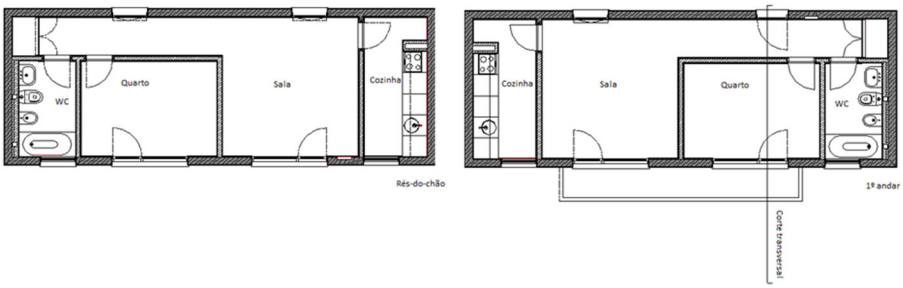


Fig. 1 Building horizontal plant after renovation



Fig. 2 Building front view, after renovation

3.1 Renovation measures

The intervention on the living space is a good opportunity to improve the energy performance of the building without increasing excessively the initial investment. However, it is important to study its impact before the final decision. Table 1 summarises the studied measures for this case study.

Table 1: Summary of the studied renovation measures per each building component

Element	Renovation Measure	Analysed Insulation type
Wall	*ETICS	*RW (thicknesses of 80, 100,120 and 140mm)
	Ventilated Façade	*EPS, *XPS and *MW (thicknesses of 60 and 80mm)
	Insulation in the inside	*EPS and *RW (thicknesses of 40, 60, 80, 100, 120 and 150mm)
Roof	Insulation above the slab	*EPS, *XPS and *RW (thicknesses of 60, 80, 100, and 120mm)
	Insulation above the roof' wooden structure	Sandwich panel with MW or XPS (thicknesses of 60, 80 and 100mm)
	Insulation above the existing fibrocement sheets	*GW and *RW (thicknesses of 80, 100, 120 and 140mm)
	Insulation between the wooden beams	*MW (thicknesses of 50 and 60mm)
Floor	Insulation above the floor slab	*XPS (thicknesses of 40, 60, 80 and 100mm)
	Insulation above the regularization concrete layer	*RW (thickness of 20mm)
	Insulation under the slab	*RW and *XPS (thicknesses of 40, 60, 80 and 100mm)
Window	New windows in PVC, Wood or Metal	Glass: 4+6+6 Low ε; 100% árgon
		Glass: 4+10+6 Low ε; 100% árgon
		Glass: 4+12+6 Low ε; 100% árgon
		Glass: 4+16+6 Low ε; 100% árgon
		Glass: 4+18+6 Low ε; 100% árgon
Heating and cooling Systems	Electric heater	
	Gas boiler	
	Heat pump	

*ETICS – External Thermal Insulation Composite System; XPS – Extruded polystyrene; EPS – Expanded polystyrene; MW – Mineral wool

4. Results

This section presents the cost optimal results obtained for the walls, roof, floor and windows considering the referred three heating and cooling systems for the analysed renovation measures. The purpose of the analysis was to find the cost-optimal solutions for each one of the building elements. Building renovation packages were not analysed. The reference solution (the starting point) included 60mm of EPS on the walls, 60mm of XPS on the roof and windows with wooden frames and double glass.

4.1 Wall

For the walls, the best solution consists in placing the insulation on the inside. This is due to the low investment needed to implement this solution. Figure 3 shows the results for different thicknesses of wall insulation and for the three heating/cooling systems analysed. The lowest point in each cloud of points is the cost optimal solution for that specific system.
Table 2 shows a summary of the best solutions per each one of the systems analysed. The best performance corresponds to 80mm of insulation on the wall when using heat pump for heating and cooling. This equipment may have a high initial cost but the energy savings along the building life cycle compensate the initial investment resulting in a lower global cost. For the other equipments

the cost optimal solution was obtained with higher insulation thicknesses.

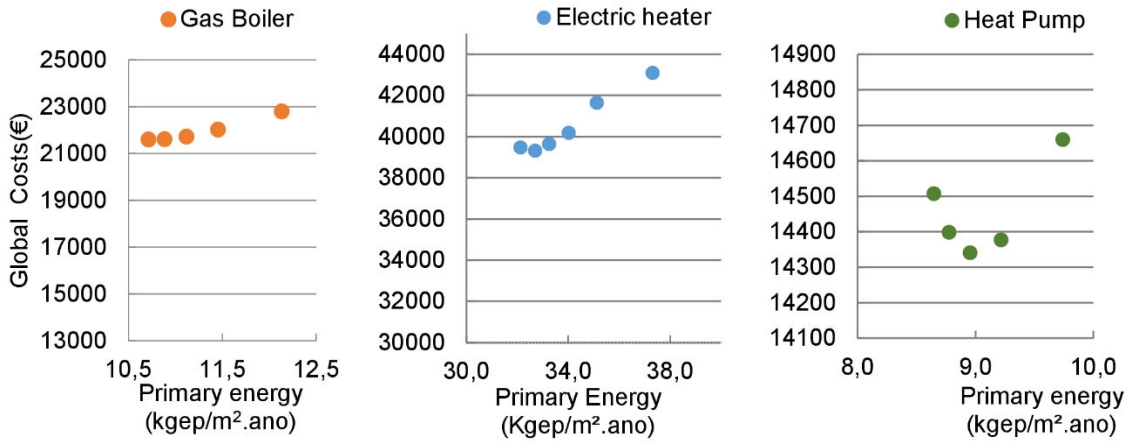


Fig. 3 Cost Optimal curves for the external walls for each of the three tested systems

Table 2: Cost optimal solutions for exterior walls per type of heating/cooling system

Equipment	Cost optimal	U-value (W/m².˚C)	Primary energy (kgep/m².year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	120mm *EPS	0,27	32,70	5593	33726	39320
Gas boiler	120mm *EPS	0,27	10,71	5593	16012	21605
Heat Pump	80mm *EPS	0,36	8,95	5108	9234	14342

*EPS – Expanded polystyrene

4.2 Roof

Among the measures analysed for the roof, the best solution corresponds to keeping the existing roof solution and applying insulation above it, placing asphalt shingle on top. Figure 4 shows the results for different thicknesses of roof insulation and for the three heating/cooling systems analysed. Per each system, the lower point represents the optimal solution which is placing rock wool with 80 to 120mm, depending on the heating/cooling system adopted, above the existing roof and cover it with shingle.

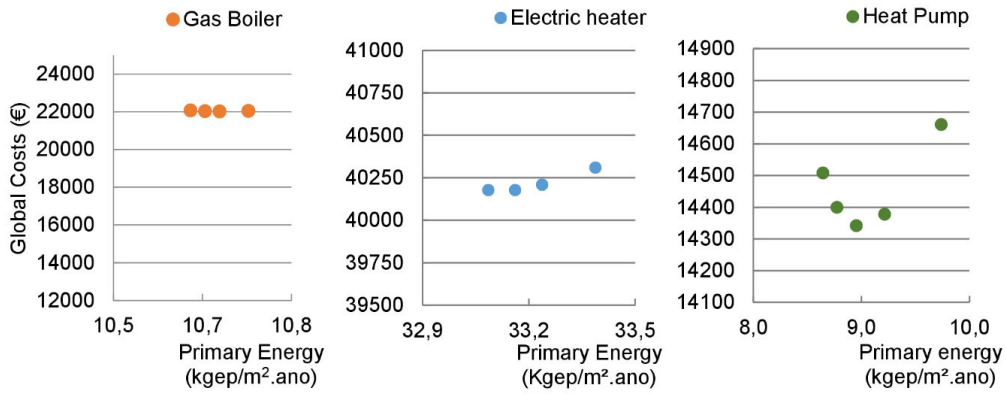


Fig. 4 Cost optimal solutions for the renovation measures in the roof per each of the tested systems

Table 3 summarises the results for the cost-optimal solutions with different heating/cooling systems. The heat pump is the equipment that combined with this solution requires the lowest roof insulation level.

Table 3: Cost optimal solutions for the Roof per type of heating/cooling system

Equipment	Cost optimal	U-value (W/m².˚C)	Ntc (kgep/m².year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	120mm *RW	0,17	33,16	5974	34205	40178
Gas boiler	100mm *RW	0,18	10,68	5927	16107	22034
Heat pump	80mm *GW	0,20	8,55	5871	8816	14687

* RW – Rock wool; GW – Glass wool

4.3 Windows

For the window frame type, PVC is the most cost effective. The changes come especially from the glass type. Figure 5 shows the results for the windows with PVC frames with different glass types. The best glass type is the 4+16+6 with argon or air inside the air gap.Table 4 summarises the cost-optimal solution for the windows with PVC frames, for the three systems analysed.

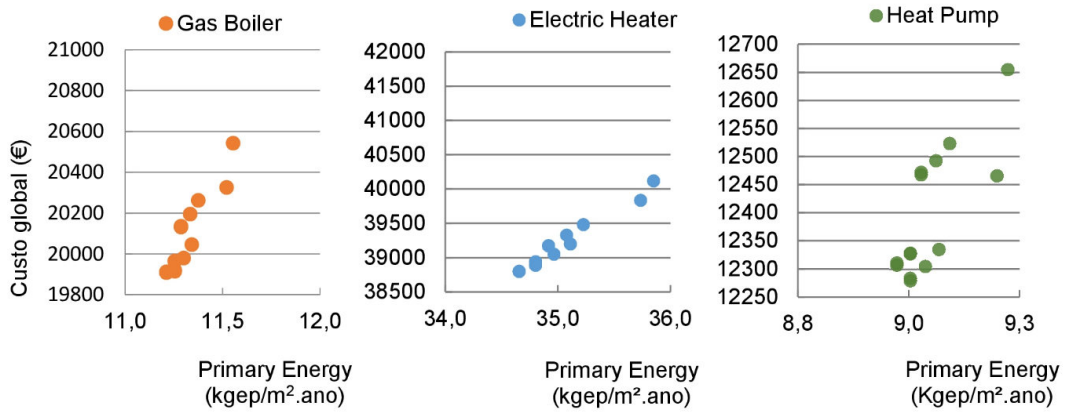


Fig. 5 Cost optimal solutions for the window renovation measures, for each one of the three analysed systems

Table 4: Cost optimal solutions for Windows with PVC frames with different systems

Equipment	Cost optimal	U_{glass}-$U_{frame.}$ (W/m².˚C)	Primary energy (kgep/m².year)	Costs (€)		
				Investment	Energy	Global
Electric heater	PVC + 4+16+6 100% Árgon	2,60-1,70	34,65	3052	35746	38798
Gas boiler	PVC + 4+16+6 100% Árgon	2,60-1,70	11,21	3052	16856	19908
Heat pump	PVC + 4+16+6	2,70-1,70	9,00	2993	9287	12280

4.4 Floor

For the floor, every solution was tested considering the creation of an air space underneath the floor slab. Taking this into account, the best solution was the application of rock wool under the slab. Figure 6 shows the results of different thicknesses combined with each one of the analysed systems. Table 5 has the compilation of the cost optimal results. The best result comes with the heat pump and with 40mm of rock wool insulation under the slab.

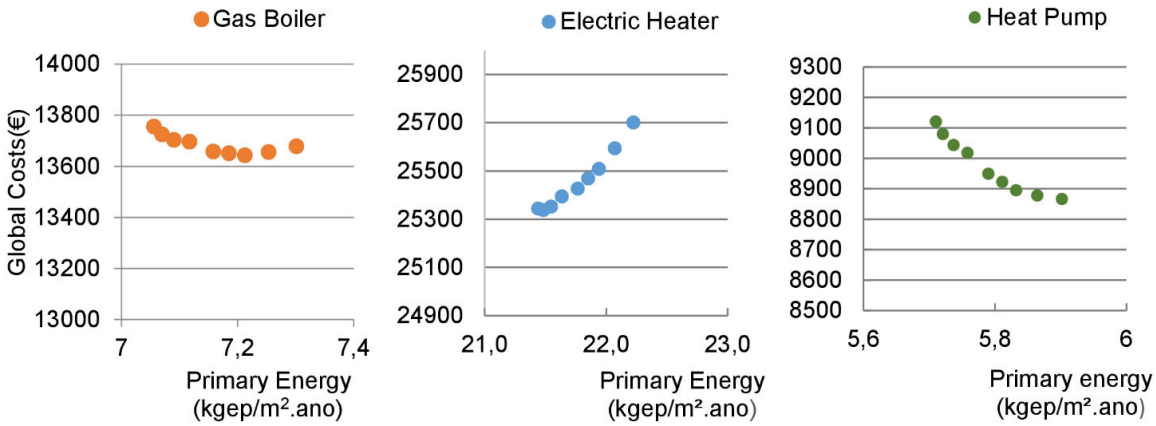


Fig. 6 Cost optimal solutions for the floor renovation measures, for each one of the three analysed systems

Table 5: Cost Optimal solution for the Floor per type of heating/cooling system

Equipment	Cost Optimal	U-value (W/m².˚C)	Primary energy (kgep/m².year)	Costs (€)		
				Investment	Energy	Global
Electric heater and cooler	140mm *RW	0,21	21,48	3180	22158	25338
Gas boiler	60mm *RW	0,42	7,21	2880	10764	13643
Heat pump	40mm *RW	0,55	5,90	2780	6087	8867

*RW – Rock wool

5. Conclusions

For each building component, the cost optimal solution depends on the efficiency of the heating/cooling equipment used. The more efficient the system the lower the level of insulation of the envelope needed. In this case, the heat pump allowed using a thinner layer of insulation to maintain the same comfort levels as the other systems.
In this particular case, the reference solution was already a good solution, considering the Portuguese patterns, unless for the floor. Therefore, the only renovation measures with significant impact on the building energy performance were those related to this building element. However, this conclusion cannot be generalized since this is not the common situation of the Portuguese existing buildings.

6. References

[1] EPBD Concerted Action Energy Performance of Buildings "*Implementing the Energy Performance of Buildings Directive – Featuring country reports of 2010*" concerted Action Comunication, 2011;
[2] Parlamento Europeu. "*Directiva 2010/31/UE Parlamento Europeu e do Conselho, de 19 de Maio de 2010 sobre o desempenho energético dos edifícios /reformulação*";
[3] EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, Directive 2010/31/EU. Official Journal of the European Union, 2010;
[4] European Commission "*Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012"*; Official Journal of the European Union; page 2012/C 115/01; 2012;
[5] European Commission "*Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012*". Official Journal of the European Union, page 81/18; 2012;
[6] WORLD ENERGY COUNCIL "*Energy Efficiency – A global review*", 2004;
[7] Ministério da Economia e da Inovação *"Regulamento das Características do Comportamento Térmico dos Edifícios" (RCCTE),* 2007

Building Envelope Retrofits for Improved Energy Performance and Thermal Comfort in Detached Houses in Serbia

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Short Summary

State-of-the-art studies indicate that the biggest energy saving potential in Serbia lies in the residential sector. These buildings mostly have poor thermal properties of building envelopes. We conduct our research to evaluate energy saving potential, cost-effectiveness and thermal comfort during the summer of three retrofit solutions for a representative house. A case study research is employed as a primary methodology, while simulation in relation to experimental research is the most dominant research tactic. The representative model of the detached house is located in Belgrade. Three retrofit solutions are evaluated through Euro-WAEBED and GEBA dynamic simulations. The results depict applied retrofit measures by annual savings, pay off period, and possible overheating in summer. Proposed retrofit strategies could be applied trough partial or comprehensive renovation for typical detached houses in Serbia.

Keywords: retrofit; building envelope; energy efficiency; overheating; house.

1. Introduction

Existing buildings significantly contribute to the high energy consumption in Serbia [2], where 38% of total energy consumption is due to the residential sector [3]. The First National Energy Efficiency Action Plan of the Republic of Serbia (NEEAP) point out that residential sector has the biggest cost-effective saving potential [4]. The average consumption for heating and domestic hot water preparation in households is approximated to 228 kWh/m^{2}a [2].

Around 70% of the population in Serbia lives in houses [5]. Most of the existing residential buildings in Serbia characterize poor thermal properties of building envelopes. Retrofit strategies that have been employed in recent years differ by the level of intervention from the value retention to the partial renovation [1]. In order to improve energy conservation, inner comfort and prevent summer overheating of the houses appropriate retrofit strategies have to be considered.

A growing body of literature has investigated the potential of building retrofit in Serbia. Main topics were renovations by passive and active measures. Energy efficiency in Serbian buildings was investigated by Sumarac [9]. For analysis of energy consumption in Belgrade, methodology was developed by B. Todorovic [10]. M. Todorovic investigated large scale residential RES integrated refurbishment [11] and refurbishment of existing multi-storey buildings in Belgrade [12]. She indicated that multi-storey housing in Belgrade has a massive energy saving potential. The work of Matic [13] analyzed renovation of multi-storey building to zero-energy and zero-carbon building. Stankovic and Nikolic [14] analyzed possible renewal of preschool facilities in Serbia trough green building technologies. Jovanovic [5] highlighted the importance of energy efficiency in single family

houses while investigated the model of energy-efficient house for the city of Nis. Stevanovic [15] analyzed the cost-effectiveness of active retrofit measures on a single-family house. Stevanovic found that investments were slow in paying off and announced that subsidies could increase retrofit rates. Bojic performed the study of refurbishment of old single family house in Belgrade [16] and described renovation scenarios for building envelope, heating system improvements and financial issues. He also investigated the impact of internal partitions on energy conservation. Bojic [17] stated that research efforts should be extended to cover multitude of interesting issues on energy conservation matching application of the envelope with better or worse thermal performances.

These refurbishments have mostly been studied in very specific case studies with focus on heating demands. The most of annual energy consumption in Serbia is due to the high heating demands. Since Serbia's average solar irradiation levels are 40% higher than the European average [7], the equal attention should be paid on the overheating during the summer months. Considering current findings and future necessities, retrofit solutions that we evaluate from the environmental/economical/social point of view, should be applicable to a bigger sample.

The goal of this paper is to evaluate building envelope retrofits by energy saving potential, cost-effectiveness, and thermal behaviour of buildings in summer. We conduct our research based on following research questions considering a common detached house in Serbia:

1) What is the energy saving potential of building envelope retrofits?
2) What is the cost-effectiveness of building envelope retrofits?
3) How do retrofits change inner comfort during the summer months?

For that purpose, we simulate one house in the initial condition and in three different retrofit scenarios. More information on methodology and our sampling procedure can be found in section below.

2. Methodology

2.1. Architectural research methods

The case study research [19] was employed as a primary methodology. We used experimental and simulation research tactics [19] to evaluate the effectiveness of the proposed retrofits regarding our research questions. Three retrofit scenarios were applied for the representative house. The proposed retrofit solutions improved thermal properties of building envelope by insulating external building components and by replacing old doors and windows.

2.2. Simulation software

Simulation software Euro-WAEBED [20] was used to estimate heating demands for the basic house and its three retrofit scenarios. GEBA simulation software [20] was used to predict thermal behaviour of the building in summer. These tools provide an appropriate accuracy of output data [21]. The tools were previously employed in research works published by Stieldorf and Krec [22-23] and other authors [24-25] to estimate energy performance of buildings.

2.3. Climate

The analyzed house was positioned in the city of Belgrade, the capital of Serbia, in Southeast Europe. To familiarize with the local climate, Figure 1 depicts mean temperatures in the city [26]. The climate data for Belgrade are used as input information for the simulations.

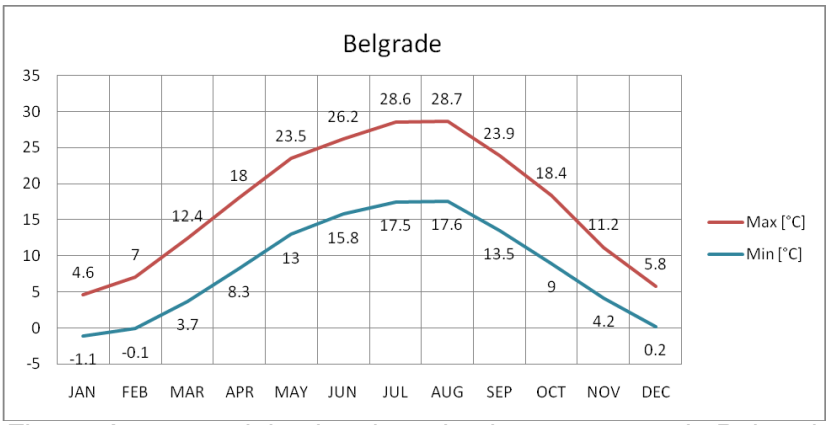


Fig. 1: Average minimal and maximal temperatures in Belgrade for the period 1981-2010 [26]

July and August are the hottest months in Serbia, while the Sun is at higher point in July. According to the Hydro-meteorological Service of Serbia, average maximal air temperature for July 2013 is expected to be 28.9°C [26].

2.4. Sampling procedure

The housing stock in Serbia was significantly enlarged during the period 1960-1990. About 1700000 housing units or 62% of total housing stock emerged within these 30 years [27]. These buildings characterize same concrete structure, brick-block walls, cement plaster and lack of thermal insulation [8]. We determined typical detached house from 1970's designed by architect Milisav Vojinovic to be the model for our simulations. The model was selected from the database of about 1300 typical housing designs from 70's and 80's in Serbia and other Ex-Yugoslavian Republics [29]. We used this selection procedure to enlarge the scope of application of our findings.

3. Simulation arrangement

3.1. Model description

The model for our investigation is a two-storey house with total floor area of 126 m^2. The ground floor has the area of 63 m^2 and the upper floor has the area of 63 m^2 as well. These two floors are heated zone. The attic is non-heated zone. A height of the building is 8.7 m and a total façade surface is 206.7 m^2. Total window area is 23.12 m^2, where 7.32 m^2 are south orientated. Entrance doors are 3 m^2.

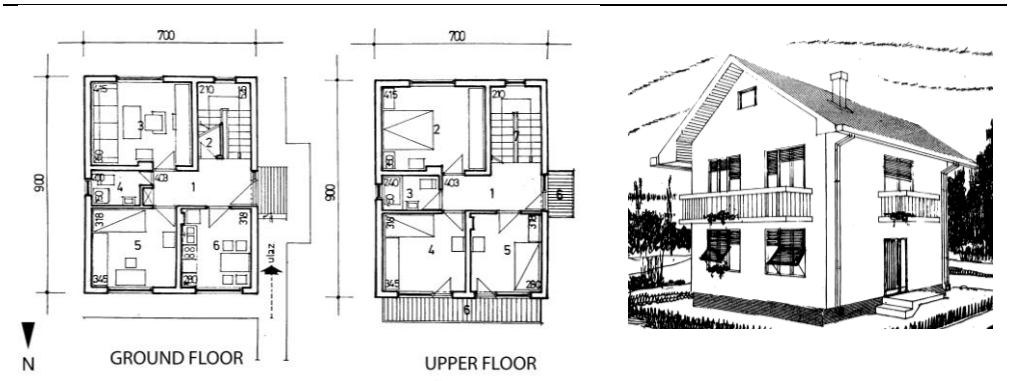


Fig. 2: Floor areas and perspective view of the representative house designed by architect Milisav Vojinovic [29]

The house is built in a concrete-skeleton construction with concrete foundations. External walls are built from brick-blocks with plaster finishing. The ceiling construction is semi-fabricated. The roof

has timber-frame construction with two slopes of 30 degrees. The roof covering are clay roof tiles. The windows are double glazed (80% of glass and 20% of wooden frames). The basic house is without any thermal insulation and has low energy performance. Thermal properties of the elements in building envelope are shown in Table I.

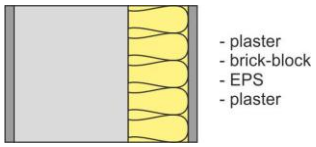
Table I. Properties of the building envelope for the basic house

Building Element	Floor	Walls	Roof Ceiling	Windows	Frames	Doors
Thickness D [cm]	56.6	22	21.5	6-12-6 [mm]	22	4
U-Value [W/m^{2}k]	1.52	0.8	0.89	2.91	1.44	2.1

3.2. Retrofit scenarios

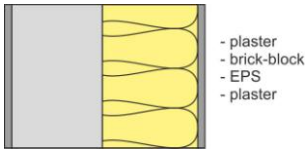
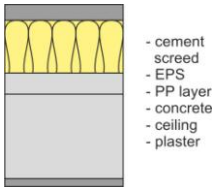
In the first retrofit scenario we improved the initial representative house by partial renovation. Improvements in this scenario considered the addition of the 10 cm polystyrene insulation (EPS) to all external walls. This investment in Belgrade cost 4600 EUR [43-46]. Structural and thermal properties of the insulated building components are stated in Table II.

Table II. Details of building elements for the first retrofit scenario (R1)

External wall

Thickness, D=32 cm U=0. 22 W/m^{2}K

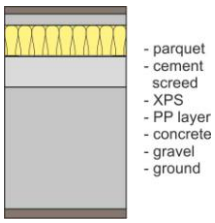
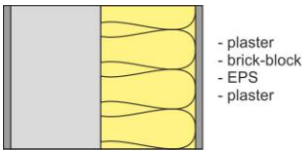
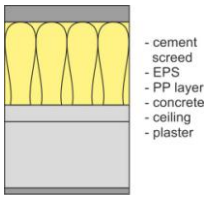
The second renovation scenario contained an addition of 20cm of EPS insulation to the external walls. Moreover, roof ceiling was upgraded with an addition of 10cm of EPS insulation and old doors and windows were replaced with double glazed PVC windows (4-12-4 mm) with shutters. This investment cost about 9800 EUR [43-50]. Improved thermal properties of the building components are shown in Table III.

Table III. Details of building elements for the second retrofit scenario (R2)

External wall	Ceiling construction	Windows with shutters
		
D=42 cm U=0.16 W/m^{2}K	D=36 cm U=0.26 W/m^{2}K	U_{frames}=1.1 W/m^{2}K U_{doors}=1.8 W/m^{2}K

The third scenario was a comprehensive renovation. The external walls were insulated with 20 cm of EPS insulation. The roof ceiling was insulated with 20 cm of EPS insulation and the floor on the ground was insulated with 10 cm of extruded polystyrene foam (XPS). Old doors and windows were replaced with triple glazed PVC windows (4-10-4-10-4 mm), while shutters for the windows were also installed. This investment in Belgrade cost about 15700 EUR [43-51]. Improved thermal properties of the building components are shown in Table IV.

Table IV. Details of the building components in the third retrofit scenario (R3)

Floor	External wall	Ceiling construction	Windows with shutters
			
D=66.6 cm U=0.33 W/m^{2}K	D=42 cm U=0.16 W/m^{2}K	D=45.5 cm U=0.18 W/m^{2}K	U $_{frames}$=1 W/m^{2}K U $_{doors}$=1.5 W/m^{2}K

Euro-WAEBED simulations took into account the presence of people, heat gains from the equipment, as well as air infiltration. For heating demands evaluation, the indoor temperature during the heating period was set to 20°C. These standard values were adopted from reference [30]. We assumed that the building was not shaded. For GEBA simulations, the south-oriented living room on the ground floor was potentially overheated space. The critical room was analyzed for the mid of July (Fig. 1).

The economical analyses were conducted by calculating the period of investment-return. For all economical analysis, mid-value of euro exchange rate of the National Bank of Serbia was taken, on the date 15.4.2013, 1 EUR= 111.73 RSD [34]. The value of the investment was determined as the average value from offers of three local construction companies. The average heat-energy price was calculated. Since single houses are not attached to the district heating system [8], the average local price of gas, wood and electricity in different tariffs was 5.11 €ct/kWh [35-38].

The applied passive retrofit measures considered energy conservation in the house. Our focus was to reduce annual heating demands of the building and to avoid the overheating in summer. According to these settings, the building envelope retrofits for the representative house provided output data that we further evaluated.

4. Results and discussion

Dynamic simulations were performed for the basic house and its three refurbishment scenarios. For each case, the paper reports the annual heating energy consumption, the annual savings, the investment return and the summer inner temperatures.

4.1. Energy efficiency

Our investigation showed that the annual heating consumption for the basic non-insulated house was 18646 kWh. Notice that the R2 scenario achieved the low-energy standard with the annual heating demands of 59 kWh/m^{2}a (Table V). The third retrofit reduced the annual consumption for 13326 kWh in total, although the passive house (PH) standard was far to be reached only through the building-envelope retrofit. To target the PH retrofit (i.e. annual heat demands of 15 kWh/m^{2}a) the additional measures including a ventilation system have to be analysed.

Table V. Annual heat energy consumption of the house

Scenario	Annual Heating Demands	Heating Demands Per m^2
Initial house	18 646 kWh	148 kWh/m^{2}a
R1	12 293 kWh	98 kWh/m^{2}a
R2	7484 kWh	59 kWh/m^{2}a
R3	5320 kWh	42 kWh/m^{2}a

The applied retrofit measures showed good energy saving potential. The output data pointed out that 34% of energy can be saved with the partial renovation. The second refurbishment scenario reduced heating demands of the building up to 60% while third scenario reduced them for 72%. Figure 3. describes the effectiveness of retrofit scenarios and the annual energy savings. Respectively to the energy savings, carbon-dioxide emissions from energy production were reduced. Therefore, proposed retrofits improved environmental impact of the building.

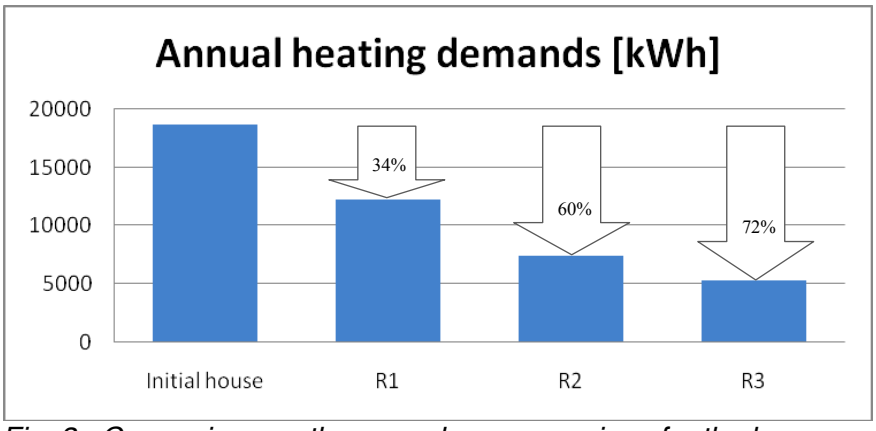


Fig. 3: Comparison on the annual energy savings for the house

4.2. Economical analysis

From the economical point of view, the partial renovation with the R1 was the most affordable option. The investment was the highest in the R3 scenario, for about 60% higher than in the R2 scenario. Despite the R1 showed the quickest financial return, the retrofit R2 demonstrated additional 26% of the energy savings (Table V). In 30 years estimation for Serbia, the R2 saved 144300 kWh more than the R1. The R2 scenario also showed better ratio of investment-return than the R3. Considering applied renovation measures, retrofit R2 was the most profitable solution.

Table VI. Value of the investments, annual savings and pay off period

Scenario	Investment	Annual heating cost*	Annual savings	Pay off **
Initial house	-	960 EUR	-	-
R1	4600 EUR	640 EUR	320 EUR	15
R2	9800 EUR	390 EUR	570 EUR	17
R3	15700 EUR	280 EUR	680 EUR	23

* Annual heating cost with average price for heating from gas, wood and electricity.
** Pay off period in a case of cash investment.

In a case of taking a renovation-loan, an offer from "*ProCredit bank*" on the date 15.4.2013 was used [39]. "*Energy efficiency loans*" have the repayment period of 5 years and an effective interest rate of 8.35%. This could prolong the calculated pay off periods for additional 6 years for the R1, 8 years for the R2 and even 10 years for the R3 scenario. Up to 15.4.2013, the renovation loans in Serbia were not favourable in comparison to other EU countries (e.g. Austria and Germany) [40].

A disparity of energy prices may be the source of impreciseness, because the financial return was calculated for the average energy price. Single prices of specific heat sources (e.g. gas and electricity) would induce quicker investment return. In our previous work, we elaborated differences in pay off period by every heating source in Serbia [8].

A trend of increasing energy prices in Serbia exist and it will also support quicker financial return. Latest increase of electricity price in Serbia took place in 2010 (10% on average) and afterwards in 2011 (15% on average) [41]. The price of gas in 2013 increased for 8.6% [42]. Recent information on future electricity prices show that increase from 10% to 12% is expected in 2013. Although the

precise data on the future prices are currently unavailable, the proposed retrofits will be more cost-effective in the years to come.

4.3. Summer conditions

The proposed retrofit measures on building envelope caused changes in the inner comfort. Regarding the retrofit solution R1, the south-oriented living room on the ground floor showed small decrease of inner temperatures during summer. The R2 with highly insulated walls, insulated roof ceiling and shuttered double glazed windows demonstrated the best results under critical summer conditions (Table VII). The house was cooled from the ground through the floor construction and protected from the excessive solar irradiation by window shutters. The inner temperatures were decreased up to 2°C in comparison to the initial case. This created more comfortable and healthier environment for living. For tenants, well-being is one of the important reasons to invest in retrofitting.

Table VII. Inner temperatures in the living room on 15. July

Temperature	Min [°C]	Mean [°C]	Max [°C]
External air	17.6	26.0	33.6
Initial house	25.0	27.5	29.5
R1	24.7	27.2	29.3
R2	23.8	25.8	27.4
R3	25.7	28.0	29.8

Interestingly, the R3 scenario influenced an increase of the inner temperatures. A combination of highly insulated walls, ceiling and floor with shuttered triple glazed windows failed to provide good inner comfort during summer months. The main reason for this was the floor insulation. In winter, insulated floor was effective to reduce heat loss where floor construction itself contributed with approximately 10% of heat demands reduction. On contrary, during summer the house was blocked to release the heat through the floor in order to be cooled down with ground temperature. Considering thermal comfort in summer months and healthy living environment, the R2 showed the best results with reduced inner temperatures (Fig. 4).

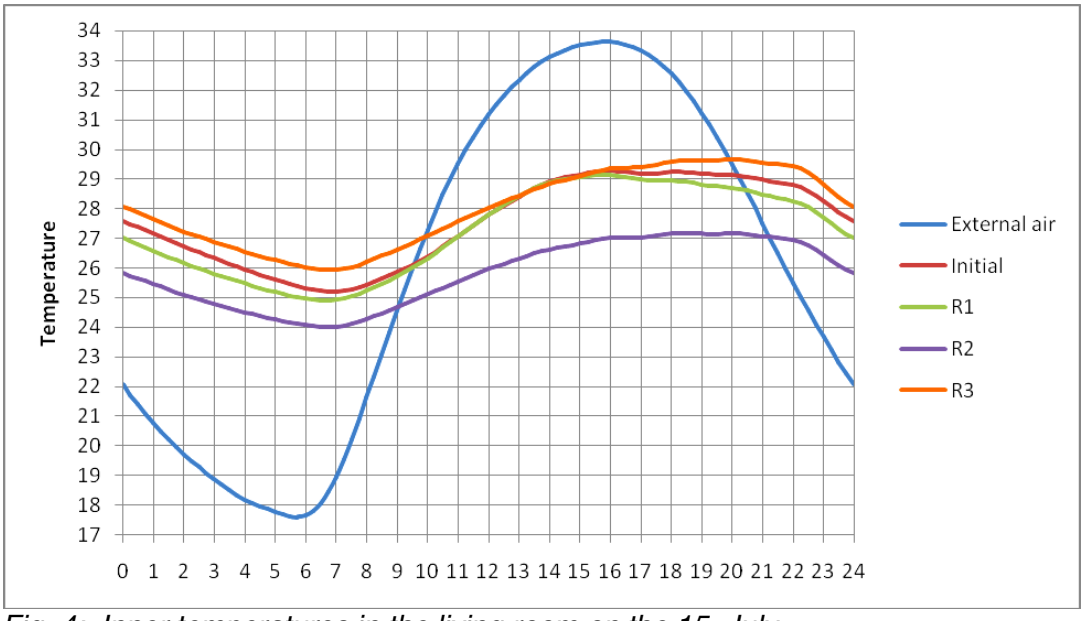


Fig. 4: Inner temperatures in the living room on the 15. July

The environmental, economical and social aspects of building envelope retrofits indicated pros and cons of the proposed solutions. We found that several refurbishments changed the building by

energy efficiency, financial benefit and inner comfort. For appropriate retrofitting in Serbia, beside the heating demands evaluation, thermal comfort and possible overheating have to be analyzed.

As we mentioned in Sampling procedure (Subheading 2.4), our chosen model regards numerous similar detached houses in Serbia. The survey of the outcomes could be used as a first step for refurbishment analysis of these houses. Dependently on the level of renovation, future investors will have an overview about retrofit saving potential.

5. Conclusion

In this paper, we evaluated the energy saving potential of the building envelope retrofits, the cost-effectiveness and the achieved thermal comfort during summer for the typical house in Serbia. The case studies and the simulation research were combined in our investigation. This drew the results that were used to assess benefits of three applied retrofits.

The current housing stock in Serbia has a great energy saving potential. With three variants of building envelope retrofits, we achieved the energy savings from 34% to 72%. The R3 scenario showed the biggest saving potential. However, the R2 scenario showed very competitive result, up to 60% of the savings (Fig. 3.).

Regarding a financial return of the investments, the R1 retrofit scenario showed the quickest pay off period and solid cost-effectiveness. The R3 scenario was the most expensive and less profitable. From the economical point of view, the second R2 scenario was the most profitable long-term solution (Table VI).

An effective retrofit for detached houses in Serbia has to take into account the critical summer conditions. Each building envelope retrofit should be carefully planned to prevent possible overheating. In our research, retrofit scenario R2 demonstrated the most beneficial result regarding inner comfort in summer (Fig. 4.).

The output data established criteria to compare the applied retrofit solutions. Three building-envelope retrofits were evaluated from the socio/economical/environmental point of view. Considering analyzed scenarios for detached houses in Serbia similar to our model, we propose the R2 scenario as the most appropriate solution.

We chose a very common house to be our model for the dynamic simulations (Fig. 2). Because of a similar economy, climate and housing stock, our findings may be used as a start point for the research on this issue in countries in the region. The findings could be helpful to learn how to retrofit the houses from 1970's and 1980's in the most suitable manner. We may recommend that for the refurbishment, house owners and planners do similar economical and non-economical assessment and chose appropriate retrofit measures for a particular house.

In our further work, we will analyse thermal behaviour of the building during summer. Further analysis should also include an equipment renovation and an effect of user behaviour on energy savings. A greater understanding of benefits of energy efficient homes could induce significant improvements in the building sector in the future.

6. Reference

[1] SCHWEHR P, FISCHER R, GEIER S. "*Retrofit Strategies Design Guide - Advanced Retrofit Strategies & 10 Steps to a Prefab Module".* IEA - International Energy Agency, Empa, Building Science and Technology Lab, Switzerland 2011.

[2] EUbuild EE Project: *"Sectoral Collaboration Project with Regard to Financing Energy Efficiency in*

Buildings within the Frame of EU Regulations and Legal Arrangements, Country report: Serbia". http://www.eubuild.com/wp-content/uploads/2011/06/9CountryReport-SERBIA1.pdf (accessed 10.02.13).

[3] Austrian Energy Agency, "*Total energy consumption by sector Serbia 2010".* http://www.enercee.net/countries/country-selection/serbia.html (accessed 10.04.13).

[4] TODOROVIĆ M. (2010) *"First NEEAP/BS national energy efficiency action plan/building sector 2009-2018. u: Study Report and NEEAP-BS for the Republic of Serbia Ministry of Mining and Energy".*, Washington: IRG, June 2010

[5] JOVANOVIC G, *"Model of energy efficient house for Nis"*. Report from KGH congress, SMEITS, Beograd, 2012

[6] EUROSTAT, http://ec.europa.eu/eurostat (accessed 01.02.13).

[7] JOVANOVIC V, *"Patterns for energy efficient design in Serbia"*. "MEHR-WERT" Architektur & Raumplanung, TU Wien, Vienna 2012

[8] JOVANOVIC V, STIELDORF K. *"Influence of Energy Prices and Income Inequalities on Retrofit Strategies in Developing Countries: Comparative Analysis of Cost-efficiency of Retrofits on Case Studies in Belgrade, Nis and Vienna".* IEWT 2013 conference, TU Wien, Vienna 2013.

[9] SUMARAC D. et al. *"Energy efficiency of residential buildings in Serbia."* Thermal Science 14.suppl. (2010): 97-113.

[10] TODOROVIC B. (1982). *"Energetika Beograda"*. Beograd 1982.

[11] TODOROVIC M. et al. *"RES integrated refurbishment of existing residential buildings to approach sustainable municipal energy system."* Klimatizacija, grejanje, hlađenje 38.3 (2009): 41-48.

[12] TODOROVIC M. et al. *"Building performance simulation for cost effective solar integrated refurbishment of urban residential buildings."* The refurbishment of existing buildings presentations, Workshop, Milan, 31st October. 2008.

[13] MATIĆ D, TODOROVIĆ M, CALZADA J. R. *"Energy refurbishment of the prefabricated residential building blocks aimed to approach zero energy status".* 43th KGH CONGRESS, BELGRADE, DECEMBER 2012

[14] NIKOLIC M, MILOJKOVIC A, STANKOVIC D. *"Renewal of preschool facilities in Serbia in the context of green building technologies."*

[15] STEVANOVIC S, PUCAR M, KOSORIĆ V. *"Potential solar energy use in a residential district in Niš."* Spatium 2009.

[16] BOJIC M. et al. *"Decreasing energy consumption in thermally non-insulated old house via refurbishment."* Energy and Buildings (2012).

[17] BOJIC M. et al. *"Evaluation of the impact of internal partitions on energy conservation for residential buildings in Serbia."* Building and environment 42.4 (2007): 1644-1653.

[18] BOJIC M. et al. *"Toward a positive-net-energy residential building in Serbian conditions."* Applied Energy 88.7 (2011): 2407-2419.

[19] GROAT L, WANG D. *"Architectural research methods*", John Wiley and Sons, 2002.

[20] "Krec" - Büro für Bauphysik, http://www.krec.at/ (accessed 01.02.13).

[21] KUNATH-RUDY M, KREC K. *"Thermal Building Simulation for Design Practice"* in: "Energy and Mass Flow in the Life Cycle of Buildings; 1996 International Symposium of CIB W67", Eigenverlag, Wien, 1996, 519 - 525.

[22] STIELDORF K, IPSER C, STEINER T, KREC K, (2011) "*Entwurfsbedingte Optimierungs-potentiale in der Energiebilanz von Gebäuden, Gebint - Gebäude maximaler Energieeffizienz mit integrierter erneuerbarer Energieerschließung"* – BauZ, Institut für Architektur und Entwerfen, TU Wien; Institut für Energiewirtschaft und elektrische Anlagen, Gruppe Angepasste Technologie GrAT.

[23] STIELDORF K, KREC K, PILS G, SCHNETZER A, *"LISI: Austrian Contribution for the Solar Decathlon 2013".* "MEHR-WERT" Architektur & Raumplanung, TU Wien, Vienna 2012

[24] IPSER C. et. al. (2012): *"Planungsleitfaden Plusenergie,Teil 3 –Parameterstudien und Planungsempfehlungen zur Entwurfsoptimierung und Steigerung der Energieeffizienz von Gebäuden, Berichte aus Energie-und Umweltforschung 56d/2012"*. Bundesministeriums für Verkehr, Innovation und Technologie, Wien, 2012.

[25] BOINTNER R. et. al. (2012): *"Gebäude maximaler Energieeffizienz mit integrierter erneuerbarer Energieerschließung, Berichte aus Energie-und Umweltforschung 56a/2012"*. Bundesministeriums für Verkehr, Innovation und Technologie, Wien, 2012.

[26] Republic Hydro meteorological Service of Serbia, http://www.hidmet.gov.rs/ (accessed 15.04.13).

[27] VUKMIROVIC D. "*Stanovi - popis stanovnistva, domacinstva i stanova in 2002".* Statistical office of the Republic of Serbia, Belgrade 2004.

[28] Statistical office of RS, http://www.stat.gov.rs (accessed 01.02.13).

[29] MIHAILOVIC Z. *“Catalogue of typical house design”*. Working group for architectural design “Nas stan”, Belgrade 1979.
[30] ZRNIC S. CULUM Z. *“Technical Regulations on Heating, Cooling and Air Conditioning”*. Naucna knjiga, Beograd, 1998 (in Serbian).
[31] INGO G, LADENER H. *"Vom Altbau zum Niedrigenergie+ Passivhaus."* Gebäudesanierung. Neue Energiestandards. Planung und Baupraxis (2009).
[32] STROM I, JOOSTEN L, BOONSTRA C. Passive House Solutions, Working paper 1.2 Promotion of European Passive Houses, 2006. http://erg.ucd.ie/pep/pdf/Passive_House_Sol_English.pdf (accessed 15.04.13).
[33] U-value-calculator, http://www.u-wert.net/ (accessed 10.03.13).
[34] National Bank of Serbia, Exchange rates at internet, http://www.nbs.rs/internet/english/index.html (accessed 12.04.13).).
[35] Electric power industry of Serbia, http://www.eps.rs/ (accessed 12.04.13).
[36] Srbija Gas, http://www.srbijagas.com/ (accessed 12.04.13).
[37] J.P. Srbijagas Novi Sad, Decision on the price of natural gas for tariff customers (in Serbian), Official gazette of RS; 93/2008.
[38] State Enterprise for Forest Management *"Srbijašume"* Belgrade, http://www.srbijasume.rs/ (accessed 15.04.13).
[39] ProCredit Bank, *Energy Efficiency Loans*, http://www.procreditbank.rs/en/strana/4111/energy-efficiency-loans (accessed 15.04.13).
[40] Aktuelle Zinsen in Österreich, Sanierungsdarlehen 5 Jahre http://www.wohnnet.at/konditionen-kreditzinsen.htm (accessed 15.04.13).
[41] News article, http://serbia-energy.com/sr/2013/01/poskupljenje-struje-nece-izazvati-inflatorni-sok/ (accessed 22.1.13)
[42] News article, http://www.vesti-online.com/Vesti/Ekonomija/278572/EPS-jos-nije-odlucio-koliko-ce-poskupeti-struja (accessed 18.12.12)
[43] Construction company, *Stim construction*, Beograd, http://www.stimgradnja.rs
[44] Construction company *AVS DOO*, Sundečićeva 9, Beograd
[45] Construction company, *Dragovic d.o.o.*, Price of production at internet. http://www.dragovic.biz/cenovnik.htm
[46] Construction company, *Gramont inzenjering*, Nis, http://telefonski-imenik.biz/kontakt/gramont-inzenjering-nis-57534
[47] *PORTA Domus Doo*, Braće Miladinov 4/16 Beograd, www.alu-pvcstolarija.com
[48] *PVC inzenjering*, Beograd, http://www.pvcinzinjering.co.rs/
[49] *AD SISTEM*, Doors and windows, Beograd, http://www.adsistem.com/
[50] *MILE plast*, doors and windows, Belgrade, http://www.pvc-mileplast.com/
[51] *Mr. Door*, Doors and windows, Belgrade, http://www.mrdoor.rs/

Life cycle assessment of wooden building systems for façade retrofitting

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Short summary

The building sector is a crucial sector for a sustainable development. It accounts for a large amount of land use, energy and water consumption, air pollution and impact on climate change. In order to reduce the energy consumption of existing buildings, the 'EFFINOV Bois' research program, a French National Research Agency (ANR) project, suggests to bring industrialised technological solutions using wood systems. These wood based multifunctional complexes can be used within the framework of retrofitting of facades.

The project aims to analyse the potentials of using a light framed wooden structure renovation technique on an existing heavy structured façade. To measure and to demonstrate the environmental progress obtained after the installation of the developed solutions, an environmental analysis has been conducted in a rigorous, quantitative, and comprehensive approach based on Life Cycle Assessment (LCA). LCA is a standardized methodology (ISO 14040 and 14044 standards) based on a quantified inventory of impacts sources such as material, water and energy consumption, waste generation and discharges of pollutants in water, air, and soil. From this inventory from cradle to grave, environmental impact indicators are computed according to NF P01-010, the French standard for environmental building products declaration.

In this study, environmental impacts of the building before and after renovation have been estimated with ELODIE, the building LCA tool developed by the French Building Institute CSTB. The environmental benefit of the renovation solutions has been calculated by making the difference between impacts of the building renovation solutions (materials production, transport, construction, use and end-of-life) and reduced impacts of lower energy consumption during the renovated building lifetime.

Four renovation solutions have been developed: low cost, high thermal performance (HTP), very high thermal performance (VHTP) and all-wood. To connect these solutions to the existing building, two types of support were considered: a facade connection (FC) or a ground connection (GC). All solutions have been adapted to an existing university building for simulation. Three types of building use have been considered for energy consumptions modelling: public assembly building (PAB), tertiary building and housing building.

The renovation solutions developed decrease the renewable energy consumption, non renewable energy consumption, water consumption, hazardous waste and climate change but increase non hazardous waste and inert waste. There is no significant gap between low cost, High Thermal Performance, Very high Thermal Performance, all-wood solutions, and between facade connection and ground connection.

Keywords: Life cycle assessment, wood, building rehabilitation, environmental impacts.

1. Introduction

The building sector is a crucial sector for a sustainable development. It accounts for a large amount of land use, energy and water consumption, air pollution and impact on climate change. In order to reduce the energy consumption of existing buildings, the 'EFFINOV Bois' research program suggests to bring industrialised technological solutions using wood systems. These wood based multifunctional complexes can be used within the framework of retrofitting of facades.

The project aims to analyse the potentials of using a light framed wooden structure renovation technique on an existing heavy structured facade. To measure and to demonstrate the environmental progress obtained after the installation of the developed solutions, an environmental analysis has been conducted in a rigorous, quantitative, and comprehensive approach based on Life Cycle Assessment (LCA).

LCA is a standardized methodology (ISO 14040 [1] and 14044 [2] standards) based on a quantified inventory of impacts sources such as material, water and energy consumption, waste generation and discharges of pollutants in water, air, and soil. In a practical way, LCA relies on the modelling of physical inflows and outflows at the product system boundaries at each step of the life cycle. It is necessary to do a mass and an energy balance.

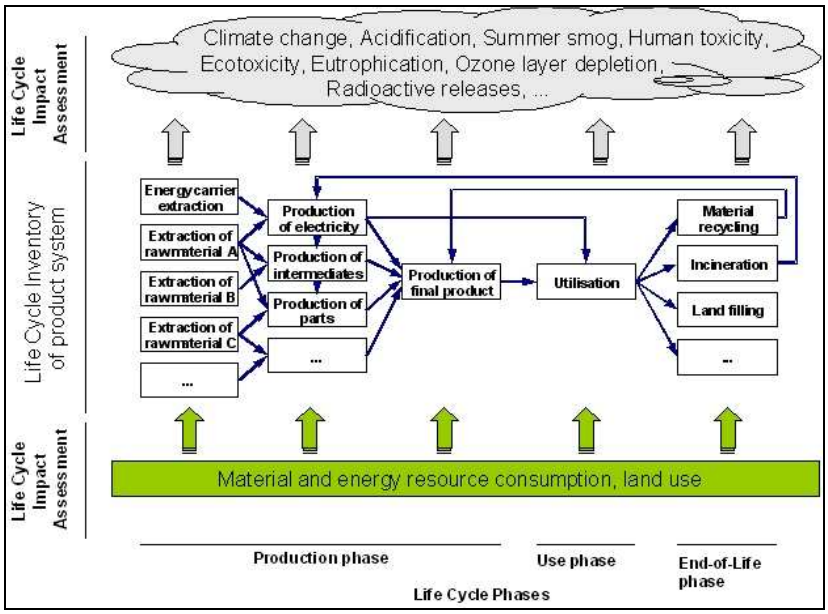


Fig. 1: Scheme of a product system's life cycle with data collection of product and waste flows and resources and emissions followed by the impact assessment of the emissions and resource consumption (source http://lca.jrc.ec.europa.eu/lcainfohub/introduction.vm)

From this inventory from cradle to grave, environmental impact indicators are computed according to NF P01-010 [3], the French standard for environmental building products declaration. Five life cycle stage are considered in NF P01-010: production, transport to construction site, construction, use and end-of-life.

2. Study description

2.1 Renovation solution description

Four renovation solutions have been developed: low cost, high thermal performance (HTP), very high thermal performance (VHTP) and all-wood. To connect these solutions to the existing building, two types of support were considered: a facade connection (FC) or a ground connection (GC). All solutions have been adapted to an existing university building for simulation. Three types of building use have been considered for energy consumptions modelling: public assembly building

(PAB), tertiary building and housing building.

In order to compare the impacts of renovation solutions developed with those of non renovated building, 27 cases have been studied:

Table 1: Studied cases

Building without renovation	BAP	Tertiary	Housing
Building after renovation, facade connection	BAP low cost	Tertiary low cost	Housing low cost
	BAP HTP	Tertiary HTP	Housing HTP
	BAP VHTP	Tertiary VHTP	Housing VHTP
	BAP All wood	Tertiary All wood	Housing All wood
Building after renovation, ground connection	BAP low cost	Tertiary low cost	Housing low cost
	BAP HTP	Tertiary HTP	Housing HTP
	BAP VHTP	Tertiary VHTP	Housing VHTP
	BAP All wood	Tertiary All wood	Housing All wood

For the buildings without renovation, the study is limited to the heating energy consumption for the building use for a period of 50 years. For renovation solutions, the assessment includes the heating energy consumption and the production, transport to pre-fabrication site, construction, use and end-of-life of the renovation materials.The renovated materials are:
- Precast wood walls with window,
- Connecting elements between the walls,
- Junction materials between wall and soil for the ground connection,
- Insulation of the floor and the roof.

The common elements between the existing buildings and the renovated buildings are not considered in this study.

The environmental impacts of the building before and after renovation have been estimated with ELODIE, the building LCA tool developed by the French Building Institute CSTB. ELODIE provides assistance for the design of environmentally friendly constructive solutions. It allows comparing several alternatives for the same building thanks to a LCA approach. The environmental benefit of the renovation solutions has been calculated by making the difference between impacts of the building renovation solutions and reduced impacts of lower energy consumption during the renovated building lifetime.

In this study, three main contributors may cause environmental impacts:
- Life cycle of renovation materials (production, transport to pre-fabrication site, construction, use and end-of-life),
- Assembling on the pre-fabrication site, transport and erection by crane,
- Energy consumption of the renovated building.

2.2 Functional unit

The functional unit is a quantitative performance which characterizes the studied product function. All the flows and impacts refer to this functional unit. The functional unit selected for this study is 1 square meter of net floor area of a building during the lifetime of 50 years.

3. Results and discussion

In this study, four key themes of the French “Grenelle of Environment” have been studied: energy, climate change, water and waste.

3.1 Energy

Regarding energy aspects in LCA according to NF P01-010 standard, there are two types of

energy:
- Consumed energy (burned) by the process (processing, transport, heating...) called fuel energy,
- Energy contained in the material called feedstock energy, which corresponds to a mobilization of a raw material with a calorific value.

These energies, whether feedstock or fuel may either come from renewable or from non renewable sources:
- Renewable energy comes from renewable resources like wind or biomass,
- Non renewable energy comes from fossil resources such as oil, uranium, coal or natural gas.

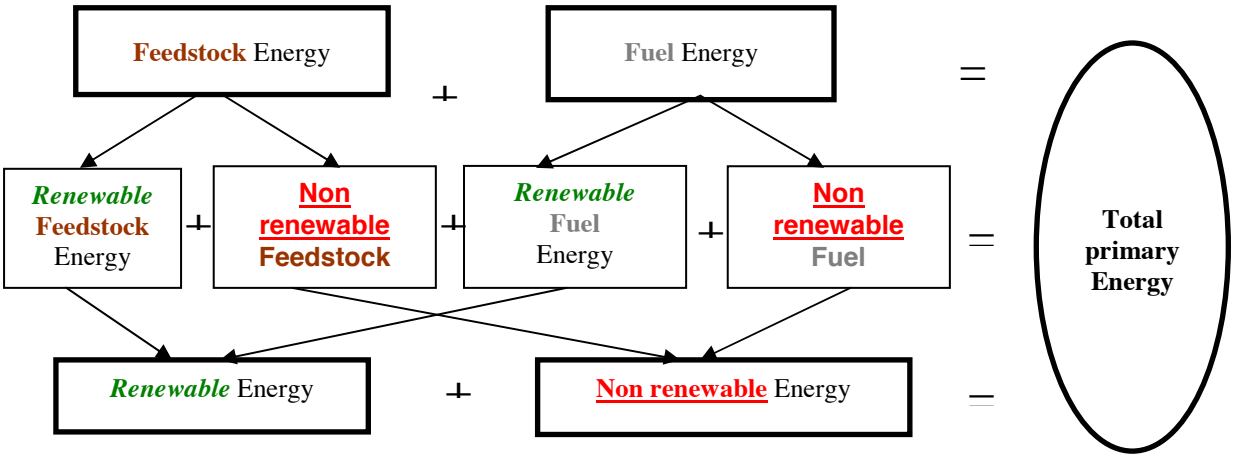


Fig. 2: Energy indicators

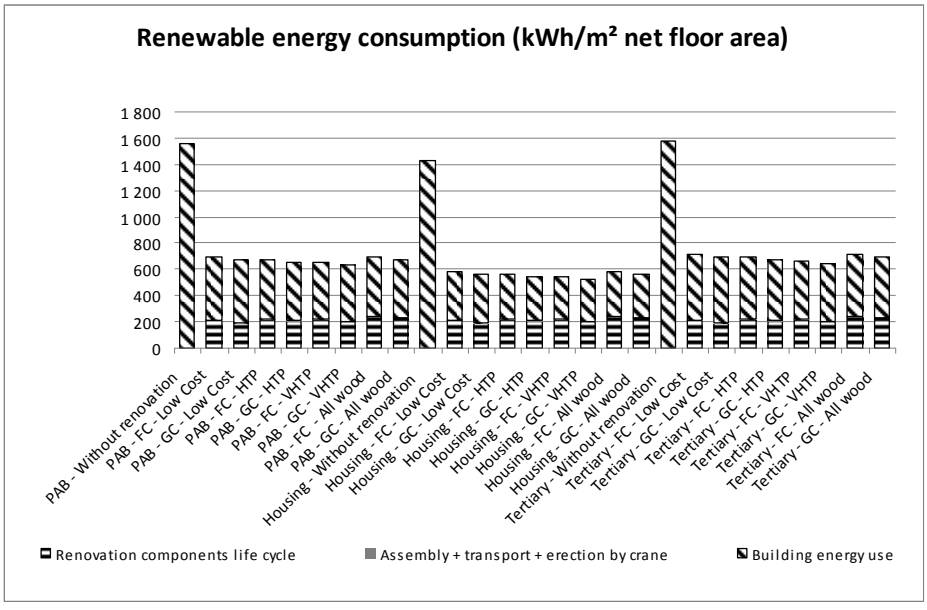


Fig. 3: Renewable energy consumption

The building renovation reduces the renewable energy consumption by 2 without significant difference between the different solutions. The renovation materials' renewable energy consumption is mainly due to the feedstock energy they contain.

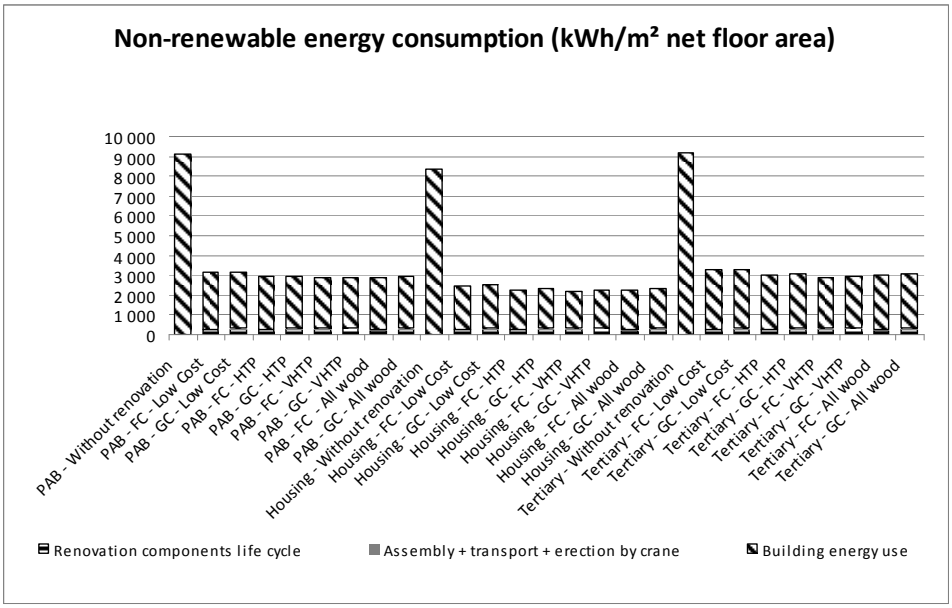


Fig. 4: Non-renewable energy consumption

The non-renewable energy consumption of the renovated building is three times lower than the non-renewable energy consumption of the existing building. The non-renewable energy of the renovation components life cycle, their assembly, transport and installation on site is low compared to the energy gain of the renovated building use whatever the chosen renovation solution.

3.2 Climate change

Contrary to minerals or fossil fuel based materials, wood molecules are the result of photosynthesis which is the transformation of carbon dioxide molecules into organic matter using solar energy. As a result, the growth of the tree captures carbon dioxide from the air. In the LCA methodology, this carbon uptake can correspond to an input or a negative emission. The uptake and emissions of carbon biomass were accounted for in this study, because the balance between uptake and emissions was not equal to zero. In the NF P01-010 standard, the reference scenario is landfilling. For wood, degradation in anaerobic conditions is incomplete and carbon contained in the product is stored for an indefinite time. A bibliographical review has been performed based on different publications including Barlaz study [4] and an average value has been found of 15% degradation rate for wood products.

The climate change indicator includes the greenhouse gases emissions from fossil origin and biomass origin. It is expressed in kg of carbon dioxide equivalent (CO_2).

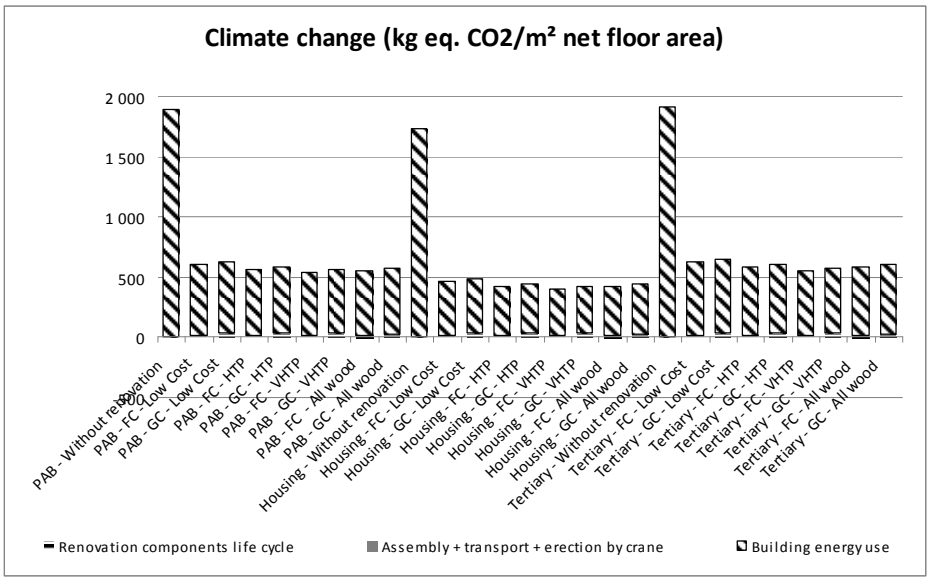


Fig. 5: Climate change

The studied solutions reduce by 3 the building impact on climate change. This reduction is achieved by low GHG balance of the materials used in the developed solutions and a significant reduction in building energy use due to the renovation. Low GHG balance of the materials system renovation is due to the fact that:
- A part of the energy used for the production of these materials comes from biomass with no impact on climate change,
- The end-of-life scenario of the wood components is the landfill. The hypothesis considered for wood is that 15% of the wood in landfill degrades to carbon dioxide (50%) and methane (50%), and 70% of the methane is burned. This scenario leads to a final storage of the carbon of a large part of the wood components, and a negative GHG balance of the wood components life cycle. This negative balance offsets the fossil GHG balance of the other components.

3.3 Water

The NF P 01-010 standard defines the indicator total water consumption as the sum of the consumption of water resources from the environment during the life cycle of the product (tap water, water from river, water from well, water from unspecified origin, except that used for cooling).

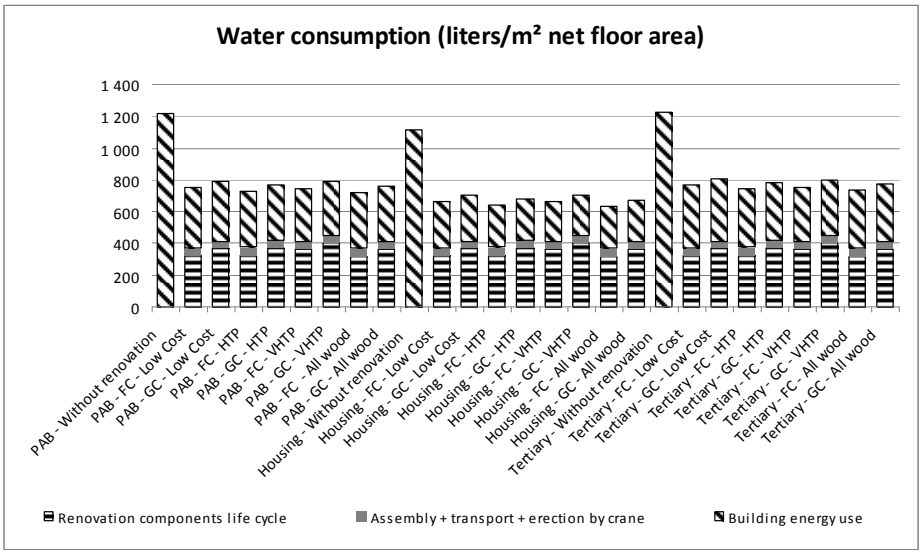


Fig. 6: Water consumption

All the developed renovation solutions reduce water consumption by 30% compared to the existing building. The water consumption evaluated in this figure is not the water consumed during the building use, considered to be identical between the exiting building and the renovated building, but the water consumption for the production of the building energy and the renovation components life cycle.

3.4 Waste

Waste indicators in NF P 01-010 standard are classified according to the European classification of waste: hazardous waste, non-hazardous waste and inert waste (nuclear waste is a special hazardous waste, it is not included in this study).

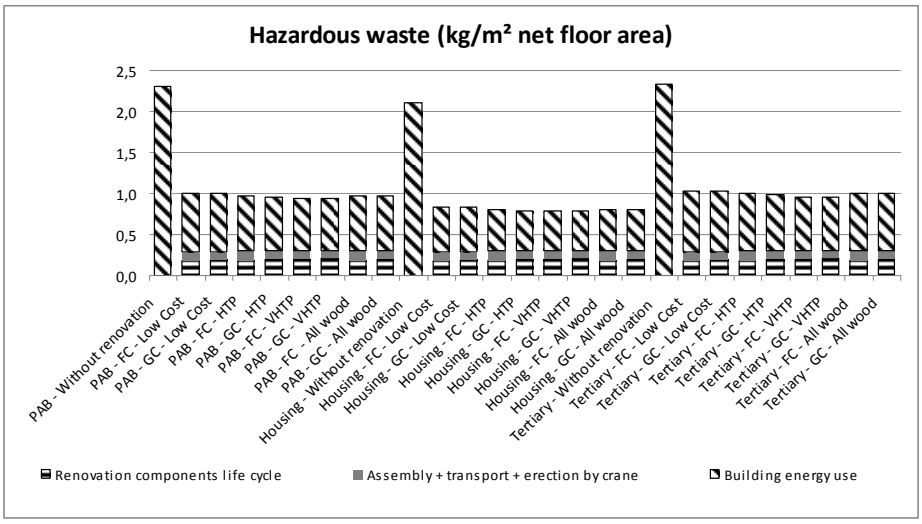


Fig. 7: Hazardous waste

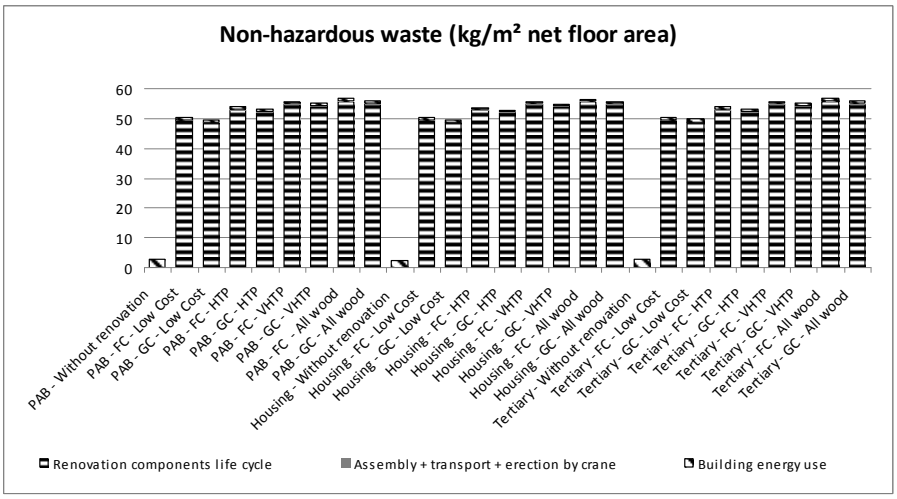


Fig. 8: Non-hazardous waste

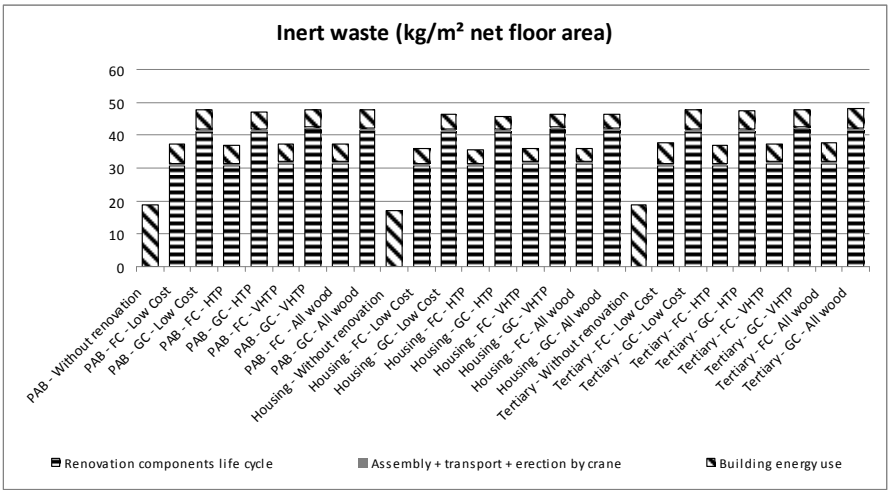


Fig. 9: Inert waste

The developed renovation solutions decrease hazardous waste, mainly due to energy production reduction, whereas they increase non-hazardous and inert waste, due to additional material disposal. The ground connection produces more inert waste than the facade connection. Nevertheless, the amount of renovation waste has to be relativized compared to waste of the whole existing building disposal, not considered here.

3.5 Discussion

Thanks to LCA methodology, this study showed that the impacts reduction due to energy saves is much more important than impacts of the facade components for most indicators, considering additional materials life cycle, assembling on the pre-fabrication site, transport to construction site, construction and energy consumption saves.

Indeed, the renovation solutions developed decrease renewable energy consumption, non-renewable energy consumption, climate change, water consumption and hazardous waste. However they increase non hazardous waste and inert waste, but the amount of renovation waste has to be relativized compared to waste of the whole existing building disposal, not considered here.

Moreover, for all the indicators, there is no significant gap between low cost, High Thermal Performance, Very high Thermal Performance and all-wood solutions, and between facade connection and ground connection, as it was already observed in thermal simulation. This is due to the too small differences in composition and thermal performance between the wooden solutions developed compared to the important energy saves of the building renovation.

4. References

[1] International Standard Organisation. *"ISO 14040, Environmental management - Life cycle assessment - Principles and framework"*, 2006

[2] International Standard Organisation. *"ISO 14044, Environmental management - Life cycle assessment - Requirements and guidelines"*, 2006

[3] AFNOR. *"NF P01-010*, *Environmental quality of construction products – Environmental and health declaration of construction products"*, 2004

[4] BARLAZ M. *"Forest products decomposition in municipal solid waste landfills"*. Waste Management 26, 2006, pp. 321-333.

Co-Benefits in Building Retrofit – Methodology proposal, tool development and a case-study demonstration

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Short Summary

The existing building stock encloses a huge potential for actions to deal with climate change and to move towards a sustainable economy, but the decision making process for its renovation keeps hampered by the evaluation of building renovation measures that only considers the direct costs, disregarding other relevant benefits and thus, significantly underestimating the full value of improvement and re-use of buildings, both in local and global economy.

The goal of this study was to identify a broader scope of effects that arise from building renovation and to propose a methodology for their quantification and integration in the decision making process in order to assist owners and promoters in the definition of the most appropriate renovation measures. These effects that arise from building renovation operations have been related with the different packages of renovation measures in order to allow comparing and ranking them through a tool developed for this purpose.

The application of the developed methodology and tool to a case study allowed to confirm the relevance of the non-financial benefits in the final evaluations, proving that not only economic criteria should support decisions in the field. An enormous influence of the categories related to the social aspects was demonstrated, as well as to the environmental parameters, clearly showing that these parameters can change the ranking between the tested renovation packages.

Keywords: Co-benefits; Sustainability; Building renovation; Multi-criteria analysis

1. Introduction

The renovation of the existing building stock is a relevant part of the actions to deal with climate change mitigation [1] and to move towards a sustainable relation with our planet [2]. This happens not only because of the reduction of greenhouse gas emissions that can be achieved by promoting the improvement of the overall energy performance of the built environment, but also by the reduction of resources depletion and minimization of waste production for which new construction is a major responsible.

Although existing buildings represent a huge potential in this areas [3], it has been found hard to fully exploit, mainly because of social and economic barriers that hamper owners and promoters in the decision making process, and mislead policy makers in the development of public support financial schemes and in the design of building directives. One of the common problems associated with the evaluation of building renovation measures is that only the energy savings and

the costs are considered, disregarding other relevant benefits and thus, significantly underestimating the full value of improvement and re-use of buildings at several levels of the economy [4].

In fact, building renovation has several side effects often yielding substantial benefits which can be felt not only at a financial level, but also at the environmental and social levels [5]. These side effects can be felt at the building level [6] by the building owner or user (like increased user comfort, fewer problems with building physics, improved aesthetics), but also at the society level [7] (like health effects, job creation, energy security, impact on climate change).

The goal of this study was the development of a methodology and a tool to support building renovation operations. This methodology should enable comparative analysis of different renovation alternatives in a holistic perspective in order to integrate the global benefits and co-benefits of building renovation in the decision process. The tool is intended to assist owners and promoters in the definition of the most appropriate renovation measures and allows the use of 34 different criteria that covers economic, environmental and social aspects, combined through the use of multi-criteria analysis.

The developed methodology and tool are strongly supported in several sustainability building rating systems such as SBTool – Sustainable Building Tool [8], LEED - Leadership in Energy and Environmental Design [9, 10], BREEAM - Building Research Establishment Environmental Assessment Method [11] and LiderA - Lead for the environment in search of sustainability construction [12] and have been applied to evaluate the renovation process of a social housing neighbourhood dated from the 1950's. This allowed to confirm that the inclusion of other effects besides saved energy and costs, clearly changes the hierarchy of the renovation solutions, and proves that a holistic perspective is necessary to reach sustainable building renovations.

2. The research methodology

The methodology for the integration of co-benefits in the decision making process and for the development of the tool to support the decision process occurred through the development of four essential steps, namely the identification of the benefits and co-benefits related to a building renovation, the assessment and quantification of each one of these benefits, their weighting and ranking, and finally the selection of the multi-criteria analysis tool.

The identification of benefits and co-benefits was performed based on the analysis of a set of methodologies for building sustainability certification [9, 10, 11, 12] and several studies on the evaluation of the benefits of existing buildings renovation [13, 14, 15]. The benefits were organized as evaluation criteria not only allowing their identification but also their evaluation and subsequent ranking. Were thus established 34 criteria for evaluating building renovation solutions, which were organized in 11 categories and by the three dimensions of sustainability: the economic, social and environmental, as described in Table 1.

For each criterion were given mechanisms for its quantification with reference to the different methodologies for sustainability assessment as well as for weighting its relative importance from the various stakeholders or beneficiaries of the building renovation perspectives (builder, designer, residents, promoters, community, etc.). To each criterion it was assigned a relative weight, so as to allow the subsequent weighting of the overall criteria in a single indicator.

Combination of the results of all the criteria to be evaluated was finally executed by multi-criteria analysis, specifically using the 'GREY Relational Analysis' [16] approach. The option was based on the non-limitation of the number of possible criteria to consider in the analysis and also for ease the entry of data. Besides this, results are provided even if not all the information is known. The approach is highly versatile allowing dealing with almost total lack of information to complete information availability. The introduction of data takes place through Excel sheets and the results are immediate allowing examining the various alternatives studied by introducing the values of each criterion and the appropriate relative weight.

Table 1: List of criteria for evaluation of building renovation alternatives

Dimension	Category	Criteria	Weigh (%)
Economic	Costs	Investment	9,0
		Maintenance	4,0
		Use	5,0
	Added Value	Real estate value	5,0
Social	Comfort	Thermal comfort	5,0
		Acoustic comfort	4,0
		Natural light	3,0
		Materials toxicity	1,0
		Air quality	3,0
		Inhabitants annoyance	4,0
	Functionality	Inclusive design	1,5
		Site management	2,0
		Interior layout adaptation	0,5
		Car parking	1,0
	Site integration	Territorial and landscape valorisation	2,5
		Awareness and education	0,5
		Surroundings regeneration	3,0
		Job creation	2,0
		Risk control	1,0
		Heritage values preservation	5,0
	Security	Fire	3,0
		Seismic	2,0
		Other risks	2,0
Environmental	Resources and materials	Materials recycling	1,0
		Materials durability	2,0
		Materials environmental impact	3,0
	Water	Water use	3,0
		Wastewater treatment	2,0
	Land use	Soil reuse	1,0
	Energy	Carbon intensity	5,0
		Renewables use	2,0
		Energy efficiency	6,0
	Waste	Waste treatment	2,0
		Waste production	4,0

3. Presentation and application of REHABILI-Tool to a study case

Based on the described methodology, a tool was developed to support the comparison of the building renovation solutions. The tool is performed based on Microsoft Excel and consists of 34 sheets for the criteria and 3 sheets in which is inserted information about the building, about the renovation alternatives and about the criteria under which the building will be evaluated. As final support to the decision making process, there are 2 sheets where comparative analysis are made out of the available data.

This chapter describes the work done before and after the introduction of data in the analysis tool, relying on the evaluation of a specific case study, namely a residential building located in Bairro Rainha D. Leonor located in Foz do Douro, Oporto.

The analyzed building is included in a renovation program of the Social Housing Neighborhood Rainha D. Leonor promoted and sponsored by the Municipality of Oporto and is presented in Figure 1 (before renovation) and Figure 2 (after renovation).



Figure 1: Building before renovation



Figure 2: Building after renovation (Base scenario)

In order to be possible to perform the calculation of each of the criterion in the tool and consequently compare different renovation scenarios, it is required the definition and characterization of each of the possible building renovation solutions by collecting data to allow the assessment of each criterion.

Once the data entry for each renovation solution is completed, the calculation is done for each criterion and the results are transferred to a multi-criteria analysis tool in order to proceed to the comparative analysis of the selected solutions. This analysis can be done overall or by sector, depending on the transposed criteria for multi-criteria analysis. Obtaining results from the multi-criteria tool is immediate and they can be analyzed both analytically and graphically by the user through specific sheets in REHABILI-Tool.

Within the present case study, three different scenarios for building renovation were evaluated:

- Base scenario: the renovation measures tested were the ones used in the recent renovation of the building. These correspond to the usual measures being used nowadays in current building renovations in Portugal;
- Best practice scenario: the package of measures used correspond to the best practice

currently available in the market, including the use of on-site renewables;
- Maintenance scenario: the original performance and characteristics of the building were kept and only maintenance and conservation measures were implemented;

For each of the alternatives for the building under study, each criterion has been quantified and the values were translated to the multi-criteria analysis tool. Once obtained the results of multi-criteria analysis for different alternatives of the building renovation, these were compared, analyzed and conclusions were found on the best solution for each dimension and still the best global solution through a rating between 0 and 1 which can be observed graphically in Figure 3 for the Base scenario, in Figure 4 for the Best practice scenario and in Figure 5 for the Maintenance scenario.

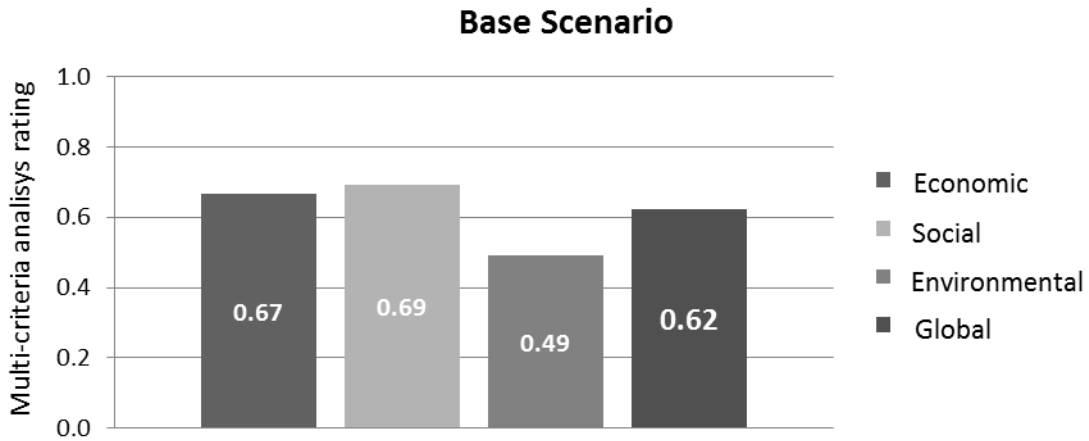


Figure 3: Results from multi-criteria evaluation for Base Scenario

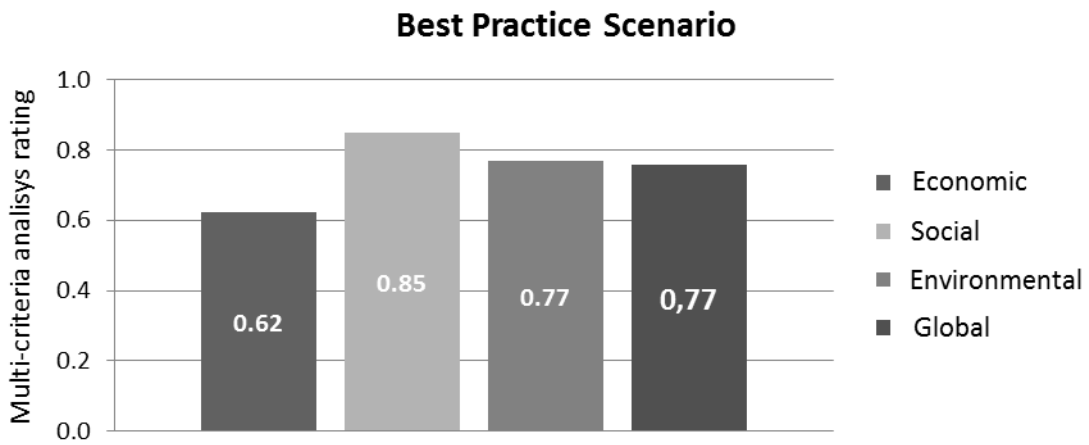


Figure 4: Results from multi-criteria evaluation for Best Practice Scenario

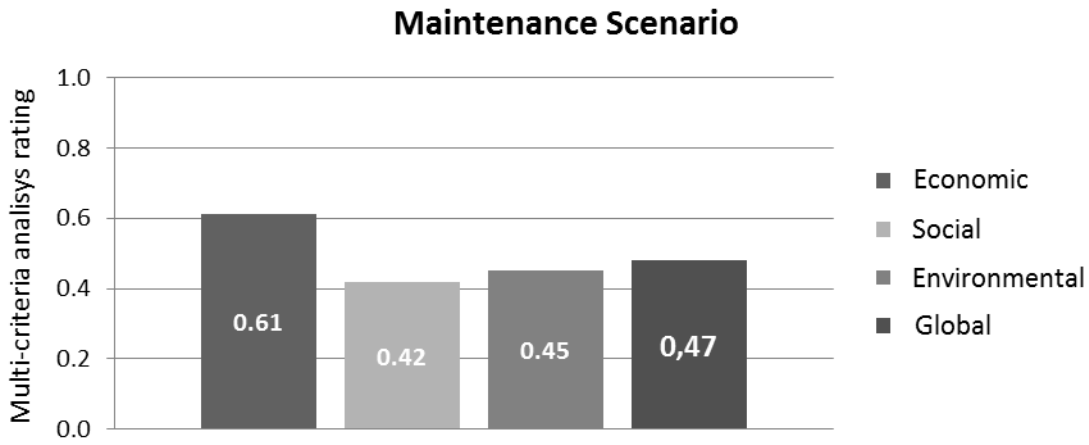


Figure 5: Results from multi-criteria evaluation for Maintenance Scenario

Comparative analyzes by sustainability dimensions held analogously to global analysis but only to the criteria of each dimension independently, allows a sectorial analysis, for the economic, social and environmental dimensions, so as to obtain a large number of perspectives and comparative data to aid in the decision making process.

Figures 6, 7 and 8 show the graphical analysis and comparison of the solutions for the different alternatives with the data of multi-criteria analysis tool for the three dimensions of sustainability.

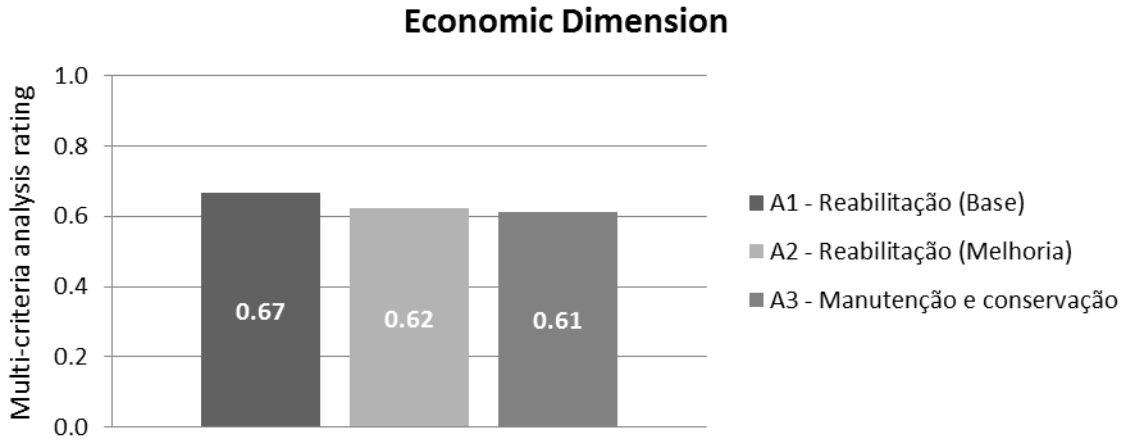


Figure 6: Results for Economic Dimension for the different renovation scenarios

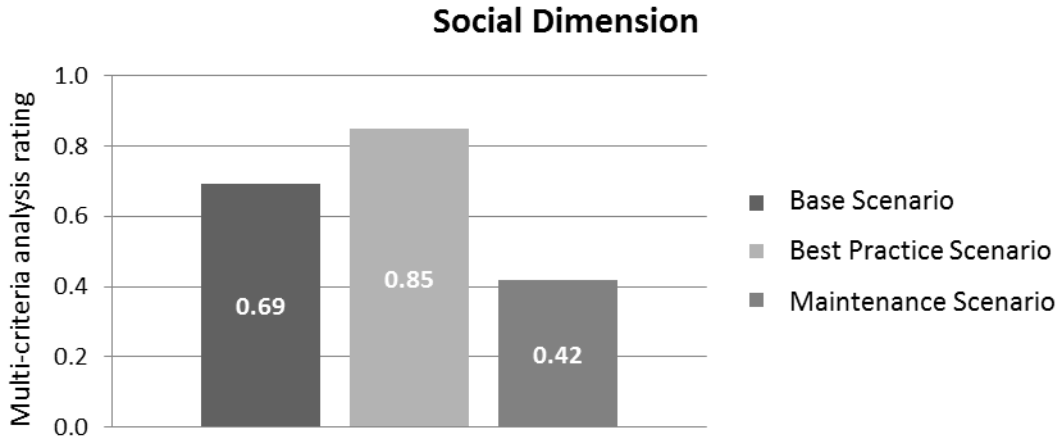


Figure 7: Results for Social Dimension for the different renovation scenarios

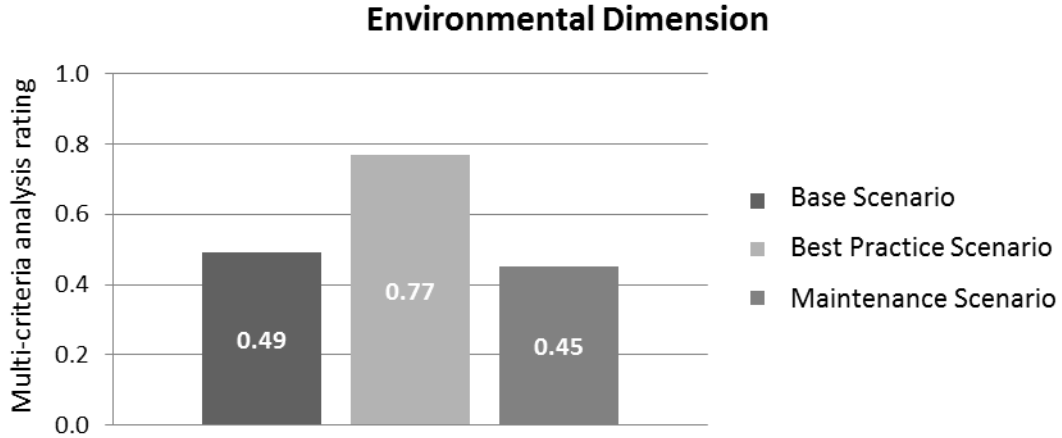


Figure 8: Results for Environmental Dimension for the different renovation scenarios

4. Discussion

From the results obtained and verified on the graphical analysis shown in Figure 9, as well as from previous Figures 3 to 8, it is obvious to conclude that the best studied alternative was the Best practice scenario. This evidence can be explained largely due to differences in classification obtained in the social and environmental aspects. This was the result of the application of the chosen constructive solutions allowing ensuring greater occupant comfort, improved equipment indoors and outdoors, higher level of security for occupants, lower energy costs, lower carbon emissions, lower water costs, lower environmental impact of the materials used and ultimately less production of non-reusable waste.

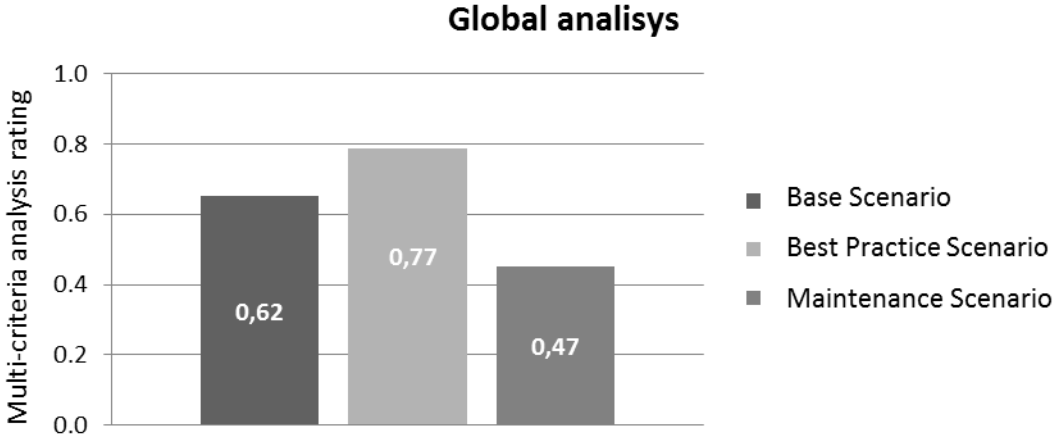


Figure 9: Results for Global analysis for the different renovation scenarios

Yet it is worth noting the slight superiority of Base scenario on the economic side, which is largely explained by the higher investment made in Best practice scenario, which still presents significant improvements in terms of running costs and real estate added value to the building.

Finally, it must be highlighted the poor results obtained with the Maintenance scenario. Despite having in its favor the extremely low value of the investment made, this turns out to be the worst alternative even in the economic dimension due to very high values of running costs and low real estate added value. In other dimensions the results with this scenario are even worse, which may be explained by the reduced intervention in a building that had clear deep intervention needs.

5. Conclusions

The primary objective of this study was the analysis of the co-benefits in building renovation and their integration into the decision making process. It was important to develop ways of helping decision-makers in choosing the best options during a building renovation process according to the particularities of the building under study, allowing that in this decision support process are considered various effects that are usually disregarded.

It was possible to present a method for integrating the benefits and co-benefits of building renovation in a decision process and it was recognized the ability of multi-criteria analysis in dealing with this type of assessment, essentially the ability to handle parameters with distinct magnitudes.

With regard to results, it must be emphasized the relevance of the co-benefits in the final evaluations, which proves that not only from an economic perspective the decisions should be taken, but also from perspectives indirectly related to the renovation measures or issues that do not affect to the same degree of importance different stakeholders. More specifically, it was evidenced the enormous influence of the categories related to the social and environmental aspects in the final standings of each alternative, more specifically in the Best practice scenario, that by adding its

rating in the environmental criteria enabled this to be the solution with the highest overall score. On the other hand, the weak ratings in the social and environmental criteria led the Maintenance scenario to be the solution with the by far worst rating.

These observations allow confirming that although sometimes a solution may not be the most attractive in economic terms can globally be the most effective and adjusted to the building under consideration. This occurs if the building renovation package meets determined criteria where quality of the constructive solutions and efficiency of equipment have great influence, thus allowing for better ratings in social and environmental aspects. This option for the quality of solutions and equipment will also lead to lower usage costs and higher property values after intervention that may justify higher initial investments. Lower affectation of the surroundings, lower resources depletion and less waste production are other relevant benefits that can be achieved with improved renovation packages.

It is intended that the analysis tool may become a practical and useful one for decision makers that through their use can build their opinion in the various building renovation solutions, and may thus decide and choose in a consistent manner, knowing the advantages and disadvantages of the different alternatives.

6. References

[1] EUROPEAN COMISSION, *"The European Climate Change Programme"*. European Communities, 2006
[2] EUROPEAN COMISSION, *"Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Roadmap for moving to a competitive low carbon economy in 2050"*, 2011
[3] BPIE, *"Europe´s Buildings Under the Microscope - A country-by-country review of the energy performance of buildings"*, 2011
[4] ÜRGE-VORSATZ D, NOVIKOVA A, SHARMINA M. *"Counting good: quantifying the co-benefits of improved efficiency in buildings",2009*
[5] IEA *"Evaluating the Multiple Benefits of Energy Efficiency"*, Workshop Report, Paris, 2012
[6] WYON D *"The economic benefits of a healthy indoor environment"*. La Riforma Medica, 109 (N2, Suppl. 1), pp 405-416,1994
[7] OECD *"The forgotten Benefits of Climate Change Mitigation: Innovation, Technological Leapfrogging, Employment, and Sustainable Development"*, 2003
[8] MATEUS R.; BRAGANÇA L. *"Sustainability assessment and rating of buildings: developing the methodology SBToolPT-H"*, Building and Environment 46, pp 1962 – 1971, 2011
[9] USGBC *"Getting LCA into LEED: A back grounder on the first LCA pilot credit for LEED",* 2009. Disponível em <http://www.usgbc.org/LEED>. Acesso em Maio 2013
[10] USGBC *"LEED 2009 for New Construction and Major Renovations Rating System"*, 2009. Disponível em <http://www.usgbc.org/LEED>. Acesso em Maio 2013.
[11] BRE *"BREEAM New Construction – Non Domestic Buildings. Technical Manual SD5073-2.02:011"* London: BRE, United Kingdom, 2009
[12] LiderA *"Liderar pelo ambiente na procura da sustentabilidade"*, 2009. Disponível em < http://www.lidera.info/?p=MenuPage&MenuId=18>. Acesso em: Maio 2013
[13] Skumatz, L. A., *"Evaluating the co-benefits of low-income energy-efficiency programs"*, 2011
[14] Skumatz L. A., *"Lessons Learned and Next Steps in Energy Efficiency Measurement and Attribution: Energy Savings, Net to Gross, Non-Energy Benefits, and Persistence of Energy Efficiency Behavior"*, 2009
[15] Skumatz L. A., *"Non energy benefits in the residential and non-residential sectors - Innovate measurements and results for participant benefits"*, Proceedings from the 2000 ACEEE Summer Study on Energy Efficient Economy, 2000
[16] Chan WK and Tong TKL, *"Multi-criteria material selections and end-of-life product strategy: Grey relational analysis approach"*, Materials & Design, Volume 28, Issue 5, Pages 1539-1546, 2007

BIPV-Standard Module for Large Scale Halls

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Short Summary

The new targets set by the EU for the building sector such as the EU-Directive on Energy Performance of Buildings (EPBD) open a new field for research and development activities which should focus on giving the best cost-effective innovative solutions in order to reduce the energy consumption in buildings. This contributes to an increase of the market potential for BIPV products and calls for a reduction of the energy needs for heating and cooling of the existing and new constructed buildings.

One approach to reduce costs in the building sector is the standardization of products, which helps improve the quality and reliability of the product. The goal of this project is to develop a Building Integrated Photovoltaics (BIPV) façade multifunctional product which could be used for both retrofitting and new construction. Simplicity of construction and cost-effectiveness are to be kept in focus. A first sketch and prototype of the module is to be developed. Studies are to be run regarding the most suitable measures of the product and the insulation material to be used taking into account costs and energy saving potential.

Keywords: Building Integrated Photovoltaics (BIPV); thermal insulation; industrial halls; cost-effectiveness; standard module; lifetime.

1. Introduction

In 2012 a PV capacity of more than 30 GW was installed worldwide, achieving a cumulated installed capacity of over 100 GW [1]. With this growing PV market, different studies do also state a growing potential of the BIPV market. A study run by EPIA estimates that 40% of the total energy demand in Europe could be supplied by roof and façade PV installations. This means an installed capacity of over 1500 GW with an annual electricity production of 1400 TWh [2].

Another factor that points out this potential is the idea of a future decentralized energy supply system. The Smart Cities idea deals with the integration of living, life, work, mobility, resources and energy concepts in the future cities. In this scenario, BIPV facades and roofs will play an important role in the local and direct energy supply (self-consumption).

Taking into account these numbers and perspectives the actual growth of the BIPV market is still too low. For example, in Germany, the installed BIPV capacity in 2009 was 1.5% of the PV capacity installed [3]. One of the barriers preventing this market to develop faster is the absence of standardized products as they are known and used in the building sector.

The actual building industry is based among other things on the standardization of products which

enable architects and designers to make faster decisions during the design phase. The standardization of dimensions and requirements for different materials allowed this industry to develop rapidly. For example, the existence of standard measures and requirements for the structural steel facilitates the designing process, ensures that a level of quality is met, and reduces the costs of the whole process. The regulation of BIPV products dimensions and requirements is expected to facilitate its implementation from the design phase to its installation.

In contrast to this idea, there are often seen custom made solutions for some buildings. In these cases, the aesthetical value is the most important factor of the design, leaving the yield to a second plane, thus, raising the costs of the manufacturing process and the installation. Both aesthetics and performance should ideally meet during the design of a BIPV product.



Fig. 1: Novartis Campus, F. O. Ghery, Basel, Switzerland.
Source: TRITEC

The actual needs of the building industry demand new PV products with integrated thermal insulation systems in order to lower the energy consumption of the building. Every type of building has different requirements and characteristics. With such a high diversified building market it is not possible to develop just one BIPV product for all buildings.

As a first approach to the development of standardized BIPV products, this project focuses on the design and construction of a standard product for a specific building category with particular dimensions and requirements. Non-residential buildings and especially industry halls with heating and cooling demand represent a large share of the potential market.

2. Industrial Halls

Factories, retail and warehouses belong to a building category where the integration of BIPV Modules in the façade is very attractive. Due to the simplicity of the architectural design and the large facade surface available, BIPV modules can be easily integrated in these buildings. Industrial halls represent a large potential BIPV market for both new building and retrofitting purposes. In most cases, these buildings have poor insulation and need refurbishment. This brings up the opportunity of adding more functions to the building material during the refurbishment phase such as higher thermal insulation and PV electricity production.

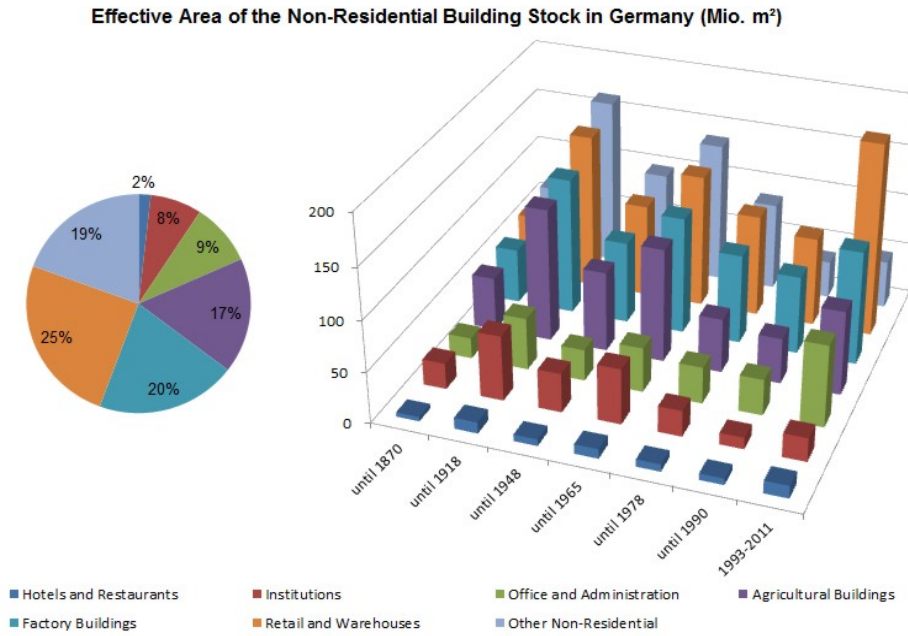


Fig. 2: Effective area of non-residential buildings in Germany [4], [5].

In Fig. 2 it is shown that these building categories represent a 45% of the effective area of the non-residential building stock in Germany. A recent study on energy efficiency in halls states that the usable net surface of heated hall buildings in Germany is estimated to be between 508 and 625 million m^2 for the building period 1960-2009 [6] (Fig. 3). As a first approach, the total façade surface can be estimated to be of around 400 million m^2 (based on a standard hall for South, East and West facades), which could mean a total installed capacity of 60.000 MWp. Due to shading and other issues, only a fraction of this area would be appropriate for BIPV.

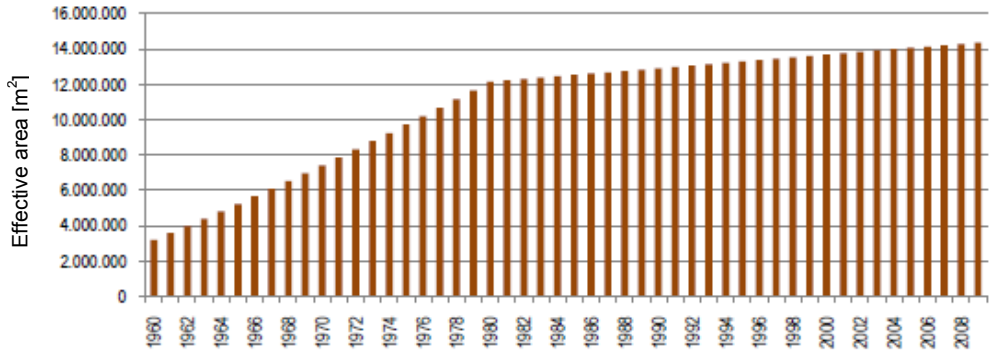


Fig. 3: Effective area distribution of heated industrial halls in Germany based on the construction year for the period 1960-2009 [6].

3. Module Design

3.1 Approach

Aim of this project is to develop a standard BIPV product with improved thermal insulation properties to be integrated in industrial halls facades. Water resistance, sealing and thermal bridges as well as the different building dimensions should be taken into account from the conception phase.

Whereas for PV roof installations there are already different solutions available in the market (75% of the expected BIPV products for 2014 are for roof integration [8]), the BIPV façade sector is not yet so far developed, and no standard solutions are available. The development of a standard module for BIPV is expected to widen the BIPV market, facilitating the acceptance from the

different actors in the building sector.

In relation to the development and study of new BIPV products for integration into steel elements for industrial halls, the first results of the research run within the NASTA project have been published [7]. Results are based on roof solutions and show that the maximum yield is obtained with standard modules, while the trapezoidal plates produce shadowing in the flexible PV elements, thus reducing the production. This kind of solution would result in a lower yield when installed in the façade due to potential shading. In contrast with the NASTA project, where the research is focused on the use of flexible modules, the approach followed in this case would be to maximize the yield by installing standard modules, thus reducing the losses due to shadowing.

A first sketch is shown in Fig. 4 with a trapezoidal plate as the core of the system, which will bring stability, ease of attachment, ventilation and a possible cabling space, while trying to limit the module weight. However, other structures are to be taken into account during the design process.

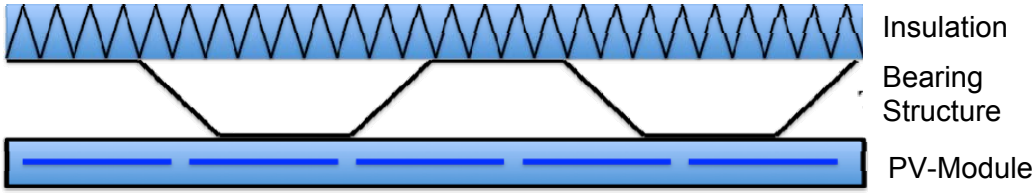


Fig. 4: First draft of a standard BIPV Module with thermal insulation

The development of a standard product provides a better quality control and a reduction of the failure rate. As the lifetime for façades should be in the range from 30-120 years, the building process becomes therefore of a great importance here.

3.2 Research tasks

3.2.1 Standard module dimensions

An important question is the standard dimensions of a PV product for the building industry. A first approach can be done through the analysis of the actual available in the market module dimensions. Fig. 5 represents the results of a market analysis of BIPV products, 79% of which are in the range of 1 – 2 m^2. A further step, in the case of crystalline modules, could be the analysis of cell and module dimensions derived from the different cell configurations, and a comparison of these with the available trapezoidal and insulation plates in the market.

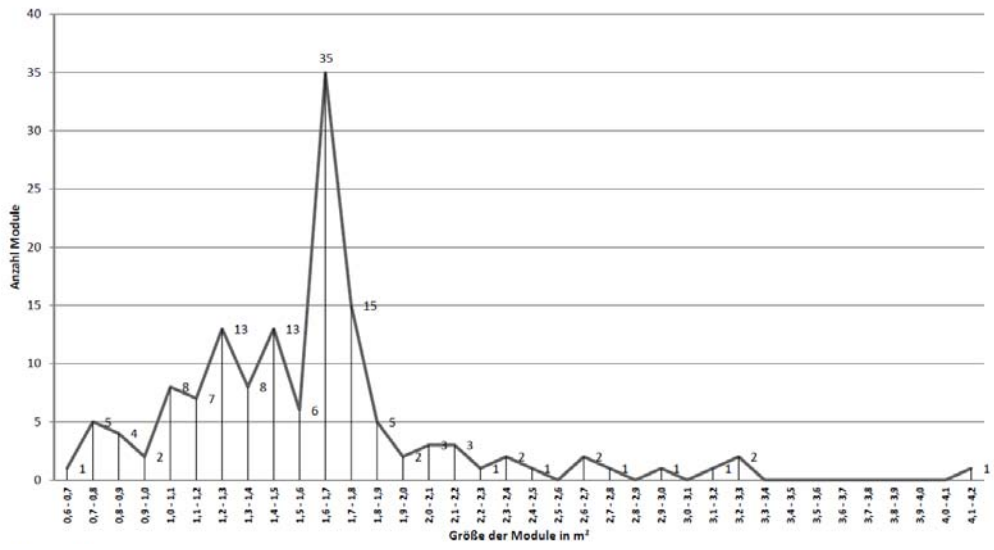


Fig. 5: Distribution of BIPV market module dimensions [8]

But the most important questions have to be answered with regard to the building typology. Therefore, a more detailed study is to be run taking into account façade products dimensions and configurations, available in the market façade systems for industrial halls, mounting systems and transport and handling best suited dimensions.

3.2.2 Insulation system

On the other side, there is the need to improve the thermal behaviour of the building stock, thus, reducing the cooling and heating demand. An analysis is to be done in this area regarding costs, thermal conductivity and lifetime of the different insulation systems. In the case of industrial buildings, where the effective surface is not as important in terms of costs as for residential buildings, a cost effective solution is to be expected.

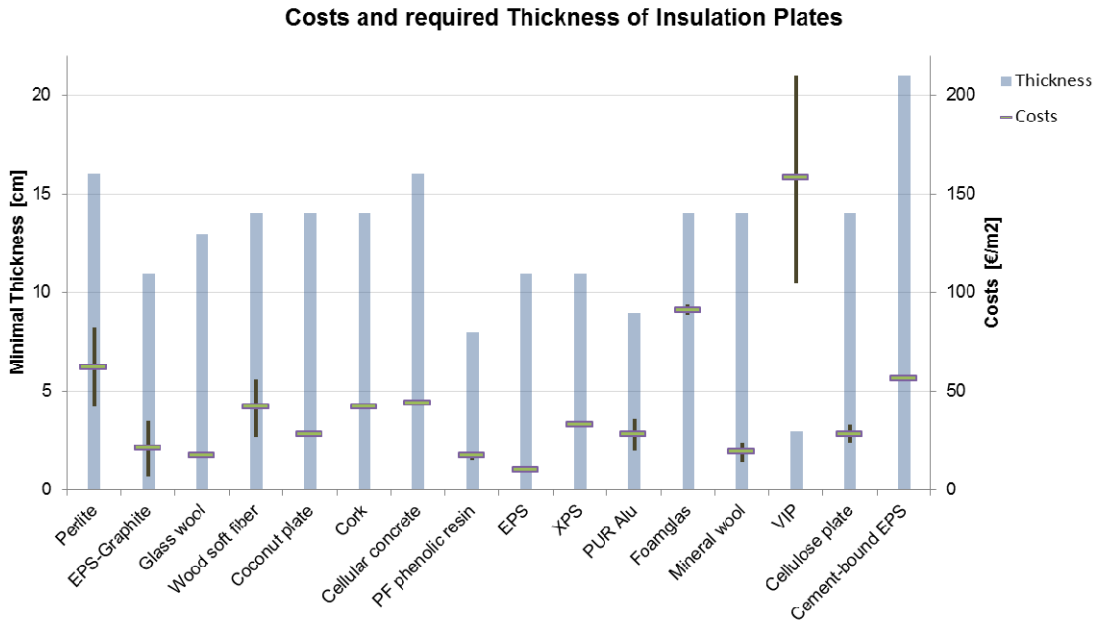


Fig. 6: Costs and required thickness of insulation plates based on a U-Value of 0.28 W/m2 K (EnEV 2009 back ventilated facade).

An analysis of the costs and thickness required by the actual regulations is shown in Fig. 6. This analysis is based on the German EnEV 2009 Standard for buildings, which requires a U-Value of 0.28 W/m^2K for back ventilated façade. Further requirements such as the Passive House Standards, are to be taken into account, and costs and energy savings in different scenarios are to be compared.

3.2.3 PV Module Configuration

Beyond the economic analysis, there are the technical issues (PV yield and thermal insulation. One yield related issue is the temperature of the PV module: a good ventilation of the back of the module is important in order to achieve good performances. At this point should be analysed whether the trapezoidal plate is the best solution or another structure would be more suitable. Further studies regarding the behaviour of the facade as a whole and the effects of the temperature gradient should be simulated and measured.

The thermal characteristics of the solution are directly related to a good design. The mounting system should minimize the thermal bridges, avoiding unnecessary thermal losses. Simulations of the different configurations are to be run in order to help in the decision making process. Analysis of the different photovoltaic technologies, their behaviour under diffuse radiation and high temperature are to be done.

In order to realize these measurements, one or more prototypes are to be built, and the selected

one is to be installed in a real façade, in order to analyse the characteristics and behaviour under real test conditions.

3.2.4 Lifetime stability

Table 1: Requirements, Standards and Tests for BIPV

Mechanical Loads			DIN EN 1991 / DIN 1055-4
PV	Mechanical Strength	3 Cycles, >5400 Pa, 1h	IEC 61215
Wind	Vibration-Resonance	--	
	Wind Pressure/Snow Load	Vacuum Cups Test	prEN 50583
		Air Chamber Test	prEN 50583
		Wind Channel	prEN 50583
	Curtain Wall – Resistance to wind load		DIN EN 12179
Fac.	Mech. Durability	5000-50000 Cycles (EN 12400)	DIN EN 1191
	Vertical load	200-800 N/Class 0-4 (EN 13115)	DIN EN 14608
	Torsion	200-350 N/Class 0-4 (EN 13115)	DIN EN 14609
Humidity			
PV	Humidity/Freeze	10 Cycles -40 to >85°C, 85%	IEC 61215
PV	Damp Heat	1000h, >85°C, 85%	IEC 61215
Facade	Curtain Wall - Water tightness		EN 13050
Temperature			
	Temperature Gradient	BIPV higher module temperature	
		Thermally induced glass breakage	
		Viscoelastic characteristics of encapsulates	
PV	Thermal Cycling	50-200 Cycles -40 to >85°C	IEC 61215
Fire IEC 61730			DIN EN 13501 / DIN 1055-4 / MBO
	Facade	GK 1-3 (<7m)	E d2 / B2
		GK 4-5 (7-22m)	C s3 d2 / B1
		*Special Buildings (>22m)	A2 s1 d0 / A2
Building Product	Non-combustibility	A1, A2	EN ISO 1182
	Heat of combustion test	A1, A2	EN ISO 1716
	Test SBI	A2, B, C, D	EN 13823
	Ignitability Test	B, C, D, E	EN ISO 11925

Lifetime stability analyses are as important as the technical or economical due to the high requirements of building products. It is important to keep in mind that building products require a much larger life time than the PV modules. Therefore, it is essential to guarantee the operability, not just of the PV Module but of the product as a whole. This will also secure the investment and ease the growth of the BIPV market.

Table 1 shows a summary of the tests and special requirements for BIVP modules. Due to the special conditions of facade integrated modules, different conditions apply. The action of wind over the whole surface of the façade exposes the buildings to different mechanical loads such as vibrations and resonance processes which can lead to cell breakage and damage of the cell connections. Higher level of humidity due to poor ventilation and high temperatures can be reached in building integrated products, thus, causing an alteration of the viscoelastic characteristics of the polymers. The behaviour of the product under these special conditions has to be analysed in the laboratory in order to guarantee the quality and lifetime of the module.

Another point of conflict is the fire safety requirements for building products. The minimum required in Germany is Class B2 (Class E as for European Standards) for buildings up to 7m. But for higher or special buildings the requirements are set in Class B1 or A2 (C and A2). Due to the higher heat of combustion value of the PV composite films and laminated glass a Class A2 cannot be achieved

[9]. Therefore, further development of BIPV Standards and test procedures is expected in the coming years in order to be able to expand the BIPV market.

4. First calculations - Costs

First calculations regarding the cost effectiveness of the solution have been performed. This analysis is done for the different insulating materials and the different types of heating energy consumed. The thickness of the insulation plate is calculated for the EnEV 2009 Standards. In order to estimate the costs and benefits, the energy savings are translated into costs depending on the heating energy used, with an estimation of the market price increase.

Table 2: Assumptions taken for the economic calculations

PV Production			Investment		
PV-Poly c-Si (15%)	150	Wp/m^2	Installed PV-Roof	1.751	€/Wp
Germany	1000	kWh/kWp.a	Insulation	Material dependent	
Façade E/W	50%		Trapezoidal plate	10	€/m^2
Façade S	70%		Module Assembly	5%	
Mean value	57%		FIT		
Façade system	85	Wp/m^2	From 01-01-2013	14.4	c€/kWh
Energy produced	85	kWh/m^2.a	Reduction	2.5%	pro year

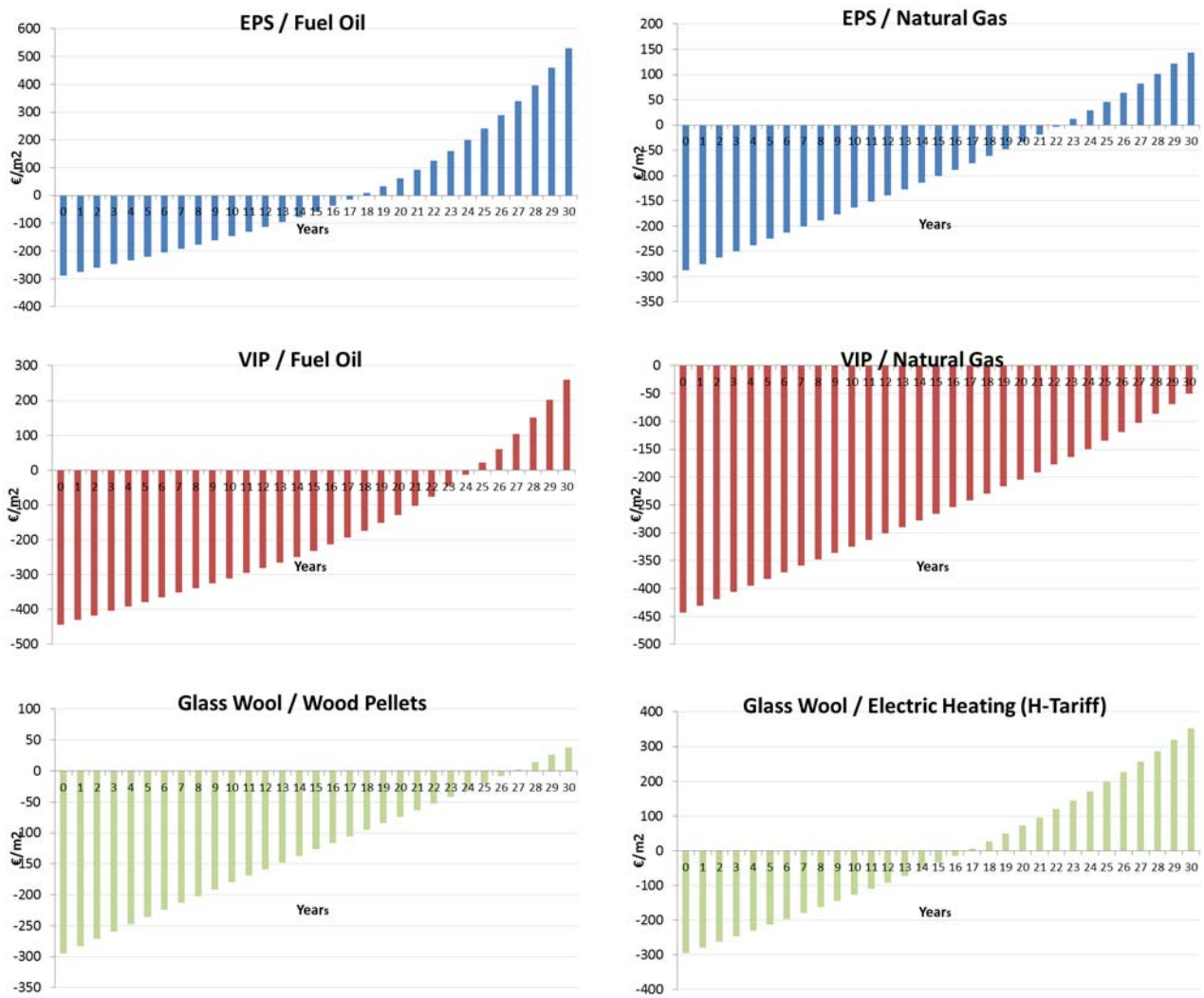


Fig. 7: Cash Flow comparison of different insulation materials and type of energy fuel used for heating of the buildings

Table 2 shows the assumptions done for the economic calculations. All estimations are done taking as a base a crystalline silicon PV module, and assuming that east, west and south facades will be used. Thus, a mean value of 57% is obtained for the whole façade system electric yield.

A deeper study should include more detailed information on costs increase per year, and maintenance cost of these installations which are expected to make the product more profitable. As a first overlook there are the graphs for selected materials and energy supply systems shown in Fig. 7. There can be seen how for standard installations where fuel oil or natural gas are used as fuel, the profitability for a common insulation system such as EPS can be high. Benefits are obtained after the 17th year when using fuel oil, or after the 22nd year when using natural gas.

All calculations are done assuming a minimum lifetime of the product of 30 years. On the other side, it is pointed out how high quality materials such as VIP would not be profitable in the case of use of natural gas due to the higher costs of the insulating material. The use of these kinds of materials could be profitable for households where the costs of the useful area per m^2 are higher and this would play an important role in the economic calculations.

5. Conclusions

The development of a standard product as well as the added thermal characteristics is expected to contribute to scale up the BIPV market. This is also supported by the increased demand on energy savings for buildings established by the EU- Directive on Energy Performance of Buildings (EPBD).

The standardization of products and regulations regarding BIPV plays an important role when trying to widen the market. Several problems have been pointed out in this paper, such as the absence of standard test for mechanical loads, or the impossibility to achieve the required Fire Class for some products. It is important to further invest in the research and development of these technologies due to their large potential.

Lifetime and feasibility of the products are another main factor, because of their expected longer lifetime. They require a big initial investment being profitable only in the long term. Therefore, analysis and tests that guarantee the operability of the systems are still needed.

6. References

[1] *“World´s solar photovoltaic capacity passes 100-gigawatt landmark after strong year”*, EPIA Press Release, Brussels, 11 February 2013.

[2] FRAILE. D. *“Building Integrated Photovoltaics: Closing the gap between the construction and PV sector”.* EPIA, DOI: http://www.internationalsustainableenergy.com; 11 May 2010.

[3] *“Potential of Building-Integrated PV 2010. Beyond Power Production”*, EuPD Research, 2010.

[4] *“Bauen und Wohnen: Baugenehmigungen / Baufertigstellungen von Nichtwohngebäuden (Neubau) Lange Reihen z.T. ab 1980“.* Statistisches Bundesamt, 2011

[5] *“Typologie und Bestand beheizter Nichtwohngebäude in Deutschland“*, BMVBS-Online-Publikation, Nr. 16/2011, August 2011.

[6] OSCHATZ B, ROSENKRANZ J, MAILACH B, GRITZKI R, KAISER J, PERSCHK A, RÖSLER M, SEIFERT J, OTTO F. *“Gesamtanalyse Energieeffizienz von Hallengebäuden”*. Fraunhofer IRB, ITG Institut für Technische Gebäudeausrüstung Dresden, Universität Kassel, Dresden, 30 June 2011.

[7] REXROTH. S. *“Energieoptimierte Stahlelementfassaden mit Photovoltaik”*. Hochschule für Technik und Wirtschaft Berlin, 5. Anwenderforum Bauwerkintegrierte Photovoltaik, Bad Staffelstein, March 2013.

[8] SCHMIDT. K-W. *“Studienarbeit „Markt und Technologieübersicht BIPV Produkte“ im Rahmen des 10 wöchigen Pflichtpraktikums der RuhrUniversität Bochum, im Studiengang Umwelttechnik und Ressourcenmanagement“*. Fraunhofer ISE, 2012

[9] ROOS. M, MISARA. S, HENZE. N. *“Untersuchungen zur Baustoffklasse von PV-Bauelementen für den Einsatz in höheren Gebäudeklassen”*. Fraunhofer IWES, 5. Anwenderforum Bauwerkintegrierte Photovoltaik, Bad Staffelstein, March 2013.

Prefabricated Retrofit Facade System – a Systemized Building Construction Detailing



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Short Summary

In comparison to a demolition of existing buildings with severe technical deficits, usually the retrofitting of buildings is more effective in order to prepare them for low energy consumption and new necessities as communication and media connection or HVAC-installation (Heat, Ventilation and Air-Conditioning). Prefabricated retrofit solutions are developed throughout Europe to enable higher levels of industrialization in building envelope modernization and hence additionally improvements in energy efficiency. Five years of experience and a reasonable number of demonstrations done with timber-based element system (TES) facades show tendencies for best-practice building construction.
This paper focuses on the jointing between single façade elements and the connection of those elements to the existing building. Being a crucial construction detail within the TES-facade, the joint area shall meet various requirements and challenges, from load bearing over hygro-thermal to fire safety functionality. The results of in-depth construction detailing lay out the requirements and principles of the TES joint.

Keywords: Energy efficiency, refurbishment, façade construction, timber construction, prefabrication, fire safety, building envelope.

1. Introduction

Prefabrication – a well-known concept in new timber construction – still needs the implementation of proper detailing considering the different circumstances and assembly methods in refurbishment in order to apply it for retrofit projects. TES EnergyFacade and the follow-up smartTES, two international research consortia, work on this idea since 2008 [1]. Since then the TES facade elements for energy efficient retrofit of the building envelope with prefabricated timber based elements are demonstrated in several projects. A first milestone was the definition of an integrated work process starting from planning, digital survey, prefabrication and assembly [2]. A key feature was the development of horizontal and vertical joints of façade elements for certain assembly routines and structural properties. Further findings are dealing with fire safety, ecologic properties, thermal and moisture behaviour in specific climate conditions. This article shows the development of principles of detailing timber framework in refurbishment; analogy to existing systematics in timber construction, the requirements, and generic solutions.

2. Retrofit with prefabricated façades

Modern, prefabricated timber frame construction is highly developed as a building system for new construction. There is also no limit for small series or so-called pilot prefabrication [3][2]. Because

of the flexibility in the production planning and manufacturing, custom timber framed components can be produced without overhead [4]. This fact makes timber framed façade elements very interesting for the refurbishment of existing buildings, because individual elements are required for almost each building and project. Numerous pilot projects and demonstrators in the context of research projects have shown that the transferability of the principles of the timber framed building on a conceptual level is possible and useful [5][6][7]. But at the detail level numerous new developments and adjustments are necessary to meet the requirements of a reliable and economically feasible design.
The accurate measurement of the façade is a prerequisite for precise prefabrication and mounting Geometry data have to be combined with a thorough survey of the existing façade construction, assessing materials, detailing, load bearing capacity and if necessary building services und further in depth information from the existing substance [2].

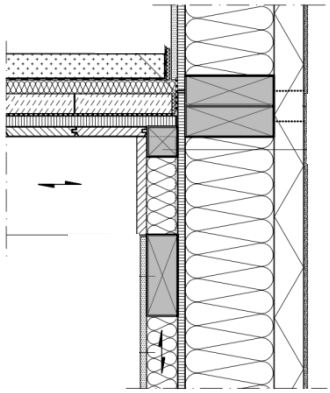


Figure 1: Vertical section of typical semi-balloon frame construction [9].

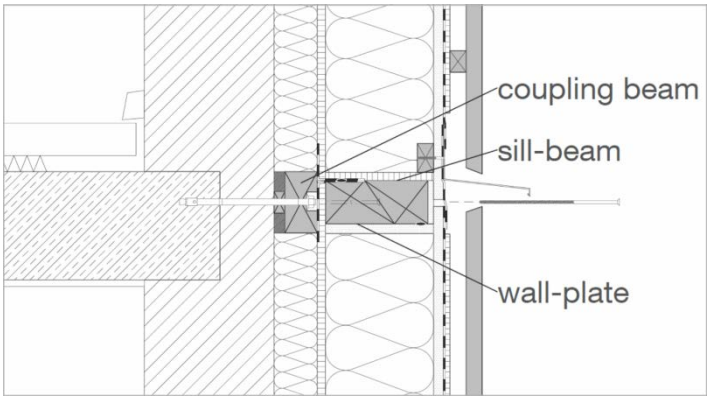


Figure 2: TES horizontal joint Vertical

3. Timber framed construction in refurbishment

3.1 Systematics of new-built timber framework and analogy

The three principles of timber frame construction are the platform frame construction, balloon frame, and the semi or virtual balloon-frame [8].
The virtual balloon-frame construction is the most suitable type as an analogy for a TES EnergyFacade element. The elements have storey-high size and are horizontally oriented; they can be produced in original upright position, put on the truck and handled on site the same way without changing orientation. All elements are stacked on top of each other and the dominant joint is the horizontal one. This has the advantage of a continuous façade layer or building skin, without interruptions and unbroken functional layers for air tightness, insulation or fire safety. In analogy to the ceiling support edge beam a so called coupling beam is introduced as a connection between the existing ceiling and the timber-framed wall. The coupling beam is adjusted exactly in height and depth. It has the additional advantage to assist horizontal alignment of TES elements. In contrast to new building in virtual retrofitting balloon-frame, no vertical forces are transferred to the coupling beam. The vertical loads are transferred only through the timber framed wall. The horizontal loads have to be induced into the existing ceiling plate. Hygrothermal exposure and wood protection of such a detailing solution can be solved in analogy to new building. The fire safety must be examined in depth because facades have a certain risk in the spread of fire and fire safety has always observed in relation with the boundary conditions of the existing building.

3.2 Definition of requirements

The number of parameters affecting the TES element and its details is large. Most influential are apart from structural issues, planning building physics of timber construction, correct production of multilayered elements and assembly on existing exterior walls. The main parameters about strengths and fixtures are derived from the load-bearing structure of the elements. As a result, they

are at the same time in conjunction with the materiality, manufacture, structural arrangement, aka. tectonics, and the assembly process. The other group of influences originates from building physics. They affect TES elements on the main inner and outer protection functions and therefore define the requirements for layering and details. In addition to the production, they are in interaction to the assembly, economy, ecology and technical building equipment and must be linked to the static requirements. These interactions take place not only within the TES system, but and above all, they are in interaction with the existing building. Some protective functions of the existing exterior wall are partially replaced by the TES, such as the thermal protection; they are fulfilled primarily by the TES envelope.

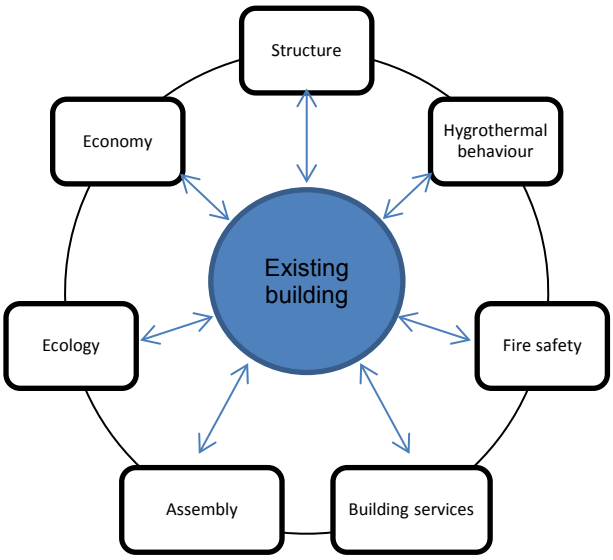


Figure 3: Parameters of a TES façade system.

3.3 Limitations of the analogy

The development of the retrofit construction system starts from the main structural influences and the appropriate way of tectonics of parts. The focus is on the area of the horizontal element joint. It is the connection of the existing exterior walls with the existing ceiling. The horizontal joint is the most relevant detail to solve from the technical and economic perspective, because it is the most frequent joint of a virtual balloon-frame. A 1950ies multi-story house with 8 apartments on four floors has a total length of basement and roof eaves joint line between circa 80 and 130 m. All other horizontal joints between the floors have a total length of approximately 240 and 390 m. The complete vertical joint length is around 65 to 75 m. It matches a ratio between vertical and horizontal joints from 1:5 to 1:7. The high deviation in this ratio clearly shows how important detailing of the horizontal joint has to be done. It influences assembly effort and costs to a large extent. The technical requirements and the effort in this area of the element have to be adjusted very carefully to avoid high costs or unforeseeable risk. The developed solutions have to be in line with the condition of efficiency. A robust solution of butt jointing two elements will reduce the risk of the construction system for failures. The detailed analysis of the construction principles on the applicability and specialties of the construction process with large-format element in refurbishment results in clear advantages for the balloon-frame principle. The requirements of the continuity of the insulation layer and the uninterrupted surface with defined axis of fixing, as alignment, and mounting aid for the façade elements are established as significant characteristics.
A further invention is the adaption layer between the uneven surface of the existing exterior wall and the plane back side of the TES element. The gap should be at least fifty millimetres wide for further filling with blown-in insulation material, preferably cellulose fibre. The process of blowing thermal insulation material in the gap has the advantage of adapting the thickness, where it is needed. Around penetrations of the exterior wall and the elements like windows, the gap should be stuffed with non-combustible mineral wool.

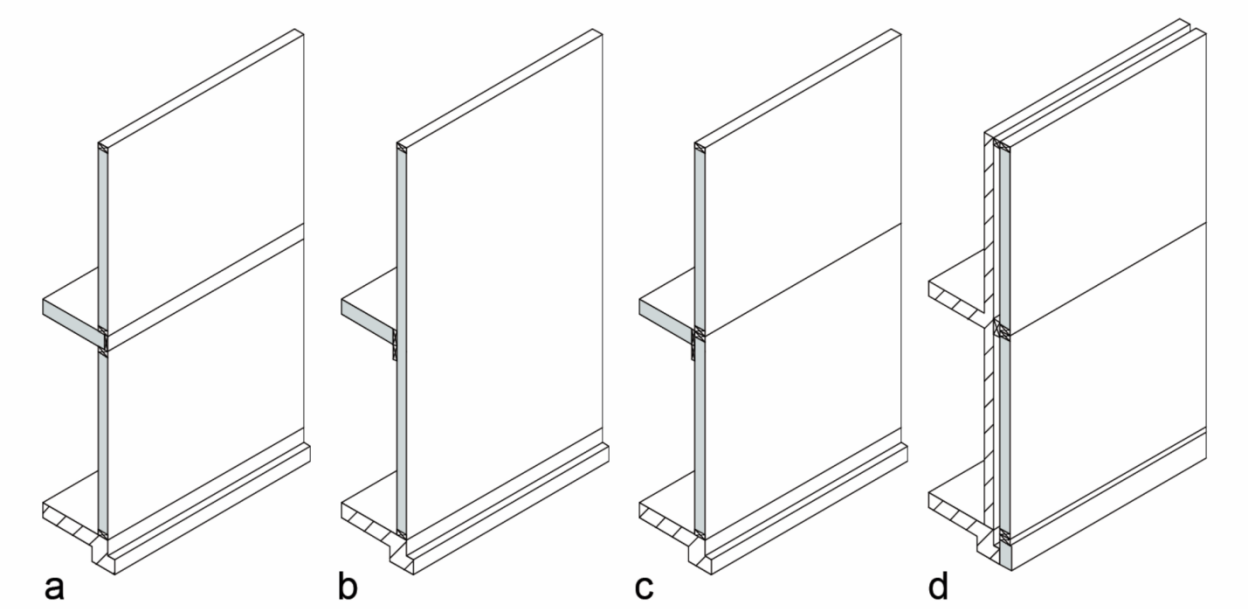


Figure 4: Development of platform frame, (a) balloon-, and semi balloon-frame (b-c) to TES (d) in analogy to (c).

4. Results in timber framework for refurbishment

4.1 Development of the horizontal construction joint

4.1.1 Principles of timber framing for refurbishment existing buildings

As in classic timber frame construction the solid wood studs are positioned in a span of 625 mm and butt-jointed perpendicular to sill-beam and wall-plate. On the element inside an OSB is applied and on the outside a gypsum fiber board. The cavities are filled with thermal insulation, e.g. cellulose fiber. Usually a timber-frame element measures about 12,0 x 3,2 m², limited by production facilities and transportation. [5]



Figure 5: Mounting a TES-Element [gumpp&maier]

While the TES-facade is built with a tolerance of +/-2 mm, the existing exterior wall deviates +/-40 mm in depth. This unevenness is leveled by the coupling beam, which is anchored into the existing wall and runs around the entire building horizontally on each floor level. Thus, while mounting, it's possible to align the façade elements to the coupling beam and fix it with self-drilling timber screws. The assembly of the elements happens horizontally row by row. The design of the element joint was inspired by the simple joining method of a tongue-and-groove connection and enhances the common butt-joint known from classic timber-frame constructions. The tongue consists of the upper element's sill-beam. The groove consists of wall-plate and the overlapping gypsum fiber

board of the lower element. That way the upper element is fitting precisely into the lower element, without any larger alignment work necessary and still guaranteeing a force-fitting connection. [5] The vertical connection is a butt-joint of two members without any further connection.

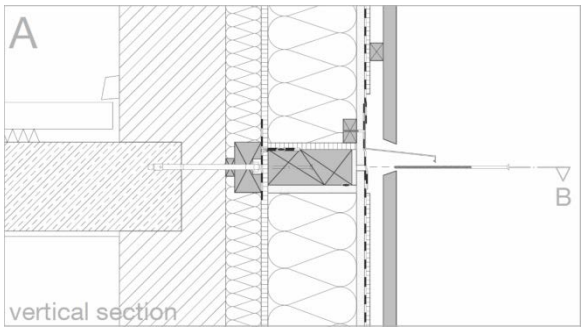


Figure 6: TES horizontal joint Vertical

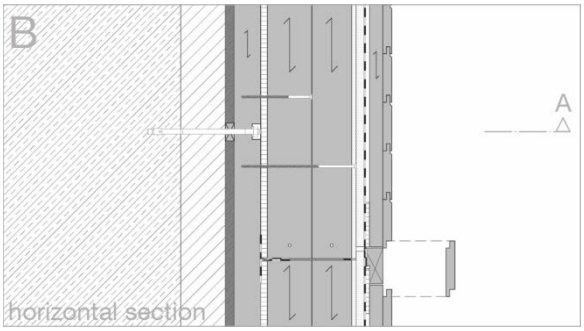


Figure 7: TES horizontal joint Horizontal

All facade components such as the window generally are integrated in the TES element, see Figure 7. This has the advantage of better manufacturing control and simplified construction site operations. The new window can be installed in different configurations as a replacement for the existing one. It can be integrated only as a supplementary window in the TES, which enhances the existing window and improves its thermal and acoustic properties. This solution is an important option for upgrading existing components of good quality, speeds up the construction process significantly and reduces disturbances of the residents.

The variety of applicable cladding materials is analog to new timber-frame buildings; however, retrofitting a larger multi-storey building, the options are strongly limited by fire safety requirements. In this paper the construction is given with a rear ventilated wooden façade.

4.1.2 Structural joint

Essentially there are two main loads (actions) on the TES-façade that have to be taken in to account constructing the loadbearing system: Self-weight and wind-load.
The self-weight of the given construction is with about 80 kg/m² (varying by thickness, thermal insulation material and cladding) comparably high. This is due to the extended timber loadbearing structure, the necessary fire safety boards, and a dense cellulose fibre thermal insulation. The vertical force caused by self-weight conducts all the way through the timber frame into a foundation system at the foot of the façade. As the vertical force accumulates over the building height, the horizontal joint between the elements is built as full form fit contact connector. (Fig. 8 No. 1)

The horizontal forces from the wind-load are induced shortest way into the next ceiling. To prevent unnecessary eccentricities the element joint is placed exactly at the height of the ceiling. So the element fixation with self-drilling screws should be horizontally in line with the ceiling anchorage. To connect both elements with the coupling beam, sill-beam of the top element and the wall-plate of the bottom element need to be on same height. This requirement is fulfilled by the tongue-and-groove connection. (Fig. 8 No. 2)

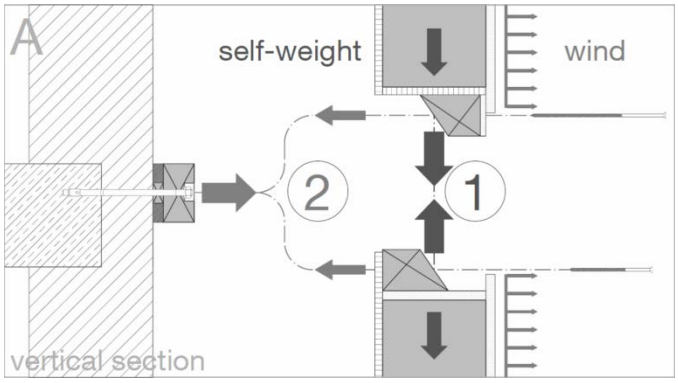


Figure 8: Force conduction

Another advantage of organising the connections in one spot is, in regard to high level prefabrication, a minimal necessary intervention from outside, which reduces onsite finish work on the cladding and thereby keeps the visual surface intact.

4.1.3 Hygrothermal behaviour of TES elements

The requirements, measures and design principles for moisture behaviour and safety of timber framed walls consist of three basic principles:

- No thermal bridges
- No convection
- Moisture management

The avoidance of thermal bridges is the first principle in detail development as no high heat-conductive material from the hot to the cold side goes through so that conduction of heat is minimised. Thus, the impact of material-related thermal bridges can be largely reduced by the use of wood or wood-based materials in the joint area. Geometry-related thermal bridges are not available on that part of the element; they are slightly more relevant at corners. They can be solved when the principle of an external insulation layer and sufficient layer thickness are taken into consideration. A flexible variation of the insulation layer thickness can be achieved by the adaptation of the depth of studs.

Moisture management also has to deal with diffusion safety of the TES layer. The back panelling of the element has to be vapour retardant. Diffusion open (to the outside) regular cross section of the element with a low s_d < 0,5m on the outside of the element and an s_d at least six times higher on the inside of the element is recommended.
Air and wind tightness of timber framed elements are one of the most important measures to stop convection of warm and moist air to the cold side of wooden parts. There are basic rules like the reduction of joints, airtight back panelling and sealing of clamped joints. Further all element joints have to be sealed with elastic rubber sealants. A proper airtight construction also improves fire safety and sound protection by overcoming leakages.
Airtightness is even more important than good diffusion properties, because through joints there is a higher risk for leakages. The horizontal and vertical TES joints have to be sealed for airtightness reasons to ensure the moisture performance and avoid heat conductivity through wet wood or insulation materials in the joint area.

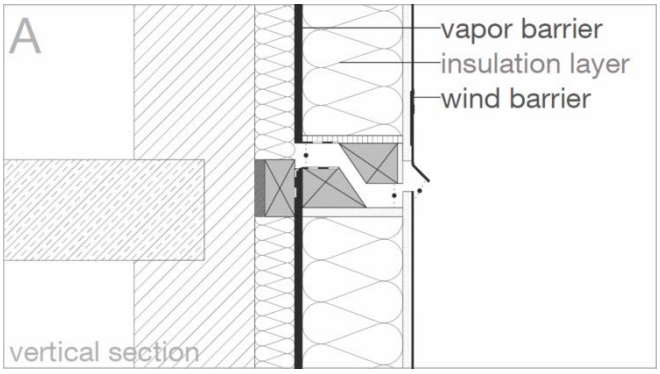


Figure 9: Hygrothermal Detail

Special attention is needed for window assembly. Penetrations offer a path for additional moisture intake into timber framework. Moisture protection from flanking/penetrating materials with high capillarity like brick wall could be a problem. An airtight closure of these penetrations is necessary. Window penetration in existing walls and TES elements requires the connection of window frame to airtight layer of the TES. Furthermore the airtightness of the gap has to be ensured especially for fire safety reasons. A closure with an airtight and fire proof box frame and sealing of the butt-joint between box frame and window frame is necessary. A window position in the existing wall is not allowed according the rules of thermal protection.
Wind tightness is provided by a wind barrier as an outer panelling or membrane of the closed TES element. The wind barrier has to be sealed at connection by tapes or clamped joints.
Besides construction material has to be dry, and elements are protected during construction by closed cavities and heavy weathering to minimize moisture intake. Diffusion open layering supports the drying capacity of elements. Hollow spaces between TES and existing walls have to be avoided and reduce the risk of uncontrolled convection. An appropriate measure is the filling of cavities with soft and dense insulation material during the assembly process. There is a good experience with blown-in cellulose fibre that has a sorption quality that can buffer the moisture from the existing exterior walls and reduces the moisture load on the wooden parts of TES.

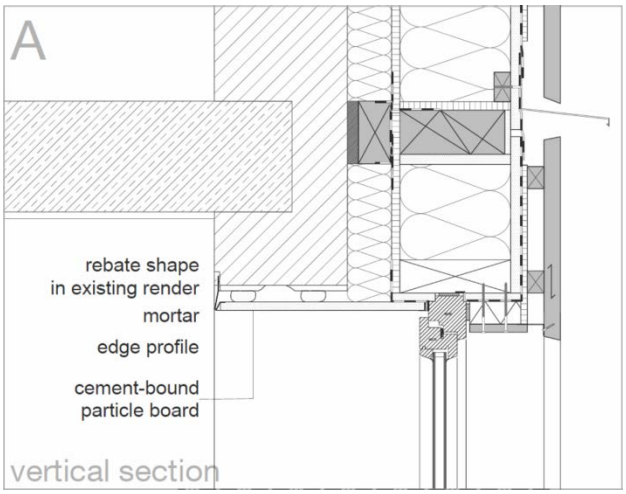


Figure 10: Detail Window

The existing wall and the window connection is very often permeable, warm and moist air is leaky into the gap, the coupling beam sits behind the insulation on the warm side and will not be damaged. See here the interrelation to other topics of building physics: hot pyrolysis gas, smoke, odors and airborne sound use same leaky paths. They will be stopped at TES element back side and at the coupling beam functioning as interruption at each floor. The window joint does not have to be fully closed, due to the second safety line described above.

The joints at the base and roof eaves as well as vertical edges are taped and sealed air-tight, what is non-trivial, since the ground from existing plaster or masonry will not show the best conditions. The elements and element joints are made air-tight with sealing stripes positioned between the elements and all paneling joints, thereby it is important that the inner sealing stripe is connected air-tightly with the OSB by sealing tape, see figure 9. This means, no warm and moist air can penetrate into the insulated compartments and reach the low-temperature side. There is no risk of condensation and moisture intake into the wood.

4.1.4 Wood protection and durability

The built-in wood and wood-based materials are sufficiently protected through compliance with the previously mentioned hygrothermal requirements and moisture management in closed timber frame components. Thus the TES elements fulfill the requirements of use class 0 [11].

4.1.5 Fire safety

Normally, the existing structure already fulfills the fire safety objectives. However the condition of the existing building has to be verified by a fire safety survey. [1] The TES-façade layer has to fulfill the requirements of the relevant building classes. In building classes 4 / 5, in which most of the potential TES-retrofitting objects are classified, or building ≥ 3 storeys, non-loadbearing exterior walls have to be at least fire-retardant (Fig. 11 No. 1) and difficult combustible cladding and insulation material of at least class C- or B-s2,d0 is required. Timber or other combustible façade materials are possible but need special construction and additional approval. Where combustible material and ventilated gaps are used the cladding must have a storey wise separation either by suitable fire stops or with a floor wise horizontal separating construction. (Fig. 11 No. 2) [1][13][14] The component requirements for the ceiling have to be taken in account especially if the existing wall is removed or quite thin. The spread of fire and smoke into the next storey in detour over the TES-façade has to be prevented. If the existing wall is removed, by definition, the TES-joint becomes part of the existing ceiling. (Fig. 11 No. 3)

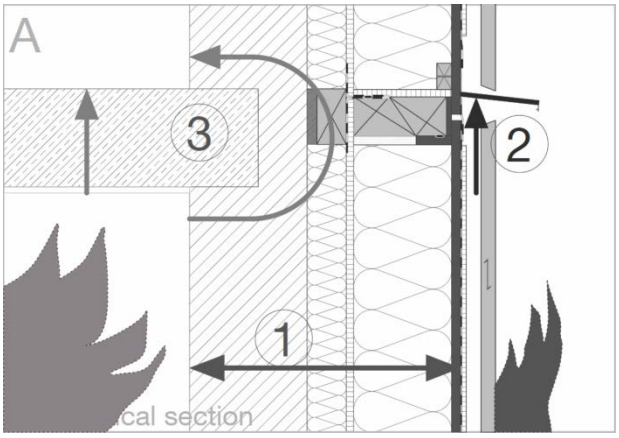


Figure 11: Fire safety detail

At the element joint closing the gypsum board layer is solved by backing the board with an additional stripe of gypsum fiber board and horizontally with another gypsum fiber board below the wall-plate.
(The fire barrier metal sheet is disposed slightly above the joint area in order not to obstruct the screwing of the sill-beam to the horizontal coupling beam.)

4.1.6 Mounting

An important difference to new building is the accessibility of the elements while mounting, because one side is blocked by the existing wall. The higher the prefabrication level the less work needs to be done on site. But, connection points will be harder to access this way. Especially if a visible cladding has been prefabricated, necessary works shall not leave any signs of destruction.

Pilot projects have shown that by sloping the cut between upper sill-beam and lower wall-plate and building a tough-and-groove connection the mounting of the elements is simplified a lot.
The screwing of the elements to the coupling beam offers a simple and uncomplicated solution.
(Before the prefabricated TES-Elements are mounted to the building, it's necessary to set the foot foundation, remove existing windows and building up surrounding scaffolding, if no elevating platform is used.)

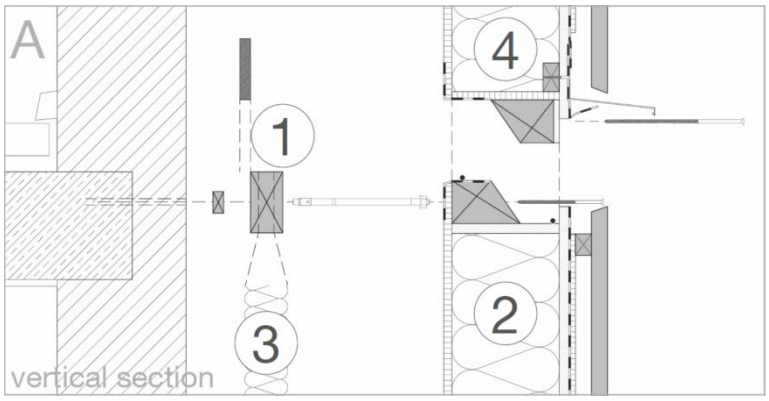


Figure 12: Mounting process

The mounting process is divided in four steps (Fig. 12):
(1) Fixing the coupling beam to the wall: For a fast mounting process and a clean plane stop for the elements the coupling beam is positioned by using a laser-assisted positioning system. The position points were taken during site measuring in the survey phase. With the help of computer-aided design a leveled plane is calculated onto the uneven surface of the existing building. The gap between existing wall and coupling beam is filled with swelling mortar.
(2) Placing the lower element, butting the wall-plate against the coupling beam, and fixing the connection with screws.
(3) Filling the adaption layer by blowing cellulose fiber through an opening in the coupling beam. (After the window reveal was made in a combination of out-run gypsum fiber board, foil and filler from the inside out)
(4) Placing the upper element into the lower element, screwing the sill-beam to the coupling beam, and closing the wind-barrier.

4.2 Principles of timber framed jointing in retrofit

For the structural connection of the TES-Façade to an existing building, the construction of the existing ceiling needs to be examined closely regarding stability and positioning. The pull-out strength of anchoring in to the floor slab needs to be determined. In some cases parts of the masonry work pass in front of the ceiling, this has an influence on the anchorage length. The self-weight of the façade needs be carried by the existing foundation. For the foundation system of the TES-Façade various solutions are available and should be chosen according to the existing laod-bearing capabilities.

The moisture management has to be dealt with like in new building. The claims for hygrothermal protection are airtightness of timber framed elements back-panelling and horizontal air stops in the vertical gap zone at each storey. The airtight sealing of the window remains a critical point. Convection and airborne sound might find also horizontal ways to neighbouring units through leakages around the box frame. Then this construction detailing can be improved from the inside after there are faults during assembly.

By adding the TES-Façade as wall part not only the fire safety of the wall as such has to be taken into account, but also the fire and smoke spread though gaps between new TES-Façade and existing structure.

5. Conclusion

Generally spoken the interface of the existing building envelope and the new timber-framed wrap around has to be planned very carefully. The building survey has to examine all types of exterior walls and junctions of existing ceilings with exterior walls. These are evident for structural jointing and critical routes for air, moisture, sound and fire propagation. In the early planning process it is prerequisite for risk mitigation. Timber framed elements for façade retrofit have no high risks as shown in the proposed robust solutions.

5.1 Outlook

The other principle details are examined in the further course of the project and published shortly in a final project report. Moreover, other variants to the positioning and improvement of the airtight layers and their connections in combination with sorptive insulation layers are tested. Another interesting issue is the capability of TES elements to provide the building envelope multifunctional properties with the integration of building service systems or dynamic energy saving concepts.
The timber-frame-system enables a self-bearing façade. Additionally loadbearing components like balconies, spatial extensions, or roof-top extensions can be built and integrated in the same system. Also HVAC-Systems can be included into TES. Research to potential topology and detailing is ongoing.

6. Acknowledgements

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7. References

[1] TES ENERGYFACADE: *TES EnergyFaçade –prefabricated timber based building system for improving the energy efficiency of the building envelope*. http://www.tesenergyfacade.com. Period from 01/2008 to 12/2009, funded by BMBF, represented by PTJ.
[2] LARSEN K E, LATTKE F, OTT S, WINTER S: *Surveying and digital workflow in energy performance retrofit projects using prefabricated elements*. in: Automation in Construction. DOI: 10.1016/j.autcon.2011.04.001. vol . 20(8). pp 999-1011. 2011.
[3] DAVIDSON C H: *The challenge of organizational design for manufactured construction. Construction Innovation*. Information, Process, Management. DOI: 10.1108/14714170910931534209. 2009. vol 9 (1), pp 42-57.
[4] JENSEN P, OLOFSSON T, JOHNSSON H: Configuration through the parameterization of building components [online]. *Automation in Construction,* DOI: 10.1016/j.autcon.2011.11.016. 2012. vol 23. pp 1-8.
[5] OTT S, LOEBUS S, WINTER S.: *Vorgefertigte Holzfassadenelemente in der energetischen Modernisierung*. in: Bautechnik, DOI: 10.1002/ bate.201330024. 2013. vol 90 (1), pp 26-33.
[6] LATTKE F, OTT S, WINTER S: *TES EnergyFaçade - Innovative vorgefertigte Fassadenelemente aus Holz*. in: Holzbau (dnq). vol 3, 2011.
[7] LATTKE F, OTT S, WINTER S: *TES EnergyFacade – Vorfertigung bei der energetischen Sanierung*. in: Bautechnik – Innovative Fassadentechnik. vol 88(9). Ernst & Sohn Verlag. Berlin.
[8] KOLB J: *Holzbau mit System – Tragkonstruktion und Schichtaufbau der Bauteile*. Birkhäuser, Basel, 2007.
[9] HUBWEBER et al.: *Holzrahmenbau. Holzbau Handbuch*. Holzabsatzfonds (ed.). Informationsdienst Holz. Reihe 1, T. 1, Folge 1. ISSN 0466-2114. Bonn. 2008.
[10] DIN 68800-1:2011-10 *Wood Preservation. Part 1: General*. Beuth Verlag. Berlin. 2011.
[11] EN 335:2006-10: Durability of wood and wood-based products – Definition of use classes. Beuth Verlag. Berlin. 2006.
[12] E2REBUILD: *Industrialised energy efficient retrofitting of residential buildings in cold*

climates, http://www.e2rebuild.eu. Period from 01/2011 to 06/2014, funded by the EU within the Seventh Framework Program (FP7).
[13] HTO Research Report HTO TP2 (High-Tech-Offensive Bavaria, Subproject 2), *Brandsicherheit im mehrgeschossigem Holzbau*, TU München 2009.
[14] HTO Research Report HTO TP 11 (High-Tech-Offensive Bavaria, Subproject 11), *Mechanismen der Brandweiterleitung bei Gebäuden in Holzbauweise*, TU München 2009.

Assessment of Double Skin Façade Technologies for Office Refurbishments in the United Kingdom

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Short Summary

There is a growing tendency towards use of Double-Skin Façades (DSFs) for office buildings in Europe. The potentialities this technology has range from acting as thermal buffer to innovative application of natural ventilation. It is still a developing research field identifying what are the most determinant architectural parameters for optimal uses of DSF. This research focuses on applying DSFs to refurbishment of buildings, which has a bigger market than new builds. Knowledge on how to select suitable DSF systems for refurbishments is scarce due to the additional constraints of existing buildings thus narrowing the number of options.

This paper reports the initial findings of the first stage of a comprehensive research, with the aim to establish an assessment methodology and a tool to identify suitable DSF systems for the refurbishment of office buildings in the UK. The assessment methodology proposed here allows to determine a group of suitable DSF technologies for each of the UK office types identified. The tool has been tested with real refurbishments case studies, which showed coherent and consistent results.

Keywords: Double Skin Façade; Office Buildings; Refurbishment

1. Introduction

The major challenge for the UK government to meet the greenhouse gases (GHG) target is to reduce the emissions related to the energy consumption of existing buildings. More than 75% of non-domestic buildings in the UK were built before 1985 and about 60% of them will still exist in 2050 [1]. Because of the lifespan of elements and components, many of these buildings will need refurbishment. This is arguably a more sustainable option compared to full reconstruction or rebuild.

A building façade represents the physical barrier between the indoor and outdoor environments and its improvement has been shown to be one of the most effective ways to enhance the indoor environmental quality and to reduce energy consumption [2]. Most refurbishments involve the replacement of the existing façade with high performance windows and walls. However, there is a growing number of applications of an additional glazed façade to the existing one - what forms a Double Skin Façade (DSF). DSFs are mainly used as a means of improving a building's environmental performance, however, the influencing parameters are many and information on their design is scarce.

This paper reports on the findings of the first stage of a comprehensive research, with the aim to establish an assessment methodology and a tool to identify suitable DSF systems for the refurbishment of office buildings in the UK. Extensive literature review has been carried out to derive the key categories of office buildings in the UK of different age and their suitability to use

DSF. Basic principles of double skin façade technologies together with their performances in temperate climate have been investigated. The assessment methodology and the related tool are proposed and applied to identify suitable DSF systems for UK offices. The paper concludes with key findings and recommendations for future work.

2. UK office building stock

To assess the potential that Double Skin Façades have in improving the performances of existing buildings it is crucial to understand the current state of the UK office building stock. On new constructions it has been demonstrated that DSFs perform better than single skin façades and, although more expensive in capital cost, they are more cost-effective in the long term [2]. When the focus switches to the existing stock, the use of DSF has to take into consideration the buildings' constraints. Therefore, a critical analysis of existing office stock is necessary to project the potential and their suitability for DSFs.

2.1 The current state

Building energy use in the UK accounts for nearly half of the total national energy consumption and carbon dioxide emissions [3]. In cities like London, this figure raises up to 61%, which is substantially higher than the average in the EU (41%) and the US (36%) [4]. Non-domestic buildings tend to have greater energy consumption per m^2 of floor area compared to dwellings and, within them, offices have the highest energy consumptions as they account for over half of the total consumption in the non-domestic sector [5]. From the carbon dioxide (CO_2) emissions point of view, office buildings account for more than 20% of total UK emissions and technically there is the potential of cutting their carbon emissions up to 80% by implementing solutions which are already available today [1]. Only focusing on low and zero carbon new buildings will not solve the emission problem because whilst 1% of the building stock is built each year, 99% is already out there [6].

The higher figures in energy consumption - when compared to other countries – are due to the fairly old building stock in the UK. Around 80% of the office floor spaces, in all regions of the UK, were built before 1990 [7] with U-values double, if not triple, than current practice. Therefore, due to their age, their poor thermal performance and the different lifespans of elements and components (i.e. the load bearing structure and the façade) most of those buildings will be refurbished in the coming years. Additionally, future regulatory and occupier requirements will increase the pace for existing offices to be refurbished.

Refurbishments of existing buildings also offer advantages over new buildings in achieving environmental and economic sustainability [8]. Hence, to meet the GHG target of 80% reduction by 2050, energy-efficient refurbishments of office buildings deserve to be prioritised in research and development.

2.2 Office types

Office building forms have evolved over time and, within its historical infrastructure and culture, the UK presents a highly varied and complex scenario. A CIBSE [9] review on the energy use in offices has identified four office types mostly classified by means of the ventilation of the building, the floor area, the external façade and the characteristics of internal spaces, as shown in Table 1.

Table 1: Office types according to CIBSE review

Office	External Facade	Ventilation	Internal Layout	Floor Area
Type 1	Masonry Wall	Natural	Cellular space	From 100 m² to 3000 m²
Type 2	Curtain Wall/Brick and Glass facade	Natural	Open plan	From 500 m² to 4000 m²
Type 3	Fully glazed	Fully A/C	Standard Features	From 2000 m² to 8000 m²
Type 4	Fully glazed	Fully A/C	Prestige Features	From 4000 m² to 20000 m²

Although the CIBSE review mainly looks at energy consumption, the four types above also represent the evolution of the office building concept over the past decades. This study shows how the size of office buildings has increased continuously as well as the need to heavily rely on HVAC systems to balance the fully glazed single skin façade – main cause of overheating in summers and heat loss in winters.

In this study, the buildings to be considered are those belonging to the first three categories as the fourth mainly represents brand new buildings which will not be refurbished any time soon. The third category encompasses recent buildings that mostly are still in the middle of their operational life. Their fully glazed envelopes often represent an impediment to applying DSFs as the complete removal of the existing façade would be necessary. Therefore, type three is not included in the current study as the likelihood of refurbishing a recent building with a major intervention is relatively small.

Another study by Steadman *et al*. [10] focuses on office building forms addressing two main parameters: lighting (i.e. artificially or day-lit) and internal layout (cellular space, halls and open-plan space). Offices are further categorised by considering the building height as a parameter, distinguishing between buildings from 1 to 4 storeys and those with 5 storeys or more. An analysis [11] of their study highlights the different categories and their percentage share as shown in Table 2.

Table 2: Office categories from Steadman et al. (2000)

Categories	Office Description	Share of the stock
Category 1	Cellular offices between 1 and 4-storey high	33.9%
Category 2	Cellular offices with 5-storey or more	5.2%
Category 3	Cellular strips around some open-plan spaces	19.5%
Category 4	Open spaces artificially lit	5.5%
Category 5	Open spaces sidelit up to 4-storey high	0.9%
Category 6	Open spaces sidelit with 5-storey or more	2.0%
	Total	67.0%

From the figures and descriptions provided in this study, the first two categories match the Type 1 described in CIBSE [9] while the last four are very similar to the Type 2. The focus of this study will therefore be based on these more detailed categories – cellular offices and open spaces – and the reason is twofold. Firstly, they represent the vast majority – more than two thirds – of the existing office stock. Secondly, they are also the older among the existing offices, being *de facto* prospective candidates for sustainable refurbishments. Although available office studies date back to more than a decade ago, they are fully representative of the buildings this research aims to cover.

3. Double Skin Façades technologies

One of the first and probably most effective actions which can be taken to reduce energy consumption of a building is to improve on its external envelope, where the internal enclosure of the building comes in contact with its immediate external micro-climate. Although most refurbishments involve the replacement of the existing façade with high performance windows and walls, there are growing examples – especially in European office buildings – of applying an additional glazed façade to the building; which in combination with the main façade forms what is mainly known as Double Skin Façade (DSF).

Double Skin Façade technologies have greatly evolved over time and, nowadays, many options and configurations are possible. It is a growing research field to identify what the key architectural parameters are and to evaluate their influence on DSF performance. When being considered as an option in refurbishment, existing buildings impose their own limitations and impediments which require a methodology for identifying suitable double-skin façades for a specific building. The following sections give a brief review on double-skin technologies; it also outlines the known

performances in temperate climate to illustrate appropriate use can reduce the energy consumption in buildings and helps to achieve the 2050 CO_2 emissions target.

3.1 History and Definition

Although Double Skin Façades are a modern, complex and technological architectural phenomenon, their principles date back in the 19th century when Jean-Baptist Jobard theorised how hot air in winter and cold air in summer should circulate between two glazed surfaces [12]. DSFs started gaining momentum mainly in 1980s with many examples spreading all over Europe. From 1990s, they have experienced a continuous growth and development. Many authors have given definitions of Double Skin Façades. Oesterle et al. [13] describe them as a technology based on a multilayer principle which consists of an external skin, an intermediate space and an inner skin. Gratia and De Herde, looking from a different perspective, describe DSFs as an “architectural phenomenon driven by the aesthetic desire for an all-glass façade” [14].

Brunoro and Rinaldi [15], specifically focussing on refurbishments, defined double-skin façades as hybrid systems, formed by the existing façade of the building and a new glass skin. Other authors provided more technical definitions mentioning or highlighting thermal and ventilations properties, architectural parameters and shading devices to be placed in the cavity. By gathering these scientific contributions a glazed double skin façade referred in this paper can be defined as a heterogeneous system made of an external glass skin and the actual building façade. The two layers are separated by an air cavity which acts as a thermal buffer zone and as a natural/mechanical ventilation channel that may or may not accommodate shading devices.

3.2 Performance overview of Double Skin Façades in temperate climates

The literature on design and performance of double-skin façades in temperate climates are few and far in between. However, these technologies, when carefully designed, seem to have been capable of significantly improving the building performance. The double skin façade acts as a thermal buffer in winter thus decreases the heating loads while in summer allows use of natural ventilation resulting in less need for mechanical air conditioning.

However, it is not as simple as it seems as many parameters contribute together to determine whether a DSF is successful or not. Gratia and De Herde [16] investigated the energy consumption of buildings with DSF and established the influence the cooling strategies and the building insulation levels have. They conclude that, by using natural cooling strategies, the energy reduction ranges from 27% (for non-insulated buildings) to 67% (for those insulated). Cetiner and Ozkan [17] compare performance between single and double skin façades. Their findings show that DSFs are up to 34% more energy efficient than single skin façades. Other studies in northern Italy [15, 18] suggest a yearly energy reduction of 35%-40% when a double skin façade is used. A study in Germany [19] also concludes DSFs can reduce the heating loads by up to 30%. An investigation using the Turkish climate raises the reduction to nearly 50% under optimal conditions [20].

Whilst most researchers agree on the potential of DSFs to reduce heating loads in winters, performance over summer appears to be less agreed upon due to the risk of overheating. The possibility to exploit natural ventilation can result in significant reductions of the runtime of ventilators and air conditioning systems. Natural airflows can also be used for night-time ventilation in hot summer days to pre-cool the building without compromising its security when the second skin is added.

However, there are authors persuaded that overheating will occur without sunscreens. The use of shading devices has been widely investigated. A study on venetian blinds proves that they have a significant influence on the thermal performance of the façade [21]. Another study [22] looks at different aspects of shading devices (location, colour and opening of the DSF) concluding that nearly a 25% decrease in cooling loads can be achieved by using shading devices. A computational fluid dynamic (CFD) investigation [19] about the optimal position of sunscreen devices within the cavity suggests that they should be placed at a maximum distance from the

inner skin but not too close to the outer skin either – if the risk of overheating in summer is to be minimised.

In refurbishments, energy savings and reduction in environmental impacts can be obtained with the addition of a second skin. A case study of energy-efficient office refurbishment in Norway using dynamic computer simulation shows that the optimal configuration enables an energy reduction of 59% [23]. Among other additional benefits, it is possible to find a better protection for the shading devices in the cavity as well as a reduction of the wind pressure effects.

Double Skin Façades have some disadvantages. The main issue is the risk of overheating the air in the cavity during summer. On the operational side there is a risk of condensation in winter time which has to be carefully managed by correct choice of materials and ventilation strategies [23]. Besides, the space needed for the second skin generally reduces the net usable area of the building. From an economic point of view, the investment and maintenance costs are higher than those of single skin façades although the extra amount of money spent is usually justified by the energy savings and the increased productivity of the occupants [24].

4. DSF systems for refurbishments

Existing constraints such as location of the building, its conditions and characteristics, etc. make refurbishments more challenging than new constructions. In case of applying double-skin façades the difficulty is even higher due to the careful design this technology is required to exploit its full potentialities. Additionally, the huge number of possible DSF systems often confuses the making of optimal choice. This section describes the methodological approach proposed to identify suitable DSF systems for the chosen UK office types and its application by means of case studies.

4.1 Existing Classifications

Classifying DSFs is complex due to numerous parameters involved; for instance, the type of ventilation of the façade, its partitioning and the ventilation of the cavity are just to name a few. Oesterle *et al*. [13] provide a classification based on the types of façade construction, as illustrated in Figure 1, which are:

- Box Windows
- Corridor Façades
- Shaft-Box Façades
- Multi-Storey Façades

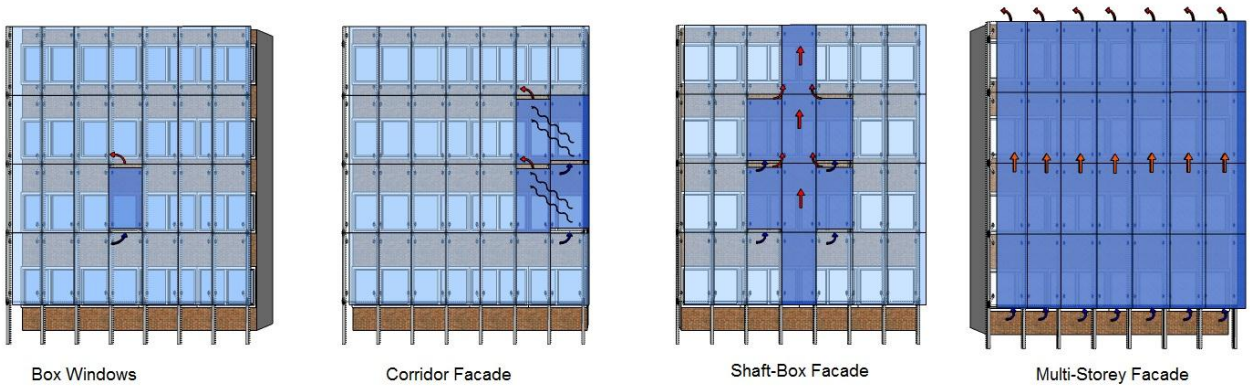


Fig. 1: DSF Construction Types

On top of these 4 types, the Belgian Building Research Institute (BBRI) [25] adds a fifth category, called the Louvers Façade. With this configuration the outer skin is composed of transparent rotating louvers that, when closed, are capable of a relatively fair airtightness. However, when opened, the ventilation is completely different from the types presented above. A well-known

example of this particular category is the Debis Headquarters building by Renzo Piano in Potsdamer Platz, Berlin.

Another classification by Arons [26] distinguishes between Primary and Secondary identifiers. In the first group, one can find Airflow Patterns and Building Height. The former represents the possible ventilation strategies – as shown in Fig. 2 – while the latter refers to the differences between low and mid-to-high-rise buildings.

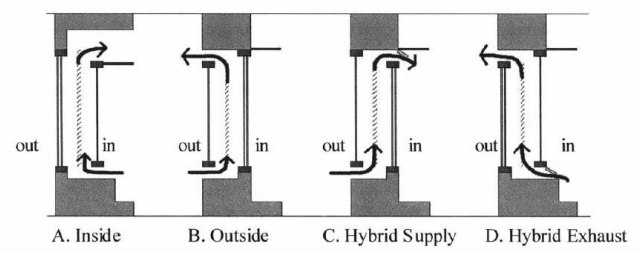


Fig. 2: Airflow Patterns for DSF (Arons, 2000)

Among the Secondary identifiers, Arons indicated more architectural parameters such as depth, width and vertical extent of the cavity, layering composition, materials and operability. Other classifications consider similar aspects and work on a three-tier approach [12, 28]. These are the façade compartmentalisation (construction types), the ventilation of the cavity and the airflow concepts. It is worth noting that the latter also includes the static air buffer behaviour which was overlooked by Arons [26]. Figure 3 shows an outline of the three-tier classification based on Haase *et al.* [27].

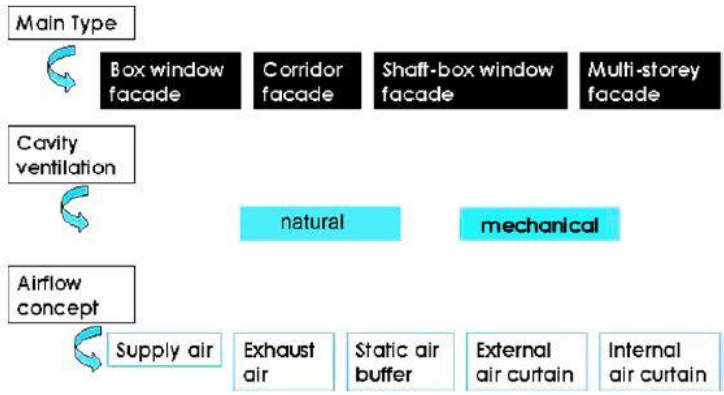


Fig. 3: Classification of Double Skin Façades by Haase et al., 2009 [27].

4.2 Proposed methodology to assess DSF systems in refurbishments

Existing classifications of DSF systems are based on design for new buildings and none of them encompasses all the key features, thus ignoring some of the possible combinations. For example, some do not address the fifth type (the louvers façade), nor do they consider the cavity width and the building height, which are crucial parameters in defining the ventilation of the double skin. Additionally, when it comes to refurbishments, they do not adequately help to identify what possible DSF systems should be used under specific circumstances.

In refurbishments, the existing building characteristics may impose impediments and limitations due to the building's structure and location as well as legal constraints etc. This is the reason why the building characteristics have to be established at the very beginning together with those associated with the double-skin façade. The diagram shown in Figure 4 is a proposed methodology to identify suitable DSF options for specific buildings based on their relevant constraints.

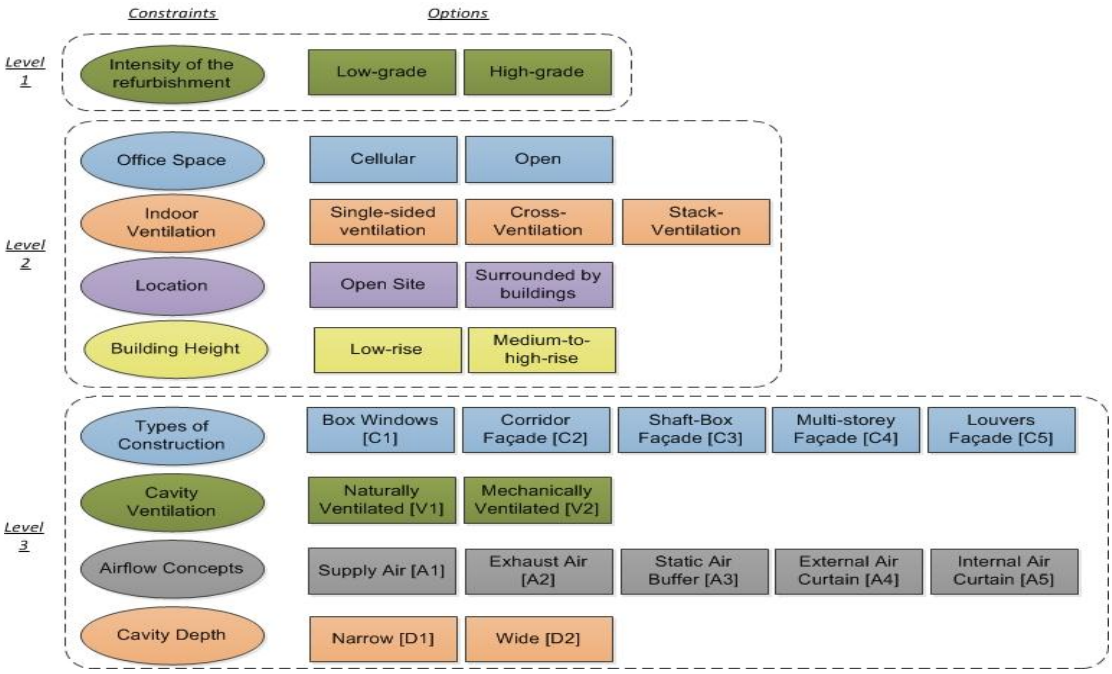


Fig. 4: Proposed methodology to assess Double-Skin Systems for Office Refurbishment

The proposed classification works on three levels, examining the intensity of the refurbishment, key parameters of the existing building and key parameters of the double-skin façade. First and foremost, the decision on the grade of refurbishment has to be taken as it influences all subsequent stages. For instance, a low-grade refurbishment is unlikely to replace all existing walls and windows, thus narrowing the suitable DSF options. Alternatively, a high-grade refurbishment may leave only the load bearing structure rebuilding all the rest from scratch and this greatly broadens the number of DSF systems that might be considered. The choice is mainly related to the available budget and the objectives the refurbishment aims for. In most circumstances, both options are possible and can reasonably be applied.

The second level takes consideration of elements related to the existing buildings. This does not include all the factors which are influential in refurbishment but only the determinants with an effect on the performance of the double-skin façade. For example, the load bearing structure is not considered as it is assumed that the existing building can sustain the weight of the second skin. The indoor ventilation of the office influences the airflow patterns of the future double-skin façade while the type of office space may point towards specific types of constructions rather than others. For instance, cellular offices provide a fair level of privacy, fire protection, and are a barrier to noise transmission. All these properties will vanish by installing some of the façades due to noise and fire transmission in the cavity.

Location and building height are often related. They mainly influence the cavity depth and, to some extent, the types of construction. Low-rise office buildings are often integrated in the urban fabric and, therefore, only the narrow cavity seems to be a viable option. High-rise office buildings, on the contrary, are generally located in a more open urban context, as a result of the architectural and design process, which often aims at communicating through the image of the building. For those then, a wide cavity is also a feasible solution.

The last level of the classification deals with key features of double-skin façades. While all the other constraints are quite straightforward, airflow patterns are worth further explanation. The supply air pattern, [A1], is the likeliest option considering the natural ventilation that a DSF allows for and also the lack of air conditioning systems that many of the offices which were examined for this study have had. The option [A4] is not realistic as the offices under examination allow for natural ventilation and a DSF designed just as an external air curtain may be jeopardised by

occupants opening internal windows. Also the static air buffer concept, [A3], may present the same issue. However, this specific airflow has to be considered as a hybrid solution within the refurbishment and not the only pattern available. Additionally, the thermal buffer behaviour of the façade is expected in winter where, generally, windows are closed.

The last two airflow patterns, [A2] and [A5], are both theoretically applicable but their feasibility has to be examined on a case-by-case basis as it might require implementing HVAC systems to mechanically achieve the desirable thermal behaviour of the façade and this aspect deals once again with the intensity of the refurbishment.

It is worth noting that the third level allows an easy classification of DSF systems. It also permits for classifying hybrid combinations, which represent growing examples in DSF installation – especially for the airflow patterns where different options may exist together within the same façade. The proposed classification is very easy to use. For instance, a façade coded as [C5].[V2].[A1].[D1] immediately describes all the different key features of its design. In case the same façade can also operate as a static thermal buffer (hybrid system), it will be possible to easily express it by using a different code such as [C5].[V2].[A1/A3].[D1].

This assessment procedure focuses on the UK offices and specifically – as described in Section 2 – on those categories that are mainly representative of the current office stock. Table 3 is an illustration of the possible combinations of DSF systems for low-grade refurbishments taking into consideration the office categories and the key features of DSF. This methodological approach, thence, enable practitioners and designers to identify the range of options for DSF technologies. Moreover, these options will form the basis of cases for use in the evaluation and optimisation studies.

Table 3: Examples of possible system combinations for low-grade refurbishments

Office Type	Ratio	Indoor Ventilation	Types of DSF	Cavity Ventilation	Airflow Concepts	Cavity Depth	Possible DSF Systems
Cellular up to 4 Storeys	50.60%	Single-sided	[C1], [C3]	[V1]	[A1], [A3]	[D1]	4
Cellular 5 or more Storeys	7.76%	Single-sided	[C1], [C3]	[V1], [V2]	[A1], [A3]	[D1], [D2]	16
Cellular - Open Plan (mixed)	29.10%	Single-sided/ Cross-ventilation	[C1], [C2], [C3], [C4], [C5]	[V1], [V2]	[A1], [A2], [A3]	[D1], [D2]	60
Open spaces artificially lit	8.21%	Cross-ventilation	[C2], [C3], [C4], [C5]	[V1], [V2]	[A1], [A2], [A3],	[D1], [D2]	48
Open spaces sidelit up to 4 Storeys	1.34%	Single-sided/ Cross-ventilation	[C2], [C3], [C4], [C5]	[V1]	[A1], [A2], [A3]	[D1]	12
Open spaces sidelit 5 Storeys or more	2.99%	Single-sided/ Cross-ventilation	[C2], [C3], [C4], [C5]	[V1], [V2]	[A1], [A2], [A3]	[D1], [D2]	48

Cellular low-rise office buildings, which form 50.60% of the stock under examination, only allow for four DSF systems. The small number is related to limited types of construction, the presence of surrounding buildings - which imply only a narrow cavity - and the single sided ventilation that limits the possible airflow patterns. Whereas in the case of mixed cellular open plan office sixty configurations are possible. This difference depends on the types of constructions, the choice on the cavity depth and the use of the DSF as a means to extract exhaust air. With sixty possible combinations to choose from, it is clear that an optimisation tool to determine the best option is

necessary. The use of stack-ventilation option has not been inserted in the table, as it is only possible if the building already has a central atrium, court or chimney. If that is the case, stack-ventilation should be a further option for each of the office types.

4.3 Case Studies

Case studies described in this section are used to illustrate the application of the proposed methodology and the assessment tool. Information on the state of the case study buildings before refurbishment has been gathered and prepared to establish the input data for the classification. By proceeding through the assessment tool, suitable DSF systems have been identified and compared, in the first two cases, with the actual system installed. The third case study building is yet to be refurbished but adopted for detailed analysis and optimisation studies in the next stage of the research.

4.3.1 GSW Headquarters – Germany

The authors have recently visited this building. Its refurbishment has been completed in 1999 as an extension of an office tower from the 1950s and the project design is by Sauerbruch Hutton Architects. This is a high-rise office building (22-storey) which consists of open plans and partitioned (cellular) offices. As explained in the assessment methodology, these buildings often have an open urban space surrounding them, which is the case for this building too.

GSW Headquarters has gone through a major refurbishment which allows for more flexibility and internal configurations. This building has been particularly designed around natural ventilation and this can be utilised approximately for 70% of the year with a 53% energy savings on heating and cooling [28]. It also has a building management system (BMS) that allows for automatic and manual operation of windows enabling optimal control options for occupants' comfort.

After the refurbishment, the building shows a shaft-box double-skin façade with a hybrid solution regarding the airflow patterns. Due to the presence of open spaces, cross-ventilation is possible acting both to supply and to extract the air. Additionally, in cold season, when the inner windows are closed the façade may act as a thermal buffer. The cavity is 90 cm deep and this has been possible because of the open site the building is located in. The cavity also allows for fair daylight without glare. However, the west-facing double skin façade is fully equipped with aluminium rotating louvers that can both be controlled automatically and manually. Due to their extreme flexibility, these louvers help to protect against morning, afternoon and low-angle winter sun. Hence the façade installed in this case after the refurbishment is a [C3].[V1].[A1/A2/A3].[D2] and it falls within those suggested by the proposed methodology for this kind of buildings as shown in Table 4.

Table 4: DSF option for Case Study #1

Office Type	Types of Construction	Cavity Ventilation	Airflow Concepts	Cavity Depth
Cellular - Open Plan (mixed)	[C1], [C2], **[C3]**, [C4], [C5]	**[V1]**, [V2]	**[A1]**, **[A2]**, **[A3]**	[D1], **[D2]**

4.3.2 Dorma Head Office - Germany

This building was completed in 1968 and then refurbished in 2002-2004, increasing its floor levels from 6 to 9. The refurbishment has been intense and the building has been completely remodelled removing the concrete units of the primary old façade and equipping it with new opening and well-insulated windows.

The building was originally designed for large open plan spaces and during the refurbishment floors had been cut out to allow more daylight to enter the building and to meet the current standards for workspaces. Considering the heavy refurbishment level of this building, the ventilation is both natural and mechanical, although the mechanical one is only used during the cooling season in south-east and south-west rooms and to extract exhaust air from the rooms when windows are open.

The key feature in this case is the airflow. This DSF is a multi-storey façade, which has structural glazed panes of the same dimensions mounted at different heights, creating thus a permanent and uncontrolled natural ventilation of the cavity. Although detailed information of the cavity depth is not available, from a reverse scaling process done on the pictures and drawings retrieved it seems it is a wide cavity and this is consistent with the open site where the building is located.

Table 5: DSF option for the Case Study #2

Office Type	Types of Construction	Cavity Ventilation	Airflow Concepts	Cavity Depth
Open Plan	[C2], [C3], **[C4]**, [C5]	**[V1]**, [V2]	**[A1]**, [A2], [A3]	[D1], **[D2]**

The double-skin façade installed is [C4].[V1].[A1].[D2], which correlates to the results from the proposed methodology as shown in Table 5

4.3.3 New England House – United Kingdom

New England House (NEH) is a 1960s building in central Brighton, UK that comprises over 11000 m² of net lettable space over eight floors and it is within a short walking distance from the central railway station. This particular building has been chosen as a key case study for the current research due to several reasons. Firstly, a report from 2004 concludes that it is structurally sound and it has substantial load bearing capacity as floors, walls and ceilings are cast and finished in concrete. Secondly, another report from 2010 identifies the poor thermal performances of the façade as the main issue. Taking all elements into consideration, including the commissioning of a business case report by the Brighton & Hove City Council, the refurbishment will take place in the near future.



Figure 5: NEH, Aerial view from South (http://newenglandhouse.org.uk)

Despite its uniform shape (see Figure 5), space distribution varies from floor to floor and also within the same floor. The result is a mix of cellular and open space offices, unevenly distributed on a floor and also throughout different floors. Although the building is centrally located, it still has enough space in its surroundings and already has a light well that can act as an airshaft. The office layout is made around the corridors in the courtyard, giving each office space the access to windows for daylighting and natural ventilation.

Table 6: DSF option for New England House

Office Type	Types of Construction	Cavity Ventilation	Airflow Concepts	Cavity Depth	Possible combinations
Cellular - Open Plan (mixed)	[C2], [C3], [C4], [C5]	[V1], [V2]	[A1], [A2]	[D1], [D2]	32

Unfortunately, the depth of the offices and the size of the whole building do not allow for a cross-ventilation strategy according to the rules of thumb described in literature [28]. By applying the proposed methodology to NEH the result is a total of 32 possible DSF configurations as shown in Table 6. It is important to clarify once again on what this result means. Thirty-two are the DSF systems suitable for NEH considering the constraints related to the building itself, such as the location, the height and the possible indoor ventilation strategies. This number represents the starting point to identify which configurations need to be further investigated to ascertain an optimum selection.

5. Conclusion and future work

Double Skin Façade is a developing technology and, when suitably applied, has the potential to offer greater environmental sustainability than the single skin facade. Current research in this field chiefly focuses on new developments yet the greatest environmental impact lies in the refurbishment of existing buildings. This research has reviewed the current state of the office stock in the UK and indicated that the majority of them are naturally ventilated with cellular or open plan format, which are suitable for the application of Double Skin Façades.

The first step towards accessing the environmental sustainability of DSF is to identify suitable systems for the refurbishment of offices in the UK. In the absence of existing knowledge, an assessment methodology based on parameters identified in the literature review has been successfully developed. This assessment tool takes into account the characteristics and functionalities of DSF systems, and more importantly, the constraints imposed by existing office buildings.

Initial tests of the proposed tool on two completed projects indicated coherent and consistent results but further refinements, additional parameters and a decision flow chart are some of the improvements already identified to be implemented. The third building, New England House in Brighton, which is going to be used as a live case study to demonstrate the true environmental sustainability of DSF through life cycle assessments, was also tested using the proposed methodology to identify the number of viable DSF strategies. This on-going research will not only evaluate the life cycle impact of the possible systems identified by the tool developed in the current study, but will also compare these impacts with the alternative generic façade systems commonly used.

This research has contributed towards the deeper understanding of DSF in the context of their application in office refurbishments. The assessment tool developed to identify the system options, although basic in its current form, is a stepping-stone towards the building up of a knowledge base to support the wider and more appropriate use of DSF for sustainable refurbishments of offices in the UK.

6. References

[1] CARBON TRUST. *Building the future, today. Transforming the economic and carbon performance of the buildings we work in*. 2009.

[2] SHAMERI MA, ALGHOUL MA, SOPIAN K, ZAIN MFM, ELAYEB O. *Perspectives of double skin facade systems in buildings and energy saving*. Renewable & Sustainable Energy Reviews. 2011;15:1468-75.

[3] BABANGIDA I, OLUBODUN F, KANGWA J. *Building Refurbishment: Holistic Evaluation of*

Barriers and Opportunities. 28th Annual ARCOM Conference - Association of Researchers in Construction Management. Edinburgh, UK. 3-5 September 2012. p. 1289-98.
[4] STEEMERS K. *Energy and the city: density, buildings and transport*. Energy and Buildings. 2003;35:3-14.
[5] PÉREZ-LOMBARD L, ORTIZ J, POUT C. *A review on buildings energy consumption information*. Energy and Buildings. 2008;40:394-8.
[6] CIBSE, BSRIA. *Refurbishment for Improved Energy Efficiency: An Overview*. In: CIBSE Knowledge Series 12. 2007. p. 48.
[7] ODPM. *Age of Commercial and Insustrial Stock: Local Authority Level 2004*. Office of the Deputy Prime Minister Publications - Crown copyright 2005; March 2005. p. 24.
[8] GWA GRIMLEY LTD. *UK Offices: Refurbishment vs. Redevelopment*. 2010
[9] CIBSE. *Energy use in offices*. Energy Consumption Guide2000.
[10] STEADMAN P, BRUHNS HR, HOLTIER S, GAKOVIC B, RICKABY PA, BROWN FE. *A classification of built forms*. Environment and Planning B: Planning and Design. 2000;27:73-91.
[11] KOROLIJA I, MARJANOVIC-HALBURD L, ZHANG Y, HANBY VI. *UK office buildings archetypal model as methodological approach in development of regression models for predicting building energy consumption from heating and cooling demands*. Energy and Buildings. 2013;60:152-62.
[12] SAELENS D. *Energy Performance Assessment of Single Storey Multiple-Skin Facades*. PhD Thesis - Catholic University of Leuven; 2002.
[13] OESTERLE E, LIEB R, LUTZ M, HEUSLER W. *Double-Skin Facades. Integrated Planning*. Munich - London - New York: Prestel; 2001.
[14] GRATIA E, DE HERDE A. *Greenhouse effect in double-skin facade*. Energy and Buildings. 2007;39.
[15] BRUNORO S, RINALDI A. *Double layer glass facade in the refurbishment and architectural renewal of exhisting building in Italy*. World Renewable Energy Congress 2011 Sweden, Linkoping, 8-13 May 2011.
[16] GRATIA E, DE HERDE A. *Are energy consumptions decreased with the addition of a double-skin?* Energy and Buildings. 2007;39.
[17] CETINER I, OZKAN E. *An approach for the evaluation of energy and cost efficiency of glass facades*. Energy and Buildings. 2005;37.
[18] BRUNORO S. *An assessment of energetic efficiency improvement of existing building envelopes in Italy*. Management of Environmental Quality. 2008;19:718-30.
[19] ARTMANN N, SATTELMAYER T, SPINNLER M. *Double-Skin Facades with Diverse Sunscreen Configuration*. International Symposium on the Application of Architectural Glass 2004.
[20] CAKMANUS I. *Optimization of Double Skin Facades for Buildings: An Office Building Example In Ankara-Turkey*. Proceedings of Clima 2007 WellBeing Indoors. Helsinki, June 10-14 2007.
[21] GAVAN V, WOLOSZYN M, KUZNIK F, ROUX J-J. *Experimental study of a mechanically ventilated double-skin facade with venetian sun-shading device: A full-scale investigation in controlled environment*. Solar Energy. 2010;84.
[22] GRATIA E, DE HERDE A. *The most efficient position of shading devices in a double-skin facade*. Energy and Buildings. 2007;39.
[23] HAASE M, WIGENSTAD T. *Double-Skin Facade Technology for Energy-Efficient Commercial Building Refurbishment in Norway*. Roomvent 2011 - 12th International Conference on Air Distribution in Rooms. Trondheim, Norway2011.
[24] POIRAZIS H. *Double Skin Facades for Office Buildings - Literature Review*. Report EBD-R--04/3. Lund: Lund University - Institute of Technology 2004.
[25] BBRI. *Source book for a better understanding of conceptual and operational aspects of active facades*. Department of Building Physics, Belgian Building Research Institute; 2002.
[26] ARONS D. *Properties and Applications of Double-Skin Building Facades*. USA: Massachusetts Institute of Technology (MIT); 2000.
[27] HAASE M, DA SILVA FM, AMATO A. *Simulation of ventilated facades in hot and humid climates*. Energy and Buildings. 2009;41.
[28] WOOD A, SALIB R. *Natural Ventilation in High-Rise Office Buildings*. New York and London: Routledge - Taylor & Francis Group; 2013.

Characterization and Classification of the Energy Performance of Facades According to Climate and Location



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Short Summary

We are in the process of developing an energy assessment tool for residential property within the framework of the SHERIFF (Hybrid and Economic System for the Flexible Comprehensive Rehabilitation of Facades) Research Project, funded by the Spanish Ministry of Economy and Competitiveness and part of the INNPACTO Program. This tool will help to make decisions about how to rehabilitate buildings in Spain. For its development, we have studied the following topics: typologies of existing enclosures, weather conditions and the most appropriate improvement actions to apply on the facade.

First of all, based on previous studies, [1, 2] this research is limited to the period between 1950 and 1980 in the Community of Madrid, Spain. A selection of neighbourhoods has been made based on the amount of buildings built during that time and their state of conservation. The most representative type of residential buildings of each neighbourhood has been chosen and building information for each property has been requested to the relevant administrative entities. A two hundred independent building inventory has been created, collecting information about multiple building enclosure typologies. This inventory has been summarised into the following typologies:

- Six different classes of opaque enclosure construction
- Two types of window construction and
- Three different sun protection typologies.

Secondly, weather conditions, guidelines and representative sections of the city street have been studied, allowing the appropriate action's definition appropriate action as (previously) defined to be applied on the enclosure. The facade has been divided into four specific areas:

- Null zone, where no solar radiation is received during the year.
- Sun protection zone, which must be protected from excessive solar radiation.
- Solar gain zone, which can take advantage of the solar collection strategy.
- Flexible zone, which requires both solar gain and sun protection.

Finally, the summarized inventory has been verified according to both the new draft and the existing Spanish regulation document (CTE).

Keywords: Rehabilitation, Assessment, Facade, Method, and Bioclimatic.

1. Introduction

The energy rehabilitation of facades in buildings has been recognized as the most efficient mechanism for the reduction of energy consumption and CO2 emissions associated with the

construction sector. To comply the objectives of energy efficiency and CO2 emissions in the framework of the European Union by 2050, Spain should increase the rehabilitation rate annual of 400,000 homes (1.5% of the existing housing stock). Which represents an increment of 1.2% more than the current rate 0.3%.[3] Moreover, at this time, the available free land in cities is practically nil, and rehabilitation is seen as the most significant construction activity for the future. This is why the SHERIFF "Hybrid and Economic System for the Flexible Comprehensive Rehabilitation of Facades" Research Project, has among its main goals to optimize the energy rehabilitation phases, starting with the energy performance of the existing facade.

The SHERIFF Research Project contains six different work packages. The first package, "Characterization and construction and energy assessment of building(s)," is in turn divided into four tasks: *E1.1. Cataloguing of the building systems's facade enclosures according to their energy behaviour. E1.2. Energy performance classification for the facades considered. E1.3. Benchmarking of the facade's energy performance before and after rehabilitation. And E1.4. Energy rehabilitation measures tool based on the previous assessment.* This document only refers to part of the work for the first two tasks, because the others are currently in development.

E1.1. Cataloguing of the building systems's facade enclosures according to their energy behaviour. The objective of this task is to define the different types of facade cladding occurring in a given period in Spain. A detailed study has been carried out in several neighbourhoods of Madrid; this methodology will be extrapolated to the whole country. To carry out this task, it has been necessary to develop a preliminary work defining the study period and the selection of the neighbourhoods. Subsequently, building files in which the information concerning the construction composition of the enclosure is gathered have been consulted. With this information, a classification of the types of opaque facade and openings has been developed.

E1.2.Energy performance classification for the facades considered. In this phase, the minimum requirements requested by the Spanish Technical Building Code (CTE) for facade enclosures and the actions that are necessary in order to reach these values were determined.
In order to classify the energy performance of the facades considered and to propose improvements, it was necessary to take the following steps:

- Study the weather conditions influencing the hygrothermal behaviour of the building.
- Determine the needs of the building envelope by using tools for studying the weather conditions of the location.
- Verify the compliance of the enclosure under study with the CTE's minimum requirements.
- Establish the annual bioclimatic strategies that comply with the CTE's provisions according to region and typology.

It is noteworthy that the study of the weather conditions was made for 25 cities, however in this document the city of Madrid has been taken as an example.

2. Cataloguing of the building systems's facade enclosures according to their energy behaviour

2.1 Determination of the study period

Between 1950 and 1980 there was a massive housing construction that resulted in more than 8.5 millions of households, representing more than 35% of the national total. During these years the construction procedures for the housing developments throughout the country were very similar. During this period, commonly known in Spain as “Desarrollismo” (Developmentalis) there was a great demand for housings in the major cities, due among other things to the mass exodus that occurred from the countryside to the city. In those years, buildings were constructed quickly and with precarious means across the country, using the same materials everywhere without any legislation in force to regulate the thermal performance of buildings and therefore the indoor thermal comfort of the homes built. All the housings built during this period have a great potential to be rehabilitated.

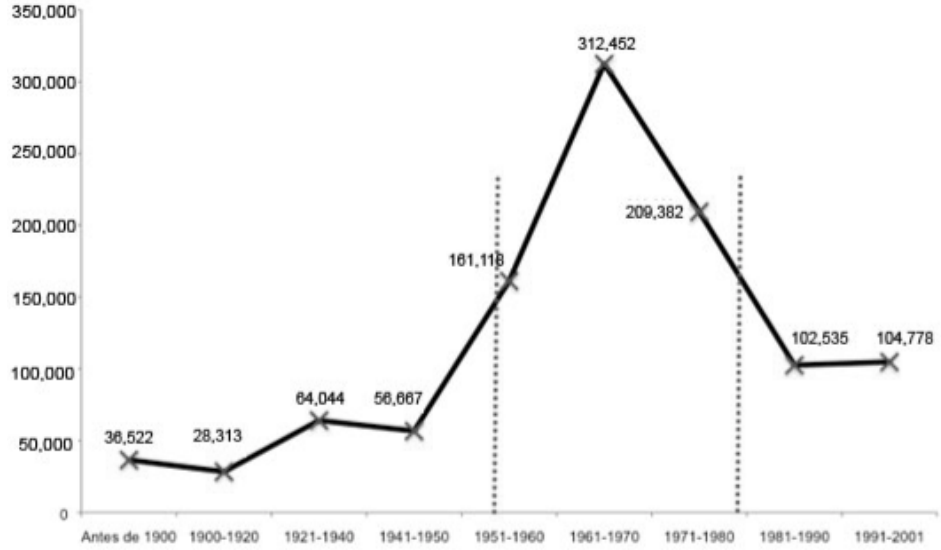


Fig. 1: Family dwellings by date of construction in the city of Madrid

2.2 Selection of neighbourhoods and constructive typologies to study

Once the study period was defined, a selection of the neighbourhoods in Madrid was made with the highest number of houses built in the chosen period.[4, 5] Then, a thorough study for the selection of facade's types in every neighbourhood was developed, considering the most representative ones. Subsequently, building information was requested from the Public Administrations (Archivo de la Villa, Gerencia de Urbanismo, Archivo Central del Ministerio de Fomento and Archivo Regional de la Comunidad de Madrid).

Table 1: Neighbourhoods with over 10,000 housings built in the period between 1951 and 1980 in Madrid

Districts	Neighbourhoods	Homes Built
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Chamartín	Prosperidad	10,219
Fuencarral	El Pilar	18,669
La latina	Puerta del Ángel	12,362
	Lucero	10,850
	Aluche	25,245
	Las Águilas	17,813
Carabanchel	Vista Alegre	13,895
Ciudad lineal	Ventas	17,177
	Pueblo Nuevo	17,310

2.3 Cataloguing of facade enclosures

The information found in the documents consulted has allowed to summarise and categorise facade enclosures in the following types:

- F.1.1. One-foot-thick solid face brick wall
- F.1.2. One-foot-thick double hollow brick wall + rendering
- F.2.1.b One-foot-thick solid face brick wall + 5cm air chamber + 4cm hollow brick

- F.3.1. Half-foot-thick solid face brick wall + 5cm air chamber + 4cm hollow brick
- F.3.2. Half-foot-thick solid face brick wall + 5cm air chamber + double hollow brick
- F.4.1. Half-foot-thick solid sand-lime face brick wall + 5cm air chamber + 4cm hollow brick

The predominant constructive configurations were firstly Half-foot-thick solid face brick wall + 5cm air chamber + 4cm hollow brick and secondly One-foot-thick solid face brick wall.

Frames are classified into two groups:

- C.1.1. Wood frames
- C.2.1. Metal frames

The conclusion is that in this period houses were built mainly with metal frames and rarely with woodworks, and in both cases without thermal break.

Glazing are classified into two groups:

- V.1.1. Single glazing
- V.2.1. Double glazing (4-6-4)

Most of the glasses found were double glazing.

Solar protections are classified into three groups:

- PS.1.1. Blinds
- PS.2.1. Slats
- PS.3.1. Lattices

The solar protections identified were mainly blinds.

3. Preliminary studies for the definition of the actions on the façade.

3.1 Weather conditions

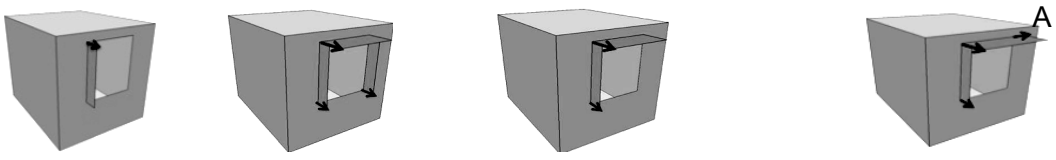
For the evaluation of the energy performance of the facades, the monthly averages of climate data have been taken from the Spanish State Meteorological Agency for the 1971-2000 period. Twenty five cities of the climatic zones established by the Spanish Technical Building Code have been selected. For each one of these cities, all the weather conditions influencing the hygrothermal behaviour of the building (temperature, precipitation, relative humidity, sun exposure and wind) have been studied. This research has been used to assess the housing needs of the twenty five cities, such as window shading or solar incidence on vertical surfaces depending on the proportion of the streets.

3.2 Need for shading in the openings

The shading and sunlight needs for a 1.20 x 1.20 m window opening in the relevant orientations (north, south, east and south-east) [6] were studied. When selecting the sizes of the solar protections, the need for shade in the summer and for sunlight in the winter has been taken into account.

Table 2: Solar protection dimensions required in Madrid (latitude 40°) for each orientation.

Zone	North	South		East		South-east		
D3	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal (A)	Vertical	Horizontal
	0.75	1.24	0.44	0.69	0.44	0.26	0.78	0.51



Note: Sizes are measured in meters

3.3 Solar incidence on vertical surfaces according to the orientation

In the study of solar incidence on vertical surfaces, the Vertical Shading Angle (VSA) was calculated according to the season and two important aspects; first, the angle between 10am and 2pm, when the solar incidence is at its highest; secondly, the solar protection and solar collection needs studied in the weather conditions.

The VSAs obtained have been drawn in order to apply them in the study of the proportions of the street section and in the actions on the facade to improve the energy performance of the building.

3.4 Proportion of Madrid's street sections

To classify the streets of Madrid, a study of street proportions has been carried out, in which the influence of the shadow of the nearby buildings on the facade has been evaluated, including the width of the section of the street and the VSA. For this task, a previous research done by Prof. Agustín Hernández Aja has been taken as a starting point.[7]

Once the results obtained, a classification of six different sections has been taken the average value of each proportion has been taken, that is to say:

- Section 01, proportion of street width and height between 0.3 and 0.5
- Section 02, proportion of street width and height between 0.6 and 0.8
- Section 03, proportion of street width and height between 0.9 and 1.2
- Section 04, proportion of street width and height between 1.3 and 1.6
- Section 05, proportion of street width and height between 1.7 and 2.0
- Section 06, proportion of street width and height >2.1

4. Actions on the envelope

4.1 Strategies to improve the energy performance in the facade according to latitude

A graphic study of solar incidence on the facade for each orientation has been carried out. The different types of street section and the AVS previously selected have been necessary for it. This work has resulted in the division of the facade into four zones depending on the most appropriate actions for improving their thermal behaviour.

These zones are:

- Z01 (Zone 01), Shadow is on this facade area. Solar gain is impossible.
- Z02 (Zone 02), Sun protections are needed to prevent solar gains (overhangs, louvres, blinds, slats, etc.).
- Z03 (Zone 03), Solar gain and prevention of heat loss are needed (greenhouse, trombe wall, thermal inertia, etc.).
- Z04 (Zone 04), Flexible zone, solar gain and sun protection are required (for example moveable sun protections).

Figure 2 shows the percentage of facade for each zone type, for the 6 types of street sections. In this case, we have studied Madrid's east and west orientations. In the sections Type T01, T02 and T03, the solar gain area (Z03) increases up to 82% when the street section grows in width. This area is 100% in the remaining street sections. When the street section is the narrowest, like Type T01, solar gain is impossible in this area (Z01), which in this case is 25% of the facade.

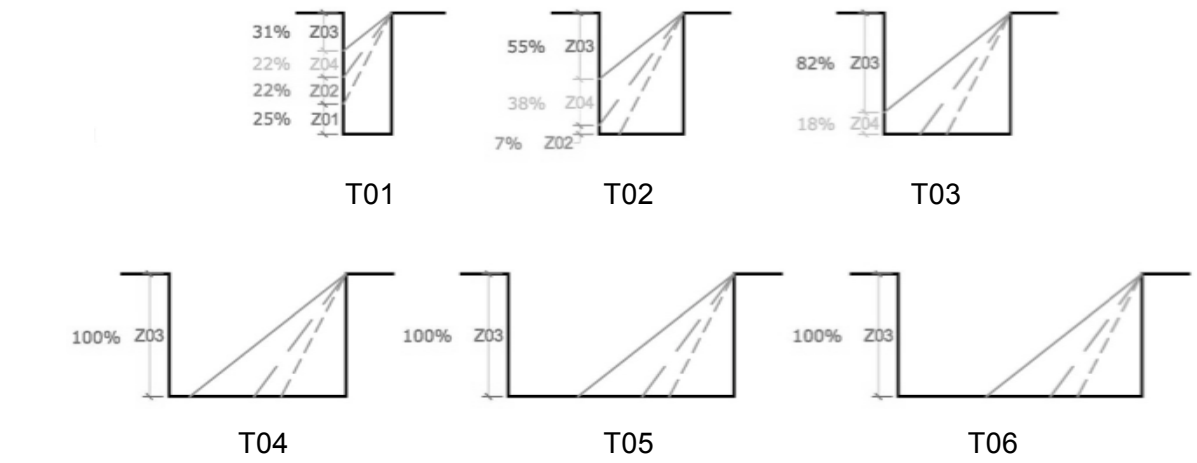


Fig. 2: Example of determining the most appropriate actions on the facade, latitude 40 ° Madrid, east orientation.

Legend:



4.2 Action requirement according to the Spanish Technical Building Code (CTE)

We have compared the theoretical transmittance of facades previously catalogued with the transmittances required by the CTE 2006 (still in effect), the CTE 2013 (draft document) and a proposal for improvement of the latter by 25%. These last data have been made taking into account that the European Standards are already establishing the steps that will be needed to get zero energy buildings.

Table 3: Transmittance comparisons: theoretical transmittance, CTE 2006 transmittance and CTE 2013 transmittance.

	Region D			
	Thermal transmittance of the facades (W/m2 K)			
Cataloguing summary	Theoretical	CTE 2006	CTE 2013	Improvement proposal by 25%
F.1.1	2.21	0.86	0.66	0.50
F.1.2	1.05			
F.2.1.b	1.22			
F.3.1	1.49			
F.3.2	1.30			
F.4.1	1.56			
	Thermal transmittance of the frames (W/m2 K)			
C.1.1	2.00	3.50	2.70	2.03
C.2.1	5.70			
	Thermal transmittance of the glazing (W/m2 K)			
V.1.1	5.70	3.50	2.70	2.03
V.2.1	3.30			

The purpose of this comparison was to evaluate the requirements needed for each type of facade according to its corresponding climate zone. Although this comparison has been made for all the areas of Spain established in the CTE, this study only shows region D, corresponding to Madrid.

5. Conclusions

The selection of the study period and neighbourhoods has allowed us to develop a detailed analysis in order to catalogue the most common facade types. The procedure used could be extrapolated to any other period that might be studied.

Knowing the composition of the facades and their cataloguing allows the thermal behaviour of the building to be established in order to make a proposal to improve according to the existing buildings.

Studying the weather conditions has allowed the identification of the specific rehabilitation actions for each CTE climate zone, namely:

- For the windows (the openings), the appropriate dimensions and location of the sun protection have been defined, which could be adapted to most of the existing openings and would be a non-intrusive installation.
- For the facade enclosures catalogued (the opaque part), which do not comply with the Spanish legislation (the current one and the one that is about to be published), a comprehensive study to evaluate the thickness of the insulation needed for each type of facade in order to comply with the legislation has been initiated/started.

6. Acknowledgements

The authors wish to thank the ABIO Research Group and the Department of Construction and Technology in Architecture, Technical University of Madrid (Universidad Politécnica de Madrid, UPM) Spain. We would also like to thank the SHERIFF Project and the Public Administrations (Archivo de la Villa, Gerencia de Urbanismo, Archivo Central del Ministerio de Fomento and Archivo Regional de la Comunidad de Madrid) for allowing us the use of their facilities and access to their archives. And finally thanks to Pablo Velez for helping us in developing this paper.

7. References

[1] CUERDA E. *"Procedimiento de análisis y evaluación para la rehabilitación térmica de cerramientos de fachada en edificios residenciales. Caso de estudio en el barrio Pinar del Rey, Madrid".* Congreso Nacional del Medio Ambiente, CONAMA. Madrid. 2012. ISBN: 978-84-695-6377-9

[2] MONJO CARRIÓ J. *"The Evolution of Construction Systems in Building Industrialization Procedures."* Informes de la Construcción, Vol. 57, nº 499-500, 2005. pp.37-54.

[3] WWF Report 2012. *"Challenges and Funding Opportunities for the Energy Efficient Renovation of Spain's Residential Building Stock".* Adena. Madrid. Spain. 2012.

[4] DE LUXÁN M. *"Estudio de las posibilidades de actuación con criterios de sostenibilidad en los barrios periféricos de Madrid".* Madrid. 2006.

[5] GÓMEZ G. *"La rehabilitación y su alcance frente a los nuevos retos."* Congreso Internacional Rehabilitación y Sostenibilidad. El futuro es posible. R+S=F. Madrid. 2010.

[6] NEILA GONZÁLEZ, F. J. *"Arquitectura bioclimática en un entorno sostenible."* 1ª edición, Munilla-Lería, Madrid, 2004. ISBN: 8489150648

[7] HERNÁNDEZ AJA, A. *"Tipología de Calles de Madrid."* Cuadernos de Investigación Urbanística. 2ª edición, Instituto Juan de Herrera, Madrid, 1995. ISBN: 8489977925

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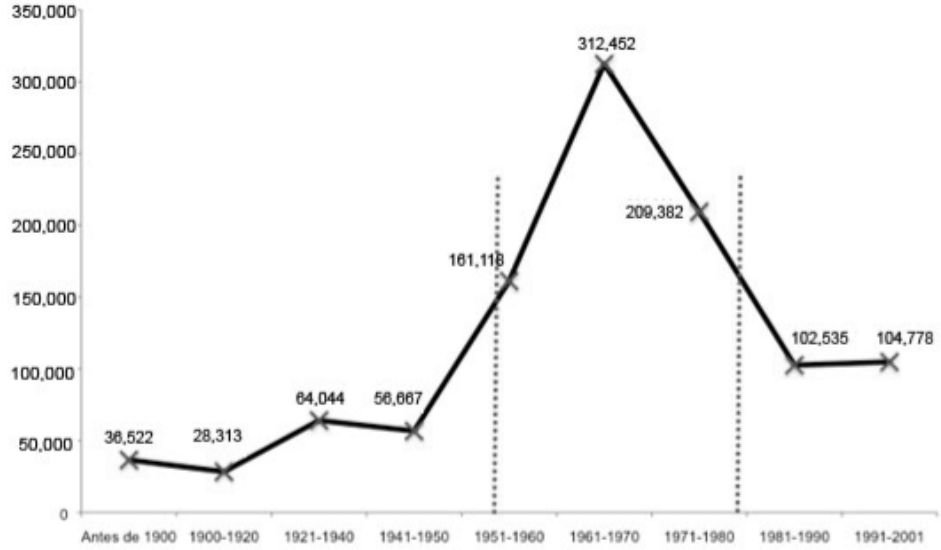


Fig. 1: Family dwellings by date of construction in the city of Madrid

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Most of the glasses found were double glazing.

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3.1 Weather conditions

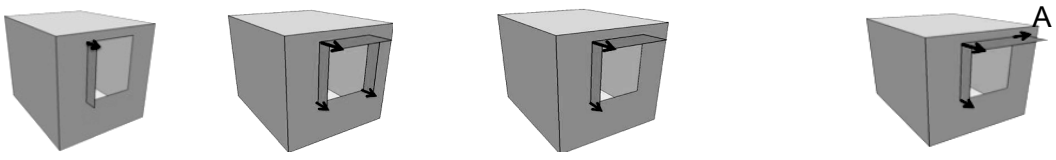
For the evaluation of the energy performance of the facades, the monthly averages of climate data have been taken from the Spanish State Meteorological Agency for the 1971-2000 period. Twenty five cities of the climatic zones established by the Spanish Technical Building Code have been selected. For each one of these cities, all the weather conditions influencing the hygrothermal behaviour of the building (temperature, precipitation, relative humidity, sun exposure and wind) have been studied. This research has been used to assess the housing needs of the twenty five cities, such as window shading or solar incidence on vertical surfaces depending on the proportion of the streets.

3.2 Need for shading in the openings

The shading and sunlight needs for a 1.20 x 1.20 m window opening in the relevant orientations (north, south, east and south-east) [6] were studied. When selecting the sizes of the solar protections, the need for shade in the summer and for sunlight in the winter has been taken into account.

Table 2: Solar protection dimensions required in Madrid (latitude 40°) for each orientation.

Zone	North	South		East		South-east		
D3	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal (A)	Vertical	Horizontal
	0.75	1.24	0.44	0.69	0.44	0.26	0.78	0.51



Note: Sizes are measured in meters

3.3 Solar incidence on vertical surfaces according to the orientation

In the study of solar incidence on vertical surfaces, the Vertical Shading Angle (VSA) was calculated according to the season and two important aspects; first, the angle between 10am and 2pm, when the solar incidence is at its highest; secondly, the solar protection and solar collection needs studied in the weather conditions.

The VSAs obtained have been drawn in order to apply them in the study of the proportions of the street section and in the actions on the facade to improve the energy performance of the building.

3.4 Proportion of Madrid's street sections

To classify the streets of Madrid, a study of street proportions has been carried out, in which the influence of the shadow of the nearby buildings on the facade has been evaluated, including the width of the section of the street and the VSA. For this task, a previous research done by Prof. Agustín Hernández Aja has been taken as a starting point.[7]

Once the results obtained, a classification of six different sections has been taken the average value of each proportion has been taken, that is to say:

- Section 01, proportion of street width and height between 0.3 and 0.5
- Section 02, proportion of street width and height between 0.6 and 0.8
- Section 03, proportion of street width and height between 0.9 and 1.2
- Section 04, proportion of street width and height between 1.3 and 1.6
- Section 05, proportion of street width and height between 1.7 and 2.0
- Section 06, proportion of street width and height >2.1

4. Actions on the envelope

4.1 Strategies to improve the energy performance in the facade according to latitude

A graphic study of solar incidence on the facade for each orientation has been carried out. The different types of street section and the AVS previously selected have been necessary for it. This work has resulted in the division of the facade into four zones depending on the most appropriate actions for improving their thermal behaviour.

These zones are:

- Z01 (Zone 01), Shadow is on this facade area. Solar gain is impossible.
- Z02 (Zone 02), Sun protections are needed to prevent solar gains (overhangs, louvres, blinds, slats, etc.).
- Z03 (Zone 03), Solar gain and prevention of heat loss are needed (greenhouse, trombe wall, thermal inertia, etc.).
- Z04 (Zone 04), Flexible zone, solar gain and sun protection are required (for example moveable sun protections).

Figure 2 shows the percentage of facade for each zone type, for the 6 types of street sections. In this case, we have studied Madrid's east and west orientations. In the sections Type T01, T02 and T03, the solar gain area (Z03) increases up to 82% when the street section grows in width. This area is 100% in the remaining street sections. When the street section is the narrowest, like Type T01, solar gain is impossible in this area (Z01), which in this case is 25% of the facade.

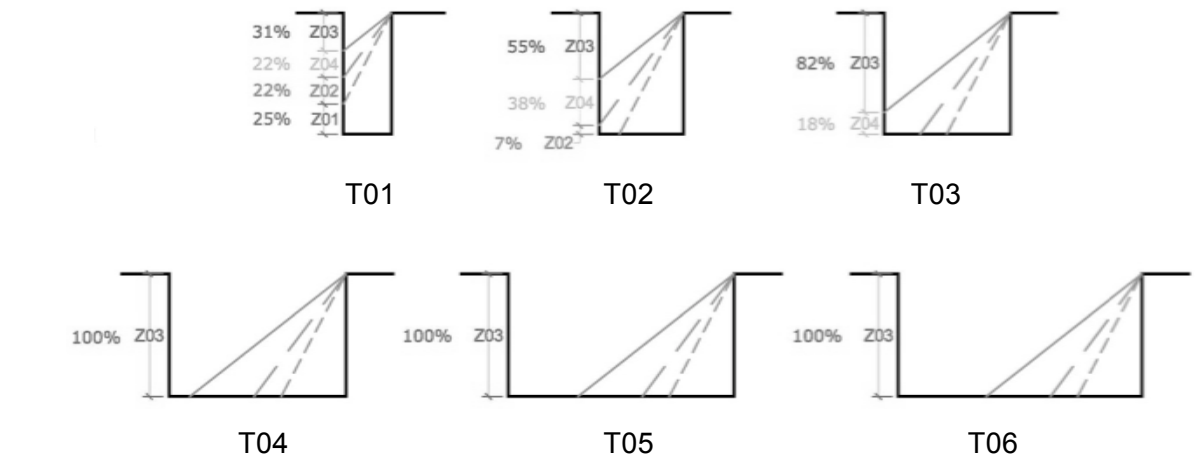


Fig. 2: Example of determining the most appropriate actions on the facade, latitude 40 ° Madrid, east orientation.

Legend:



4.2 Action requirement according to the Spanish Technical Building Code (CTE)

We have compared the theoretical transmittance of facades previously catalogued with the transmittances required by the CTE 2006 (still in effect), the CTE 2013 (draft document) and a proposal for improvement of the latter by 25%. These last data have been made taking into account that the European Standards are already establishing the steps that will be needed to get zero energy buildings.

Table 3: Transmittance comparisons: theoretical transmittance, CTE 2006 transmittance and CTE 2013 transmittance.

	Region D			
	Thermal transmittance of the facades (W/m2 K)			
Cataloguing summary	Theoretical	CTE 2006	CTE 2013	Improvement proposal by 25%
F.1.1	2.21	0.86	0.66	0.50
F.1.2	1.05			
F.2.1.b	1.22			
F.3.1	1.49			
F.3.2	1.30			
F.4.1	1.56			
	Thermal transmittance of the frames (W/m2 K)			
C.1.1	2.00	3.50	2.70	2.03
C.2.1	5.70			
	Thermal transmittance of the glazing (W/m2 K)			
V.1.1	5.70	3.50	2.70	2.03
V.2.1	3.30			

The purpose of this comparison was to evaluate the requirements needed for each type of facade according to its corresponding climate zone. Although this comparison has been made for all the areas of Spain established in the CTE, this study only shows region D, corresponding to Madrid.

5. Conclusions

The selection of the study period and neighbourhoods has allowed us to develop a detailed analysis in order to catalogue the most common facade types. The procedure used could be extrapolated to any other period that might be studied.

Knowing the composition of the facades and their cataloguing allows the thermal behaviour of the building to be established in order to make a proposal to improve according to the existing buildings.

Studying the weather conditions has allowed the identification of the specific rehabilitation actions for each CTE climate zone, namely:

- For the windows (the openings), the appropriate dimensions and location of the sun protection have been defined, which could be adapted to most of the existing openings and would be a non-intrusive installation.
- For the facade enclosures catalogued (the opaque part), which do not comply with the Spanish legislation (the current one and the one that is about to be published), a comprehensive study to evaluate the thickness of the insulation needed for each type of facade in order to comply with the legislation has been initiated/started.

6. Acknowledgements

The authors wish to thank the ABIO Research Group and the Department of Construction and Technology in Architecture, Technical University of Madrid (Universidad Politécnica de Madrid, UPM) Spain. We would also like to thank the SHERIFF Project and the Public Administrations (Archivo de la Villa, Gerencia de Urbanismo, Archivo Central del Ministerio de Fomento and Archivo Regional de la Comunidad de Madrid) for allowing us the use of their facilities and access to their archives. And finally thanks to Pablo Velez for helping us in developing this paper.

7. References

[1] CUERDA E. *"Procedimiento de análisis y evaluación para la rehabilitación térmica de cerramientos de fachada en edificios residenciales. Caso de estudio en el barrio Pinar del Rey, Madrid".* Congreso Nacional del Medio Ambiente, CONAMA. Madrid. 2012. ISBN: 978-84-695-6377-9

[2] MONJO CARRIÓ J. *"The Evolution of Construction Systems in Building Industrialization Procedures."* Informes de la Construcción, Vol. 57, nº 499-500, 2005. pp.37-54.

[3] WWF Report 2012. *"Challenges and Funding Opportunities for the Energy Efficient Renovation of Spain's Residential Building Stock".* Adena. Madrid. Spain. 2012.

[4] DE LUXÁN M. *"Estudio de las posibilidades de actuación con criterios de sostenibilidad en los barrios periféricos de Madrid".* Madrid. 2006.

[5] GÓMEZ G. *"La rehabilitación y su alcance frente a los nuevos retos."* Congreso Internacional Rehabilitación y Sostenibilidad. El futuro es posible. R+S=F. Madrid. 2010.

[6] NEILA GONZÁLEZ, F. J. *"Arquitectura bioclimática en un entorno sostenible."* 1ª edición, Munilla-Lería, Madrid, 2004. ISBN: 8489150648

[7] HERNÁNDEZ AJA, A. *"Tipología de Calles de Madrid."* Cuadernos de Investigación Urbanística. 2ª edición, Instituto Juan de Herrera, Madrid, 1995. ISBN: 8489977925

Evaluating the energy savings potential of window refurbishment



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Short Summary

A saleable software was created for the evaluation of built-in windows and the savings effect to be attained by building in new windows. With the help of the program Uwin the energy savings can be prognosticated in case of refurbishing by consultations with suppliers of windows, facades and glazing.

The program starts with guideline values which can be adjusted and refined step by step. The calculated energy savings are indicated in kWh/m² as final energy (as QE in kWh/m²a). According to the operation of the rapid access field the result can be issued with or without heat loss by airing as well as with or without solar gain.

The program anticipates that the window is protected from insolation by lateral and horizontal components. It also anticipates that there is a building opposite. The linked Ug-value measuring tool was tested by appropriate procedures and the results were evaluated.

The software Uwin is available in German only on the project website www.fenstercheck.info.

Keywords: window; refurbishment; energy savings potential; energy-efficient buildings.

1. Introduction

Windows are an energy sensitive part of the building façade. In case of a planned window refurbishment however, it is often difficult to evaluate the energy savings potential of such a measure, especially if no product information about the built-in glazing and frame is available.

Within the frame of the project „Development of a new evaluation tool to determine the energy savings potential of window refurbishment including effects of glazing, frame and connection“ [1], a saleable software was created for the evaluation of built-in windows and the savings effect to be attained by building in new windows. With the help of the program Uwin the energy savings can be prognosticated in case of refurbishing by consultations with suppliers of windows, facades and glazing.

The program starts with guideline values which can be adjusted and refined step by step. The calculated energy savings are indicated in kWh/m² as final energy (as QE in kWh/m²a). According to the operation of the rapid access field the result can be issued with or without heat loss by airing

as well as with or without solar gain.

The program anticipates that the window is protected from insolation by lateral and horizontal components. It also anticipates that there is a building opposite. The linked Ug-value measuring tool was tested by appropriate procedures and the results were evaluated.

2. Results

As a basis for the project, Kurz und Fischer GmbH have compiled the results of their business experience gained by acting as consulting engineers in the field of building physics. With reference to windows and glazing it is

- knowledge of the ageing process of windows and glazing of several typical objects
- knowledge of typical processes of planning and decision-making, depending on structures, i.e. private ownership, condominiums, property of building societies, municipal buildings etc.
- requirements referring to analysis instruments, i.e. the measuring system and the software for analysing and consulting.

On this basis a definition was found to differentiate between characteristics to be gained by in-situ measuring of the base and by appearance and comparison with data supplied. The development of a measuring tool is concentrated to glazing (not to the whole window), and, because of the considerable dependence on geometrical facts, to collect the influence factors of the other components by a calculation software to be developed.

The structure consists of about twenty input masks that are to be operated alternatively depending on the task (selection, multiple selection or manual input). The select buttons were as detailed as possible illustrated by symbols, so that the program can be operated intuitively. In addition input routines were structured to make it possible from the beginning to receive return data fast and easy to explain and, in the course of further input, more and more precise.

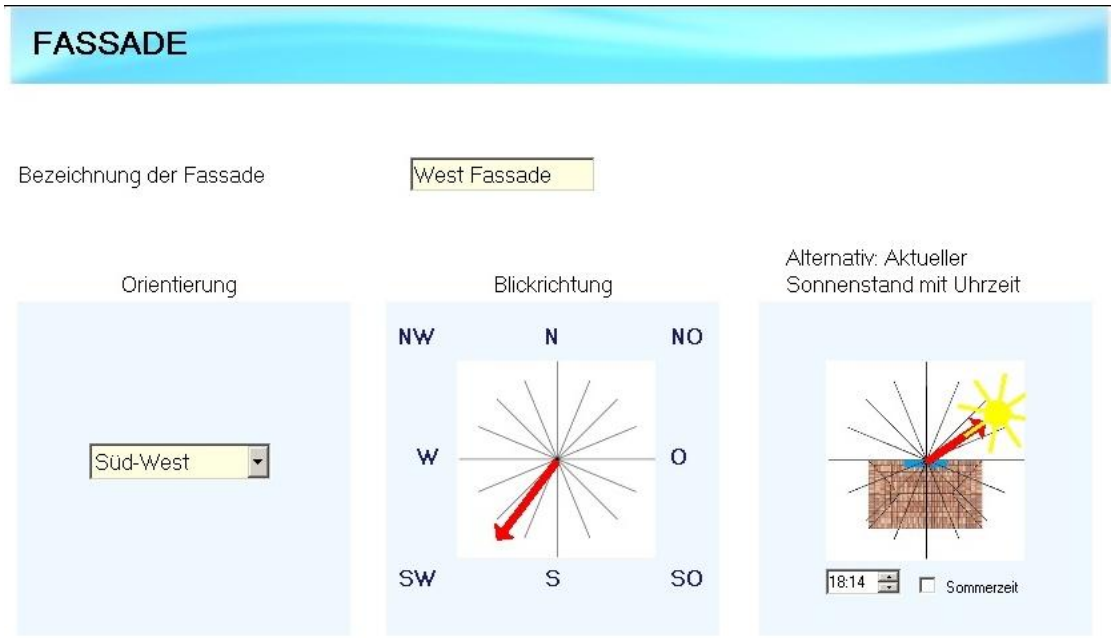


Figure 1: Example of an intuitively operable input screen for selecting the façade orientation.

The evaluation of the market data and the material data of glazing delivered results that indicate in which way data of the built-in windows can be collected and where, above all, measuring is appropriate.

The report function was created to achieve a preliminary evaluation with little input. It is, however, connected to a graphic design that indicates the probability of the result. A description of the program and an operating manual were worked out. The most important functions of the program were provided with tool tip texts.

In the course of the project a saleable full version (Uwin) was programmed well in time taking into consideration suggestions for optimizing. The program was tested by several users, among them the Hochschule für Technik und Wirtschaft in Berlin. The results of the test were commented. After examination some of the suggestions were realized in the final version.

The Ug-value measuring tool was tested by appropriate procedures and the results were evaluated. The software offers an opportunity to calculate the solar gain and the heat losses caused by airing.

With the help of the program Uwin the energy savings can be prognosticated in case of refurbishing by consultations with suppliers of windows, facades and glazing. Additional functions are included in the program. According to the type of problem and the motivations the program offers to the user either a prompt result or a more precise calculation in a particular case. Therefore, the program starts with guideline values. They can be adjusted and refined step by step. If the input referring to a built-in window can be specified the result of the calculation can be improved considerably.

The user is enabled to define in advance standard values of the project and of the types of windows available. For consultations the data of several types of windows available can be put in before and selected accordingly. Windows for comparison can be imported and managed continually.

In addition to the mere indication of energy savings a range of additional information will be registered for internal use. That can deliver important data for working out an offer. At the same time the program can be used for recording the results of the investigation. If several windows have been recorded the results refer to the total outcome, that means an average U-value for the whole window surface will be calculated. In the same way the energy savings refer to the number of all windows, if necessary with various formats, different orientation etc.

The calculated energy savings are indicated in kWh/m² as final energy (as QE in kWh/m²a). According to the operation of the rapid access field the result can be issued with or without heat loss by airing as well as with or without solar gain.

Access to the internet enables to fill in missing local data and procures information on the respective state of the Federal Republic, region of summer climate, year of test reference (region), altitude above sea level, wind zone, wind speed, heavy rain region, estimated rainfall per year.

Even without internet an approaching definition of additional input is possible. There is a map of Germany and by clicking the respective siting with the arrow to the object the data will be transferred to the program. For verification latitude and longitude appear on top right as GPS coordinate. Direct input is possible too, provided a GPS set is at the object consultant´s disposal.

To evaluate the exposure of a building to wind photographs have been used to show the wind situation symbolically.

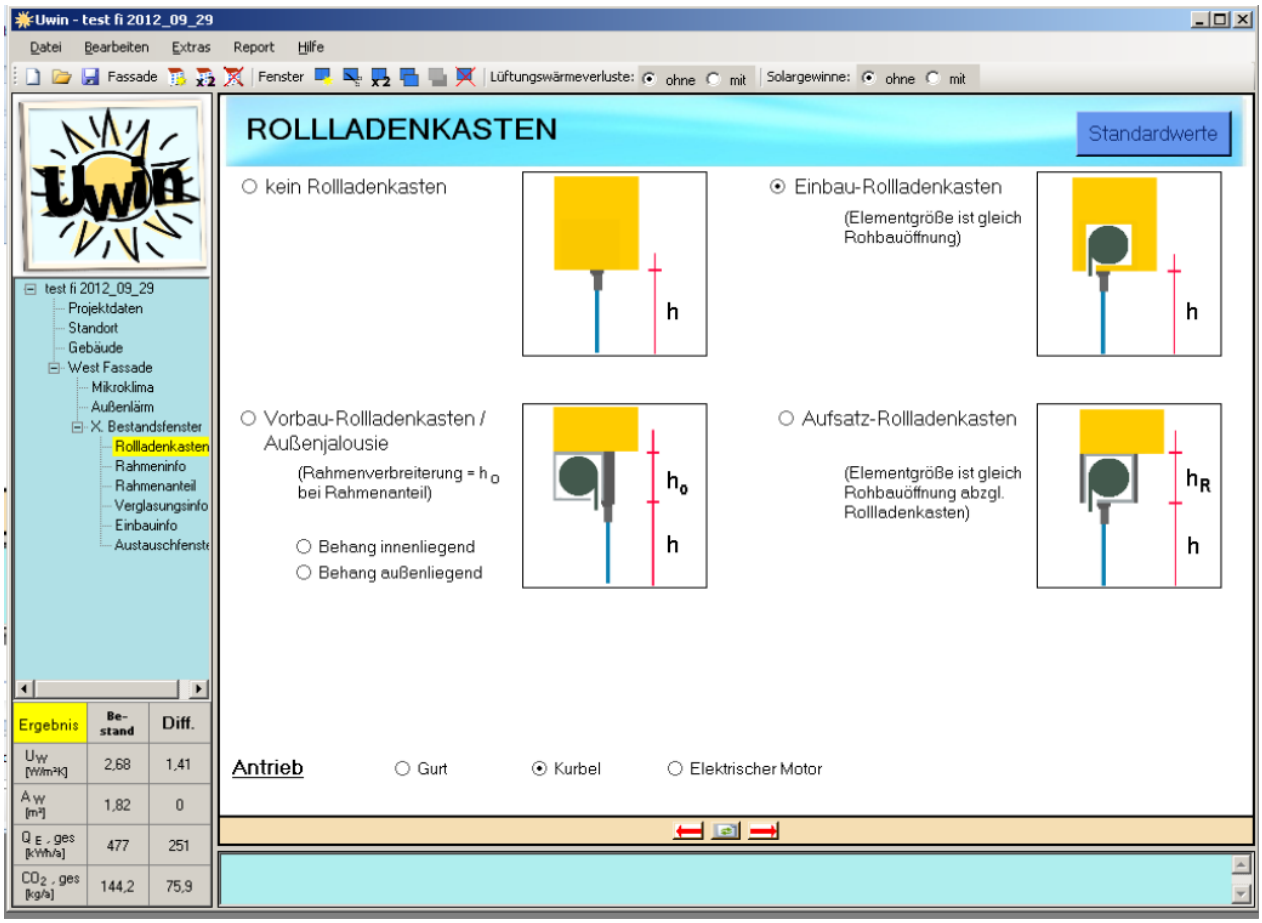


Figure 2: The software works with user-defined default values for a quick first result but quite many details can be added for an increased accurateness.

Knowledge of the openings of a building under construction is important for finding out the surface and the length of the respective share of frame, glazing, shutter, panelling, the length of sealing and the factor of loss by thermal bridges. The program allows the entry of the essential types of shutters. According to that the implemented methods of calculation are adjusted.

2.1 Shading

The program allows to anticipate the protection of window from insolation by lateral and horizontal components. It also anticipates that there is a building opposite.

The program calculates the solar gain of the window on base of the quantity of radiation depending on orientation and shading. It is to be taken into consideration that the degree of utility of the solar gain per year is generally at 1. In practice solar gain can be realised only partly, depending on the share of window surface, kind of utility, solidity of the building and the heating system.

2.2 Fringe information

It is possible to register the constructions characteristics depending on the respective age and with regard to the type of frame. The registration of the type of frame with windows made of wood and aluminium is essential to the evaluation of the temperature factors at the glass insert and is given only in an informative manner. It is not essential for the calculation of the U-value. The frame depth of wooden windows is used to calculate the U-values of frames according to affix D3 of DIN EN ISO 10211:2010-05.

The registration of the functional joints is used to establish the factor of joint leakage. Those results influence the loss of heat by airing of the built-in windows in connection with the length of joints. The registration whether there exist frame ventilators in faced frames or as combined form is important for making offers and, therefore, will be recorded. Ventilations in flats and apartments (to which belong airing elements that are not for windows and can, for example, be situated under the window sill) will not be shown in the program.

From the large number of different window types, mainly installed in residential buildings,
15 basic types were selected and implemented.

The total surface of the window elements is calculated by the shares of frames, glazing and panels leading to the absolute value. There is also issued the surface of glazing and of the frame as absolute value as well as the respective percentage.

Furthermore, the program delivers as result of the calculation the length of the installed joints of the building, the window seals (single) and the border connections of glass and panels.

2.3 Glazing info

It is possible to select single, double or triple glazing as insulation unit. For double glazed window the constellation 2 x 1 and for special double window and casement window constructions the constellation 2 + 1 is provided.

The calculated Ug-values of the glazing are also considering inclination. Therefore, the tool is also suitable for the glazing of skylights and winter gardens. If a built-in window has any bars a selection menu appears for a more detailed description of the kind of bars according to the classification of DIN 4108-4:2013-02, table 10. If built-in windows are to be evaluated the spacing stay must be distinguished.

2.4 Report function and data transfer

The dates are internally recorded in the XML-format. The Uwin-project-data-file can be opened as XML or as TXT file and be used by subsequent programs.

The results of the measuring by the U-value tool Uglass can be directly entered in the program. Thereby, a calculation with realistic input data is possible.

3. Outlook

Experience gained by testing and first measuring results achieved by practical use give grounds for expectations that there will be a large field of application of the tool for U-value measuring on the spot in the future.

In addition to that the application of the software will, independent of the use of the measuring tool, be an aid in advising customers on the spot by experts of the window business as well as by energy consultants. The high flexibility of the program, the suitability for various tasks (rapid evaluation of single windows, evaluation of whole facades or buildings) were proved by the tests.

The results of the measurements by the Uglass tool, which to a certain extent were made at new buildings, have indicated that applying the developed tools will not only be useful for the evaluation of old buildings but also for the quality control of buildings under construction.
Therefore, an impetus can be expected leading to higher standards of quality control in the production of insulated glass. In this way the superior aim of energy-saving building can be supported. The results achieved up to now have confirmed the importance of tools to be widely applied.

The software Uwin is available in German only on the project website www.fenstercheck.info.

4. Acknowledgements

This research was carried out as part of the project “Development of a new evaluation tool to determine the energy savings potential of window refurbishment including effects of glazing, frame and connection” and was funded by the German Federal Ministry of Economics and Technology by resolution of the German Federal Parliament.

[1] *GLASER S. (Red.) “Entwicklung eines neuartigen Bewertungstools zur Bestimmung des Energieeinsparpotenzials von Fenstern bei Sanierungsmaßnahmen unter Berücksichtigung von Verglasung, Rahmen und Anschlüssen”*. Final report to BMWi project (FkZ 0327654K-Q), downloadable at www.fenstercheck.info

Monitoring results of PCM-systems for room cooling



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Short Summary

Two different cooling systems with PCM – a sun protection system and a ventilated cooling ceiling – were installed in four office rooms in Karlsruhe, Germany, and monitored during summer 2010. The thermal behaviour of the systems was measured and compared to an identical reference room without cooling system. To avoid any interference from the users and to get defined boundary conditions, the measurements were performed on weekends with electrical heaters to simulate internal gains. With each of the PCM systems, the maximum operative room temperature could be reduced by 1-2°C, while a reduction of 2-4°C could be achieved with both systems together. While the ventilation system helped to regenerate the PCM, the regeneration of the PCM by night-time ventilation only was a problem.

Keywords: Phase Change Material (PCM); latent heat storage; room cooling; energy-efficient buildings; thermal comfort.

1. Introduction

Phase change materials (PCM) offer a promising alternative to conventional cooling systems. The passive nature of the latent heat storage process allows a high potential for energy efficient systems, especially if combined with some kind of free cooling to regenerate the PCM during the night. Two such systems – a sun protection system with PCM [1] and a ventilated cooling ceiling with PCM - were installed in some office rooms in Karlsruhe, Germany and were monitored during summer 2010. One office room was equipped with the PCM sun protection system, one with the ventilated cooling ceiling with PCM, and one with both systems. The thermal behavior of the systems was measured and compared to an identical reference room without cooling system. The measurements were carried out in a funded project [2].

2. System description

2.1 Sun protection system with PCM

Even if exterior sun protection systems are preferable, interior systems are installed in many buildings. The reasons range from the sensitivity of exterior systems to surrounding conditions like strong winds, to architectural considerations, or simply costs. Conventional interior sun protection systems consist of horizontal or vertical slats, usually with high reflective properties on the side

facing the exterior. A major problem of interior systems is the solar absorption on the blind, which leads to uncomfortably high temperatures at the blind surface and a large secondary transmittance, thus resulting in a high solar heat gain coefficient. This problem can be greatly reduced by incorporating PCM into the blind to cut temperature peaks. In the case of incoming solar radiation, the blind can only heat up to the melting temperature of the PCM because the melting starts and the absorbed heat is stored as latent heat. A further increase in temperature cannot occur until the PCM is completely melted. The PCM thus decreases the blind surface temperature as well as the g-value of the system. The mode of operation of a sun protection system with PCM is depicted in Figure 1. By choosing the melting temperature and amount of PCM accurately, the system can be designed to store the solar radiation energy absorbed during a whole day in summer.

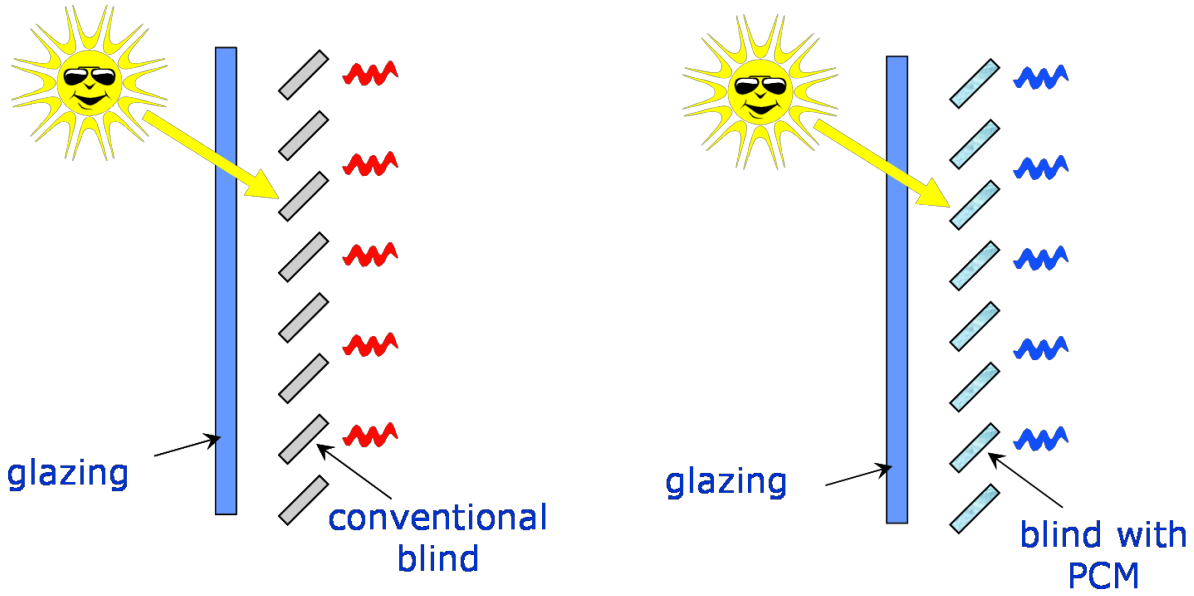


Figure 1: Diagram of a conventional sun protection system (left) and a sun protection system with PCM (right). While the conventional system heats up by absorbing solar radiation, the PCM limits the blind surface temperature to the melting temperature of the PCM.

A first prototype of such a sun protection system with PCM was developed by Warema, the leading manufacturer of sun shading systems in Germany. The PCM used was Delta®-Cool 28, a salt hydrate with a melting range between 26°C and 30°C and a melting enthalpy of 188 J/g produced by the company Dörken. Dörken also provided the encapsulation of the PCM, a hollow polycarbonate blind with a 12 mm gap filled with the PCM and sealed at the ends, so each square meter of blind area contained about 17 kg PCM. To ensure a good sun protection performance, the PCM-filled slats were covered with a white fabric with a normal-hemispherical solar reflectance of 0.78 (Figure 2). Finally, the slats were attached to a rail that was fitted to the ceiling.



Figure 2: Polycarbonate blind with Delta®-Cool 28 (left) and blind covered with highly reflective sun protection fabric (right).

2.2 Ventilated cooling ceiling with PCM

The second system to be monitored was a rear-ventilated cooling ceiling with PCM. The system setup is depicted in Figure 3. During the day (cooling mode), the warm room air is cooled down by the PCM in the ceiling in circulating operation. During the night or when the environmental conditions are favourable (regeneration mode), cool outside air is driven over the PCM to regenerate it.

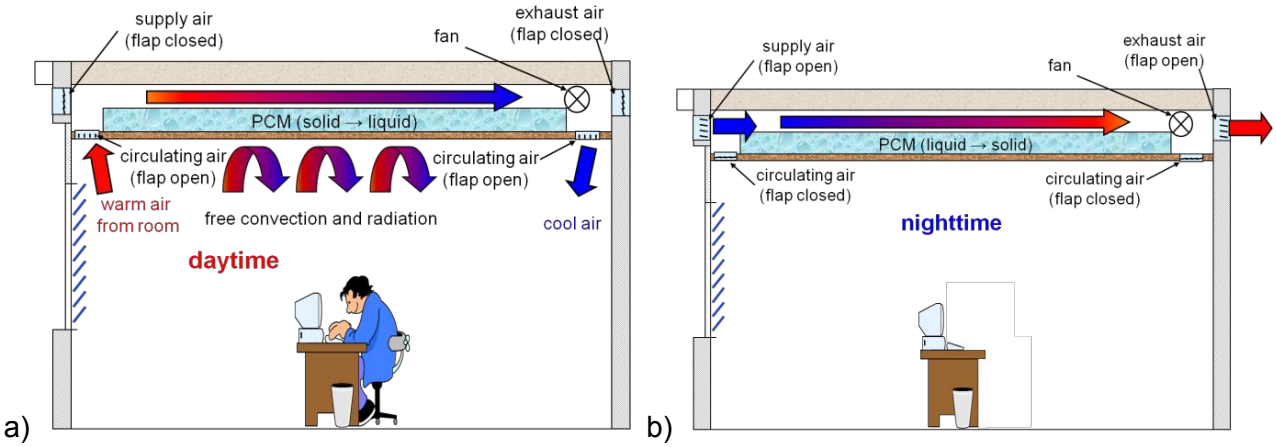


Figure 3: Cooling (a) and regeneration mode (b) of the ventilated cooling ceiling with PCM.

In a first step, laboratory measurements in a defined test room were made to investigate the system behavior and to get experimental data about the system performance [3]. It was found out, that the cooling power of the airflow alone was relatively small, but that a significant cooling power could be achieved directly through the ceiling. Due to these results, the volume flow rate of the air through the ceiling was designed to be as high as possible. Of course, the usual restrictions due to draft and sound protection applied.

3. Monitoring rooms and setup

3.1 Description of monitoring rooms

Four adjacent office rooms in the fifth floor of an office building in Karlsruhe, Germany, were available for the tests. The windows are oriented westward with a window area of about 50% of the outer façade surface. One room was equipped with the sun protection system with PCM, one with the ventilated cooling ceiling with PCM, and one with both PCM systems. The fourth, unmodified room without any cooling system was used as reference room. Each of the rooms was occupied by two people, and contained typical office equipment like computers and monitors. In spite of existing conventional exterior sun shading systems and interior vertical blinds for glare protection, all of the rooms had overheating problems.
In the two rooms with the ventilated cooling ceiling PCM boards were laid on top of the bearing for the suspended ceiling (Figure 4). The boards from the company Dörken were filled with DELTA®-COOL 24, a salt hydrate with a melting range between 24°C and 28°C and a melting enthalpy of 158 kJ/kg. The amount of PCM in each of the rooms was 6.5 kg/m^2. An exhaust ventilation system completed the setup (Figure 5).



Figure 4: Installation of the ventilated cooling ceiling with PCM. On the front left is the globe thermometer for measuring operative room temperature.



Figure 5: Motor-controlled ventilation flap (left) for nightly regeneration and exhaust-air ventilation system (right).

In contrast to the picture in Figure 3 b), it was not possible in the monitoring rooms to connect the air inlet for the regeneration mode directly to the suspended ceiling. Instead, the outside air entered the room via the ventilation flaps in the upper part of the façade and then mixed with the room air before it reached the PCM. This decreased the system efficiency for the regeneration process, but it could not be avoided due to structural requirements.

In the two rooms with the PCM sun protection system, the interior blinds were replaced by the PCM blinds (Figure 6) which had very similar solar optical properties [1]. To regenerate the PCM during the night, the windows could be tilted. In the room with both PCM systems, the regeneration process of the PCM in the blinds could also be supported by the ventilation system of the cooling ceiling.

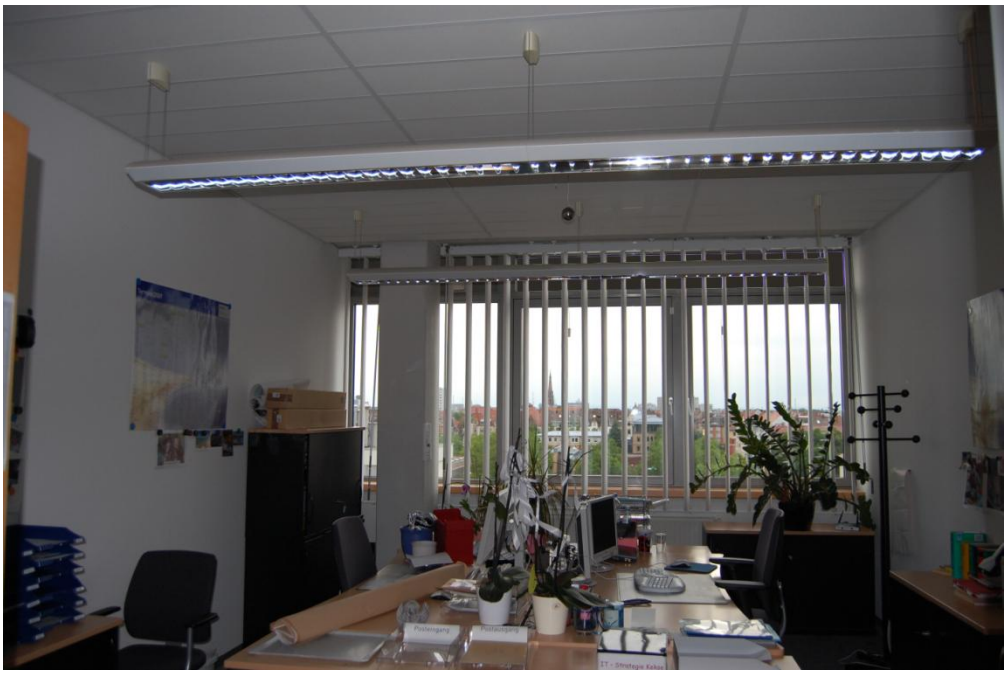


Figure 6: Office with PCM sun protection system installed as vertical blind.

3.2 Monitoring setup

It was found, that the user influence was quite big and made it impossible to extract the effect of the PCM systems from the measured data. To avoid this, measurements were performed during the weekends without any users. The internal gains were realized by electrical heaters with a constant power of 500 W between 9 am and 5 pm. The exterior sun protection system was not used and the windows were closed. The interior blinds were put at 90° (open position) for maximum view-through until the direct solar radiation reached the façade, which happened at about 2 pm. From then on, the blinds were positioned at cut-off angle in hourly intervals to get maximum view-through in combination with good solar shading. At the end of the measurement period, the blinds were turned to 90° again to achieve a good thermal coupling to the outside air for regeneration. The blinds were never retracted to the side.
In the rooms with the ventilated ceiling, the volume flow rate was set to 150 m^3/h (air exchange rate of about 2/h) during cooling mode and to 300 m^3/h (air exchange rate of about 4/h) during regeneration mode. The regeneration was time controlled and took place between 9 pm and 5 am with an additional temperature control, so the ventilation system worked only when the inlet air was cooler than the room air. The ventilation flaps in the façade were closed during cooling mode (purely circulating operation) and opened for the regeneration mode.

The data measured were the temperatures in the systems (at different positions on the PCM blinds and on the PCM boards in the ceiling), the inlet and outlet air temperatures in the ventilated ceiling, and the operative room temperature at a height of about 2.5 m. The cooling power of the air flow was calculated from the temperature difference between inlet and outlet air, the heat capacity of the air 0.34 Wh/(m^{3}K) and the volume flow rate.

4. Results

4.1 Ventilated cooling ceiling with PCM

Figure 7 depicts the measured operative room temperature in the office room with ventilated cooling ceiling with PCM and in the reference room as well as the system temperatures in the ceiling. As soon as the electrical heaters are turned on, the operative room temperature started to rise in both rooms. However, until 2 pm the temperature in the room with the PCM ceiling always stayed about 1°C colder than in the reference room. When the direct solar radiation reached the west facade at about 2 pm, the cooling effect of the PCM ceiling increased further with the maximum operative room temperature at about 32°C compared to 34°C in the reference room. The system temperatures in the ceiling show, that the PCM induced a temperature difference in the air flowing through the ceiling of about 2-4°C, which corresponds to a cooling power of 100-200 W. Since this is not enough to compensate the 500 W of the electrical heaters plus the solar gains, a significant cooling power has to be transmitted from the PCM directly through the ceiling construction. This could be validated by other measurements not presented here.

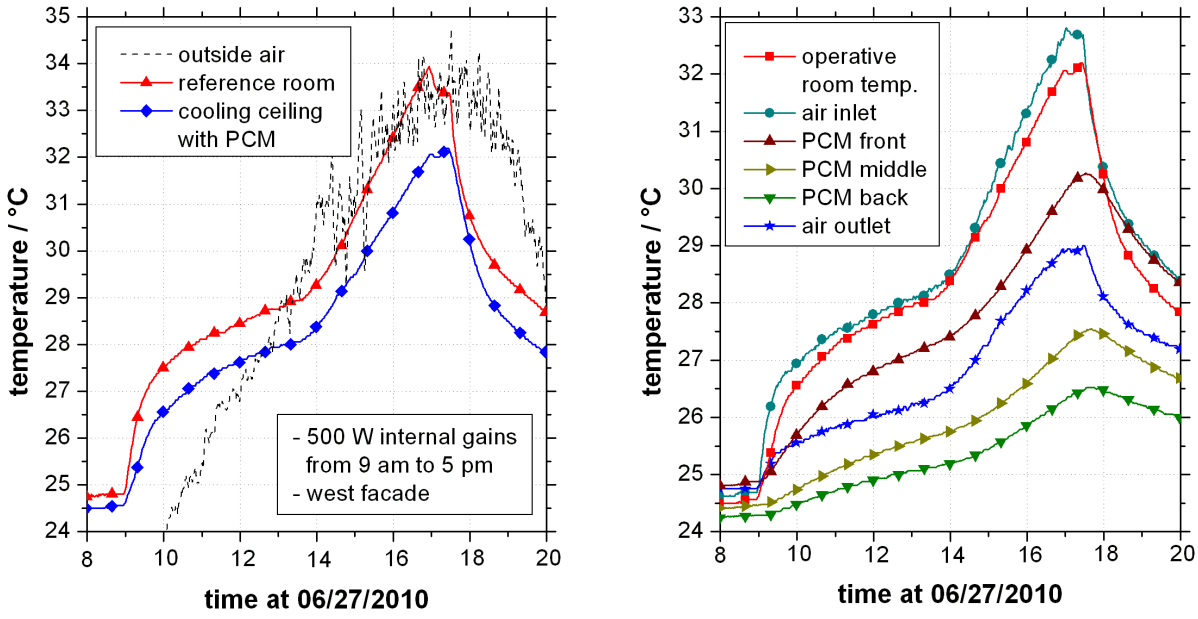


Figure 7: Measured operative room temperature on a warm summer day in the office with ventilated cooling ceiling with PCM and in the reference room (left) and system temperatures in the cooling ceiling (right).

The regeneration of the PCM in the ceiling was investigated for two scenarios:

- ventilation system on and windows closed,
- ventilation system on and windows tilted.

In both cases the PCM could not be regenerated completely during the night. However, this was mainly due to the fact, that the cool outer air could not reach the PCM ceiling directly, but mixed with the room air first.

4.2 Sun protection system with PCM

The measured operative room temperature in the office room with the PCM sun protection system and in the reference room as well as the system temperatures of the PCM blinds are depicted in Figure 8. The course of the operative room temperature in the two rooms was very similar until about 2 pm, when the direct solar radiation reached the west façade. From then on, the operative room temperature in the reference room increased quicker and reached higher maximum values than in the room with the PCM blinds. The PCM blinds reduced the maximum operative room temperature by about 2°C. The room side surface of the PCM blinds stayed quite cool (Figure 8 right) with maximum temperatures of about 28°C (the melting temperature of the DELTA®-COOL 28). Conventional inner blinds typically achieve much higher temperatures as can be seen by the temperatures of the air gap between blinds and glazing that reached maximum values of 38°C. Thus the PCM blinds help to improve thermal comfort for the inhabitants by reducing the radiant heat flow from the glazed part of the façade.

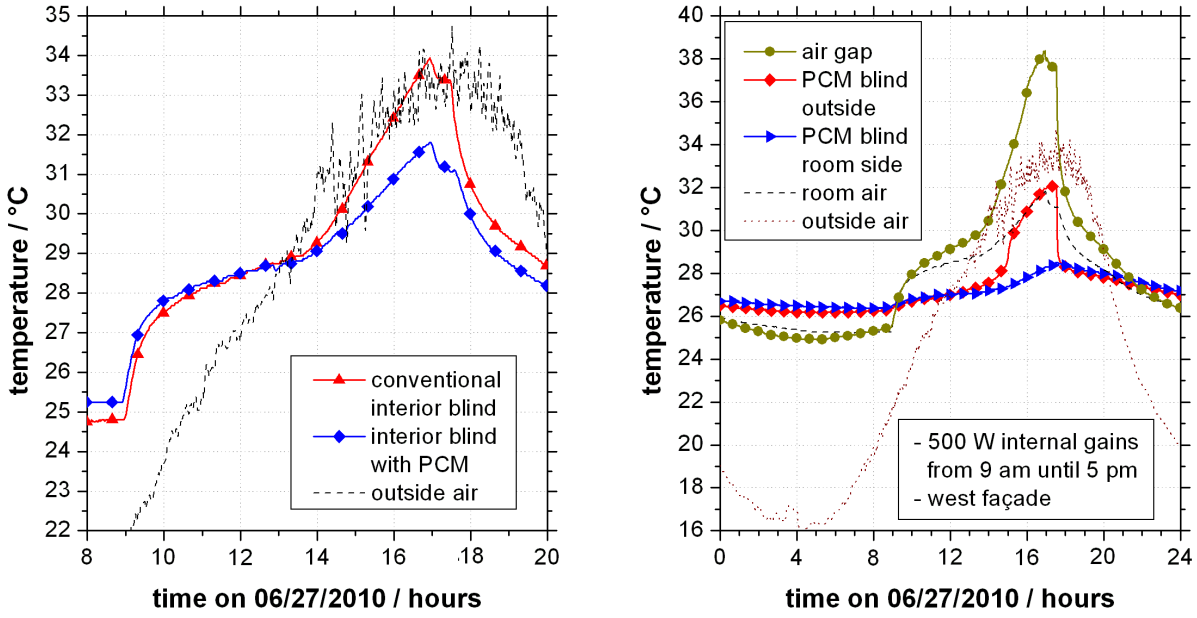


Figure 8: Measured operative room temperature on a warm summer day in the office with PCM sun protection system and in the reference room (left) and system temperatures of the PCM blinds (right).

The regeneration of the PCM in the blinds was investigated for three different scenarios:

- windows tilted without ventilation system,
- windows closed with ventilation system (ventilation flaps open), and
- windows tilted with ventilation system (ventilation flaps open).

Even with nightly outside air temperatures as low as 14°C it was not possible in the first and second scenario to regenerate the PCM completely. Only a combination of tilted windows and ventilation system achieved satisfying results.

4.3 Synergy effects

Possible synergy effects when using more than one PCM system were investigated in the room where both PCM systems were installed. For comparison, Figure 9 shows the measured operative room temperature in all of the four monitoring rooms. Without direct solar radiation (until 2 pm), the operative room temperature in the room with both PCM systems was quite similar to the temperature in the room with the PCM cooling ceiling. From then on, the cooling effect of the PCM sun protection system started to combine with the cooling effect of the PCM cooling ceiling. This re-

sulted in maximum operative room temperatures about 2°C lower than in the rooms with only one PCM system and almost 4°C lower than in the reference room.

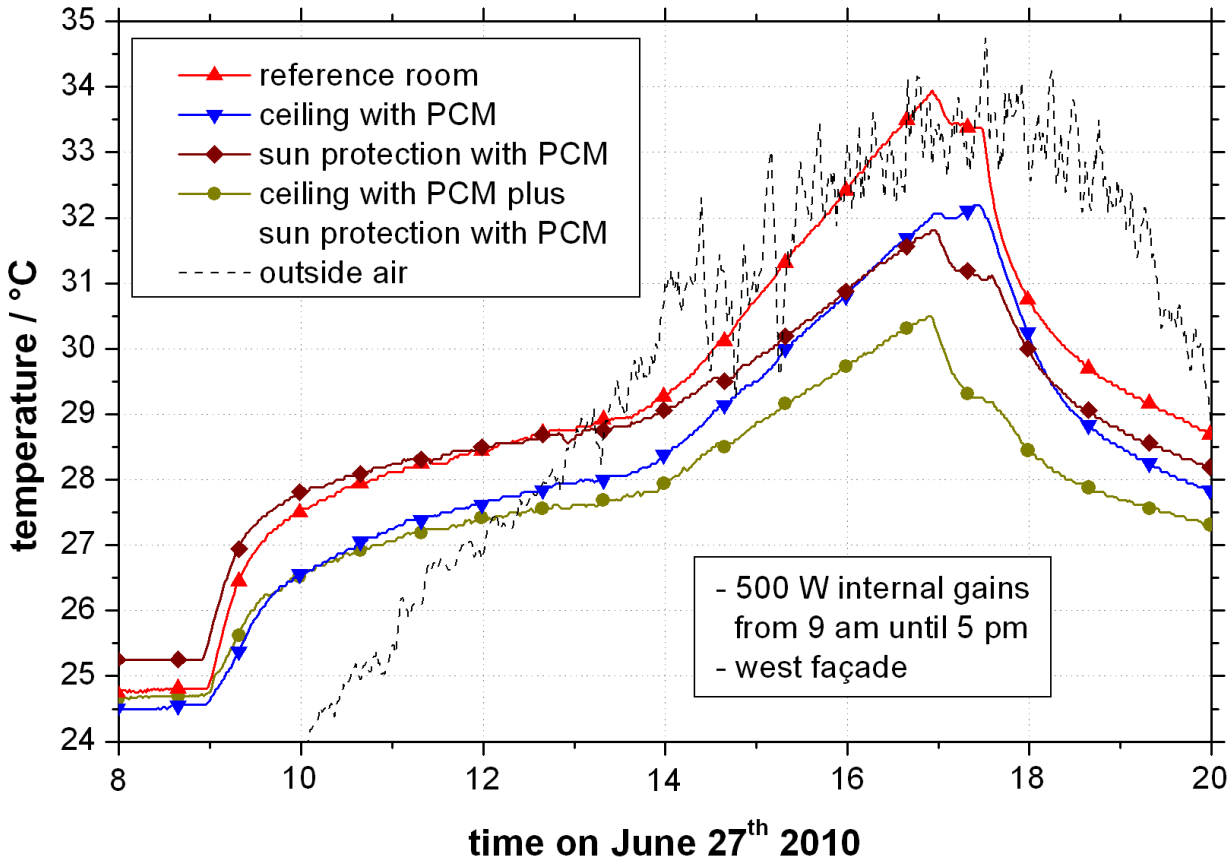


Figure 9: Measured operative room temperatures on a warm summer day in all of the four office rooms.

5. Conclusions and Outlook

The measurements showed that the two PCM systems investigated here - a ventilated cooling ceiling with PCM and a sun protection system with PCM - could reduce the operative room temperature significantly. While each of the systems worked well separately, a combination of the two systems showed considerable synergy effects, reducing the operative room temperature even further. However, the regeneration of the PCM by natural night-time ventilation only was a problem in the test rooms. For the PCM sun protection system the regeneration should be supported by a ventilation system, while for the cooling ceiling with PCM the outside air should be guided directly onto the PCM.
The results showed that PCM systems can be used for room cooling, but the setup and especially the regeneration of the PCM has to be planned carefully.

6. Acknowledgements

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[1] WEINLAEDER H, KOERNER W, HEIDENFELDER M. *“Monitoring results of an interior sun protection system with integrated latent heat storage”.* Energy and Buildings, 2011, Volume 43, pp 2468-2475.

[2] WEINLÄDER H. *“Entwicklung und praxisnaher Test der Performance von Gebäudekomponenten mit PCM in Demonstrationsobjekten”*. Final report BMWi project (FkZ 0327370U), TIB/UB Hannover, http://edok01.tib.uni-hannover.de/edoks/e01fb12/727481797.pdf

[3] WEINLÄDER H., KRANL D., STRIEDER B. *“A ventilated cooling ceiling with integrated latent heat storage: test room measurements”*. Intelligent Buildings International, 2013, DOI:10.1080/17508975.2013.775098

Cost-effective and high performance renovation of existing residential multi-family buildings in three European countries



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Extended Abstract

The built environment is a central aspect of daily human life. Building processes are also among the most cost intensive processes that we come into contact with. As for residential buildings, many people take 20 or 30 years, or even more, to pay back their home loans. Refurbishment of buildings is seen as a possible major contribution to lowering the impact of buildings on the environment [1] while being, ideally, economically promising and keeping the social identity of our built environment. On the other hand, regulations are often centered on the sustainability of new buildings [2], and there is a lack of regulations tailored to refurbishment [3]. At the same time existing buildings are seen as a key factor in local identity, and as a hub of socio-ecological development [4].
The EU funded BEEM-UP project (Building Energy Efficiency for Massive market UPtake) [5] has the goal to demonstrate the economic, social and technical feasibility of retrofitting initiatives for a 75 percent reduction in energy consumption in existing buildings, and lay the ground for massive market uptake. BEEM-UP involves key expertise to implement and demonstrate innovative building and energy management approaches with the overall aim to improve energy efficiency in existing buildings and obtain better indoor comfort conditions in three ambitious retrofitting projects. The main emphasis is placed on the economic and ecological life cycle assessment and comparison of the different projects and applied measurements in Sweden, the Netherlands and France. All projects are large-scale residential buildings with a focus on social housing, apartments and flats. All three sites are representative examples in the respective countries of building cohorts that are due for refurbishment.
One of the main goals of the BEEM-UP project is to compare the refurbishment approaches of the different countries, and to provide an exchange regarding related problems and solutions. For this purpose an ecological as well as life cycle cost assessment has been carried out for all three sites. For each site six refurbishment scenarios have been defined through intensive consultations with the building owners and other stakeholders, for instance tenants or tenant representatives. First preliminary results indicate that it is economically and technologically feasible to achieve 75 percent reductions in energy consumption for the existing building stock.
However, these preliminary findings point to institutional and social impediments that may not lead to massive market uptake in the social housing real estate community. Social housing institutions face distinct regulations and economic constraints, which can inhibit their uptake of energy retrofit policies [6]. On the one hand, national and EU wide policies nudge building owners towards basic energy-efficiency measures. On the other hand, institutional factors historically embedded into the social housing framework like rent controls and governmental rent subsidies inhibit a more equitable distribution of refurbishment costs between tenants and building owners. Moreover, discounted third-party capital is limited and subsidies at the national and local levels cannot

support the level of refurbishments needed across the housing stock.
However, there is economic value in energy-efficiency refurbishments of the building stock. An increasing number of studies document increased transaction values for buildings that are relatively more energy-efficient [7,8]. However, BEEM-Up has shed light on other sources of value at the property level. Namely, firms that have developed the product, process and organizational innovations associated with energy-efficiency retrofits could be financially more nimble and efficient in their housing portfolio relative to their non-innovative peers. In addition, there are more ways than transaction value and rental income to see the financial benefits of energy-efficiency. Alternate sources of income from renewable energy and even less explored financial benefits from taxation and depreciation that are currently linked to energy-efficiency investments are another source of savings for energy-efficiency that is far less explored. Thus, political and economic capital is required to shift institutions and firms towards an innovation mind-set to meet the needs of an ecologically improved building stock.

References

[1] EC Energy-Efficient Buildings PPP, Multi-annual roadmap and longer term strategy; European Commission: 2010.
[2] Meijer F, Itard L, Sunikka-Blank M (2009) Comparing European residential building stocks: performance, renovation and policy opportunities. Build Res Inf 37 (5-6):533- 551. doi:10.1080/09613210903189376
[3] Femenías, P.; Lindén, A.-L. Energy Efficiency in Public Housing in Sweden: Integrated Strategies to Overcome Market Barriers. In Energy Efficiency in Housing Management; Niebor, N.; Tsenkova, S.; Gruis, V.; van Hal, A., Eds.; Earthscan Publishing: forthcoming.
[4] COE Council of Europe Framework Convention on the Value of Cultural Heritage for Society CETS No.: 199.http://conventions.coe.int/Treaty/Commun/QueVoulezVous.asp?NT=199&CM=8& DF=04/01/2012&CL=ENG (Accessed on 9 January 2012)
[5] http://www.beem-up.eu/
[6] Nieboer, N., Tsenkova, S., Gruis, V., and Van Hal, J. (2012) Conclusion. In Energy Efficiency in Housing Management. Routledge. New York.
[7] Brounen, D. and Kok, N. (2011) On the economics of energy labels in the housing market. Journal of Environmental Economics and Management, 62:166-179. Retrieved from http://www.sciencedirect.com/science/article/pii/S0095069611000337.
[8] Hyland, M., Lyons, R., and Lyons, S. (2012) The value of domestic building energy efficiency–evidence from Ireland. University of Oxford Department of Economics Working Paper Series, No. 614. Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2096296

Keywords
Retrofitting; social housing; energy consumption; energy efficiency; LCA; LCC; economic performance

Innovative modernization of historic buildings – pilot schemes in Vienna



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Full Paper

1. Introduction

Economic as well as energy and climate-political specifications require new criteria for the holistic modernization of houses of the era of promoterism (Gründerzeit). Innovative reconstruction solutions are on display in Vienna and are being evaluated from the point of view of economic efficiency, energy efficiency, legal framework and users' satisfaction using several demonstration objects within the scope of the research project "Günderzeit with future prospects". Present results have uncovered that a wide range of innovative and practically useful components are available for the comprehensive and highly innovative modernization of houses of the era of promoterism, with which historical buildings under favorable framework conditions, can also be converted to the nearly zero-energy or energy-plus standard.

Extremely strong external walls of solid brick masonry, road façades designed in a complex manner, often with stucco ornamentation, immense floor heights and wooden beam ceilings or massive arched ceilings above the basement as well as wooden frame windows with single glazing and room-kitchen layouts: these are the typical attributes of houses of the Promoterism era that were built between 1848 and 1918. Seen from the point of view of the available stock of promoterism houses in urban areas, the spectrum ranges from the multistory workers' residence in the suburban area – many with façades that have in the meantime, been cleaned-up – up until the palace of the era of promoterism at the center of the city.
All over Austria, there are more than 600,000 apartments in buildings of the construction era preceding 1919 thus making the ratio of the stock of promoterism houses in Austria a total of approximately one-fifth. In Vienna alone, there are about 200,000 primary residential apartments in this building segment. Of about 35,000 buildings that were constructed in Vienna before 1919, about 20,000 classical apartment houses make up promoterism in a narrower sense.
The sustenance and further development of this stock of buildings is therefore a central task confronting the residential and real estate sector in the face of the huge number of promoterism residential structures available and the strongly growing need for apartments. The reconstruction of buildings of the era of promoterism is realized virtually at the point of intersection of architectural and building-cultural issues as well as construction-related legal requirements for the attainment of binding energy and climate-political targets in conjunction with the search for adapted technical solutions that can be implemented in a user-adequate and cost-efficient manner.

The project "Gründerzeit with future prospects" that was launched in 2009 within the scope of the research and technology program *Building of tomorrow Plus* of the Federal Ministry of Transport, Innovation and Technology and will run till 2015, is committed to this assignment.
In addition to basic research work on technological, economic, legal and social-scientific issues, individual sub-projects stretch from component development up until the implementation of demonstration projects. Innovative reconstruction solutions will be developed on the basis of five demonstration objects that may be used as a model for houses of the promoterism era and

subjected to comprehensive power consumption and comfort monitoring.
The major objectives in the implementation of innovative measures are the improvement of living comfort, reduction of energy consumption, usage of more efficient and possibly CO_2-neutral heating systems, improvement of architectural quality and thereby, overall guaranty for a contemporary living standard. The prerequisite is, in any case, a sound static condition of the respective building since the measures required for the static retrofitting of the object – particularly in the event of a planned expansion of the attic – may by far, transcend all economic considerations.
Attention should be drawn explicitly to the fact that this is not about simply “wrapping up” houses of the promoterism era and thus “sacrificing” a central urban architectural building segment to a banal efficiency and modernization approach. On the contrary, the major challenge lies in developing innovative solutions for buildings of the promoterism era that are structurally adequate and technically as well as economically implementable.
The spread of the results – multipliable innovative reconstruction concepts that are particularly adapted to the conditions of the stock of promoterism buildings – will be realized amongst others, through the project website www.gruenderzeitplus.at.

2. Energy efficiency and technical solutions [1]

There is a widely held view that the energy-technical quality of buildings of the promoterism era is “not so bad anyway” given the “thickness of the solid brick walls”. This is correct only insofar as a building of the promoterism era has better average values than for instance, a non-reconstructed building of the 1960s. the fact however is that buildings of the promoterism era with a typical thermal heat need within the range of 120-160 kWh/m².a is “worse off” by the factor 5 to 10 than residential buildings that are newly constructed in accordance with today’s customary low-energy or passive house standard. By replacing windows alone, the energy performance of a building of the promoterism era can be improved by just 10 percent.
On the contrary, innovative reconstruction measures can translate into a thermal heat requirement of less than 30 kWh/m².a also for the stock of the promoterism era thus attaining a contemporary energy-technical standard.
It can also be justifiably argued that not all technical standards based on today’s criteria should be applied to historical buildings; this fact is also reflected in the Building Ordinances of the Federal States with numerous exceptional provisions for buildings with segmented façades, buildings in protected zones or monument-protected buildings. Practical examples however show that there are still enormous architectural and technical potentials lying dormant also in buildings of the promoterism era, with which excellent results can still be achieved even in relation to comfort and ease and that have so far, hardly been exhausted.

3. Legal challenges [2], [3]

Major legal questions in the reconstruction of buildings of the promoterism era arise in connection with the utilization of neighboring plots in the insulation of fireproof walls (minimum standard of energy vs. property), for sustaining side gaps and building lines (intrusion in the subjective rights of neighbors) as well as in respect to restrictions in monument-protected buildings and buildings in protected areas (public service restrictions).
While reconstructing the demonstration building in Wißgrill Alley, the huge number of detached fireproof walls particularly proved to be problematic because the installation of insulation on the firewalls requires the consent of the neighboring property owner. There can be no insulation without such consent – a delicate issue that was successfully resolved through high communication competence and creative offers. Even though detached fireproof walls do not constitute any architectural characteristic of buildings of the promoterism era, they may constitute up to one-third of the façade area. The insulation of the fireproof wall is thus compelling from the point of view of energy efficiency and living comfort.

4. Costs and Economic feasibility [1]

The decision on if and how a building of the promoterism era should be reconstructed depends largely on the costs of the measures implemented as well as on economic feasibility. From the point of view of the property owner, the user-investor dilemma – seeking to ascertain if the measures (window replacement, façade insulation, renewal of the heating system) associated with energy savings “pay off” – is of less relevance as a consequence; rather it is more relevant if a (higher) overall dividend can be achieved in the medium to long-term. In the process, not only will investment costs and attainable savings flow into the costs of energy, but also the usage of residential building promotion funds and finally also, tax-related aspects. Moreover, it is also customary practice to expand the attic in the reconstruction of a building of the promoterism era, which in most cases, finally enables the realization of positive overall proceeds. The reason for this is that tenancy-rights-related statutory provisions strictly regulate rents that can be charged. In case of reconstructed old buildings, reference value rent applies to fresh tenancy, and clearly higher rent can be charged for reconstructed attic apartments. Should residential building promotion funds be used however, only a so-called maximum covering sum can be charged for the term of the state loan; the tenant will then be paying back the complete costs of reconstruction; proceeds will be realized only thereafter.

5. Monitoring

To be able to make a clear statement on the actual performance of the building and the individually applied technologies, buildings must be subjected to a technical power consumption and comfort monitoring. In addition to the measurement of power consumption and comfort parameters, user-satisfaction and economic feasibility of the reconstruction measures can also be evaluated within the course of extensive monitoring. From the viewpoint of building developer and property owner, monitoring constitutes a significant instrument of quality assurance with multiple benefits. In addition to the high level of safety during initial operation and acceptance certification of the building, the constant optimization of operational management leads to a reduction of running expenses and thereby, to the improved rentability of the building. In addition to this, learning experiences that have been gained and facts acquired with respect to the behavior of the building will be used directly in future projects.
In the course of the leading project “Gründerzeit with future prospects”, documentation and the related monitoring will be done in line with Best Practice examples through a period of two years. For the first time ever, highly innovative reconstruction measures will be applied on promoterism buildings in the individual demonstration projects and subjected to attendant research works covering the following dimensions:

- Documentation of applied technical reconstruction measures particularly innovative measures on the building shell and the building equipment and appliances
- Documentation of the costs of the innovative reconstruction measures for investment and running operational management
- Monitoring of energy consumptions and central comfort parameter through two years including evaluation and the optimization of operational management
- Social-scientific attendance through survey conducted on residents (satisfaction with reconstruction particularly with the innovative measures implemented)
- Certification in accordance with the Building Evaluation system TQB
- Recapitulative evaluation and presentation of results, conclusions regarding further development of the funding of residential constructions

6. Demonstration buildings

6.1 Demonstration project Wißgrill Alley [4], [5], [6]

The first demonstration project was successfully completed already at the start of 2011. It is a comprehensive reconstruction including the expansion of the attic that was implemented by Ulreich Bauträger as property owner and building developer along with Gassner & Partner as General Contractor for planning and design.



Object Wißgrill Alley before and after comprehensive reconstruction and attic expansion (Photos: Ulreich, Gassner & Partner)

The building in Wißgrill Alley in Vienna Penzing was constructed at the turn of the millennium and thus belongs to the category of houses of the promoterism era. The object is in the direct proximity of a rail route and has a huge number of detached fireproof walls and a segmented street façade.
The holistic modernization of the building was at the forefront of the demonstration project to guaranty a contemporary living standard with high living comfort. The aim was to present a sustained system solution with the energy refurbishment of the old building and the highly efficient expansion of the attic, which shows reproducibility for a good number of houses of the promoterism era. A qualitatively highly valued reconstruction of the building could be realized through the implementation of the following measures:

- Joining of apartments for the realization of the contemporary concept of space
- Expansion of attic floor for the creation of additional utility area
- High insulation standard of all external structural components
- Renewal of all windows and doors
- Airtight design of structural component connections
- Integration of thermal solar panels in façade area
- CO_2-neutral thermal supply through pellets-central heating system
- Renewal of all supply lines through central access
- Application of efficient building equipment and appliances and external illumination with LED
- Draining of basement floor for the sustenance of the structural substance of building
- Roof integration of photovoltaic modules as isolated application for an attic apartment
- Automatically-controlled sunshade system on the attic floor
- Integrated greening on slanted roofs and flat roofs
- Creation of balconies and terraces in yard
- Area greening also spanning neighboring yard and designing of exterior space
- Erection of elevator within the building

Altogether, the thermal heat requirement could be reduced by more than 80%, it is approximately 30 kWh/m²a in the essential part, 17 kWh/m²a on the attic floor. The attainment of the target values could be confirmed through energy consumption monitoring.

The applied controlled inflow and outflow ventilation systems contributed significantly to the

efficient reconstruction through heat recovery. A reason for the decision to install the controlled ventilation devices was the location-related high level of dust and noise exposure due to proximity to the rail route. To generate facts for other construction projects, the building developer decided to also partially apply ventilation solutions without heat recovery in addition to devices with heat recovery to investigate impacts from a measurement-technical point of view. This facilitates the direct comparison of the performance of the individual ventilation variations.
Four different ventilation concepts that were captured from a measurement-technical point of view and are to be evaluated, were applied in Wißgrill Alley:

- Central comfort ventilation system for apartments in newly expanded attic floor and partly in the main part of the building
- Single room ventilation devices with heat recovery system
- Apartment-wise waste air facilities with window frame ventilation
- Window ventilation

As is well-known, the behavior of the user has the strongest impact on the comfort parameters CO_2 content and relative humidity, which provides information on the quality of ambient air. Yet the comparison of the CO_2 content of the 4 ventilation concepts applied shows clear differences. The CO_2 content in comfort ventilation ran quite constantly through the period of 3 months. Only a few measurement values exceeded the reference value in accordance with Pettenkofer of 1000 ppm. The measurement values of the remaining ventilation concepts are subject to a much higher band width and are constantly at a higher level. A tendency can be observed, towards a drop in the CO_2 content of the single room ventilation device and window frame ventilation during the months of summer. This is attributable to the additional length of time in which the windows are kept open when external temperature increases.

6.2 Demonstration project Kaiser Street

The reconstructed demonstration object in Kaiser Street of the 7th municipal district of Vienna is the monastery building of the Congregation of the Mission of the Holy Vincent de Paul (short: Lazarists). The planning and local building supervision was done by Architect Kronreif_Trimmel & Partner (Arch. Günther Trimmel). The building was erected in 1904 and is part of a square ensemble comprising a church and a residential building opposite the monastery. The complete ensemble is monument-protected. The reconstruction that was completed in May 2013 shows that a modern living standard is possible even upon compliance with the requirements of monument protection.

In addition to the thermal reconstruction of the roof truss, yard façade and fireproof walls and the application of a central ventilation system with heat recovery and particularly the installation of interior insulation and complementation of the box-type windows to be sustained by applying inward lying wooden window frames that are suitable for passive houses, can be highlighted as innovative reconstruction measures.

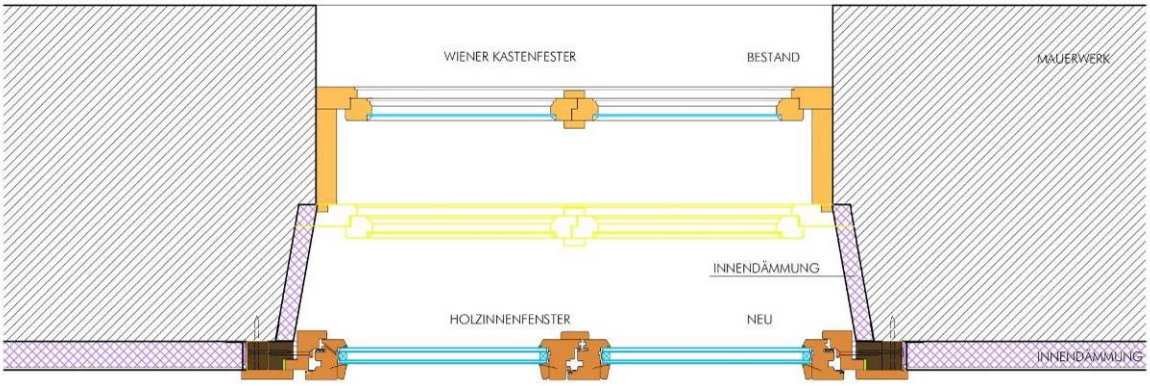


Square and Street view of Kaiser Street before and after reconstruction (Photo: AKP)

External insulation did not come into question in the face of the sustenance-worthy, segmented closer façade comprising small ceramic tiles. The thermal improvement of the building shell was possible only through the application of interior insulation.

The possible consequences of different interior insulation systems were highlighted, evaluated and examined for damage hazards. The major parameters for hazard assessment in the process were external impacts such as climate and exposure to driving rain, internal impacts such as interior air humidity and user's behavior and structural component-related impacts such as water absorption and water retention capacity and the diffusion behavior of construction.
Investigations carried out by the Construction Physics company Schöberl und Pöll using the software Ham4D_VIE of the Technical University of Vienna revealed a maximum insulation strength under conservatively assumed marginal conditions with capillary-active material of 2.5 cm for the long-term safety of the structural component.[7]
The structural-physical computations made by the company Xella Porenbeton were done using the non-steady computation program WUFI-Pro 5.0. According to the simulation, there will be no further rise in the water content of the brickwork in the following years at 8 cm interior insulation. The complete wall structure dries up in the dry seasons of the year and there is subsequently, no increased accumulation of humidity in the wall construction.
In the aftermath of the computations and experience reports, a 5 cm strong insulation system without diffusion barrier and with capillary-active mineral insulation board was applied.
To counter the uncertainties emanating from the structural-physical simulations regarding the maximum strength of interior insulation, the construction was subjected to permanent monitoring. Together with the Technical University of Vienna, the structure is monitored at different cross-sections within the scope of "Gründerzeit with future prospects" using measurement sensors integrated in the brickwork and the risks or eventual accumulation of moisture ascertained and evaluated.

Solution was worked out for the reconstruction of the monument-protected box-type windows in cooperation with the Federal Bureau of Monument Protection, in which the external wings the box-type windows are retained, maintained and refurbished. The interior wings are dismantled, the box extended and a wooden window suitable for passive houses and with 3-fold thermal protection glazing installed. The overall U-value of the window construction is specified by the window constructor as Uw= 0.9W/m²K.



Kaiser Street: Box-type window with interior insulation, old interior wing shown in yellow (Source: AKP)

6.3 Demonstration project Eberl Alley

Another demonstration object in Eberl Alley, 2nd District (Property owner: Kronberger, Planning: Schöberl&Pöll) is to go down in the history of refurbishment in Vienna, as the first house of the promoterism era that is reconstructed in compliance with passive house standard. The house that

was erected in 1888 was badly damaged in 1945 after being struck by a bomb and was reconstructed in the year 1952. The windows overlooking the street were replaced by plastic windows in the seventies. The peculiarity is that reconstruction is performed in cooperation with all tenants and can be implemented without renting-out.





Pilot Project Eberl Alley: First reconstruction in Vienna in passive house standard (Photo: Kronberger)

Since no building of the promoterism era has ever been reconstructed as passive house all over Austria, the project commands a high demonstration value. The reconstruction of the façade to passive house quality and the installation of passive house windows and doors as well as the high quality insulation of the ceiling of the lower floor stand out as major actions undertaken. Moreover, an additional living room was created in the course of expanding an attic floor. The reconstruction contains the renewal of the complete building equipment and appliances and electro-technical equipment including conversion to energy-efficient lighting system. A groundwater thermal pump and a photovoltaic facility were installed for the supply of heating.





Eberl Alley: Groundwater thermal pump and extraction well

A reduction of thermal heat needs by more than 90% was attained through the measures adopted. The energy balance sheets of the building show that the designated reconstruction measures

achieve passive house standard on one hand while immense energy savings are generated on the other hand. With innovative refurbishment measures implemented and adequate power supply put in place, the overall assessment of energy indicates that savings in excess of 80% can be realized specifically in relation to thermal heat needs, energy needs, primary energy needs and CO_2e emissions!
In addition to the positive ecological impacts, modern living standard can be created by increasing thermal comfort and reducing energy consumption following the implementation of the innovative package of measures.

6.4 Demonstration project David‘s Corner [8]

The ensemble of three buildings of the promoterism era in Vienna Favoriten forms the corner of a typical perimeter block development. But for a few exceptions, the 34 residential units were still in their original room-kitchen configuration. Altogether, the three buildings including the 5 business premises on the ground floor have a utility area of 2,350 m². Two objects have a cleared façade, one object, a fully preserved segmented façade. The objects were in a state that strongly requires reconstruction (moisture, leaking roof, leaking windows etc.). With warehouse halls covering most of its area, the yard was in a desolate situation. The thermal heat requirement of the 3 objects before reconstruction was about 121 kWh/m²a, heat supply was realized through gas converters, while hot water preparation was realized through electrical storage heater in individual apartments.
The buildings are owned by Condominium Immobilien. After a long planning phase, the project is being implemented by Bluewaters, the real estate trustee chancery Dirnbacher, Treberspurg & Partner Architekten and Imoplan ZT for building equipment and appliances. Completion is scheduled for 2014.



Ensemble David‘s Corner, Yard view in accordance with planned reconstruction (Photo, Graphics: Bluewaters)

At the center of the project is the joint development of all three objects. In addition to the restructuring of the yard that will also span neighboring plots and the joining as well as redesigning of the residential layout plans, thermal optimizations make up all external structural components, the efficient expansion of the attic floor and the joint house service facilities-related development of the ensemble make up the peculiarities of this demonstration project. A controlled living room ventilation system is applied with heat recovery in combination with central heating supply with low temperature heating system supported by a solar-thermal facility. The thermal heat requirement can be reduced by factor 5 through the refurbishment measures adopted.
The implementation of the overall concept shows that a highly grade energy-related refurbishment is not only technically feasible with the availability of the respective large utility area but also economically feasible in non-profit yielding locations.

7. References

[1] AMANN C. et al.; Gründerzeit mit Zukunft Subprojekt 2: Grundlagen und Machbarkeitsstudien, 2012
[2] HUETTLER W., SAMMER K.; Innovative Sanierung von Gründerzeitgebäuden – Technische Optionen und rechtliche Fragen; Immolex 9/2010 237-243, 2010
[3] HAVEL M.; Qualitativ hochwertige Sanierung von Gründerzeitgebäuden – Arbeitsbehelf für Sanierungswillige aus der Sicht der Praxis, 2011
[4] JOERG, B.; RAMMERSTORFER, J.: Lüftungsanlagen in Gründerzeitgebäuden – Machbarkeitsstudie im Rahmen des Leitprojekts „Gründerzeit mit Zukunft“, 2011
[5] GASSNER R., ULREICH H.J., AMANN C., HUETTLER W., RAMMERSTORFER J., VARGA M.; Machbarkeitsstudie für das Demonstrationsprojekt „Wißgrillgasse“, 2010
[6] RAMMERSTORFER J. et al.; Gründerzeit mit Zukunft Demonstrationsprojekt Wißgrillgasse – Dokumentation und Monitoring, 2013
[7] SCHOEBERL H.; LANG C.; HOFER R.; Thermische Sanierung von Gründerzeitgebäuden – Machbarkeitsstudie Innendämmung, 2011
[8] AMANN C.; RAMMERSTORFER J. et al.; Machbarkeitsstudie für das Demonstrationsprojekt „David‘s Corner“, 2010

Energy Demand Calculations – View from Above



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Short Summary

Paper deals with energy demand calculations based on stochastic principles. This allows for the use in very early stage of the design, because there is not necessary to wait for complete set of input data. At the same time, such calculations can be used for quick analysis of larger group of building having their main parameters within given range. Overall tendencies, possibilities of refurbishment etc. can be evaluated from the calculated results.

Keywords: Integrated building design, energy demand calculations, stochastic approach

1. Introduction

In principle, at least two different approaches in calculation and interpretation of theoretical energy demand of buildings can be identified. For the first approach, very detailed multi-zone and dynamic models are used, with the best possible description of all parameters, detailed information on building use, local climatic data etc. for one studied building. This is very useful especially for research on new technical systems, for analysis of measured data and for detailed performance estimation. Large amount of input data is needed.

At the same time, it seems to be necessary to have an instrument allowing the observation of the problem “from above” by slightly simplified calculation, but for larger group of buildings. This approach is suitable for overall assessments, for studies on tendencies in particular typological group of buildings, for setting of targets and policy making. Such approach can be used as a real design supporting tool as well – advantageously in one package from the very early stage of the design to final delivery of the project.

2. Procedure and input data

The core model remains in all studied cases identical, based on usual procedure according to international standard [1] The calculations using steady state monthly method are repeated automatically for large amount of combination of input data (typically several hundred up to thousands). Stochastic principles for selection of input data and for expression of the results are used [2].

In general, all input data can be set in different modes:
- exact value, if available,
- reference to standard or legislative requirements (upper limit or lower limit, as interval),
- most realistic default values created automatically within the software tool.

The results are expressed in the form of statistic evaluation of all calculations done for generated data sets (overall distribution, minimum and maximum for 90% of results, mean value, probability of reaching usual targets). A sensitivity analysis can be used for "fine-tuning" in the next step of the building design.

3. Examples

3.1 Thermal transmittance requirements

Example 1 represents the simplest use of this type of calculations. Discussion about future target level for mean value of thermal transmittance of building envelope was based on such results. Method of reference building [2] was used considering following value of thermal transmittance: wall 0,30 W/(m^{2}K), roof 0,24 W/(m^{2}K), windows 1,50 W/(m^{2}K), slab on the ground 0,45 W/(m^{2}K). Fig.1 illustrates clearly that setting of one constant limit only is not an optimal option. The effort for reaching of such targets differs by different group of buildings.

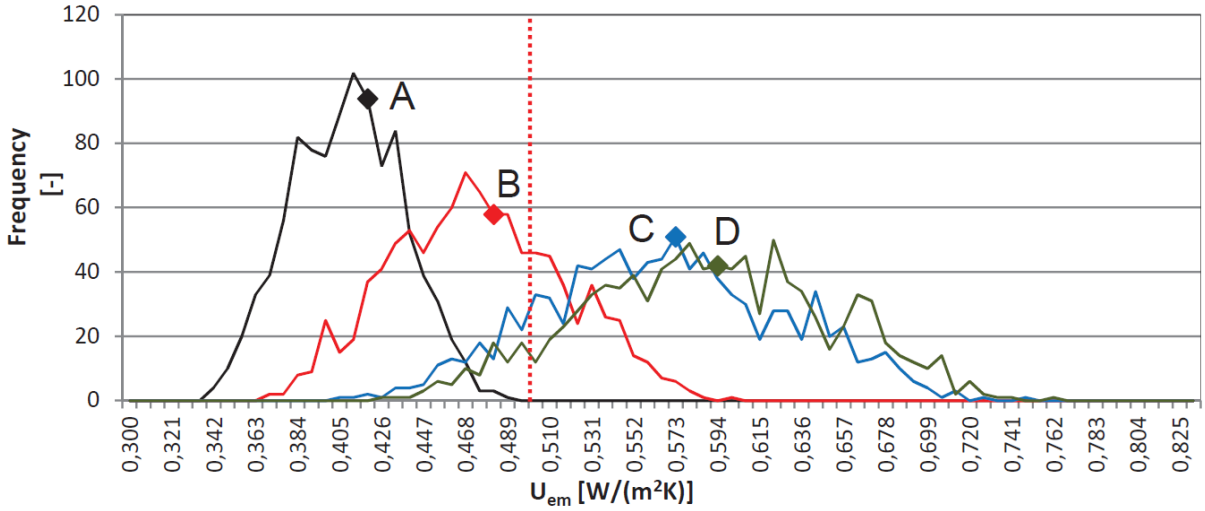


Fig.1 Distribution of mean value of thermal transmittance of building envelope (U_{mean}) for 4 types of buildings: small (A) and large (B) family houses, small (C) and large apartment buildings (D). U_{mean} = 0,5 W/(m^{2}K) represents the discussed requirement. Each curve represents results for 1000 combination of input data according tab.1.

Tab.1 Main input parameters for calculation in example 1

	Type	Built volume [m^3]	Number of floors	Fenestration ratio (differs per facade orientation) [%]
A	Small family house	240 – 560	1	5–35
B	Large family house	400 – 1 000	2–3	5–35
C	Small apartment building	1 500 – 6 000	4–7	10–50
D	Large apartment building	3 000 – 15 000	7–10	10–50

3.2 Space heating demand

Fig.2 brings overall information on apartment buildings with the built volume 5 000 m^3 – 8 000 m^3) having required value of thermal transmittance [2] by all building components. No data about building geometry was known. Different information was available on heat recovery from ventilation air and about number of inhabitants.

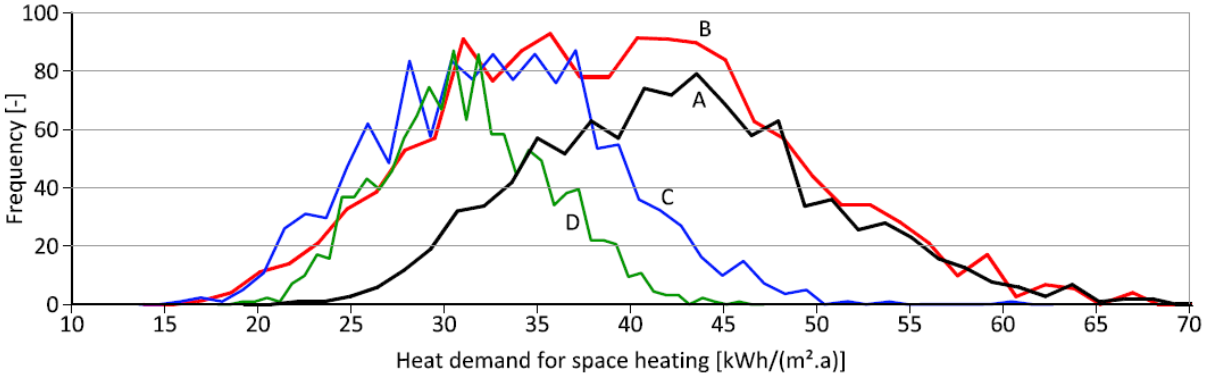


Fig.2 Comparison of heat demand for space heating of middle size apartment buildings with required values of thermal transmittance [2]. In cases A, B, C no information about building geometry, orientation, compactness, fenestration ratio, shading and number of inhabitants was available. Following values were considered more exactly in case D: Built volume 6500 m^3, number of inhabitant 45. Overall efficiency of heat recovery from ventilation air was considered as follows: A no recovery, B no information about heat recovery available which means the efficiency varies from 0 % to 70 %, C and D: efficiency 70 % exactly.

3.3 Refurbishment targets

The stochastic method was used to analyze the energy saving potential of refurbishment of middle-size apartment buildings. This set of virtual buildings is characterized by simple cubic form, built volume in the range 5.000 m^3–8.000 m^3 and 4 to 8 floors. The compactness level varies in the range 1,0–1,2. Compactness level is defined here as the ratio of the area of vertical part of building envelope to its possible minimum for given geometry. The dimensions are created automatically within the given parameters for each round of calculation. Fenestration ratio is considered for each façade orientation as follows: S 35 %, W 25 %, E 25 %, N 20 %. The number of inhabitants is determined indirect as 35 m^2/person.

The stochastic energy demand calculation was performed for the existing stage and for different levels of refurbishment (Tab.2) in 1.000 plausible combinations in each case. The results are presented in Tab.3 and Tab.4. For the first two refurbishment levels (envelope upgraded to today's requirements or recommendations, respectively [3]) natural ventilation is expected. Mechanical ventilation with heat recovery is planned for higher levels of refurbishment. Level 04 contains components suitable for passive house level. Only level 05 expects the change of layers in floor slab (mostly very costly and complicated operation). The generated geometry of the overall sample of buildings is characterized by a mean value of A/V (surface area/volume) 0,37 m-1 and a mean value of floor area 1.980 m^2.

Tab.2 Basic data on energy quality of virtual apartment building in Example 3

Altern.	Thermal transmittance U [W/(m^2K)]				Heat recovery efficiency [%]
	Wall	Window	Roof	Floor	
Exist.	1,40	2,5	1,0	2,0	0
01	0,30	1,5	0,24	2,0	0

02	0,25	1,2	0,16	2,0	0
03	0,25	1,2	0,16	2,0	70
04	0,20	0,9	0,10	2,0	70
05	0,20	0,9	0,10	0,45	70

Tab.3 Summarized results for Example 3

Altern.	Mean value of thermal transmittance U_{em} [W/(m^{2}K)]	Heat demand for space heating [kWh/(m^{2}a)]			Probability of reaching targets of 50 kWh/(m^{2}a) [%]
		Mean	95 % of values		
			above	below	
Exist.	1,42	145	118	176	0
01	0,56	52	37	70	45
02	0,48	42	28	58	78
03	0,48	28	19	38	100
04	0,39	20	13	29	100 (passive by 14 %)
05	0,35	17	10	25	100 (passive by 35 %)

Tab.4 Space heat demand and potential for its reduction evaluated from mean values for buildings in Example 3

	Exist.	01	02	03	04	05
Space heat demand per capita [MWh/(pers.a)]	5,5	2,0	1,6	1,1	0,8	0,6
Reduction of space heating demand [MWh/a]	----	177	194	222	237	244

4. Conclusion

The described method has a large potential for further development by increasing of building typologies, by setting default values for different climatic conditions. A simplified but correct estimation of cooling energy demand would be welcomed as well. For educational purposes and for wider use a computer tool with simple dialog via internet was already prepared [4]. It enables quick evaluation of space heat demand, in each case based on 1000 combination of input data for studied apartment building (or group of buildings). Similar approach could be effectively used during evaluation of applications for public support of energy advanced solutions. This approach was used [5] for overall estimation of total costs (investment + operation costs in 30 years) for apartment buildings in the discussion about cost-optimum level requirements [6].

Acknowledgements
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References

[1] EN ISO 13790 Energy performance of Buildings – Energy use for space heating and cooling
[2] TYWONIAK J, ANTONÍN, J, KOPECKÝ, P. "*Stochastic Approach for Useful Energy Performance Calculations"* Proceedings SB13 conference, Munich, 2013
[3] CSN 73 0540-2 Thermal protection of buildings. Part 2: Requirements, UNMZ 2011
[4] http://optimalizacebudovy.fsv.cvut.cz
[5] TYWONIAK J, "*Report on testing of cost optimum methodology"* Study for Joint Research Centre EU, Institute for Energy, 2011
[6] Commission delegated regulation (EU) No 244/2012

CESBA – a collective initiative for the new building culture in Europe

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Short Summary

CESBA „Common European Sustainable Building Assessment“. is a collective initiative for the new building culture in Europe. To reach the EU 2020- goals a common, regional adaptable, mass-oriented approach is needed. CESBA as a bottom up policy harmonization process by project partners from several transnational EU-projects and delivers a framework for this highly political course. Join CESBA on http://wiki.cesba.eu/.

Keywords: CESBA, building culture, building assessment, Europe, bottom up process, open source, NENA-Network

1. CESBA – a collective initiative for the new building culture in Europe

The building sector is a cornerstone of the EU climate protection program and has an important role to play in the achievement of the Europe2020 strategy, in particular in relation with the flagship Initiative “Resource efficient Europe”. The significance of the sector is illustrated by the fact that the construction market accounts for 10% of GDP in the EU and that construction and use of buildings influence 42% of energy consumption and about 35% of greenhouse gas emissions.

Further buildings play a central role in our societies, providing places to live, work or enjoy leisure activities. They are the basis of our urban environment, impacting the social, economic and ecologic aspects of our lives. Indeed, our health, comfort and safety as well as our economy and our natural environment are strongly connected with the construction sector activities.

Building culture is not only defined by the sum of certain quality indicators. The processes including certification, training and assisting services along the whole building life-cycle are significant parts too. However, the plethora and mismatch of building regulations at EU and national levels leads to considerable administrative burdens, confusions among the actors and to a very fragmented sustainable construction market.

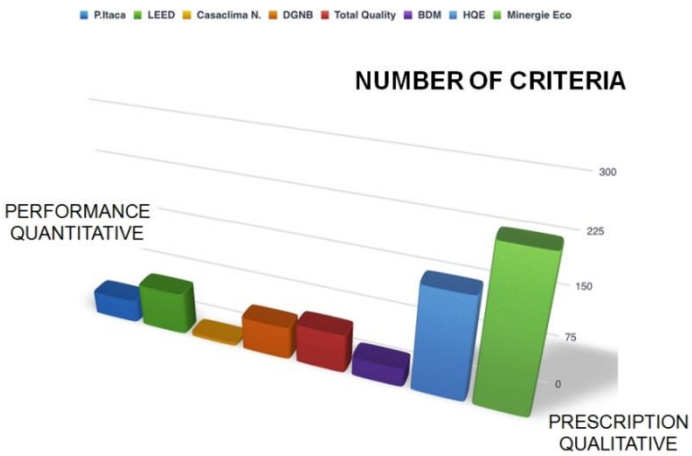
2. Toward the harmonization of sustainable building assessment

Since the launch of the first environmental building assessment system in 1990 (BREEAM), the number of labels and certifications in Europe has proliferated, in particular in the last period.
A transnational survey and comparison of the existing sustainable building rating systems available in Europe has been carried out in the context of the Interreg projects Enerbuild (Alpine Space) and IRH-MED (Med). The surveys showed that more than 60 different assessment systems are

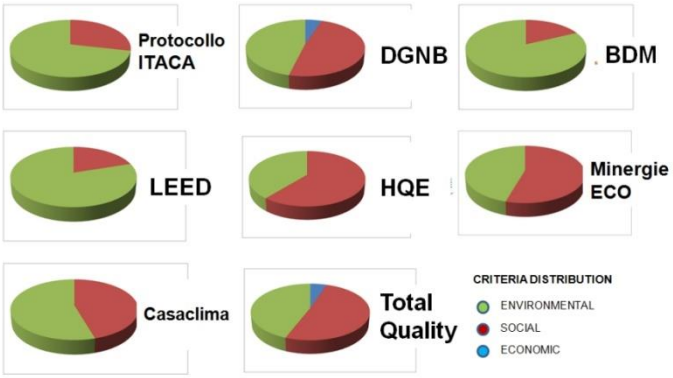
available at local, national and international level but also that they differ in many important aspects. The main consequence of the absence of a common approach is the impossibility to compare the assessment results produced by the different tools. Consequently the scenario seems very confused.

The main critical issues that emerged from the study are:

- very different frameworks of the assessment tools;
- different assessment methods: coexistence of performance based and strategy based tools;
- different number and type of issues included in the tools;
- different ways to score the performance.



Different number of criteria in some of the main certification systems



Different distribution of criteria among the key issues: environmental, social and economic

These substantial differences between the assessment systems are not facilitating their wide diffusion at the European level. Common public policies and common market actions would need a common approach. The first steps toward the needed harmonization of the sustainability certification systems should be:

- to define common principles regarding building sustainability certification;
- to define a core of common criteria and indicators that would allow a comparison between the performances of buildings certified with different labels.

The first point concerns the need to agree for instance about the sustainability issues that should be taken in account, the assessment methodology, the contextualization procedures and the structure of tools. The second point means that it would be necessary to identify at European level a common set of key criteria (and relative indicators) that should be adopted by the national/regionals labels in the way to allow the comparison of buildings performance.

To reach this objective the CESBA framework has been launched starting from the clustering of several EU projects that have addressed the issue of sustainable building assessment harmonization: Enerbuild, AlpBC, CABEE, Marie, IRH-MED, CEC5, OpenHouse, SuperBuildings. The idea is to implement a common platform between the European regions with the objective to follow in the definition of a common approach to environmental building certification and to promote the harmonization of certification systems.

The core of CESBA initiative will be the common European set of assessment criteria for sustainable building. The aim is to establish a shared least common denominator for the rating systems used in Europe, in the way to make possible a comparison between the labels and to have a common understanding of environmental, social and economic priorities. More specific set of criteria, context based, will also be defined at macro-regional level (Alpine regions, Mediterranean regions, North regions, etc) and at regional level.

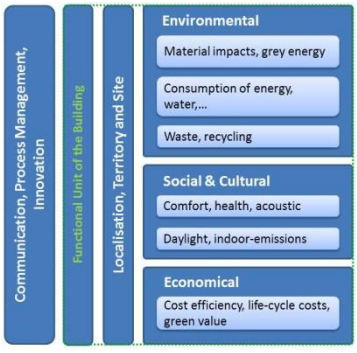
3. CESBA – Common European Sustainable Building Assessment

The development and implementation of new standards require synergic actions and initiatives. Current building assessment tools not only have variable elements including structure analysis, assessment methodology, and the identification of variable impact issues but also use different scoring methodologies. This lack of conformity makes comparison of results difficult. A harmonization is needed.

The participation of the civil society is essential in the bottom-up approach of generating common mass-oriented, open-source building sustainability assessment guidelines as well as in the establishment of building standards for the constructing of building stock itself. The system of analysis that describes the sustainability quality of buildings must be transparent to the layman.
As Europe is a mélange of regional building cultures European buildings standards must be open to regional needs and circumstances.

CESBA discuss and unites following aspects of future building culture:

1. Quality indicators to measure the quality of the building processes and the achieved quality standards. These indicators consolidated in the following framework, which goes along with the suggestion done by CEN/TC 350 and 6 European projects:



2. Integration of all aspects of the building life cycle: Services, Trainings and Certification processes for all aspects along the building life cycle. Purpose and target setting, design tendering, Planning, Procurement, Implementation, Commissioning, Monitoring / Usage.



Performance indicators can play an important role in all the life cycle stages of a building and for different key users. Investors and developers can use them to define the performance targets. Public organizations in defining the tenders for Green Public Procurement. Professionals as guideline in the design phase and comissioning. In the use phase the indicators allow to understand if the building is correctly managed.

The adoption of shared common reference indicators by building certification systems, training organizations, consultancy activities, etc.. will facilitate a common approach at European level toward sustainable building. This would help the fulfillment of the EU objectives in this field.

4. The “Mass certification” approach

One of the main intents of CESBA is to promote the mass certification of public buildings firstly, and private buildings as next step. To reach the objective of 100% of buildings certified, it is necessary to adopt assessment systems that follow some key principle:

- regional contextualization. The assessment systems must reflect the local environmental, social, economic priorities. This has to be reached adopting an opportune weighting system of criteria;
- open source. The framework will be developed with the contribution of all the stakeholder in building sector. A shared framework has a better opportunity to be accepted and to reach a wide diffusion;
- use of local technical standards. Professionals are usually trained about energy calculation methods adopted locally and that are used in the mandatory energy certification. The request to perform calculation using technical standards used or developed in other countries or regions could be a barrier to the diffusion of building assessment;
- time effective. The assessment process has not to request too many time resources. For this reason the mass oriented assessment systems shouldn’t include a large number of criteria, focusing on the assessment on the key ones;
- low cost. The overall cost of the building assessment and certification process should be not expensive. High cost are a major barrier in the diffusion of environmental labels.

These characteristics are more used for the assessment systems promoted by public organizations and usually applied in tendering, incentive based policies and building regulations.

5. Next steps for CESBA:

1. Defining and collecting front runner projects and activities in all parts of CESBA, establishing an open source knowledge-hub - http://wiki.cesba.eu/. The wiki approach will facilitate the increase of the CESBA framework trough the contribution of experts all around Europe;

2. Holding follow up meetings and open exchange among all stakeholders – common CESBA Sprint Workshop http://www.cabee.eu/events/. Exchange and interaction between the stakeholders is considered a priority in the CESBA process. CESBA is a multi-user framework that intends to be used by all the stakeholders in the building sector;

3. Structuring the collective process (CESBA task force, regional CESBA contact points). CESBA is characterized by an open source approach. This means that it is requested the collaboration and contribution of the collectivity that will be reached by means of the establishment of local contact points.

4. Further political engagement of all kind of stakeholders including civil society. To reach the objective of adopting a common approach to sustainable building assessment is fundamental to obtain the political sustain of the stakeholders. For obtaining it, specific actions will be implemented to disseminate the CESBA open source approach.

5. Promotion and collaboration activities JOIN CESBA - http://wiki.cesba.eu.

Human Scientific Factors to Enhance Life Cycle Sustainability of Housings



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Short Summary

The presented work is dealing with psychological and physiological contributions to enhance the performance of blue, green or smart housings and dwellings.

Based on scientific research results the main goal of the work is to define ways of enhancing the life cycle sustainability of housings by considering the human quality factors.
Another task is to explain the thesis that sustainability without humanity is an insufficient goal and with regard to housing structures hardly realizable.

Within the paper a scientific methodology (Research Report Part I) will be presented which is able to analyse precisely the human quality of housing projects. It comprises all essential factors which are relevant for the performance and acceptance of buildings from a human perspective. The topic will be explained in the form of real projects and respective research results (Research Report Part II).

Keywords: life cycle sustainability; housing; human quality; housing psychology; housing physiology; housing theory; housing quality analysis

(A) Introduction and Correlations

The **main thesis** of this work implies that humane building leads sustainable building. Concerning housings we can state, that without humanity there is of course no social, but also no economic, nor ecological sustainability possible at all.

This thesis can preliminary be explained (illustrated) by mentioning at least three correlations.

(1) Prolonging the duration of use and the life cycle endurance

There is one main causal connection to be considered: The higher the human quality of residential buildings the longer and more intensively they will be occupied on average.
Usually the by far biggest amount of resources and energy has to be spent during constructing buildings: It starts with the production of raw materials, the manufacturing of building materials, the fabrication of structural elements and components used for constructing houses. Next all these materials and products have to be transported to the building plot and at last the construction of the building itself. Understandably the whole procedures need lots of energy and resources. If we

take into account the whole life cycle effort of resources and energy, it becomes immediately clear that this initial stage of a buildings life cycle requires the by far biggest share.
Further high peaks of energy and resources effort are usually phases of reconstruction or remodelling. The final peak of a buildings life cycle is reached when demolishing and disposing the materials. Perhaps in a further step a new building will be erected and the life cycle starts again.
The longer the period between erection and demolishing the less resources are spent on average per year. The more years of occupation the lower the average amount of spent resources and energy.
Of course the ongoing consumption of energy (heating, cooling, electricity etc.) is of importance as well as the sort of used materials. But independently from this the duration of buildings "life" remains as one main (and often not fully recognized) factor of life cycle sustainability which used to be frequently underestimated or not even realized in its whole momentous context.

The duration of buildings existence usually depends on two major qualities: the technical/material/physical quality and the human quality.
As we all know the physical quality depends on the used materials and the structural engineering.
But what does the human quality rely on? That is depending on physiological, psychological and social factors (see below). What we can state in advance is that, the higher the human quality or living quality of a building the longer it will tendentially be used, the less often it will be reconstructed or remodelled in order to meet the human needs or even demolished and built new - which of course is related to the highest waste of resources and energy.
The longer the period of occupation, or more specifically the longer the period between constructing and reconstructing or demolishing the higher is generally the impact on life cycle sustainability.

(2) Reduction of urban sprawl and splinter development / dispersed settlements

The second aspect concerning sustainability and human housing quality is dealing with the topics urban sprawl and uncontrolled settlements in the open country - the so called dispersed settlements.
It is well known that dispersed settlements from an ecological point of view used to be highly problematic. First of all they produce much more traffic compared to compact settlements; second, the whole infrastructure that has to be build and maintained in order to reach every single house is enormous; third, they also usually need much more resources and energy during building and occupation; and so on. So this form of settlement used to be on principle not very sustainable at all.
But what has this got to do with housing quality?
The less quality high density housings are able to provide, the more often people tend to built their own "sweet" home out in the country. In order to prevent dispersed settlements we have to construct buildings of high living quality in higher density areas. Consequently we may reach the point that wishes to change the habitat do not come up in peoples minds that easily.

(3) "Leisure escape" from cities

The lower the habitation quality of housings plus surroundings used to be in cities and in high density areas, the stronger the intentions of people to leave the place any time they are able to. Human beings are usually looking for places which fit to their natural needs and which are offering some recreational values.
So some people seek to build or buy a second home close to nature if they can afford it. Some people are renting their little green spaces or allotment gardens where they can stay near the city. In Austria and parts of Germany such spaces are called "Schreber-Gärten". In Russia and eastern Europe the so called datchas are very common for the same reason. Usually a datcha is a small weekend house with a little garden around. Similar trends can be obeyed in many regions all over the world.
All these trends lead to the same consequences: They produce more traffic and also a higher consumption of energy and resources. And all these trends have the same purpose: to

compensate the deficiencies and errors of urban housings and housing developments.
If a residential area is able to provide a high habitation quality and additionally some recreational effects, the inhabitants would have less reasons to escape from their home at any spare time. And they would of course have less reasons to build or buy a second home in the nature, too.

Intermediate Conclusion

The term habitation quality or human quality reveals as one of the major factors for the sustainability of buildings and settlements. If we disregard the human quality factor in its whole momentous impact, the topic sustainability of housings can hardly be reached.

Concerning traffic and housing there are two studies recently published [1], [2] dealing with the connections between individual mobility and housing.
These studies are posing very clearly, that certain forms of housing produce either more or less individual motorised traffic. In very dispersed regions the level of motorisation is the highest. (Which means the number of motorised vehicles per 1000 inhabitants is the biggest.) This context is not a big surprise but there is another result which is very remarkable concerning the entire energy consumption of a family household including everything: heating/cooling, electricity etc. plus traffic. If one compares the overall energy consumption of a so called low-energy-house with car to an average standard house without car, the latter features a much more better performance.
Types of settlements where people need at least two or more cars are much less sustainable even if the buildings themselves were constructed in a sustainable way. As a first main conclusion we have to develop types of housings and settlements where people don't need cars or even do not have the desire to use them very often.
Other results of the studies show very clearly, that dispersed settlements require an outstanding higher amount of infrastructure concerning not only streets but anything else like electricity, water supply, wastewater disposal and so on. The effort is not only higher when constructing all the infrastructure but also during the whole life cycle for maintaining the infrastructure and keeping it in appropriate condition.
So what shall we do now? Shall we force people to live in high density areas? Despite the fact that this would not be very humane it would not be very effective too - because of (3).
It would be much more effective to develop housings and settlements of high density plus high habitation quality where people like to live and where they do not have the desire to escape anytime they can, where they are encouraged not to use cars but other forms and means of locomotion.
As a summary we can state that high density without high human quality is senseless and sometimes counterproductive.

If we consider the results of (1), (2), and (3) we can conclude that it all mainly depends on one central term - the human quality of housings. Therefore the first step ought to be explaining the "human housing quality", which has been done during the theoretical and empirical research presented in this paper.

(B) Research Report Part I: Housing Theory and Science

(B1) Background and Problem Definition

The theoretical research dealt with the exploration of the scientific basics for designing and analysing human living spaces (=human habitats). During the research an overall theoretical conception - a **theory of human habitat systems** (shortly 'habitat theory') [3] has been developed which is able to comprise the complex systemic interconnections between human being, dwelling and housing environment. The term 'habitat' includes in this context the whole living space related to housing: dwelling plus interior as well as exterior areas (green spaces, balconies, terraces etc.) and the immediate surrounding field.
The main aim behind was to generate a comprehensive theoretical conception which indicates profound conclusions for conceiving housings close to human nature and needs, based on

stringent scientific fundaments.
From the theoretical perspective there is a deep gap between architecture and human sciences.

- Architects are planning and developing habitat-structures (buildings and spatial structures). They are therefore concerning themselves with housings a priori – i.e. before they are inhabited. So the architectural education is mainly based on technical and artistic fundaments that are adjusted to the construction and forming of buildings.
- Human scientists (like psychologists) can rely on a wide scientific fundament that is primarily related to the human being. They are ordinarily investigating housings after they have been erected and inhabited for a while (i.e. a posteriori). The real objects of investigation are thereby human beings in the respective spatial or social context. They do not offer an appropriate methodology for analysing housing concepts. They may give advices by mentioning some relevant aspects from their special perspectives, but it is commonly not their aim to create theories for planning housing structures.

Behind that planning theoretical deficiency another main deficit is hidden. There has been no definition of the **human habitat** itself so far - a definition which is valid from a general scientific perspective and which describes the essential characteristics of a human habitat in a compact and practicable way - so that it can be used as a basis for the creation of a housing theory.

As one result of that splitting a scientific conception was missing which could define human habitats in such a comprehensive way that conclusions for forming and conceiving housing structures can be drawn. This "lack of theory"[4] has been mentioned several times in the respective scientific literature [5], [6] and has been extremely evident within the housing-related sciences, especially in architecture [7].

The specific aims of this work can be explained by mentioning the leading questions: Which characteristics do edificial or spatial structures have to feature in order to be able to become a humane living space (a habitat) in its best sense - and therefore also become sustainable in an human way? And: How can the human quality of a habitat be defined scientifically?
Leading hypothesis: The human quality of a habitat is determined by the quality and quantity of the actual and possible relations between the human being and his habitat plus environment. Therefore the whole "system" human-dwelling-environs (= habitat system) had to be ascertained and defined.
Working hypothesis: The human quality of a habitat can be defined by identifying the respective habitat system.
In this context the theory of human habitat systems is providing a tool to define the human quality of apartments, buildings, residential areas etc. - be they either planned or built.

(B2) Short Portrait of the Research Work

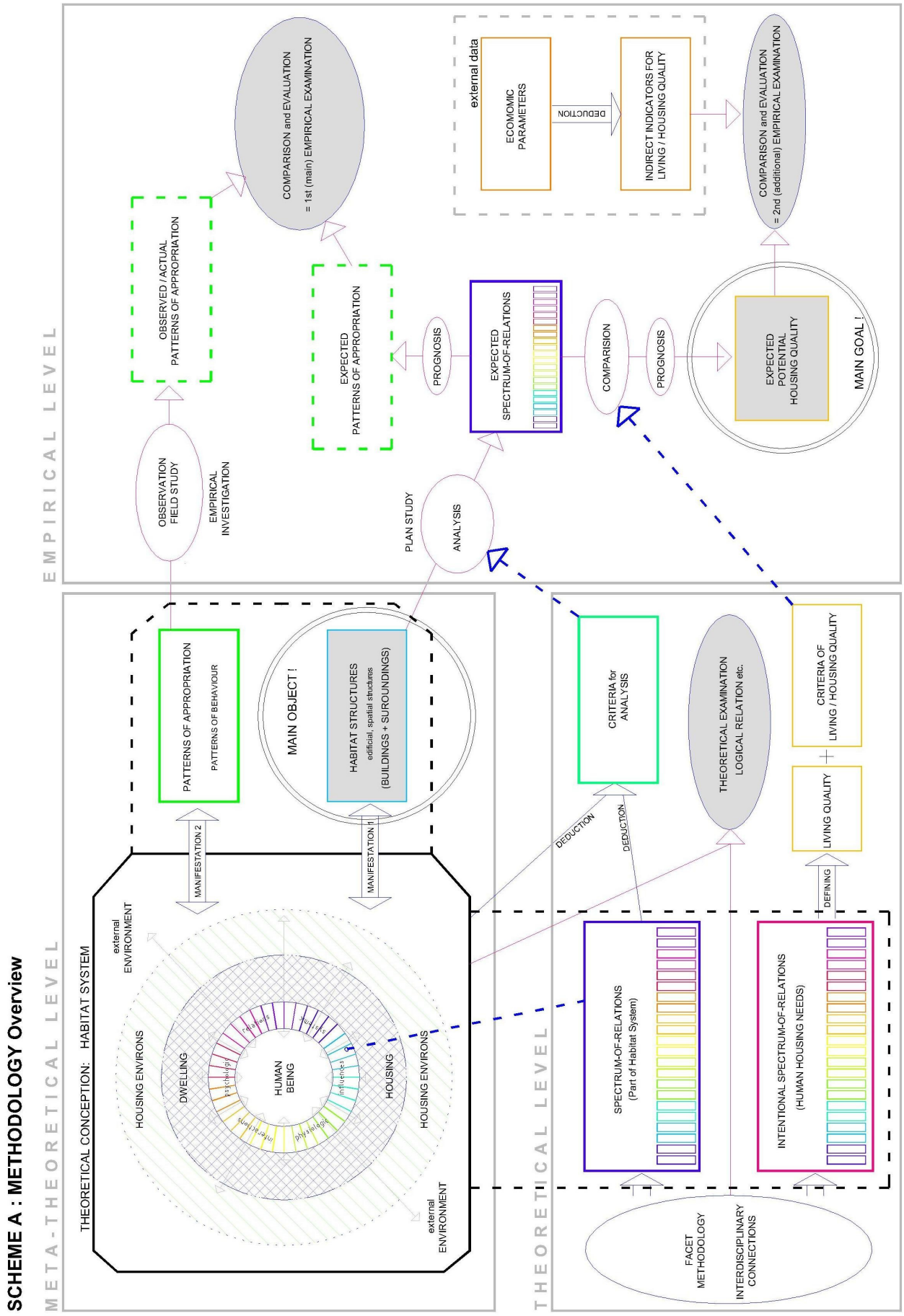
The research has been carried out on 3 main levels. (see also scheme A)

(1) Meta-theoretical Level (Scientific Theoretical Work)

On the first level the theoretical fundamentals - a **theory of human habitat systems** - had been conceived by a detailed definition of:

- the habitat system and its primary components/elements
- the relations and exchange processes, which are determining the characteristics of the system
- the interconnections between habitat system and the edificial, spatial structures (**habitat structures**) which are representing the physical manifestation of a habitat system
- the interconnections between habitat system and patterns of use and behaviour of their inhabitants (**patterns-of-appropriation**) which are representing the behavioural manifestation of a habitat system.

According to the main aim the theoretical conception has been composed systematically and pursuant to clear scientific theoretical principles (e.g. Logic of Research, C. Popper [8]). The **primary target** was to structure the theoretical conception logically and traceably with clear sentences which can be examined theoretically and/or empirically.


SCHEME A : METHODOLOGY Overview
META-THEORETICAL LEVEL
EMPIRICAL LEVEL
THEORETICAL LEVEL
THEORETICAL CONCEPTION: HABITAT SYSTEM
external ENVIRONMENT
HOUSING ENVIRONS
DWELLING
HUMAN BEING
HOUSING
PATTERNS OF APPROPRIATION
PATTERNS OF BEHAVIOUR
MANIFESTATION 2
MAIN OBJECT !
HABITAT STRUCTURES
edificial, spatial structures
(BUILDINGS + SURROUNDINGS)
MANIFESTATION 1
OBSERVATION
FIELD STUDY
EMPIRICAL
INVESTIGATION
OBSERVED / ACTUAL
PATTERNS OF APPROPRIATION
COMPARISON and EVALUATION
= 1st (main) EMPIRICAL EXAMINATION
EXPECTED
PATTERNS OF APPROPRIATION
PLAN STUDY
ANALYSIS
PROGNOSIS
EXPECTED
SPECTRUM-OF-RELATIONS
COMPARISION
PROGNOSIS
external data
ECOMOMIC
PARAMETERS
DEDUCTION
INDIRECT INDICATORS FOR
LIVING / HOUSING QUALITY
COMPARISON and EVALUATION
= 2nd (additional) EMPIRICAL EXAMINATION
EXPECTED
POTENTIAL
HOUSING QUALITY
MAIN GOAL !
CRITERIA for
ANALYSIS
DEDUCTION
DEDUCTION
THEORETICAL EXAMINATION
LOGICAL RELATION etc.
CRITERIA OF
LIVING / HOUSING QUALITY
LIVING QUALITY
DEFINING
SPECTRUM-OF-RELATIONS
(Part of Habitat System)
INTENTIONAL SPECTRUM-OF-RELATIONS
(HUMAN HOUSING NEEDS)
FACET
METHODOLOGY
INTERDISCIPLINARY
CONNECTIONS

(2) Theoretical Level

(2a) **Spectrum-of-Relations** and **Human-Housing-Needs** [10]

On this level the relations between the human being and his housing environment have been compiled. Which interconnections, exchange processes and relations are there on principle between a human being and his housing environment?
The first main target was to explain and define the relations within a habitat system, between a human being and his habitat, his living environment (the spectrum-of-relations).
The second main target was to explain and define the most important needs that are related to the habitat and generally to "homo sapiens". This is of special importance because the term "living/housing quality" can only be defined by the help of the so called human-housing-needs (the intentional spectrum-of-relations).
In order to meet these objectives, interdisciplinary connections have been assembled systematically. Especially human sciences like housing psychology first of all, as well as environmental psychology, social and developmental psychology, housing physiology, building biology etc. provided substantial contributions to the whole spectrum.

(2b) Theoretical Examination
The newly developed theoretical conception had to comply with the following criteria [9]: It has to be synthetic without internal contradictions. This also implies a theoretical examination in the form of logical analysis. It must not be metaphysical or esoteric etc. Which means that it must not defy examination, be it empirical and/or theoretical.

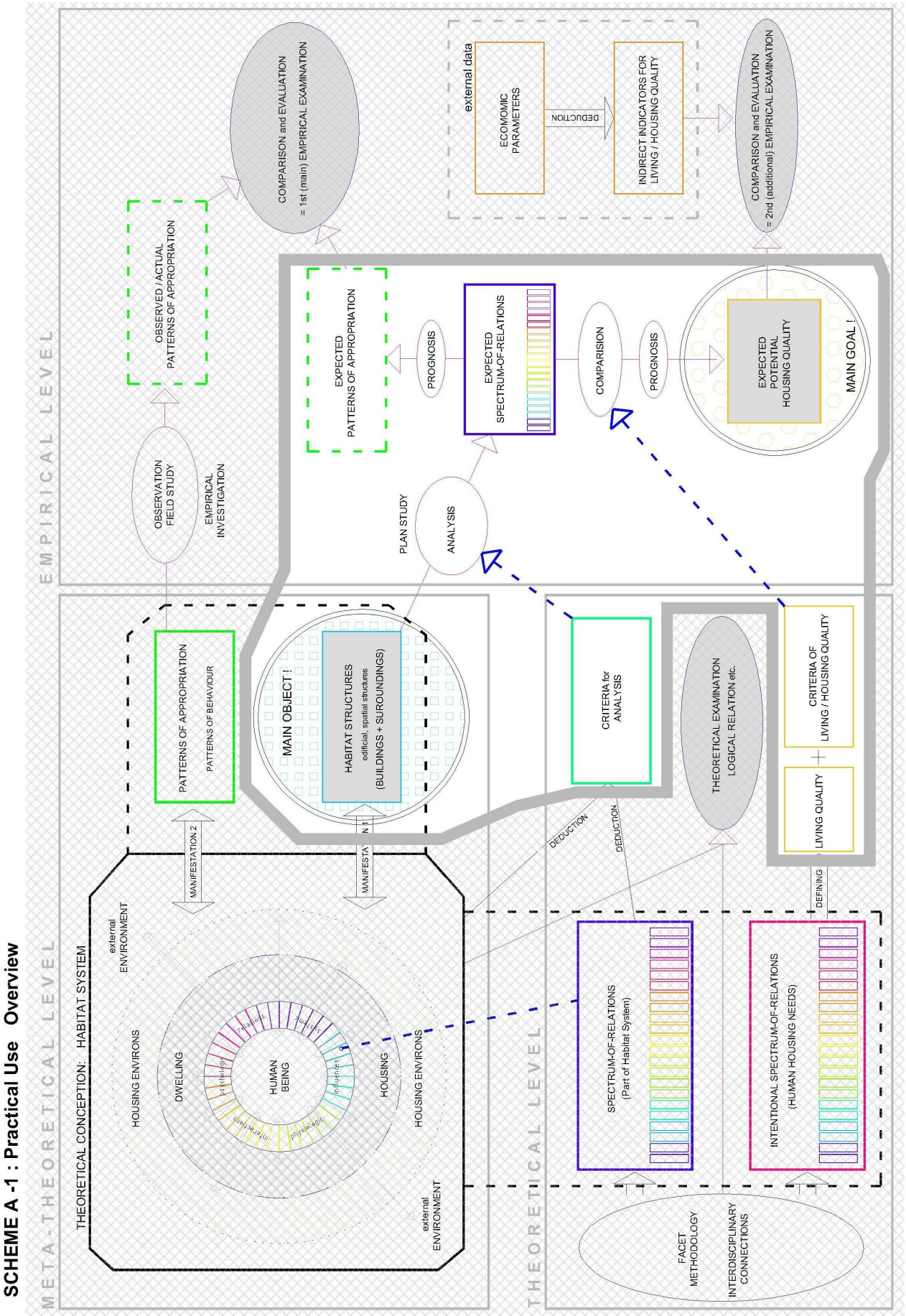
(3) Empirical Level

The empirical examination consisted of analysing existing housing objects.

(3a) **Analysing habitat structures** [11]
Step 1, Compilation of Criteria for Analysis: First the criteria and parameters for analysis have been derived from the theoretical basis (the human habitat system including the spectrum-of-relations). In this initial stage the **methodology of analysis** had been conceived in general.
Step 2, Selection of built examples: Because the habitat theory is meant to be of general validity, it was essential to choose an appropriate variety of different housing objects.
Step 3, Analysing work: The selected housing objects had been investigated by studying and analysing plans and other documents. The analyses are primarily able to generate two results: the expected patterns-of-appropriation and the expected housing/living quality of the respective object.

(3b) **Documenting the patterns-of-appropriation**
A habitat system is manifesting itself in a behavioural sense in the form of patterns-of-appropriation - i.e. patterns of use and behaviour of their inhabitants. Appropriation is in this context standing for establishing a relationship to one's own living environs and it also means that a physical, spatial environment becomes a personal living space (a habitat!). Appropriations can be empirically explored and described by observing actual processes (behavioural patterns) or traces and signs of use, adaptation, shaping, forming etc. I.e. patterns-of-appropriation are empirically recognizable.

(3c) E**valuation and Empirical Examination**
First Empirical Examination plus Evaluation: The next step has been represented by the evaluation of the findings and conclusions of analysis (3a) and field research (3b).
By **comparison** between the expected patterns-of-appropriation (3a, step 3) and the observed actual patterns-of-appropriation (3b) the habitat theory or respective sentences of the theory could have been verified or falsified.
Second Empirical Examination: Additionally the results of analysis has been compared with several so-called "economic" parameters (as far as available) like vacancies, duration of occupancy etc. All those parameters are representing in this context indirect indicators for housing quality.


SCHEME A -1 : Practical Use Overview
META-THEORETICAL LEVEL
EMPIRICAL LEVEL
THEORETICAL LEVEL
THEORETICAL CONCEPTION: HABITAT SYSTEM
external ENVIRONMENT
HOUSING ENVIRONS
DWELLING
HUMAN BEING
HOUSING
HOUSING ENVIRONS
external ENVIRONMENT
PATTERNS OF APPROPRIATION
PATTERNS OF BEHAVIOUR
MANIFESTATION 2
MANIFESTATION 1
MAIN OBJECT !
HABITAT STRUCTURES
edificial, spatial structures
(BUILDINGS + SURROUNDINGS)
OBSERVATION FIELD STUDY
EMPIRICAL INVESTIGATION
OBSERVED / ACTUAL PATTERNS OF APPROPRIATION
COMPARISON and EVALUATION
= 1st (main) EMPIRICAL EXAMINATION
PLAN STUDY
ANALYSIS
EXPECTED PATTERNS OF APPROPRIATION
PROGNOSIS
EXPECTED SPECTRUM-OF-RELATIONS
COMPARISION
PROGNOSIS
EXPECTED POTENTIAL HOUSING QUALITY
MAIN GOAL !
external data
ECONOMIC PARAMETERS
DEDUCTION
INDIRECT INDICATORS FOR LIVING / HOUSING QUALITY
COMPARISON and EVALUATION
= 2nd (additional) EMPIRICAL EXAMINATION
CRITERIA for ANALYSIS
DEDUCTION
DEDUCTION
THEORETICAL EXAMINATION
LOGICAL RELATION etc.
CRITERIA OF LIVING / HOUSING QUALITY
LIVING QUALITY
DEFINING
SPECTRUM-OF-RELATIONS
(Part of Habitat System)
INTENTIONAL SPECTRUM-OF-RELATIONS
(HUMAN HOUSING NEEDS)
FACET METHODOLOGY
INTERDISCIPLINARY CONNECTIONS

(B3) Conclusions and Resume

Potential Impact on Sustainable Housing Practice (Analysing, Planning and Designing)

The potential impact can be explained by comparing the two schemes A and A-1: After the research works the potential practical use became clearly visible. By means of the criteria for analyses we are able to check out the potential housing/living quality of buildings and residential areas in detail and in advance; and we are able to define the expected patterns-of-appropriation in advance.
This leads us to one major goal: it becomes possible to carry out analyses on a scientific and systematic basis **before** the building is erected and occupied, still **during the stage of planning**.

Afterwards we are able to return to the main task and to answer the initial question:
How can we enhance the human quality of housings and settlements and therefore also their sustainability?
- By using this sophisticated methodology of analysis during planning and hand in hand with planning.
- By using this methodology of analysis before reconstructing a housing complex, remodelling a building, or redeveloping a whole housing settlement.

Finally optimization of habitation quality as well as reduction of deficits become possible. By a clear and detailed definition of the specific qualities of an object, such analyses could support avoidance of deficiencies and provide the basis for various improvements concerning the human-related aspects.

Sustainability plus Benefit to the Inhabitants

The research results could provide contributions to enhance sustainability on three levels:
- ecological sustainability: prolonging the life-cycle endurance of buildings; reduction of dispersed settlements, splinter developments, urban sprawl; reduction of leisure "escape" and traffic etc.
- social sustainability, of course: increase of human housing quality, living quality, better interpersonal relations between the inhabitants, etc.
- and also economic sustainability: higher occupation rate, higher quality for equal price, etc.

The benefits are on principle valid for all forms of housing, i.e. the high-budget as well as the low-budget segment. With the latter there are even much more improvements necessary and possible.

(C) Research Report Part II: Examples and Analyses

The ongoing practical research is illustrated with the aid of 3 examples:
See appendix: Examples 1 to 3

Example 1: "Pruitt Igoe" - the most unsustainable housing complex in history [12], [13]

Example 2: "Terrace-house-settlement"; Sustainability despite energetic / thermic deficits?

Example 3: Cohousing project; Social plus ecological sustainability? [14]

These three examples are just meant to offer a short insight for a better understanding of the topic. The complete analyses are of course much more comprehensive and detailed.

Example 1: Pruitt-Igoe

"The most unsustainable housing complex in history caused by psychological deficits"

Housing object:

"Pruitt-Igoe"
St.Louis, USA
ca. 2800 housing units
completion 1956
occupation peak 1957: 91%
1965 occupation rate ca. 33%
1971 only 600 Inhabitants left
demolished 1972 - 1976



Main reasons for the failure were psychological planning mistakes. First of all: wrong zoning within the building.

(A) Semi-public areas within the building without possibilities for visual control lead to:

- "silent" vandalism (deteriorations)
- aggressive vandalism (damages)
- places of fear ("Angsträume")
- stronger tendencies for crimes
- ... and even crimes occurred within the buildings communal areas



(B) Semi-public areas directly abut on private ones, this leads to:

- "crowding" situations
- antagonistic behaviour
- diminished feeling of being secure
- reduced willingness to get into contact with others
- reduced responsibility for the living surrounding
- lack of social control

  ... which amplifies the consequences of (A)



This vicious circle started turning from the beginning - very slowly but consequently and unstoppably. All this ended up in the complete demolition of the whole housing complex, which therefore became the most unsustainable housing project so far
- despite the fact that from a constructional point of view the buildings were better than most of the others in the surrounding at that time.
- despite the fact that the comfort of the apartments were clearly above the average standard of this period.

References (pictures): www.pruitt-igoe.com

Example 2: "Terrace-house-settlement"

"Human sustainability lacking energy-efficiency"



Housing object:

"Terrace-house-settlement"
Graz, Austria
552 housing units
planning 1965
built 1972

Housing Concept:

- separate individual apartment units
- each unit has got a private terrace or balcony or a small garden
- In the outside: attractive semi-public areas with various possibilities for appropriation
- no motorised traffic within the settlement
- including places for social interactions, places for playing, places to stay for people of any age.
- high personalization potential (most apartments)
- private spaces without heteronomous control
- high sensory variety (visual first of all)
- etc.



The housing complex had been built 40 years ago and is still fully occupied - despite several constructional deficiencies concerning thermal insulation, moisture penetration etc.
- and despite several psychological deficits: some small parts of corridors and staircases are lacking social control; the higher floors are more isolated from the area-of-appropriation etc.
But this deficits are obviously outweighed by the positive aspects.



Conclusion: If a building complex has got a high human quality it remains occupied even if the physical factors are not very sustainable.

Example 3: "Cohousing - Lebensraum"

"Human and ecological sustainability"

Housing object:

Cohousing project
"Lebensraum" ("Habitat")
Gänserndorf, Austria
32 housing units
built 2005



Ecological Building Concept:

- natural and recyclable building materials
- very low energy building
- high thermic insulation
- use of solar energy (passive and active)
- ecological water management
- ecological waste management
- etc.



Housing Concept:

- separate individual apartment units
- each unit has got a terrace or balcony and a small garden, where the inhabitants can stay private
- high personalization potential
- attractive and spacious communal rooms and areas, located at the right positions
- offering opportunities for various forms of social interaction
- offering appropriate facilities for people of any age
- integration of natural elements
- special offer for children: "adventure" area - not predetermined by adults
- semi-private corridors (partly problematic)
- no public areas, little contact to people outside the settlement
- high systemic isolation (infrastructure etc.)



The housing concept tries to comprise ecological, biological and social issues in order to reach a sort of overall sustainability.
It aims for combining humanity with ecological building standards.



References (basic data and pictures): homepage www.derlebensraum.com

References

[1] "*Wie Wohnen Mobilität lenkt*", VCÖ-Forschungsinstitut, Wien 2010

[2] Tobias Weiß, "*Nullenergiegebäude im städtischen Kontext*" (engl. Zero-Energy Buildings in an Urban Context), in Journal "Erneuerbare Energie" 01/2013, p.32-35, Ed.: AEE Institute of Renewable Energy, Gleisdorf

[3] Harald Deinsberger, "*Funktionalität im Wohnbau" - Wann "funktioniert" ein Wohnbau in menschlicher Hinsicht?* ("*Functionality of Housings*") in "Cloud-Cuckoo-Land", International Journal for Architectural Theory, Nov. 2012, Ed.: Brandenburgische TU Cottbus in cooperation with American and Canadian universities, online: www.cloud-cuckoo.net

[4] cf. Eduard Geisler, "*Psychologie für Architekten*" (Psychology for Architects), p.75, Deutsche Verlags-Anstalt, Darmstadt, 1978

[5] cf. Peter King, "*Using Theory or Making Theory: Can there be Theories of Housing?*" p.41 in Housing, Theory and Society, Vol.26, No.1, Pub.: Routledge Informa Ltd London 2009

[6] cf. Allen, C. & Gurney, C. ‘‘*Housing and Social Theory*’’, p.3-5, European Network for Housing Research Newsletter, 3/1997

[7] cf. Antje Flade "*Architektur - psychologisch betrachtet*", S. 56, Verlag Hans Huber, Bern, 2008

[8] Karl Popper, "*Logik der Forschung*" ed.: Herbert Keuth, Mohr Siebeck Verlag, 11.Aufl., Tübingen 2005

[9] cf. Karl Popper "*Logik der Forschung*", p.15f, ed.: Herbert Keuth, Mohr Siebeck Verlag, 11.Aufl., Tübingen 2005

[10] cf. Harald Deinsberger, "*Die Psycho-Logik von Wohnbaustrukturen*" *Die Beziehung Mensch-Wohnung-Umfeld und ihre systemischen Grundlagen*, BoD Verlag, Norderstedt/Hamburg 2007

[11] cf. Harald Deinsberger, "*Interpretation or Analysis of Housings*" *Contradiction or useful Completion ... and what about the Theory of Housing?* ("*Wohnbau-Interpretation oder Wohnbau-Analyse" Widerspruch oder sinnvolle Ergänzung ... und wo bleibt die Wohnbau-Theorie dabei?*), in "Cloud-Cuckoo-Land", International Journal for Architectural Theory, Dec. 2008, Ed.: Brandenburgische TU Cottbus in cooperation with American and Canadian universities; online: www.cloud-cuckoo.net

[12] cf. also Oscar Newman, "*Creating Defensible Space*", Institute for Community Design Analysis, Rutgers University, 1996

[13] cf. www.pruitt-igoe.com

[14] cf. www.derlebensraum.com

OPEN HOUSE: Common European methodology for assessing building sustainability

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Short Summary

Sustainable construction is a relatively new concept that aims at integrating the objectives of sustainable development into the construction activities. Multiple methodologies and approaches for assessing building sustainability at international, European and national level are being used. However most of them form part of national initiatives and consequently are only used at national level. Also, many of these assessment methodologies are conceptually developed without user-friendly applications, thus not meeting the industry needs of responding to manageable steps in practice.

ACCIONA Infrastructures as coordinator and Fraunhofer as chair of the Scientific and Technical Committee lead the European project OPEN HOUSE (OH) financed by the European Commission within the seventh Framework Programme (FP7). The project aims to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings by means of an open approach and technical platform. The methodology was developed on the basis of existing systems, international initiatives and European standards with a view to harmonizing building assessment. It includes a set of qualitative and quantitative indicators grouped in 6 categories: environmental, social, economic, technical, process and location.

OPEN HOUSE methodology was implemented in 68 buildings used as case studies distributed in 35 European countries in order to assess the applicability of the methodology and to gather constructive feedback to improve it. This paper focuses on the first analysis of the feedback from case studies. It reveals that the OH online assessment tool is user-friendly and facilitates the building assessment. The OH methodology is seen as holistic and covering all aspects of sustainability. In addition, the analysis shows that there is still work needed to adapt the set of indicators to national context but most of them were applicable in all European countries.

On the basis of the feedback analysis, this first version of the OH methodology will be refined in order to establish a European reference point for building sustainability labelling.

Keywords:OPEN HOUSE; Building Sustainability Assessment; Assessment tool; Case studies.

1. Introduction

According to the DG Environment, construction constitutes one of the largest waste streams within the EU (it accounts for 450 million tons of waste every year and represents about one fourth of all the waste generated in Europe). About 40% of the overall energy consumption in Europe is related to the building domain and represents about 1/3 of Europe's CO2 emissions [1]. More than 50% of all materials extracted from earth are transformed into construction materials and products, the domain also uses 25% of all virgin wood [2]. Construction works also account for 16% of the water annually used worldwide [3]. However, the importance of the construction sector is not manifested only in its impact on the environment. Also on the level of society considerations, construction practices affect core issues, such as accessibility, comfort, health, safety and security.

Sustainable construction is a relatively new concept that aims at integrating the objectives of sustainable development into the construction activities. Building projects can be regarded as sustainable only when all the different dimensions of sustainability – environmental, economic, social and cultural – are taken into account. Developing and using building sustainability assessment methods is one solution to explore in order to promote a more sustainable built environment [4].

At International, European and National level a number of methodologies for assessing the sustainability have been developed like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), SBTOOL, DGNB Certificate(certificate from the German Sustainable Building Council) or LEnSE (Label for Environmental, Social and Economic buildings). Also, during the last years international, European and national standardisation bodies have developed sustainable construction standards. International Organization for Standardisation (ISO) and the European Committee for Standardisation (CEN) have worked actively in the last few years to define standard requirements for the sustainability assessment of buildings.

The main challenge of the European project OPEN HOUSE is to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings. The OPEN HOUSE methodology aims at being user friendly but also scientifically rigorous. It is developed with a transparent approach enabling stakeholders and the general public a free access to an open source of information through an accessible platform.

The following paper presents the OPEN HOUSE methodology as well as the experiences after the completion of 68 case studies carried out in different European countries in which the methodology has been applied and tested.

2. Materials and Methods

2.1 OPEN HOUSE Methodology

The European project OPEN HOUSE (FP7 ENV-2009.3.1.5.2) has been established under the framework of a FP7 R&D programme by a European consortium of 20 partners from research institutions, the building industry and the political sector. Running from February 2010 to July 2013, its objective is to merge existing methodologies for sustainability assessment of buildings towards a common view. With the aim of being widely adopted in Europe, the OPEN HOUSE methodology is developed in a fully transparent, collective and open process, with extensive communication and interaction between all stakeholders.

The OPEN HOUSE methodology has been developed on the basis of existing methodologies like BREEAM, LEED or DGNB, international initiatives like iiSBE or SB Alliance as well as standards from ISO/TC 59/SC 17 and CEN/TC 350.
It also includes outcomes from former or current EU projects, like LEnSE or SuPerBuildings, with the adoption of a common structure for sustainability assessment of buildings.

The first version of the OPEN HOUSE methodology is composed of 56 indicators classified in six categories: Environmental Quality, Economic Quality, Social/Functional Quality, Technical characteristics, Process Quality and The Location (Figure 1) [5].

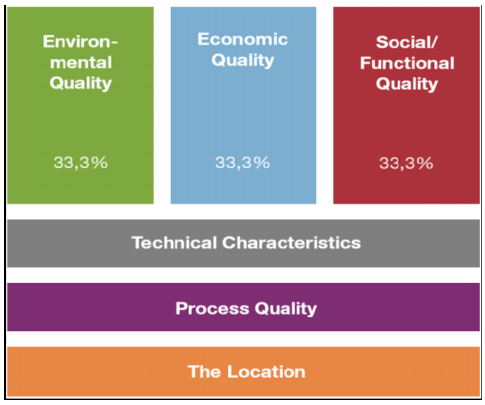


Figure 1: OPEN HOUSE categories for the sustainability assessment of buildings

The analysis of more than 60 assessment methodologies led to the identification of more than 500 indicators. Methodologies analysed vary from regional ones like the one developed by the Basque Government to worldly renowned systems like LEED or BREEAM [6,7].

Finally, 56 sustainability indicators were selected after being grouped into the six categories and questioned by the partners for their acceptability and feasibility in different European countries. This set of indicators is optimised for office buildings and versions for other building types will be developed in the following phases of the project.

Furthermore, 30 indicators were identified by the project partners as essential for the sustainability assessment and highlighted as ‘core indicators’. The complete list of indicators can be found in Figure 2.

The comprehensive description of the 56 indicators can be found in a reference document called Assessment Guideline. This guideline includes information regarding: objective of each indicator, assessment methodology, calculation - rating and documentation guideline.

In the first version, for each sub-indicator a maximum of 100 points can be achieved: the baseline of 10 points is obtained by fulfilling the standard of the specific EU country – the maximum by achieving best practices towards sustainability goals (e.g. targets of the EU in 2020) [5].

As mentioned in ISO 21929-1 [8], there are no commonly agreed methods for weighting. Hence, the OPEN HOUSE partners are elaborating a weighting strategy based on the analysis of the ones from existing methodologies and including the opinion of different stakeholders from the building sector.

2.2 Case studies

In order to assess the applicability of the OPEN HOUSE methodology and to gather constructive feedback to improve it the methodology was implemented in 68 buildings used as case studies distributed in 35 European countries (Figure 3). The test of all indicators in case studies will allow a general improvement of the assessment guideline as well as the integration of national peculiarities in terms of calculation methods, rating and documentation requirements.

Environmental Quality	**1.1**	**Global Warming Potential (GWP)**
	1.2	**Ozone Depletion Potential (ODP)**
	1.3	**Acidification Potential (AP)**
	1.4	**EutrophicationPotential (EP)**
	1.5	**Photochemical Ozone Creation Potential (POCP)**
	1.6	Risks from materials
	1.7	Biodiversity and Depletion of Habitats
	1.8	Light Pollution
	1.9	**Non-Renewable Primary Energy Demand (PEnr)**
	1.10	**Total Primary Energy Demand and % of Renewable Primary Energy**
	1.11	**Water and Waste Water**
	1.12	**Land use**
	1.13	**Waste**
	1.14	Energy efficiency of building equipment (lifts, escalators etc.)
Social / Functional Quality	**2.1**	**Barrier-free Accessibility**
	2.2	Personal Safety and Security of Users
	2.3	**Thermal Comfort**
	2.4	**Indoor Air Quality**
	2.5	Water Quality
	2.6	**Acoustic Comfort**
	2.7	**Visual Comfort**
	2.8	**Operation Comfort**
	2.9	Service Quality
	2.10	**Electro Magnetic Pollution**
	2.11	**Public Accessibility**
	2.12	Noise from Building and Site
	2.13	Quality of the Design and Urban Development of the building and Site
	2.14	Area Efficiency
	2.15	**Conversion Feasibility**
	2.16	**Bicycle Comfort**
	2.17	**Responsible Material Sourcing**
	2.18	**Local Material**
Economic Quality	**3.1**	**Building-related Life Cycle Costs (LCC)**
	3.2	Value Stability
Technical Characteristics	4.1	Fire Protection
	4.2	Durability of the structure and Robustness
	4.3	Cleaning and maintenance
	4.4	Resistance against hail, storm high water and earthquake
	4.5	Noise Protection
	4.6	**Quality of the building shell**
	4.7	**Ease of Deconstruction, Recycling, and Dismantling**
Process Quality	**5.1**	**Quality of the Project's Preparation**
	5.2	Integral Planning
	5.3	Optimization and Complexity of the Approach to Planning
	5.4	Evidence of Sustainability during Bid Invitation and Awarding
	5.5	**Construction Site impact/ Construction Process**
	5.6	Quality of the Executing Contractors/Pre-Qualification
	5.7	Quality Assurance of Construction Execution
	5.8	**Commissioning**
	5.9	Monitoring, Use and Operation
The location	**6.1**	**Risks at the Site**
	6.2	Circumstances at the Site
	6.3	**Options for Transportation**
	6.4	Image and Condition of the Location and Neighbourhood
	6.5	Vicinity to amenities
	6.6	Adjacent Media, Infrastructure, Development

Figure 2: OPEN HOUSE indicators (core indicators are in bold)

Two kinds of assessments were conducted during the case studies:

- Basic & Quick Sustainability Assessment: to get a first idea of the sustainability level and propose actions to improve it. The evaluation of the building performance is based on assumptions.

- Complete Sustainability Assessment: to give a whole overview of the sustainability performance of a building. The Evaluation of the building performance is based on detailed documentation.

The assessment of the case studies was done thanks to a user-friendly online tool developed during the project (http://oh.building-21.net/). With the help of this online tool the calculation and rating system was transformed into an easy questionnaire whose answers led to the automatic calculation of the score achieved.

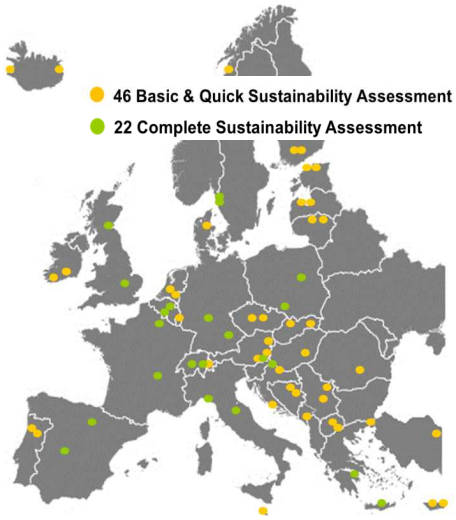


Figure 3: OPEN HOUSE case studies

Apart from the assessment of each case study the assessors were required to provide information about applicable norms and national practices for each of the OPEN HOUSE indicators. The goal was to collect essential information about country regulations and best practices. Moreover, the assessors needed to complete a feedback for each of the indicators. The feedback form was provided as an excel spreadsheet with drop down menus options and open narrative feedback to be entered. The goal of these forms was to collect feedback in a standard way in order to automatically process and analyse the information. In addition, all assessors were specifically asked to provide the time they spent on assessing their building with OPEN HOUSE (excluding training, administration, filling in the feedback forms, national standards/regulations).
Thanks to feedbacks from case studies, questionnaires and workshops it will be possible to develop specific weights and benchmarks for each European country in order to take in account regional particularities.

3. Results and Discussion

3.1 Estimated assessment time

Regarding the estimated assessment time, for Basic & Quick Sustainability Assessments the time spent varied from 38 hours to 113 hours. The average time necessary to carry out the Basic & Quick Sustainability assessment was 96 hours (12 days).Complete Sustainability assessment was more time consuming and the time spent varied from 50 to 320 hours and the average time was 202 hours (25 days).

3.2 Category applicability

The applicability for the six categories is represented in Figure 4, based on the feedback from 52 case studies. The environmental quality was considered as completely applicable for 20 case studies (38%) and partly applicable for 29 (56%). The reason for not being always applicable mostly came from the difficulty to carry out the LCA, either because of lack of information concerning the building components or because of the complexity of the assessment method. However, LCA indicators were positively evaluated as important indicators for a sustainability assessment.

The social quality was considered as completely applicable for 20 case studies (38%) and partly applicable for 31 (60%) The reason for not being always applicable mostly came from the fact that some indicators (like Public Accessibility or Service Quality) were not considered as relevant for a sustainability assessment of small office buildings and that additional measurements (e.g. for indoor air quality) or specific simulations were not available.

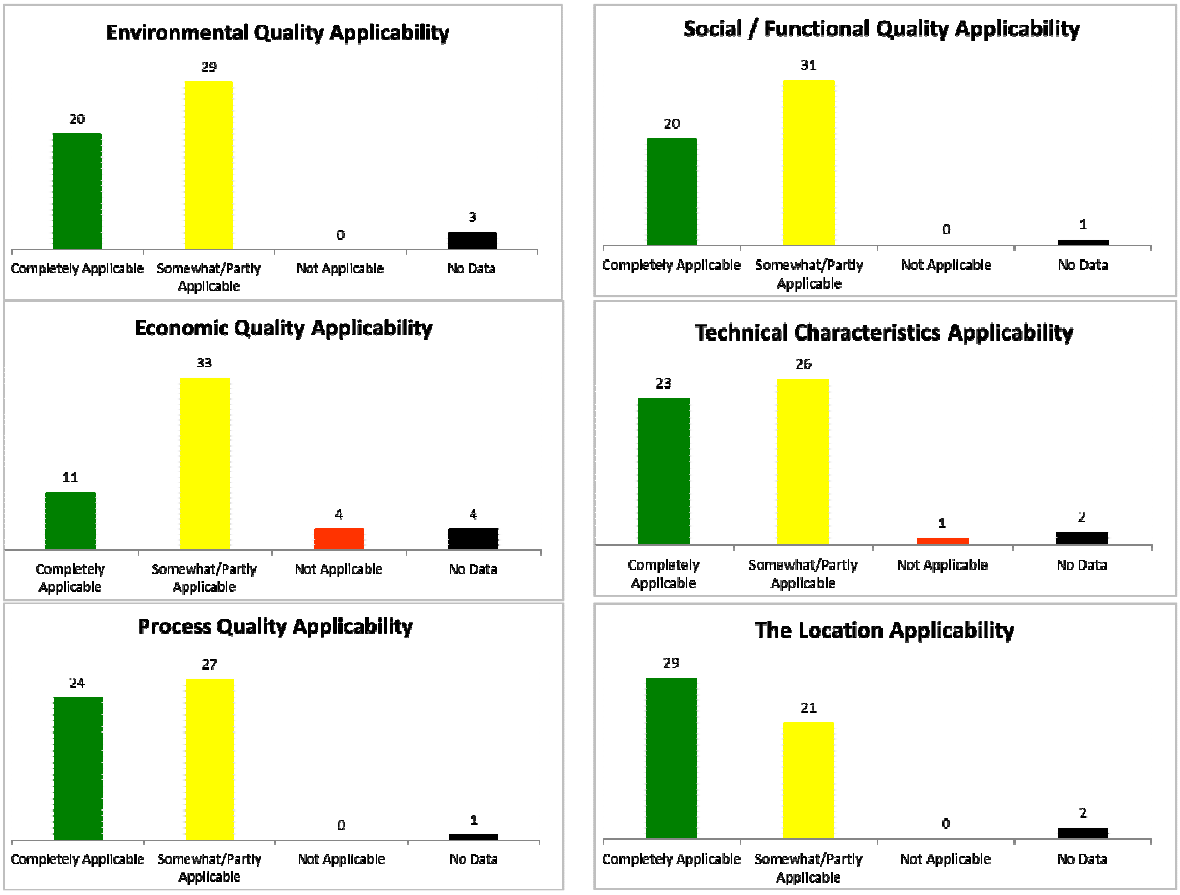


Figure 4: Category applicability

The economic quality was considered as completely applicable for 11 case studies (21%), partly applicable for 33 (63%) and not applicable for 4 (8%). The reason for not being applicable mostly came from the difficulty to carry out the LCC, because of lack of information concerning the costs of building components and the seldom use of LCC in Europe.

The technical characteristics category was considered as completely applicable for 23 case studies (44%), partly applicable for 26 (50%) and not applicable for 1 (2%). The reason for being partly applicable mostly came from the difficulty to gather documentation.

The process quality was considered as completely applicable for 24 case studies (46%) and partly applicable for 27 (52%). The main reason for not being applicable was the difficulty to access documentation that was not produced during the planning phase, but required by the assessment.

The Location category was considered as completely applicable for 29 case studies (56%) and partly applicable for 21 (40%). The reason for being partly applicable mostly came from the difficulty to gather documentation.

3.3 Compatibility for different building types

Most of the selected case studies were office buildings and the applicability of the methodology for office buildings was considered as very high as there were only few comments stating problems related to this typology.

On the other hand, out of all case studies, 7 buildings mostly had educational or cultural use. The feedback comments showed that no changes were needed to adapt the current version to educational or cultural buildings, and the methodology was flexible enough to be applied to

different kinds of buildings with quite similar uses.

3.4 Compatibility for different construction phases

The distribution of case studies on the next diagram shows that most of case studies were new buildings (built in the last 10 years), but existing buildings recently refurbished as well as under construction or in design phase were also represented (Figure 5).

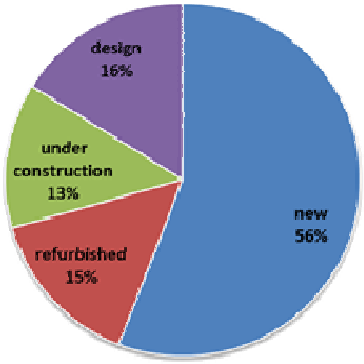


Figure 5: Construction phases represented by the case studies

The OPEN HOUSE assessment methodology was developed with the idea that the sustainability assessment starts early in the design phase and continues until the building is built and occupied. However, if the assessment is done during the planning phase, there are uncertainties about the final concept of the building and it is also neither possible to evaluate the construction phase nor measure the indoor air quality for example. If the assessment is done only after construction, it may be difficult to get information about the planning process or the building materials.

3.5 Compatibility between different countries

The scores obtained for all categories by each case study are presented and grouped by country for a first overview of national performances (Figure 6). Moreover, this first assessment is not representative of the final building performance according to the concept of the OPEN HOUSE methodology because weightings for sub-indicators and indicators have the default value 1 and benchmarks are the same for all countries.

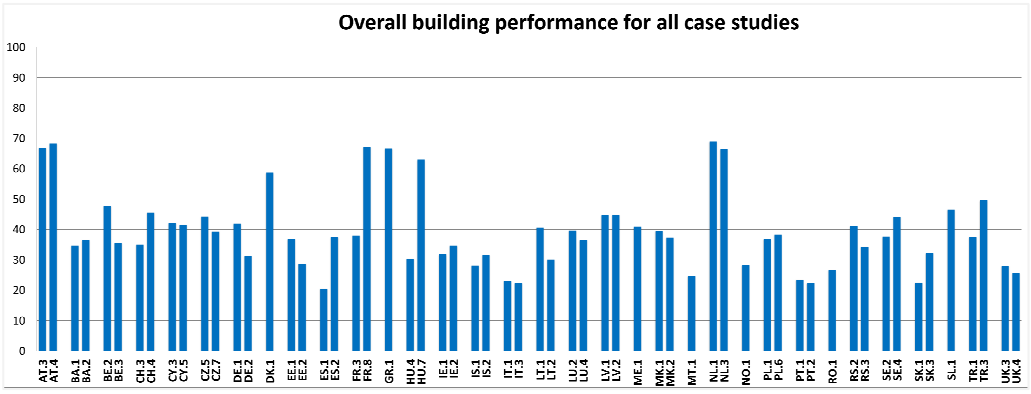


Figure 6: Overall building performance for all case studies in different countries

In general the overall building performance (average of environmental, social/functional and economic categories) performance was quite similar for different case studies in the same country, except in Hungary and France where big differences could be seen, due to the difference in the Economic Quality. In the end, the overall building performance may be a good indicator of the

national building practices performance in the variety of European countries (Figure 6). Of course, in order to validate this statement, data from more than 2 case studies per country are necessary.

The overall performance of each case study was quite low (on average 40%, the best one achieving 69%). The average score for each category was: 33% (environmental quality), 56% (social functional quality), 34% (economic quality), 45% (technical characteristic), 55% (Process Quality) and 63% (location). The low performance can be explained by the high influence of the economic quality (33% of the overall performance) for which low score was achieved due to the poor availability of data concerning the Life Cycle Costs.

4. Conclusions

The OPEN HOUSE methodology was successfully implemented and tested in 68 buildings used as case studies distributed in 35 European countries in order to assess the applicability of the methodology and to gather constructive feedback to improve the assessment. The first analysis of the feedback from assessors revealed that the online assessment tool is user friendly and facilitates the building assessment.

The OPEN HOUSE methodology was seen as holistic and covering all aspects of sustainability. Some aspects to be improved from the methodology were the time needed to assess the building and the data requirements in some indicators.

The methodology was considered as highly applicable to office buildings and flexible enough to be applied to other building types (educational or cultural buildings). When the assessment was done during the planning phase, there were certain uncertainties about the final concept of the building and this difficult the assessment of some indicators. In some case studies in which the assessment was done in existing buildings it was difficult to get information about the planning process or the building materials. For each category, it seems that case studies located in the same country achieved a similar score. If we consider that these buildings are representative of the best local practices, their performance can be used to scale the local reference values. However, more than 2 case studies per country are needed for precise benchmarking.

5. References

[1] European Union Directive on the Energy Performance of Buildings (EPBD2002/91/EC)
[2] World Watch Institute, http://www.worldwatch.org
[3] Report of the taskforce on sustainable construction composed in preparation of {COM (2007) 860 final} “A Lead Market Initiative for Europe” Accelerating the Development of the Sustainable Construction Market in Europe.
[4] MATEUS R, and BRAGANÇA L. “Sustainability assessment and rating of building: Developing the methodology SBTool^{PT}H”. Building and Environment, DOI: 10.1016/j.buildenv.2011.04.023; 2011, Volume 46, pp. 1962-1971
[5] PEYRAMALE V, EBERL S, ESSIG N. “OPEN HOUSE: An online platform for a transparent and open methodology to assess the sustainability of buildings”. International Journal of Sustainable Building Technology and Urban Development, DOI:10.1080/2093761X.2012.745803 Volume 3:4, pp. 316-321.
[6] BREEAM, available at www.breeam.org
[7] LEED, available at http://www.usgbc.org
[8] ISO 21929-1:2010, Sustainability in building construction- Sustainability indicators- Part 1: Framework for development of indicators for buildings, 2010.

Development of a Performance Based Evaluation Method for Carbon Management of Existing Building in Egypt



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Keywords: Carbon management; Existing Buildings; Performance Based Evaluation;

1. Short Summary

The need to de-carbonize existing buildings with the use of various renovation approaches is on the rise. This paper reviews the key drivers in the literature and describes a performance based evaluation method to assist in the decision making to renovate existing buildings. A base case of an existing apartment building was used to demonstrate the effectiveness of a proposed evaluation method. The result of the study recommends the inclusion of the key drivers and proposes a method to quantify the performance of the proposed renovation scenarios and provides the owner with a decision making method to minimize carbon impacts associated with the renovation and operation of the existing buildings in the future.

2. Introduction

With energy efficiency and carbon emissions growing in importance in recent years, more detailed exploration into the sources of carbon emissions can be seen in recent research work. Looking at the close relationship between energy consumption and carbon emissions, energy consumption can be used as a rough indicator as to the carbon emissions - where renewable resources are not the main source of energy. Statistics show that an estimate of 40 percent of total energy consumption worldwide goes into the building and construction industry [1]; therefore, the building sector is a significant contributor of carbon as well as other emissions [2]. On a building level, the most commonly used mode of energy accounting in buildings is calculated either though energy analysis or using guidelines set by the ISO (International Standardization Organization) for Life-Cycle Assessment (LCA)[3]. Using LCA to determine the impact of a building on the environment involves accounting for and calculating all the energy processes revolving in and around the production, maintenance, demolition and running costs of the analysed building. These processes are generally divided into two distinct categories: embodied energy processes and operational energy processes; the energy products of which sum up to the total life-cycle energy of a building.

Although the overall impact of a building cannot be assessed solely on either embodied energy or operational energy on its own; the study and optimization of each of the two sub-components has the potential to explore the factors affecting each and eventually reaching a compromise. Therefore as can be clearly deduced, the study of embodied energy has notable reason for slowly gaining importance and becoming a topic of further research. However, while studies have been conducted in many countries worldwide; the localized analysis of embodied energy in the building industry in Egypt remains a topic of discussion. An important point to note as discussed by Haynes[4] is the separation between embodied energy and embodied carbon. The distinction is important since a comparison of embodied energies of two buildings might show that one has higher energy content than the other. However energy content alone should not be considered as an indicator to its impact on the environment, as the very same building with higher embodied

energy may be of a clean renewable source whereas that of the building with lower energy may be based off of fossil fuels-having overall a greater environmental impact.

Locally in Egypt, where the current supply for energy is in need of expansion in order to cover the growing energy demands, a reduction of embodied carbon content through the replacement of current energy sources with clean renewable energy would be of significant impact in the construction sector. Based on energy reports from 2009 published by the Energy Information Administration under the Department of Energy [5]; Egypt's main sources of energy were oil and natural gas accounting for 47 and 48 percent of the country's total energy consumption respectively. Such a high reliance on fossil fuels indicates a high level of embodied carbon since not only will transportation be based on fossil fuels, but also nearly all other processes including material extraction and/ or manufacturing, processing and then later assembly, maintenance and disassembly would all rely on carbon-embedded energy sources as well.

3. Literature Review

3.1 A General Overview

A general overview of the existing literature on embodied energy has shown and confirmed the growing importance and consideration of embodied energy in the growing trend of more energy conscious building. Embodied energy which is the amount of energy that goes into creating a final product; assesses and calculates the amount of energy invested into producing the materials used in creating it, the energy invested in extracting these materials as well as the energies consumed in any associated transportation processes, assembly, fixing, and the eventual maintenance and demolition of the product. Where the calculation of embodied energies of simple products constructed of a single material and of a single source may be simple and straightforward, the calculation of the embodied energy of a building with its vast number of components and subcomponents is far more complex. In order to accurately calculate a building's embodied energy each and every underlying component must be traced back to its original source and have all energy investments into its production calculated. These calculations need a vast amount of records, data and precision in order to present accurate results. These factors in addition to a diverse "un-standardized" calculation procedures have resulted in an abundance of embodied energy calculations varying in both accuracy and precision; thus, also making them difficult to compare and optimize. Hence, it comes as no surprise that a review of existing literature shows an agreement regarding the inaccuracy of embodied energy calculations and the large variability of results. The literature repeats that existing frameworks of calculation which in themselves broad and not stringent enough causing differences in methodology and discrepancies in calculations. Furthermore, even works such as the ICE database a project published by the University of Bath – considered to be the most widely used existing database for carbon emissions- is in itself acknowledged by its authors to have a degree of inaccuracies in its inventory despite attempts to adhere to a standardized procedure in publishing the embodied energy coefficients but remains a central source for most of the quantitative coefficients on a variety of material types.

3.2 Classification of the literature

A review of existing literature shows that the current research work in the field of embodied energy can be divided into three main categories: 1) *Standardization* of embodied energy calculation methods, their frameworks as well as their boundaries; 2) *Application* of methods and Analysis of Case-studies by building type; 3) *Optimization* of Low/Zero Carbon (LZC) material use and de-carbonization using smart retrofit proposals to lower the overall direct and indirect energy use; and 4) Scalability of approaches and means of evaluation. These initiatives although explored partially through recent work are generally in early stages of exploration, and thus identify gaps in the existing literature and field, and thus mark areas in need of further research.

3.2.1 Standardization of methods

An important point of recent research has been revolving around the method of embodied energy calculation. A review of existing literature repeatedly calls for the need of establishing standardised

calculation methods for estimating accurately embodied energy in buildings. A search for a standardised methodology or set of guidelines to abide by when calculating embodied energy is not existent at the moment thereby resulting in discrepancies and variations in energies reported. The work of Manish Dixit, Jose Fernandez-Solis, Sarel Lavy and Charles Culp at Texas A&M University is invaluable in this field. Work published includes an extensive overview of existing literature and in three different papers published in 2010, 2012 and 2013 attempt to identify the parameters and existing guidelines that could help establish clearer calculation methodologies, frameworks and system boundaries for embodied energy calculations. In their first paper Dixit et al. [6] establish the existing gap in comparable embodied energy databases. Based on this conclusion their second work then focuses on the existing parameters that could aid in creating a unified protocol or set of guidelines, for a more standardized calculation method in determining embodied energy. Simultaneously, the work also identifies the challenges in existing resources and the causes of discrepancies and inaccuracies that would need to be minimized in order to reach a more accurate and comparable set of results. Their most recent work published earlier this year (2013) builds on earlier work and proposes a boundary definition to unify the energy processes accounted for in embodied energy calculations. A model such as this one if abided by internationally would allow for standardized comparison between calculations globally.

3.2.2 Application of methods

While some sources worked on optimizing the actual calculation procedure, other sources conducted calculations based on one of the existing methods to draw general conclusions from case-studies on different building types. Among the case-studies conducted is Bruno Lee, Marija Trecke and Jan Hensen's study of industrial halls[7]. The case-study conducts a comparison between the embodied energy of a simple rectangular industrial hall using three different materials: once fully in steel, once in concrete and once as a hybrid system; concluding that the all-concrete alternative had largely greater energy content in comparison. By contrast, a report published by [8] employed an alternative approach to case studies; breaking down the components of the building under examination and determining the components' corresponding embodied energies. Instead of treating buildings as a whole; this breakdown allowed for the clear identification of building constituents most responsible for embodied energy content.

3.2.3 Optimization of materials

Another series of works acting in parallel to those of the previous two is the attempt to optimize material selection itself when minimizing embodied carbon. Work in this field ranges from the selection of a single material and its optimization, to analysis of certain systems or entire buildings. These works try to identify the components that would result in reduced energy embodiment and suggest possible alternatives to functional equivalents with higher energy or carbon contents. Work such as that of Venkatarama and Jagadish [9] has tested the variations and differences in embodied energy contents of a range of different brick-types, mortars as well as floors or roofing systems. Conclusions show and list the different material types tested in order of highest to lowest embodied energy content; the results of which would allow energy conscious selection of material by designers. Other studies such as that of Shukla et al. [10] conducted studies on the scale of a home; comparing the embodied energy of an abode home to that of a traditionally constructed home built out of concrete, cement and burnt brick. The outcome of the test showed that the use of adobe reduced the embodied energy per 100 m² of built-up-area by 245 GJ; showing the significance of material selection on the overall energy content. Other sources such as the work of Ramesh and Crishna [11, 12] tackle more specific topics local to a particular area such as the use of vernacular materials for construction and the optimization of reinforced concrete through consideration of embodied energy within [13] or the assessment of the amount of embodied energy found in various types of stone used in construction in the UK [11]. Looking at the life-cycle of buildings, other sources look to reduce operational costs and energies, by optimizing the choice of materials for different building components. Utama and Gheewala for instance examine the use of local building materials and their relationship to reducing energy consumption in one-landed homes in Indonesia. The use of bamboo double-walls or sugar mill ash for bricks for instance are alternatives specific to the local region suggested to replace materials of higher energy content for

walls [14]. A paper of similar direction by Radhi [15] focused on wall-cladding systems, testing the carbon emission reductions in terms of reduced embodied and operational energies. Here the tests are based off a case-study building in the United Arab Emirates (UAE) testing a variety of cladding materials. Stucco, aluminium siding and vinyl siding are among some of the materials tested and results show a maximum CO_2 reduction when Exterior insulation and finishing systems (EIFS) are used and least reductions occur when a masonry veneer is used.

3.2.4 Scalability of methods

Other published work such as that by Emmanuel and Baker look at the larger picture in some of their work and lists a set of “drivers” suggested by Davies and Osmani that could push construction towards lower carbon construction [16]. These suggestions as discussed by Emmanuel and Baker[17] can be divided into three main categories; financial, technical and legislative. These “drivers” suggested by Davies and Osmani are a parallel route to carbon reduction in construction. Where research in the reduction of embodied energy and carbon emissions focuses on the micro-scale of an individual building, larger-scale incentives such as these could have a profound effect on neighbourhood, district and city-scales. With the implementation of such incentives research being done in narrower fields could be taken from theory or single case-studies to potential large-scale implementation.

4. Research approach

In order to begin work in this field, it was first necessary to conduct a general literature review both internationally as well as locally in order to determine the local lags in research. Based on this research it was decided that a localized framework for the calculation of embodied energy in existing buildings in Egypt was the area of work most needed to suit both markets of design and construction. This was concluded as further research and the optimization of construction materials, alternative construction systems or even transportation processes to reduce embodied energy totals would be reliant on the former establishment of a fixed framework or calculation methodology; and thus must be established beforehand. In absence of comparative studies locally, a residential apartment building case study was selected to calculate the total embodied energy of the building and compare it to similar building worldwide. This case-study was intended to act as a prototype for the calculation of embodied energy of a building; acting as an initial benchmark to introduce embodied energy calculation in the local research market. Two retrofit scenarios were then studied to understand the impact on carbon emissions using a performance based calculation method. A set of conclusions and future areas of research to advance this work was documented.

4.1 Proposed framework

The structure of the proposed framework is similar to previous frameworks in the literature, however, adding the building life cycle stages; and make the main drivers of embodied energy visible across the building life from construction to obsolesce. This resulted in three main drivers visible in the framework; the energy embodied in construction (CE), energy embodied in Transportation (TE), and the energy embodied in the material (ME). The calculation method followed an (I/O) input output process using a carbon calculator to calculate the embodied energy and a simulation tool to calculate the predicted operational energy of the building (Fig.1). The framework is comprised of the Input Building Design Parameters, the Embodied energy component (EE), the Operational Energy (OE) component and the Output energy component which is the total of both (Fig.2).

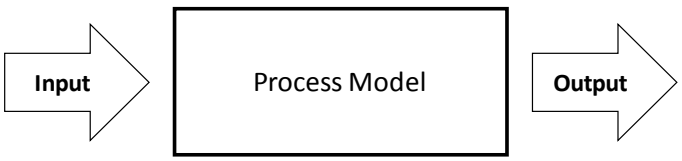


Fig.1: Input Output (I/O) Model

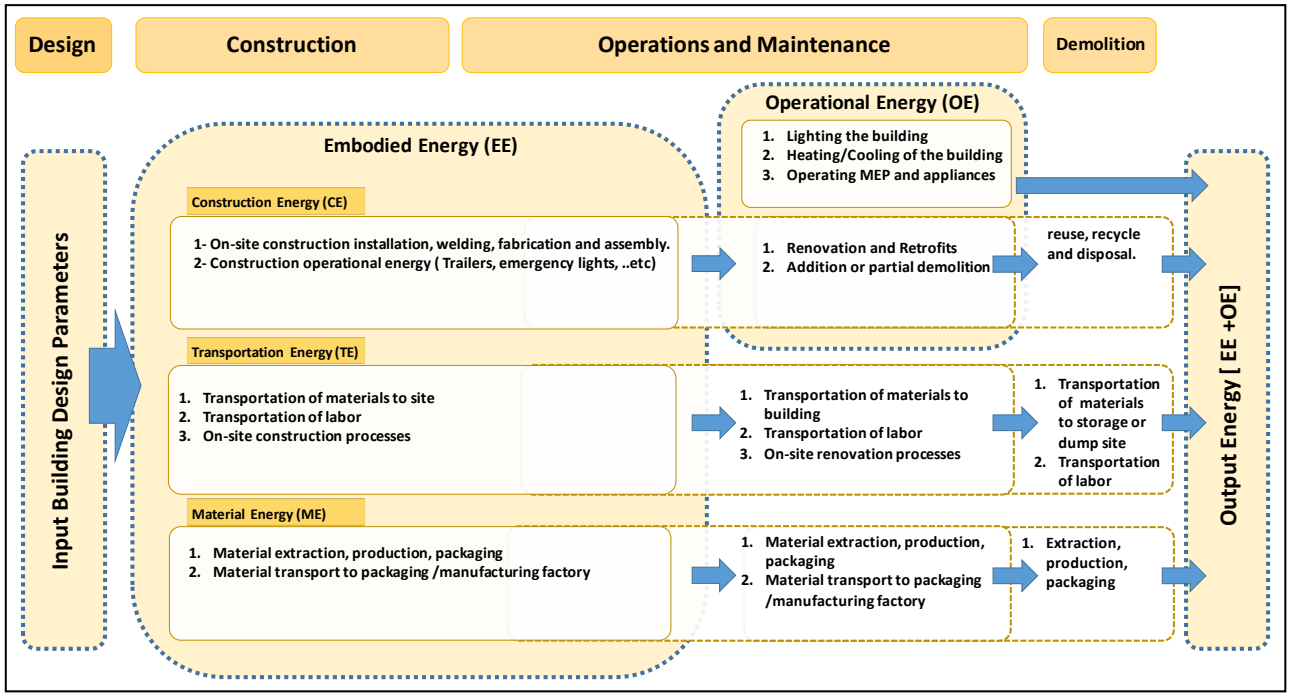


Fig.2: Proposed framework

5. Case-Study

5.1 Building Information

The case study is comprised of a three-storey residential building located in New Cairo, Egypt. The building consists of forty apartments ranging from 100 – 204m^2 in area each; amounting to a total area of 6,339m^2 of net usable residential space. Other spaces encompassed within the building include an underground garage and storage; a main lobby area, outdoor gardens, as well as a laundry to serve the residents; totalling to a final area of 12,610m^2. The structural design of the building is a reinforced concrete skeleton structure of the beam and slab type with brick internal partitions, typical building process in Egypt. The envelope of the building consists of red-brick walls (25cm in thickness) for external walls, held together using ordinary mortar 'Portland cement'. In terms of finishing, the external walls are coated with plaster and three coats of paint. Doors within the building are divided into three material types: metal doors, aluminium doors and wooden doors. Windows are all made of aluminium, and aluminium screens are used throughout the building complex to regulate the amount of direct sunlight allowed into the building.

5.2 Methodology and Reasoning for tool selection

After reviewing a series of calculators available online to calculate embodied energy and carbon, the calculator created by the Environmental Agency was selected for conducting the base-line carbon study. Since the assessment of initial carbon content in the existing residential building is only a portion of determining the impact of the building's entire life-cycle, a suitable calculator had to be selected that would fit within the larger framework opted for and explained previously. The calculator provided by the Environmental Agency allowed for the calculation of pure initial embodied energy (irrespective of the operational and demolition energies) and calculated the embodied energy from 'Cradle to gate' including the carbon emitted during transportation processes. Since there are no calculators modified specifically to Middle-East or the region in general, the calculator was used with caution and awareness that the carbon emission factors embedded will provide results that are not specific to the region. With this in mind the intention was to begin with a basic case-study using the existing calculator; accumulate the sources of possible differences that would make the calculations more accurate and specific to the region, identify the factors and processes that may affect the results and modify accordingly in future calculations.

5.3 Performance based Evaluation

To encourage the usage of performance-based evaluation (PBE) of the existing buildings, it is essential to shift the current regulatory systems from prescriptive to performance- based approach. A prescriptive approach “describes the way with a building asset has to be constructed instead of the ends of the building process, and it is related with type and quality of materials, method of construction, workmanship. Such approach is strictly mandated by law, codes, standards, regulations and it is based on past experience and consolidated know-how. Using a PBE approach does not preclude the use of prescriptive specifications. Although the benefits of the adopting of a PBE approach are significant, it is recognized that employing a performance-based approach at any stage in the building process is more complex and expensive than using the simpler prescriptive route. So, the application of this approach should not be regarded as an end in itself. When simple building are concerned or well proven technologies are used, the use of prescriptive codes results more effective, efficient, faster, or less costly, so prescriptive specifications will continue to be useful in many situations. Therefore, to better utilize the above framework, a newer generation of tools is required to have the ability to simulate not just the operational energy alone but the overall Life Cycle Energy inclusive of the Embodied Energy (EE) and Operational Energy (OE) through the integration of both carbon calculators and performance based simulation tools (Fig. 3).

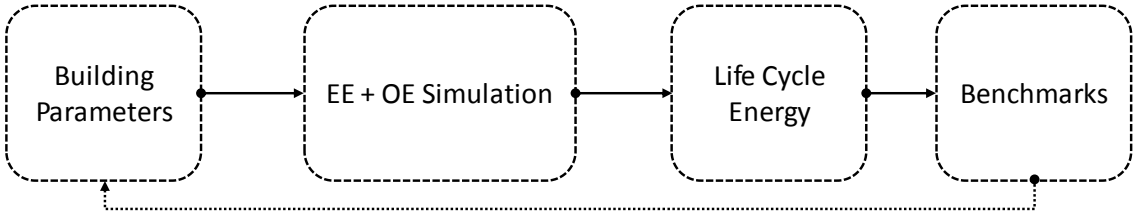


Fig.3: PBE Approach

5.4 Results

5.4.1 Quantities, Comparison and Discussion

After converting the material amounts obtained from the bill of quantities into the required input format in tonnage, the carbon emissions were estimated to be 3,663.8 tonnes of fossil CO2e broken down as shown in (Fig.4). According to the calculation method, the emissions are estimated to be within -/+ 25% of the actual expected value. Comparing the results to similar calculations conducted by other research entities the results seem to fall within acceptable ranges (Fig.5). It is however difficult to rate the accuracy of the results as the results are often reported in different units and no standardized published ranges exist as references.

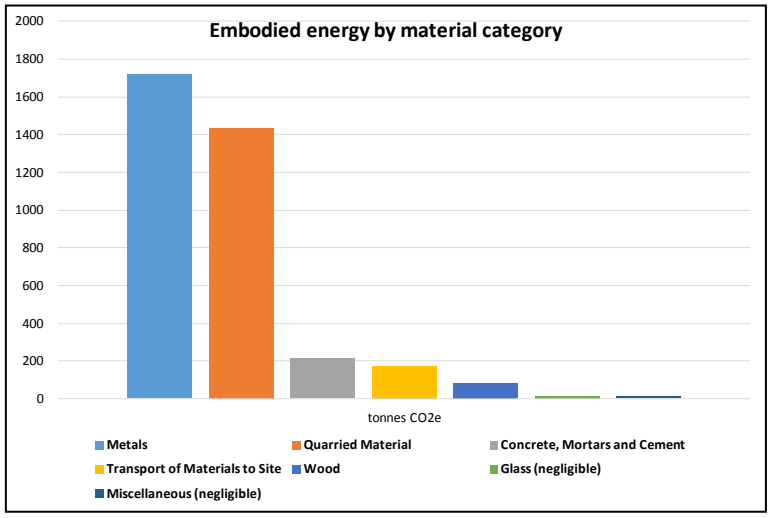


Fig.4: Embodied Energy by Material Category

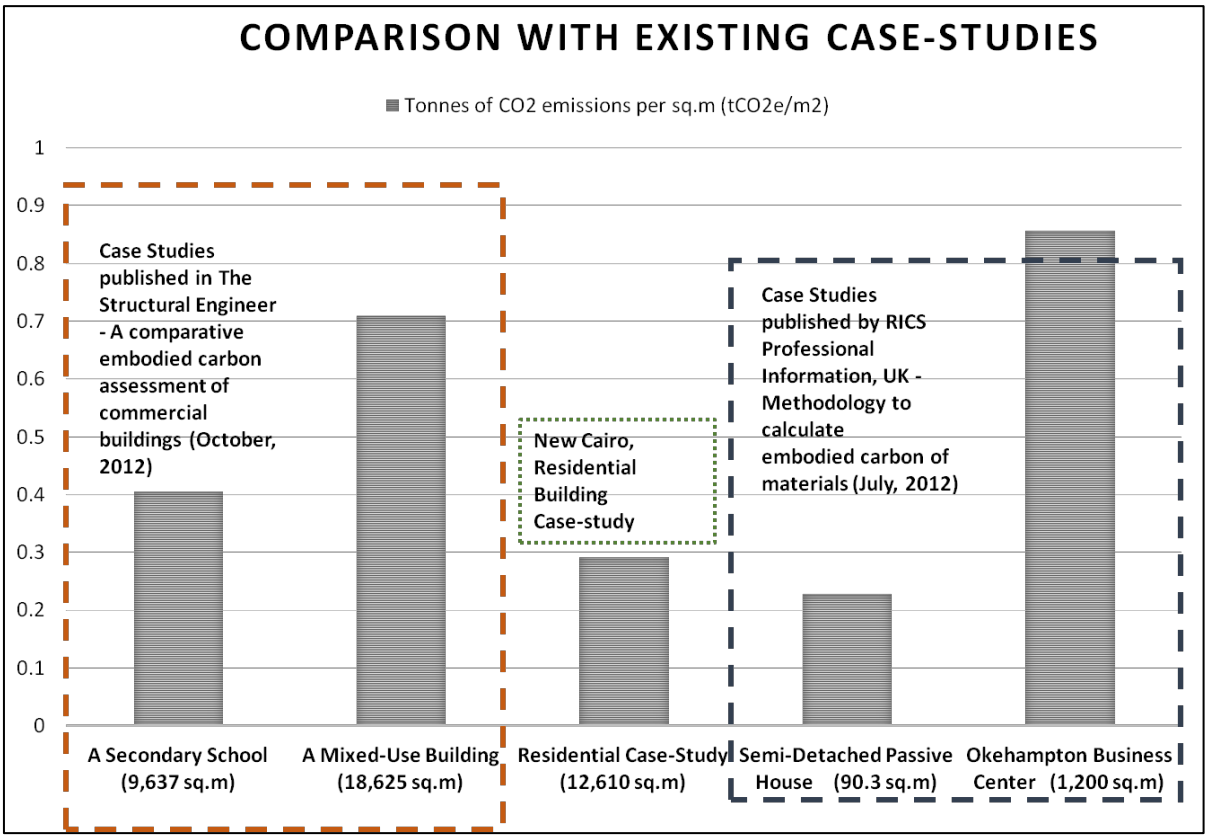


Fig.5: Comparison with Existing case studies

5.4.2 Limitations faced and assumptions made

Limitations faced while conducting the case study included the absence of a tool specific to Egypt or the Middle-Eastern region in general. Differences in geographic location signify differences in local materials, local production processes and carbon emissions in transportation and energy production. These differences thereby signify different carbon emission factors for the embedded materials in a region such as the Middle-East as compared to the emissions factors tabulated by the ICE – Inventory of Carbon Emissions - which is specific to the processes and emissions in the UK. This therefore indicates an expected inaccuracy in results when using the calculator in for a building in the Middle-East. Furthermore, among the inconveniences that was encountered while conducting calculations was that reported quantities were rarely reported as a weight. Instead reported quantities varied in units (sq.m., meter run, as well as in number of individual units) all of which had to be converted to obtain the tonnage of the materials used. Where sufficient dimensions where not provided, realistic assumptions were made associated to cross-sections of hand-railing systems, dimensions of doors, window frame etc. As paints were reported in term of surface area coverage, a standard assumption was made that every litre of paint covers an area of 12 m^2. Regarding the sources of the materials, where clear reference to the origin of the material was not made and re-tracing the specific origin of the batch of material on-site was not possible, an acceptable assumption was made from among a list of known places of import. Accordingly steel was assumed to be imported from China arriving by boat through the Ain Sokhna Port. Aluminium was assumed to be coming in from a production facility 100 km North of Luxor, totalling transportation distance of about 578 km to site. Similarly glass was assumed to be brought in from a production facility in Ain el Sokhna, totally 140km from point of origin to site

6. Discussion of research gaps, results and analysis

Throughout the research process several gaps in the field of embodied energy were identified.

Among topics of further potential research and study are the following:

1. The establishment of a parallel Carbon Emission's Coefficient Inventory such as that of University of Bath (ICE – Inventory of Carbon & Energy) that is specific to the local region[18].
2. A need for alternatives to high embodied energy construction materials currently used extensively in the Egyptian construction market such as: the reinforced concrete solid-slab, cement mortar and burnt clay bricks.
3. A search for alternative, renewable resources to substitute current high carbon-content energy sources. High embodied energy does not necessarily mean high embodied carbon.
4. Creating a set of guidelines for designing low-embodied energy buildings
5. Advancing the capabilities of simulation tools to cover a wider scope of the building life cycle.

7. Conclusion and future work

7.1 Data and research need locally

Localizing the literature review to the Middle-East and more specifically Egypt, the search identifies a large gap in published work. Differences between local building techniques, building materials; their extraction processes as well as their maintenance and transportation are all parameters that would significantly alter the expected embodied energies calculated when compared to results conducted in other countries. Differences in construction approaches and techniques reflecting local needs, trends, climatic zones, economic constraints and material availability are all parameters affecting the embodied energy of a building. When checked against existing studies done in other countries such those done in the Australia, India, the UK or the US, local results would certainly output completely different results than its counterparts. This prediction thus brings to attention the large gap in existing work, and the need of organized research work in this area.

Based on the local and international literature review a need for a localised standard for the calculation of embodied energy is needed. Although the significance of embodied energy has not yet been acknowledged nationally within Egypt, its importance is growing internationally and will need to be introduced gradually. Further research on embodied energy is especially important in a hot country such as Egypt because the embodied energy as a component of the total life-cycle energy is larger than that of an equivalent building in a colder country due to higher operational energies and as a result of more extensive heating loads. As stated by Nebel et al. [19] *"In heating dominated regions, embodied energy represents a relatively low percentage of total life-cycle energy, which may not be true for a moderate or cooling dominated region due to the latter's relatively low operational energy."* Therefore with embodied energy holding a greater share of the life-cycle energy (LCE) in hot countries, investing in research in this field would lead to a significant reduction in overall LCE.

7.1 Decarbonizing Existing Buildings

When decarbonizing a building, it is important to note that a building passes throughout many processes before reaching the end of its life-time and its point of demolition or reuse. At each of these stages different mechanical and non-mechanical processes take place, each of which consume energy and add to the total embodied energy content. With all these processes taking place, there is ample opportunity at each of these instances to reduce the amounts of energy being expended and carbon embedded.

7.1.1 Decarbonisation of Operational Energy Processes

When looking at existing buildings, because the possibilities in terms of material replacement are limited; most research has focused on the reduction of carbon content through the reduction of operational energy. Amidst the limited amount of work on decarbonizing existing buildings limited

research[17] explains different methods of reducing energy consumption in buildings. Depending on local climatic conditions, heating and cooling load reductions are approached differently. Other aspects however, remain the same for all regions. Among the recommendations made are the installation of control systems that allow users to monitor and adjust temperatures according to their needs, the replacement of high energy-consuming lights by installing low-carbon emitting light sources such as LED lamps, and the use of more efficient appliances, electronic devices as well as machinery. In temperate, cooler climates, the addition of insulation to all large surfaces to reduce heat loss is also a major factor. According to the Energy Saving Trust[20], the insulation of walls, lofts and flooring in their respective order contribute to most savings in terms of carbon emissions when compared to the insulation of other elements. It can be placed internally or externally depending on the building type and height, and windows can be secured through the installation of secondary glazing systems, the use of double-glazing or triple-glazing, and draught-proofing against unintended leakages. Where in cooler, more temperate climates the focus is on reducing heat from escaping, in hot climates the goal is to increase air movement and the prevent more heat from entering. The use of vegetation and shading structures to increase airflow through reduced temperatures around the building is essential. Furthermore, vegetation-based solutions are among the recommendations made for reducing heat admitted into buildings and can be employed in the form of surrounding vegetation, planting roof gardens and the use of landscape. Water features on the roof are also highly recommended to prevent exposed roof-surfaces. Vegetation on the roof is in fact recommended in both hot and cold climates.

7.1.2 Decarbonisation of Material Energy and Construction Processes

In an existing building the flexibility and impact of this section is relatively limited because the building has already undergone most construction processes; and materials have already been consumed. However, potential exist during maintenance and refurbishment. Below are some recommendations that can be conducted during refurbishment.

1- Materials in need of replacement can be exchanged with similar materials of lower embodied energy and carbon-emission. These materials could be of a local source to reduce transport energy, could have low extraction energies and may have low processing energies. Also they would preferably have an expected life-time equally as long as the expected life-time of the building or longer, and/or be capable of re-use or recycling at the end of the building's lifetime.
2- Construction processes during all maintenance works should be kept as minimal as possible without endangering the safety of the building (which would need more intervention)
3- All minor and major works should employ minimal energy expenditure.

7.1.3 Decarbonisation of Demolition Processes

The end of the building life-cycle is reached when the building under consideration undergoes demolition, reuse or the recycling of its original components. For an existing structure whose structural system and materials are already in existence, decarbonisation can be employed by demolition and disassembly processes that are as energy and time efficient as possible. A low energy-consuming technique of disassembly over a long period of time could very well amount to the same amount of energy expended by a high-energy content demolition method; hence, the factor of time is an important consideration.

8. References

[1] DIXIT, M.K., C.H. CULP, AND J.L. FERNÁNDEZ-SOLÍS, *"System boundary for embodied energy in buildings: A conceptual model for definition."* Renewable and Sustainable Energy Reviews, 2013, 21(X): p. 153–164.

[2] Royal Institution of Chartered Surveyors, "*Methodology to Calculate Embodied Carbon of Materials."* 2012, RICS Books (Royal Institution of Chartered Surveyors).
[3] DIXIT, M.K., ET AL., "*Need for an embodied energy measurement protocol for buildings: A review paper."* Renewable and Sustainable Energy Reviews, 2012, 16(6): p. 3730-3743.
[4] HAYNES, R., "*Embodied Energy Calculations within Life Cycle Analysis of Residential Buildings."* 2001.
[5] Energy Information Agency (EIA) Egypt - Country Analysis Briefs. 2012.
[6] DIXIT, M.K., ET AL*., "Identification of parameters for embodied energy measurement: A literature review. Energy and Buildings,"* 2010, 42(8): p. 1238-1247.
[7] LEE, B., M. TRCKA, AND J.L.M. HENSEN, "*Embodied energy of building materials and green building rating systems—A case study for industrial halls."* Sustainable Cities and Society, 2011, 1(2): p. 67-71.
[8] YOLLES H., "*Embodied Carbon, Sustainable Office - A Supplementary Report,"* S.W.R.D.A. (RDA), Editor, 2010.
[9] VENKATARAMA REDDY, B.V. AND K.S. JAGADISH*, "Embodied energy of common and alternative building materials and technologies."* Energy and Buildings, 2003, 35(2): p. 129-137.
[10] SHUKLA, A., G.N. TIWARI, AND M.S. SODHA*, "Embodied energy analysis of adobe house. Renewable Energy,"* 2009, 34(3): p. 755-761.
[11] CRISHNA, N., P.F.G. BANFILL, AND S. GOODSIR, "*Embodied energy and CO2 in UK dimension stone."* Resources, Conservation and Recycling, 2011, 55(12): p. 1265-1273.
[12] RAMESH, S., "*Appraisal of Vernacular Building Materials and Alternative Technologies for Roofing and Terracing Options of Embodied Energy in Buildings."* Energy Procedia, 2012, 14(0): p. 1843-1848.
[13] YEO, D. AND R.D. GABBAI, "*Sustainable design of reinforced concrete structures through embodied energy optimization."* Energy and Buildings, 2011. 43(8): p. 2028-2033.
[14] UTAMA, A. AND S.H. GHEEWALA, "*Influence of material selection on energy demand in residential houses."* Materials & Design, 2009, 30(6): p. 2173-2180.
[15] RADHI, H., "*On the optimal selection of wall cladding system to reduce direct and indirect CO2 emissions."* Energy, 2010, 35(3): p. 1412-1424.
[16] DAVIES, P. AND M. OSMANI, "*Low carbon housing refurbishment challenges and incentives: Architects' perspectives. Building and Environment,"* 2011. 46(8): p. 1691-1698.
[17] EMMANUEL, M.R. AND K. BAKER, "*Carbon management in the built environment."* 2012: Routledge.
[18] HAMMOND, G. AND C. JONES, "*Inventory of Carbon & Energy: ICE.*" 2008: Sustainable Energy Research Team, Department of Mechanical Engineering, University of Bath.
[19] NEBEL, B., A. Alcorn, and B. Wittstock, "*Life Cycle Assessment: Adopting and adapting overseas LCA data and methodologies for building materials in New Zealand.*" 2011, Ministry of Agriculture and Forestry.
[20] ENERGY SAVING TRUST (EST). *Energy Saving Assumptions*. 2013 [cited http://www.energysavingtrust.org.uk/ May 1, 2013].

Better understanding and modelling of user behaviour in (nearly) zero energy buildings



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Short Summary

Employees and staff influence building operation in various ways. The subjective opinions and resulting behaviour of users are not only determined by ‘objective’ comfort parameters (temperature, draught), but depend decisively on social aspects [1,2]. What makes the user of a building satisfied with his physical working environment?

Parameters, which determine comfort related behaviour and user satisfaction, can be found on personal and organisational level. Two main factors influencing user satisfaction and behaviour are: (1) Individual possibilities to control work environment and comfort, e.g. can users influence operating parameters of the technical systems? (2) Information on the building and its operation, e.g. do users have the feeling that their concerns and complains are taken seriously, do they feel involved in the energy performance of the building?

To get an overview of the social and psychological factors that play a role in the context of the built environment in office buildings, a questionnaire was created by author Magdalena Wicher. The findings should provide an indication for the social interrelation of the agents and thus be integrated in an agent based model (ABM).

The questionnaire about the social and psychological factors affecting satisfaction in office buildings has been distributed through an online tool (unipark) in Austrian buildings that are designed as lowest energy buildings and with plus-energy building techniques. It has also been used to analyze a low-energy high-rise office building in Graz, Austria, which will be the reference for the ABM. The questionnaire is online-based and was created in the form of a post-occupancy evaluation. POE surveys are a common instrument for assessing user satisfaction in buildings and to evaluate the indoor thermal comfort [3,4].

The questionnaire contains several items on staff’s behavior in non-comfortable indoor conditions which allows to analyze the effects of user behavior on energy consumption of the building. Among these it also provides input data concerning the comfort of occupants for an agent based modelling (ABM) of the user behaviour.

Agent-based modelling (ABM) is a simulation methodology that can account for the interaction between agents, e.g. the exchange of informational messages between individuals in an network can be modelled and how this exchange affects changes in behaviour [5]. ABM has attracted wide interests in the social sciences because it is particularly able to reflect the relationship between human behaviour and factors present in the environment that can influence human behaviour.

Agent-based modelling also plays an upcoming role in environmental psychology. The simulation of the complex interaction of humans and their social and physical environment is characterised by the complexity of the involved factors and processes [6].

The activities of the staff of a high rise office building in Graz to realize their personal thermal comfort conditions are the starting point for the ABM. Persons are assumed to be comfortable if indoor conditions are within the “comfortable” region of the comfort diagram according to the PMV/PPD-model of ISO 7730. A list of possible activities to alter the thermal comfort variables is available, among others: turning on the central heating system, opening the door of the own room to the corridor, opening the window next to the own working place, turning on a fan on the own desk, change one’s clothing.

Persons like to talk about thermal comfort and thermal variables in the office, in specific if conditions prevailing are on the brink of the comfort region. People also talk about their activities to reach the comfort region. So chats among colleagues are the relevant occupants’ interactions that are taken into account. Agents will act, if the limit of their accepted operative temperature/ humidity/ draught region is reached. Colleagues acting the same way will improve the conditions. Colleagues counteracting will worsen the situation.

It is the goal of the ABM to model the collective effect of user activities. Questions of interest are: To what extent can an “average user” be defined? Is the “average user” always (in all temperature domains) the same? Are there any indications for clustering of user behaviour? When do agents act? When do agents communicate? A first simple model will provide stochastic communication within the same room, an advanced model will let agents communicate with all other agents according to a „friend“-relationship (same project, same room, same preferred comfort range).

The agent based simulation could further be used to draw conclusions of the building’s operational energy use. The suitability of the model of agent based social simulation of user behaviour for the context of (nearly) zero energy office and service buildings is tested.

Keywords: User behaviour; nearly zero energy office buildings; quantitative social research; agent based modelling

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References

[1] BROWN Z. *“Occupant comfort and engagement in green buildings: Examining the effects of knowledge, feedback and workplace culture”* PHD Thesis, University of British Columbia, Vancouver, 2009

[2] ROHRACHER H, ORNETZEDER M. *“Wohnen im ökologischen Haus der Zukunft. Eine Bestandsaufnahme sozio-ökonomischer Projekte im Rahmen der Programmlinie Haus der Zukunft”.* Berichte aus Energie- und Umweltforschung. BMVIT, Vienna, 2008

[3] KEUL A. *“Umweltpsychologische Evaluation (POE) von sechs Wiener Passivhaussiedlungen (225 Wohneinheiten) im Vergleich zu konventionellen Bauten (156 Wohneinheiten)“* Proceedings Wiener Wohnbauforschungstag 17.11. 2009.

[4] LEAMAN A, BORDASS B. *”Are users more tolerant of `green´ buildings?”* Building Research and Information 35(6) 2007, pp. 662-673.

[5] CHEN J, TAYLOR J.E, et al. *"Modeling building occupant network energy consumption decision-making: The interplay between network structure and conservation."* Energy and Buildings 47(0) 2012, pp.515-524.

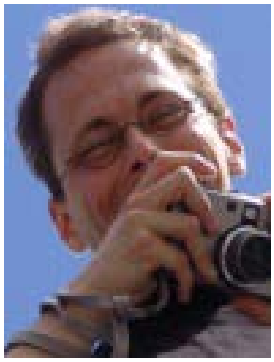
[6] MOSLER H.-J, TOBIAS, R. *“Simulation und Modellierung”* In: LANTERMANN E.-D, LINNEWEBER V. *„Enzyklopädie der Psychologie“,* Volume 1. Hogrefe, Göttingen, 2008, pp. 899-928.

Timber in the City



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Abstract

In recent years, the so-called long-term environmental sustainable CLT (cross-laminated timber) building system has been a topic of great interest for multi-storey apartment buildings. This system can be an alternative to current reinforced concrete building systems and it offers great advantages in cost, speed and carbon reduction, while opening many questions in the design field.
In this paper, we present innovative student design projects for mid-rise buildings made of CLT. The presented projects are a part of the master studio “Timber in the City – Red Hook”, held at TU Graz, Faculty of Architecture in the summer semester 2013. The first objective of the project was to investigate the possibilities for design using scale models, in combination with parametric design and engineering. The second objective was to define an innovative and interactive facade system as a sustainable design element.

Keywords: timber, mid-rise building, sustainable building system

1. Introduction

Single-family buildings constructed with the Cross Laminated Timber (CLT) system are already fully established in Europe, given that the level of energy efficiency of these buildings may be compared with passive houses. Another very important application is the reconstruction of facades, where panels are used with solar panels to achieve high-performance insulated facade elements [1].

In the last few years, there has been a rapid and noticeable development of CLT building systems for multi-storey apartment buildings. The height of constructed multi-storey apartment buildings is closely linked to the building codes and building insurance in individual countries, and it varies between three floors in Austria to thirty floors in Sweden.

Presently, the tallest timber buildings in Europe are the eight-storey residential building “Bridport House”, designed by Karakusevic Carson Architects, and the “Stadthaus”, designed by Waugh Thistleton Architects in Hackney, London. In Australia the highest building is the recently completed ten-storey apartment building “Forte”, designed and constructed by Lend Lease in Victoria Harbour, Melbourne. In 2012, the Canadian architect Michael Green developed the so-called FFTT system, proposing 30-storey buildings with predominantly wood solutions (with steel beams) for high-risk seismic areas like Vancouver [2].

2. CLT in Multi-Storey Buildings

The reason for the rapid development of the CLT structural system and the establishment of related building codes is associated with climate change and multiple benefits of CLT, such as structural and environmental behaviour. From a structural point of view, its benefits concern mechanical properties across to advantages during assembly, which also influences, the financial benefit of this product.

Cross Laminated Timber panels can be produced in a factory environment with different surface qualities, which means the material is faster to use and build on site and therefore highly cost-effective. In the production, the timber panels undergo a process whereby they are stacked crosswise on top of each other and glued to each other with high pressing power to form large-format solid timber elements. The crossways arrangement of the longitudinal and crosswise laminates reduces the swelling and shrinkage in the board plane to an insignificant minimum, while its static strength and shape retention increase considerably.This process delivers an alternative to concrete and steel that can withstand the same pressure as prefabricated concrete [7]. A part of the fabrication process is CNC milling, with the opening and guides for installation milled for each individual panel. In Austria the maximum panel size is about 3m x 16m x 0.5m and is limited by means of transport.

From an enviromental point of view, wood is naturally CO_2 neutral and energy efficient in every respect. For example, by using CLT one ten-storey building reduces CO_2 equivalent emissions by more than 1,200 tonnes when compared to concrete and steel [2].

The largest influence on the final price of CLT buildings is determined by the price of the raw material and labor costs, which vary extremely across countries. On the one hand, the price of the raw material wood for such buildings is 10% higher than the price of the material for massive constructions like concrete or brick. On the other hand, however, prefabricated CLT panels increase productivity by lowering labor requirements and facilitating assembly. This decreases the total building costs about 40% compared to the same buildings built with reinforced concrete [2].

All these benefits have convinced many countries all over the world to use CLT technology, along with their willingness to change the national standards according to the constantly improving CLT building technology. In many innovative projects [2], [3], [4], [5], [6] they try to push the boundaries of the building possibilities and to show the great potential of this building system. If we consider the use of CLT in hybrid structures, it facilitates the use of such constructions in multi-storey buildings in countries with highly restrictive building codes.

From an architectural point of view, wood greatly improves the quality of a building's interior or exterior space. In contemporary architecture, there are a number of architects who use a wood structure as primer or secondary structure. In the projects "Centre Pompidou" in Metz and "Haesley Nine Bridges" the architect Shigeru Ban used glulam structures for the primer non-standard roof construction. For the Tamedia New Office Building in Zürich Ban designed a five-floor building with the main modular structure entirely in timber. Although the design possibilities of CLT for multi-storey buildings have not been sufficiently explored, there are currently many initiatives worldwide that promote wood as a sustainable building material.

One of these initiatives was a competition for Canadians and Americans in 2012/13 on the topic "Timber in the City". The program intended to engage students and young architects in repurposing old cities with buildings that are made from renewable resources. The competition challenge was to design mid-rise, mixed-use housing units sited in Red Hook, Brooklyn. The main focus was on the structural use of timber, with an emphasis on innovations in wood design. This interesting competition inspired us to choose a similar competition program for our master studio, for which we restricted the topic timber to CLT panels and the Kielsteg system. We placed this limitation bearing in mind the timber industry in our country. Austria is a European country with a century-long timber building tradition that has led to innovations like the CLT [7] and Kielsteg [9] technology. Austria introduced the CLT structural system in one and two-storey house building.

Kielsteg elements are lightweight and strong wooden construction elements that can be used to build roofs and structural floors with large clear spans. They have a linear cellular structure, with strips of timber forming top and bottom flanges, and are connected by zigzag webs of plywood or oriented strand boards (OSB) [9] .

The Austrian forest industry is a sustainable system and companies producing CLT panels and Kielsteg elements obtain raw material from sustainable cultivated forests. Additionally, the building codes and insurance requirements in Austria are very strict and the maximum height of buildings is limited to three floors.

3. Challenges of Timber

The master studio “Timber in the City – Red Hook” held in the summer semester 2013 had the aim to investigate the possibilities to use timber technology as the primary structure or part in a hybrid building structure for mid-rise buildings (Fig. 1).
The first objective of the studio was to define parametric design tools to include static calculations in the early stage of the design process. This approach proved highly flexible in terms of the design decision and real-time feedback for the designer concerning the spans and size of the building elements according to the allowable stresses in the construction. At the same time, our approach allowed us to explore how parametric modelling can contribute to conceptual exploration and how the size of CLT panels and Kielsteg elements can influence the existing design. In addition to parametric design, the students checked their project development by making digital fabricated scale models. The students could rely on their scale models to directly verify the design and remove any flaws affecting the structural stability or aesthetics of the building.
The second objective was the definition of an innovative and interactive facade system as a sustainable design element.



Fig. 1 Scale models of the studio project “Timber in the City”

A special focus of the project was the efficient use of standard materials in hybrid structures, such as wood-concrete or wood-steel. In fact, it is well known that the inefficient pre-fabrication of panel elements often produces off-cuts and waste, which greatly increases the costs of a building. This is why the process of design in this project started with geometry and static conditions. The students were introduced to the fabrication process, technical possibilities and limitations of CLT and Kiel-steg elements, as well as to the mechanical constraints and geometric conditions that satisfy the requirement of material cost-effectiveness.

3.1 Design

An interesting fact is that schools of architecture worldwide do not study the CLT structural system, so there is a lack of understanding of the system or of a more extensive use of this material in design. The CLT system (if present) is usually part of the curriculum of civil engineering schools. This situation opens up many questions, from the structural to the formative aspects.

Timber design can be defined as the most modern method of construction in the market in terms of contemporary “information society”. No other system could explain better the relationship between technology, fabrication methods and architecture [8]. In this way, the proposed parametric approach is an ideal connection for the process of design.

The master studio projects were not strictly limited to the current technical achievements; accordingly, the students were strongly supported to develop new ideas to combine new materials and techniques.

The next part of the paper gives a brief description and shows images of some of the students’ projects.

3.2 Students’ projects

3.2.1 Alfred Angerer, “Hanging Gardens of Brooklyn”

The main idea of the project was to develop a hanging hybrid timber mid-rise building (Fig. 2a). The main structure consists of a CLT core and two steel grates (Fig. 2b). The first steel grate is in the middle of the building and serves as a technical floor. The second one is at the top of the building. Sixteen timber boxes are supported by these elements (Fig. 2c). The advantages of the system are that it is a load-bearing structure without load-bearing walls, it has free floor plan organization (Fig. 2d) and a non-structural façade. The roofs of some boxes were designed as green gardens with multi-functional potential.

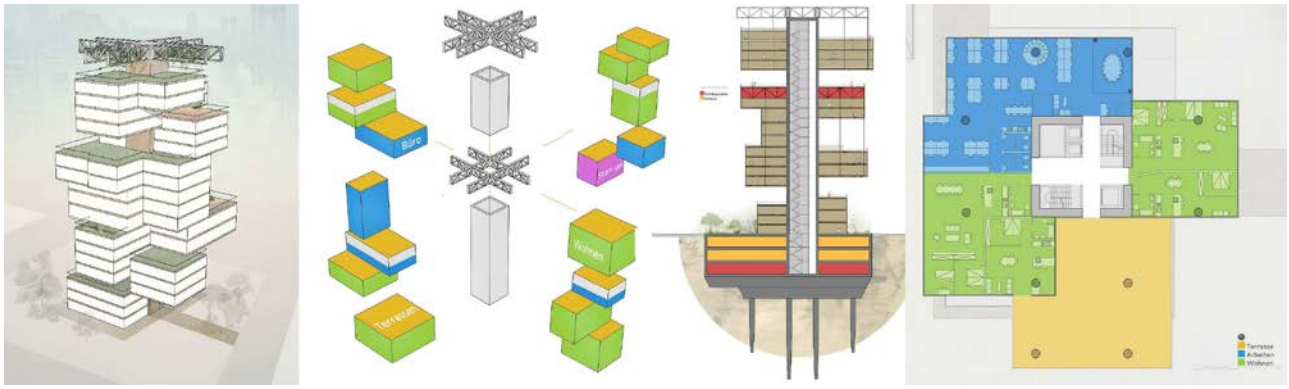


Fig. 2a) Hanging Gardens of Brooklyn, b) the load-bearing structure, c) a section, and d) the free floor plan

3.2.2 Hugo Bernard-Lecharpentier, “Roof Structure”

The whole site is covered with a quad glulam structure. All the four buildings (two apartment and two administation buildings) have CLT cores and slabs and vertical supporting glulam elements (Fig. 3a). The interactivity of the system is integrated in the roof. The glulam roof system is covered with a tensile sensor structure that can be closed and opened depending on different environmental factors like temperature, average radiation, cloud factor or diffuse horizontal radiation (Fig. 3b).



Fig.3 All-timber structure (a) with an interactive roof structure; (b) a render and scale model

3.2.3 Ivana Djuric, “Pipe Structure”

The core (made of curved CLT panels), two glulam bamboo pipes and planar CLT slabs are the main structural properties of this timber structure (Fig. 4a). The free form shape of the bamboo pipes offers an interesting organic appearance and dynamic of the floor plans (Fig. 4b). At the facade level, the grid structure of the pipes is “repeated”, with the irregular bamboo structure adding a special dynamic quality to the planar facade envelope (Fig. 4c).

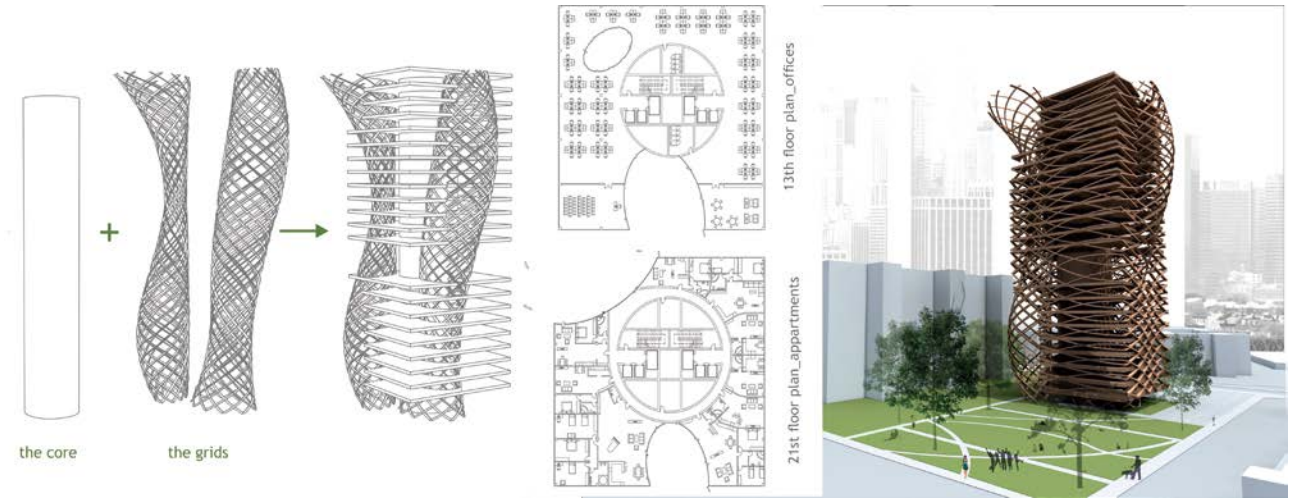


Fig. 4a) Structural system, b) the ground floors, and c) a 3D model

3.2.4 Patrik Müller, “Twimber Towers”

Two twisted towers with a quadratic plan floor are connected via a wood production area at the height of the first two floors (Fig. 5a). Above the two common floors, each tower has 15 floors. The

structural system is completely made of CLT panels. The purpose of the shear CLT walls (Fig. 5b) is to stabilize the twisting geometry of the building. The CLT columns on the facade follow the twisting form; the facade itself is made of insulated glass. The twisting form provides a better flat orientation in the south direction. The twisting design process projects onto the glass facade with different color settings.



Fig. 5a) Twimber Towers project, b) the shear walls in the floor plans, and c) a scale model with an interactive facade

3.2.5 Katharina Puck, “Organic Tower”

The inspiration for this project came from the Aqua Tower in Chicago by Studio Gang Architects. Unlike the prominent horizontal divisions of the Aqua Tower, the Organic Tower has prominent both horizontal and vertical divisions (Fig. 6). The number and size of vertical supports came from a parametric structural analysis. In order to respond to the overheating cubic form design, an organic quality was added to serve as active shadowing elements. The CLT walls and slabs are connected with a locking system. Thanks to the parametric and static model, it was possible to calculate the total number of supports, whose thickness is in correlation with the length of each individual support.

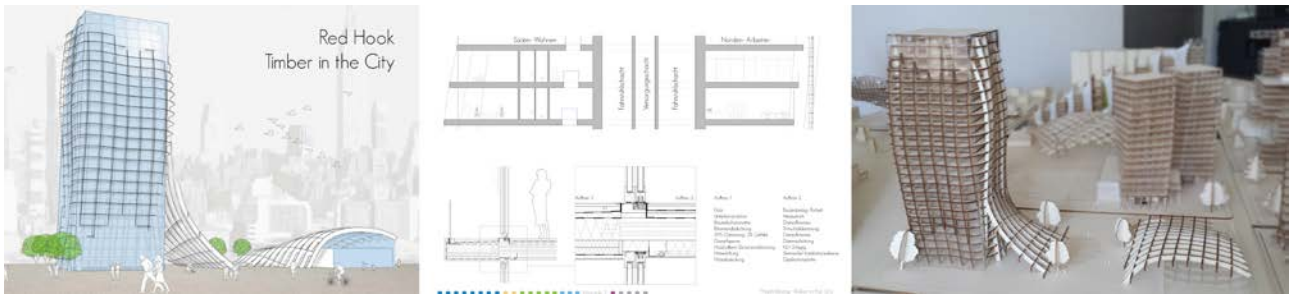


Fig. 6a) Render, b) construction details, and c) a scale model of the “Organic Tower”

4. Conclusions

Many prejudices about wood as a building material in contemporary architectural practice have led to concrete and steel being the most frequently used materials in the construction of multi-storey buildings. These materials and buildings significantly contribute to large volumes of CO_2 output and

climate change. A current challenge concerns the promotion of alternative materials for this type of buildings. Many initiatives worldwide promote multi-storey buildings constructed of wood, which is indicative of a desire to change the situation.

The possibilities of designing multi-storey buildings made of timber are poorly studied, and through our studio “Timber in the City” we tried to evaluate the formal potential of this material. In the first stage of the design process, we implemented parametric design and static calculations, and in the second phase we studied the possibilities of using interactive facade systems. As an analysis of the students’ work, it can be concluded that architectural design with timber offers a great potential and the use of different systems such as CLT, laminated wood or Kielstieg combined with concrete or steel offers up to a 90% better CO_2 balance than standard buildings. The question how the building industry and markets perceive timber buildings is still strongly related to financial interest and safety standards.

5. Further work

In order to further examine the potential of these systems, we plan an intensive cooperation between architects, construction engineers and technologists in the next studio. It will include:

- Analysis of the structural system of the traditional Japanese pagoda buildings
- Possibility of fabrication of curved CLT panels to be used in non-standard structures
- Formal value of single-curved Kielstieg elements and the possibility of their fabrication
- Examination of the possibility of using different types of wood for CLT panels. This primarily refers to using tropical timber (more weather resistant) for the outer panel layer.

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7. References

[1] SPINELLI A, CALLEGARI G: *“Naturwall©—timber multifunctional systems in refurbishment sustainable process”* In: Structures and Architecture: New concepts, applications and challenges, CRC Press, edited by Paulo J Cruz, 2013
[2] GREEN M, Karsh E: The case for Tall Wood buildings, Final research report, 2012
[3] http://www.cfmoller.com/p/HSB-2023-Vasterbroplan-i3048.html at 15.3.2013
[4] http://www.cwcdemoproject.ca/en/faqs.php at 16.7.2013
[5] http://www.softwoodlumberboard.org/Programs/CallforProposals.aspx at 3.5.2013
[6] Skidmore, Owings& Merrill, LLP:Timber Tower Research project, Final report, 2013
[7] KLH, Cross Laminated Timber Structures, KLH massivholz GmbH, 01/2011
[8] SCHEURER F, SCHINDLER C, BRAACH M. From Design to Production: Three Complex Structures Materialised in Wood. In: 6th International Conference Generative Art. Milan, edited by Celestino Soddu, 2007
[9] http://www.kielsteg.at/ at 10.3.2013

Criteria of Mobility for Sustainable Buildings



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Short Summary

Part of the research project “life cycle improvement of the building quality” (“LQG”), financed by the Austrian Research Promotion Agency (FFG) and six industry partners is the comparison of sustainable building certification systems.

This study describes the differences concerning infrastructure and mobility in several building certfication systems for residential buildings: the Austrian klima:aktiv declaration system and Total Quality Building (TQB) certification system are compared with the German Sustainable Building Council (“Deutsches Gütesiegel für Nachhaltiges Bauen”, DGNB), the Swiss MINERGIE-ECO® and with two international systems, Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM). It demonstrates how these systems deal with the aspects of infrastructure and mobility, where the deficiencies are and how the criteria could be improved. Moreover, the Swiss leaflet SIA 2039 Mobility – Energy Needs Dependent on Building’s Location (“Mobilität – Energiebedarf in Abhängigkeit vom Gebäudestandort”) is described and applied in its corresponding calculation tool.

Infrastructure and mobility is treated differently in all the systems. Some system boundaries simply ignore aspects of mobility for building declarations in order to do it correct in a “scientific way”. Thinking in a holistic way, from the point of sustainability it is clear that a “passive house” or “plus energy house” does not really work if you need lots of energy for mobility by using this building. A building depends completely from the site, it never changes the site. Therefore the system boundaries have to be extended from the building itself to the urban settlement. Examples are discussed.

Keywords: Certification systems, mobility, system boundaries

1. Introduction

Within the current 5 years cooperative research project about “life cycle improvement of the building quality” (LQG - “Lebenszyklusorientierte Qualitätsoptimierung von Gebäuden”, 2008-2013), financed by the Austrian Research Promotion Agency (FFG – “Österreichische Forschungsförderungsgesellschaft”) and six industry partners, 5 Austrian Universities of Applied Sciences develop inter alia a qualitative database [1] [2]. National and international building rating systems and certification systems, which are analysed by the 5 Universities of Applied Sciences in various ways, do have crucial parts in quality assurance and optimization of buildings. Thereby the criteria of urban building and qualities of buildings are inspected as well by the University of Applied Sciences Upper Austria.

The problem of the system boundaries in rating systems can be figured out well. Are we permitted to refer to a “passive house” or “plus energy buildings” as such, if mobility becomes a grave factor for the energy consumption of a building due to the building’s site? Should the energy demand respectively the energy consumption be assessed without mobility factors anyway? Nowadays, the

term “total energy balance” has to be taken literally and should not ignore basic holistic coherences under the guise of “clean scientific separation”. Fig. 1 shows the system boundaries in “plus energy” houses. The primary energy demand can only be reduced by a conscious use of materials, mobility and energy. “Passive houses” are defined as a necessary loss minimizing, but only with the additional profit-maximizing strategy, which means the use of renewable energies as photovoltaic systems, solar thermal systems, etc., it is possible to achieve the “plus energy“ area. If credits for mobility and grey energy should be produced additionally, the application is unavoidable.

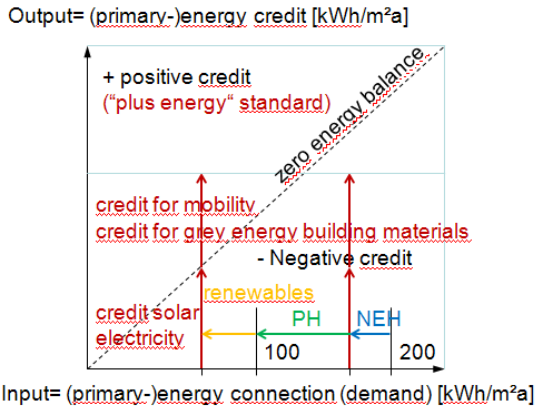


Fig. 1: System boundaries “plus energy” house

2. Urban building aspects of building rating systems

In order to achieve the highest aim of quality optimization of buildings, the user satisfaction, as many criteria of the comprehensive building ratings as possible should be performed eminently. Commencing with a comfortable indoor air quality, which is obviously measureable with appropriate methods with different efforts, a high user satisfaction can also be improved by building structures and location factors. Criteria for mobility respectively infrastructure figure a high importance in these aspects, whereas mobility factors are not only defined by the motorised private transport, because this assumption resulted in the known uncomfortable indications as urban sprawl, environmental pollution and the daily traffic jams in agglomeration areas. These problems will intensify: the trend is towards from 577 cars per 1,000 inhabitants in Austria at present to 680 cars per 1,000 inhabitants in 2021 [3].

Hence, urban and traffic planner demand the first priority for the public transport facilities as tram, underground and bus over the motorised private transport. In addition, safe and secure foot and cycle paths, car-free areas and connections with attractive private and public green spaces have to be encouraged. A previous research project exposed an approximate compliance of the requirements of energy-efficient and ecological urban construction and the parameter for child- and family-friendly urban construction. Moreover, the “house in Green” (rural area) is not identical with the child-friendly construction, quite the contrary: moderate concentrated building structures are mostly more child-friendly than detached houses [4].

3. Survey of building certification systems

The interest in building certification systems increased sharply in recent years. Therefore, more investors discern that sustainability is dependent from both energy-efficiency and consideration of comprehensive ecological, social and economical factor. As a result the approach of lifecycle orientation enforced – at least theoretical. The practical realization will take still a few years due to the enormous complexity of this theme. Basically each relevant certification program affords significant approaches towards broad optimizations of buildings, even if they have various focuses.

Several Austrian rating systems, including klima:aktiv, IBO Ökopass and TQB-Total Quality Building, are long-term securely established. Furthermore, following international certification systems

are appreciable in the German-speaking regions: “Passivhauszertifizierung” (passive house certification) (PHI, Germany), DGNB-“Deutsches Gütesiegel für Nachhaltiges Bauen” (Green Building Certification for Sustainability), Minergie (Switzerland), LEED-Leadership in Energy and Environmental Design (USA), BREEAM-Building Research Establishment Environmental Assessment (GB) and EU Green Building. Since the standard literature about building certification is rather spare, the book “Zertifizierungssysteme für Gebäude” (certification systems for buildings), which was published in 2010, constitutes an important basis for interested parties, who want to enter into the topic [5]. Nevertheless, the book do not contain Austrian building rating systems, but it issues a compact survey concerning main points, costs, etc. of national and international rating systems [6]. The free declaration system “klima:aktiv” can be referred as the simplest system, whereby approaches of ecological, social and economical sustainability are assessed in addition to climate protection and energy-efficiency. TQB is a long-term developed and detailed system, which is 100 % compatible with klima:aktiv. In consequence of the partial specific national requirements the national systems should be preferred from the viewpoint of the authors. Nevertheless, a known international system as LEED or BREEAM can provide advantages for international investors, especially in non-residential construction. Information about the relevant systems and further links can be found in the qualitative database of the research project mentioned in chapter 1 [7].

4. Criteria in building certification systems

It is striking that criteria for location and mobility are considered and assessed particularly different, in marked contrast to criteria for energy-efficiency, which are defined by the EU Directive about the energy performance of buildings (apart from LEED: ASHRAE Standards) [8] [9]. For the comparison only the available catalogues of criteria for residential buildings are used intentionally, but not the particular existing catalogues for urban quarters, although these building certification systems should integrate the most significant aspects of urban building to be holistic orientated systems [10]. The strict separation in building level and urban planning level can result in doubtful partial assessments and is contrary to the holistic approach from the viewpoint of the authors. Fig. 2 depicts a survey of the comparison of the different certification systems for residential buildings. The green bars show the total amount of the criteria, the blue ones the amount of infrastructure criteria and the red bars the amount of density respectively space efficiency. The several systems are described in the chapters 4.1 to 4.6 in detail.

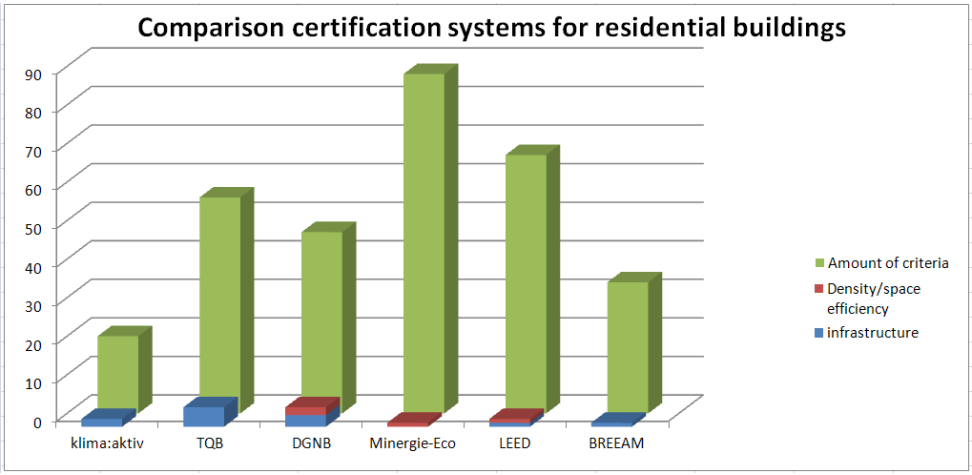


Fig. 2: comparison between the certification systems for residential buildings

4.1 KLIMA:AKTIV

Although klima:aktiv constitutes rather the lowest standard of comprehensive rating systems and does not refer as “certificate” but as self-declaration system, the most important mobility factors can already be assessed: The quality of infrastructure is defined by food supply, leisure facilities, childcare, education, public transport stops as well as foot and cycle paths and cycle storage pos-

sibilities. The demand of the everyday life should be located within a radius of 500 m linear distance and has to be verified in a site plan. The mobility factors are listed in the category “Planung und Ausführung” (Planning and Execution), whereby criteria for site and mobility can achieve maximal 60 out of 1120 possible points (the overall result is limited with 1000 points). Fig. 3 gives a survey of all categories of the assessment klima:aktiv. The percentage of the category planning amounts to 8.93 %, taking into account that only 38.7 % of it deal with site and mobility factors (demand of everyday life, parking spaces for bicycles, etc.) [10].

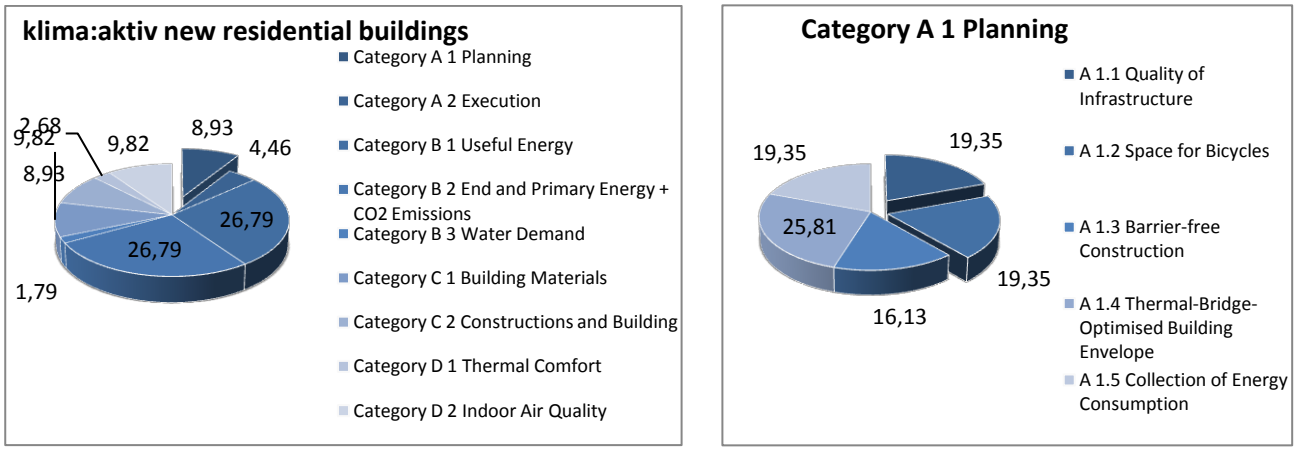


Fig. 3: System "klima:aktiv": survey of all categories of the assessment an categorie A1 in detail. The highlighted parts contain criteria for mobility, 38.7 % of 8.93 % and thus 3.5 % of the total rating deal with mobility [10].

4.2 TQB

This system is a combination of several proved Austrian systems (klima:aktiv, IBO Ökopass, TQ 2002). It can be referred as the most comprehensive and scientifically sound national system and the compatibility with klima:aktiv has to be particularly emphasised. They are nearly identical, TQB divided the requirements into several criteria, but more detailed, whereas klima:aktiv summarizes them in only one criterion. Consequently, a certification process can take place in various phases. The proportion of the energy-efficiency assessment was systematically reduced, to get an equivalent distribution of the requirements for the 5 categories with 200 out of 1000 points each: site/facilities, economical and technical quality, energy and supply, health and comfort as well as resource-efficiency. For that reason the klima:aktiv mobility factors can be found in TQB in principle, but in a more differentiated way. Depending on the distance to the factors e.g. connection to the public transport (300-500 m) or quality of the local supply, of leisure facilities and social infrastructure (500-1000 m) points are assigned. Moreover, the safety of access routes and biking facilities are rated.

4.3 DGNB

The DGNB-quality label is a certificate of the second generation and had the potential to be an international groundbreaking system. Indeed the system takes an exceptional position in comparison with the other systems, because site and mobility factors are assessed in a separate category, but this category does not influence the total evaluation of the buildings, it is mentioned additionally at the certificate. Consequently, it does not play a decisive role in awarding the label (Gold/Silver/Bronze), how the criteria for site and mobility are rated. Hence, situations are possible that buildings are assigned with “Gold”, although the site and mobility factors are miserable. Since the first system release in 2008/2009 it has been criticised on the part of the author that buildings are inextricably linked with their locations and the assessment of the site must not take place separately. Meanwhile following “scientific need for editing” is mentioned in the standard literature for building certification: It says that the current solution was a pragmatic approach to establish a German system, but has to be revised now. Especially the assessment of the site quality should have an influence on the total assessment similar to BREEAM and LEED. The structure emerged

due to the time pressure during the system development, but for several years the balance limits have been enhanced for energetic assessments [5]. As a consequence of the lack of influence, the mobility factors in the DGNB system are not amplified in this paper. In main system only the convenience for bicycles and space efficiency is assigned.

4.4 MINERGIE ECO®

The Swiss system MINERGIE® is available in several versions, where only MINERGIE ECO® is comparable with the assessment of the other systems. At the moment about 200 residential buildings are certified with MINERGIE ECO® in total [11]. Site factors are listed in the category "Gebäudekonzeption" (GN 16) (building concept) and do not have any influence on the result of the assignment. Expandabilities (densification) are rated with only 1.16 %, mobility factors are missing, although the Swiss leaflet 2039 would provide a scientific basis for these factors [10]. In chapter 5 the leaflet and the Swiss situation are described more detailed.

4.5 LEED

Due to 25,000 registrations and about 6,000 certifications of residential buildings in 2009 [5] LEED can be referred as one of the most important international certification system and is surely the most well-known. In "LEED for Homes" the certification levels "Certified", "Silver", "Gold" and "Platinum" can be achieved. Criteria concerning site and mobility are evaluated in the categories Location & Linkages (LL) and Sustainable Sites (SS). LL5 (Community Resources) has a percentage of 2.2 % of the total weighting and assesses the distances to public facilities. Depending on distance points are assigned, if the distance is a ¼ mile (400 m) the maximum points are given, otherwise the facilities have to be maximal a ½ mile (800 m) away from the building. SS6 (Compact Development), which rates the amount of dwelling units per acre (4,046 m^2) of buildable land, attends with 2.9 % to the total evaluation.

4.6 BREEAM

BREEAM is the oldest certification system, hence it was developed 1990, and is considered as basis for the international systems of the first generation (as LEED). It can already refer to 800,000 registrations of residential buildings and 115,000 certifications in GB (2009), of which residential buildings constitute a large part [5]. In total 9 categories are assessed, which are similar in the various versions. In this paper the "Code for Sustainable Homes (CSH)" (2007) is treated. The certified buildings are sectioned in 6 levels; the best buildings can achieve level 6 "Outstanding", followed by "Excellent", "Very Good", etc. In category 1 "Energy and CO_2-Emissions" the criterion ENE8 (Cycle Storage) influences the total result with 4.1 %. Apart from the Cycle Storages there are not any site or mobility criteria.

5. Extended criteria for mobility: leaflet SIA 2039

5.1 General information

Based on the Swiss vision of the 2,000 Watt Society and different deduced leaflets, e.g. SIA 2040 "Effizienzpfad Energie" (Efficiency Path Energy) and SIA 2032 "Graue Energie von Gebäuden" (Grey Energy of Buildings), the leaflet SIA 2039 "Mobilität – Energiebedarf in Abhängigkeit vom Gebäudestandort" (Mobility – Energy Needs Dependent on Building's Location) and the for that reason developed ExcelTM-Tool [12] were published by the Swiss Society of Engineers and Architects (SIA – Schweizerischer Ingenieur- und Architektenverein) in 2011. The purpose is to point out, how criteria for mobility will be considered via the urban planning and the building certificates in future and the provision of a scientific evidenced calculation option for the building-related mobility.

As a strategy of the Swiss Federal Council the 2,000 Watt Society is a criterion for the climate and environmental policy with a continuous output of primary energy of 2,000 Watt and 1 ton CO_2-equivalent per person and year. Initially the building-related mobility is included in the energetic overall view (non-renewable primary energy, greenhouse gas emissions) and mean values are used through correction factors for unknown user mobility. Moreover, the grey energy for the pro-

duction and maintenance of vehicles and infrastructure is considered. The used data for the mundane and non-everyday mobility are predicated on the micro-census Switzerland of 2005. The appertaining socio-economical influencing factors as income, occupation and origin of the users do not affect the results; therefore the data of the average Swiss user is applied. If the mobility behaviour is known, the dedicated calculation method has to be chosen. The calculation is effected by the means of individual-related information and additional of the energy reference area of the building. Due to the available exemplary calculations following perceptions derive therefrom: Optimum locations and mobility facilities enable about 40 % lower energy consumption and greenhouse gas emissions in comparison with the Swiss average values. Detached houses have to feature better values in production and operation to achieve the overall goal. Since the mobility rates in rural areas are more adverse than in urban areas, the requirements are tighten. Fig. 4 represents the interaction for buildings with unknown user mobility, the calculation of the primary energy from everyday mobility. The interaction can be applied for the greenhouse gas emissions.

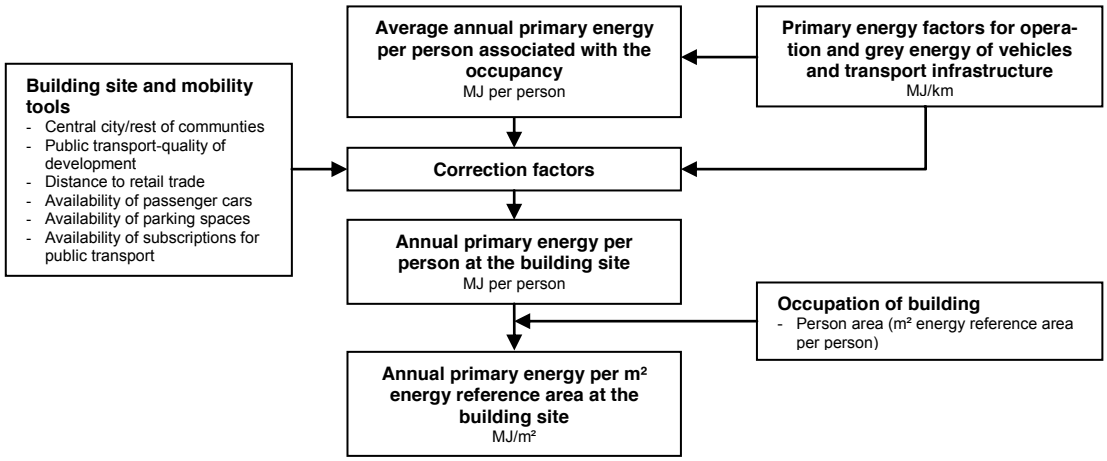


Fig. 4: Interaction for buildings with unknown user mobility [12]

5.2 Results

The optimal sites and mobility facilities enable already an approximately 40 % lower energy consumption and green house gas emissions as opposed to the Swiss average values. As a consequence, detached houses do have to show appropriate values in production and operation to achieve the total goal. In rural areas the requirements intensify due to the unfavourable mobility situation. Fig. 5 reveals the results of SIA 2039 comparing urban and rural area and the car fleets of 2010 and 2050.

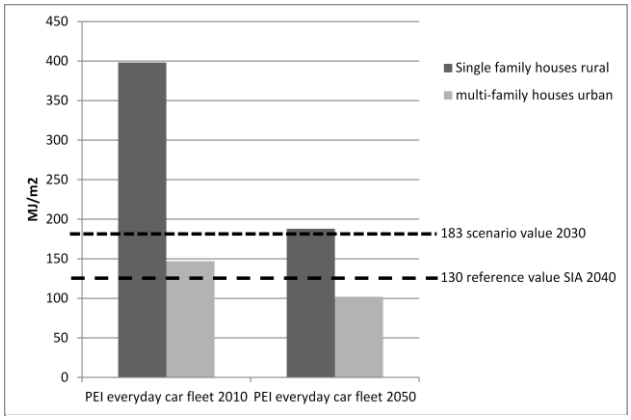


Fig. 5: Results of SIA 2039 comparing urban and rural area and car fleets of 2010 and 2050. The PEI requirements of SIA 2040 can only be achieved in the urban area with the car fleet of 2050 [12]

6. Examples

The following chapters 6.1 to 6.3 describe several examples, whose executions are comprehensive and which focus on the holistic approach.

6.1 Active house as power plant

The two-storey detached house is located in Leonberg, Germany and is executed as a net “plus energy” building”. Following data point out the energy efficient building technology and are displayed in Fig. 6 [13]:

- Southbound pent roof with 15 kWp solar power system and 7 m² solar thermal system
- Solar yield of up to 14,500 kWh/a = 60 kWh/m²a
- 30 kWh/m²$_{\text{Living space}}$a heat demand
- Building management system and monitoring for load-management
- Wall: 0.22 m thermal insulation 032, u-value=0.15 W/m²K
- Roof: u-value=0.12 W/m²K
- Windows: u-value=0.9 W/m²K, 3-glasses-insulation glazing, U_g=0.6/0.7 W/m²K
- n50=0.75 h^{-1}, ventilation with 85 % heat recovery
- Ground heat exchanger air
- Heat pump COP 4.5-5.0 / 3 probes with 95 m / floor heating system, but operation only as an exception
- Buffer storage 825 litres
- Control of the hours of operation of domestic appliances
- Consumption: heat pump 15 kWh/m²a, household 25 kWh/m²a

The domestic electricity has a high utilization rate (at least 50 %) by means of load-management and application of power surplus (20 kWh/m²a) for private electromobility (10,000-15,000 km/a) and battery storage (6-8 kWh).

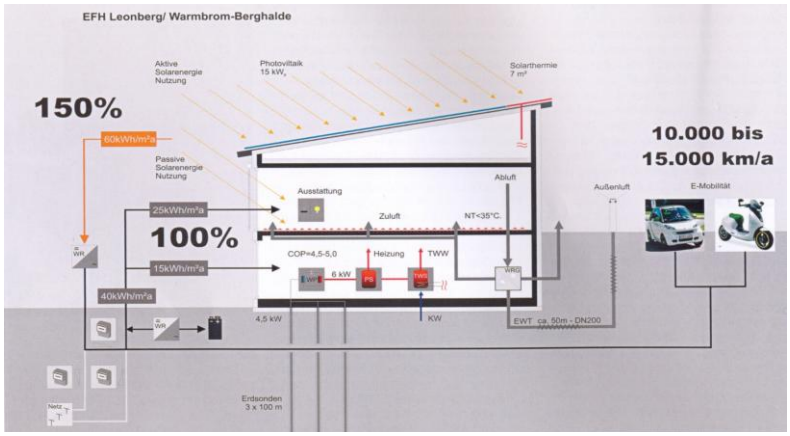


Fig. 6: Active house as power plant - system scheme [13]

6.2 Energy Performance Certification for Settlements in Lower Austria

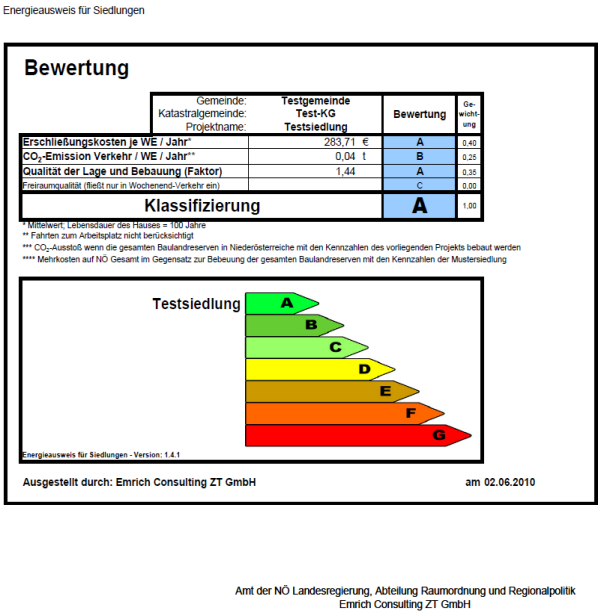
The Energy Performance Certification for Settlements in Lower Austria is not an Energy Performance Certification as usually, instead it assesses following aspects:

- Building land efficiency
- Transport infrastructure: examines internal and external transport infrastructure. Internal transport infrastructure means the pipe lengths of supply (water, district heating, etc) and the external transport infrastructure contains the distances to the connections to supply systems (drainage, electricity supply, noise barrier, etc.).
- Quality of open spaces: evaluates the total length of the road network and the length of ways which are particularly attractive for pedestrians, private green areas, noises, etc.
- Connection and transport: deals with distances to the next center, local supply, playground, stop of public transport, etc. on weekdays (from Monday to Friday) and on weekends

(Saturday, Sunday and on holiday)

- Situation and development: contains the topography of the building (whether it is situated on the northern/southern/… slope), the type of building and the orientation of the area, which is averted from the street.

The results are displayed like Energy Performance Certifications in categories A to G (see Fig. 7). Partial results are the development costs per dwelling unit and year in €, the CO2 – emissions per dwelling unit and year in tons, the quality of the situation and development (factor) and the quality of open spaces, which influences the transport of the weekend. Each partial result is displayed in a specific category A to G, too, multiplied by their individual weighting factor and summed up to a total category result [14].


Energieausweis für Siedlungen

Bewertung

Gemeinde: / Katastralgemeinde: / Projektname:	Testgemeinde / Test-KG / Testsiedlung	Bewertung	Gewichtung
Erschließungskosten je WE / Jahr*	283,71 €	A	0,40
CO_2-Emission Verkehr / WE / Jahr**	0,04 t	B	0,25
Qualität der Lage und Bebauung (Faktor)	1,44	A	0,35
Freiraumqualität (fließt nur in Wochenend-Verkehr ein)		C	0,00
Klassifizierung		A	1,00

* Mittelwert; Lebensdauer des Hauses = 100 Jahre
** Fahrten zum Arbeitsplatz nicht berücksichtigt
*** CO_2-Ausstoß wenn die gesamten Baulandreserven in Niederösterreiche mit den Kennzahlen des vorliegenden Projekts bebaut werden
**** Mehrkosten auf NÖ Gesamt im Gegensatz zur Bebeuung der gesamten Baulandreserven mit den Kennzahlen der Mustersiedlung

Energieausweis für Siedlungen - Version: 1.4.1

Ausgestellt durch: Emrich Consulting ZT GmbH am 02.06.2010

Amt der NÖ Landesregierung, Abteilung Raumordnung und Regionalpolitik
Emrich Consulting ZT GmbH

Fig. 7: Energy Performance Certification for Settlements results [14]

6.3 Urban quarters

Portland is with 600,000 inhabitants the largest city in the U.S. state of Oregon and pioneer in the matter of environmental protection. Until 2050, Portland wants to reduce the CO_2 – emissions by 80 %. Heretofore the emissions are decreased by 26 % per head compared with 1990 due to their long-term comprehensive planning. The city addresses contemporary traffic, production and efficient use of energy, recycling and forestation. Additionally measures like standards, inducements and taxes are established. Moreover, the effects of urban sprawl are reduced with the improvement of the public transport and the expansion of the cycle network. More than 22,000 people go to work by bike, much more than in other cities in U.S. [15].

Based on the analysis of certification systems for residential buildings four certification systems for urban quarters, DGNB for new urban quarters, BREEAM for Communities, LEED Neighborhood Development and Green Star Communities, are researched. Fig. 8 shows the comparison between these certification systems with regard to criteria for infrastructure and density in relation to the total amount of criteria. LEED has the highest amount of criteria and the percentage of infrastructure and density criteria is with 30 % the highest compared with the other systems, too. Criteria in BREEAM achieve a share of 25 % of the total rating, in DGNB and Green Star 18 % [16].

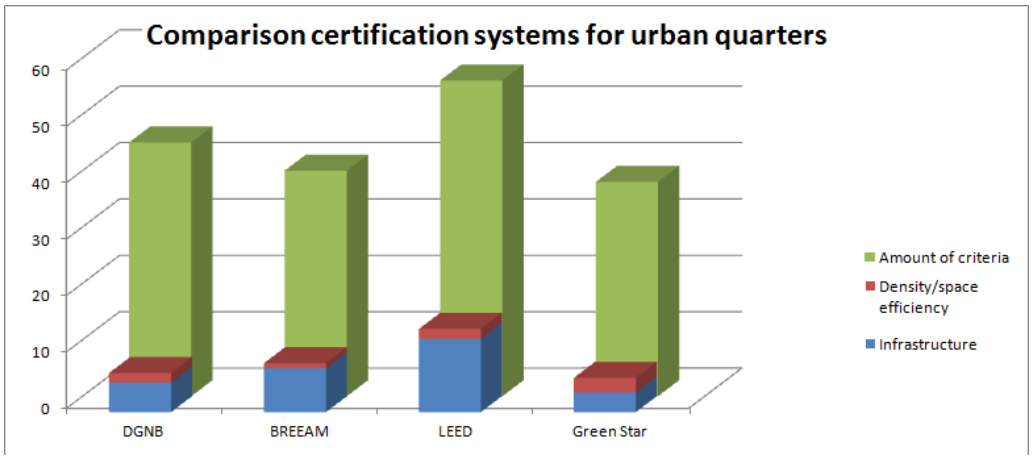


Fig. 8: Comparison between the certification systems for urban quarters [16]

7. Discussion and conclusion

Building certification systems serve as quality assurance and quality optimization of buildings. These criteria for energy efficiency are treated broadly coherent at least in Europe, whereas criteria for site and mobility are viewed different in various certification systems. In DGNB these criteria are not included in the overall assessment, which can be referred as a historic mistake as the total separation of building certificates and urban quarter certificates, since every building is not mobile and consequently inextricably linked with the site. Holistic orientated assessments do have to consider these factors, because the system boundaries redeploy off buildings to urban planning dimensions. The Austrian systems klima:aktiv and TQB already set very detailed parameters for accurate ratings as distances to public transport connections or to local supplies. Nevertheless, a scientific basis was missing so far for comprehensive assessments of mobility factors, even with unknown mobility of the user. These gaps are filled by the leaflet SIA 2039, which covers the building-induced mobility in the energetic overall consideration. Consequently, the leaflet and its calculation tool is currently the state-of-art tool for the interface of mobility and immobility. Precisely why, it has to be questioned, why they did not develop new criteria on the basis of SIA 2039 in the new version of the Swiss system MINERGIE ECO®, which was revised in July 2012. As a result of the comparison, all building certification systems have to be reworked until they achieve an ideal mixture of all aspects of mobility and until all their requirements are easily comprehensible and reasonable.

8. References

[1] SCHRAG T, STOCKER E, HEIDUK E, GOLLNER W, LEINDECKER H. C, WARTHA C. *"Integral Improvement of Buildings".* Proceedings of e-nova conference 2009, Pinkafeld, Austria, pp. 39-47.

[2] LEINDECKER H.C. *"Tools for Quality Optimization of Buildings – A New Database".* 13.International FM&REM Congress Proceedings, Kufstein, Austria, 2011, pp. 101-106.

[3] HAAS. *"Mobilität ja, aber bitte schlau – VW-Trendforscher in Linz".* Oberösterreichische Nachrichten vom 14.10.2011. pp. 10.

[4] LEINDECKER H.C. "Densed Urban Building Structures as Child-Friendly Habitation Environment". Centaurus Verlag Herbholzheim, ISBN 3-8255-0460-3,2004, pp. 208.

[5] EBERT T, ESSIG N, HAUSER G. *"Zertifizierungssysteme für Gebäude. Nachhaltigkeit bewerten, Internationaler Systemvergleich, Zertifizierung und Ökonomie".* Edition Detail Green Books, München, 2010.

[6] GEISSLER S. *"Das richtige Gütesiegel für den richtigen Zweck".* IBO Magazin Edition 3/11, 2011, pp. 4-6.

[7] LQG. *"FFG-Forschungsprojekt Lebenszyklusorientierte Qualitätsoptimierung von Gebäuden".* Qualitative Datenbank. URL: http://www.lqg-projekt.org/, Path: Ebene 1: Konzept, Ebene 2: Initiierung, Ebene 3: Zertifizierungen (FH OÖ), 2012.

[8] European Union (EU). *"Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings"*. Brussels, 2002.

[9] European Union (EU). *"Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)"*. Strasbourg, 2010.

[10] DORNIGG I. *"Criteria for Mobility in Building Certification Systems".* Bachelor Thesis, University of Applied Sciences Upper Austria – Campus Wels, 2012.

[11] MINERGIE®. "*Gebäudeliste*". [Online]. Available: http://www.minergie.ch/gebaeudeliste.html. [Accessed 02 05 2013].

[12] SWISS SOCIETY OF ENGINEERS AND ARCHITECTS (SIA): *"Merkblatt SIA 2039: Mobilität – Energiebedarf in Abhängigkeit vom Gebäudestandort"*. Zurich, 2011.

[13] FISCH M.N. "*Aktivhaus – Gebäude als Kraftwerk*". Xia-intelligente Architektur 01-03/2011, pp.12-13.

[14] EMRICH CONSULTING ZT GmbH. "*Energieausweis-fuer-Siedlungen_v1.4.1*", Lower Austria, 2010.

[15] ELFLEIN N. "*Best Practices rund um den Globus*". Pictures of the Future Frühjahr 2013, pp. 72.

[16] DORNIGG I. "*Mobilitätskriterien in Zertifizierungssystemen für Stadtquartiere*", Master Project Report, University of Applied Sciences Upper Austria - Campus Wels, 2013.

High Performance Buildings Quality Assessment



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Short Summary

The focus of the research project “life cycle improvement of the building quality” (“LQG”), financed by the Austrian Research Promotion Agency (FFG) and six industry partners is to develop, analyze and evaluate methods to assess planning decisions with their consequences on the life time of a building [1]. The project has two main outputs. One is the creation of a common database on building life cycle data as well economical as ecological, the other is a comprehensive guideline on sustainable building.

The “Database of Quality” follows the initial idea that a holistic improvement of the quality of buildings over their entire life cycle can be achieved by adding quality assurance methods with one aim in mind, the contentment of the user of a building. Building certification systems are one possibility to get a higher level of quality performance [2]. From one partner in the project – FH Wels – a lot of quality assurance methods from different certification tools were tested. These studies are put into the comprehensive guideline.

The guideline is structured on the life cycle of a building and contains defined time slots, where decisions are necessary and what information will be helpful for a decision maker. The focus of the common database will lie on facts, which have to be estimated during the planning of the building. This comprehensive guideline is placed in an internet portal, which gives quick access to the scientific data that will be presented online.

Keywords: Building certification systems, Quality assurance

1. Introduction

As part of the research project “life cycle improvement of the building quality” (“Lebenszyklusorientierte Qualitätsoptimierung von Gebäuden – LQG”) a database is created. This is done to increase the approachability of the information provided and to spread the background and knowledge further. Especially landowners who plan to construct a building should know about the ecological impact and life cycle data. The usual interest concerns mainly investment costs and time as well as creating the building according to the owner’s wishes. Particularly quality over the whole life cycle is an argument that applies scientists and house owners [1].

With the Austrian Research Promotion Agency (Forschungsförderungsgesellschaft – FFG) financing the project, it runs for five years but ends in October 2013. Five Austrian Universities of Applied Sciences work together with six industry partners and the main output beside the database is a comprehensive guideline. The industry partners support the project with their know how.

Beside a rising demand for comfort the operating costs and expanses along the life cycle of the building should be kept low. High performance buildings combine this argument together with further advantages. To enhance a standard house, different topics need to be considered at subsequent time periods. At first the energy efficiency is used to reduce losses for example prevented with insulation. Secondly the energy optimization maximizes the profit by using solar power or else. With the calculation of life cycle costs substantial decisions can be reached at their best before the building ecology gives a statement about the impact on the environment. To reach the occupants satisfaction finally, the building biology and quality assurance along with certification should be considered.

2. Database of Quality

2.1 Formation

The structure of this database is built up as a dynamic matrix (see Fig. 1). The first vertical trace follows the five chronologic phases of the lifecycle of a building: concept, planning, construction, utilization, demolition/recycling. The horizontal succession of the columns is called “levels” and help to provide details on the topics. The second level allows the main phase to be more precisely described. With the third level topics like project-management, energy, building biology, building ecology and economics may be selected like a filter, while the fourth level provides additional information that serves as an overview for better understanding of the challenges inherent in building construction. The descriptions should be for people with lower levels of experience in planning sustainable buildings. The fifth level provides the detailed information on specific topics which arise within the project and continues deepening the knowledge. Here you can find LQG research reports and a variety of master and bachelor thesis done by the LQG partners. For example many guidelines on how to carry out quality testing methods from the FH Wels are placed here. The sixth layer provides the space for references, standards, important links and reports generated outside of this research project [1], [3].

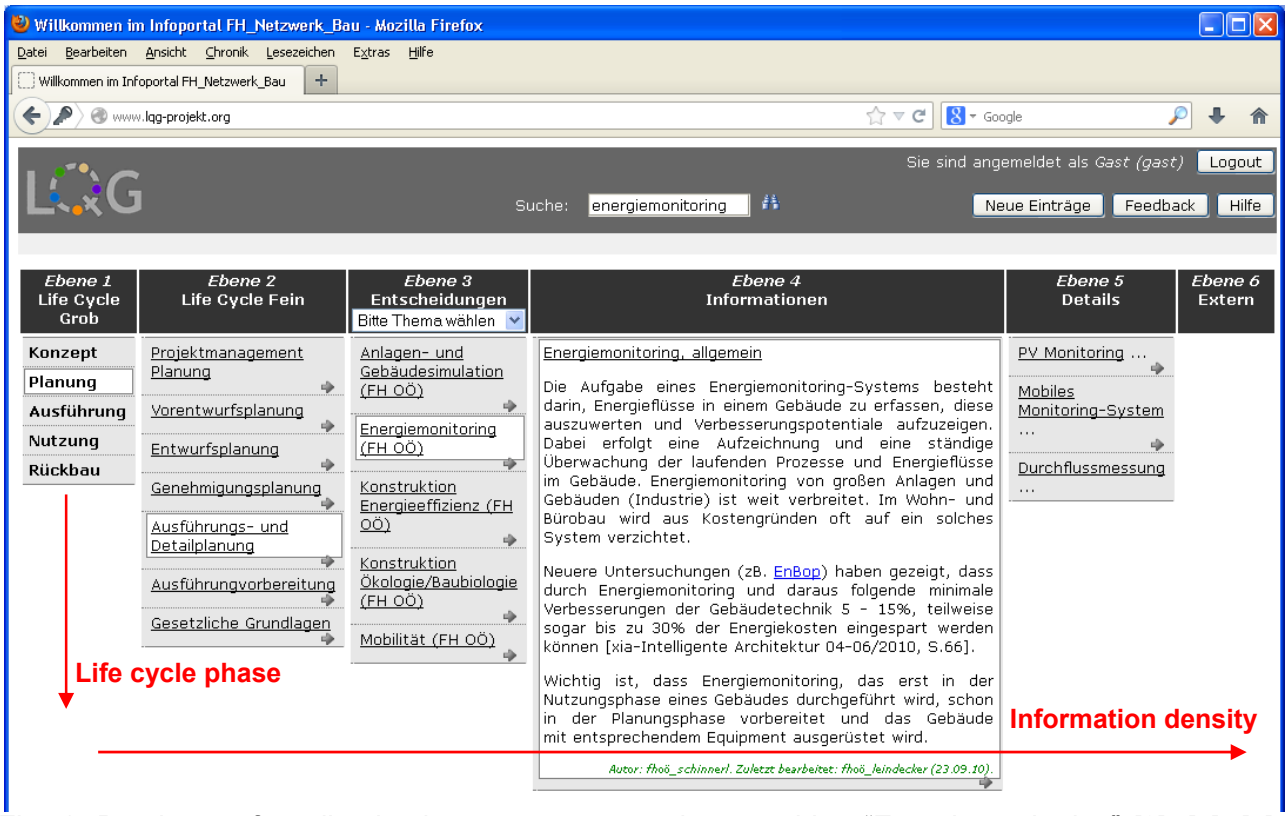


Fig. 1: Database of quality, basic structure, example: searching “Energiemonitoring” [3], [4], [5].

2.2 Expansion of the Database

The Database of Quality is filled with issues according to the relevant work package of each University of Applied Sciences (in German: Fachhochschulen – FH) involved in the project. The project management in addition to the development and the realization of the database is done by the FH Tirol Kufstein beside quality assurance energy efficiency and life cycle costing. The main topics of the FH Burgenland Pinkafeld are life cycle analyses and the database of quantity. Parallel the FH Kärnten Spittal contemplates life cycle costs among a tool for the early planning phase. From the FH Joanneum Graz LCA and LCC of facade elements come with a test in a concrete application. The FH OÖ Campus Wels is responsible for quality assurance particularly tools concerning energy efficiency, building biology, occupant satisfaction together with processing the database [3].

With the button “register as visitor” everyone can enter the database and read articles but has no rights to delete or add further postings. Only certain persons relating to the research project LQG can do so. Either the text is directly written in the database or a MS Word document is uploaded. Beside these possibilities one could upload full PDF documents or single pictures and diagrams.

2.3 Database of Quantity – “Energieausweis Plus”

Common competences should be used in the database of quantity called “Energieausweis Plus”. In comparison with an usual software for the creation of an energy performance certificate this should additionally provide data for LCA and LCC as an optimal planning tool. The first projection was already published [6] and further improvement is planned [3].

3. Examples

The database focuses on the fact of improving the quality of buildings enormously with quality assurance methods. This should happen along the life cycle to secure occupant satisfaction. One possibility is the certification of buildings with systems like TQB, DGNB, LEED or BREEAM [3], [7], [8].

3.1.1 Life Cycle Costs

Path to the issue life cycle costs:

- Level 1: Planning
  because LCC should be considered already at an early stage of the building’s life cycle
- Level 2: Basic design
  to achieve a result some facts have to be known so things can be adapted appropriate
- Level 3: related articles appear with the choosing the filter economy
  a variety of articles about LCC are available and described closer in level 4

One article called LCA/LCC explanatory notes offers the opportunity to choose between three sub-articles, where one again relates to LCA in the planning phase and explains two calculation tools. The Eco2Soft presents results about environmentally friendly facts like the acidification potential, the global warming potential and the primary energy index. With the MS Excel based tool “Econ Calc” comparative calculations were computed. This calculator is available at the klima:aktiv homepage. The aim is in principle given in figure 3 and can be reached with the econ calc.

With the correct decisions at the beginning of the life cycle of a building the operating costs can be minimized and this needs not to be done at the expenses of the customer comfort. The green line indicates the discretion in decision-making and decreases enormously in the first phases. The lines coloured red, orange and blue rise in contrary constantly with the decision about the angle α or β made already at the very first phases (see Fig. 2).

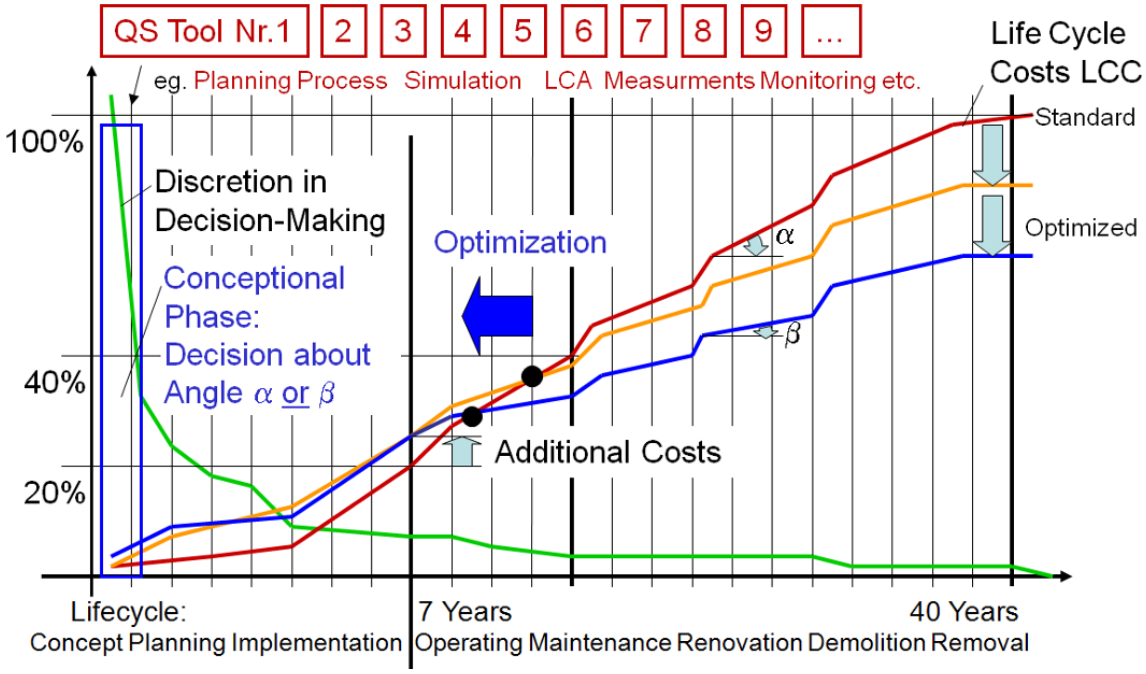


Fig. 2: Decision-making and costs according to the life cycle of a building [9]

3.1.2 Building Biology

With Austrians spending about 90% of their lifetime indoor the conditions in there are important for the wellness and health of peoples. Beside mold and carbon dioxide, radon is an issue concerning folks. As odourless inert gas radon is formed in the ground and is absorbed by humans. It can harm the respiratory system especially the lunge and cause cancer. Through leakages in grounding building elements the gas attains our houses, gathers and reaches serious concentrations [4]. The University of Applied Sciences Upper Austria Campus Wels did several measurements with interesting findings. In the context of a “Benchmark”-project and in collaboration with AGES radon measurements were done in passive houses. The results showed (see Fig.3) that when the ventilation system was switched off, the concentration of radon went up extremely [3], [10].

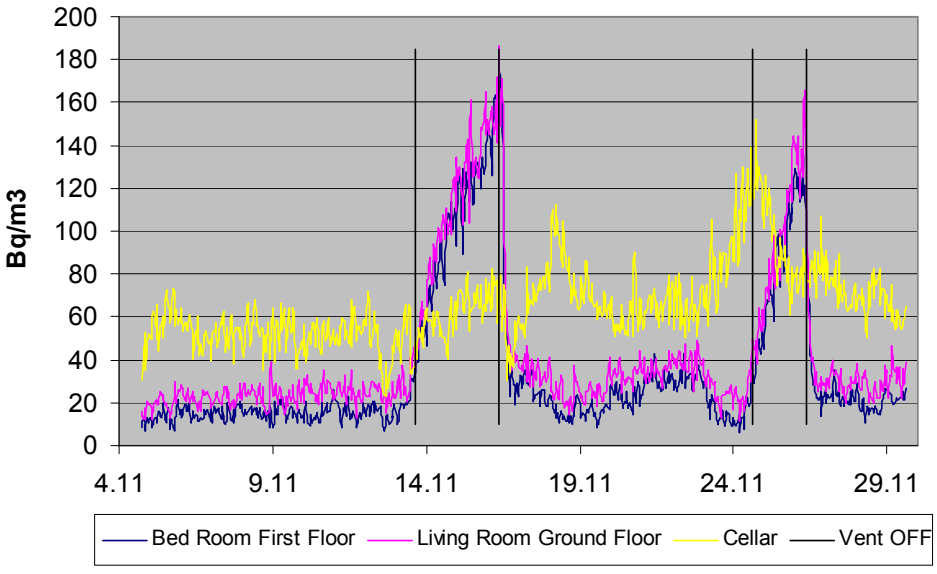


Fig. 3: Radon concentration measurement in a passive house in Haag, Austria [10]

Path to related articles about the issue occupant satisfaction (see Fig. 4):

- Level 1: Implementation
  issue about the used materials, quality assurance on the building lot
- Level 2: Approval
  inspection whether the materials are really applied, quality assurance of completion
- Level 3: Indoor air with the filter building biology (in German: Baubiologie)
  as typical building physics matter including thermal comfort
- Level 4: Indoor air quality
  concerning building biology with healthy building and living;
  a description of radon, formaldehyde and volatile organic compounds is given
- Level 5: further articles
  radon in detail, radon measuration and radon in low energy-buildings and passive houses

Because of radon being already important for building owner's when the choice of location has to be made, the articles can also be found under concept/initiation/location/building site analysis.



Fig. 4: Path to articles about radon [4]

3.1.3 Occupant Satisfaction

One of the most ambitious aim of projects is the well-being of occupants. Because of the complex opportunity to measure satisfaction, this issue often is neglected. Every person experiences heat and cold differently and that leads to very personal results.

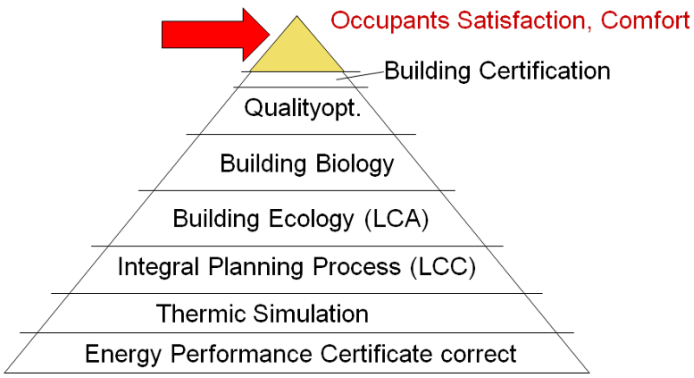


Fig. 5: Pyramid of quality of buildings [9]

The figure (see Fig. 5) indicates the building optimization assembled with energy optimization, building biology and ecology along with quality assurance [9].

With a questionnaire the satisfaction of house owners was requested. Several accommodation units were consulted and a ranking list with the most important facts was disposed. Beside the air quality, the acoustic conditions and the temperature also the current health was observed. Moreover the energy savings, safety, design and offers of public transport were scrutinized [11].

Path to related articles about the issue occupant satisfaction:

- Level 1: Usage
  to evaluate a building the residents have to experience the house and live in it, as figure six indicates this is, what the building is made for and when the occupants do not feel well, they will not want to live in the building
- Level 2: Utilisation phase
  as most suitable phase of a buildings life cycle to include occupant satisfaction beside energy monitoring, examples for the utilisation phase are the move-in, renovation works or a change of users
- Level 3: Occupant satisfaction
  this level offers three different articles to deepen the knowledge on level 4 and some more on level 5

3.1.4 Solar Monitoring

With the user name and the password given in the article about PV monitoring in level 5 the online data of the PV system installed on the FH Wels can be seen. Therefore the available link leads to the homepage for the “Solarportal FH Oberösterreich”. From a variety of days, month and years the previous measurement data can be checked. Fig. 6 illustrates the radiation colored orange and the produced energy in dark blue of the days in February 2013. Even for every hour of the day the data is given which can be seen for 11th.February 2013 in Fig.7.

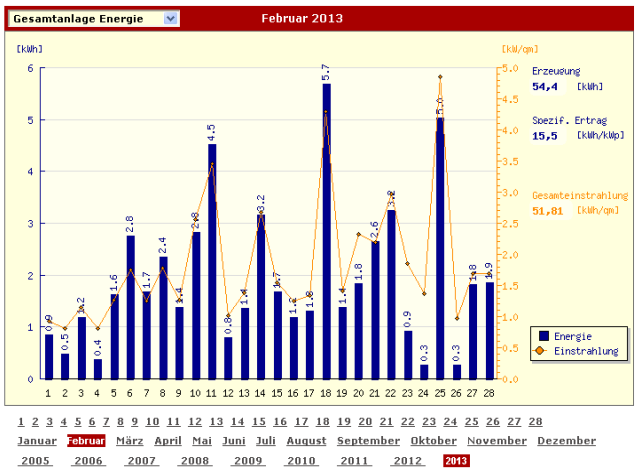


Fig. 6: Monitoring of PV system owned by the FH Wels for February 2013

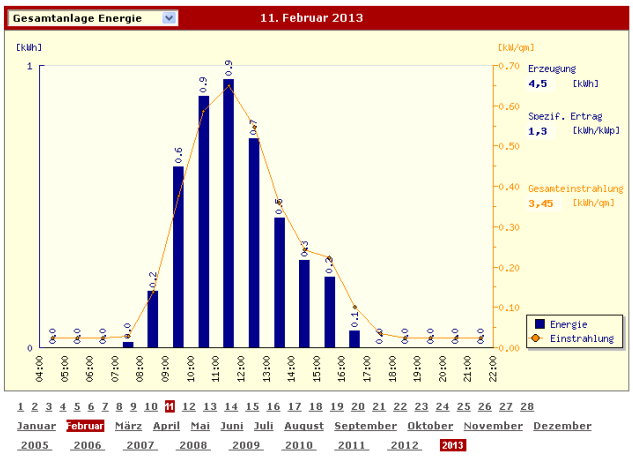


Fig. 7: Monitoring of PV system owned by the FH Wels for 11.February 2013

To check actual data of different PV module types in Wels the user can start with choosing usage in the first level. In the second level it concerns facility management and the filter energy for the third level. This offers the possibility to select energy monitoring and read the article about the general facts in level 4. The choice to read the information provided to this issue leads to a switch of the path in the database. This happens automatically and leads to a change in the phase of the building’s life cycle from usage to planning. Furthermore the subject in the second level changes and only in the third level the issue remains constant. In case the user knows the topic of interest or related key words one can always use the search function to reach a quick result.

Path to the online data of the PV monitoring system of the FH Wels (see Fig. 6 and 7):

- Level 1: Planning
  already at an early stage of the project quality assurance and control are important
- Level 2: Detail engineering
  a certain equipment has to be provided and included in the construction of the building
- Level 3: Energy monitoring
  for this issue the filter energy can be used
- Level 4: Energy monitoring in general
  with a short article about challenges and advantages of energy monitoring systems the user gets to know what it is all about
- Level 5: PV monitoring
  the provided article describes detailed costs, the measurement setup and results referring to the site in Wels

Beside the choice of the date, different types of PV modules and even errors can be seen on the homepage with the solar monitoring data. All information to check the functionality of the site can be viewed and so the maximum power output is ensured because in case something breaks or other problems appear in the monitoring data the response can be seen.

3.1.5 High Performance Buildings

Creating high performance buildings requires a variety of complex issues which can be split into seven main sections. Already included in figure 6 five out of seven topics are listed according to their importance and level of difficulty. In a students project each issue was examined more closely with interesting conclusions.

1. Energy efficiency (minimization of losses)
   In association with buildings insulation, air ventilation systems including heat recovery and a tight building envelope in combination with the avoidance of thermal bridges are important, just like a compact A/V-ratio [12].
2. Energy optimization (maximisation of gains)
   Beginning with a certain standard of energy consumption of the building the performance is improved with active components and energy storage systems. Beside these key components the user behaviour is an essential factor [13].
3. Life cycle costs
   For the calculation of costs over the life cycle of a building the tool Econ Calc was used. Four different building types were compared with the biggest saving potential in the renovation of old buildings to low energy buildings [14].
4. Building ecology
   Including life cycle analyses this provides the possibility to decide whether anything is environmentally friendly. For example the calculator Eco2Soft offers this potential with a big database in the background [15].
5. Building biology
   For a better indoor quality harmful substances should be avoided and the usage of natural resources focused for example with clay. Measurements of certain substances in the air can show positive the effect with only a little bit higher additional costs [16].
6. Quality assurance and certification.
   Declarations like TQB, DGNB, LEED and BREEAM can assure the quality of the building. Another possibility is the installation of a monitoring system or different measurement and instrumentation equipment with communication systems [2]. Although this can only assure mainly physical criteria, the connection with the occupants behaviour and satisfaction (see below) has to be mentioned.
7. Occupant satisfaction
   A closer description of this issue and results of this project part is given in chapter 3.1.3 Occupant Satisfaction.

4. Discussion and Conclusions

Up to now the database of quality has reached a certain grade of complexity and is already publicly available. With the adjustment according to the life cycle of a building the ordinary user can handle it easily and find one's way. For experts especially the deeper levels provide general reference work. To improve further development the database is verified by the industrial partners, who experience it in commercial practice. The spread competences of the different universities of applied science secure a diverse knowledge and approach [3].

With all the research done pursuant to the project "life cycle improvement of the building quality" ("Lebenszyklusorientierte Qualitätsoptimierung von Gebäuden – LQG") the network called "University of Applied Science_network_building" ("FH_Netzwerk_Bau") is an established partner. Beside declaration tools for buildings particularly life cycle costs and life cycle assessment can be comprehensively advised.

5. References

[1] SCHRAG T, STOCKER E, WARTHA C, HASLER E, LEINDECKER H. *„Combined Database for LCC, LCA and Life Cycle Quality". Proceedings of IALCCE* - Life-Cycle and Sustainability of Civil Infrastructure Systems, Vienna, 2012, pp. 343-350.

[2] EBERT T, EßIG N, HAUSER G. *„Zertifizierungssysteme für Gebäude. Nachhaltigkeit bewerten, Internationaler Systemvergleich, Zertifizierung und Ökonomie"*. Edition Detail Green Books, München, 2010

[3] LEINDECKER H.C. *"Tool for life cycle improvement of the building quality".* Proceedings of e-nova, Pinkafeld, 2011, pp. 81-88.

[4] LQG PROJEKTTEAM. *"Wissensdatenbank"*. http://www.lqg-projekt.org/, accessed on 17.04.2013

[5] STOCKER E, ALDE H. *"HOW TO – Einführung & Orientierung in der Datenbank für User"*. Kufstein, 2010

[6] SCHRAG T, HEIDUK E, GOLLNER W, LEINDECKER H, WARTHA C, SCHINNERL S, STOCKER E. *„Lebenszyklusanalyse eines Gebäudes"*. Forschungsforum der österreichischen Fachhochschulen – FFH 2010, Pinkafeld, pp. 263-270.

[7] PAMMER J. *"Vergleich der Gebäudezertifizierungssysteme LEED und DGNB mit den österreichischen Bewertungssystemen klima:aktiv und TQB"*. Master Thesis, University of Applied Sciences of Upper Austria, Wels, 2011

[8] SCHMID S. *„Entwicklung eines Beratungsinstrumentes unter Gegenüberstellung der internationalen Gebäudezertifizierungssysteme BREEAM, LEED und DGNB zur Entscheidungshilfe im integralen Planungsprozess"*. Master Thesis, University of Applied Sciences of Upper Austria, Wels, 2011

[9] SCHRAG T, STOCKER E, HEIDUK E, GOLLNER W, LEINDECKER H, WARTHA C. *„Ganzheitliche Optimierung von Gebäuden – Ein FH-Plus in Coin Projekt"*. Proceedings of e-nova, Pinkafeld, 2009, pp. 39-47

[10] FELLINGER G. *„Measurement in Passive Houses"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2010

[11] REISCHL L. *"Occupant Satisfaction of Residential Buildings".* Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

[12] NITZKY M. *"High Performance Buildings – systems of energy efficiency"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

[13] LECHNER R. *"High Performance Buildings – Energy Optimization based on Active Components"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

[14] GERGELY F. *"High Performance Buildings – Life Cycle Costs Methods"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

[15] LECHER F. *"High Performance Buildings – Life Cycle Analysis"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

[16] GRÜBLER M. "*Building biology for healthy residential buildings"*. Bachelor Thesis, University of Applied Sciences of Upper Austria, Wels, 2012

Assessment of an Office Building in Serbia by New Proposed Methodology - „OPEN HOUSE“



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Short Summary

The Construction Cluster „DUNDJER“ participates in the 7th FP European project entitled OPEN HOUSE (7th FP ENV - 2009.3.1.5.2). The overall objective of OPEN HOUSE is to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings by means of an open approach and technical platform. OPEN HOUSE will develop a transparent approach able to emerge collectively in an open way across the EU. This approach will be communicated to all stakeholders and their interaction and influence on the methodology will be assured in a democratic way. The baseline will be existing standards (both CEN/TC 350 and ISO TC59/SC17), the EPBD Directive and its national transpositions and methodologies for assessing building sustainability at international, European and national level. This paper deals with practical assessment of an office building after reconstruction in Serbia.

Keywords: building assessment, sustainable building, european norms, ecologic building, energy efficiency, location

1. Introduction

Open house project involves 11 countries of the EU and the Western Balkans. Active partner at the project (FP7-ENV 2009) is a Construction Cluster Dundjer from Nis.

The scientific and technical objectives of the project OPEN HOUSE are:

• to define OPEN HOUSE approach: open and transparent european platform for sustainable construction,
• to promote OPEN HOUSE approach and define the mechanisms of interaction between the project and the decision-making factors,
• to build OPEN HOUSE platform: to support pan-european effort for a common view of sustainable construction,
• to consolidate the method of application and evaluation methodology: the choice of test examples and decision-making mechanisms,
• to evaluate and improve the methodology by using the results of the test examples and other similar cases, as well as other observations of decision makers,
• further development and use of OPEN HOUSE methodology.

Basics methodology consists of the following assessment:

• environmental quality,
• social-functional quality,
• economic quality,
• technical characteristics,
• process quality (design and construction),
• the position of the building (location).

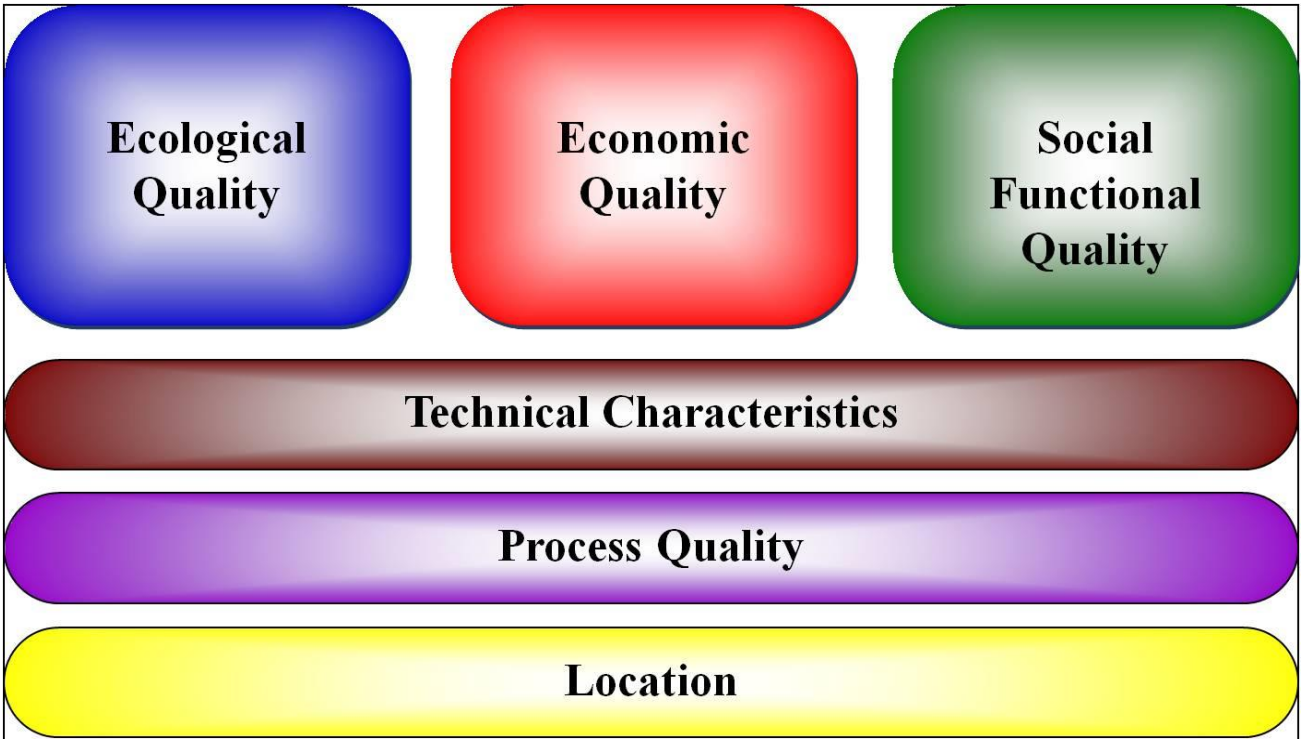


Fig. 1: **Open house shema**

Construction with emphasis on the cost during the building exploatation period is an economic method that aims to provide information before decisions making and to point out the savings when choosing the appropriate design solution including the cost of the product, service, energy efficiency.

During the analysis of the costs of the exploitation of the facility one should consider the costs that should be in accordance with the description and size of the object known in the evaluation. For the purposes of this analysis, the calculation period is limited to 50 years. The initial investment can be considered when the building is delivered to the investor, and is ready to use. This price includes the design of the structure, systems, installations, components, connections with suppliers and energy, and commissioning. These are costs that are presented to the investor.

When evaluating a particular attention has been given to the life cycle of the building - Life Cycle Assessment (LCA). LCA results of the building which is estimated, will be counted in a standardized manner and evaluated using benchmarking assessment. The goal of all LCA study is to analyze and subsequently evaluate the corresponding performance of "life cycle" of the building.

BUILDING ASSESSMENT INFORMATION													
BUILDING LIFE CYCLE INFORMATION													SUPLEMENTARY INFORMATION BEYOND THE BUILDING LIFE CYCLE
A1 – 3			A4 – 5		B1 – 7					C1 – 4			D
PRODUCT STAGE			CONSTRUCTION PROCESS		USE STAGE					END OF LIFE STAGE			Benefits and loads beyond the system boundary
A1 Raw materials Supply	A2 Transport	A3 Manufacturing	A4 Transport	A5 Construction – installation process	B1 Use	B2 Maintenence	B3 Repair	B4 Replacement	B5 Refurbishment	C1 Deconstruction	C2 Transport	C3 Waste processing for reuse, recovery or recycling	C4 Disposal	Reuse Recovery Recycling Potential
					B6 Operational Energy use									
					B7 Operational Water use									

Fig. 2: **Building assessment information**

2. Project description

The case-study building hosts J.P. “Razvoj” (Public/Municipality Enterprise “Razvoj”). The Eterprise supports urban development of Municipality Knjaževac, and controls public investments, including design of major projects and objects. The Enterprise takes part in regional development and supports research in collaboration with research institutions, usually with University of Niš.
The building is located in the downtown of city Knjaževac, in pedestrian zone, close to main administrative municipality institutions. Face of the building is west-southwest oriented, without shadowing obstacles. The view from the building front side is to the small city central park and river Timok. The building has 3 main floors and an attic. In the 3rd floor are located offices, and in attic small conference hall, which is used also as a design studio for working team consultations.
The reconstruction of building was accomplished in the year 2005, with steady improvemen especially in energy consumption. This is the only office building with heating/cooling system based on heat pump. In addition, there is design of using solar energy (PV system) on the south oriented part of the roof. The design draft for using PV solar energy shows ability for using 200 m^2 (roof area) for PV panels. After completing, it would enable saving up to 15-20% of total energy consumtion.
Modeling the thermal energy balance of buildings is recently a challenging task for local architects and engineers. Directive EPBD (2002/91/ES) is recently enforced by local Energy Law, but in the time of building design and construction, the elements of design like glazing areas or windows thermal characteristics, the climate zone, the orientation, and the type of construction (e.g. high or low thermal inertia) have not been considered in a way to optimize their thermal contribution to the whole building’s energy balance. The measuring system, necessary for proper assessment and improvement, has to be realized in near future.
All the sustainability aspects (environmental, social/functional, economic, technical, process, location), are assessed “as is”, according to given scale. For Economic Quality assessment, the

bill of quantities is now out of date, due to unrealistic prices of some materials and works, and using some not any longer used materials (with not standardized quality) and equipment with not strictly defined efficiency, and, finally, local rate of inflation (over 10 %). Sensitivity analysis, being considerable politically dependent, is even more complex, and somehow rather unpredictable.
It is worthy to mention that this building was chosen, it seems, occasionally, and not as an example of good practice. The building is located in underdeveloped part of Serbia with all consequences to quality of building and, consequently, building sustainability. But, it is, in a way, representative case of construction technology in southeast Serbia.

RS.2 Knjazevac – JP DIREKCIJA SERBIA			
1	**Environmental Quality**	**Indicator Score %**	**Indicator Weight**
1.1	Global Warming Potential (GWP)	0	1
1.2	Ozone Depletion Potential (ODP)	0	1
1.3	Acidification Potential (AP)	0	1
1.4	Eutrophication Potential (EP)	100	1
1.5	Photochemical Ozone Creation Potential (POCP)	0	1
1.6	Risks from materials	0	2
1.7	Biodiversity and Depletion of Habitats	40	2
1.8	Light Pollution	100	2
1.9	Non-Renewable Primary Energy Demands (PEnr)	0	2
1.10	Total Primary Energy Demands and Percentage of Renewable Primary Energy	0	2
1.11	Water and Waste Water	10	3
1.12	Land use	50	3
1.13	Waste	10	3
1.14	Energy efficiency of building equipment (lifts, escalators etc.)	0	3

2	**Social / Functional Quality**	**Indicator Score %**	**Indicator Weight**
2.1	Barrier-free Accessibility	0	4
2.2	Personal Safety and Security of Users	7	4
2.3	Thermal Comfort	28	3
2.4	Indoor Air Quality	19	4
2.5	Water Quality	80	4
2.6	Acoustic Comfort	65	3
2.7	Visual Comfort	71	2
2.8	Operation Comfort	86	3
2.9	Service Quality	20	4
2.10	Electro Magnetic Pollution	50	4
2.11	Public Accessibility	100	4
2.12	Noise from Building and Site	100	3

2.13	Quality of the Design and Urban Development of the building and Site	0	4
2.14	Area Efficiency	100	3
2.15	Conversion Feasibility	44	2
2.16	Bicycle Comfort	0	2
2.17	Responsible Material Sourcing	0	2
2.18	Local Material	0	2

3	**Economic Quality**	**Indicator Score %**	**Indicator Weight**
3.1	Building-related Life Cycle Costs (LCC)	44	4
3.2	Value Stability	26	4

4	**Technical Characteristics**	**Indicator Score %**	**Indicator Weight**
4.1	Fire Protection	0	4
4.2	Durability of the structure and Robustness	50	4
4.3	Cleaning and maintenance	95	3
4.4	Resistance against hail, storm high water and earthquake	0	4
4.5	Noise Protection	10	4
4.6	Quality of the building shell	7	4
4.7	Ease of Deconstruction, Recycling, and Dismantling	3	3

5	**Process Quality**	**Indicator Score %**	**Indicator Weight**
5.1	Quality of the Project’s Preparation	31	4
5.2	Integrated Planning	100	4
5.3	Optimization and Complexity of the Approach to Planning	21	4
5.4	Evidence of Sustainability during Bid Invitation and Awarding	5	2
5.5	Construction Site impact/ Construction Process	0	3
5.6	Quality of the Executing Contractors/Pre-Qualification	50	3
5.7	Quality Assurance of Construction Execution	50	4
5.8	Commissioning	50	4
5.9	Monitoring, Use and Operation	36	3

6	**The Location**	**Indicator Score %**	**Indicator Weight**
6.1	Risks at the Site	91	2
6.2	Circumstances at the Site	71	2
6.3	Options for Transportation	25	4
6.4	Image and Condition of the Location and Neighbourhood	78	3
6.5	Vicinity to amenities	86	4
6.6	Adjacent Media, Infrastructure, Development	56	3



Fig. 3: **Case study building**

Source: Construction cluster DUNDJER Nis, Serbia

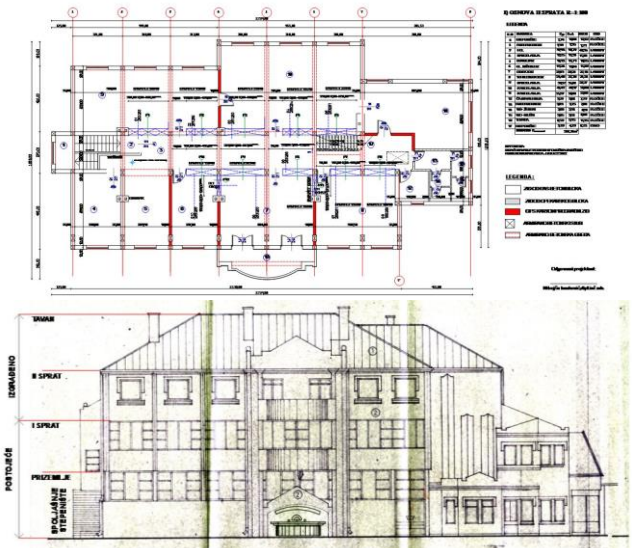


Fig. 4: **Ground plan and front look of the building**

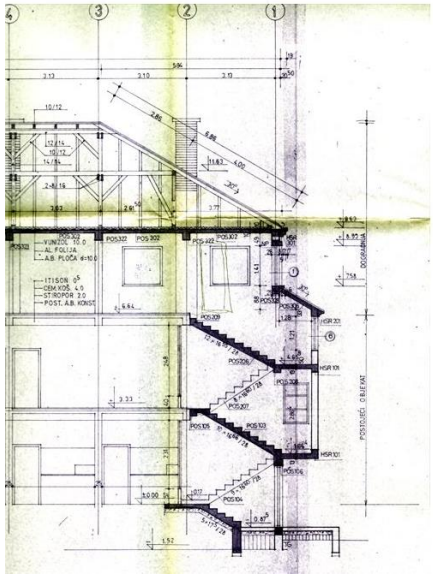


Fig. 5. **Section of the building**

Building Type
Office

Building Phase
In use
Date of Completion: 2005

Building Characteristics
Total Floor Area: 340 m²
Number of stories: 3

Address
Street Kej Dimitrija Tucovica 30
City Knjazevac
COUNTRY Serbia

Assessor
Name: Biljana Avramovic
Company: Construction cluster DUNDJER Nis, Serbia

Building Owner
Name: Municipality Knjazevac
Company: JP Direkcija Knjazevac

Architect
Name: Nebojsa Ivankovic
Company: JP Direkcija, Knjazevac

Assessment Methodology
OPEN HOUSE v1.1 (01/2012)
Basic & Quick Sustainability Assessment - Complete Sustainability Assessment

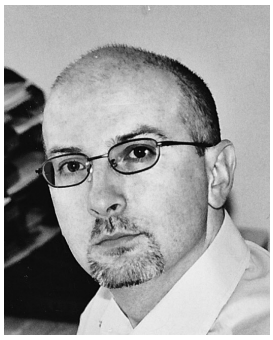


Fig. 6. **Building designer: Dipl. Ing. Arch. Nebojsa Ivankovic**

3. References

[1] Seventh Framework Programme, Theme 6: Environment. Grant Agreement no. 244130, Annex I– “Description of Work”.
[2] T. BECK, S. EBERL, N. ESSIG, M. FISCHER, V. PEYRAMALE. „D1.5 Baseline Model and Assessment Methodology”, Seventh Frame Work Programme, 2011, EU.
[3] www.openhouse-fp7.eu (state 22.05.2012.)
[4] N. ESSIG, S. EBERL, T. BECK. “OPEN HOUSE - a European Methodology for Assessing the Sustainability of Buildings”, 1st World Sustainability Forum, 2011, Germany.
[5] EN 15459 : “Energy performance of buildings – Economic evaluation procedure for energy systems in buildings.”
[6] EN ISO 15686-5: “Buildings and constructed assets — Service life planning - Part 5: Life cycle costing.”
[7] EN ISO 15686-9 – “Buildings and constructed assets – Part 8 Reference service life and service life information.”
[8] MEINS, WALLBAUM ET AL. “Sustainability and property valuation: a risk-based approach. . (2010). Building Research & Information 2010, 38(3), 281-301.
[9] ROB P. GERAEDTS “Upgrading the flexibility of buildings,” CIB World Congress, April 2001.
[10] Recommendation SIA 112/1, 2004: “Sustainable Building –Building Construction”, Swiss Society of Engineers and Architects.
[11] Six steps resulting in a flexibility index of the building. Source: LEnSE: Methodology Development Towards a Label for Environmental, Social, and Economic Buildings, Indicator: Increase Ease of Building Adaptability.

Case study: Green family house in Slovenia, from planning until certification



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Short Summary

Case study of the real life example where individual low-energy building in Maribor, Slovenia has been carefully planned, built, supervised and certified as low energy (LE) building. Consultants for sustainable construction where tightly involved in all stages, from the very beginning of the building design. Blower Door tests for air tightness and thermography have been used, not only for the proof of the sustainability of the complete building, but also for the quality checking during the building process. All phases have been well documented, from planning, via on site measurements until the acquisition of grants by Slovenian Eco Fund. Also similarity and differences of sustainable building sector in Slovenia and Austrian region Styria has been discussed.

Keywords: green building, certification, eco subvention, real life example

1. Green buildings in Slovenia, past and present

1.1 Comparison Slovenia vs. Styria

Despite Slovenia and Styria are comparable on forest coverage (over 50%), the share of the wooden buildings is significantly higher in Styria then in Slovenia, where over 80% of the new buildings are classical massive buildings. That means more difficulties to reach low energy (LE) and passive house (PH) standards and more embedded energy in the buildings.

For comparison here are some basic information, regarding the size and forest coverage, between Slovenia and Styria:

	Styria	Slovenia
Size:	16,387 km^2	20,273 km^2
Population:	> 1,200,000	> 1,900,000
Forests:	8.530 km^2	10.124 km^2

When Slovenia has joined EU a number of European directives came into force in the field of sustainable buildings. System of lending and granting subsidies has been successfully established for the construction of LE and PH facilities through Slovenian Eco Fund.

1.2 Design of LE and PH buildings

Professional basis for making well-insulated buildings in Slovenia are given with the norms and regulations. The main one is PURES and associated technical guidance TSG-1-004: 2010 [1], both from 2010. Based on those regulations, variety of software solutions for building physics calculations (Archimaid FIBRAN, Energija 2010-Knauf, Building Physics 4.0 URSA, etc…) has been offered for free, mainly by our main insulating materials companies.

Darmstadt Passive House Institute guidelines and PHPP software are used in planning and building of LE and PH buildings. Main low-energy criteria is computational energy consumption for heating (<25kWh/m^{2}a for LE and <15kWh/m^{2}a for PH). Additional demand is the minimal air tightness of the building that should be: <1.0 h^{-1} for LE and <0.6 h^{-1} for PH. Controlled ventilation with heat recovery is mandatory.

1.3 Slovenian Eco Fund

Eco Fund, the Slovenian Environmental Public Fund, is operating under the jurisdiction of the Ministry of Agriculture and the Environment. Data from the annual report of the Eco Fund [5] shows that the average annual Eco Fund subsidies for the construction is for approximately 80 individual buildings (the LE or PH implementation), with around 1.000.000 EUR. Eco Fund support only LE and PH buildings and the value of subvention diverse from type of building (payments are carried out after fully completed construction).

Bottom tables (Table 1 & Table 2) shows the accurate data regarding the years 2010 and 2011 and are summarized and taken from the annual report. [5]

Tabela 6: Dodeljevanje nepovratnih finančnih spodbud po javnih pozivih 3SUB-OB10, 4SUB-OB10 in 5SUB-OB10

Ukrep		Vrednosti v EUR		
	Odobreno		Podpisane pogodbe	Izplačano
	Št. naložb	Na podlagi izdanih odločb		
Solarni ogrevalni sistemi	829	793.636	779.294	812.771
Toplotne črpalke	984	735.800	730.300	672.818
Kotli na lesno biomaso	725	1.015.339	1.023.983	1.025.955
Zamenjava zunanjega stavbnega pohištva	5.884	4.388.442	4.398.765	4.274.521
Toplotna izolacija fasade	615	2.017.272	2.068.584	2.612.930
Toplotna izolacija strehe	298	329.983	328.705	289.789
Energijsko učinkovito prezračevanje	186	359.646	355.140	297.489
Gradnja ali nakup nove NEH/PH	98	1.183.759	1.165.275	308.418
Vgradnja termostatskih ventilov in hidravlično uravnoteženje ogrevalnih sistemov	8	28.200	28.200	20.796
Vgradnja sistema delitve stroškov	7	6.857	6.857	5.392
Skupaj	**9.634**	**10.958.934**	**10.885.103**	**10.320.878**

Table 1: Eco Fund report 2010 [5]

Tabela 7: Dodeljevanje nepovratnih finančnih spodbud po javnih pozivih 6SUB-OB11 in 7SUB-OB11

Ukrep		Vrednosti v EUR		
	Odobreno		Podpisane pogodbe	Izplačano
	Št. naložb	Na podlagi izdanih odločb		
Solarni ogrevalni sistemi	1.363	1.261.490	1.221.323	776.130
Toplotne črpalke	2.181	1.316.965	1.259.512	673.552
Kotli na lesno biomaso	1.227	1.738.425	1.661.257	990.336
Zamenjava zunanjega stavbnega pohištva z lesenim	1.221	1.772.720	1.722.537	1.197.408
Toplotna izolacija fasade	1.135	4.775.693	4.596.908	2.456.032
Toplotna izolacija strehe	290	356.985	338.367	181.901
Energijsko učinkovito prezračevanje	179	352.072	333.461	96.057
Gradnja ali nakup nove NEH/PH	74	951.546	900.000	29.008
Vgradnja termostatskih ventilov in hidravlično uravnoteženje ogrevalnih sistemov	32	201.266	197.784	21.867
Vgradnja sistema delitve stroškov	31	59.242	58.130	5.961
Skupaj	**7.733**	**12.786.404**	**12.289.279**	**6.428.252**

Table 2: Eco Fund report 2011 [5]

Eco Fund main criterion for the allocation of subsidies, for the construction of houses, takes into account the energy consumption for heating per m^2 of net heated surface of the object. Surface and heat consumption is calculated according to the PHPP 07 [2].
Condition for LE is heat consumption per square m2 <25kWh/m^2a and for PH it should be <15kWh/m^2a. Additional criteria regarding carpentry (windows and doors), insulation and heating system with controlled ventilation that have the heat recovery included, usually originate from the PHPP calculation.

2. Role of SB experts during design and building process

Involving of SB experts in all phases is essential. Also the investor must fully cooperate and have in mind the goal of low energy or passive house consumption. A control measurement before final works was done, that included simultaneous inspection with thermography camera while the blower door test was being executed, to discover weak points --as it was for example bad sealing around otherwise PH certified attic door (Fig. 1) and sunroof windows (Fig. 5e). Weaknesses revealed by the measurements have been corrected before the final measurement, certification and the occupation of the residents.

3. Observed residential family building in Maribor

3.1 Description

The observed building in Maribor (Slovenia) has four floors, including basement, ground floor, first floor and attic with external dimensions 9.10 m × 10.10 m. The net area of the accommodation is 257m^2 and heating and hot water preparation is covered with the 8kW heat pump (air/water) and central controlled ventilation with heat recovery is included for all for floors. The outside wall, which is essentially clay hollow brick POROTHERM system DRYFIX thickness of 25cm, is surrounded

with 20cm of the EPS insulation with λ = 0.032 W/mK. The building is heated by floor heating system at all floors. Special attention has been made to the implementation of the air-tightness of the building. Certification and Funding has been successful. In the very article presents, the observed individual residential building, whose construction started by excavating works, began in July 2012. The investor is a family with two children that build it for their own needs. Construction is now finalized; and family moved into the house at the end of April 2013.
The building has 4 floors, including basement, ground floor, first floor and attic. It has hipped roof with brick cladding. External dimensions are 9.10 m × 10.10 m. Technical Area (heating and hot water, is done with a heat pump (type air/water SAMSUNG EHS) with the power of 8kW, controlled ventilation with heat recovery is performed centrally and located in the basement of the building. Living rooms are at the ground floor, sleeping and working areas on the first floor and children rooms are in the attic. The net area of the accommodation is accord. to PHPP 257m^2. The building is surrounded by a thermal envelope, where also the basement foundation slab and the external basement walls are covered with 20cm of XPS insulation with λ = 0.035 W/mK.
In the hipped roof, in addition to 4cm THD-Agepan plates, that serve also as back decking, insulation from cellulose flakes with λ = 0.039 W/mK in thickness from 40cm to 50cm was blown in.
The windows are all three-layer glass, in between filled with argon gas, where in the value of the thermal conductivity the glass part has Ug = 0.7 W/(m^{2}K). The total value of the individual windows (glass and plastic frame) does not exceeds the Uw = 1.0 W / (m^{2}K). Main door is also LE certified product intended for the construction of low-energy building with U_d <0.92 W / (m^{2}K)
The building is heated by under floor heating system at all floors. For controlled central ventilation unit of central ventilation system with heat recovery for all rooms, Systemair VR700 DCV has been chosen.
All built-in thermal insulation materials and equipment for heating and controlled ventilation are certified and carried out by authorized service providers. Special attention was paid to the implementation of the air-tightness of building, which is described below.



Figure 1: LE family house during construction [4]

3.2 Airtightness; execution and on-site control

Each investor is required to familiarize themselves with applicable laws, standards and regulations that must be followed in the construction of the building. One of those areas is the air tightness requirements, which are defined by PURES and technical guidance TSG-1-004: 2010 [1].

It is essential to pay attention to air tightness in the construction or renovation of the attic.

It is recommended to carry out two measurements:
• the first measurement is carried out at a stage when the eventual elimination of errors is still possible, for example after all installations, when all penetrations in the outside walls and the perimeter of the building are carried out and at least provisionally sealed, but still available for corrections,
• the final measurement is carried out prior to the occupation with residents, to confirm the final stage and get the final result, which is present in the results of measurements (so called Blow door measurement Protocol), that is to be presented to the Eco Fund

Costs of the measurements are minimal, compared to what awaits the investor if after a period of exploitation; defects are shown in the facility, due to inadequate air-tightness. The integration of a specialist for Building Physics is essential at the planning stage of the LE- or PH-house, when the construction details of which depends the air tightness, are done. Here is of a great help PHPP software tool (Figure 2), developed at the Passive House Institute Darmstadt-u [2].

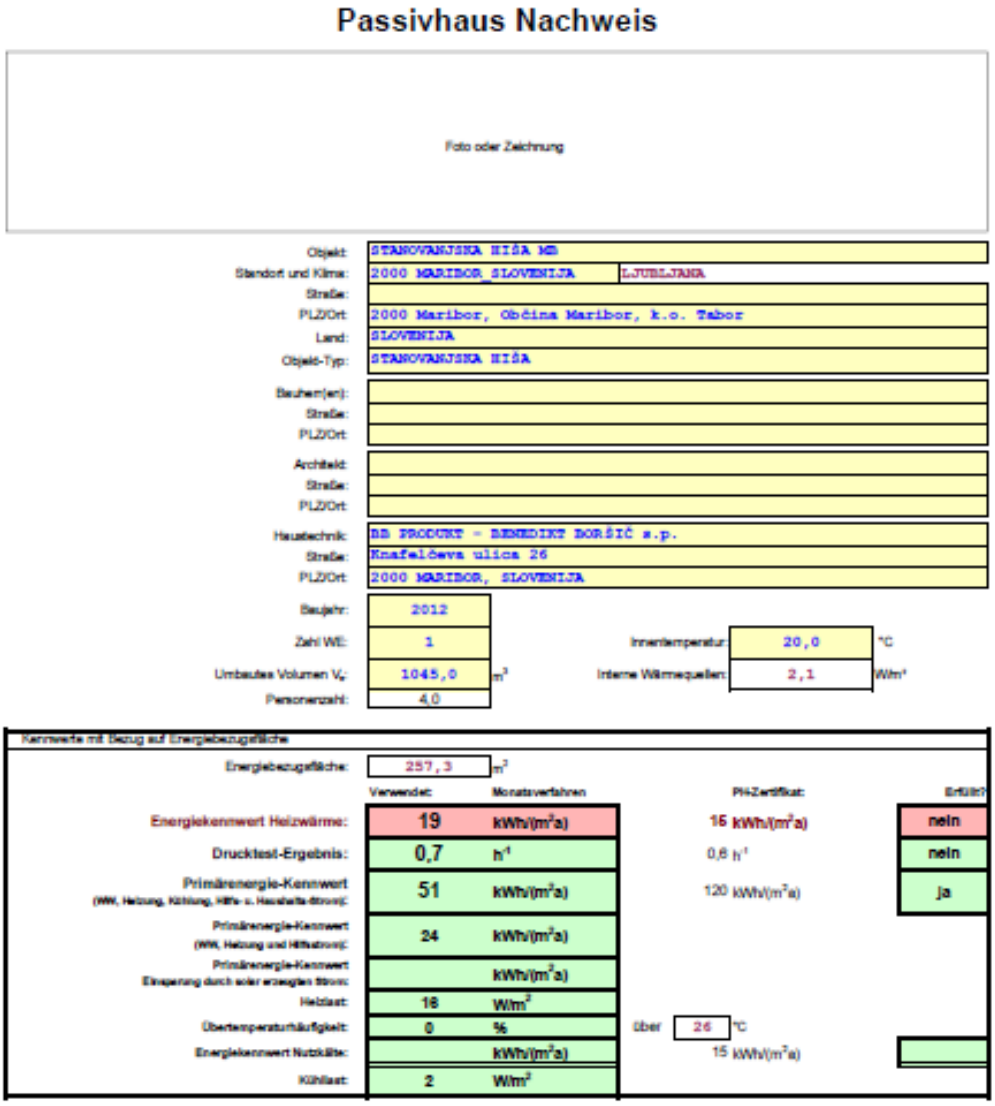


Figure 2: PHPP software - calculation of the observed object/first page results [4]

3.3 Why must the building be air tight

If the house is equipped with controlled ventilation and heat recovery (which is “must be” for LE-low energy house or PH-Passive House), then is generally known that better air tightness also mean the better energy efficiency of the building and lower costs for heating.

That is the reason, that the measurement of air tightness, so-called "blow door test", should primarily be understood as an aid in the construction phase and the way to the higher quality and as a tool to prevent subsequent problems in the maintenance of the building. It is essential to know that the air tightness of the building is not only in the domain of a single expert or craftsmen.

Coordinated work of all participants in the building process is obligatory.



Figure 3: Measuring device "Minneapolis Blower Door" [4]



Figure 4: Openings and penetrations must be properly sealed [4]

3.4 THERMOGRAPHY IN CONNECTION WITH "BLOW DOOR"

Experiences, when it comes to air tightness measurements on site, are showing the great potential of detecting hidden failures at the time of construction, immediately after the air tight layer is done. Especially using also the thermography camera at the same time the blower door test is in the progress.

Implementation is very simple. While the air tightness measurement is in the progress, the fan creates a vacuum. Simply by using the thermography camera on walk around tour in the building, we detect details where air is blow-in, while blow door fan creates a vacuum.

Pictures below are more than eloquent. They were carried out at the first measurement on the observed object, at the stage when the outside layer has been carried out and the errors were detected and after that with appropriate interventions successfully removed:

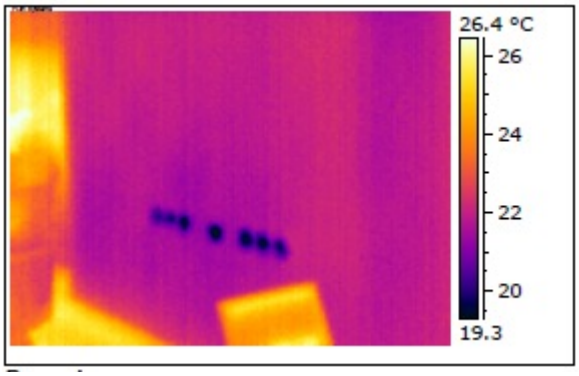


Figure 5a: Plain electrical boxes on the outside walls have been used (help: additionally sealed cans or by installing special air-tight cans) [4]

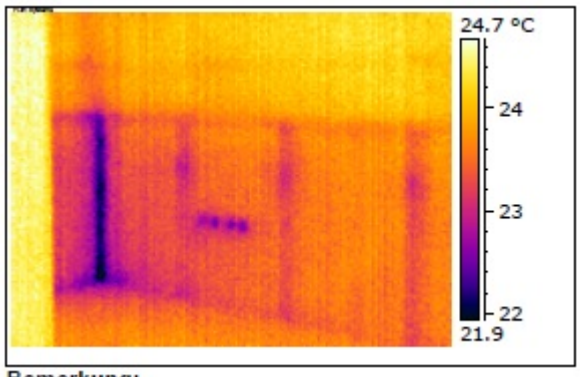


Figure 5b: on the picture visible lightweight substructure is shown in the attic on the outside wall external corner (no direct intrusion of air through the airtight envelope, further action is not required, the situation will be normalized after the façade EPS envelope is done) [4]

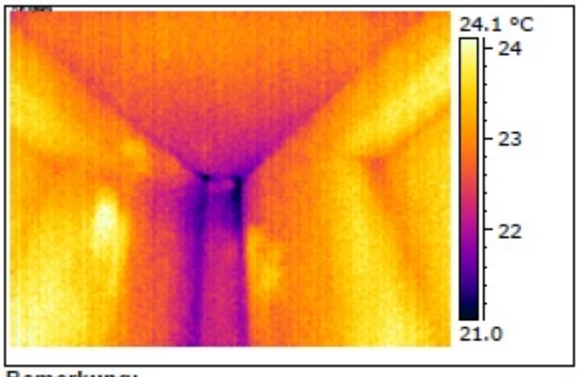


Figure 5c: Corner windows from PVC (the window manufacturer detail for corner windows should be better) [4]

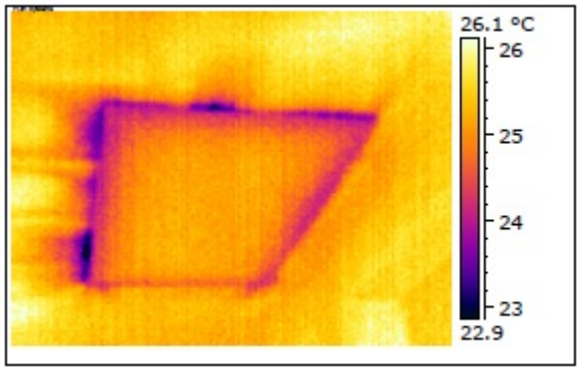


Figure 5d: pull-down stairs to the unheated attic part of the hipped roof (error: the lid does not close as it should, because it is a special type of pull-down stairs for passive houses; it was repaired) [4]

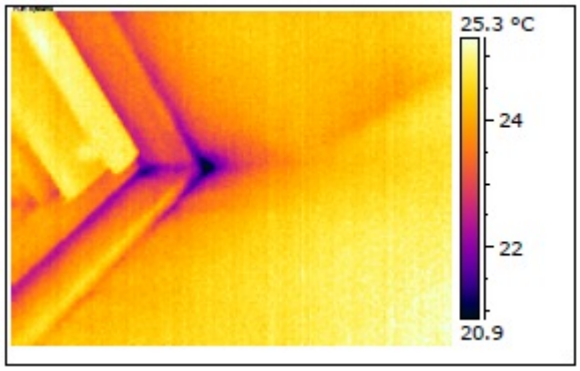




Figure 5e: sunroof window corner (error was detected after the removal of plasterboard: air tight layer was not properly sealed to the sunroof window frame) [4]

By proper use of a thermography camera in combination with the measurement of air tightness, errors can be easily detected. Errors are not visible with the naked eye because they are usually hidden in the structure. Here is an example of than significant contribution of an experienced construction professional to the correct assessment of the situation. Through the visualization of the status quo, using modern techniques and subsequently review the situation after the recovery, in the case of the use of thermography, we can really enjoy in those images.

In the case of Eco Fund founding [3] it is mandatory to submit the end measurement protocol of the air tightness. To get the LE house consumption among 15 – 25 kWh/m^{2}a the required level of air tightness is $n_{50} \leq 1.0\ h^{-1}$.

For the observed object, we planned airtightness in the PHPP $n_{50}<0.9\ h^{-1}$, but after the first measurement some improvements and repairs have been carried out and we were able to get even better result. Implementation of the two measurements was done in accordance with the European standard EN 13829, Method A.

For the observed object is the final measurement result, confirmed with the official protocol was:

$$n_{50} = 0.74\ h^{-1}.$$



o BlowerDoor Testu

Objekt:

EDH
Ivetic Vojislav
Kettejeva 6
SI-2000 Maribor

Datum testa: 11.04.2013
Izmenjava zraka (N50) pri 50 Pascal
v skladu z EN 13829, Metoda A

n50 = 0,74 1/h

Zahtevano po: DIN 4108-7

n50 ≤ 1,0 1/h

Rezultati preskusov izpolnjujejo zahteve.

18.04.2013

Gerlinde Wöhry

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Figure 6: Final first page of the Protocol measurements on the observed object

4. Conclusion

Subsidiaries of the Eco Fund do not cover all extra cost of LE or even PH building, but they can certainly help investors in decision making “pro et contra” for LE or PH Building.

Benefits of LE and PH Buildings are not only in the lower cost of living and higher life quality in those buildings, but also in long-term sustainability for our society.

A construction of those buildings is forcing us (investors, the building experts and all the craft workers) in the detailed planning and detailed execution of planned details. And as the end result the residents get a more enjoyable and affordable place for living.

Extra effort and more attention in the design stage can ensure a comfortable stay for many years of the life cycle of the building.

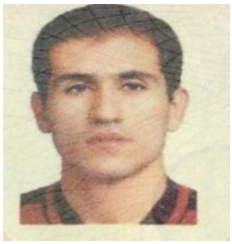
5. References

[1] PURES and Technical guidance TSG-1-004: 2010
[2] www.passiv.de, Passive House Institute Darmstadt
[3] www.ekosklad.si, Eco Fund, Slovenian Environmental Public Fund, Bleiweisova 30, Ljubljana
[4] Photo archive: Benedikt Borsic, www.gb-hisa.si and Veronika Madritsch, TB fuer Bauphysik LESKI, Knittelfeld (Avstrija), www.gbc-net.com
[5] Eco Fund Year Report 2011, Ljubljana, March 2012

Improving comfort condition in the building



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Abstract

Appropriate energy efficiency and conservation strategies are essential for establishing optimal thermal comfort conditions in the buildings. In this regard, the building envelope has a major influence, and must be taken into consideration. In this study, the hourly variation of thermal comfort parameters of a building in Rasht (Iran), in warm seasons, is analyzed with Energyplus software. The walls of this building are made of horizontal hollow bricks, with a complementary thermal insulating layer from inside or outside. Natural ventilation based on the level of thermal comfort conditions has also been taken into consideration. The results make clear that high thermal inertia of the building envelope and natural ventilation with appropriate night purge sequence increase the thermal comfort level in all the floors of the building.

Keywords: Comfort condition; Building construction; Natural Ventilation; Thermal insulation.

1. Introduction

The thermal comfort depends on many parameters, such as the activity rate of persons, the indoor temperature, relative humidity, air speed and the temperature of surfaces surrounding the indoor space. Many investigations have been presented dealing with the thermal comfort condition.

E.S.Lee [1] investigated the effect of external overhang on the thermal comfort condition. Also, C.Huizenga [2] highlighted the influence of parameters related to the window. W.N.Hien [3] investigated the effects of double glazed facade with ventilation system on the energy consumption, thermal comfort and condensation in comparison with single glazed facade system, using TAS software. He showed that double glazed facade with natural ventilation were able to minimize energy consumption as well as to enhance the thermal comfort. G.F.Menzies [4] showed how to select the double pane glazing window based on thermal comfort. S. Atthajariyaku [5] presented an alternative methodology of real-time determination of optimal indoor-air condition for HVAC system in order to achieve thermal comfort. E.L.Olsen [6] evaluated the potential of energy savings of several different systems in a new building outside London, using EnergyPlus software.

In this paper, the hourly effect of using the thermal insulation and hollow bricks in the building external envelope exposed to natural ventilation at night, based on the level of thermal comfort conditions has been investigated for Rasht (IRAN). The simulation has been performed using Energyplus software in warm seasons. In the present study, the thermal comfort has been investigated in two configurations:

a) The effects of using thermal insulation and hollow bricks in external building, envelope on thermal comfort condition in sedentary and low activity rate condition,

b) The effects of using natural ventilation in the building on thermal comfort condition in sedentary and low activity rate condition,

The main objective of the current work is to determine how the thermal comfort condition can be

improved, without increasing the building cost using advanced building technology construction, such as hollow brick or insulation.

2. Simulation software

The building energy simulation program Energyplus™ was used in present study to predict the thermal comfort in a building in Rasht. Energyplus™ (version 1.2.3.031) is made available by the Lawrence Berkley Laboratory in USA. Energyplus calculates thermal loads of buildings by the heat balance method. This method takes into account all heat balances on outdoor and indoor surfaces and transient heat conduction through the building. The simulation results of Energyplus have been validated through numerous analytical, comparative, and empirical tests. Although Energyplus is capable of simulating heating, ventilation, and air conditioning (HVAC) systems, the details of HVAC systems are not modeled since the primary objective of the study was to examine the influence of windows on thermal loads of buildings. In Energyplus, the heat transfer by radiation, convection and conduction is calculated at each time step. The U-values are not constant through the simulation because the radiation and convection heat transfer is calculated by algorithms that take into account parameters such as temperature difference between the surface and the air [7, 8 and 9].

2.1 Weather data

Computer simulation software requires hourly weather data including dry bulb temperature, dew point temperature, solar radiation, air speed and direction. Since weather conditions can vary significantly from year to year, there is a need to derive typical meteorological year (TMY2) data to represent the long-term typical weather condition over a year [10]. In the present study the TMY2 data has been generated using two different software (Weathergenrator [11] and Meteonorm [12]). Afterwards, these data have been compared with the one measured by the meteorology office of Tehran, and have been validated [13].

3. Description of the building

The thermal comfort of a typical residential building including 4 floors has been evaluated by computer simulation. The building plans have been depicted in Fig 1. In this building, each floor has 4 similar zones. Different types of windows and doors have been used in the building. The thermal properties of materials used in wall, ceiling, floor and other components of the building are displayed in Table 1. The values are in accordance with ISO 12524-6, M19 [14, 15].

3.1 Internal heat gains

The rate of internal heat gains has been determined in accordance with M19 [14], as follows:
a) Number of persons
In this research the number of person has been determined, based on the area of the rooms: 3 people for rooms with area lower than 60 m^2, 4 people for rooms between 60 to 85 m^2 areas and 3 people for rooms with areas upper than 85 m^2.
b) Lighting
The lighting power is determined as follows:
- In the rooms 2, 3, 6, 7 and 8, 200 watts, and
- In the rooms 1, 4 and 5, 100 watts.

c) Electrical equipments
In each room, the thermal power generated by electrical equipments is as follows:
- 125 watt for appliances working constantly
- 150 watt for electrical equipments that are used during a fraction of time

The hourly variations of the internal heat gains schedules have been shown in Fig 2.

4. Calculating thermal comfort

First, the hourly inside temperature has been obtained using simulation by Energyplus software.

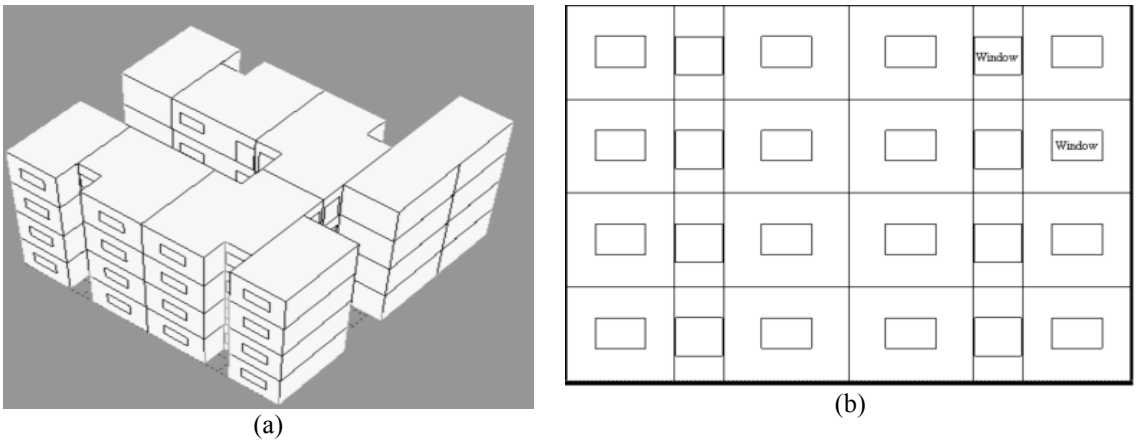


Fig. 1: Plan of the building (a) Isometric view, (b) Front view, and (c) Top view

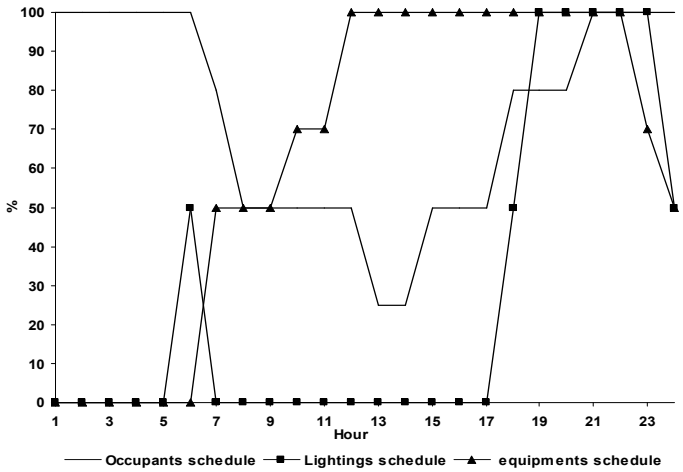


Fig. 2: Hourly schedule of internal heat gains

Afterwards, the thermal comfort has been calculated, based on method explained in the ISO 7730[15]. In this investigation, the people are assumed to wear summer dress and the hourly thermal comfort has been calculated in several air speed configurations, for sedentary and low rate activity, from the 5th (May) to the 10th (September) month.

The thermal properties of the clay block and hollow brick used in the external envelope of the building are shown in Table 2. and Fig 3. Also, during natural ventilation period with windows wide open, from 10:00 at night to 9:00 in the morning, the air change is assumed to reach 3 volumes per hour. The rest of the time, air change rate is taken equal to 1. Table 3 shows combinations in different models that are compared in this research. In some models used insulation as Table 4. All models have been simulated in different indoor air speed conditions: 0.5, 1, 1/5 and 2 m/s, for sedentary and low activity rate. The variation of the air speed can be provided using ceiling fans.

Table 1: Walls, ceiling and floor construction

Layers (inner to outer)	d Thickness (cm)	λ Thermal cond. (W/(m.K))	ρ Density (Kg/m3)	C_p Specific heat (J/(kg.K))
External Walls				
Gyspum plaster	3	0.43	1200	1000
Clay block	15	0.5	580	800
Cement plaster	3	1.15	1800	1000
Internal Walls				
Gyspum plaster	2	0.43	1200	1000
Gypsum block	8	0.43	1200	1000
Gyspum plaster	2	0.43	1200	1000
End Roof				
Gyspum plaster	3	0.43	1200	1000
Clay block	30	0.96	1160	900
Lightweight aggregate	5	0.2	600	800
Lightweight concrete	5	0.35	1100	1000
Asphalt	5	0.7	2100	1000
Internal Roofs				
Gyspum plaster	3	0.43	1200	1000
clay block	30	0.96	1160	900
Lightweight concrete	5	0.35	1100	1000
Mosaic	4	1.75	2200	1000
Floor				
Lightweight concrete	15	0.35	1100	1000
Cement plaster	3	1.15	1800	1000
Mosaic	4	1.75	2200	1000
Door (Wood)				
Wood	5	0.26	120	1600
Door (Iron)				
Iron	0.2	50	7800	450
Window with single pane glazing				
Single	0.4	1	2500	750

Table 2: Hollow brick

Name	λ W/m.K	ρ kg/m3	C_p J/kg.K
M1	**0.2879**	**646.7**	**800**
M2	**0.2891**	**629.8**	**800**
M3	**0.2345**	**697.3**	**800**
M4	**0.2119**	**684.3**	**800**
M5	**0.2187**	**546.0**	**800**
M6	**0.2056**	**683.2**	**800**

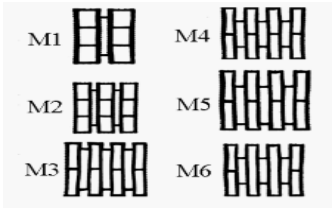


Fig. 3: Hollow brick

Table 3: All models

Case*(model)*	Type of Block	Insulation used	Air Change
1 *(Reference)*	**clay block**	**-**	**1**
2	**clay block**	**-**	**3**
3	**M1**	**-**	**1**
4	**M2**	**-**	**1**
5	**M3**	**-**	**1**
6	**M4**	**-**	**1**
7	**M5**	**-**	**1**
8	**M6**	**-**	**1**
9	**clay block**	**In the External Wall 5 cm**	**1**
10	**clay block**	**In the End Roof 10 cm**	**1**
11	**M1**	**-**	**3**
12	**M2**	**-**	**3**
13	**M3**	**-**	**3**
14	**clay block**	**In the External Wall 5 cm**	**3**
15	**clay block**	**In the External Wall 5 cm and End Roof 10 cm**	**1**
16	**clay block**	**In the External Wall 5 cm and End Roof 10 cm**	**3**
17	**clay block**	**In the End Roof 10 cm**	**3**

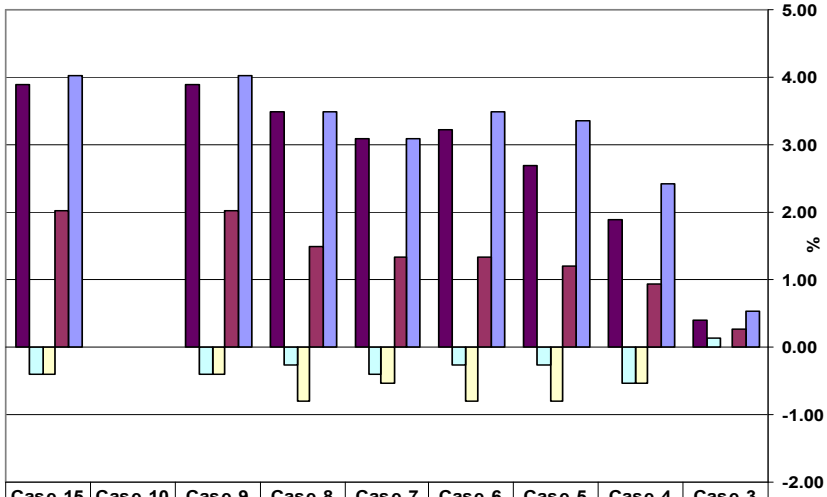
Table 4: Insulation properties

Name	λ W/m.K	ρ kg/m3	C_p J/kg.K
Insulation	0.037	35	1450

5. Results and discussion

5.1 Effect of building construction materials

The simulation have been performed for the models with 1 m/s air speed and air change rate equal to 1, in sedentary activity (models 3, 4, 5, 6, 7, 8, 9 and 15). The results have been compared with model 1 (Reference model) to determine the effect of building construction materials on the thermal comfort. The compared results have been showed in Fig 4 for room 6 in the first floor. The result shows that in the first floor, the thermal comfort condition in the rooms 6, 7, 2, 3, 5, 4, 8 and 1, changes respectively from best to worst. The change of the wall construction material leads to variations lower than 4%, in comparison with the reference model.



	Case 15	Case 10	Case 9	Case 8	Case 7	Case 6	Case 5	Case 4	Case 3
May	4.03	0.00	4.03	3.49	3.09	3.49	3.36	2.42	0.54
June	2.02	0.00	2.02	1.48	1.34	1.34	1.21	0.94	0.27
July	-0.40	0.00	-0.40	-0.81	-0.54	-0.81	-0.81	-0.54	0.00
August	-0.40	0.00	-0.40	-0.27	-0.40	-0.27	-0.27	-0.54	0.13
September	3.90	0.00	3.90	3.49	3.09	3.23	2.69	1.88	0.40

Fig. 4: Improved percent of thermal comfort with changing the building construction in comparison with model 1 (Room 6 floor1)

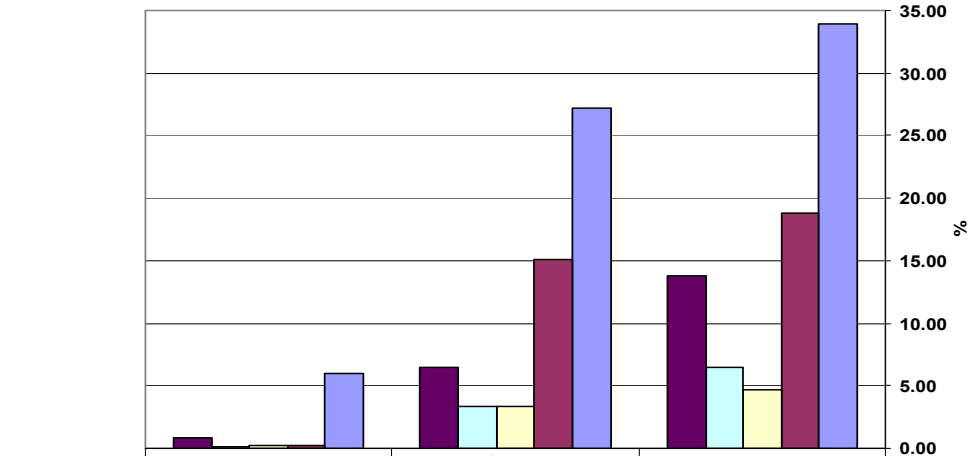
5.2 The effect of room orientation

The simulation have been performed for the first floor of the model 1, with 1 m/s indoor air speed, and an air change rate equal to 1, in sedentary activity condition. The results have been compared between rooms to determine the effect of orientation on the thermal comfort condition. Fig 5 shows the comparative result in the different orientations in the first floor. It can be seen that the thermal comfort condition in the north of the building is better than other parts, especially in comparison with the eastern rooms.

5.3 Effect of night-time natural ventilation (night purge)

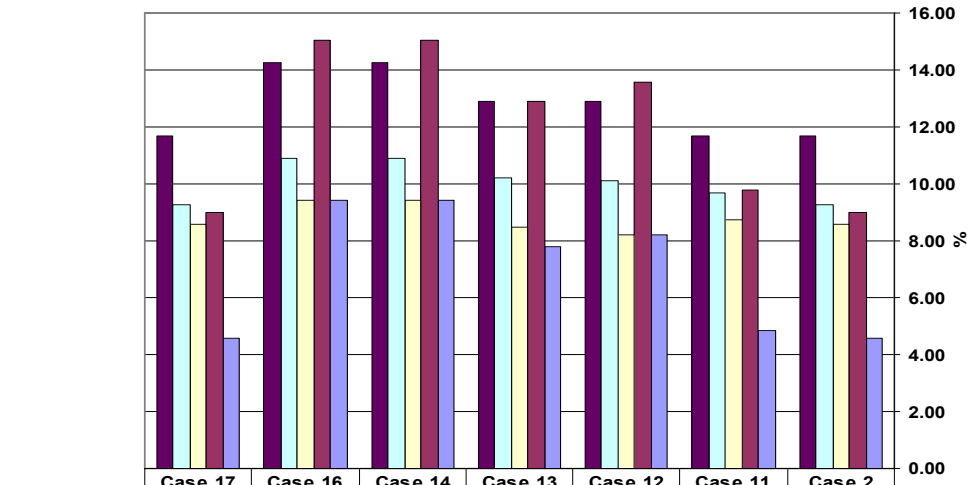
In this part, the simulation has been performed for the room 6 in the first floor, which in best thermal comfort condition, according to the results of part 5-1, with 1 m/s air speed in sedentary activity, for models 2, 11, 12, 13, 14, 16 and 17. The night air change rate, between 22:00 and 9:00 o'clock, is taken equal to 3. The results have been compared with model 1 (Reference model with air change rate equal to 1) to achieve simultaneous effect of building construction and night natural ventilation on the thermal comfort. Fig 6 shows the comparative result for Room 6 in the first floor.

The results put into evidence that the thermal comfort condition in the north part is better than other parts. The result shows that improvement caused by high rate of air change during the night is about 4-11% for the hot season, during the summer.



	West	South	North
May	6.05	27.15	33.87
June	0.27	15.05	18.82
July	0.27	3.36	4.70
August	0.13	3.36	6.45
September	0.81	6.45	13.84

Fig. 5: Improved percent of thermal comfort with changing the direction of room in comparison with East direction



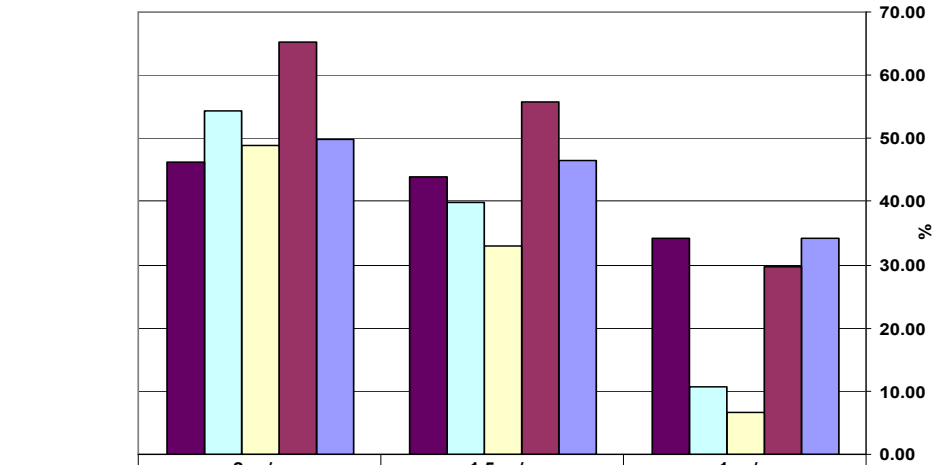
	Case 17	Case 16	Case 14	Case 13	Case 12	Case 11	Case 2
May	4.57	9.41	9.41	7.80	8.20	4.84	4.57
June	9.01	15.05	15.05	12.90	13.58	9.81	9.01
July	8.60	9.41	9.41	8.47	8.20	8.74	8.60
August	9.27	10.89	10.89	10.22	10.08	9.68	9.27
September	11.69	14.25	14.25	12.90	12.90	11.69	11.69

Fig. 6: Improved percent of thermal comfort using night ventilation with different building construction in comparison with model 1 (Room 6 floor1)

5.4 Effect of air speed

The simulation has been performed for room 6 in the first floor with best thermal comfort condition, with an air change rate equal to 1, in sedentary activity . The room has been compared in four air speed conditions: 0.5, 1, 1/5 and 2 m/s. The results have been compared with model 1 (reference model with 0.5 m/s air speed) to achieve the effect of increasing air speed from 0.5 to 2 m/s on the thermal comfort. Fig 7 shows the comparative result for room 6 in the first floor. It can be

concluded that using a ceiling fan to increase air speed improves more efficiently, from 10 to 65%, the thermal comfort during the hot season.



	2 m/s	1.5 m/s	1 m/s
May	49.87	46.57	34.14
June	65.26	55.85	29.64
July	48.92	33.06	6.72
August	54.37	39.78	10.69
September	46.37	43.82	34.14

Fig. 7: Improved percent of thermal comfort by increasing air speed in comparison with 0.5 m/s (Room 6 floor1)

5.5 Effect of activity level

The simulation results for room 6 in the first floor, with an air change rate equal to 1 (reference model) have been compared with the model 1 with sedentary and low activity level. Fig 8 shows that, by changing the activity level from low activity to sedentary, the thermal comfort change is more noticeable.

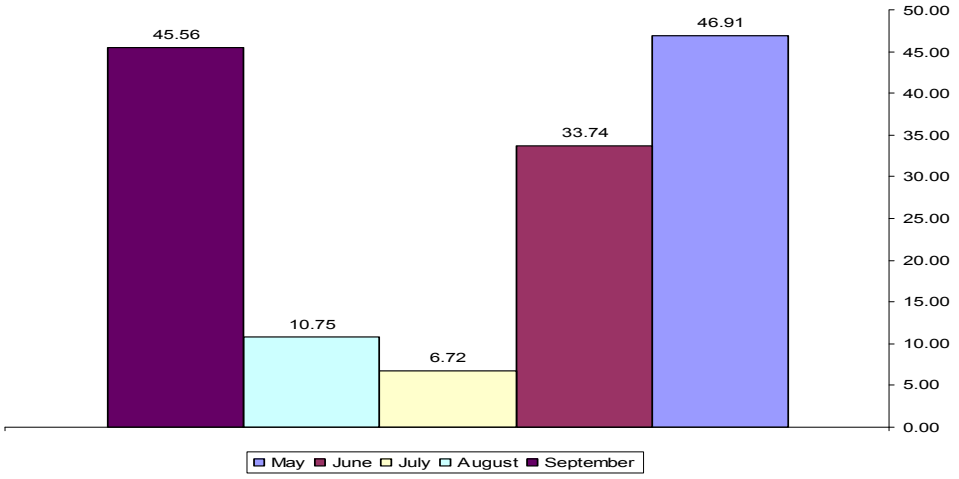


Fig. 8: Improved percent of thermal comfort by changing the activity level from low to sedentary activity (Room 6 floor1)

6. Results and discussion

In this paper, the hourly effect of using the thermal insulation, with hollow brick external walls, accompanied with natural night ventilation, based on the level of thermal comfort conditions has been investigated. Based on the results, the following conclusion remark can be formulated:

1- The best thermal comfort condition is achieved in the first floor of the building, in rooms 6, 7, 2, 3, 5, 4, 8 and 1 (descending order).
2- In cases without night ventilation and without air speed increase, changing the building construction material of the reference building has not a noticeable effect on the thermal comfort condition (maximum 4%), despite the increase of the build cost.
3- In case with night ventilation, without air speed increase, changing the building construction of the reference building has a more noticeable effect on the thermal comfort condition (4 to 11%).
4- In case without night ventilation, with air speed increase, the thermal comfort change is more noticeable (about 10 to 65% in all month).
5- The change of activity level, from low activity to sedentary, leads to a more noticeable change of the thermal comfort.

In consequence, using night ventilation with ceiling fans (to increase air speed) is suggested to improve the thermal comfort condition. This change is cost effective, and can be suggested for new and existing buildings in Rasht and other regions with similar climate.

7. References

[1] LEEA E.S, TAVIL A. *"Energy and visual comfort performance of electro chromic windows with overhangs"*. Building and Environment, 2007, Volume 42, pp. 2439-2449.

[2] CHARLIE H, HUI Z, PIETER M.T, YU E.A. *"Window Performance for Human Thermal Comfort"*. University of California, Berkeley Progress Report, 2005.

[3] WONG N.H, WANG L, AIDA N.C, ANUPAMA R.P, WEI X. *"comfort and condensation for a typical office building in Singapore"*. Energy and Buildings, 2005, Volume 37, pp. 563–572.

[4] MENZIES G.F, WHERRETT J.R. *"Windows in the workplace: examining issues of environmental sustainability and occupant comfort in the selection of multi-glazed windows"*. Energy and Buildings, 2005, Volume 37, pp. 623–630.

[5] ATTHAJARIYKUL S, LEEPHAKPREEDA T. *"Real-time determination of optimal indoor-air condition for thermal comfort, air quality and efficient energy usage"*. Energy and Buildings, 2004, Volume 36, pp. 720–733.

[6] ERIK L.O, QINYAN C. *"Energy consumption and comfort analysis for different low-energy cooling systems in a mild climate"*. Energy and Buildings, 2003, Volume 35, pp. 561–571.

[7] ZHIQIANG J.Z, QINGYAN Y.C. *"Performance of coupled building energy and CFD simulations".* Energy and Buildings, 2005, Volume 37, pp. 333–344.

[8] LOMAS K.J. *"Empirical validation of building energy simulation programs"*. Energy and Buildings, 1997, Volume 26, pp. 253-275.

[9] Energyplus Software :www.energyplus.com , Accessed 21 April 2013.

[10] APPLE L.S, CHOW T.T, FONG K.F, JOHN Z.L. *"Generation of a typical meteorological year for Hong Kong"*. Energy Conversion and Management, 2006, Volume 47, pp. 87–96.

[11] DEGELMAN L.O. *"A statistically based hourly weather data generator for driving energy simulation and equipment design software for building*". Department of Architecture Texas A&M University, College Station, TX 77843-3137, USA.

[12] Meteonorm documentation software version 5.102. http://www.meteonorm.com Accessed 21 April 2013.

[13] EBRAHIMPOUR A, MAEREFAT M. *"A method for generation of typical meteorological year"*. Energy Conversion and Management, 2010, Volume 51, pp. 410-417.

[14] Iranian standards for buildings. Ministry office of buildings and constructions No. 19, 2001.

[15] ISO/FDIS 15099. *"Thermal Performance of Windows, Doors and Shading Devices Detailed Calculations"*. 2002.

Integration of Zero Energy Standards into Student Accommodation: Demonstrated through a Case Study of Lancaster University Residences in the UK



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Summary

The paper aims at the possibilities of converting the student accommodation of University of Lancaster (UK) into zero energy building. The analysis has been carried out on the typical student accommodation unit and an evaluation has been completed on the amount of energy saved, carbon emission reduction and energy produced by renewable sources. The paper also provides results of a study of climatic conditions of Lancaster and its influence in the design, based on which zero energy building techniques have been used to make the building energy efficient. In the study, the thermal efficiency, daylight factors, artificial lighting and energy production are considered to make the units sustainable. Series of computer simulations have been completed on the unit to assess the impact of thermal insulation on space temperature and energy uses, window openings to admit in the required light and use of solar collectors to produce energy. This particular building and site has been selected as it could become the template of student accommodation in the UK. As per statistics, there has been an increase in the demand for student accommodation with the increased flow of foreign students coming to the UK. This phenomenon has forced mainly university to expand their accommodation infrastructure and the University in conjunction with the University Partnerships Programme who were able to develop accommodation with standards of Ecohomes. The study looks at the possibility of achieving zero energy standards for the Ecohomes so that it could be used as design template to build greener student accommodation around the country to answer the demand.

Keywords: Eco Residences, Zero Energy Building, Student Accommodation, Building Simulation, Photovoltaic Cells, Energy Consumption

1. Introduction

With the existing energy crisis and increasing global warming around the world, designing buildings which are energy efficient have become a prime importance for developed countries like USA, Germany, and many others which consume major part of the world energy. In most developed countries, energy efficiency standards are incorporated into the building regulation in order to reduce the overall energy consumption. Zero energy buildings are a breed of buildings which help to produce energy from green sources and reduce energy consumption. There have indications all around that the climate is changing and it is the human beings who are majorly responsible. Predominantly because of the emission of greenhouse gases, particularly carbon dioxide has added to the deterioration of nature. It is important that all nations join hands together to make our earth free from carbon emissions.
Approach towards Zero Energy Buildings (ZEB) will be a big step to achieve the same. A ZEH combines state of the art, energy-efficient construction techniques and equipment with renewable energy systems to return as much energy as it takes on an annual basis. It is a known fact that a

normal bases renewable energy cannot fulfil the energy requirement all round the year. That is in case of nights in absence of solar energy, it has to depend on the national energy grid. At the same time, there are occasions when solar energy is not used by the occupant and therefore the energy produced is supplied back to the grid. This is used by the public utility giving the occupants the full retail value of the energy. In this context, the paper presents recent developments in how the UK is planning on moving towards energy-efficient building standards and ultimately towards zero carbon levels.

2. Moving Towards Energy-Efficient Buildings in the UK

2.1 Recent Developments

The 2003 Energy White Paper demanded for more energy-efficient buildings as part of energy policy of UK [1]. This was very well reflected in the years 2006-2008 with the tightening of energy efficiency within the building sector. It has a long term goal of cutting down carbon emission by 80% by the year 2050. It aimed at cutting down energy consumption by 80% in comparison with a building which have been built by 2002 building standards. The other major rating system is the Code for Sustainable Homes which has been introduced by the government in 2007 replacing the Ecohomes [12]. This is used to rate housing in the public sector and buildings which undergo major refurbishment or new buildings. Ecohomes look out for a wide range of sustainable issues in which energy efficiency is only one. Requirement for good practice and advanced practice is set by the Energy Trust for achieving low energy buildings [2].
In addition, Association for Environment Conscious Buildings' (AECB) CarbonLite program specifies silver and gold standards, the latter approaching a zero energy building. In housing particularly, in order to improve the efficiency of all the residential accommodation, local authority had been given the responsibility of considering measures as per the Home Energy Conservation Act 1995. It was projected that between 1996 to 2010 there will be a cut down of 30% in the energy usage, but as per reports to Department for Environment Food and Rural Affairs (DEFRA) [3], there have been only 14.7% of cumulative improvement by the end of March 2004 and most of it was achieved without the Home Energy Conservation Act [4]. As for the present day, the goal is to achieve the 2016 target of making all new housing zero carbon and follow that by the 2019 target of making all new non-domestic buildings zero carbon in the UK. Even if the goal is fulfilled, it is important to address the existing building sector and particularly residential sector which also has to be energy-efficient [9].

2.2 EU Zero Energy Building Legislation

"All the buildings build after 31st December 2018 will have to produce as much energy as they consume on-site, says the European Parliament, amending the 2002 Energy Performance of Buildings Directive (EBPD). MEPs also call for the more public investment in energy-efficient buildings." [5]. The target is that an EU member state must ensure that by above date all the newly constructed buildings will consume as much energy it can produce on-site. Again, MEPs defined a Zero Energy Building (ZEB) as a building, where as a result of very high level of energy efficiency, the overall annual primary energy consumption is equal to or less than the energy production from the renewable energy source on-site [5]. The proposal will lead to high insulation of buildings so as to reduce the energy consumption and to meet the remaining energy demand by effective incorporation of appropriate renewable energy into the building including all type of residential buildings.
In the present scenario, on-site energy production does not work out to be cost effective. That is when we compare PV power stations and large wind turbines to small PV panel and wind power respectively. To make it more economically sustainable for the consumers, they must be given the freedom to produce energy off-site. This is possible in the form of community wind farm or solar farms for which the local authority has an important role to play. Majority of the European citizens live within the urban setting and in such situations it is difficult to install ground source heat system and roof spans are also limited. Zero energy is achieved by producing energy in the summer and

utilising it in the winter or the reverse of it. The very nature of zero energy makes it limited to a set of buildings and the application of the idea in a massive scale is still not very clear.

2.3 Zero Energy Building Concept

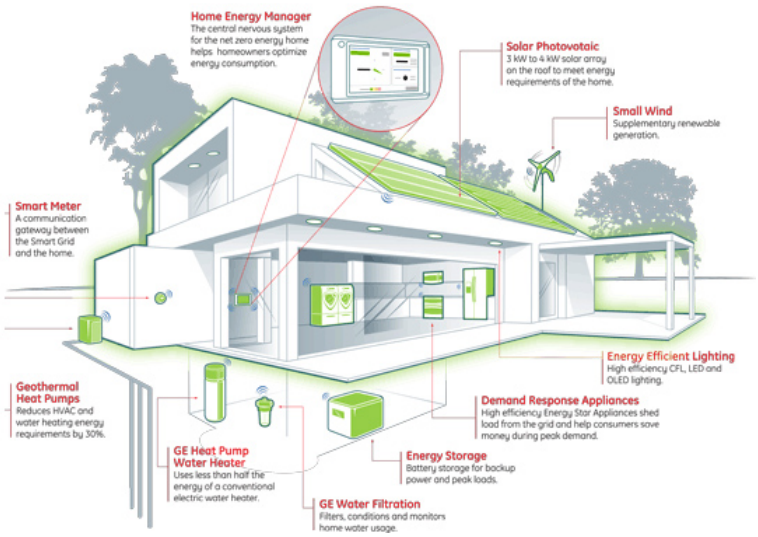


Fig. 1 Zero Energy House Concept

A Zero Energy House combines state of the art, energy-efficient construction techniques and equipment with renewable energy systems to return as much energy as it takes on an annual basis (see Fig. 1). If you see on a normal bases renewable energy cannot fulfill the energy requirement all round the year. That is in case of nights in absence of solar energy it has to be depended on the national energy grid. At the same time, there are occasions when solar energy is not used by the occupant and the energy produced is supplied back to the grid. This is used by the public utility giving the occupants the full retail value of the energy.

"Zero is the cross over point between a building that consumes the resource and one that produces the resources. Conceptually building has no impact. First on the definition front –the word "zero" is really "net zero". The sum of the flows is equal and opposite. This does not imply zero consumption from the national grid." [6]. The emphasis is on the amount of consumption (demand side) or on the various ways on alternate energy could be produced (supply strategies) and whether the methods used meet the zero energy standards. There are four aspects of ZEB which are as follows: Net zero site energy; Net zero source energy; Net zero energy cost; Net zero energy emission [7].

In the paper, the study is based on the assessment of the amount of energy that could be saved by means of passive design solutions. It aims to explore how far the definition of zero energy homes is practical and cable of producing desired result .The present ZEB definition does not adapt to the idea of producing energy off-site. Residential sector does consume a good percentage of national energy. It is therefore important that residential sector meets the ZEB standards and that the load on the national grid is reduced and energy used is greener. A question therefore arises how a house meets a ZEB standard? How different will be the outlooks of the zero energy houses in comparison with that on non-zero energy houses?

The definition of Net Zero Energy Building (NZEB) used by the industry committee is: "...where, as a result of the very high level of energy efficiency of the building, the overall annual primary energy consumption is equal to or less than the energy production from renewable energy sources on site". [6]. Torcellini et al (ACEEE 2006) identified the following main definitions of zero energy buildings (ZEB) [8]:

- Net zero site energy- A site ZEB produces as much energy that will be equivalent to the amount required by it in a year.
- Net zero source energy- A site ZEB produces as much energy by the renewable source whose total will be equal to the primary energy used to generate energy.
- Net zero energy cost- In a cost ZEB, the amount of money which the utility pays to the owner should be equal to the money paid by the owner for the energy services used in a year.
- Net zero energy emission- Building which produces as much emission free renewable energy as that of the consumed emission produced by the energy sources.

3. Case Study

3.1 Eco-Friendly Student Accommodation at Lancaster University



Fig. 2 Exterior view of student accommodation

In the year 2008, BREEAM rated the Eco Residences at Lancaster University with an 'Excellent' rating. Carbon footprint per student was said to be of 25% less than targeted carbon emission rates required by building regulations (see Fig. 2). The Eco Residence is a template for easily constructed sustainable university accommodation. It marks the last phase of the agreement between University Partnership Programme (UPP) Ltd and University of Lancaster dating 2003 in which redevelopment of student accommodation was one of the main goals. It has been one of the largest projects undertaken. The project has delivered 4347 rooms over three phases, with an investment of £180 million [10]. The final stage of the scheme has provided 963 additional students rooms which are completed as per UPP eco accommodation model. The eco accommodation reduces the carbon emission by 30% by using timber from sustainable sources. Energy and water saving features have been integrated into the accommodation. The students are encouraged to live in a sustainable environment by providing online monitoring system of their utility consumption and by integrating recycling schemes into their residences.

3.2 Design Solutions



Ground Floor



First Floor

Fig. 3 Residences' layouts

Town houses and cluster houses were the two layouts developed by UPP Ltd and Lancaster University for the Eco Residences (see Fig 3).

Town house: It consists of a large kitchen with dinning along with living room at the ground floor. A unit accommodated about 12 students and each floor, starting first floor four bedrooms and two bathroom/toilet facilities included. The town house is grouped in residences of 3 to 5 units together were each unit measured 6m wide and 12 in lengths. These dimensions made it possible to span the floor without the support of the load bearing walls. Therefore it gives it a possibility to reconfiguration of the floor plan in the future [11].

Cluster flat: It contained six en-suites flat with sharing kitchen/dining and living. The flat is approximately 12 wide and 24m long. It has a central staircase which is shared by two flats in each floor and each unit is four storied. For the future reconfiguration, the floor has been spanned between the external wall and the central corridor. Great care has been taken into the insulation of the accommodation. The insulation is 50% better than stated in the current building regulation [11].

3.3 Sustainable Features

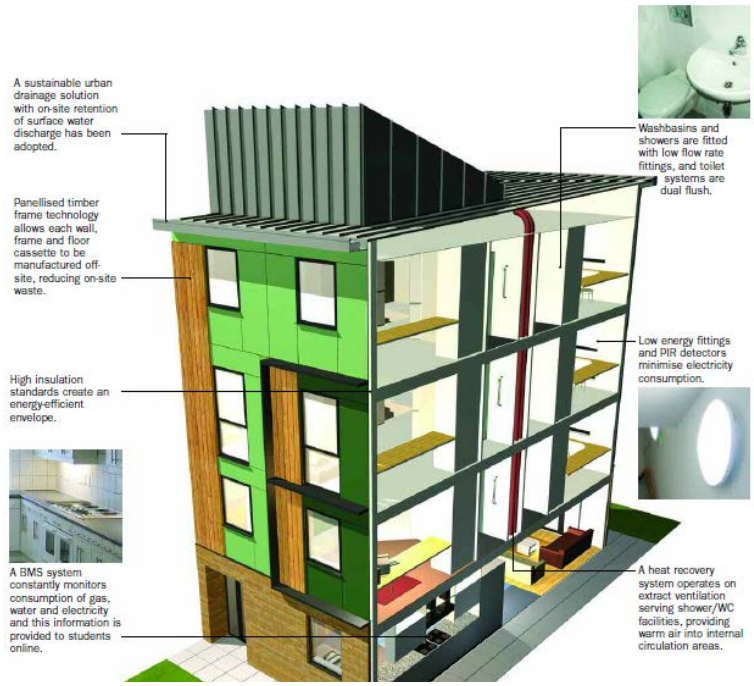


Fig. 4 Eco residence

The Eco Residences had the following features in terms of an eco-friendly construction technology implemented to make the building sustainable and a superior services used to cut down energy consumption [11] (see Fig. 4):

- It has been constructed out of panelised wooden frames which make it possible to construct the door and window off-site hence reduce onsite waste and also speed up the building process. The which is been used has been sourced from the FSC (Forest Stewardship Council). When it comes to shower heads, wash basin and toilets are delivered in prefabrication, which is fully tiled and needs only to be fitted in the correct position and connected.
- Care has been taken to look into the fact that the materials used for construction are non-toxic.
- Lower level of the building is exposed with the brick work and the higher level is gladded with cement cladding and cedar cladding panels.
- A very high energy efficient envelope is achieved by providing high insulation standards.
- Each room is facilitated with a small radiator which is controlled by a thermostatic radiator valve.
- Communal areas are installed with PIR (passive infrared sensors) detectors to ensure lights are switched on only when it is needed and also the lights are of low energy.
- Unexpected use of high wattage appliances is prevented by implementing mini circuit breakers into the study room.
- Heat from the waste water is tapped by using heat recovery system which is connected with the shower, washbasin and toilet facilities which is later used to heat the internal space.
- Toilets are installed with dual flush systems and low flow rate fittings are used to washbasins and shower heads.
- On-site retention of surface water discharge has been adopted to have a sustainable urban drainage solution.
- BMS systems are installed which enable the students to keep track of their energy consumption in terms of gas, water and electricity.

3.4 Simulation Studies

In order to make an effort to understand whether energy is effectively used or wasted, a monitoring is essential. Most of the student accommodation uses energy more than what is required due to improper planning. For example designing a passage space which can be lit up by natural light can save considerable energy for lighting. At the same time, students must be aware of the consequences of energy wastage and possibilities of energy conservation in today's lifestyle. Designing an energy-efficient accommodation will enable them to improve their outlook of students towards energy conservation.

The building which has been selected for simulation studies is an eco-friendly student accommodation at Lancaster University. The aim of the study is to use an existing building considering a particular unit and later projecting the results on the building blocks with similar

features. Moreover, it will explore the possibilities to make eco-friendly buildings zero energy buildings by using renewable sources of energy sources.

The building: County field flats are four stories high, with the entire one bedroom flats are arranged along the east- west axis and the two bedroom flats are aligned perpendicular to the one bedroom flats. One bedroom flats are arranged in blocks containing 3, 4 and 7 flats in a block. Breakup of the blocks provides space for passage which used as disability access to ground floor rooms. This helps to reduce the wind pressure on to the buildings and again to blow in wind into the courtyard which blocked from other sides. Each single room flats consist of the following spaces: Lobby; Ground floor bedroom (designed for those with disabilities in certain cases); Kitchen; Living; Staircase shaft; Passage spaces; Bedrooms (12 rooms); Toilets (6 in total) (see Fig. 5).

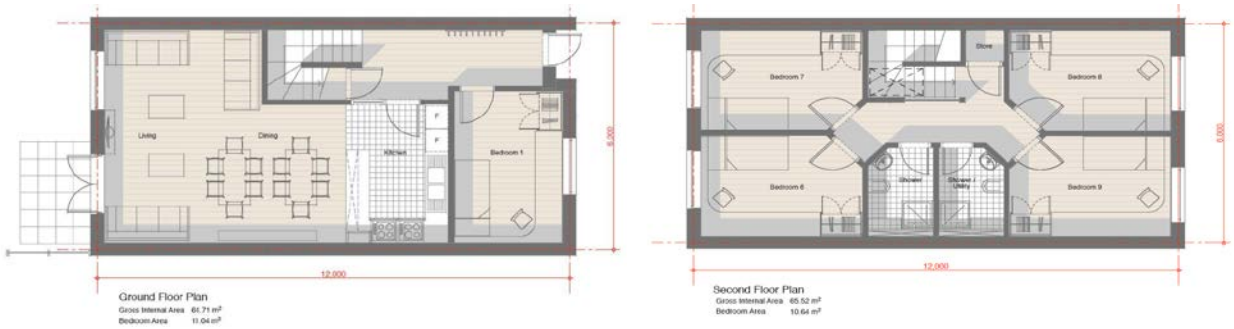


Fig. 5 Ground floor plan (left) and typical upper floor plan (right)

3.5 Energy Consumption and Internal Spaces

In order to make the student accommodation a zero energy building using renewable sources, it is important to comprehend the amount of energy required to run the accommodation units. Energy required to run the units has to be calculated and verified with the readings obtained to cross check the definiteness of the findings. Energy consumption is calculated using the chart obtained from the carbon footprint website. It gives the average value of the number of times a particular appliance will be used in a year. This data used to project the yearly consumption by correlating it with the watts of the corresponding appliances. The results have been obtained are explained in the form of graphs and its interpretations are illustrated in the paper.

Lobby/Staircase: These are spaces which are used round the day. The major requirement is lighting and space heating. This has been provided with glass door in order to maximise daylight whereas for staircase shaft there is no openings and as result, it demands artificial lighting. Motion sensors are installed for efficient lighting in the passage spaces.
Living room: It is basically used in the morning for casual sitting in the morning for breakfast or become communal spaces for the students from 6pm to 10.30pm.
Kitchen: This is a space which is used without any fixed pattern from morning to evening as different students has different timings for cooking. More or less this space is heavily used from 6pm to 10pm. Kitchen space contributes to the energy consumption by the usage of appliances, hot water for cooking and dish washing and space heating requirement.
Bedroom: The spaces where students spend majority of their time in a student accommodation. During the time activity that involves energy consumption are lighting, use of laptops and space heating. In normal weekdays, a student spent about 12 to 14 hours of a day in the room which is normally from evening to morning.
Bathroom/Toilet: The prime usage time will be 7.00am to 8.30am. This space contributes to the energy consumption by the lighting and greatly by the hot water requirement.

Table 1 is showing a typical single unit and its energy consumption.

Table 1 Energy consumption of a single unit

ROOM	APPLIANCE	NO.	A.U.	O.M.Cons. (kWh)	W. Cons. (kWh)	T.A.Cons. (kWh)
LOBBY	24W FLUROSCENT	1	7			61.30
STAIRCASE SHAFT	14W CFL	6	5-7	102.9	70.20	173.10
PASSAGE 3LEVELS	8W CFL	2	5-7	58.80	28.80	87.60
TOILETS 6 no.	8W CFL	1	1			17.52
BEDROOM 12 no.	18W CFL	1	8-12	423.36	311.04	782.40
	LAPTOP 64W	1	6			1681.92
	MOBILE CHARGER	1	4			0.22
LIVING	18W CFL	2	3-5	26.46	21.6	48.06
	T.V. 68W	1	2			49.64
KITCHEN	18W CFL	1	6			39.42
	KETTLE 1542 TIMES- 0.11 kWh/use	1				169.20
	MICROWAVE- 96 TIMES- 0.945 kWh/use	2				181.40
	ELECTRIC OVEN- 135.1 TIMES- 1.52 kWh/use	2				410.70
	ELECTRIC HOB- 424 TIMES- 0.71 kWh/use	2				602.10
	FRIDGE FREZZER 206 kW/yr	3				618.00
	TOTAL ENERGY CONSUMED BY THE APPLIANCES FOR A SINGLE UNIT IN A YEAR					**4979.62**

A.U.- Average Usage Hours. O.M.Cons- Total Energy Consumption in non-winter months. W.Cons.- Energy Consumption in Winter Months. T.A.Cons.- Total Annual Consumption

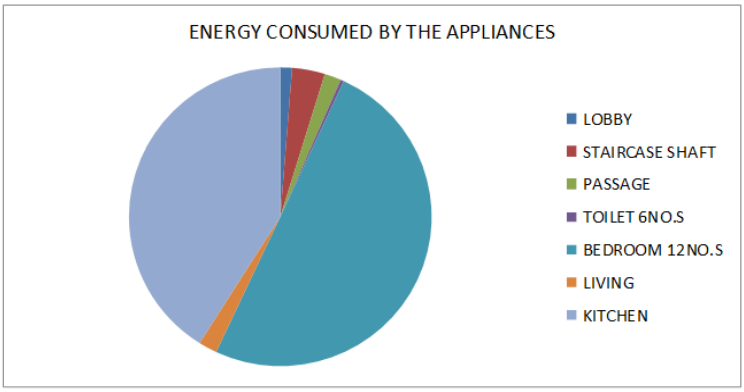


Fig. 6 Energy consumed by different rooms

Fig. 6 clearly shows that maximun energy is used by bedrooms when summed together followed by kitchen. Energy consumption by the appliances when 12 bedrooms are put together constitutes half of the energy consumed by the entire unit excluding the energy consumed for heating. Lobby space, staircase shaft, passage, toilets and living rooms when together only consumes a small portion of energy. The reason behind this is that in all other spaces within the unit, energy is consumed only for lighting and energy required for it can be reduced drastically by using an energy-efficient lighting system. Moreover, these are the two major spaces in which students spent their most of time, and which involves utilisation of appliances which consume the most of energy. The energy consumed for appliances sums up to 4979.62 kWh of energy excluding the energy required for heating.

3.6 Energy Consumed for Heating

The model of a single unit is developed in Ecotect software and it has been simulated to perform the thermal analysis. The analysis has been carried out by providing selected materials with appropriate u-values as specified by the Code for Sustainable Homes.

External fabric: Constructed with thermal efficient timber cassette shell that has a u- value of 0.14W/m^2 K.
Roof: Engineered I beams were used, filled with recycled newspaper insulation with 100mm wood fibre with OSB top and bottom and an internal vapour control large to the underside of the OSB. U-value of 0.12 W/m^2 K.
Floors: Constructed from concrete planks with 150mm foam insulation under a 50mm screed with 50mm edge upstand. U-value of 0.15 W/m^2 K.

Doors and Windows: Windows with triple glassed FSC certifnied with U-value of 1.2 W/m^2 K. External doors U-value of 1.1 W/m^2 K [12].

The design standards have been integrated with the architectural design as specified by the code. The PassiveHaus design certifies the building when the heating energy spent on heating is not more than 15kWh/m^2/year [13]. After simulation, the value obtained is approximately 33 kWh/m^2/year which is double to the value set by the standards of PassiveHaus.

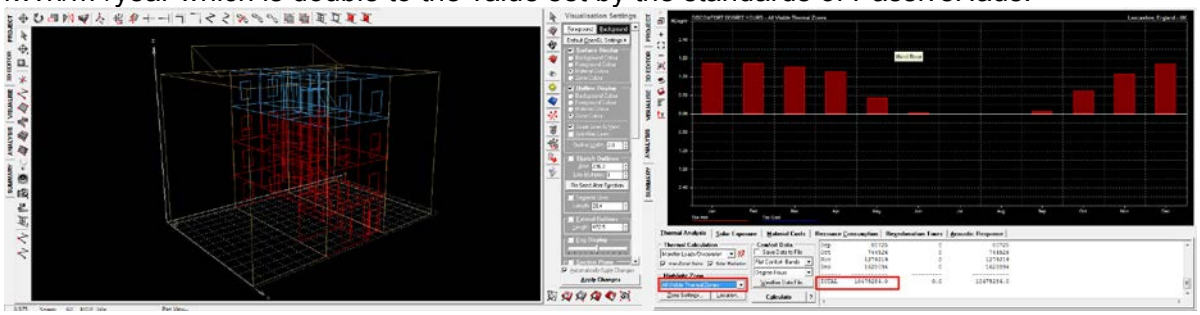


Fig. 7 Ecotect model (left) and total heating loads of the entire unit (right)

Thermal analysis has been carried out considering comfort band between 18-23°C with occupancy rate of four per zone and internal air change is taken to be as still air. Operational hours are set from 18pm to 8am. Each floor has an internal floor area of 78.37 m^2. Simulation studies have shown that there is a gradual increase on the loads from first floor to third floor. At the same time, heat required for ground floor is greater than the first floor. The ground floor layout has less inetrnal walls. Third floor plan has the highest annual consumption of 41.79 kWh/m^2 and first floor has the lowest which is 29.14 kWh/ m^2. Considering all other zones together, the annual energy spent is 10475.28 kWh with an average of 33 kWh/m^2 of energy is spent on heating. Summarising both the energy required for heating and for appliance adds up to 15454.9 kWh as per the rates of British gas, 1kWh cost 15.3 pence on an average [14]. Thus cost £2364.57 a year and £197.04 a month.
The goal was to find the amount of energy that can be produced by wall mounted or roof mounted photovoltaic (PV) panels that can help to cut down the energy consumption from the national grid.

4. Conclusion

In order to demonstrate the energy generation, a comparison of the two sets of model has been carried out; the model with wall mounted PV panels has given a better result. The reason being that southern wall gets more solar radiation compared to the roof as the sun stay very low in the sky for the major part of the year. In the other model, the PV panels were overshadowed by the neighbouring panels which resulted in providing the more space in between which in turn resulted in less productivity per unit area. The vertical stacking of PV panels on to the wall has proved to be more effective than arranging PV panels on to the flat roof when it comes to energy produced per unit area.
By using a wall mounted Crystalline Silicon cell module (15% efficiency), it can achieve 20.45% of annual savings whereas a roof mounted can only save up to 8% on the energy consumption. For the very same reason wall mounted reduces electricity bill by £483.6 which is double of the amount saved by roof mounted systems. The same is reflected in the case of CO_2 reduction. Roof mounted reduce CO_2 emission by 1.8 tonnes annually whereas wall mounted cut down CO_2 emission by 2.8 tonnes annually.
CIGS cells with increased efficiency (19%), a much better performance than crystalline silicon cell module were achieved. The difference between powers generated by both the models is not as significant. Annual generation by the wall mounted is 3159.06 KWh and the energy generated by roof mounted is 2634.24KWh. Roof mounted CIGS cells helps to cut down CO_2 by 2.5 tonnes annually whereas wall mounted cut it down by 3.05 tonnes. Wall mounted cut down 24% of annual energy cost whereas roof mounted is only capable of cutting it by 17%.

Using a CNT based cell module (50% efficiency), more than the total sum of the energy generated by the other two cells were achieved. It cuts down CO_2 emission by 7.7 tonnes in the case of wall mounted and 5.04 tonnes when it comes to roof mounted system. The most important part is that it can generate more than 50% of total annual consumption by the wall mounted systems and the energy consumption cost is reduced to half the total annual amount.
Today, 85% of the UK market consists of crystalline silicon. The reason is that the UK market is dominated by the smaller roof top application. Compared to crystalline silicon, the market of tin film photovoltaic has increased from 7% to 17% over the recent years but only 10% and 12% efficiency module is available commercially. CNT based cells module technology is not available in the commercial market. They are supposed to dominate the market of solar power by the year 2020. The cost will be less than half the price of crystalline module available in the present market. Therefore, the Eco Residences can meet zero energy standards by CNT based cells alone in the future. However, for the present day only the combination two or more renewable energy is required to meet the zero energy standards. By using 19% efficient CIGS based cell can produce enough energy for the unit to offset the energy requirement for appliances. It is best to combine solar power with ground source heating system which can substantially cut down the energy requirement for heating and meet the standards of zero energy building.

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6. References

[1] DTI, Energy White Paper: Our Energy Future- Creating a Low Carbon Economy (Feb 2003). [Online], [Accessed December 2009], Available at National Archives: http://webarchive.nationalarchives.gov.uk/tna/+/http://www.dti.gov.uk/files/file10719.pdf/

[2] ENERGY SAVING TRUST, 2010. Building Regulation Covering Energy Efficiency. [Online], [Accessed on July 2010], Available at: http://www.energysavingtrust.org.uk/business/Business/Housing-professionals/Building-Regulations-covering-energy-efficiency

[3] DEFRA, Online], [Accessed May 2010], Available at: http://www.defra.gov.uk/

[4] ENERGY CONSUMPTION IN THE UNITED KINGDOM (2001), [Online], [Accessed November 2009], Available at: http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file11250.pdf

[5] EUROPEAN ELECTION, 2009. All New Buildings to be Zero Energy from 2019 say MEPs. [Online], Ref: 20090422IPR54163, [Accessed on April 2010], Available at: http://www.europarl.europa.eu/sides/getDoc.do?type=IM-PRESS&reference=20090422IPR54163&language=EN

[6] ECEEE, 2009. Steering Through the Maze #2: Net Zero Energy Buildings: Definitions, Issues and Experience, [Online], [Accessed November 2009], Available at: http://www.eceee.org/buildings/MazeGuide2-NetzeroEnergyBldgs.pdf

[7] ENERGY EFFICIENCY AND RENEWABLE ENERGY, 2009. Net-Zero Energy Commercial Building Initiative. [Online], [Accessed December 2009], Available at: http://www1.eere.energy.gov/buildings/commercial_initiative/zero_energy_definitions.html

[8] TORCELLINI P., PLESS S., DERU M., CRAWLEY D., 2006. Zero Energy Buildings: A Critical Look at the Definition, In: National Renewable Energy Laboratory, NREL/CP-550-39833, California, June 2006.

[9] POWER WATCH, 2010. Domestic Energy Use in the UK – Power Conservation, Transport and Use. [Online], [Accessed on May 2010], Available at: http://www.powerwatch.org.uk/energy/graham.asp

[10] UNIVERSITY PARTNERSHIPS PROGRAMME, 2008. The Eco Residence at Lancaster University. [Online], [Accessed on July 2010], Available at: http://www.upp-ltd.com/university/lancaster/

[11] UNIVERSITY OF LANCASTER, UPP, GWP, 2009. Eco Residences – Eco-friendly Student

Accommodation, [Online], [Accessed on January 2010], Available at:
http://www.upp-ltd.com/publications_pdfs/upp_eco_lancs.pdf

[12] COMMUNITY AND LOCAL GOVERNMENT, 2007. The Code for Sustainable Homes. [Online], [Accessed on May 2010], Available at:
http://communities.gov.uk/documents/planningandbuilding/pdf/1161997.pdf

[13] LOW ENERGY HOUSE, 2010. PassivHaus Design Standards. [Online], [Accessed on May 2010], Available at:
http://www.lowenergyhouse.com/passivhaus-standard.html

[14] BRITISH GAS, 2007. British Gas Domestic Electricity Charges Pence Per KWH, [Online], [Accessed on May 2010], Available at:
http://www.britishgas.co.uk/pdf/House%20std%20tables_elec.pdf

[15] THAMBI, S.T. 2010. Integration of Zero Energy Standards into Student Accommodation - Lancaster University Accommodation, The University of Sheffield, September 2010.

A Study on Assessment Methodology to Measure Carbon Reduction Potentials of Recycling Building Materials considering Avoided Impacts



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Short Summary

This is a basic study on developing an assessment technique to objectively measure environmental loads of recycling building materials throughout their life cycle. At present, the building materials industry does not have any detailed procedures and standards necessary in estimating greenhouse gas emission caused by manufacturing and utilization of products developed using waste materials as ingredients. Therefore, it is necessary to develop an assessment methodology with which to measure in advance the environmental loads that can be lowered at waste recycling. This study aims at proposing a life-cycle assessment method to quantitatively assess potential environmental load reduction of recycling building materials by each stage, such as manufacturing, use and disposal of building materials made using recycled materials.

Keywords: Carbon emission reduction; Life Cycle Assessment; Environmental impacts; Avoided Impacts; Recycling Building materials.

1. Introduction

The amount of waste generation in Korea's construction field is displaying a continuous trend of increase from 26% to more than 51% over the last ten years. The actual rate to recycle construction wastes as cyclic aggregate is approximately 22%. This means that most construction wastes are simply recycled for soil banking or covering and that the rate of recycling for concrete and subbase, the highly economical uses, is very low at around 14%. In addition, as demand for new building construction and reconstruction increases rapidly, the problems associated with insufficient amounts of natural aggregate collection are worsening and an enormous national budget loss is incurred due to land damage and natural environmental destruction resulted from development of aggregate supply sources. Accordingly, it has been necessitated for the construction industry to make efforts for preventing waste of natural resources and reducing environmental load and greenhouse gas emission caused by resources development and use by turning wastes into resources. In other words, it is required to suppress generation of construction wastes by developing technologies for efficient recycling and reuse of waste resources and to implement a low-carbon resource recycling system by turning wastes into resources in the building products fields.
However, building materials fields are currently lacking detailed procedures and standards necessary for estimating the amount of greenhouse gas emission generated by production and use of building materials. Therefore, it is difficult to establish objective environmental load reduction plans through improvement of product applicability or reusability by assessing potential environmental impacts and analyzing processes in which greenhouse gas emission is concentrated. In addition, a methodology to estimate life cycle greenhouse gas emission specialized to the construction industry is not yet established and implementation of national LCI

DB(Life Cycle Inventory Database)[1] to represent each material is insufficient. This results in a shortage of basic data for $LCCO_2$ assessment of carbon reduction-type building products using recycled resources. Therefore, it is required to develop standards for assessment technologies to measure in advance the environmental loads according to materials used in production, the manufacturing process and utilization of the manufactured products.

2. Objectives and Scope

2.1 Objectives

This is a basic study on developing an assessment technique to objectively measure environmental loads of recycling building materials throughout their life cycle. At present, the building materials industry does not have any detailed procedures and standards necessary in estimating greenhouse gas emission caused by manufacturing and utilization of products developed using waste materials as ingredients. Therefore, it is necessary to develop an assessment methodology with which to measure in advance the environmental loads that can be lowered at waste recycling.
Recycling building materials are produced using mainly waste and, thus, the ratio of natural resources content is low. As much as so, different assessment scenarios must be applied to measuring environmental impacts by life cycle and a methodology to estimate carbon dioxide emission according to each scenario must be established in detail. This study aims at proposing a life-cycle assessment method to quantitatively assess environmental impacts of recycling building materials by each stage, such as manufacturing, use and disposal of building materials made using recycled materials.

2.2 Scope

Although there can be various methods of quantitatively assessing environmental performance depending on the points of view, this study uses an analysis method based on $LCCO_2$ (Life Cycle CO_2) in relation to climate change agreements, which are emerging as an international issue. Building materials undergo numerous processes during their life cycle, ranging from production and use to disposal. Using the $LCCO_2$ assessment method, data on the inputs and outputs in each stage can be gathered, and data on environmental load generated during the product life cycle can be developed.

3. Methodology

3.1 Definition of the $LCCO_2$ assessment

$LCCO_2$ is defined as a technique of quantitatively assessing potential environmental impacts during the product life cycle ranging from production to disposal based on CO_2 equivalent (CDE). A typical technique of quantitatively measuring the environmental load generated by the use of products and services is the LCA (Life Cycle Assessment) methodology set forth as an international standard. By applying this methodology, the environmental load of natural resources, human health, and ecosystem according to the production and use of a target object can be evaluated quantitatively. With greenhouse gas (GHG) becoming an issue nowadays due mainly to the advent of climate change conventions and certified emission reduction (CER), the $LCCO_2$ technique -- which takes into account only the global warming potential (GWP) among the LCA results -- has been brought to the fore. In other words, $LCCO_2$ complies with the LCA methodology based on the international standard ISO 14040. With regard to the environmental impact in the life cycle of products and

[1] LCI DB (life cycle inventory database) is the database that has listed waste discharged from the resources, energy, and system inputted into the environment during the life cycle ranging from the extraction/gathering of raw materi-als required for production, processing, transport, and use of a product to the disposal of the product.

services, however, the $LCCO_2$ technique is defined as the environmental impact assessment method expressed as GWP index.

3.2 Process of the $LCCO_2$ assessment

3.2.1 Functional units and reference flow

LCA is carried out targeting the final products or services having main functions. Therefore, it is very important to set functional units. The purpose of a functional unit is to quantify the services offered by a product. The reference flow of materials and energy is then set by interpreting the functional units based on the performance of the targeted product. Here, reference flow indicates the number or quantity of products required to carry out functional units.
In the product $LCCO_2$ assessment, the method of setting functional units is based on the unit product sold in the market. When the functional units are unclear, or to aid in a third party's understanding, a separate functional unit for the product concerned can be set as necessary. When the production process of products released in the market is the same, but the sales type and size of the products differ according to consumer requirements, units such as 1kg and 1ton of a product can be used as basis.

3.2.2 System boundary

A system refers to an aggregate of a series of activities that carry out clearly defined functions. In a broad sense, a system covers the acquisition of raw materials up to product use by industrial companies or consumers and final disposal of the product. The system boundary is decided by the unit processes included in LCA, and the scope, by intended use, limitations of data, expenses, assumptions, and intention to apply the research results.
In ISO 21930, an international standard on the building products' environmental declaration, the products' environmental information from cradle to grave should be drawn based on the information modules described in ISO 14040 and ISO 14044. Accordingly, the life cycle of building materials can be divided into 4 stages: production, construction, use, and disposal stages.
The environmental impacts according to the flow of materials and energy in each stage can be calculated based on CO_2 emissions. The following describes the system boundaries for the building materials' $LCCO_2$ assessment:

A. **System boundary of material production:** This boundary includes all the processes of pro ducing the building materials to be inputted into a building by consuming the resources and energy required for production, such as the extraction/gathering of natural resources and re cycled resources and manufacture of products into finished goods or semi-finished goods. T he data to be collected in this stage are activity data related to natural resources extraction/g athering, intermediary and final product production activity data, and transport data between raw material extraction/gathering and manufacturing workplace or between manufacturing w orkplaces.

B. **System boundary of construction:** This boundary includes the process of transporting ma terials constituting a building from the material production site to the construction site and the stage of completing the building by inputting building materials, energy, and various mac hines by construction techniques. The object of data collection in this stage is the data on th e transport means, distance, and cargo in the transport process and data of raw materials u se volume of machines inputted in the site construction process.

C. **System boundary of use and maintenance:** This boundary includes the process wherein a user maintains a gradually wearing and tearing building through additional repair and main tenance while the user resides in the building until the completed building is demolished. Th e types of activity data to be collected in the use stage are the quantity of materials and ener gy volume inputted for maintenance and transport activity data of the transported materials.

D. **System boundary of disposal and recycling:** When the use of a building ends, this bound

ary includes the following, i.e., when a building is demolished using equipment, the building waste is transported to a building waste materials processing plant for reclamation or incineration or recycling as raw materials of other products. In this stage, data derived from demolition activity, data by reclamation, incineration, and recycling according to disposal mode, and transport activity data from the demolition place to each processing place are collected.

$LCCO_2$ in the building materials can be calculated as the total of the values of activity data in each stage of the life cycle multiplied by the relevant basic unit of CO_2 emission. As set forth in the building products' EPD criteria or carbon emission assessment guidelines, the system boundary or information module in each stage of the life cycle is decided. Likewise, unit processes within each boundary are defined, with each carbon emission according to the activities in the unit process subsequently calculated.

3.2.3 Data Collection

It is important to know what is connected and what flows in each stage of the life cycle, since LCA is the process of quantifying the flow of materials and energy. To prevent the omission of data on various inputs and outputs generated during the building's life cycle and to collect quantified data, the category of data to be collected should be set, and the relevant parameter list should be made in advance.
The data collection scope is divided into field data collection scope and general data collection scope. General data include disclosed general data including national LCI data and selected foreign database. Field data include the data preferentially collected from the participating companies' workplaces. The general data collection scope differs depending on the collection scope of site data. For example, general data disclosed with the consent of participating companies can be used in relation to raw materials, utilities, and external process facilities having difficulties in collecting data.
In principle, activity data needs to be collected based on field data. When field data cannot be collected, however, general data can be used. System boundary for data collection is divided into 4 stages in line with the building materials' life cycle; the data collection method of each system boundary can be summarized as follows (table 1):

Table 1: Data collection method of each system boundary

System Boundary	Information Module	Input data	Output data	Types of Activity data
Material Production Stage	Raw material supply	Material, Energy	CO_2 eq	Activity data related with raw material and energy production
	Transport	Energy	CO_2 eq	Transport data between manufactories
	Manufacturing	Material, Energy	CO_2 eq	Activity data related with end product manufacture
Construction Stage	Transport	Energy	CO_2 eq	Transport data between product manufactories and construction site
	Construction – installation process	Energy	CO_2 eq	Activity data related with construction machinery
Use & Maintenance Stage	Use	Energy	CO_2 eq	Activity data related with energy consumption of end product
	Maintenance	Material, Energy	CO_2 eq	Activity data related with product maintenance
	Transport	Energy	CO_2 eq	Transport data between product manufactories and building
End of life Stage	Disassemble	Energy	CO_2 eq	Activity data related with dismantling product
	Transport	Energy	CO_2 eq	Transport data between building and disposal facility
	Recycling	Material, Energy	CO_2 eq	Activity data related with waste treatment for recycling or reuse
	Disposal	Energy	CO_2 eq	Activity data related with waste landfill or waste incineration

4. Proposal for measuring CO_2 reduction

4.1 Expanding System Boundaries

The model in life cycle assessment to describe resources and energy flow in the ecosystem is basically divided into an environmental sphere and a technical sphere. Environmental sphere is where natural resources and primary energy before the stage of artificial processing exist and technical sphere is where human activities take place. The system boundaries for life cycle environmental impact assessment on a target are generally limited to the acts of processing, construction, utilization and disposal that take place within technical sphere. Environmental impacts are calculated by collecting the relevant data and applying the corresponding LCI DB by each input substance.
However, in case a waste substance discharged within specific system boundaries inside technical sphere, such as recycling building materials, is processed and utilized as a recycling resource or biomass within another system boundaries, it is necessary to add a new circulatory sphere so that to explain the phenomenon of a cyclic closing that takes place within technical sphere. This special circulation of recycling materials is illustrated in figure 1. As for recycling resources, collection and disposal of the resources take place within technical sphere. Accordingly, by expanding system boundaries to include collection and disposal of materials, both carbon reduction occurring in the stage of collection and potential environmental load reduction occurring in the stage of disposal must be taken into consideration.

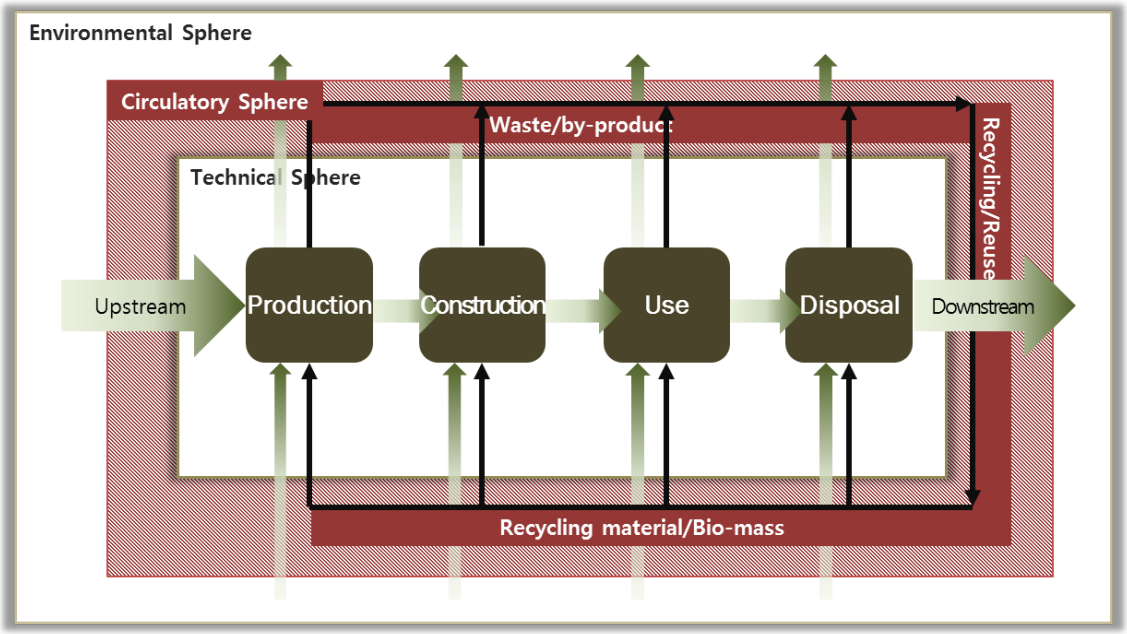


Figure 1: Illustration of circulatory sphere for the recycling materials

4.2 Considering Avoided Impacts

In life cycle assessment, avoided impacts refer to considering potential environmental impacts occurring before or after an assessment period established with life cycle of an assessment target within the system boundaries. As system boundaries changed according to assessment period expanding to be longer than the life cycle of an assessment target, the quantitative environmental impacts estimated are expressed as relative values in this study. Figure 2 explains how different the system boundary is to consider the avoided potential impacts by materials recycling.

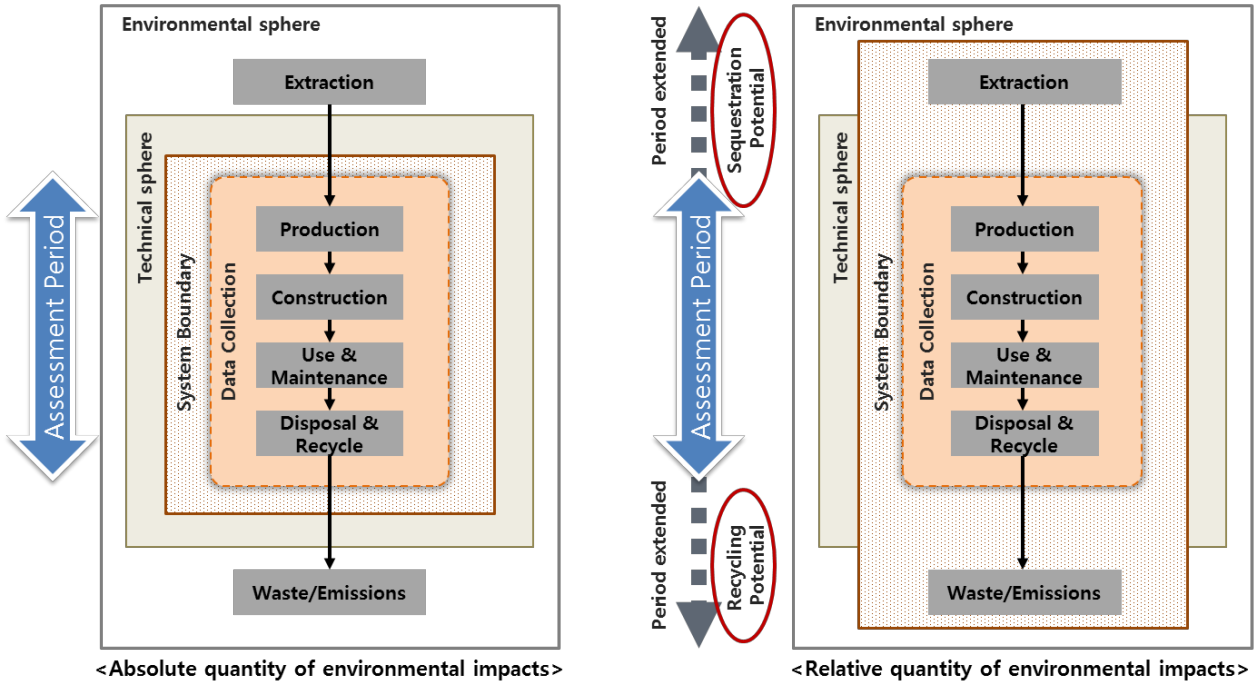


Figure 2: Comparing the system boundary for absolute quantity and relative quantity

An example of considering avoided impacts in an environmental impact assessment is the carbon sink effect acknowledged in the Kyoto Protocol. As Kyoto Protocol acknowledges afforestation and farming land development as carbon sink activities, for carbon-based products that absorb carbon in the materials stage, the amount of carbon absorption is deducted from the total carbon emission. Likewise, additional natural resources and energy consumption can be prevented by recycling or reusing waste. Considering potential environmental impact reduction effects as such within the system boundaries of an assessment target, the avoided impacts can be calculated quantitatively.
The potential amount of carbon reduction in the stage of materials collection and the potential amount of carbon reduction in the stage of disposal can be called sequestration potential and recycling potential respectively. In this study, the avoided impacts by resource recycling, potential carbon reduction in the stage of materials collection and the potential carbon reduction in the stage of disposal were expressed as reduction potential, sequestration potential and recycling potential respectively. Figure 3 is the formula for calculating the relative quantity of carbon emissions during entire life cycle of recycling building materials.

- $LCCO_2 = C_P + C_C + C_{U\&M} + C_{D\&R}$
- $C_P = C_E + C_M + \sum C_{ti} - C_{Sequestration}$
- $C_C = C_I + \sum C_{ti}$
- $C_{U\&M} = C_U + \alpha(C_E + C_P + \sum C_{ti} - C_{Sequestration})$
- $C_{D\&R} = C_D + C_R + \sum C_{ti} - C_{Recycling\ potential}$

- C_P = carbon emissions during material production stage
- C_M = carbon emissions from final product manufacturing
- C_E = carbon emissions from raw material and resources excavation
- C_P = carbon emissions from final product manufacturing
- C_T = carbon emissions from transportation of raw material, products or waste
- $C_{Sequestration}$ = carbon reduction by using carbon-sink materials or carbon-based materials
- C_C = carbon emissions during construction stage
- C_I = carbon emissions during building construction or assembling building parts
- $C_{U\&M}$ = carbon emissions during building operation and maintenance
- C_U = carbon emissions from building operation
- α = coefficient of maintenance cycle, (=assessment period/durability period of material)
- $C_{D\&R}$ = carbon emissions during building demolition, waste disposal, recycling and reuse
- C_D = carbon emissions from building demolition
- C_R = carbon emissions during recycling or reuse process
- $C_{Recycling\ potential}$ = carbon reduction by substituting recycled material for virgin materials

Figure 3: The formula for calculating life cycle CO_2 of recycling building materials

4.3 Case study

Figure 4 is case studies of carbon reduction potential which applied the $LCCO_2$ formula. In the first assessment, the absolute amount of carbon emission was estimated using the same system boundary model as the one used in the existing carbon labeling system. In the second assessment, calculation was carried out by expanding system boundary to the stages of materials collection and recycling in order to take into consideration the potential carbon reduction amount generated by recycling of resources.

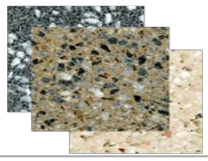
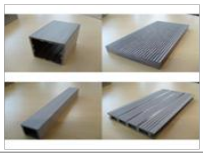
		Production	Construction	Use & Maintenance	Disposal & Recycle	Reduction Potential	Total
Fumed silica insulation board 	Absolute quantity	1.43	0	0	0.0641	X	1.5 kgCO2e/ea
	Relative quantity	1.43	0	0	0.0641	-1.23	0.265 kgCO2e/ea
Stone dust artificial marble 	Absolute quantity	21.5	0	0	0.254	X	21.7 kgCO2e/ea
	Relative quantity	21.5	0	0	0.363	-20.2	1.65 kgCO2e/ea
Stone dust concrete panel 	Absolute quantity	33.2	0	0	0.683	X	33.9 kgCO2e/ea
	Relative quantity	33.2	0	0	0.975	-31.2	2.97 kgCO2e/ea
WPC window profile 	Absolute quantity	1.12	0	0	0.0143	X	1.13 kgCO2e/m³
	Relative quantity	1.12	0	0	0.0086	-0.913	0.215 kgCO2e/m³

Figure 4: Case studies of carbon reduction potential of recycling building materials

5. Conclusions

The life cycle of recycled building materials consists with the stage of production, the stage of construction, the stage of application and maintenance and the stage of disposal. The sum of emission amounts resulted from activities in each stage is the life cycle carbon emission amount.

A. **Production stage:** The sources of carbon emission activity in production stage include raw materials for production, energy collection, manufacturing process and transportation of raw materials and energy. If raw materials are the source of carbon absorption, according to the carbon reduction effect generated by carbon sink, the amount of carbon emission can be lo wered as much as the amount of absorbed carbon.

B. **Construction stage:** The sources of carbon emission activity in construction stage are largely divided into activity to transport building products to a construction site and activity to assemble the building products using construction equipment. The amount of carbon emissions is calculated by adding emission amounts caused by each activity.

C. **Use and maintenance stage:** The sources of carbon emission activity in application stage are divided into an activity to use building products and an activity to repair the products in o rder to maintain their performance during the period of use. The amount of carbon emission generated by the application of building products can be calculated based on the amount of

energy use and the amount of carbon emission generated by maintenance activities can be calculated by estimating repair cycle based on the product lifespan in comparison to total application period and then multiplying the repair cycle with the amount of product input in the initial phase.

D. **Disposal and recycling stage:** The amount of carbon emission generated by disposal of building products is calculated by adding the amounts of emission from dismantling the products and recycling activities, and then deducting the amount of carbon reduction resulted from production of natural resources that are substituted with reused or recycled materials.

The results of this study can be used in deriving detailed procedures and standards of an assessment to measure environmental loads in relation to recycling materials used in processing of building materials, final products developed using the materials and their manufacturing processes. Further studies can be implemented in a direction to specify applicability and suitability of the assessment methodology in identifying causes of environmental loads, which are generated due to unique characteristics of recycling products, such as recycling and transport of waste, and also of other environmental loads occurring internally in manufacturing plants.

6. Acknowledgement

The work presented in this paper is a part of the study on the Construction Technology Innovation Project (project number 11-Technology Innovation-F04) which has been funded by the Ministry of Land, Transportation and Maritime Affairs.

7. Reference

[1] Korea Institute of Construction Technology, Life Cycle Inventory(LCI) Database for Finishing Materials using in super tall building, Ministry of Land, Transport and Maritime Affairs, 2011
[2] Korea Institute of Construction Technology, The Environmental Performance Assessment and Revitalization Strategy for Han-Ok, Ministry of Land, Transport and Maritime Affairs, 2010
[3] Korea Institute of Construction Technology, National Life Cycle Inventory(LCI) Database for Building Materials, Ministry of Land, Transport and Maritime Affairs, 2008
[4] Korea Institute of Construction Technology, An Environmental Assessment Method of Sustainable Building Materials and Recycling Techniques, Ministry of Land, Transport and Maritime Affairs, 2000
[5] Carbon Footprint Labelling guideline, Korea Environmental Industry and Technology Institute, 2010
[6] Sa-Yong Kim et al. Environmental Life Cycle Assessment, Sigmapress, 1998
[7] Sung-Hee Kim, Chang-U Chae, A Study on the Estimation of the Environmental Load Intensity for the Life-cycle of Hanok, The Korea Housing Association, Spring Conference 2010 vol. 1, p332-337
[8] International Standard ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework, 2006

Using MFA for the performance economy: a case study of industrial storage



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Summary

Sustainability requires the development of new economic frameworks and business models for a better management of materials and energy. For example, the performance economy (as well known as product-service system) proposes new function-based business models instead of product-based business models. Performance economy can be applied by companies through dematerialization of their offers and rental of a service. In this case, companies keep ownership of materials involved in the service provision over their life cycle, which gives a strong incentive to optimize resource efficiency.

This study aims to rigorously quantify environmental impacts of the performance economy in the case of industrial storage, by comparing the rental of metal-textile storage structures with classic storage solutions (like warehouses). To accurately take into account the management of materials and the reuse cycles (e.g. logistics, stock management), a material and energy flow analysis (MFA) is carried out, using the Umberto® tool. Based on representative demand profiles, various use scenarios are defined and analysed. A Life Cycle Assessment (LCA) is then carried out to compare this service provision with plausible alternatives.

Over five environmental indicators (primary energy consumption, climate change, abiotic depletion, photochemical ozone formation and water consumption), it has been shown that rental of metal-textile storage structures can have a lower environmental impact than classic storage solutions. Environmental benefits of metal-textile structures are even higher when storage of non-standard pallets occurs (due to the modularity of the structure) or when stock turnover is high (due to the proximity of the structure). However, benefits can be lower whether the pallets are stored for a short time, or the supplier of structures is far from the need of storage.

To conclude, thanks to its lightness and the reuse of materials, as well as the modularity of the design, metal-textile structures could be lower environmental impact solutions for industrial storage and could bring flexibility and reactivity compared to classic storage systems.

References

[1] Stahel, Walter (2010) The Performance Economy, Second Edition, Palgrave-MacMillan, London, 350 pages, ISBN 978-0-230-58466-2

[2] Paul H. Brunner and Helmut Rechberger (2003), Practical Handbook of Material Flow Analysis, CRC Press, ISBN 978-1-56670-604-9

Keywords

Performance economy; Material Flow Analysis (MFA); Life Cycle Assessment (LCA); Industrial storage; Product-Service System (PSS).

Full Paper

1. Context and objectives

Sustainability requires the development of new economic frameworks and business models for a better management of materials and energy. For example, the performance economy (as well known as product-service system) proposes new function-based business models instead of product-based business models. Performance economy can be applied by companies through dematerialization of their offers and rental of a service. In this case, companies keep ownership of materials involved in the service provision over their life cycle, which gives a strong incentive to optimize resource efficiency.

Performance economy has been experienced in different sectors (e.g. printing, transport ...) and is nowadays considered as a way to reconcile economy and sustainable development. This observation is mainly due to the fact that in a performance economy system, added value of a product or service and natural resources consumption are decoupled. In some case a reduction by 30% to 50% of raw material and energy consumption per unit of service have been observed by shifting from classic business model to performance economy business model. An explanation for this reduction is that this new business model is intrinsically opposed to planned obsolescence business model. Indeed, as the added value of a system is measured by the performance of the system, companies involved in a performance economy business model have a high interest to reduce their consumption of raw materials and energy per unit of service, driver for the product price.

Industrial storage is a sector in which performance economy has been developed for a long time. Indeed, instead of building a shed, a company which have some storage need can rent a logistic service or rent a metal-textile structure in order to insure merchandise storage. These two types of service have been developed mainly because of:

- Technical issues: Reactivity, modularity ...
- Economic issues: Risk management, financial investment ...

Nowadays companies are less and less interested by building their own warehouse. Indeed, this classic solution for industrial storage is not flexible for companies because:

- It needs a high investment and have a long return on investment
- It is not well sized for seasonal activities
- It consumes time to build
- Companies need a high visibility on their storage need and evolution
- It is considered as fixed assets

Even if performance economy of storage sector has not grown first from environmental drivers, the Serge Ferrari Company was interested to assess the environmental impact of different storage solutions. More than a classic environmental comparison, a specific analysis has been realized on the rental system of metal-textile structures to make possible interaction with environmental performance of industrial storage. Indeed, metal-textile structures show interesting properties like:

- Obsolescence risk management: unlike simple warehouse or logistic platform, there is no risk of obsolescence in the case of metal-textile structure because if a company do not need storage space anymore, metal-textile structure can be disassembled and use in another place.
- Proximity: Metal-textile structure can be assembled on-site where the need of storage is required. This specific feature permits to reduce the use of trucks to transport merchandise between storage place and need.
- Modularity: Metal-textile structure can be adapted to merchandise that have to be stored and in particular when merchandise is stored on non-standard pallets. Indeed, in classic logistic platform, when non-standard pallets are used, racks cannot be used so logisticians need to store on the floor (they cannot store in the whole space of the warehouse).

This study aims to rigorously quantify environmental impacts of the performance economy in the

case of industrial storage, by comparing the rental of metal-textile storage structures with classic storage solutions (like warehouses) on realistic storage need scenarios. To accurately take into account the management of materials and the reuse cycles (e.g. logistics, stock management), a materials and energy flow analysis (MFA) is carried out, using Umberto® tool. Based on representative demand profiles, various use scenarios are defined and analysed. A Life Cycle Assessment (LCA) is then carried out to compare this service provision with plausible alternatives.

This study has been performed using two types of data:
- Primary data : specific data collected from industrial companies
- Secondary data : generic data available in Life Cycle Inventory databases

According to its lightness and modularity, metal textile structures are foreseen to be interesting solution for industrial storage compared to classic warehouse and logistic platform. In this comparison perspective a best case/worst case approach have been used. This means that:
- Favourable hypothesis have been chosen for classic warehouse and logistic platform (Best case)
- Unfavourable hypothesis have been chosen for metal-textile structure (worst case)

This point of view allows robust conclusion if metal-textile structure presents better environmental performances than other solutions.

The different storage solutions analysed in this project are presented in Figure 1.

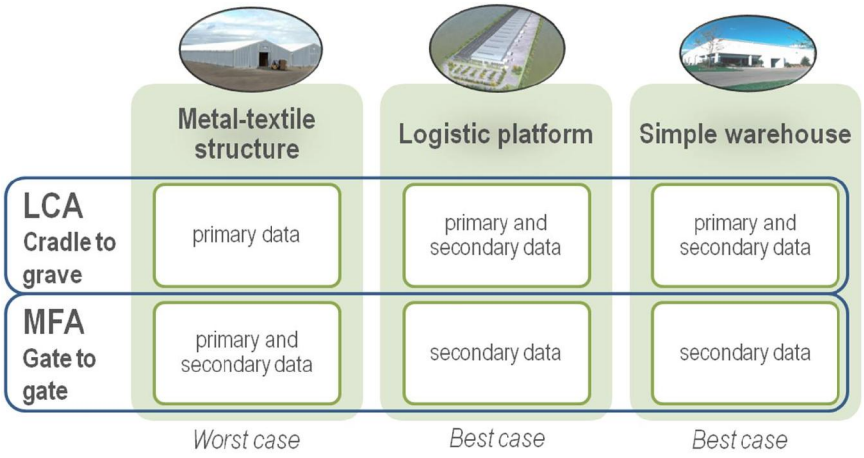


Fig.1: Storage solution analysed in the project

In order to compare these different storage solutions, 2 specific scenarios have been defined, based on case study, and are presented in figure 2.

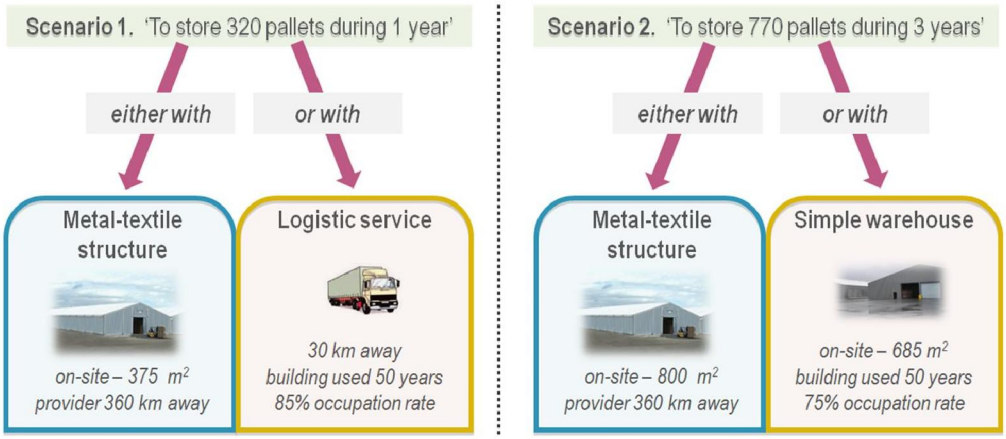


Fig.2 : Scenarios analysed for industrial storage solutions comparison

2. Methodology

The rental of metal-textile structures has some specificity compared to simple warehouse or logistic platform. Indeed, this type of system needs a material management of parts (storage, repair, reuse loops ...). According to this complexity, Material and Energy Flow Analysis has been carried out in order to evaluate “gate to gate” results of this system. Then, Life Cycle Inventories have been used in order to add upstream and downstream flow and going to a “cradle to grave” Life Cycle Assessment.

2.1 Material Flow Analysis

Material flow analysis (MFA) is a comprehensive assessment of the flows and stocks of materials within a system defined in space and time. It connects sources, pathways, as well as intermediate and final sinks of a material. Because of the law of conservation of matter, inputs and outputs have to be balanced on different levels of the system (unit process, part and whole system). MFA is mainly used as decision-support tool in resources management and wastes management and more generally in environmental management.

An MFA delivers a complete and consistent set of information about all flows and stocks of a particular material within a system. The term material stands for both substances and goods, depending on the system modelled and objectives of the MFA. Materials can be chemical elements, substances, mixtures of substances, commercial products, etc. Through balancing input and output, the flows of wastes and environmental loadings become visible, and their sources can be identified. The depletion or accumulation of material stocks is identified early enough either to take countermeasures or to promote further build up and future utilisation. Moreover, minor changes that are too small to be measured in a short time scale but that could slowly lead to long-term damage also become obvious.

In MFA, systems (defined in space and time) are modelled using 3 elements:
- Places: physical or conceptual location which is source or sink of materials
- Processes: natural or man-made phenomenon which lead to modification of material or energy. Processes are defined by the relationship between input and output.
- Flows: Material or energy transfer per unit of time from a place to a process (input flow) or from a process to a place (output flow).

MFA methodology is complementary with other tools like Input/Output analysis or Life Cycle Assessment. The objectives of MFA are:
- Delineating a system of material flows and stocks by well-defined, uniform terms
- Reducing the complexity of the system as far as possible but based on robust data and usable for decision making
- Presenting and assessing the relevant flows and stocks of a system in a reproducible, understandable and transparent way and revealing sensitivities and uncertainties
- Using the results as a basis for managing resources, the environment and wastes

MFA model for metal-textile structures rent is presented in figure 3.

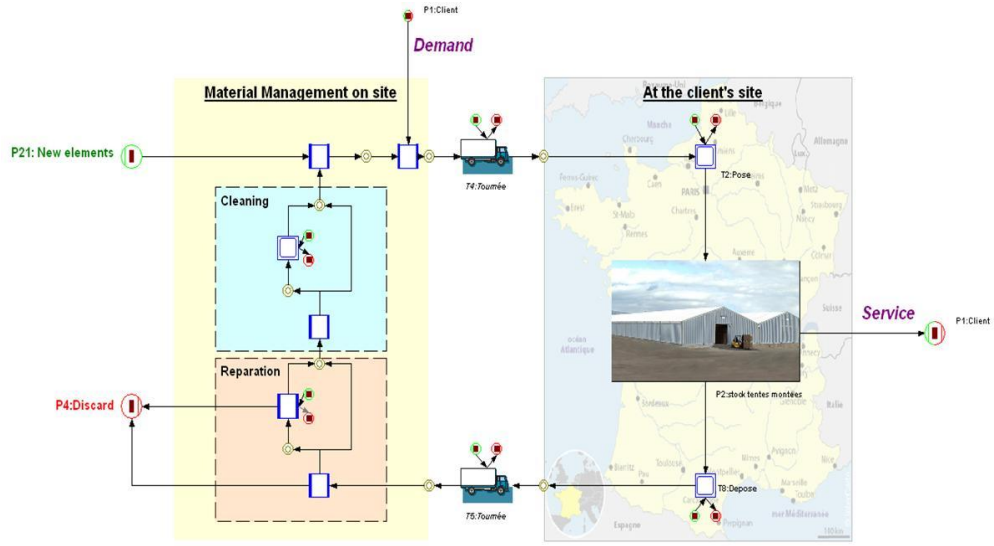


Fig. 3: MFA model of a metal-textile structure rent for industrial storage using Umberto® software

2.2 Life Cycle Assessment

According to ISO 14040, Life Cycle Assessment is a method to assess environmental aspects and potential impacts associated to a product, by:

- Compiling an inventory of relevant inputs and outputs of a product's system;
- Evaluating the potential environmental impacts associated with those inputs and outputs;
- Interpreting the results of the inventory analysis and the impact assessment in relation to goal and scope.

The goal and scope govern the way these three steps are conducted; this approach is named "goal dependent". From this initial definition, four phases are identified:

1. Goal and scope: this step defines exactly why and how the study will be performed. An important aspect is the way in which methodological choices are to be made.
Examples of such decisions include how the system's boundaries are used, allocation procedures, and the way impact assessment procedures are applied;

2. Inventory: phase where the life cycle of TFE's product is carefully modelled as a set of interrelated processes. The emissions and the use of resources for each process are compiled, and the result is a long list of emissions and consumed resources;

3. Impact assessment: the inventory result cannot be evaluated without a good understanding of environmental relevance of an emission or resource extraction. In impact assessment, inventory results are therefore grouped together or classified into a number of impact categories, such as climate change, ecotoxicity, and depletion of fossil resources. By using a set of characterization factors, an impact category indicator result can be compiled. This results in an environmental profile of usually 10 to 20 impact category indicator results. As optional procedures, these indicator results can be normalized and weighted to get a better understanding of the meaning of the impact category indicator results.

4. Interpretation: the inventory and impact assessment results are interpreted in relation to original goal and scope of the study. A number of procedures are used to check the validity of the conclusions of the study. These procedures include uncertainty analysis, sensitivity analysis, consistency checks, and issues relating to impact assessment.
LCA is an iterative methodology, that's why each phase is interrelated.

The LCA methodology is standardized at the procedural level of the ISO standards 14040 (AFNOR, 2006) and 14044 (AFNOR, 2006).

There are two essential principles in the LCA methodology:
- The multi-criterion approach (a set of environmental impact indicators is studied);
- The multi-step approach (every life cycle step is part of the study, from raw material extraction till end of life).

The multi-criterion and multi-step approach of LCA is presented in figure 4.

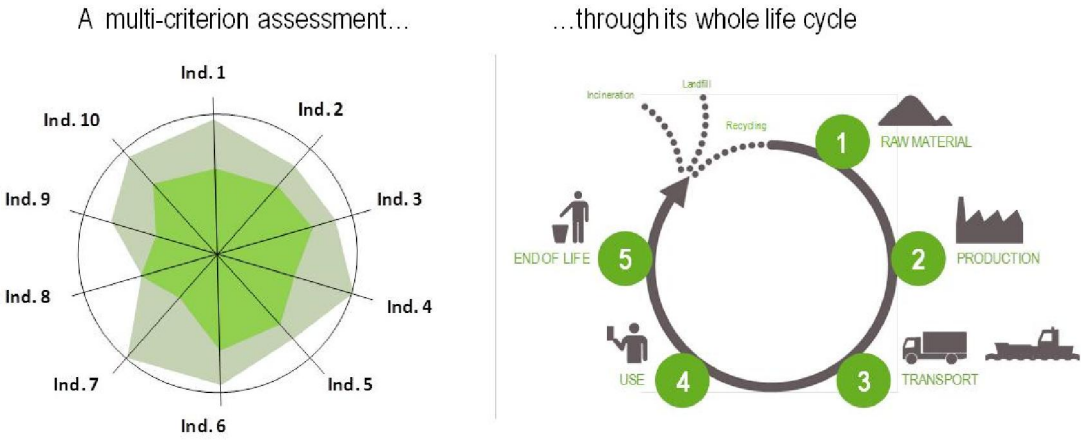


Fig. 4: Schematic representation of a life cycle assessment

3. Results

Five environmental impact indicators have been analysed:
- Total energy consumption (in MJ)
- Climate change (in kg CO_2 eq)
- Photochemical ozone formation (in kg C_2H_4 eq)
- Abiotic resource depletion (in kg Sb eq)
- Water consumption (in m^3)

Comparative results of two basic scenarios analysed are presented in figure 5.

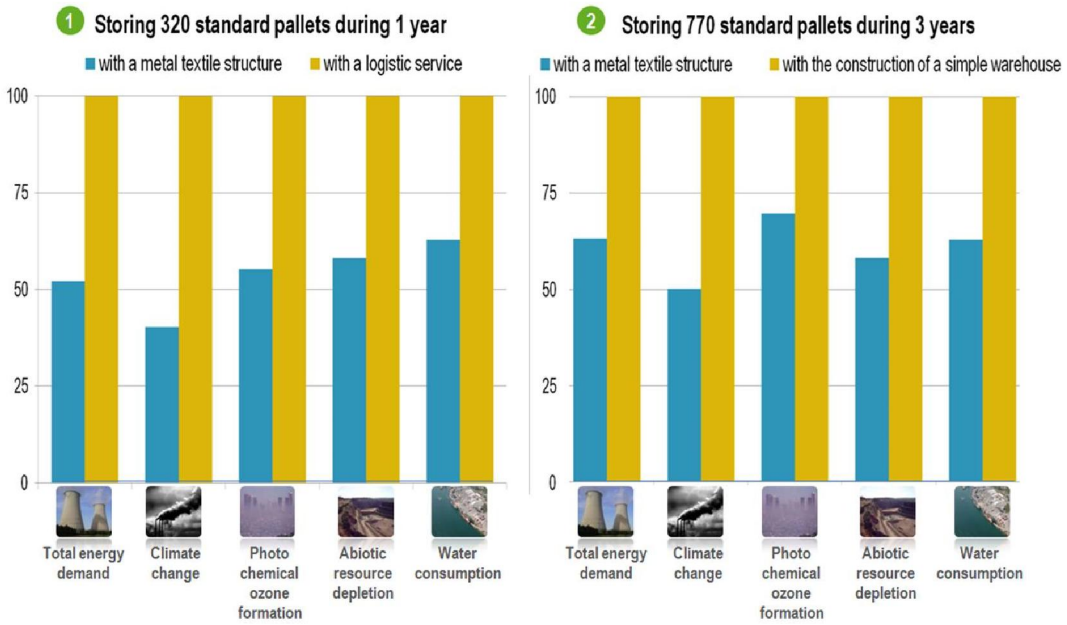


Fig. 5: Comparison of the two scenarios

Starting from these basic scenarios, a succession of sensitivity analysis has been performed with two objectives:

- Test data robustness
- Highlight some specificities of metal-textile structures (management of materials obsolescence risk, modularity ...)

Due to the risk of obsolescence, the effective lifetime of a warehouse can be only about 30 years instead of 50 years (lifetime generally used in LCA). In this case, environmental burdens per unit of service of the logistic platform increase.

Therefore, a sensitivity analysis on effective warehouse lifetime has been performed and results are presented in figure 6.

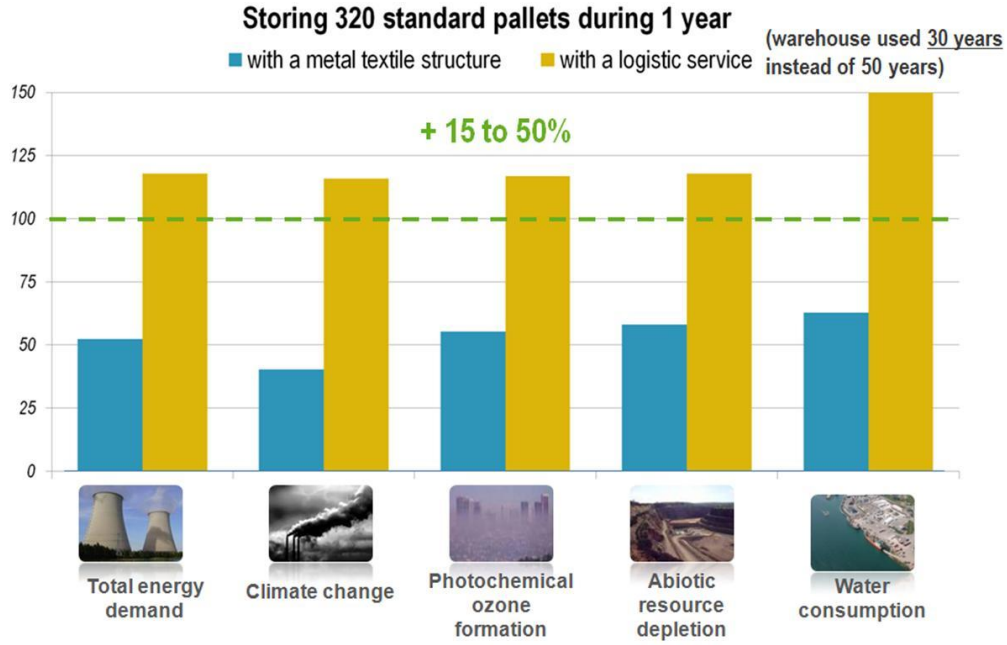


Fig. 6: Sensitivity analysis on the effective warehouse lifetime

Another specificity of metal-textile structures is that they can be adapted to specific pallets contrary to logistic platforms which generally need to store these non standard pallets on the floor (instead of using racks).

Therefore, a sensitivity analysis on the pallet type has been performed and results are presented in figure 7.

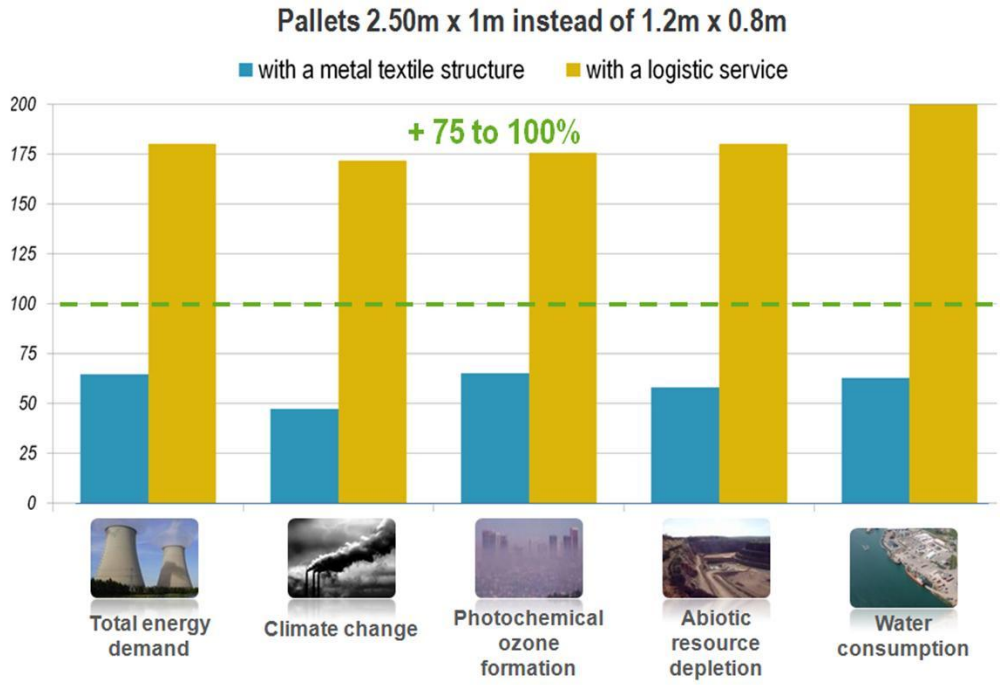


Fig. 7: Sensitivity analysis on pallet type

4. Interpretation and discussion

Comparison between different storage solutions shows that over five environmental indicators (primary energy consumption, climate change, abiotic depletion, photochemical ozone formation and water consumption), the rental of metal-textile storage structures can have a lower environmental impact than classic storage solutions (logistic platform and warehouse).

Thanks to its lightness and the reuse of materials, as well as the modularity of the design, metal-textile structures could be lower environmental impact solutions for industrial storage and could bring flexibility and reactivity compared to classic storage systems.

Environmental performances of metal-textile structures compared to other storage solutions are mainly due to:

- The lightness: reduction of material input per unit of service
- The proximity: reduction of pallet transport by truck
- The modularity: adaptation of the storage solution volume (no oversize needed)
- The efficient management of material (wastes reduction): reusing, repairing, remanufacturing and finally recycling

Moreover, this performance economy business model shows interesting properties which lead to higher benefits than the standard case. Indeed, thanks to the modularity, metal-textile structure can be adapted to non standard pallets, unlike logistic platform which are efficient for standard pallets (storage on racks) but less efficient with non standard pallets (storage on the floor). Metal-textile structure is also a solution which manages the risk of material obsolescence by reusing materials in another place where there is a storage need. Indeed, in the case of classic warehouse or logistic platform, if there is no longer storage need at proximity, the building becomes obsolete and most of materials involved in the building will not be used in another building.

However, this study shows that metal textile structures are not always better than other solutions on an environmental point of view. Indeed, when the storage need is far from the metal-textile structures supplier and when the storage time is low, environmental burdens per unit of service due to transport, assembly and disassembly of the structure is high.

Nevertheless, metal-textile structures are not destined to replace logistic platform or private warehouse which present other function that cannot be meet by metal-textile structures (thermal and phonic insulation, resistance to breaking in, etc). Moreover, environmental argument is not leading the choice of industrials for their storage solution because the decision in mainly based on technical and economic arguments.

Finally, this project shows some environmental benefits of technical textile in one specific application (metal-textile structures for industrial storage) but these types of textiles have many applications (in substitution to other materials). For example, technical textile can be used for:

- Frontage protection
- Dividing wall
- Signage
- Ceiling
- Specific architecture
- ...

Based on this project, thanks to its resistance and its lightness, technical textile may present environmental benefits compared to other materials. Technical textile presents many applications which need to be assessed on an environmental point of view.

Specific application of technical textile in events sector (e.g. Olympics Games) is presented in figure 8.



Fig. 8: Example of technical textile used in the building sector: The 2012 London Olympics Games

Identification of climate neutral buildings using LCA – Case studies from the project ÖKOPLUS-KOMPLEX



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Short Summary

The paper summarizes main findings of the Austrian research project “ÖKOPLUS-KOMPLEX”, which investigated technical, ecological and economic pre-conditions for the implementation of plus energy and climate neutral building concepts. The paper focuses on the results concerning the technologies, which can be used to produce more energy on the buildings surface than needed by its residents in the operation phase, how life cycle assessment (LCA) was used to determine climate neutrality of the building, and the impact of setting different system boundaries on the results.

Keywords: Plus energy building, climate neutral building life cycle assessment (LCA) greenhouse gas emissions

1. Introduction

The construction and operation of buildings contributes significantly to the Austrian greenhouse gas emissions (GHG-emissions) and energy consumption. In the recent years so-called “plus-energy-buildings” were developed and first demonstration buildings installed, to reduce GHG-emissions and energy consumption in the building sector. In general the term “plus-energy-buildings” is used for buildings which generate more electricity than is needed by its resident within one year. However, there is no commonly accepted definition of “plus-energy-buildings”. Therefore in the project ÖKOPLUS KOMPLEX the concept of climate neutral buildings was investigated. Climate neutral buildings are defined as buildings which reach at least zero GHG-emissions over the total life-cycle of the building (including construction, operation, and demolition), due to the compensation of GHG-emissions with surplus energy (Figure 1). If climate-neutral-buildings are possible, and which technical, environmental and economic requirements are necessary for such buildings, was investigated in this project.

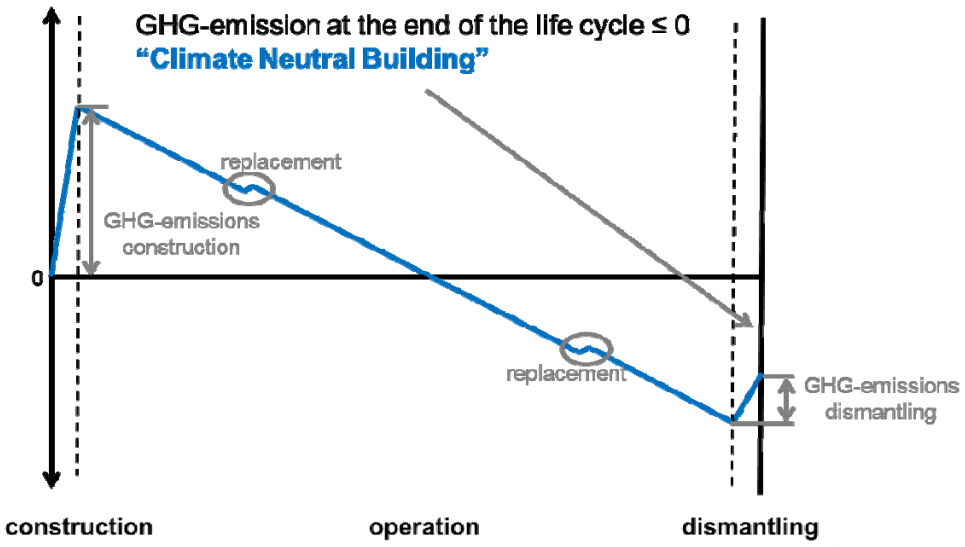


Fig. 1: Concept of a climate neutral building

2. Content of the project ÖKOPLUS KOMPLEX

Content of the project was the investigation of the possibilities to reach climate neutral buildings, with real existing buildings as starting point. In the first step GHG-emissions and non-renewable primary energy demand for construction, operation and demolition of the buildings was determined. Subsequently all relevant technologies for energy production on the building surface and within the building were identified. For the most promising technologies combinations of buildings and "technology options" were investigated. For selected combinations a technical, environmental and economic assessment was performed.

3. Results

Results are the GHG-emissions and non-renewable primary energy demand of the investigated buildings for the actual condition, identification of relevant technologies for plus-energy-buildings (technology options), an electrical energy balance for different technology options, and the environmental and economic assessment of buildings and technology options.

Starting point for the assessment was the selection of six existing buildings: three single family homes, one multi-story building, an event-building, and a housing complex.

The investigation of GHG-emissions and the non-renewable primary energy demand for the actual condition showed:

1. In the construction phase of the investigated buildings the potential to reduce GHG-emissions and non-renewable primary energy demand is rather low. Nevertheless, using insulation material with low GHG-emissions and low mass (amongst others by using "light" construction material e.g. "hollow concrete construction") GHG-emissions can be reduced.
2. The operation phase of the building has a significant influence on the GHG-emissions and the non-renewable primary energy consumption. A high energy efficiency of the building, minimizing the use of fossil energy carriers and maximizing the use of renewable energy carriers leads to a significant reduction of GHG-emissions during the operation phase.

Relevant technologies for heat and electricity production with renewable energy carriers in plus-energy-buildings are:

- photovoltaic (PV)
- small wind turbines
- small hydro power plants
- heat generation and combined heat and power generation with biomass

- solar thermal heat plants
- heat pumps

All these technologies, with the exception of small hydro power plants (due to the site specific and limited usage options), were examined more closely.

For the combinations of technology options and buildings, which resulted in a “plus-energy-production”, an environmental assessment was performed. The development of GHG-emissions and non-renewable primary energy demand for the total building life-cycle (construction, operation, demolition) was estimated. The economic assessment was performed for two buildings in combinations with technology options, which lead to climate neutrality. Economic aspects of electricity and heat production were investigated and the additional investment costs for plus-energy-buildings estimated.

Based on the results of the technical, environmental and economic evaluation, the following conclusions are drawn:

- Electric “plus-energy-production” is for all investigated buildings possible. In the planning phase, however, optimizing the system design and minimizing the energy demand is important.
- Suitable technologies for electric energy generation are photovoltaic and small wind turbines. Photovoltaic plants have a high building surface area demand, which is a disadvantage for multi-story buildings. The energy output of small wind turbines is strongly site specific. A detailed technical and economic planning based on the geographic and legal framework is necessary.
- Suitable technologies for thermal electricity generation are heat pumps, pellet boiler and solar thermal plants. Pellet boilers show an advantage for electric “plus-energy-production” due to the significant lower electricity consumption compared to the heat pump. Solar thermal plants are in competition for buildings surface space with photovoltaic plants.
- The environmental assessment showed that climate-neutral-buildings are possible. The investigated technology options are environmental optimized alternatives, which demonstrated the maximum GHG-reduction potential.
- The results of the environmental assessment are strongly influenced by assumptions, which are basic for the assessment (e.g. are GHG-emissions investigated or the primary energy demand, which energy carrier is substituted by the surplus electricity of the buildings).
- The building site is crucial for the mobility behavior of the residents. If the GHG-emissions for transport are included in the assessment, none of the investigated buildings reaches the status of a “climate-neutral-building”.

4. Acknowledgement

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Sustainability issues in the valuation process of project developments



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Short Summary

This paper presents a system to incorporate the economic benefits of sustainability into the valuation of real estate project developments. The impact is provided through the consideration of quantified sustainable qualities of buildings in the determination of the interest rate in the valuation process. Furthermore, it highlights the added value that sustainable features and the relevant certification systems bring to a project development. Using a catalogue of parameters, key parameters are identified for the specific project development to be valuated. These parameters are then quantified by means of distribution functions and checked for interdependencies. This analysis, and with it the results of a sustainability valuation, are incorporated into the calculation of the market value and the Internal Rate of Return. Results are communicated according to the input data through distribution functions. The valuation system makes investment decisions easier to understand and emphasises the positive impact that sustainable features can have on the economic success of real estate projects.

Keywords: project development, sustainability, valuation, real estate industry, certification systems, profitability, integral

1. Introduction

The prolific use of the term “sustainability” by the media and even more so by the advertising industry has turned it into a word which for many people has become no more than a marketing tool or a catchphrase. Yet the basic values that stakeholders, especially in the building industry, ascribe to the term are vital to the continued existence of our society: sustainability describes actions that do not compromise the ability of future generations to meet their own needs. The real estate industry has recognised this fact and has developed a number of certificates designed to help measure and implement sustainability. Nevertheless, the economic success of a property will always come first for investors.
The foundations for this success are laid at the start of a project, in the project development phase. Decisions taken at this stage are often not based on actual data, but on the experience and the intuition of the project developer. This makes it hard later for the stakeholders to understand the reasons behind those decisions; the process appears opaque. It is important, therefore, to find a way to include the sustainable features of real estate in the early stages of project planning and at the same time to achieve a balance between the sustainability and the economic success of a project. Other aspects that are often neglected in favour of investment costs are the follow-up costs and the life-cycle costs. When evaluating the estimated costs of a project in the early stages of

planning, each cost assessment relies on forecasts. However, people often forget that forecasts are not always accurate; instead, they tend to treat those numbers as deterministic values.
This paper aims to propose a model for the valuation of project developments under consideration of sustainability issues that provides the basis for informed decisions. The result is a systematised and transparent valuation model for project developments which will help to provide a sound and comprehensible basis for investment decisions and optimizations in the planning process. As a basis for the valuation model, a sustainability evaluation created for the project in addition to the data relevant for the project development is used. All project-relevant parameters from the sustainability certificate are contained in the valuation – including “soft”, not directly measurable factors. Another intention of this paper is to show that sustainability adds value for all stakeholders. A positive correlation between the economic success of a single project as part of the real estate industry and the fulfilment of sustainability criteria will be illustrated, which constitutes a win-win situation for all stakeholders.

2. Sustainability in project development

Sustainability and sustainable development are today firmly anchored in politics, society and in the minds of the people. Efforts are being undertaken in many areas to implement the idea of sustainability. This is also true for the construction and real estate industry, which is at the forefront when it comes to topics such as the responsible use of resources, waste management and other issues relevant to sustainability. The following quote clearly illustrates the importance of sustainable building:

Sustainable building means ... constructing and preserving buildings which, instead of being an inherited liability, will prove to be an asset for generations to come. [1, p. 221]

As the real estate industry produces objects that will be in use for at least decades, if not centuries, it must carefully assess the whole life cycle or usage period of any building being constructed [2, p. 48 ff]. Building sustainably, in a way that makes a building fit for the future, means fulfilling all ecological, economic, sociocultural, functional and technical requirements now and in the near future, cf. [3, p.8].

2.1 The significance of sustainability in the real estate industry

Over the past years, sustainability has become an integral part of the real estate industry. However, the added value of sustainability is different for each of the stakeholders. From an economic point of view it is important to ensure low operating costs and good value retention, while a positive ecological performance is seen as an intangible additional asset. Others, especially international investors, increasingly view property certificates as a good way to assess the quality of the object. Marketing provides another incentive for building sustainably. Recent studies have shown that sustainable properties have a higher sales potential than other buildings. In February 2012, the German bank “Deutsche Hypothekenbank” published a paper entitled “Sustainability in the real-estate industry”, which discussed the significance, the goals and the implementation of sustainability. The paper calls sustainability a social “megatrend” which influences people’s living conditions and behaviour. It cites mass production, electrification and globalisation as megatrends of the past. Sustainability has developed into a competitive factor due to its positive economic impact, its efficient use of resources and the eco-friendliness of sustainable buildings. This constitutes an advantage for investors, owners and users at the same time. All the above-mentioned factors have led to the establishment and growing recognition of sustainability certificates in the recent past, cf. [4, p. 5 ff].

2.2 Sustainability certificates

2.2.1 Objectives of sustainability certificates

The aim of sustainability certificates is to transparently and publicly detail the sustainable features of a building as well as to create economic advantages for property developers and investors. When it comes to direct competition and to decision making in the course of a project, it is important to be able to measure individual sustainability aspects [5, p. 6]. As well as serving as indicators for sustainability, certificates also act as important planning and optimisation tools.

2.2.2 The ÖGNI/DGNB system as a valuation basis for project developments

Valuation systems and their certification labels are now used on an international level, with some of them also catering to differing national standards. The most widely known of those systems are the British BREEAM system and the American LEED system. In German-speaking countries, the most popular system is ÖGNI/DGNB. It is also referred to as a "second generation system" because of its holistic approach to both time and topics. Most certificates divide the valuation areas into three main groups: ecology, economy and social issues. With three additional groups – technical quality, process quality and quality of the location – the ÖGNI/DGNB system provides a comprehensive set of data for valuation, which for example already includes life-cycle costs.
By looking at individual criteria, it becomes clear that there is a lot of common ground with the goals of project development, mainly when it comes to the economic criteria of life-cycle costs and value retention. But also other criteria linked to the topic of functionality play an important role, such as space efficiency and conversion capability. At the same time, the valuation system enables us to rate so-called "soft factors", for example the flexibility of use, using checklist points.

2.3 Implementing sustainability aspects in the course of the project development

New concepts and measures will be necessary in the future in order to implement sustainability effectively in project developments. Some of these are integral approaches which are already being used for the development and planning of projects. Integral planning means a simultaneous development of concepts in the different design disciplines [6, p. 42 ff] as opposed to the usual way of consecutively working on one project after the other.
The authors believe that for an effective implementation and coordination of the concept of integrated planning, we need an additional concept, namely the concept of *integral project management* or *integral project controlling*.

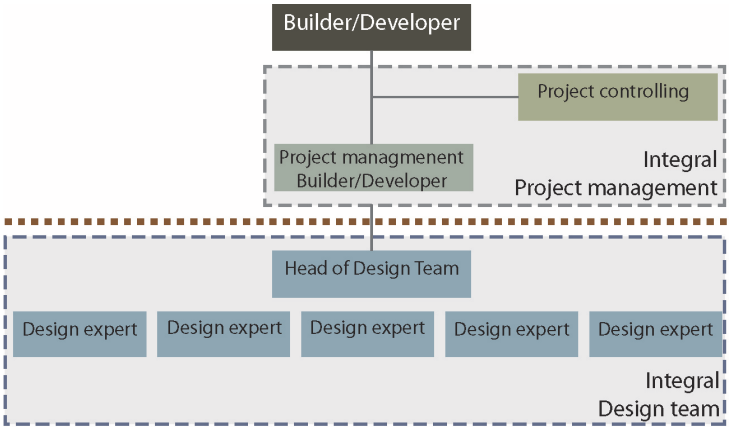


Fig. 2: Organisational structure for integral processing. [7, p. 87]

Integral project management thus meets a need arising from integral planning, namely to coordinate all stakeholders in the project as well as the design team in a holistic way. Integral project management differs from traditional project management in its focus, which lies on finding holistic and life-cycle oriented solutions and in implementing sustainability. The valuation model can be used in integral project management as a tool for improving planning and developing processes.

3. Valuation methods for project developments

The valuation of real estate, unlike the valuation of project developments, can draw on numerous standardised procedures. This kind of valuation serves various purposes and is carried out for many different reasons, but it is always a way of quantifying the economic benefit of an object without taking into account the subjective value for the stakeholders [8, p. 43].

3.1 The valuation method: basic requirements

In order to be able to choose or to draw up a valuation model for project developments, at first there has to be taken a look at how this kind of valuation differs from the valuation of real estate. Other than the pre-investment analysis, which would be useful for the valuation of project developments, traditional valuations are carried out on existing objects already in use. The valuation of preliminary designs happens much earlier, on the basis of much less information.

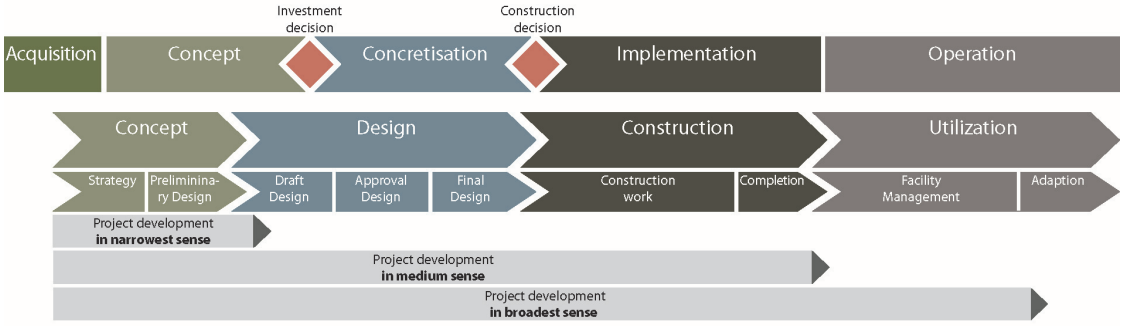


Fig. 3: Phases of project development. [7, p. 25]

The input parameters needed for the analysis, especially cost and benefit, are only available as forecasts. The range of fluctuation for those forecasts is still very wide, because many factors involved, such as dimensions and quality, cannot yet be determined [7, p. 24 ff].
Moreover, the valuation model has to be able to include the sustainable properties of the object into its market value. This can happen [3, p. 12] either by adding to or subtracting from the final market value or through an integrated approach, which directly influences the market value. In the valuation method the second option was chosen, because an integrated approach promises a more exact forecast through its direct effect on the value.

3.2 Creating a valuation model for project developments

The requirements specified above can only be fulfilled by the dynamic methods [9, p. 642] of a pre-investment analysis. From this group, the method most suitable for the valuation of project developments is DCF analysis. This allows for the inclusion of the life cycle, is very customisable when it comes to the periodicity of payments, and offers a high degree of transparency. In order to include the monetary impact of sustainable properties in the valuation of an object, it is indispensable to include the life cycle or the respective usage phase.

4. Valuation model

Using the aspects and requirements outlined in chapters 2 and 3, a valuation model was developed based on the DCF method, and the analytical interdependencies of the main project-specific parameters from the sustainability certificates and the project development were implemented. The valuation method comprises two sub-processes:

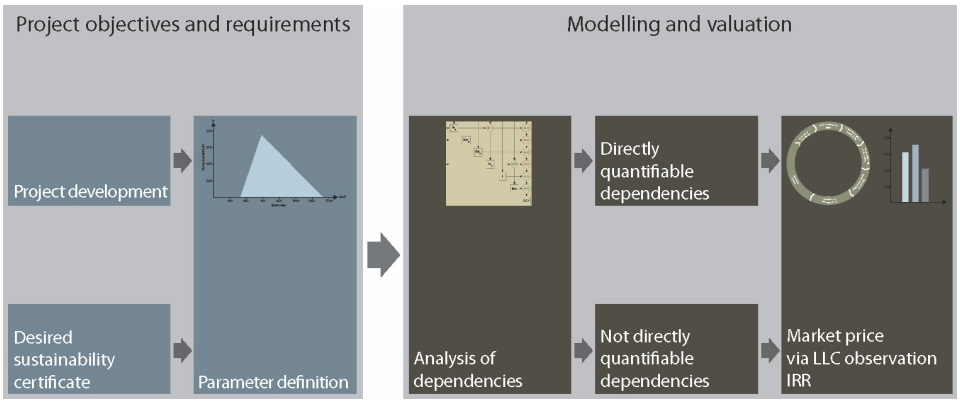


Fig. 4: Valuation process under consideration of sustainability issues

4.1 Input parameters and their quantification

The valuation model based on the DCF method requires a certain number of input parameters, mostly comprising revenue, expenses and general data. The input parameters are themselves influenced by input variables and preconditions, which were summarised in a parameter catalogue specific to the project development, cf. [7, p. 121 ff]
For example, rent prices not only depend on the features of the property but are also influenced by other variables. Within the valuation system these variables are referred to as project development parameters, and they also reflect the objectives established for each project. Occasionally these parameters can also be found in the sustainability certificates, for example when it comes to user satisfaction. In order to rationalise the evaluation process, the parameter catalogue is built up based on the individual project development [7, p. 122], with the relevant parameters being specially selected for each project.
Since it is not always possible to directly quantify the “soft factors”, parameters are divided into those that are directly quantifiable and those that are non-directly quantifiable. Directly quantifiable parameters can be incorporated via specific mathematical interdependencies, meaning their value can be clearly described. On the other hand, non-directly quantifiable parameters do not have a clearly identifiable impact on the result of the evaluation and define themselves via an indirect benefit – it is, therefore, not possible to establish a clear value. However, by using the ÖGNI/DGNB criteria it is possible to award so-called “checklist points” if certain criteria are fulfilled or if a building has certain features. Depending on their weighting, these points are then integrated into the sustainability evaluation. This option of using a catalogue of questions makes it possible to put into numbers parameters that are in themselves not quantifiable.
The actual quantification of the input parameters is carried out via distribution functions, since using probabilistic methods increases the general objectivity of the result. Indicating deterministic values creates the impression of a certain level of certainty, although in reality there is a margin of fluctuation. However, by processing the margins of fluctuation as distribution functions it is possible to predict the probability of a certain value actually being achieved. The investor can then use this information to take decisions on investments or construction projects and to determine budgets, thereby actively shaping his risk policy, cf. [10, p. 372].

4.2 Valuation process

The first sub-process shown in Fig. 4 describes the project objectives and requirements, which form the basis for identifying and quantifying the main project-specific parameters. The second sub-process is where the actual valuation takes place within the framework of the valuation model. Through this valuation the dependencies of the parameters are analysed and divided into directly quantifiable and non-directly quantifiable parameters. Finally, the distribution functions of the input parameters are aggregated using a Monte Carlo simulation.

4.2.1 Analysis of dependencies

The valuation model is primarily based on the DCF method. While the dependencies and mathematical connections of the input data within the DCF method are sufficiently defined, the way in which the input data for the DCF method is provided is not determined. In chapter 4.1 it was pointed out that the project-specific parameters influence this input data. These two areas (the DCF method and the provision of input data) are combined to form one single system, resulting in an overall system with inherent feedback effects and multiple interdependencies from single parameters.
The *N² chart* [11] method was chosen for quantitative analysis of the connections between the individual parameters. As well as information about how the parameters are linked, this method also provides data on changes in the value of the components that are influenced and on the relativity of the interaction. This analysis is carried out separately for each specific project in order to identify the respective interdependencies.

4.2.2 Quantification of dependencies

In order to incorporate the previously analysed dependencies into the evaluation model, it is first necessary to determine the quantification process. Directly quantifiable interdependencies are characterised by the fact that one value in the valuation system exercises a clear mathematical influence on another. Therefore, changing the value of the respective parameter has a direct influence on the resulting value.
For those correlations that are not directly quantifiable, the question is how to integrate the abstract checklist points from the sustainability certificate into the resulting value. In this paper, non-directly quantifiable correlations are understood to be a *mathematically non-obvious influencing of the independent parameters*.
For the purposes of the evaluation process it was decided to incorporate sustainable features, which are not directly quantifiable parameters, through the DCF method's interest rate and also in the risk situation. This interest rate shows not only the possible interest generated by an alternative investment but also the project-specific risk, cf. [12, p. 84 ff]. Therefore, the interest rate is formed using a base interest rate and a risk premium linked to the property. One of the hypotheses of this paper is to illustrate how checklist points can be used to include sustainability evaluations in the risk premium of the interest rate. Generally, a low interest rate means a low project-specific investment risk compared with a riskier project. Assuming that sustainable real estate can achieve a higher yield [3, p. 28 ff], a large number of checklist points improves the project's economic situation and reduces the investment risk [13, p. 14].
The WACC method [14, p. 85] was selected to determine the interest rate in the DCF process, since it provides the most practice-oriented approach. This method uses the interest rate as a weighted rate comprising interest from equity capital and debt capital. This approach can be used in all projects and is based on real interest rates that are easy to calculate.

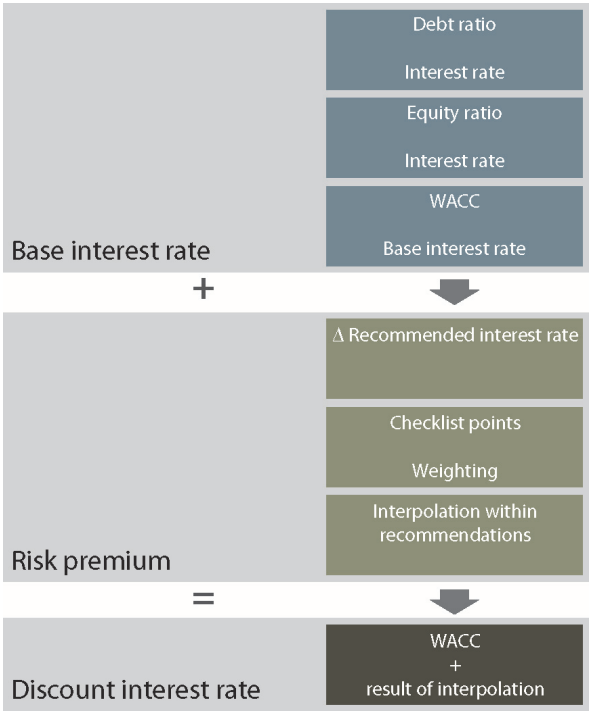


Fig. 5: Method for calculating discount interest rate

Since it is very difficult to determine the effect of non-directly quantifiable correlations, in practice it helps to calculate the risk premium using empirical data. At the time of writing this paper such research data were not available. Therefore, information from the *Austrian Association of Sworn and Certified Court Experts* was used. Included in this information are recommended interest rates divided into bands according to use and location [15, p. 97]. These interest-rate bands are set out by the Association's committee, meaning that they document the empirically calculated bandwidths found in real estate valuations. After limiting the bandwidth for the risk approach, the next task is to judge the situation within the bandwidth. This is carried out using checklist points from the selected

parameters based on the sustainability criteria. Using half the value of the bandwidth, the weighted average in applied in such a way that 0 checklist points result in an increased risk and, as such, form the upper value of that half of the bandwidth; vice-versa, 10 checklist points result in a low risk and form the lower value of that half of the bandwidth. The idea behind using only half of the value of the bandwidth is that sustainably valued real estate, as is the case with every new building project, conforms to the legal requirements and the state of the art. Assuming that the bandwidth covers the interest rate from good to bad real estate, and that the real estate to be valuated is no worse than average, only half of the bandwidth in the risk premium of the interest rate can be considered. The reasoning behind this is that it improves marketing possibilities of sustainable real estate and, as a result, improves the risk situation.
The following example is designed to illustrate and clarify the process. The WACC base interest rate was set at 4.9%. According to the recommendations, the total margin of fluctuation is 2.5%. This results in a bandwidth of +/- 1.25% and, therefore, a possible improvement of 1.25%. In this example the weighted average of checklist points gives a value of 6.4. For the interest rate this means a reduction of 0.8% from the basic interest rate, resulting in an interest rate of 4.1%.

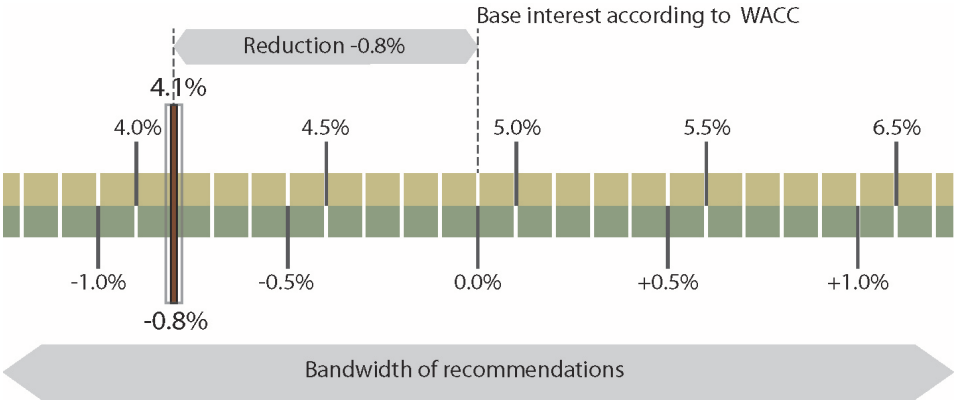


Fig. 5: Fluctuation range of discount interest rate
To provide a better correlation between sustainable features and the discount interest rate in the DCF-valuation method greater empirical research throughout the years has to be done. Results from this research would improve the quality of the outcome of the developed valuation system. Although for the demonstration of the functionality of the system the present available database is sufficient.

4.2.3 Discussion and evaluation of the results

Two different sources of data are available: the specifications / real estate data resulting from the project development; and the data from the sustainability evaluation (pre)certificate according to the ÖGNI / DGNB criteria.

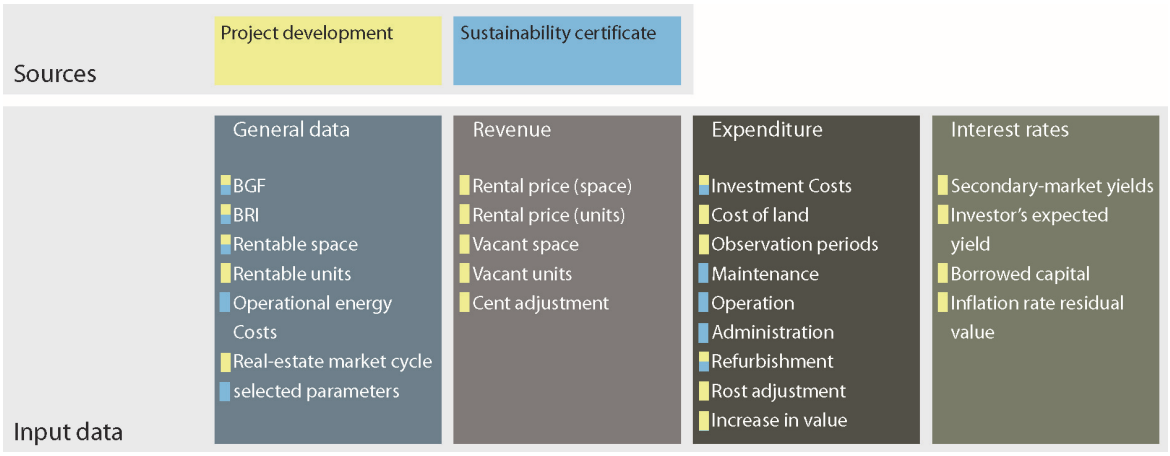


Fig. 6: Input data for valuation (including source)

Whenever the assessor believes it is necessary, input data are entered using triangular distribution. This will especially be the case in situations where future developments are subject to an understandably quantifiable margin of fluctuation.
The next step is to implement the interdependencies that have been assessed. Directly quantifiable correlations are entered into the valuation system as conventional calculations via a table calculation programme. Non-directly quantifiable correlations whose values have been calculated using checklist points are incorporated into the discount interest rate using the method described.
The necessary calculation steps are carried out using the table calculation programme Microsoft Excel. The triangular distributions entered are processed via the application @risk and aggregated using the Monte Carlo simulation method integrated into the programme [7, p. 145 ff]. The terminal value is also calculated by extending the DCF method through to the end of the expected end of life. However, in this case the increased forecasting uncertainty means that a different discount interest rate is calculated for the residual value using the method described in 4.2.2.
The valuation leads to a distribution function of the market value calculated on the basis of market rental prices. Absolute profitability [16, p. 630] of the investment is given as soon as the DCF-based value exceeds the value of the investment costs. This method can, for example, also be used to calculate minimum rent prices with a predetermined interest rate or to calculate discount interest rates with predetermined investment costs.
In general, yield figures are generated in order to determine the profitability of developing a project. Parallel to the holistic approach represented by the sustainability evaluation, the Internal Rate of Return (IRR) is calculated as a property-specific dynamic yield. The IRR shows the average interest return during the periods observed and can be compared in its interpretation with the initial yield [17, p. 293].

5. Evaluation

For validation purposes a sample project was selected from the author's work as an auditor at the ÖGNI / DGNB. The project in question has already been put into operation. Indeed, this was one of the reasons why it was selected, as valuing a real-life building offers interesting comparisons with model-based valuations.

5.1.1 Sample project

The sample project is an office complex in Austria with a gross volume of around 52,000m³ and around 10,300m² of rentable space. During the design process one of the main focuses was to make the complex as multifunctional as possible while also taking into consideration the concept and atmosphere of modern offices. The building comprises five floors made up of office space and, to a lesser extent, business premises. It is accessed via a central atrium that can be used for a range of purposes.

5.1.2 Input data

The input data were taken from the sustainability evaluation and are complemented by information provided by the operator / developer according to the method described in chapter 4.2.3. For the discount interest rate a value of 5.4% has been determined. The bandwidth is 2.0% and was taken from the recommended interest rate of the Austrian Association of Sworn and Certified Court Experts. The relevant and identified checklist points of the sustainability assessment for the sample project are indicated at 7.6 CHP. By performing the interpolation in the indicated bandwidth, a deduction of 0.76% from the base interest rate results. This implies a discount rate of 4.64% for the DCF valuation.
This practical valuation experiment confirmed the added value for the project development and the potential alternative use of data from the sustainability certificate.

5.1.3 Valuation and results

After gathering the input data in a careful and comprehensible way, the valuation itself was carried out using the method described in chapter 4.2.3. The results are shown as distribution functions in

Fig. 6 and are interpreted in the following way.
There is a 95% probability that the market value will not fall below €19,963,170. The most likely market value is €21,486,036 (the modal value). There is a probability of just 5% that a market value of over €23,956,129 can be achieved. A deterministic valuation carried out at the same time produced just one single value of €21,435,779. While this figure is roughly the same as the modal and median value, the probability of it actually being achieved is only around 50%. An independent valuation commissioned by the developer gave the property a value of €23,000,000, though this is optimistic.
There was also a good level of correlation regarding the Internal Rate of Return. The calculations indicated that there was a 95% probability that the IRR would not fall below 4.72% and not exceed 5.70% – very similar to the value of 5% given by the developer based on building operations.

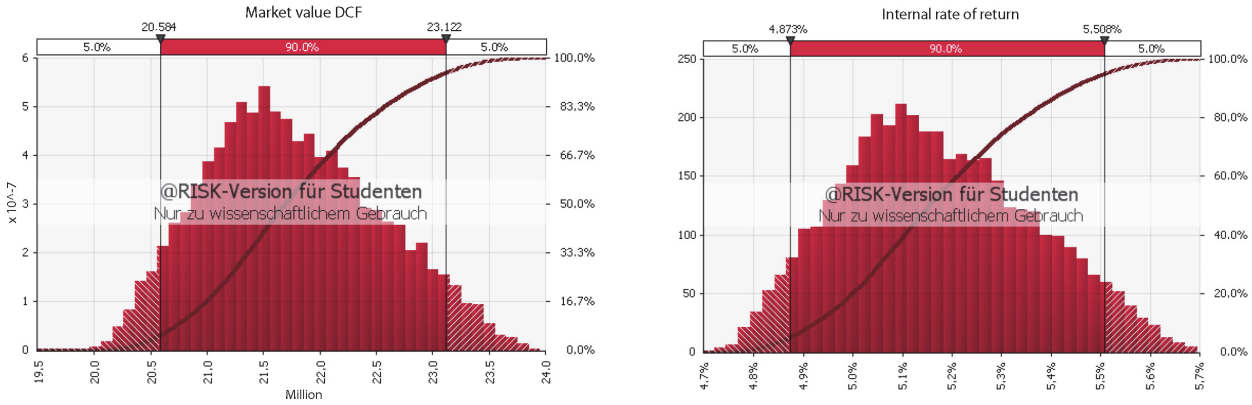


Fig. 6: Results of sample project valuation

6. Limitations of the valuation

This valuation method provides systematic and sound access to the real-estate project development process. At the same time, it does not claim to treat the topic exhaustively or to take into consideration all aspects and interdependencies. Successful project development cannot be planned down the very last detail and cannot be calculated using digital building models. So what are the limitations of this valuation method?
As the project development valuations are forecasts, it cannot be assumed that the forecasted values will actually be achieved. In particular it is important to remember that *each forecast is only as good as its input data*, cf. [18, p. 764]. That makes it clear which area we must focus on for the valuation. There is a vanishingly small probability that the forecasted value will be 100% identical to the actual value. As a result, valuations only make sense if they are used to compare different planning variants and/or to judge potential improvements. In such cases the absolute, forecasted values are of secondary importance – instead, it is the differences between the valuations of the variants that are of greatest interest. Provided these requirements are adhered to, it can be assumed that the best possible decision was taken using the information available at the time of the valuation. Processing the input parameters via distribution functions also contributes to making the result as objective as possible.
All valuation methods show their limitations when it comes to creative and aesthetic aspects. However, there is no doubt that excellent architecture makes buildings more attractive and, ultimately, increases their value on the market. One appropriate and recognised way of ensuring such excellence is by launching an architectural design competition. In doing so it can be assumed that, at least concerning the design, the best possible result will be achieved. However, it is more than questionable whether this assumption holds true in all cases. The same goes for valuations of functional aspects, though in this case compiling operational processes or spatial and functional programmes make it easier to produce an accurate valuation.
It is also very difficult to calculate how the synergy effects of a project development will influence nearby properties, the surrounding area or even the wider region. A good example of this is the attempt to make an area more attractive by developing individual properties like urban entertainment centers. The actual effect of these properties is difficult to predict, since it depends

on a large number of boundary conditions that cannot be controlled. In practice we also commonly see the opposite effect – making one area of a city more attractive drives down property prices in neighbouring areas. All of these processes have an impact on the social fabric and, consequentially, the purchasing power of the population. A drop in purchasing power makes an area less attractive and leads to falling prices. The result is an increase in the number of vacant properties, which again leads to a further drop in property prices. Developments such as these cannot be predicted and, as such, cannot be taken into consideration when carrying out a valuation.

7. Conclusion

This paper describes a system for valuing property developments that gives sustainable features the recognition they deserve, through consideration in the discount interest rate. The valuation system itself is divided into two processes. In the first process the main project-specific parameters are identified and quantified using division functions. In the second process the parameters are analysed for dependencies (divided into directly quantifiable and non-directly quantifiable dependencies), which then are incorporated into the valuation as risk-minimising influencing factors. The incorporation is carried out through a reduction of the discount interest rate. The extent of this reduction is determined by an empirical bandwidth of the interest rate and the amount of check list points resulting from the sustainability assessment. The final step is to calculate the market price and the Internal Rate of Return as distribution functions using an adapted DCF method via a Monte Carlo simulation. The system was validated using a practical example. The results of this validation were very similar to those achieved using alternative valuation methods used in the real estate industry.
The method developed in this paper represents a practical valuation tool that can be used in all phases of real estate project development, right through to the final design phase. For decision makers this tool significantly improves the process of investment decision making through easier comprehensibility and, as a result, the optimisation process. This is because the results achieved are based on actual data and, at the same time, incorporate both sustainability and profitability requirements. Compared with deterministic methods, this valuation system paints a more realistic picture and provides superior levels of information by carrying out quantification using probabilistic methods and thanks to the probabilities integrated into the division functions. One key advantage of the tool in practical situations is that it creates a highly transparent system that is easy to understand, especially for investors and financing institutions. Through the paper it was also possible to highlight how fulfilling sustainability criteria adds value to a project development. All in all, this valuation system can make a significant contribution to risk management in project developments.
One possible way of further developing the valuation system would be to transform it into an independent IT tool that would standardise the input parameters as far as possible. Greater empirical research is still needed into the correlation between the sustainable features of a building and the discount interest rate in the DCF process. Further work is also needed on integral approaches in both project management and project development, especially concerning operational processes.
By developing this valuation method it has been possible to illustrate a positive correlation between the economic success of a project and the fulfilment of sustainability criteria. This constitutes a win-win situation for all stakeholders.

8. References

[1] WALLBAUM H. *"Forschung und Praxis im nachhaltigen Bauen - Herausforderungen, Trends und Hindernisse in Zukunftspotential Bauwirtschaft "*, Eigenverlag, Dresden, 2011
[2] WALLBAUM H, KYTZIA S, KELLENBERGER S. *"Nachhaltig Bauen"*. vdf Hochschulverlag AG, Zürich, 2011
[3] MEINS E, ET AL. „Nachhaltigkeit und Wertermittlung von Immobilien“, Eigenverlag CCRS, Zürich, 2011
[4] DEUTSCHE HYPO. *"Nachhaltigkeit in der Immobilienwirtschaft "*, Eigenverlag, Hannover, 2012
[5] EBERT T, ESSIG N, HAUSER G. *"Zertifizierungssysteme für Gebäude "*, DETAIL, München,

2010
[6] ACHAMMER C. "*Sustainable Shopping Centers“*. German Council Magazin 4/10, Eigenverlag, Ludwigsburg, 2010
[7] FRÖCH G. *„Probabilistische Bewertung und systematische Optimierung von Projektentwicklungen unter Berücksichtigung von Nachhaltigkeitskriterien“,* Dissertation im Eigenverlag, Innsbruck, 2012
[8] PFNÜR A. *"Modernes Immobilienmanagement* ", Springer-Verlag, Berlin Heidelberg, 2011
[9] BONE-WINKL S, SCHULTE K, SOTELO R, ALLENDORF G, ROPETER-AHLERS S. *"Immobilieninvestition“* in Immobilienökonomie, Oldenbourg, München, 2008
[10] FRÖCH G, SANDER P. *"Projektkosten- und Risikoanalyse mittels probabilistischer Methoden“*, Tagungsband des 1. agenda4 Forschungssymposium ", Eigenverlag agenda4, München, 2009
[11] NASA. *"Systems Engineering Handbook SP-610S "*, National Aeronautics and Space Administration, Washington, 1995
[12] BIENERT S, FUNK M. *"Immobilienbewertung Österreich"*, Edition ÖVI Immobilienakademie, Wien, 2007
[13] ZIMMERMANN J, SCHAULE M. *"Untersuchung des Einflusses von Merkmalen der Nachhaltigkeit auf den Verkehrswert von Immobilien "*, Eigenverlag des LBI, München, 2011
[14] GONDRING H. *"Risiko Immobilie "*, Oldenbourg, München, 2007
[15] KRANEWITTER H. *"Liegenschaftsbewertung "*, Manz, Wien, 2010
[16] SCHULTE K, ALLENDORF G, ROPETER-AHLERS S. *"Immobilieninvestition“* in Immobilienökonomie , Oldenbourg, München, 2008
[17] ROTTKE N, WERNECKE M. *"Lebenszyklus von Immobilien*“ in Immobilienökonomie, Oldenbourg, München, 2008
[18] TAUTSCHNIG, ARNOLD; FRÖCH, GEORG: *"Praktische Umsetzung von probabilistischen Kostenermittlungen im Hochbau“* in Die wirtschaftliche Seite des Bauens, Institut für Bauwirtschaft und Baubetrieb, Eigenverlag TU Braunschweig, Braunschweig, 2010

Non-state market driven governance in the Green Building sector

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Short Summary

This study addresses the role of ÖGNI in the Vienna real-estate market and puts a more detailed focus on members and auditors as part of the stakeholders to identify innovative impulses in the Vienna real-estate market to analyse the linkages between economy, politics, and society.
The real estate sector is one of the most dynamic economic sectors which contributes negatively to the environment and society in many ways (e.g. inefficient use of materials, water, land, etc.) and can therefore be seen as one of the major threats to sustainability in the future. This contribution investigates the dynamic development in the green building market in Austria and specifically in Vienna and focuses on the non-state market driven environmental governance processes led by the green building councils. The role of these non-profit oriented councils within the internationally powerful real estate and construction market appears to be a quite specific one. There are a lot of critical voices among scholars which alert us that such industry dominated environments are mainly serving the market while neglecting public interests. But we can also think of arguments, however, why it is extremely important to create networks being managed by non-governmental organizations (NGOs) in order to fill the gap between public and private interests. Therefore the role of different kinds of organizations in fostering sustainable development has become a broad field in governance related research [1]. Within this research the role of NGOs as governance actors for sustainable development is becoming increasingly relevant. Since NGOs are involved in processes aimed at raising quality standards in different areas, e.g., forestry management, marine protection, the scientific community can build upon a growing empirical basis.

Keywords: Governance, Green Buildings, NGO, networks, ÖGNI, third-party certification

1 Introduction

The goal of this paper is to identify innovative trends in the Vienna real estate market which have been activated by the Austrian Green Building Council (ÖGNI). Furthermore the analysis of the council and its third-party role has provided insights into its ability to act as a bridging institution between the state, the market, and the public. The analysis focuses on the council's network and its activities. This contribution is following a case study approach in order to analyse the ÖGNI and its effects on the real estate market in more detail. For this purpose we conducted an online survey and interviews both addressed to ÖGNI and its network members. The first preliminary results have already shown that the real estate environment in Vienna has shifted its interests towards sustainability and that the dynamics of the network actively contribute to new developments in the building sector.

The overall goal of the study is to analyze non-state market driven governance, by taking ÖGNI as a basis for a case study. In this respect, we looked at the role of this organisation as an independent and external institution in the area of real estate certification. By analysing the entire network of the organisation, different roles inside ÖGNI became more apparent. The study is combined with already existing findings from the international analysis from the World Green Building Councils (WGBCs) 2011 [2]. Therefore the organisational structure, the defined goals and activities of the councils were taken and processed into a questionnaire.

The study has been structured along two parts: A theoretical part that illustrates the concepts of non-state market driven governance and the international application. The second part consists of a case study analysis about ÖGNI by putting a detailed focus on its members and auditors.

2 Non-state market driven governance processes

Non-state market driven governance is embedded within a framework of existing sub-levels (i.e. regional governance, global governance, corporate governance, economic governance, see [3]). All these concepts are representing the obliteration of borders between politics and society. They have a normative entitlement of increased participation of various stakeholders that is manifested in policy networks and public-private-partnerships.

Some authors see the development of non-state governance regimes in weakly regulated and inefficient policy areas [4]. However, these regimes do not exist apart from political regulations. Moreover decision makers take part in governance networks by having a central role [5].

The enforcement of complex areas that are difficult to overcome through ordinary measures (governing) over a long period of time can be seen as an important contribution to non-state market driven governance regimes [6]. Simply spoken, these governance regimes are wisely taken, if ordinary political processes act inertially and ineffectively. The role of NGOs in these governance regimes is of increasing importance. The independent role of these organisations, which seem to act apart from political- and market structures, makes them more effective in dealing with certain problems. [7] argue that NGOs as non-state actors still have an influence in political decisions. Especially in the environmental and sustainability sector NGOs became more and more integrated in decision making processes. This can be seen in international negotiations, where NGOs represent certain groups of society. Contribution of NGOs in political discussions is traced back to the mid-19th century [8].

As discussed before NGOs are often acting as third parties. Dixit [9] argues that third parties remain in a neutral outside position that allows independent decisions. Contribution of NGOs therefore allows new forms of decision making that is decisively marked through a good

cooperative situation between state and non-state actors. Consequently, NGOs fulfil a bridging function between public and private actors.

The real estate sector is also organised internationally by NGOs that share the common goal to create worldwide more sustainable buildings (labelled as blue or green buildings). The foundation of the WGBC in 2002 made a progressive step to form an umbrella association that includes all regional green building councils that are organised as an NGO. The overall goal of this association is the improvement of building standards that are provided via certificates. The ÖGNI is one of 93 of such regional NGOs that pursue common goals in an international network. All regional NGOs act independently in their countries and exchange themselves through the WGBC. These links can be seen as a learning network with the central aim to exchange knowledge and experience about building certification. Especially in this sector, powerful real estate enterprises are driven by increasing their profits that could make the observer sceptical about the added value for society. This study tries to identify strengths and weaknesses of these new non-state market driven governance regimes by investigating the case of ÖGNI.

3 ÖGNI's contribution to the green building market in Vienna

ÖGNI was established in 2009 through an initiative of a number of active players in the Austrian real estate industry. ÖGNI is a non-profit organization and does fit into the category of non-governmental organizations (NGOs). As mentioned it is part of the 93 WGBC members with the status of a 'prospective member'. The office of the NGO, headquartered in Linz, is supported by a team of ten people. The duties of the office are the support of experts and projects, the organization of events and the management of the website.

ÖGNIs objectives are defined in the form of key performance indicators. The growth in membership to 500 members in the next three years is at the forefront, followed by an increase in the number of certified buildings. Therefore important strategies are the on-going recruitment, open and transparent communication, a permanent event management, as well as continuous public relations by media campaigns.

The research project was designed as a single case study, which falls in principle within the qualitative research paradigm, but it takes both qualitative and quantitative sources for analysis of the selected case. In this case, the organization ÖGNI is the research object to be identified and its role in contributing to sustainable real estate market is analysed. Case studies are used in a variety of disciplines, especially in areas where it is important to analyse complex social phenomena (Yin 2003).

The case study was embedded in a conceptual framework that provides the basis for the case study analysis. The empirical part was preceded by an extensive literature and Internet research on ÖGNI. This research formed part of the basis for the subsequent interview with the founding president of ÖGNI and also served as the basis for the development of the online questionnaire. The questionnaire was designed together with the management of ÖGNI, who supported the research team with data from the members and auditors database. It became clear fairly soon after the start of the study that the online questionnaire would be addressed to different stakeholder groups. Originally a mere member survey was planned. As a result of the initial research it was decided relatively quickly to interview the auditors as well. As a matter of fact the third group had to be taken into consideration - those who are both members and auditors.

For the online survey, ÖGNI has provided the research team with a list of 239 email addresses. Out of them 206 people could be contacted and received an invitation for the online survey. A total of 90 people completed the questionnaire. Out of them 27 people are exclusively members, 30 auditors and 33 auditors, who are also members of the ÖGNI. This corresponds to a response rate of 43.7%. Parallel to the online survey, the research team decided to create a list of project participants of those buildings in Vienna, which were certified by the DGNB certification system.

The case study is designed as a target group specific analysis and therefore we were interested in the different stakeholders' perceptions. The questionnaire focuses on members and two different types of auditors, the ones being members and the others who do not belong to ÖGNI's member network. The final part of the questionnaire was targeted at all respondents and focused on the general perception about the organisation ÖGNI and its activities. Thus members and auditors listed in the ÖGNI member directory were contacted and invited to participate in the online survey. A total of 90 people completed a questionnaire. The majority are male respondents (80%). The age distribution of respondents is normally distributed between 25 to 50 year old, with the exception of the most represented age group of 40 to 44 year old, which is extremely over-represented with about twice as many people in this age group compared to the neighbouring group of 30 to 39 year old. In the 55 + age group an uneven distribution can be seen in the sample. It represented more 60-64 year olds than 55-59 year olds. Overall, it can be said that the survey in terms of age groups covering a very broad cross section of age.

Having a look at the educational level it becomes clear that most of the respondents have an academic background (82%). Profession shows an enormous variety, but can be summarized to be located in the construction sector in general. More clusters can be identified in the project development-, architecture-, consulting-, as well as in engineering area. On the management level there are a few nuances across divisional or departmental managers. Overall, people are consistently well educated and most of them in leadership positions. This result could be expected in the field of sustainable building development. Therefore, we can infer that the network of ÖGNI consistently includes representatives in leadership positions and academics.

This study is dealing extensively with ÖGNI, to find out if this organization, founded in 2009, occupies a governance function as a mediator between business, politics and society, and how it makes an active contribution to the implementation of sustainable development in the property sector. The underlying hypothesis is focused on the role of ÖGNI as independent and external ('third party') organization for building certification, which can be defined as a part of a non-state market-driven governance regime by having an important bridging role inside complex stakeholder groups. Here, the organization as a NGO is assumed to have a comparative advantage in the area of moderation and mediation between business, politics and society. The situation in Austria is so mounted that the Austrian Climate Strategy (BMLFUW 2007), especially the issue of energy efficiency in buildings, is more addressed than the issue of the development of sustainable buildings. Consequently a market-driven initiative like ÖGNI would have a great potential to initiate innovative market impulses towards sustainable buildings. Especially auditors in the sample see a big potential in having ÖGNI as a coordinating institution holding the position of a third party institution. Certification is seen as the key for improving the standards of buildings and to make the market aware of these standards. They see the network as a valuable asset for improving their own businesses and to share and exchange knowledge. Auditors do see a big potential at the Austrian but specifically at the Viennese market for sustainable buildings whereas members are more sceptically. Members do see ÖGNI as an information provider and they see the network as a possibility to keep them informed and integrated. It can be interpreted as a knowledge receiver function whereas auditors share knowledge with other auditors and actors in the network. Altogether this can be interpreted as a valuable non-state market driven governance mechanism which has room for improvements but has already initiated dynamic developments on the real estate market.

4 Results and conclusion

The aim of the study was to provide new impetus to the real estate market specifically in Vienna. Although ÖGNI operates nationally, it has to be mentioned that its main activities could be identified in Vienna. A second aim was to analyse and evaluate the role of ÖGNI as a governance actor. Strengths and weaknesses were analysed having a look at the network. The results are

presented in the following analogy referring to the case study analysis presented along different respondents, namely members and auditors of ÖGNI.

The members use ÖGNI as a networking platform, where they are primarily focussed on networks in the context of their own profession. This can be clearly seen as an advantage, since the network activity has direct relevance to developing a sustainable building industry. Moreover, the members who participated in the survey largely come from industry. It can be stated that ÖGNI provides a platform for the exchange of industry-specific activities and is described by its members as a valuable networking instrument as reflected in the literature on non-state market-driven governance.

The main strength is seen in the increased media presence of ÖGNI. The real estate market moves more and more towards sustainability and related activities are demand driven from the customer (investor) side. The active public relations are seen as an awareness instrument that is used in the entire real estate industry. An additional strength is the certification. It is described as a long term investment by investors and customers (owners) are demanding certificates as found in interviews.

The weaknesses generally refer to the information provided and in particular to the lack of structure of this information. It can be subsumed that ÖGNI provides information, but too much in terms of volume, or in an unstructured way. This is an important issue for an organization that provides information in addition to the general public, especially for its own members. As the number of activities is relatively large in relation to the size of the organization, structuring problems are quite common. Non-profit organizations in general have a comparative disadvantage towards private organizations with respect to the availability of resources.

The second identified weakness is focused on certification. According to the members certification could be improved. The DGNB certification system however provides ample space for improvement and sees itself as a learning tool. As such it will be continuously adapted in order to make it more effective. One area that was rated ambivalently is transparency. The result shows that transparency is a sensitive topic that is barely recognized by individuals, because transparency has been called both strength and weakness. It can also be associated with excessively existing information or the lack of structure of this information, as this may also lead to non-transparent process.

Members see a benefit in their membership. It is mainly the building certification, which has a high priority to them and can be seen as "the strength" of the ÖGNI. However certification strengthens the position of ÖGNI and thus the quality of the organization. Membership is the opportunity to actively participate in this area. This can be interpreted as a win-win situation for the members of ÖGNI and considering its activities in the field of certification also for ÖGNI, especially in Vienna where there is high recruiting potential due to the vast number of enterprises in and around the city.

For the auditors the improvement of the certification system is of major importance. Main shortcomings are named as a need for simplification and a more transparent approach. For networking reasons auditors see ÖGNI as a vital instrument. 80% of the auditors from the sample are linked with other auditors in the green building market. This network plays an important role for the continuous improvement of the certification system, since auditors can share their experience directly if they are members as well. The practice of application and their exchange is an important factor regulating ÖGNI who sees the continual improvement of the system as one of the overarching goals. The auditors also see a great potential for sustainable construction in Austria, which occurs mainly due to increased market demand, but also the positive attitude of all the actors involved.

Next to the networking possibilities, public events are also important to the respondents. Moreover, events can also be seen as an instrument for networking, which is actually used relatively often. In

the opinion of the respondents, ÖGNI has a social responsibility, which can be summarized into two areas. On the one hand the awareness of the general public, in which the issue of sustainable construction becomes more acquainted and on the other hand in the awareness of the members that should partly implement this awareness into sustainable outcomes.

The general opinion in relation to the work of the ÖGNI has been very positive. Two major areas were considered separately - the organization and the certification. The assessment of the organization clearly shows that the ÖGNI has a clear focus on Austria and there especially on Vienna. In Vienna, most DGNB certified buildings are located and the city is also seen of having great potential to improving the quantity of DGNB certified buildings. Vienna will establish a leading role in the sustainable office sector in the near future leading to a headquarters function in Austria and drive the market towards sustainability. This is a beneficial effect due to the institutionalization of ÖGNI as stated by respondents. The certification system is clearly perceived as market appreciation, the type of certification has not provided any disadvantages due to lack of experience over longer periods. There is wide consensus that deciding whether a building certificate is sought or not, will be decided solely by the project participants and will thus be a market-driven decision, which is not controlled by any political action (policy push '). Since ÖGNI in its capacity as third party institution awards and promotes the development of sustainable construction, one can speak of an existing non-state market-driven governance regime, which in his actions and engagements supports the overall policy framework without being a political decision maker.

References

[1] JORDAN, A. 2008, *"The governance of sustainable development: taking stock and looking forward."* Environment and Planning C: Government and Policy 26, pp. 17-33.

[2] Sedlacek, S. and Maier, G. 2012, *"Can green building councils serve as third party governance institutions? An economic and institutional analysis."* Energy Policy 49, pp. 479-487.

[3] Benz, A., Lütz, S., Schimank, U.und Simonis, G. (Hrsg.) 2007. *Handbuch Governance. Theoretische Grundlagen und empirische Anwendungsfelder.* VS Verlag für sozialwissenschaften: Wiesbaden.

[4] Gulbrandsen LH. 2010. *Transnational environmental governance. The emergence and effects of the certification of forests and fisheries.* Edward Elgar: Cheltenham.

[5] Smith T M, Fischlein M. 2010. *"Rival private governance networks: Competing to define the rules of sustainability performance."* Global Environmental Change 20: 511-522.

[6] Cashore B. 2002. *"Legitimacy and the privatization of environmental governance: How non-state market-driven (NSMD) governance systems gain rule-making authority."* Governance 15(4): 503-529.

[7] Saunier RE, Meganck RA. 2007. *Dictionary and introduction to global environmental governance.* Earthscan: London.

[8] Charnovitz, St. 1996. *"Two centuries of participation: NGOs and international governance."* Journal of International Law Vol. 18: 183-286.

[9] Dixit A. 2009. *"Governance Institutions and Economic Activity."* American Economic Review 99: 5-24.

Socioeconomic logical attributes to complement LCA results in building material selection in Brazil

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Short Summary

True measurements and evaluation of the sustainability level of products and systems must encompass social and economic aspects. Observed throughout entire life cycles, these factors are the incentives and the inhibitors of potential environmental improvement. However, LCA has traditionally focused on environmental aspects, and even ISO 14040:2006 limits the analysis to environmental effects. This paper aims at using the set of socioeconomic subcategories, proposed by UNEP's guidelines for social LCA, as logical attributes to assist design decision-making processes regarding choices of construction materials. The validity of the attributes in the Brazilian construction sector is evaluated, considering information availability. These attributes are expected to complement and enlighten ranking of alternatives beyond environmental evaluation or when it is not enough to establish a clear ranking between them. Targeted materials and systems will be those associated to the highest life cycle environmentally impacts based upon previous studies of a sample of typical practice Brazilian buildings. Considering the current embryonic stage of Brazilian LCA studies and of consideration of social and economic aspects worldwide, this paper expects to enhance the discussion on integrated life cycle accounting of multidimensional sustainability aspects, and to add practicality to data that are usually perceived as too specific to be properly used by designers and contractors.

Keywords: Life Cycle Assessment (LCA); social; economic; building materials; life cycle indicators; life cycle attributes.

1. Introduction

Aiming at diminishing the negative side effects of human action in the natural environment, sustainability has become the guiding paradigm for humanity's further development [1]. Worldwide, there is a broad consensus that true measurements and evaluation of the sustainability level of products and systems must encompass social and economic aspects.

Companies are increasingly confronted with questions from different stakeholders regarding their social performance; and society's expectations for them to enhance corporate social responsibility is a challenge that has been accepted by those corporations who wish to conduct business in a more responsible way [2]. In that matter, the Global Reporting Initiative (GRI) stands out as an organization that aids companies' communication regarding sustainability, providing a framework for reporting economic, environmental and social aspects.

Observed throughout entire life cycles, socioeconomic factors are the incentives and the inhibitors of potential environmental improvement. However, Life Cycle Assessment (LCA) has traditionally focused on environmental aspects, and even ISO 14040:2006 limits the analysis to environmental effects. In the LCA community, the idea of broadening the analysis to include socioeconomic aspects is taken up by combining the environmental life cycle assessment (ELCA) with life cycle costing and social life cycle assessment (SLCA) to life cycle sustainability assessment [3]. While

ISO 14040 and 14044 serve as international standards for Environmental LCA, there is still little experience with the use and implementation of SLCA as a tool [1]. Recommendations based on LCA do not address possible trade-offs between environmental protection and socioeconomic concerns [2], which raises questions about LCA's ability to support actual decision-making in companies aiming for sustainability. In an effort to take a step towards SLCA standardization, UNEP/SETAC Life Cycle Initiative published the Guidelines for Social Life Cycle Assessment of Products [4], aiming to provide a framework to assess social impacts across product life cycles.

1.1 The Brazilian construction sector

The construction sector plays an increasingly important role on regional and global economies, contributing to jobs generation, to the development of new technologies and infrastructures and to quality of life enhancement. However, the environmental liabilities that arise from construction activities are quite large: approximately 25% of all raw materials extracted from the lithosphere are consumed for building construction [5]; about 23% of the energy produced in Brazil is consumed by the residential sector [6]; and a great part of anthropogenic carbon emissions come from building activities. Because of those significant figures, great attention has been paid to the construction sector's initiatives and measures towards more sustainable practices, usually focusing, however, on the environmental side of sustainable development.

The insertion of socioeconomic aspects on building activities can be common when aiming to assess financial viability of different project choices. However, when considering construction performance in a life cycle perspective, companies usually fail to take into consideration the performance of all of their supply chain contributors. Life cycle studies in Brazil still struggle with the lack of inventory data, which diminishes researchers and designers ability to produce and use, respectively, reliable life cycle results. With SLCA and LCC the main obstacles remain the same.

Aiming at providing more complete and thorough results to aid designers' decision making processes, the present article (i) proposes a set of socioeconomic attributes, based on UNEP/SETAC published guidelines [4] and (ii) evaluates the viability of such attributes through a survey of sustainability reports of different Brazilian companies that produce building materials with highest contribution to a building's environmental load.

Previous studies ([7]; [8]) used four Brazilian case studies to show that, for a certain typology, a core database of about 12 materials and components provides a very accurate description of a building's embodied energy and carbon profile, which streamlines indicator's monitoring scope. The same set of materials and components was used here, to which the socioeconomic attributes were applied.

2. Methodological approach

2.1 Selection of attributes

Life Cycle Initiative's published guidelines [4] state that the bases for Social LCA are the subcategories, which are socially significant themes or attributes, categorized into stakeholders and impacts. The main categories comprise "workers", "consumers", "local community", "society", and "value chain (non-consumers) actors".

Subcategories are defined for each of these stakeholder categories. In this paper the abovementioned subcategories were used as logical attributes to assess the possibility of performing socioeconomic life cycle studies of the Brazilian construction sector, following UNEP/SETAC's guidelines. Chart 1 presented below indicates all the subcategories listed by the published guidelines, and which will be used here.

Stakeholder categories	Subcategories
Stakeholder “worker”	Freedom of association and collective bargaining Child labor Fair salary Working hours Forced labor Equal opportunities/discrimination Health and safety Social benefits/social security
Stakeholder “consumer”	Health and safety Feedback mechanism Consumer privacy Transparency End of life responsibility
Stakeholder “local community”	Access to material resources Access to immaterial resources Delocalization and migration Cultural heritage Safe &healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder “society”	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Stakeholder “value chain actors”	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

Chart 1: Stakeholder categories and their respective subcategories [4].

2.2 Verification of feasibility

In order to assess the feasibility of using the mentioned subcategories as attributes, to characterize an initial consideration of social and economic aspects in building material selection in Brazil, main production companies' sustainability reports have been analyzed. In theory, all information regarding the listed attributes should be public and available. In the country, however, there is a historic deficiency of such information, and of government policies and inspection demanding its disclosure.

The attributes were evaluated within companies that produce 12 materials/components, which were listed by [7] and [8] as top contributors to embodied energy and carbon in selected Brazilian case studies. The studied typology was basically low-rise (up to 3 floors), low window-to-wall ratio, reinforced concrete-framed, masonry façade and partitions, and ceramic or metallic roofing buildings. Results obtained showed that the ranking was composed by: Portland cement and ready mixed concrete, ceramic brick, steel rebar, PVC tubes and conduits, sawn timber (planks), sawn roundwood, roof steel structure, ceramic tile, plywood, hydrated lime and adhesive mortar.

Wherever possible, materials contained in the ranking were clustered into sectors of production, to facilitate data gathering and interpretation, *e.g.* steel rebar and roof steel structure were grouped and jointly assessed as “steel”. The respective sectorial associations disclosed the reports analyzed. Manufacturing companies that were geographically close to the cases studied by [7] and [8] were prioritized. When such companies have not published reports nor displayed the needed information in their websites or other information vehicles, reports of other companies, typically larger, were evaluated instead.

Results are presented for each material/component or production sector, indicating to which extent the information regarding the selected attributes is available. The scope is later on enlarged to assess information availability related to each stakeholder category, considering all top 12

materials/components.

3. Results presentation and discussion

3.1 Portland cement and concrete

To evaluate information availability regarding the production of cement and concrete in Brazil, the sustainability reports of *Holcim*, one of the largest manufacturer in the country, was analysed. *Holcim* has a unit in the municipality where studies performed by [7] and [8] took place. Chart 2 shows which of the attributes were contemplated by the mentioned report.

Stakeholder categories – cement and concrete	Attributes – cement and concrete
Stakeholder “worker”	Freedom of association and collective bargaining; Child labor; Fair salary; Forced labor; Equal opportunities/discrimination; Health and safety; Social benefits/social security.
Stakeholder “consumer”	Health and safety; Feedback mechanism; Consumer privacy; Transparency; End of life responsibility.
Stakeholder “local community”	Access to material resources; Access to immaterial resources; Cultural heritage; Safe & healthy living conditions; Respect of indigenous rights; Community engagement;;Local employment; Secure living conditions.
Stakeholder “society”	Public commitments to sustainability issues; Contribution to economic development; Technology development; Corruption.
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 2: Attributes contemplated by Holcim’s report.

3.2 Steel

Brazil has a significant number of steelmaking companies, with most of them complying with a national institute, *Instituto Aço Brasil*. The sustainability report evaluated here was, therefore, the document published by that Institute, because of its relevant and larger coverage of the national steelmaking sector. Chart 3 indicates the attributes that were contemplated by the referred report.

3.3 PVC tubes and conduits

The socioeconomic information availability of PVC materials was evaluated through *Braskem*’s published sustainability report, since it is one of the major manufacturers in Brazil. Though not located in the region of study, it does, however, supply materials to that area. Chart 4 summarizes the attributes found in the report.

Stakeholder categories – steel	Attributes – steel
Stakeholder “worker”	Freedom of association and collective bargaining; Child labor; Fair salary; Working hours; Forced labor; Equal opportunities/discrimination; Health and safety; Social benefits/social security.
Stakeholder “consumer”	Health and safety; Feedback mechanism; Consumer privacy; Transparency; End of life responsibility.
Stakeholder “local community”	Access to material resources; Access to immaterial resources; Cultural heritage; Safe & healthy living conditions; Respect of indigenous rights; Community engagement; Local employment; Secure living conditions.
Stakeholder “society”	Public commitments to sustainability issues; Contribution to economic development; Technology development; Corruption.
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 3: Attributes contemplated by national steel institute’s report.

Stakeholder categories – PVC	Attributes - PVC
Stakeholder “worker”	Freedom of association and collective bargaining; Child labor; Fair salary; Forced labor; Equal opportunities/discrimination; Health and safety; Social benefits/social security.
Stakeholder “consumer”	Health and safety; Feedback mechanism; Transparency; End of life responsibility.
Stakeholder “local community”	Access to material resources; Access to immaterial resources; Cultural heritage; Safe & healthy living conditions; Community engagement; Secure living conditions.
Stakeholder “society”	Public commitments to sustainability issues; Contribution to economic development; Technology development; Corruption.
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 4: Attributes contemplated by Braskem’s report.

3.4 Wood

The informal nature of wood extraction and production in Brazil poses considerably challenges to sustainability assessments. The available report found, in this case, was a document prepared by the World Wide Fund for Nature (WWF), adapted to the Brazilian scenario [9]. The so-called “Keep it legal” report lists the main obstacles found in certifying Brazilian wood and fighting corruption, and focuses on providing guidelines to assure supplier’s compliance with regulations. The attributes found in the document are listed in Chart 5.

Stakeholder categories - wood	Attributes - wood
Stakeholder “worker”	-
Stakeholder “consumer”	Transparency
Stakeholder “local community”	Community engagement
Stakeholder “society”	Public commitments to sustainability issues; Prevention & mitigation of armed conflicts; Corruption.
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 5: Attributes contemplated by WWF’s national report on certified wood.

3.5 Ceramic bricks and tiles

As observed with wood, production of ceramic materials in Brazil also has an informal character. The national association of the ceramic industry, ANICER, provides a certain level of information regarding national manufacturing. ANICER has already invested in LCA and disclosed comparative studies between ceramic and concrete blocks. The Association, however, does not publish a sustainability report, summarizing social, economic and environmental data of its member companies. A survey of all information available in their website was performed. Information regarding the proposed attributes, however, was not found.

3.6 Adhesive mortar

There is a considerable number of companies that manufacture adhesive mortar in the study area. They do not, however, publish sustainability reports, which might be explained by their local and limited market. The report evaluated in this case was published by *Camargo Corrêa*, an industrial group with high levels of adhesive mortar production and commercialization.

Stakeholder categories – adhesive mortar	Subcategories – adhesive mortar
Stakeholder “worker”	Child labor; Forced labor; Equal opportunities/discrimination; Health and safety; Social benefits/social security.
Stakeholder “consumer”	Health and safety; Transparency; End of life responsibility.
Stakeholder “local community”	Access to material resources; Access to immaterial resources; Cultural heritage; Safe & healthy living conditions; Community engagement; Local employment; Secure living conditions.
Stakeholder “society”	Public commitments to sustainability issues; Contribution to economic development; Technology development; Corruption.
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 6: Attributes contemplated by Camargo Corrêa Group’s report.

3.7 Hydrated lime

Analogously to the case of adhesive mortar, the local companies that manufacture hydrated lime do not publish sustainability reports. To assess the socioeconomic information availability of hydrated lime production, *Votorantim*’s report was analysed, since it supplies its products in a national scale.

Stakeholder categories – hydrated lime	Subcategories – hydrated lime
Stakeholder “worker”	Freedom of association and collective bargaining; Child labor; Forced labor; Equal opportunities/discrimination; Health and safety; Social benefits/social security.
Stakeholder “consumer”	Health and safety; Feedback mechanism; Transparency; End of life responsibility.
Stakeholder “local community”	Access to material resources; Access to immaterial resources; Cultural heritage; Safe & healthy living conditions; Respect of indigenous rights; Community engagement; Local employment; Secure living conditions.
Stakeholder “society”	Public commitments to sustainability issues; Contribution to economic development; Technology development; Corruption
Stakeholder “value chain actors”	Fair competition; Promoting social responsibility; Supplier relationships.

Chart 7: Attributes contemplated by Votorantim’s report.

3.8 Information availability per stakeholder category

In order to identify the levels of information availability within the different stakeholder categories, Fig. 1 indicates how each sector complied with the disclosure of the proposed attributes, dividing results by stakeholder group. Steel and cement/concrete stood out as the materials/components with most information publicly available.

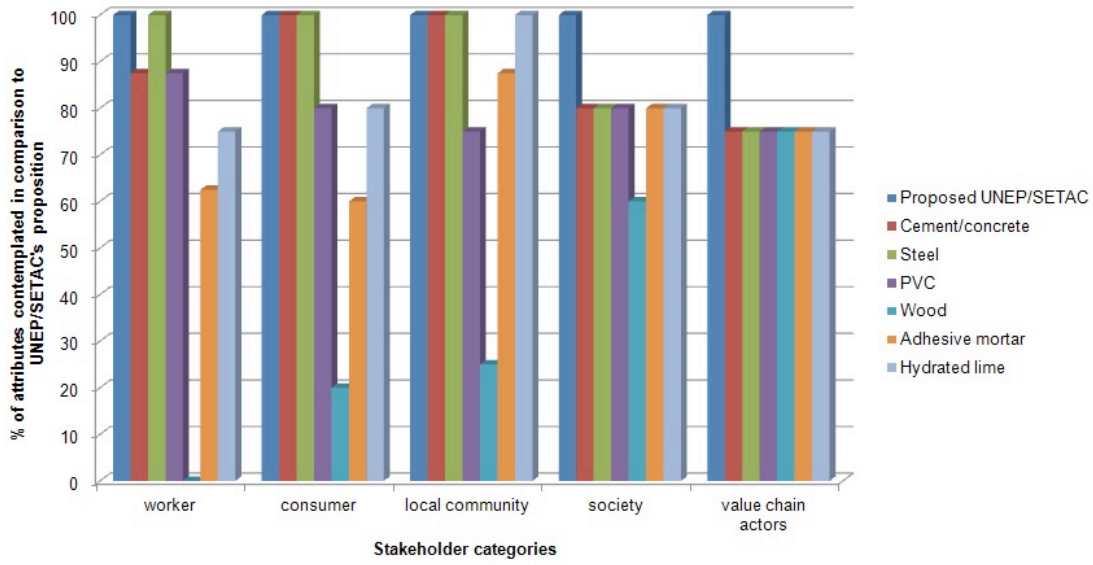


Fig. 1: Attributes information availability, divided by stakeholder, for each material/set of materials.

4. Final considerations

Observed throughout entire life cycles, socioeconomic factors are the incentives and the inhibitors of potential environmental improvement. Still most national life cycle studies fail to consider those aspects in their evaluation, which diminishes the results’ potential to substantially aid decision makers in regards to sustainability. Brazilian historical deficiency in data availability creates many obstacles to LCA experts to provide reliable and thorough results. Within the national building sector, specifically, many academic efforts have been observed to create databases and aid designers’ in project choices, but showing wide methodological variation. However, the current policy adopted by many national companies to protect their internal processes data many times

prevent delivery of trustworthy and strong life cycle results. Considering the mentioned situation, performing a complete Social Life Cycle Assessment consists in a great challenge for the Brazilian construction sector.

In an attempt to begin the insertion of social and economic aspects in daily designer's practice, and to follow the international trend of truly assessing sustainability, considering the "triple bottom line" nature of its concept, this paper evaluated the possibility of using UNEP/SETAC proposed socioeconomic impact subcategories as logical attributes, to be used when environmental evaluation is not enough to establish a clear ranking between different alternatives. Results showed that companies with higher market breadth and, consequently, with higher industrialization level, disclose more complete sustainability reports, usually in compliance with GRI's guidelines. Smaller companies, in almost all cases, did not publish any sort of reports. In the case of wood and ceramics, the informal nature of their production in Brazil implies in a significant lack of information. In such cases, suppliers' ratification projects can assure social and economic responsibility, as recommended by [9].

Steel stood out as the material with most information availability, probably due to the aggregation of different large manufacturers in a national association, which impels companies to disclose results, and even to improve their production processes, as a propeller to increase competitiveness. Finally, results highlighted that, in the current data availability status, the use of impact subcategories exclusively as logical attributes could aid in the process of inserting social and economic evaluations in the construction sector. Some product categories, however, would be harmed in the decision-making procedures due to failure in reporting adequacy of their supply chain contributors and of their own production process.

5. Acknowledgements

Authors thank CNPq and CPFL Energia/ANEEL R&D funding line for the financial support to this research project.

6. References

[1] REITINGER C, DUMKE M, BAROSEVCIC M, HILLERBRAND R. *"A conceptual framework for impact assessment within SLCA"*. The International Journal of Life Cycle Assessment, DOI: 10.1007/s11367-011-0265-y; 2011, Volume 16, pp. 380-388.

[2] DREYER LC, HAUSCHILD MZ, SCHIERBECK J. "*A framework for Social Life Cycle Impact Assessment"* The International Journal of Life Cycle Assessment; 2006, Volume 11/2, pp. 88-97.

[3] KLOEPFFER W. *"Life Cycle Sustainability Assessment of Products (with Comments by Helias A. Udo de Haes, p. 95)"*. The International Journal of Life Cycle Assessment; 2008, Volume 13/2, pp. 89-95.

[4] BENOÎT C, MAZIJN B (eds). *"Guidelines for social life cycle assessment of products."* Available at: www.cdo.ugent.be, accessed in Mar 1st, 2013; 2009, ISBN: 978-92-807-3021-0.

[5] BRIBRIÁN IG, CAPILLA AV, USÓN AA. *"Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential"*. Building and Environment; 2011, Volume 46, pp. 1133-1140.

[6] AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. *"Atlas de Energia Elétrica no Brasil"*. Brasília, 2008. Available at: www.aneel.gov.br, accessed in Oct 1st, 2012; 2008,158 p.

[7] SAADE MRM, SILVA MG, GOMES V. *"Methodological discussion and piloting of LCA-based environmental indicators for Brazilian building materials"*. Proceedings World Building Council 2013, Australia, 2013.

[8] SILVA MG, GOMES V, FRANCO, HG, SCHWAMBACK D, SAADE MRM. *"Study of embodied energy and $CO_{2eq.}$ as eco-efficiency descriptors of Brazilian building materials"*. Proceedings Conferencia Internacional del Analisis de Ciclo de Vida, Mendoza, 2013.

[9] MILLER F, TAYLOR R, WHITE G. "*Keep it legal".* Gland, Switzerland: Global Forest and Trade Network, World Wide Fund for Nature, 2006. 64 p.

Indicators to Support Sustainability and Performance-Based Selection of Structural Frame Alternatives in Concrete: Validation at Typical Floor and Superstructure Levels



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Short Summary

Given the difficulty to insert life-cycle assessment (LCA) and life cycle costing (LCC) in daily routine of structural design practices, this paper presents a set of LCA-and-LCC-based indicators that integrates functional, environmental and economic performance requirements. The goal is to allow proper design decision-making support and a broader, life-cycle, sustainability evaluation of concrete structural frames. Using a case study approach, it focuses on different residential concrete building flooring systems to show the application feasibility at typical floor and whole superstructure levels. To calculate environmental and economic indicators, Life-365 software was used to predict service life and estimate LCC for the flooring systems, while cradle-to-gate LCAs were performed for the structural materials employed. For the conditions studied, *(i)* prestressed flat slabs showed better functional and economic results than reinforced concrete waffle slabs, which, however, presented the best environmental performance. Results also *(ii)* confirmed the validity to analyse a typical storey in lieu of the whole superstructure; *(iii)* revealed that designing by the Brazilian concrete structural design code, for a marine environment, does not ensure compliance with the recent national performance standard, ABNT NBR 15575:2013, requiring strategies to increase concrete structures' service life, and that *(iv)* design life associated to unit of structural area are convenient functional unit descriptors for superstructure as well as floors, ensuring proper comparison among structural components performing same structural function over a given lifespan.

Keywords: sustainability; indicators; LCA; LCC; structural frame; concrete flooring system; performance requirement.

1. Introduction

Research initiatives for new generations of sustainable buildings assessments state that buildings sustainability level should always be described using indicators. The selection and justification of indicators should be based on clear understanding about the issues of concern and the relevance of building sector to these issues [1][2][3]. Defined as a parameter or value derived from parameters, an indicator should be relevant, measurable and adequate to the analysis [4], whilst remaining objective and providing traceable results. Since indicators main functions are quantification, simplification and communication, they can be used for assessment, diagnosis, comparison and monitoring [5].

Worth mentioning, the work carried out in the past decade within the European thematic network "Construction and City Related Sustainability Indicators"- CRISP provided a database of circa 500 indicators. Later, this network carried out studies concerning the application of these indicators to performance-based buildings. It was concluded that considerable additional work was still required to achieve European indicator systems that could be widely used to support and encourage successful adoption of the performance approach to buildings design and construction [2].

The existing sustainable buildings assessment systems offer a number of indicators to be used in different contexts and building life cycle phases [2]. Research projects like SUPERBUILDINGS (Sustainability Performance Assessment and Benchmarking of Buildings) and currently OPENHOUSE aim to develop a logical structure for them, among other goals. While the first focused on research and development of indicators, their reliability, comparability and validity, the latter develops and tests assessment methodologies through case studies [1].

European Standards developed by CEN TC 350 - "Sustainability of construction works" - acknowledge that environmental, economic and social performances are all important dimensions to make a good sustainability assessment at the building level. Indicators can thus be developed and used separately or together to indicate various sustainability aspects of buildings [6]. However, advancement in all three dimensions of the sustainability tripod is not equally balanced. Literature review [7] has pointed out many unsolved difficulties regarding integration of social aspects to environmental life-cycle assessment, mainly because the former methodologies are still embryonic and lack consensus on crucial impact integration and calculation steps.

Life cycle-based studies have shown the structural frame and envelope as major contributors to material environmental loads of a building [8][9][10][11][12]. However, service life, durability, and role played by structural frames have not gained enough attention in sustainable buildings assessment systems, except perhaps for AQUA [13] and CASBEE [14], which include measures to minimize structural materials resources and service life extension of the structural frame among their encouraged sustainability strategies [15].

Considering *(i)* that service life of the structural system ultimately defines the lifespan of a building, *(ii)* the role of structural systems in environmental terms, mentioned by studies in other contexts, and *(iii)* the complete absence of data in this regard in Brazil, this work is dedicated to the study of structural systems typically used in Brazilian residential concrete buildings typology. For that, this paper aims at proposing a set of LCA- and LCC-based indicators to evaluate sustainability aspects of concrete structural frames from a life cycle perspective. A case study approach was adopted to investigate its feasibility to compare sustainability performance of different concrete building flooring systems. Other relevant building systems as well as the relation with the other parts of the building and the impacts on the technological system as a whole are being targeted by parallel research and are therefore beyond the scope of the present paper.

2. Methodological approach

The present study comprised the following steps: *i)* literature review, covering the concept and methodology for developing sustainability indicators for the building sector, and the building performance requirements recommended by the Brazilian performance standard [16] as well as ISO 6240 [17] and ISO 6241 [18]; *ii)* proposition of a set of indicators for concrete structural frames, based on functional, environmental and economic performance requirements; *iii)* application of these indicators for election from a choice of structural flooring systems at the design stage. The final sessions of the paper are dedicated to results, discussion and final remarks.

2.1 Selected set of indicators for structural frames selection

The functional indicators proposed in this paper refer to structural safety, adaptability and durability requirements [16][17][18]. The environmental performance indicators are based on ISO/TS 21929-1 [5] and mainly associated to resource management. They measure environmental performance of structural frames in accordance with ISO 21931-1 [19] methodological guidelines. Economic indicators describe monetary flows connected to the building. The indicators suggested in this

study were life cycle costs and local economy support. Table 1 shows the proposed set of indicators, filtered by predefined criteria [15][20].

Table 1 - Set of functional, environmental and economic indicators filtered based on specific criteria [19][20] and proposed for buildings structural frames selection

Indicators for structural frames / elements	
Functional (associated to performance requirements)	***Span over height ratio* (ℓ/h)** between the structural element span and its dimension in the corresponding direction, [m/m]
	***Column density**:* structural floor area over number of columns (m^2/nr), [m^2]
	Beam over slab height ratio, [m/m]
	Reuse potential (% prefabricated with connections for disassembly), [% volume]
Environmental (associated to resource management)	***Embodied CO_{2e}* (ECO_{2e})** [$kgCO_{2eq}$/fu]; (obtained through CML 2001 v.2.05 environmental impact assessment, regarding the global warming impact category).
	***Embodied Energy* (EE)** [MJ/fu];
	***Blue Water Footprint* (bWF)** [m^3/fu]; (surface and groundwater used, except water for turbine use)
	***Materials resource consumption* (Mc)** [kg/fu]:(steel + concrete+ plywood formwork).
	***Non renewable Content* (NRc)** [$kg_{\text{tot abiotic mat}} - kg_{\text{recycled}} - kg_{\text{reused}}$] [kg/fu]
Economic (associated to life cycle costs)	***Life cycle costs* (LCC)** [$/fu];
	Local economy support (**LES)** local materials over total materials cost (percentage of material and products extracted or fabricated locally, within a 300 km radius), [% cost].

2.2 Case studies description

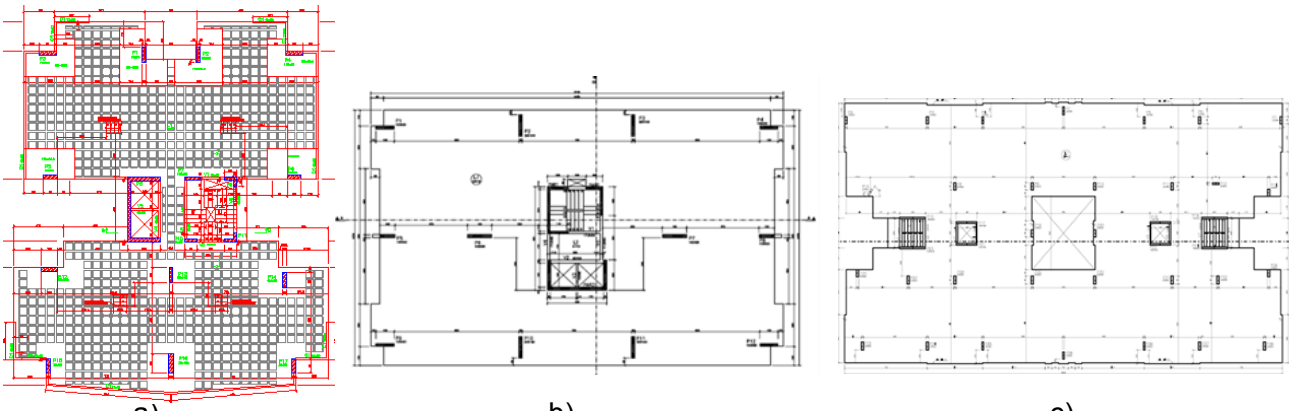
Three case studies on structural flooring systems, used in different residential concrete building typologies in the Brazilian coastal area are presented. They comprise low-and medium-rise concrete-framed residential buildings. Case study (CS) 1 has a total built area of 5,829.19 m2, in 6 floors (24 apartments), with a 27.5cm-thick reinforced concrete waffle (RCW) slabs flooring system. CS 2 (8,841.37m2 in 15 floors; 48 apartments) and CS 3 (4,943.31m2 in 6 floors; 32 apartments) have 18cm-thick prestressed concrete flat (PCF) slabs flooring systems (Figure 1). The structural materials' usage was quantified for all three buildings from structural design drawings provided by the local construction company, including labour calculated from reference costs tables (February 2013) from the Federal University of Espírito Santo's construction costs estimates laboratory [21]. For each case study, environmental indicators were calculated for two situations: one typical floor and the total superstructure. Foundations were disregarded to isolate the effects of soil's carrying capacity on sizing, and consequently on material consumption.

2.3 Calculation of multidimensional indicators

Data for computing the functional indicators was extracted from structural design shop drawings and calculation sheets provided by the responsible structural design practices.

Cradle to gate LCA studies for calculation of the environmental indicators were supported by software SimaPro 7.3 and performed following ISO 14040 [22] methodological guidelines. Thus, transportation and building construction, use and end of life stages were disregarded. Modelling of CP III-32 blended cement production has not considered any impact allocation criterion between steel and ground granulated blast furnace slag (ggbs). This assumption reflects the current practice of considering ggbs as a waste, with no environmental load, and is also aligned with ISO 14040 [22] recommendation to avoid allocation whenever unessential. Allocation is a widely recognized and challenging methodological problem in LCA for its potential significant impact on the results, but was not imperative for this study's purpose. Data for materials production cycle modelling were taken from national literature [23] or adapted from processes within SimaPro built-in Ecoinvent and ELCD databases [24] upon switching into the Brazilian energy mix. Data from Worldsteel database [25] however, could not be edited. Table 2 shows the functional unit adopted

and data sources used for modelling the studied production processes.



a) b) c)

Figure 1 – Case studies' typical floor plans: a) CS 1 RCW slab: b_{rib} = 15cm, h_{flange} = 5cm, distance between rib axis = 90cm; b) CS 2 PCF slab; c) CS 3 PCF slab.

Table 1 - Functional unit and inventory data source for the materials studied.

Construction materials	Functional unit	Data source
Concrete (fck 30MPa) [a]	1 m^3	Silva, 2006 [23]
Portland cement (CPIII-32) [a]	1 ton	Silva, 2006 [23]
Steel rebar (reinforcing steel)	1 ton	ELCD (European life cycle database) [24]
Plywood formwork, Sand, Gravel	1 m^3	Ecoinvent [24]
Wire Rods (prestressing steel)	1 ton	Worldsteel Association [25]

[a] Concrete mix with cement type CPIII-32 (66% of ggbs as clinker replacement in cement)

Service life is defined as the period between construction and the time to the first repair (tr), which may be determined using quantitative service life models for a particular element in a given environment. In this study, software Life-365 v.2.1.1 supported the prediction of service life and life-cycle costs of reinforced concrete structures exposed to chlorides [26]. Parameters considered are structure type and dimensions; temperature, chloride exposure conditions; concrete mix characteristics, such as water to cementitious materials ratio (w/cm), and replacement of cement (%) by slag, Class F fly ash, or silica fume (SCMs); steel type, and steel over concrete cross sectional area ratio (%).

To enable comparison and level the life span to reach 50-years design life, which is the minimum required design life (DL) of Brazilian residential buildings [16], LCA-based indicators considered the necessary repair schedules: 10 % extra volume of material was therefore added to the overall material consumption of the respective floor for each predicted flooring system repair event.

50 years was then considered as the reference period for the LCC studies, being 2013 set as the reference year. LCC indicators have also considered the same repair schedule. Life-cycle cost was calculated as the sum of the initial construction costs and the discounted future repair costs including labour, over the design life of the flooring system. The Inflation rate (%) is the annual rate at which the prices of goods and services will increase over the future; the Real discount rate (%) is the annual rate at which future costs are discounted to base-year dollars, net of the rate of inflation (that is, it is the real discount rate, which does not include the effects of changes in the prices of goods and services). Future material and labour costs are calculated on a present worth basis using the inflation rate, *i*, and the real discount rate, *r*. The present worth, *PW*, of a future cost *c* in year *t* is given by Eq.1.

$$PW = c \left(\frac{1+i}{1+r}\right)^t \qquad \text{Eq.1}$$

Annual inflation rate of 6.59% and real discount rate of 7.5% were adopted. These figures respectively represented (in April 2013) the Price index to consumer rate (IPCA), defined by the Brazilian Institute of Applied Economic Research (IPEA), and the special system of liquidation and custody rate (SELIC) established by the Brazilian Monetary Policy Committee. A 10-year interval between repairs was adopted, being the date of the first repair based on the service life predicted for each case study.

The local economy support (LES) indicator, on its turn, was calculated considering a 300 km radius threshold, established to better reflect the conditions in the region of study, for which there are plenty of known material suppliers available within a smaller radius than the usual 800-km limit suggested by some rating systems.

3. Results and discussion

Concerning the functional performance, CS2 (PCF slab) presented the best performance for span over height ratio and column density indicators. As to the reuse potential indicator, all three slabs were cast in situ and not designed for disassembly. CS1 (RCW slab) has better end-of-life performance, due to smaller spans which make demolition easier and safer, resulting in lower demolition costs than the PCF slabs used in CS2 and CS3. Furthermore, reinforcing steel has higher recycling market value than prestressing steel. Notwithstanding, the flooring system with no beams and longer spans (CS2) provides increased adaptability. Table 3 shows functional indicators' results. The highlighted values are the best among alternatives.

Table 2 – Functional indicators results for the three case studies

Functional Requirements	Indicators	Typical floor		
		CS 1	CS 2	CS 3
Structural safety	*Span over height ratio (ℓ/h)* [m/m]	24.7	**40.3**	33.3
Maintenance and constructability	*Reuse Potential* (% volume prefabricated with connections for disassembly) [% volume]	0	0	0
Flexibility/ adaptability	*Column density:* gross floor area over number of columns (m^2/ n^o), [m^2]	17.8	**30.6**	19.8
	Beam over slab height ratio, [m/m]	1	1	1
Durability	*Estimated Service life* [yrs] = time to first repair	**11.7**	11.2	11.2

The results of service life prediction for the studied conditions (Table 4) confirm the need of a repair schedule for each alternative to ensure service lives of 50 years, which means that, under those conditions, designing by the Brazilian standard NBR 6118 [27] does not assure compliance to NBR 15575 [15]. The environmental indicators per functional unit were multiplied by consumption of each material in mass or volume, including the material added by predicted repair events, and then divided by m^2 of structural area, in order to obtain each indicator per m^2. At typical floor scale, the PCF slabs of CS 2 (15-storey building) and CS 3 (6-storey building) presented the best results for EE and ECO_{2e}, respectively, while CS 1 (6-storey building with RCW slabs) showed best results for bWF, NRc and Mc. Results for the whole superstructure showed a similar trend, except for EE, whose best result pointed to CS 1 (Figure 2).

Service life estimated by software Life-365 v.2.1.1 for all case studies was similar because they had identical characteristic strength (30 MPa), mix composition and minimum concrete cover (c_{min}=2.0cm). LCC estimation by the software considers only concrete and rebar data. Thus, an input data adaptation was required to include plywood formwork and prestressing steel costs and labour concerning construction and maintenance. Therefore, for one typical floor, the total cost of plywood formwork including labour was divided by the concrete volume, and then added to the concrete cost with labour per cubic meter. Similarly, cost of steel input represents the weighted average between reinforcing and prestressing steel costs per kg, including anchors and labour. LCC for CS1 was 14% greater than for CS3, while the differences between CS2 and CS3 (~4%)

were negligible. Table 4 presents values of LCC indicators for the three typical floors, showing the best results for CS 3.

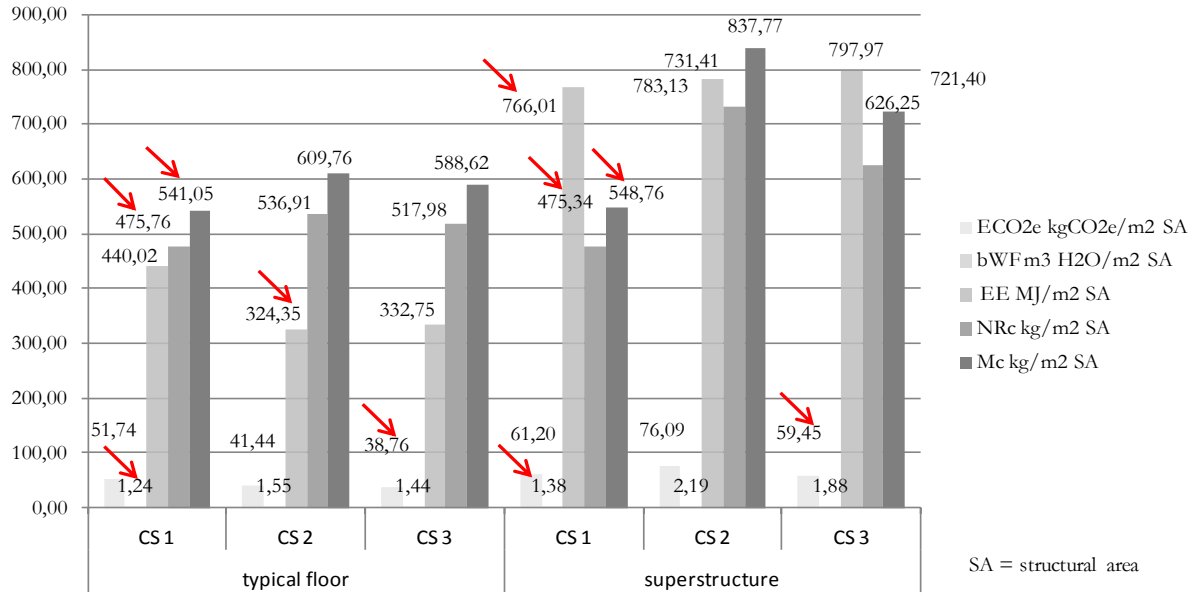


Figure 2 - Environmental indicators (ECO2e, bWF, EE, NRc and Mc) normalized per unit of structural area, calculated for a typical floor and whole superstructure of the case studies, assuming implementation of measures to achieve a 50-year DL, in accordance with Life-365 v.2.1.1 software

Table 3 - Service life and life cycle costs estimated for the three case studies using Life-365 v2.1.1.

Case study (CS)	Typical floor slab	Estimated Service life [years]	Life cycle costs (LCC) US $ /m^2 structural floor area						
			Initial costs					Repair costs[b]	Total life cycle cost
			Plywood formwork[a]	Concrete	Rebar	Prestressing steel	Total initial costs		
1	RCW	11.7	13.34	28.24	45.90	0.00	87.48	254,03	341,55
2	PCF	11.2	10.71	32.30	21.58	11.10	75.61	236,24	311,89
3	PCF	11.2	12.96	31.22	19.52	8.83	72.53	227,94	300,35

[a] considering plywood formwork reuse of five times maximum.
[b] values corresponding to four repair events discounted to present value.

Savings may result from the initial or maintenance costs of the structural frame itself, or given by optimization of other building systems. An LCC indicator calculation encompassing both the envelope and structural systems, for instance, should address the savings provided by *(i)* the lowest column density of CS 2 (Table 2) concerning parking spaces and typical floors adaptability, *(ii)* the reduction from a 27.5cm-thick waffle slab (CS 1) to 18cm-thick PCF slabs of case studies 2 and 3 on envelope plaster and coating consumption and costs, and *(iii)* the smallest dead weight of CS 1 RCW slabs (equivalent to a 14.7cm-thick flat slab) contribution to whole superstructure sizing and foundations. Savings resulting from design for disassembly-oriented options are more difficult to estimate, but could also be captured by the LCC calculation. As the envelope system was out of the scope of this paper and monetary figures and flows related to such additional data are usually not readily available at the structural design offices, they were not provided for the studied cases. Implementation of continuous value engineering techniques during an integrated design process would enable reasonably accurate estimation and allow the recommended approach.

For local economy support indicator (LES), the PCF slabs' systems of the typical floors in Case studies 3 and 2 presented the best results, with local materials responding respectively for 43% and 42% of total material costs, followed by the RCW slabs' system of Case Study 1 (32%).

4. Final remarks

The use of different databases for production cycles modeling, due to discrepancies or deficiency of national and international reference data for insertion in LCA platforms, may compromise accuracy of LCA-based indicators results, but still provides some reference. Also regarding these indicators results, the study showed that design life associated to unit of structural area are convenient functional unit descriptors for superstructure as well as floors, ensuring proper comparison among structural components performing same structural function over a given lifespan.

At whole superstructure scale, Non Renewable content (NRc), Material content (Mc), blue Water Footprint (bWF) and Embodied Energy (EE) indicators pointed to CS 1 (RCW slabs) as the best solution concerning the environmental dimension, while the Embodied CO_{2eq} indicator (ECO_{2e}) pointed to CS 3 (PCF slabs) as best performing flooring system. Concerning the indicators of the economic and functional dimensions, PCF slabs performed best. Therefore, next research steps include application of analytic hierarchy process to define relative importance of indicators in each dimension structuring them in a decision matrix assembling different weighting scenarios, to streamline choice of a single solution, whenever indicators show contrasting trends.

For vertical typologies, to proceed with the analysis of a typical structural floor in lieu of the whole building superstructure - analogously to structural design common practice - seems to be potentially valid. Amongst the five environmental indicators, four of them showed similar trends at both typical floor and whole superstructure scales. Embodied Energy indicator shifted trend when zooming into typical floor scale. The local economy support indicator provided useful information when applied to a typical floor. Due to the limited number of case studies, these findings are promising but still exploratory. Twenty-eight case studies are currently under analysis. If the observed tendencies are also confirmed for this larger sample, it might provide a significant reduction of time and effort for data collection. Also, enlargement of the case study library will provide robustness to analysis and allow in-depth statistical treatment and more assertive conclusions.

Exploring the most cost-and environmentally-effective strategies for increasing concrete structures service life exposed to a marine environment is also of interest. It is expected that this set evolve to a framework of functional, environmental and economic indicators as a tool to support design decision-making regarding important sustainability aspects in concrete structural frames selection.

5. Acknowledgements

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6. References

[1] SUPERBUILDINGS. FP7 Cooperation Programme. *Newsletter 2*, July, 2011. (Available on line at, http://cic.vtt.fi/superbuildings/. [Accessed on 02/23/2012]).

[2] CRISP – Construction and City Related Sustainability Indicators. *EC FP5 CRISP indicator analysis,* PeBBu generic task 2, final report, 2005, CIBdf, the Netherlands.

[3] LUETZKENDORF, T., HAJEK, P., LUPISEK, A., IMMENDOERFER, A., NIBEL, S., HAKKINEN, T. *Next generation of sustainability assessment – top down approach and stakeholders needs*. In: World Sustainable Building Conference - SB11 HELSINKI. Proceedings, theme 4, p.359-374, Finland, 2011.

[4] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT. *Environmental Indicators: Development, Measurement and Use*. OECD, 2003, Paris.

[5] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION – ISO/TS. Technical Specification 21929-1. *Sustainability in building construction -- Sustainability indicators -- Part 1: Framework for development of indicators for buildings*. 2006, Genève, Switzerland.

[6] UNITED NATIONS. UN ST/ESCAP/2561 (2009) – *Eco-efficiency indicators: measuring*

resource-use efficiency and the impact of economic activities on the environment. 28p. Thailand. (Available on line at, http://www.unescap.org/esd>. [Accessed on August/2010]).

[7] REAP, J., ROMAN, F., DUNCAN, S., BRAS, B. *A survey of unresolved problems in life cycle assessment. Part 1: goal and scope and inventory analysis*. International Journal of Life Cycle Assessment.v.1, p.1-11. May, 2008.

[8] DOBBELSTEEN, A.A.J.F., ARETS, M. J. P. AND LINDEN, A.C.V.D. *Smart sustainable office design–effective technological solutions, based on typology and case studies*. In: YANG, J. et al. Smart & sustainable built environments, Wiley-Blackwell, p. 3-13, 2005.

[9] DOBBELSTEEN, A.A.J.F., ARETS, M. AND NUNES, R. *Sustainable design of supporting structures. Optimal structural spans and component combinations for effective improvement of environmental performance*. Construction Innovation, v.7.n. 1. p.54-71, Emerald, 2007.

[10] HAAPIO, A., VIITANIEMI, P. *Environmental effect of structural solutions and building materials to a building.* Environmental Impact Assessment Review, v.28, 2008, p.587-600.

[11] KELLENBERGER, D., ALTHAUS, H. *Relevance of simplifications in LCA of building components*. Building and Environment, v. 44, n. 4, 2009, p. 818-825.

[12] MOON, K. S. (2009) *Sustainable design of tall building structures and façades*. In: SASBE 2009. Proceedings… v.1, pp.1- 8.

[13] AQUA. "*Edifícios habitacionais - Processo AQUA"© FCAV* – Fevereiro 2010 - Versão 1. Disponível em: http://www.sustentech.com.br/arquivos/AQUA_Residencial.pdf. Acesso em: julho/2011.

[14] CASBEE-NC, JSBC 2010. *Comprehensive Assessment System for Built Environment Efficiency – for New Construction*. Japan Sustainable Building Consortium. Technical Manual. 2010 edition. Tool 1.

[15] OLIVEIRA, F. R. M.; SILVA, V. G.; SILVA, M. G. (2013) *Indicators to Support Sustainability and Performance-Based Selection of Structural Frame Alternatives in Concrete: Preliminary Validation at Element Level.* In: SB13 Munich - Implementing Sustainability-Chan(g)ces. Munich 24-26 April, 2013. Proceedings, p.1-8, Germany.

[16] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. *Edificações habitacionais – Desempenho,* NBR 15.575: 2013. Rio de Janeiro, 2013, RJ, Brasil (in Portuguese).

[17] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION – ISO. Standard 6240. *Performance standards in building - Contents and presentation*. 1980, Genève, Switzerland.

[18] _____ISO. Standard 6241. *Performance standards in building - Principles for their preparation and factors to be considered.* 1984, Genève, Switzerland.

[19] _____ISO. Standard 21931-1. *Sustainability in building construction– Framework for methods of assessment of the environmental performance of construction works - Part 1: Buildings*. 2010, Genève, Switzerland.

[20] OLIVEIRA, F. R. M.; SILVA, V. G.; SILVA, M. G. *Towards Integration of environmental, functional and economic indicators for envelope and structural frame selection: proposal for discussion at the conceptual design stage.* In: World Sustainable Building Conference - SB11 HELSINKI, 18-21.oct.2011. Proceedings, theme 4 - Sustainable processes and eco-efficient technologies, p. 502-509, Finland, 2011.

[21] *Tabela custos referenciais* labor/ct-ufes padrão IOPES fev/2013 (ls=129,88%; bdi=28%). Available at: <http://siteiopes.no-ip.info/.>. Access in March, 2013 (in Portuguese).

[22] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION – ISO. Standard 14040: *Environmental Management – Life Cycle Principles and Framework*. Switzerland, 2006.

[23] EHLEN, M. A. *Life-365 Service life prediction model*, *v.2.1 – Users Manual*. USA, Jan, 2012.

[24] SILVA, M. G. (Coordinator). *Concreto de alto desempenho com elevados teores de escória de alto-forno: estratégia para consolidar o mercado da escória de alto-forno em cimentos e concretos.* Núcleo de Excelência em Escórias Siderúrgicas (NEXES). Centro Tecnológico, Universidade Federal do Espírito Santo, 2006 (Research report, in Portuguese).

[25] GOEDKOOP, M., SCHRYVER, A., OELE, M., DURKSZ, S., ROEST, D. *Introduction to LCA with SimaPro 7*, 2010 . Available at:<// http: www.pre.nl.>. Access in January 2012.

[26] FINKBEINER, M., DOWDELL, D., INABA, A., YOUNG, S. B. World Steel Association. *Life Cycle Assessment Methodology Report,* 2011. Avaiable at: http://worldsteel.org/dms/internetDocumentList/bookshop/LCA-Methodology-Report/document/LCA%20Methodology%20Report.pdf >. Acess in March 2012.

[27] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. ABNT. NBR 6118:2007. *Projeto de Estruturas de Concreto - Procedimento*. 2007, 221p. RJ, Brasil (in Portuguese).

Performance of Domed Roofs using a New Computer Model

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Short Summary

Domed roofs have been adopted by architects and engineers throughout the North Africa and other hot dry areas. However, the solar performance of such forms has rarely been quantitatively studied. In this study, variation of the direct solar radiation (DSR) over domed roofs was estimated and compared with standard horizontal flat roofing used in the typical houses.
A number of investigations have been carried out on domed shapes with varying cross section ratio (height/width) and orientations to study their solar performances. The geographical latitude (30 N) has been chosen to represent the hot region areas. The comparison showed that the use of the domed roofs leads to a significant improvement of indoor space in summer. The height-to-width ratio (Cross Sectional Ratio) has a significant impact on the solar performance

Keywords:Circular Dome, Roofs, Solar Performance, Curved Surface, Direct Solar Radiation.

1. Introduction

Economic buildings can be built in such a way that the structural elements are designed and oriented to take maximum advantage of the local climate (Sanjay et al, 2008). Olgyay [2] and Fathy [3] indicated that the curved roofs can reduce local radiant flux on a rounded surface. As a result, the heat flowing into buildings will be reduced. Bahadori [4] mentioned that domed geometrical structures with vents in their crowns increase natural ventilation through buildings. As a result, the indoor air will not become humid and the mean radiant temperature can be reduced. Gadi [5] reported that about 40% of domed roofs would be reduced from direct solar radiation. According to Vector [6], at noontime, the dome's performance is always better than that of a horizontal surface.

2. The Geometrical Resemblance

Wang [7] mentioned that the continuous curved surfaces could be approximated using a finite number of small flat planes. Elseragy [8] also explained that it is possible with an acceptable result to undertake calculation of radiation incidence on a large number of infinitesimal tilted planers that resembled the curved forms
In this study, the curved exposed surface has been divided into a number of small flat planers called "elements", The element can be a horizontal, vertical, or tilted surface; the slope angle for each element is different from the others, depending on the surface curvature of the exposed surface. The solar irradiation on each element depends on its specific orientation and tilt angle, and upon the other common parameters such as the time, latitude, atmospheric conditions and ground reflectivity. The total solar radiation received by the entire exposed surface can be estimated as the sum of the irradiation on the surfaces of all elements.

3. Geometrical Descriptors

If the geometrical characteristics (curvature parameters) of a domed form are well defined, the tilt

and azimuth angles for all elements can be determined. In this paper the geometrical characteristics are the height(H), depth(D), and width(W) of the dome form. As shown in Figure 1. The dome geometry was split into a number of segments (M-1) and rings (N-1).

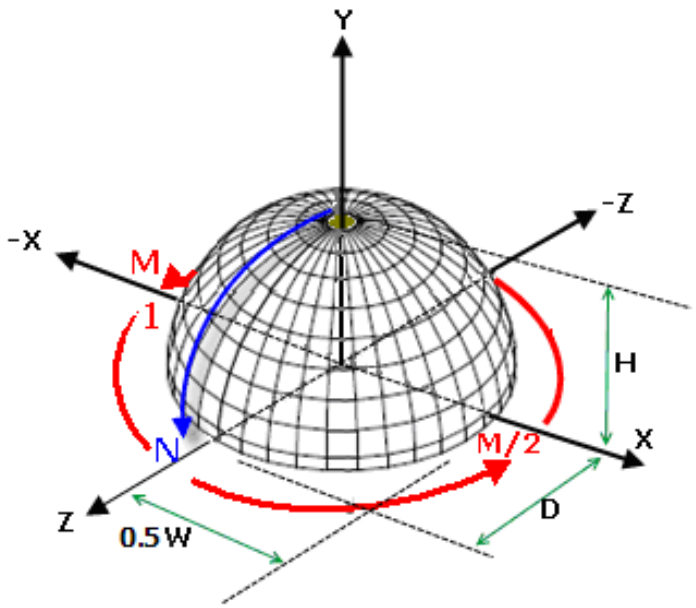


Fig. 1: A 3D-view of dome configuration

result is a grid consisting of a number of planar trapeziums (N-2)x(M-1), and a set of planar triangles (M-1) at the top of the dome. Each trapezium element has a node at each corner and each triangle has three nodes. M is the number of points (nodes) that are distributed on the perimeter line of the dome base, N is the number of nodes distributed along the curved line of the cross section. It is important to point out that the more resembling planar elements, the more accurate the result will be. The planar elements that have the same tilt angles constitute one horizon ring around the vertical axis (y-axis). Moreover, each group of planar elements has the same azimuth angles (same orientation) constitutes one segment.
The generated elements are mainly trapeziums and only one ring at the top of the dome consisted of triangular elements (due to that all the top nodes share the same location). The curved exposed surface of the circular dome CD can be defined as a (N-1)x(M-1) grid mesh. The mesh includes MXN nodes. The x, y, and z coordinates for all nodes can be changed by altering the dimension of the cross-section form.
The dome model is represented as shown in Figure 2. by a flat-bottom semi elliptical configuration (circular in CD). It is possible to define the exact position (x, y, z) of the node P on the dome surface by using the concentric circle method and through the following three steps:

Step 1 The elevation of the node on the dome surface can be determined by using the following equations.

$$TT=180//N-1 \quad (1)$$

$$y=H \text{ Sin } TT \quad (2)$$

Step 2 Consider the cross-section-shaped elliptic (circular in CD) at a certain height (y) above the horizontal base and determine its semi-major and semi-minor axes (radius=R).

$$R=NW=W/2 \text{ Cos } TT \quad (3)$$

R=ND=D SinTT (4)

Step 3 The position of a node at the new circular with the coordinates *x* and *z* can be located from the following formulas

x=RCos T (5)

z=RSin T (6)

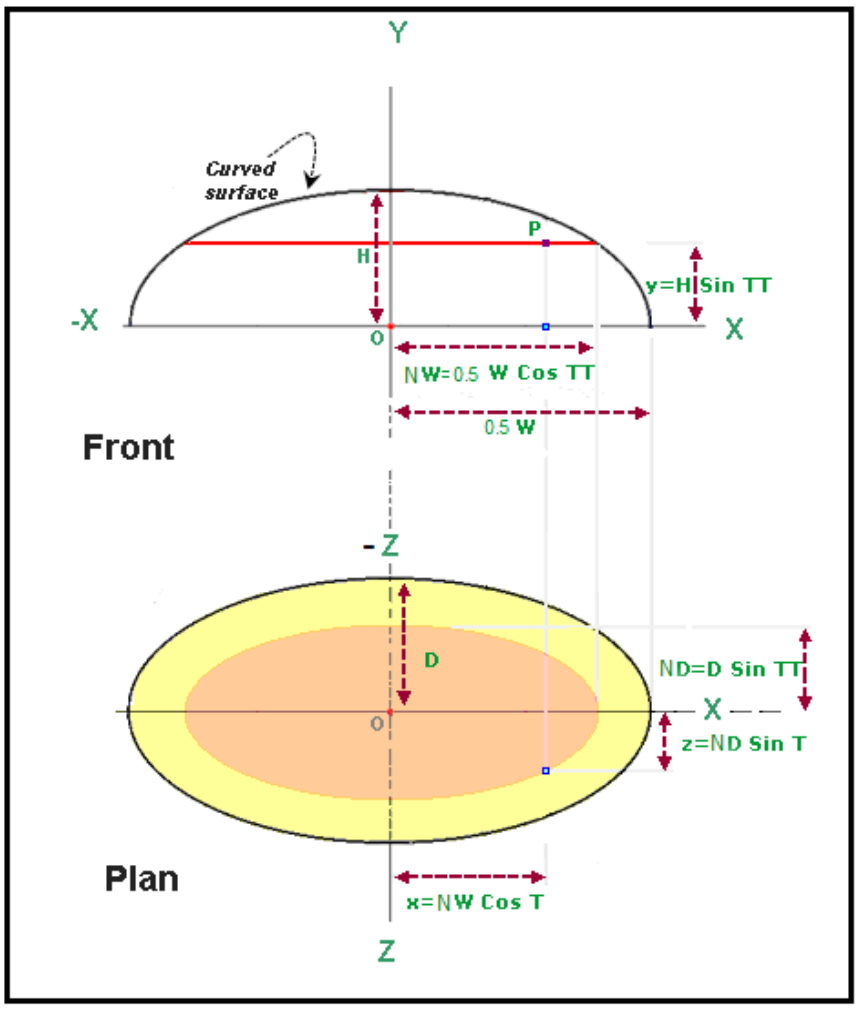


Fig. 2: A plan and cross-sectional view of dome form

4. Calculation of direct solar radiation

Several geometric calculations are needed to compute the DSR received by the dome surface: the slope, the area, and the azimuth angle for each grid cell. For area calculation, a simple algorithm was developed to calculate the area of trapezium and triangular elements. The tilt angle for each element on the dome surface is the angle between the element surface and the horizontal plane. the element's azimuth angle(ξ) for each element depends on the element angle (ψ) and that element's deviation (de) from the x-axis. The element angle can be measured on the horizontal plane, from the positive z-axis to the surface normal of the element. The surface azimuth angle (sh) for the domed form can be defined with respect to the z-axis, which is perpendicular on the cross section form.

In the Southeast and Northeast quadrants, the sign convention used for the element's azimuth angle is negative. In contrast to this, the element's azimuth angles in the Northwest and Southwest quadrants are positive.

The azimuth angle for each element in the Southeast quarter equals the surface azimuth of the dome (the angle between the south and the z- axis) minus the element angle. In this quarter, the element angle equals the deviation angle.

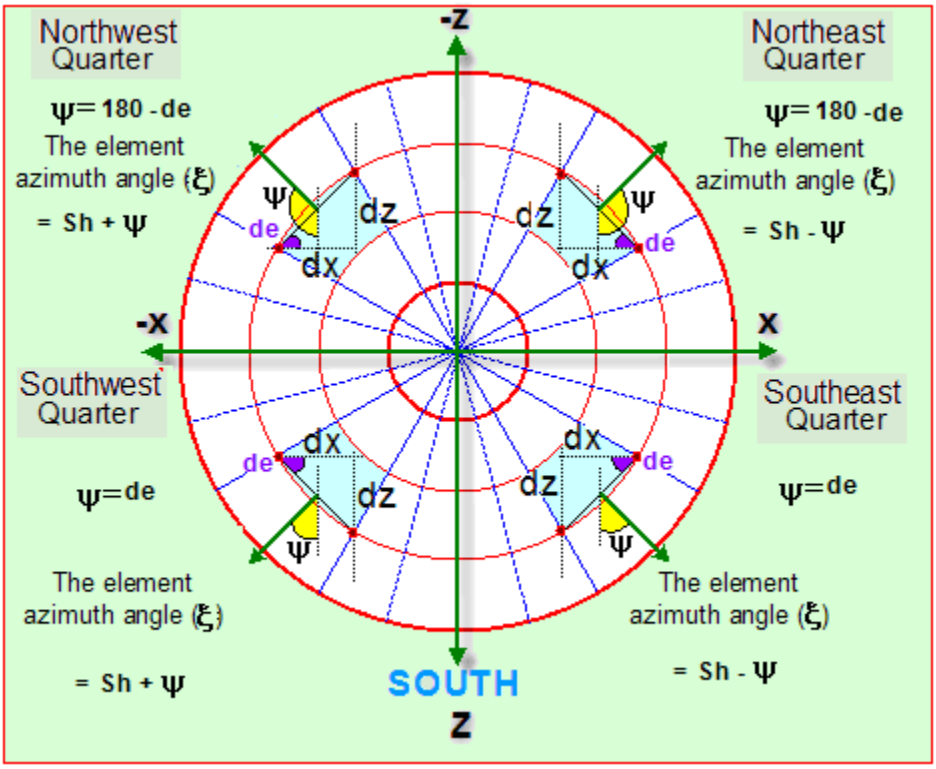


Fig. 3: The element azimuth angle for different elements with respect to the x and z axes

$$\psi = de = \tan^{-1}\left|\frac{dz}{dx}\right| \tag{7}$$

$$\text{The element's azimuth angle} = \xi = sh - \psi = sh - \tan^{-1}\left|\frac{dz}{dx}\right| \tag{8}$$

The following simple relation gives the element's surface-azimuth angle in the Northeast quarter:

$$\psi = \pi - de = \pi - \tan^{-1}\left|\frac{dz}{dx}\right| \tag{9}$$

$$\xi = sh - \psi = sh - \pi + \tan^{-1}\left|\frac{dz}{dx}\right| \tag{10}$$

In this quarter the sign convention used for the element's azimuth angle is also negative. For the surface-azimuth the following simple relation gives angles of elements in the Northwest quarter:

$$\psi = \pi - de = \pi - \tan^{-1}\left|\frac{dz}{dx}\right| \quad (11)$$

$$\xi = sh + \psi = sh + \pi - \tan^{-1}\left|\frac{dz}{dx}\right| \quad (12)$$

The sign convention used in this quarter for the element's azimuth angle is positive. The azimuth angle of each element in the Southwest quarter equals:

$$\psi = de = \tan^{-1}\left|\frac{dz}{dx}\right| \quad (13)$$

$$\xi = sh + \psi = sh + \tan^{-1}\left|\frac{dz}{dx}\right| \quad (14)$$

The sign convention used for ξ, is positive.

5. Validation of the Developed Program

The performance of the developed simulation program has been validated through comparing its results with the results of three different proven available models, namely ESRA, SRSM and RadOnCol. Three statistical indicators were used: root mean square error, RMSE, mean absolute error, MAE, discrepancy percentage, DP.
Comparison results (Table 1) for DSR intensity have illustrated a good agreement in the summer and excellent agreement during the winter months.

Table 1: Comparison results for DSR intensity in terms of MAE, RMSE, and DP

	MAE			RMSE			DP		
	Rad	ERSA	SRSM	Rad	ERSA	SRSM	Rad	ERSA	SRSM
Summer	1.56	-0.28	0.21	1.67	0.04	0.376	3.1	-4.2	-3.9
Winter	0.65	1.02	0.8	0.66	1.06	0.846	9.4	-0.93	1.86

6. Solar Performance of a Circular Dome.

This section examines the solar performance of seven CDs (CD is a dome having a circular base) surfaces with different curvatures, and compares the received solar radiation on their exposed surfaces to the solar radiation received on the horizontal surface. The cross section ratio (*CSR1*) between the vertical (the height of dome) and the radius of the dome base is used to define the curvature of the dome surface. Due to geometry of a CD, which is fully symmetrical, it does not have a particular orientation as in the case of elliptical dome. In other words, a CD shape faces all directions equally at the same time. For this reason, there is no impact of dome orientation on the

amount of solar radiation received by the exposed surface, since the DSR received by the CD surface is independent of the azimuth angle. Therefore, the changes of the solar performance of a dome are solely a consequence of the solar elevation angle.
In order to evaluate the effect of curvature (*CSR1*=0.5, 0.8, 1.0, 1.25, and 2) on the solar performance on CD surfaces, the insolation values of DSR received by the exposed surface of the CDs have been shown at latitude 30° north of the Equator (North Africa and other hot dry areas.), under different climate conditions (summer- winter), the form distribution of DSR on all of these shapes have an identical trend performance. However, worth to mention that there is a small distinguishing difference in the magnitude between the values of both seasons. It can be seen from figures 4 and 5 that the direct solar radiation per unit area received by the flat horizontal roof is higher than the domed roofs of various geometries in the midday. However, when considered on the total direct solar radiation of the roof itself, then the domed roof receives the highest value compared with the flat roof of the same base area.

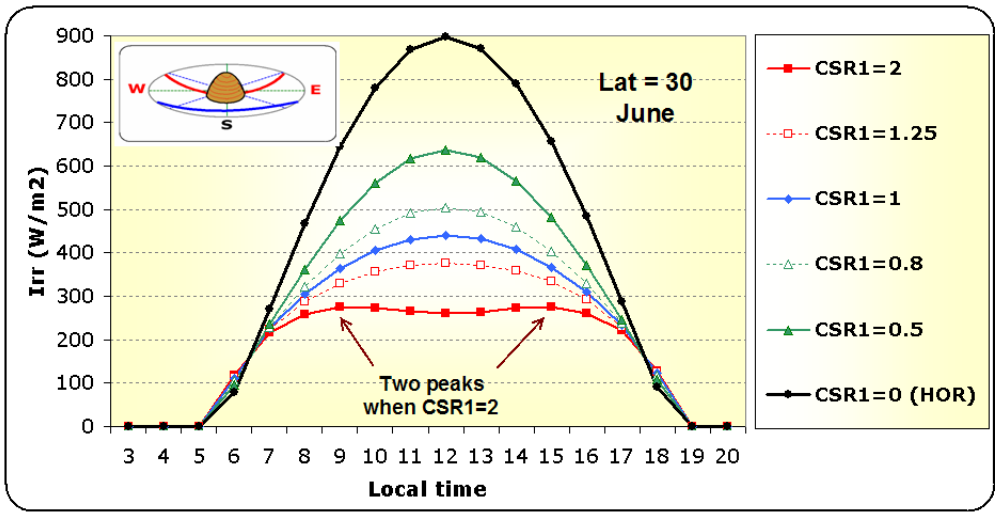


Fig. 4: DSR on CD surface during summer at 30°N

It is clearly recognized that all DSR curves have similar characteristics. At the Summer Solstice, each curve increases gradually from the intersection point at 6:30 am until it reaches the highest value at 12 noon when it drops gradually till it interacts with the other curves at 5:30 pm. All curves are symmetrical at about the noon axis. The distribution forms with *CSR1* equals two remains constant most of midday. The horizontal surface receives a maximum DSR. Curves in Figure (4) also indicate that all domes receive approximately the same values of DSR at either the early morning or the late afternoon. As can be seen from the same figure, as the *CSR1* increases the DSR incident on the dome surface decreases. Receiving less DSR during summer may add some credits for employing a domed surface with a higher cross-section ratio. However, it is necessary to keep the loss in the intensity as small as possible in the winter.
Figure (4) shows that throughout the day there is only one time-period *(6:30-5:30)* in which horizontal roof receives more DSR than that received by curved roofs. This scenario has not existed in winter time, as seen in figure (5), which created two desirable times during the early-morning and the late-afternoon. Both two periods are similar in that the horizontal surface receives less DSR than the curved surface.
In winter months, the daily DSR variation profile, as shown in the figure, can be divided into three periods. The first period is at the early morning from sunrise to 9 am, when all curves ascend individually from the sunrise point at 7 am, reaching approximately 300 W/m^2 at 9 am.
The second period (midday period) is from 9 am to 3 pm, all distribution forms soared independently from the intersection point at 9 am to the highest values at midday when each curve decreased sharply till intersecting again at 3 pm (third period). Results in Figure (5) suggest that the received DSR on curved surfaces decreases with the increase of the cross-section ratio.

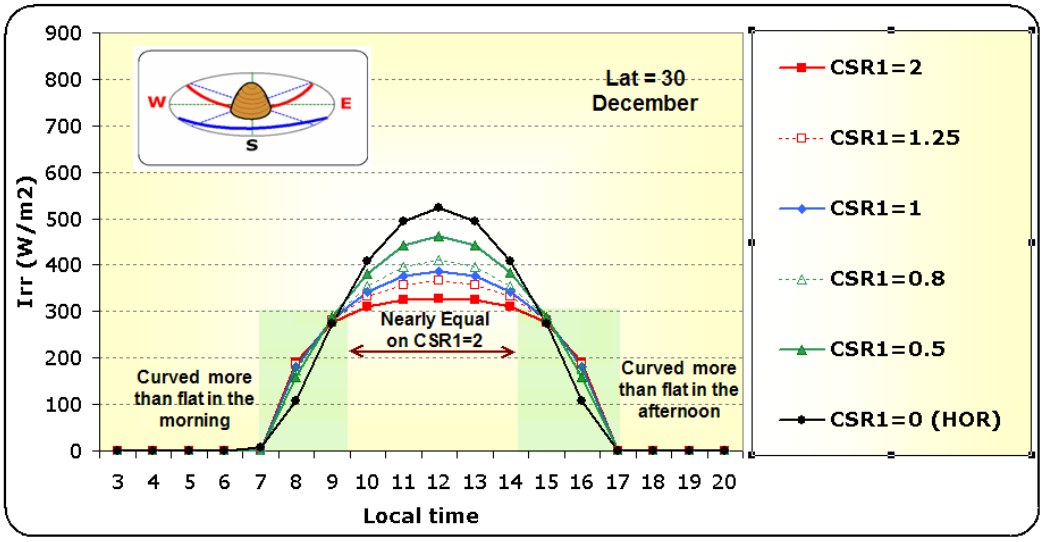


Fig. 5: DSR on CD surface during winter at 30°N

The result showed that the solar performance of circular dome is affected by its curvature in a following way: In summer, the circular dome with the highest ratio performs better than with low ratio at any orientation. In winter, the circular dome with the low cross section ratio is more preferable (receives maximum solar gain) than the circular dome with the highest ratio. In general, the circular dome is desirable in summer. However, the flat surface more efficient in the winter.

7. References

[1] SANJAY & SHAND P. "*Passive cooling techniques of buildings: past and present- A review*". Department of mechanical Engineering, National Institute of technology, Jamshedpur, INDIA, 2008

[2] OLGYAY V., "*Design with Climate*". Princeton University Press., Princeton, 1973

[3] FATHY H., "*Natural Energy and Vernacular Architecture*." Chicago and London, the University of Chicago Press, 1986

[4] BAHADORI N, HAGHIGHAT. "*Passive cooling in hot arid regions in developing countries by employing domed roofs and reducing the temperature of internal surfaces*." Building and Environment, Vol. 20, No. 2, pp. 103-113,1985

[5] GADI M. "*A Novel roof-integrated cooling and heating system*." International Journal of Ambient Energy, Vol. 21, No. 4, pp 203-212, 2000

[6] VICTOR M. "Solar performance of hemispherical vault roofs, building and environment." Vol. 38, pp 1431-1438, 2003

[7] WANG S, BOULARD T. "*Measurement and prediction of Solar Radiation Distribution in Full-Scale Greenhouse Tunnels*." Agronomie, Vol. 20, pp. 41-50,2000

[8] ELESERAGY and GADI, "*Computer simulation of solar radiation received by flat roof in hot-arid regions*." Eighth International IBPSA Conference, Eindhoven,

Embodied energy and CO2 emission associated with building construction by using I/O based data and process based data in Japan



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Summary

This study quantifies the embodied energy and embodied CO2 associated with building construction by using energy intensities and CO2 intensities obtained by process analysis and I/O analysis, and compare with each others in Japan.

The energy intensity and CO2 intensity table is calculated, which is based on 2005 I/O tables in Japan. In the intensity table, intensities of energy consumption and CO2 emission are shown as values of MJ and kg-CO2/million Yen, and each values are shown as based on producer's and purchaser's prices. It can be possible to calculate embodied energy and CO2 emissions due to constructions of various buildings.

The process-based data were referred to existing databases in Japan.

In this study, following comparisons are implemented;

・Comparison on energy intensity and CO2 intensity of building materials of the different databases: Cement, concrete, steel, glass, glass wool and lumber.

・Comparison on embodied energy and embodied CO2 of building by using different databases: a reinforced concrete office building and a steel frame structure office building.

The energy and CO2 emissions associated construction buildings were calculated by using energy intensity and CO2 intensity obtained by the I/O based analysis and the process based analysis. The results showed that many of intensities by obtained I/O analysis are larger than the intensities by obtained process analysis. The embodied energy and CO2 of office buildings by using I/O analysis are approximately 13% larger as the results of process based analysis.

Keywords: Embodied energy; Process based database; I/O based database

1. Introduction

Environmental and energy saving initiatives are becoming important strategies in the building sector today. Most of cases focus on operating stage of buildings. Building sector consume a lot of materials and components. When we look at energy and CO2 emission associated with building construction, embodied energy and CO2 occupy about 11% roughly in Japan, and it suggest that we should consider embodied energy and CO2.

If the energy saving strategies effect and reduce operating energy in near future, importance of embodied energy and embodied CO2 will increase.

Life cycle assessment is the one of the popular tools to assess building environmental loadings.

There are several issues among the life cycle assessment, different data collection measures, various or unclear data boundary condition settings and so on.

This study tries to make clear how different inventory databases influence on embodied energy

and CO2 emissions of buildings by comparing exiting databases.

This study selected three databases, JLCA-LCA Database, EE/EC database based on 2005 IO Table in Japan and Ecoinvent, and compared energy intensities and CO2 intensities of building materials and components. Furthermore, the study conduct analysis of embodied energy and embodied CO2 of a reinforced concrete building and the steel framed building.

2. LCI databases

2.1 Trend of databases

This study reviews LCA tools and LCI databases around the world. Fig.1 shows that LCI databases around the world and clarifies based on the methods of process-based analysis, I/O based analysis or hybrid analysis. This study could find 42 databases and most of the databases are created based on the process based methods.

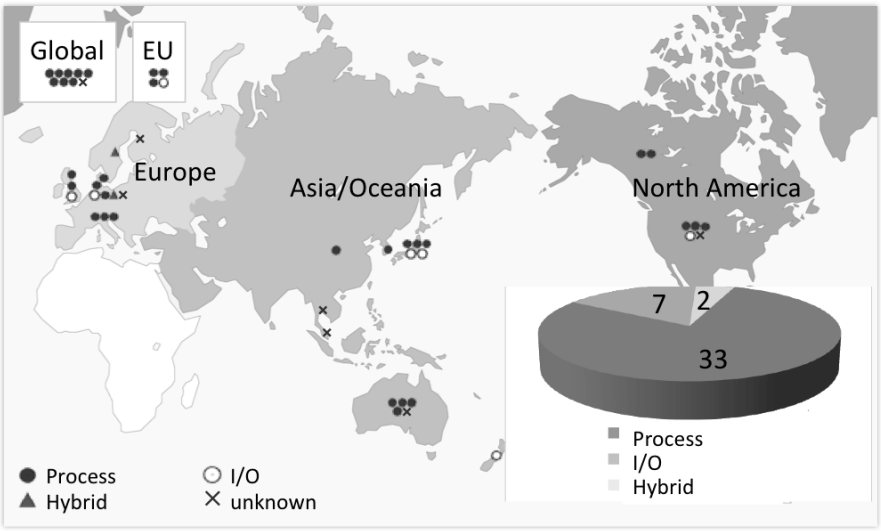


Fig.1 LCI databases in the world

3. Analysis of energy intensity and CO2 intensity of building materials and buildings

3.1 Summary and methods

This study selected three databases, JLCA database, IO database in Japan and Ecoinvent v2.2 compared these databases each other, and the energy intensities and the CO2 intensities of main building materials and components. Furthermore, the study conduct analysis of the embodied energy and the embodied CO2 associated with building construction.

This study conducted two case studies;

- Comparison on energy intensity and CO2 intensity of building materials
- Comparison on embodied energy and embodied CO2 of a steel frame building and a reinforced concrete building.

3.2 Selected databases for the case study

There are several databases in Japan and three database were selected considering characteristics of the process based database and the I/O based database, and the difference by the region.

- JLCA database in Japan
- Ecoinvent in Swiss
- EE/EC Database based on 2005 I/O Table in Japan

Table 1 Selected databases

		Total number of data	Number of data relating buildings	Data creation method
DB-1	JLCA	550	71	Process
DB-2	Ecoinvent	4000	39	Process
DB-3	EE/EC database 2005 I/O	401	57	I/O

3.3 Analysis

JLCA-LCA Database and Ecoinvent v2.2 provide energy and other environmental loading data for each items with explanation boundary conditions and the remarks by the data providers. JLCA-LCA 's energy data provide as consumption of electricity, crude oil, kerosene, coal and so on. It needs to convert these data into primary energy by using the primary energy factor.

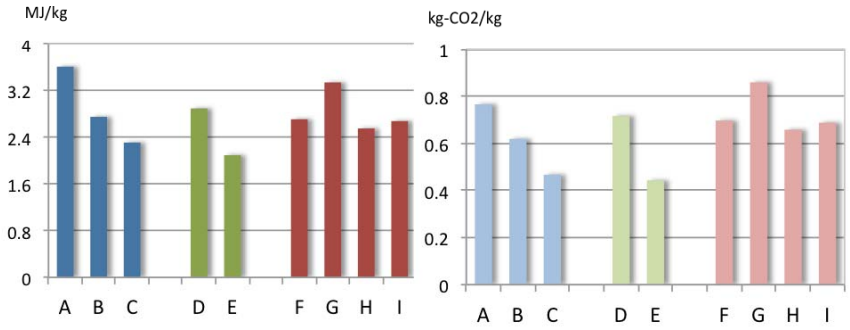
EE/EC database based on 2005 IO Table provides the energy intensity and CO2 intensity data. The unit of energy intensity and CO2 intensity of the I/O based database express MJ per 1million Yen and kg-CO2 per 1million Yen. This study converted these intensities into the unit uses MJ per kg or MJ per m3 and kg-CO2 per kg or kg-CO2 per m3 by using purchasers' price and quantity data of cost estimation information.

4. Results

4.1 Comparison on the energy intensity and the CO2 intensity of building materials

Fig.2, Fig.3 and Fig.4 show that the energy intensity and the CO2 intensity of cement, reinforced steel bar and sheet glass.

(1) Cement

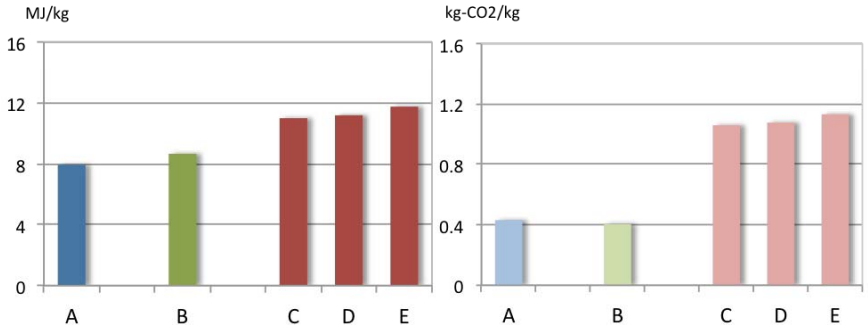


Legend of Fig.2

DB		Items
DB-1	A	Portland cement
	B	Fly ash cement Class B
	C	Portland blast-furnace cement Class B
DB-2	D	Portland cement
	E	Fly ash cement
DB-3	F	Portland cement
	G	High early strength portland cement
	H	Portland blast-furnace cement Class B
	I	Fly ash cement Class B

Fig. 2 Energy intensity and CO2 intensity of cement

(2) Reinforced steel bar

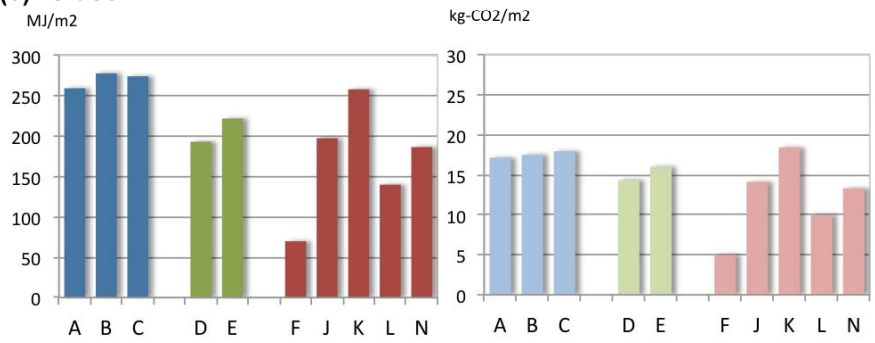


Legend of Fig.3

DB		Items
DB-1	A	Steel bar
DB-2	B	Electric furnace, non-low alloy
DB-3	C	Cold rolled & drawn profiled bars 1
	D	Cold rolled & drawn profiled bars 2
	E	Cold rolled & drawn profiled bars 3

Fig. 3 Energy intensity and CO2 intensity of reinforced steel bar

(3) Glass



Legend of Fig.4

DB		Items
DB-1	A	Flat glass
	B	Tempered glass
	C	Multiple glass
DB-2	D	Sheet glass
	E	Sheet glass coated
DB-3	F	Float plate glass
	G	Heat-reflective glass
	H	High performance heat-reflective glass
	I	Multiple glass
	J	Tempered glass

Fig. 4 Energy intensity and CO2 intensity of glass

4.2 Comparison on embodied energy and embodied CO2 of buildings

(1) Summary of buildings

A reinforced concrete building and a steel framed building are compared. Table 2 shows summary of these buildings, and Table 3 shows material quantities of the buildings. This study covers only seven building materials, concrete, reinforced bar, steel frame, timber, plaster board, glass wool and sheet glass.

Table2 Summary of case study buildings

	Bldg.A	Bldg.B
Structure	RC	S
Total floor area	9,097m2	9,097m2
Number of floors	10F, 1BF	10F, 1BF
Building type	Office	Office

Table 3 Material quantity of case study buildings

Main materials	(unit)	Structure	
		RC	S
Concrete	m3	0.919	0.426
Reinforced bar	t	0.122	0.036
Steel frame	t	0.009	0.103
Timber	m3	0.016	0.006
Plaster board t12.5	m2	0.777	1.012
Glass wool t50	m2	0.202	0.154
Sheet glass t12	m2	0.186	0.400

(2) Reinforced Concrete structure Building

Fig.5 shows the embodied energy and the embodied CO2 of the reinforced concrete building by using DB-1, DB2 and DB3. The result of embodied energy of DB-3 is 6.3 % larger as the result of DB-1, and the results of embodied CO2 of DB-3 is about 18% larger as the result of DB-1. Concrete and the reinforced bar occupy about 80% of embodied energy and embodied CO2.

(3) Steel structure buildings

Fig.6 shows the embodied energy and the embodied CO2 of the steel frame building by using DB-1, DB2 and DB3. The result of embodied energy of DB-3 is about 16 % larger as the result

of DB-1, and the results of embodied CO2 of DB-3 is about 28% larger as the result of DB-1. Steel frame occupies about 60% of embodied energy and embodied CO2.

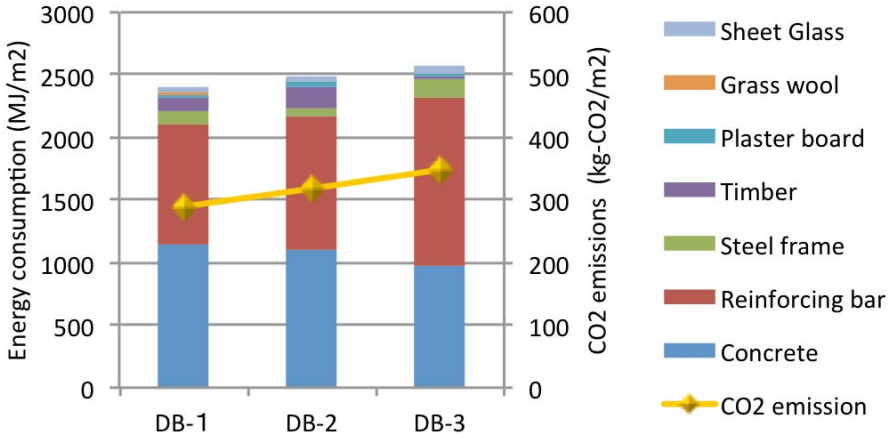


Fig. 5 Embodied energy and Embodied CO2 of Reinforced Concrete Building

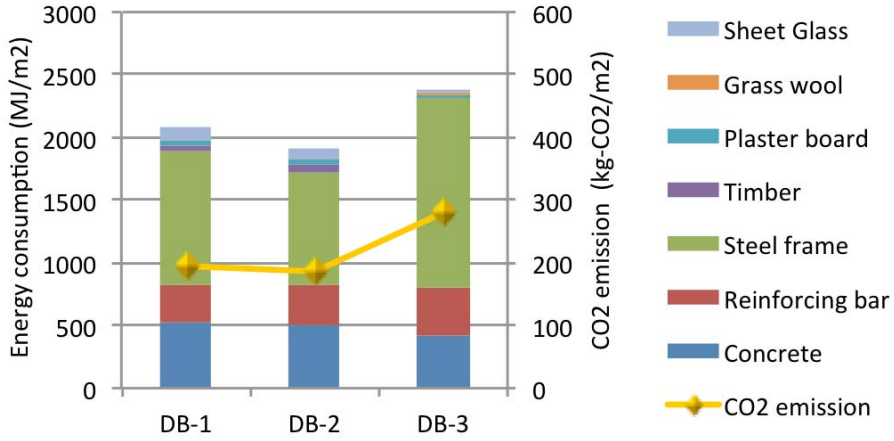


Fig. 6 Embodied energy and Embodied CO2 of Steel frame Building

5. Conclusions

This study conducted reviewing existing LCI databases and comparative case study on energy intensity and CO2 intensity by using different databases. The results show that different databases bring different results of embodied energy and embodied CO2 of buildings, and suggest that it is needed to prepare more accurate databases. This study compared only three databases and the number of building materials was limited to use as comparative study.

References

[1] Manish Kumar Dixit, José L. Fernández-Solís, Sarel Lavy, Charles H. Culp, Identification of parameters for embodied energy measurement: A literature review, Energy and Buildings, 42 (2010) 1238–1247
[2] JLCA- LCA Database, Life cycle Assessment Society of Japan, 2004
[3] SimaPro 7, Pre Consultants
[4] Ecoinventv2.2, Swiss Center for LCI
[5] Tatsuo Oka, CO2 intensities due to construction in various industrial sectors based on 2005 Input/Output Table, Journal of Environmental Engineering (Transactions of AIJ), Architectural Institute of Japan, Vol.653, 2010.7
[6] Noriyoshi Yokoo, Tatsuo Oka, Hiromi Numata, Keizo Yokoyama, Tatsuo Oka, Embodied energy and embodied CO2 associated with Building Industry in Japan, Proceedings of SB13 Conference in Munich, April, 2013
[7] Shunsuke Kaido, Noriyoshi Yokoo, Yukihiro Kawazu, Tatsuo Oka, Assessing trends in Embodied Energy and CO2 emissions Associated with Building Construction in Japan, Proceeding s of SASBE International conference in Delft, May, 2009

Combining Concepts of Energetic, Environmental and Economic Life Cycle Balance towards an Integrated Life Cycle Approach



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Short Summary

For the economic and environmental optimization of new construction projects as well as renovations, it is essential to estimate the resource consumption, e.g. of different design alternatives, at a very early stage of planning.

This paper presents an integrative environmental-economical model built on the life cycle costs model LEKOS [1], developed by Danube University Krems, and the environmental assessment software ECOSOFT by IBO. Purpose of the system integration is a combined economic and ecological life cycle model for buildings, realised in an easy-to-use tool for the evaluation of life span resource consumptions at different stages of the service life of the building.

The particular challenge is to link the various levels of detail and different system logics of real estate, construction ecology and energy optimization.

Acknowledgments:
The paper is based on the research project „LEKOECOS - A combined economic-ecological life cycle assessment model“ which is implemented through the research programme Haus der Zukunft Plus and financed by the Austrian Federal Ministry for Transport, Innovation and Technology.

Keywords: Life cycle costs; life cycle assessment; economic and environmental building optimisation; life cycle design tools

1. Motivation

Sustainable construction and refurbishment of buildings requires to know the economic and ecological resources consumed during building life cycle at an early stage of planning, in order to choose the optimized alternative.
The presented model LEKOECOS shows a combined life cycle model for buildings, developed on the basis of LEKOS, representing the life cycle costs model of the Danube University, and ECOSOFT, the ecological assessment tool of IBO. The model combines an economically and ecologically relevant catalogue of basic elements with the criteria of klima:aktiv and uses an implementation in an excel-tool. Validation of the model is done using practical examples of buildings. The great challenge in this project is the combination of details and systems as used by the real estate industry, the ecological assessment of construction and the energy optimization business.

2. Idea of the project LEKOECOS

It is the aim of the development plan of LEKOECOS (project duration March 1st 2012 until 31st January 2014, project supported by FFG) to create a simple tool that allows to determine the expected resource consumption over the life cycle of a building. The new tool represents a new model for the life cycle of buildings and is based on the life cycle costs model LEKOS of the Danube University, with main emphasis on costs, and on the ecological assessment tool ECOSOFT of the Austrian Institute for construction and ecology (IBO), with main emphasis on the ecological assessment of construction elements.

The first step is the establishment of a catalogue of economic and ecological basic elements. It is intended that the life cycle model for buildings LEKOECOS allows the combined economic and ecological optimization already at an early stage of the planning process, at a stage with various possibilities for planning variants. The calculation of life cycle costs is relevant for users, facility managers and owners of buildings as they have to judge on the long-term affordability of a property or estate. As opposed to that, benchmarks like CO_2-equivalents or the Global Warming Potential (GWP) are mainly of relevance for the public sector, e.g. with respect to meeting the target requested in the frame of the Art.15a B-VG agreement for the reduction of greenhouse gas emissions in the building sector or in the frame of the Kyoto-protocol.

Until now the corresponding analysis for costs or the ecological assessment of construction elements was carried out by a separate analysis using different tools. The combined tool allows for the integrated examination of economic and resource related performance. The tool supports the combined efficient use of financial means and natural resources and thus contributes to the protection of the environment and to the strengthening of the economic competitiveness.

Up from January 2014 the tool will be available for free download with a technical description and a user manual.

3. Life cycle costs programme LEKOS and eco software ECOSOFT

ECOSOFT was developed by IBO - Österreichisches Institut für Bauen und Ökologie on the basis of Microsoft Excel and is a software for the ecological assessment of building constructions and building equipment (HVACR). ECOSOFT may be applied to new buildings as well as to refurbished buildings.

The basis for the calculation in ECOSOFT is given by the table of reference values by IBO including more than 500 materials. The table is by default provided as part of the software and other data records can also be incorporated. With ECOSOFT is possible to determine the ecological effects of new buildings, refurbishments and waste management processes.

Moreover the following ecological benchmarks may be calculated: global warming potential (GWP),

acidity potential (AP), primary content of of renewable and non-renewable energy (PEI e, PEI ne), POCP, EP, OI3-Index (benchmark based on GWP, AP, PEI), indicator for waste disposal (EI). The results of the calculation are presented as an “environmental certificate for buildings”. Evaluation of these ecological parameters is based on the standardised method of LCA (Life Cycle Assessment), systematically determining the environmental impact of products, services or processes during certain stages of their service lives or throughout their entire life cycles.

LEKOS refers to the model for the expectation of life cycle costs for buildings and was developed by the Danube University Krems. It was one of the results of the basic research project “life cycle costs of building” that was funded by the “Klima- und Energiefonds” within the programme „Energie der Zukunft“ (Energy of the Future). The model also provided the basis for the standardised structure of life cycle costs which became the fundament of the new Austrian Standard B1801-2 [2].

Since 2009, comprehensive analyses and parameter studies according to Austrian Standard B1801-2 were carried out with LEKOS on various newly constructed and refurbished residential buildings, office buildings, and business centres, determining life-cycle costs values to generate planning recommendations for optimised follow-up costs. The current version of LEKOS has been available since 2012 as a product of the construction software ABK by the company ib-data. The LEKOS model is clearly structured according to the current standards of ÖNORM B1801-1 [3] and ÖNORM B1801-2. It contains no database, but is, however, equipped with various default settings and values.

4. Stages and boundaries of life cycle approach

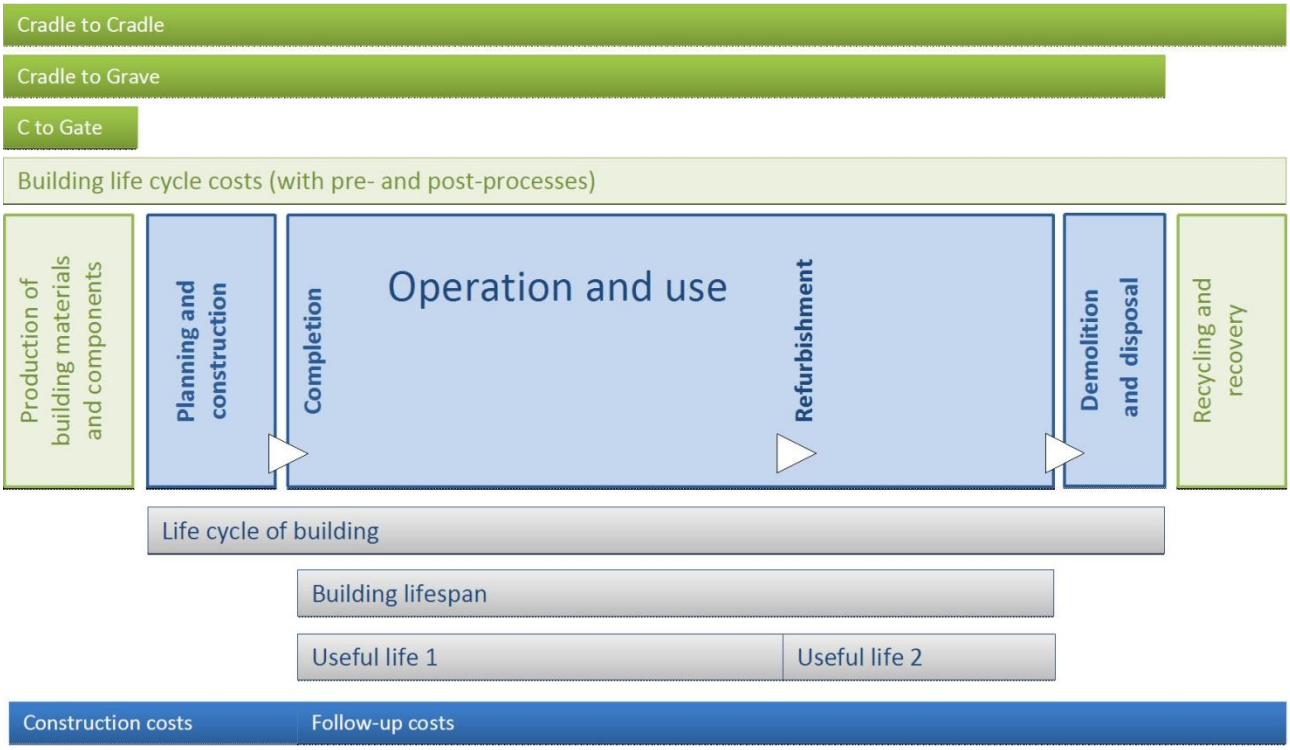


Figure 1. Building life-cycle costs and resources

One major challenge of the project LEKOECOS is the consistent combination of different approaches. Figure 1 shows the slightly different approaches of the economical and environmental definition of a building’s life cycle. The life cycle costs are the total costs of a building amounting throughout its life cycle. It is divided into construction and follow-up costs according to Austrian standards. Construction costs are those occurring during the planning and construction stage, whereas follow-up costs comprise of usage costs during the period of utilisation, and costs of demolition and disposal of the building. Life cycle costs can be seen as a parameter for a building’s economical sustainability.

The stage before planning and construction, in which the construction materials and components of the building are produced, is often taken into account for the evaluation of environmental sustainability of buildings. From an ecological point of view, the processes taking place after demolition and disposal of the building, such as recycling, recovering, or re-usage of materials and components, are of additional interest. Taking into account merely the production of building materials and components from raw material extraction to dispatching at the factory gates is called a “Cradle-to-Gate” view. Incorporating the stages of planning, construction, and usage as well as demolition is called a “Cradle-to-Grave” view. Closing the ecological cycle i.e. recycling, recovering, or re-using construction waste material is called “Cradle-to-Cradle”.

5. The concept of economical/environmental life cycle model LE-KOECOS

The tools LEKOS and ECOSOFT start each from a different degree of detail. The life cycle costs analysis of LEKOS is carried out on an aggregated level whereas ECOSOFT is working on a more detailed level of elements (construction elements and building equipment). In order to combine the two tools it is necessary to define a level of detail that allows to establish a working interface between the two tools. In this way several elements of ECOSOFT were combined in order to represent typical construction elements or building equipment for a defined type of building. At the same time it was necessary to install and maintain the compatibility with the structure of LEKOS. This approach induced for LEKOS the integration of additional data into the system in order to be able to produce the necessary ecological benchmarks.

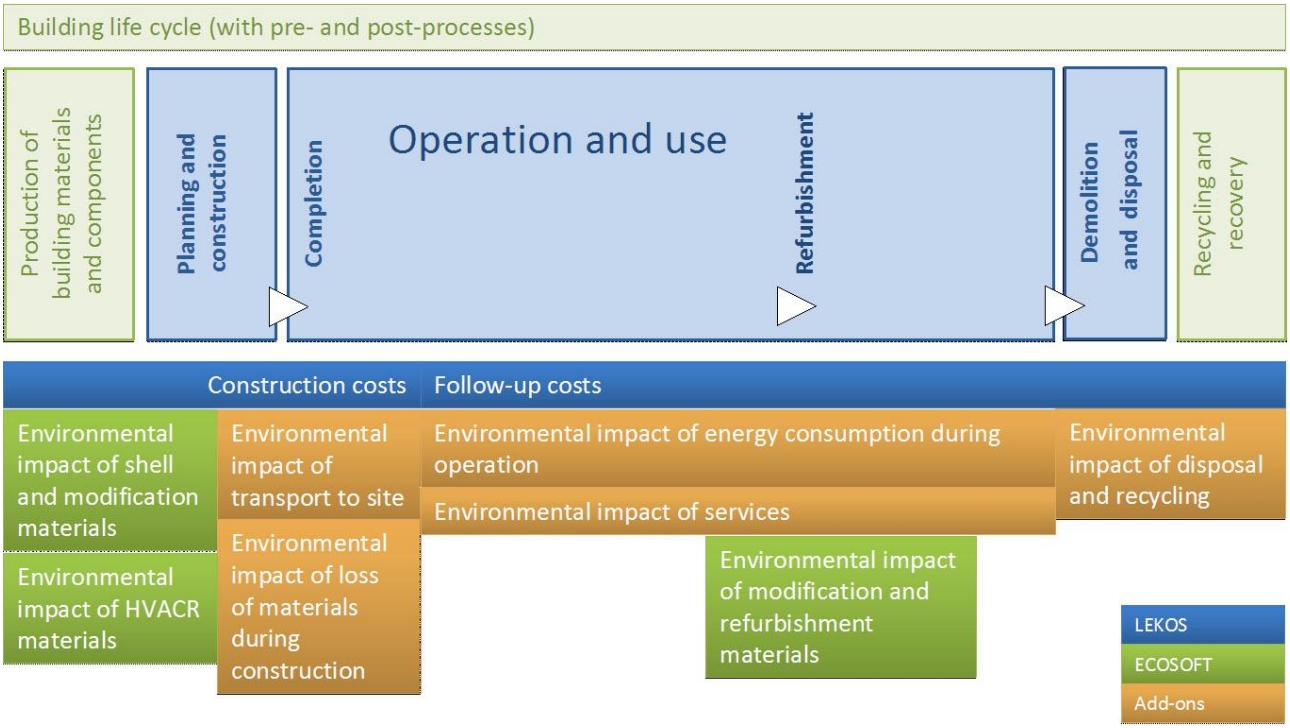


Figure 2. Costs and environmental impacts in a building’s life cycle

In a first step it was necessary to analyse both tools in order to decide on a degree of detail that is applicable for both tools. The analysis of the basic models revealed that the life cycle costs programme LEKOS has not only a much more complex structure than the ecological evaluation tool ECOSOFT, but also offers a comprehensive analysis of the building’s entire life cycle. Therefore, the decision was made to use LEKOS as the basic model and to adopt and expand the ECOSOFT model according to the structure of LEKOS.

Figure 2 schematically shows costs and environmental impacts evaluated by the LEKOECOS

model throughout the entire life cycle. The colour coding indicates which of the existing components of the base models can be adapted and used, and which model extensions are required. The life cycle costs model LEKOS (blue) covers the building's entire life cycle fairly well, whereas the ECOSOFT tool (green) is particularly suitable for the environmental assessment of building materials and components contained in shell construction and extension, as well as in HVAC. As a result, model components are added (brown) allowing environmental assessment of the life cycle stages planning and construction, operation and utilisation, as well as demolition and disposal or recycling.

Environmental impacts due to transport of materials and components to the building site and due to loss of material during construction are mapped with the LEKOECOS model. The energy consumption during construction is only partially taken into account since is negligible in comparison to the life cycle energy consumption. The environmental impacts during the stages of operation and utilisation mainly result from the energy consumption during building operation. The LEKOECOS model, however, maps also the environmental impacts resulting from services that are directly related to the operation of the building, such as buildings management or maintenance and cleaning services.

6. Basic elements catalogue and energy consumption during operation

Based on the process as described in part 2 a catalogue of basic elements is in development. It comprises typical elements of construction and building equipment (HVAC) for pre-defined types of buildings - that is office buildings, schools and residential buildings - and the corresponding eco-indicators for the construction and the operating phase.

At an early stage of planning only rough data on the quality of the building are available. However, data for energy consumption and the choice of energy carriers are a prerequisite for the determination of environmental performance indicators of the construction phase and the operating phase. Environmental performance indicators together with cost indicators for construction and operation are necessary for an integrated optimisation of the system.

In order to allow for the application of benchmarking tools in real estate without knowledge of details of the building, a classification of “low”, “medium” and “high” quality is widely used. The qualities “high”, “medium” and “low” are assigned to different concepts of buildings and related costs that are activated when choosing one of the qualities.

This approach of classification in the benchmarking of real estate is used to determine energy related eco-indicators in LEKOECOS. For example, for the input parameter “energy consumption” the user of the LEKOECOS tool may choose between “low”, “medium”, “high”. With that choice a scenario with all necessary parameters for energy consumption is activated in the background.

7. Results of the economical/environmental evaluation

The results of the LEKOS life cycle costs model are organised according to ÖNORM B 1801 part 1 (construction costs - Baugliederung) and ÖNORM B 1801 part 2 (follow-up costs). An analysis of the results' structures from an environmental point of view has shown that they are also suitable, with a few minor modifications, for presenting the ecological result of the LEKOECOS model. Not only the costs themselves, but also environmental indicators are displayed per cost position in the combined economical and environmental life cycle costs model. Some cost positions were, however, further subdivided to meet ecological demands. On the other hand, relevant environmental impacts are not associated with each individual cost position, nor is it possible to scientifically represent these with the data and methods currently available.
Therefore a structure of the LEKOECOS model with a clear allocation of economical and environmental results is given.

For the first version of the model the Global Warming Potential (GWP) was selected as a suitable indicator. It is comparatively easy to let the LEKOECOS model calculate further environmental indicators (AP, PEI, etc.) by extending the stored database.

Figure 3 presents the economical and environmental model's result showing costs and Global Warming Potential (GWP) as an example for individual cost positions, such as construction costs (floor construction) as well as annual (auxiliary power) and perennial (façade repair) follow-up costs.

Position in accordance with B 1801-1 and 2 Examples		Costs	GWP
E2.C.04	Floor construction	€	kg CO_2 eq.
F3.1.b	Auxiliary power	€/year	kg CO_2 eq./year
F7.1-4.C	Repair of façade	€/repair	kg CO_2 eq./repair

Figure 3. Presentation of economical and ecological model's result

8. Environmental impacts in the building life cycle

To define system boundaries, an evaluation of the ecological relevance of the individual products, processes and services of the building life cycle was therefore performed. In essence, each cost position was examined for relevant environmental impacts of various pre-products and sub-processes. The following environmental impacts were taken into account: production of materials and building components, freight and passenger transport, usage of cleaning agents, energy consumption during construction and building operation, waste disposal processes. Figure 4 depicts the simplified results of this environmental impacts analysis, and thus the system boundaries of the LEKOECOS model.

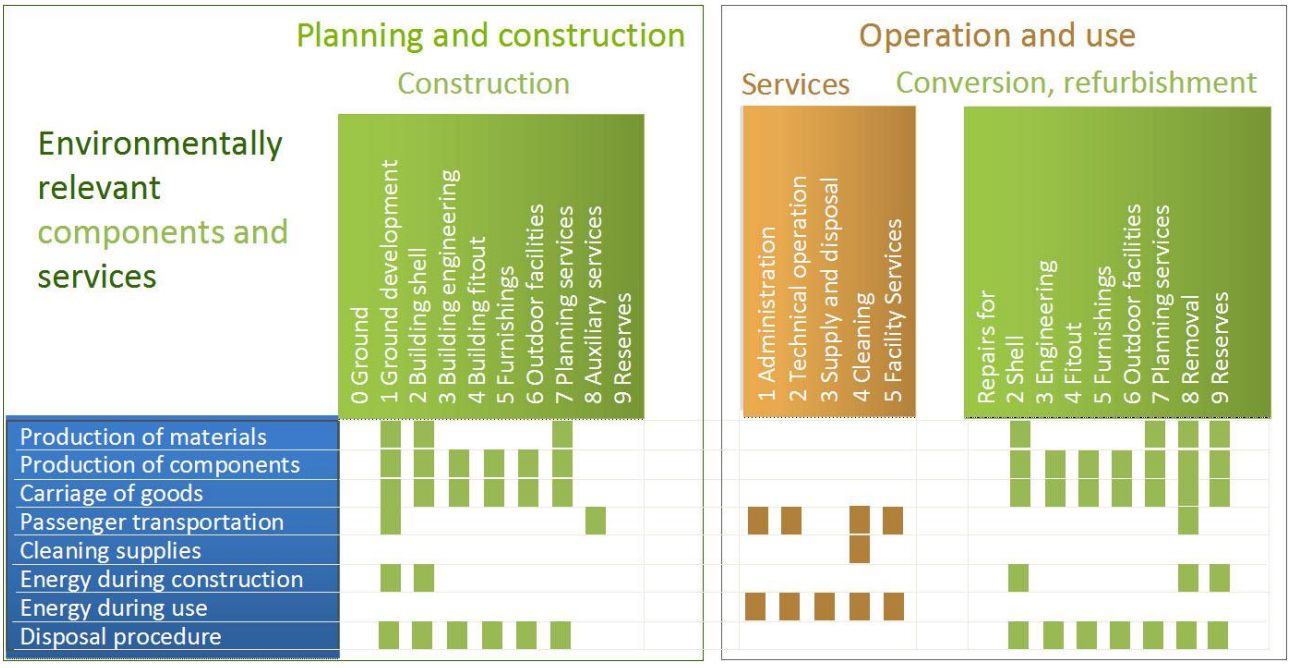


Figure 4. Environmental impacts of products, processes, and services of the building life cycle

9. Benefits of an integrated life cycle approach

The LEKOECOS project shows very clearly that the ambitions and requirements of ecology and economy do not differ greatly when considering the entire building life cycle. In both cases, the

focus is on optimising life cycle resource consumption. The individual resources may also be viewed financially, such as raw materials or energy. By combining the ecological and economical life cycle analysis, the user can simultaneously optimise all resources pertaining to the building life cycle. The LEKOECOS model allows the determination of important parameters for which, at present, calculations using two or more different tools are needed, causing partial overlapping of the respective input data and not guaranteeing complete consistency of parameters. The model's development also demonstrated that input data for cost determination can be, to some extent, gathered from the intermediate results of the life cycle analysis and vice versa. Apart from the simplified comparability of ecological and economical parameters, another major advantage of LEKOECOS is the reduced time and effort concerning data input.
The model's development also shows that methods and tools for economical evaluation have provided valuable input for the scope and system boundaries of the evaluation of ecological resource consumption. Thus, portions of the life cycle costs tool LEKOS have been adapted accordingly and used for the determination of ecological parameters. An inverse approach is also conceivable.

The LEKOECOS model will allow us to obtain new insights into the ecological-economical optimisation of a building during its entire life cycle. We will be able to identify potential ecological and economical conflicts of goals at the planning stages of buildings and solve them by optimising planning.

References

[1] Floegl Helmut: Berechnung von Lebenszykluskosten von Immobilien. Research project „Nachhaltig massiv“, Austrian Association for Building Materials and Ceramic Industries of the Austrian chamber of commerce. Krems 2010. http://www.nachhaltigkeit-massiv.at/wp-content/uploads/images-nachhaltigkeit-massiv/AP11_LZK-Modell_Endbericht1.pdf

[2] Austrian Standards Institute (2011) ÖNORM B1801-2 – Buildings project and property management – part 2: Follow-up costs, 2011 04

[3] Austrian Standards Institute (2009) ÖNORM B1801-1 – Buildings project and property management – part 1: Building construction, 2009-06

Can form follow energy? – Critical factors in modelling for computational design optimization

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Short Summary

The claim, that form can be derived from a desired performance, is quite popular among practitioners of architecture. Nowadays a lot of projects apply computational optimization methods to achieve this goal. The paper deals with the question in how far building geometry can be derived from the demands placed on it using such methods. It is highlighted that the process of defining the computational model always precedes a performance-based generation of a design. Thereby a model is defined, which can generate possible solutions to a given problem. These variants can be searched for optimal solutions (solutions which correspond to the performance criteria).
By using a simple case study, the automatic reproduction of the Socrates house, it is shown which factors must be considered when modelling for design optimization and how these factors actually influence the extent a form can be derived from certain performance criteria. It is argued that to be able to purely derive form from performance the generative model of the optimization model must be able to systematically vary topological as well as metrical properties of the building geometry.

Keywords: performance based design, optimization, design methodology, modelling

1. Introduction

Performance-based design (PBD) is one of the guiding principles of recent developments in architectural design methods. The idea of PBD is to derive architectural solutions (such as a building form) on the basis of the demands placed on them (performance criteria). Among others, one performance criteria is the energy demand of a building, also referred to as energy performance [1]. The energy performance is influenced by several factors: firstly produced by the geometry of the building, secondly by the materials of which the building is made and thirdly, by technical equipment used in the building. In the following we only refer to the first factor, the geometry of the building. This is particularly due to the fact, as the geometry of a building creates the conditions for the potentially possible energy gains and losses of a building. Of course thanks to the use of materials and technology on the one hand one can minimize deficits that are due to the geometry of the building (avoidance of thermal bridges by adding insulation, increasing the efficiency of the system technology) or use it's potentials (such as photovoltaic and solar thermal systems on sunny surfaces or the placement of thermal mass in sunny places in the interior of the building). However, the definition of the geometry of the building usually stands in front of such interventions and therefore can be regarded as the essential step in the design process.
Using computational methods, the search for an optimal geometry can be supported because they enable to generate and evaluate a large number of designs in a relatively short time. Criteria that are hard or slow to evaluate by humans, thus can be effectively integrated into the design process [2]. Optimization methods play an essential role for this. They also provide the key tool for PBD [3].
In the following we will examine in how far a form can be derived purely from the performance by an optimizing process, as it is propagated by the slogan "form follows performance" [4]. Therefore we will illustrate the basic functioning and the potential of optimization methods using a simple

case study. Based on this case study we will furthermore highlight critical factors which limit the extent to which form can purely follow performance.

2. Case study – The Socrates House

The Socrates House represents a very early example of a building form optimized in terms of passive use of solar energy [5]. This follows a simple principle. The walls and roof of the house were aligned in a way that the interior of the building gets as much sunlight as possible in winter and as little as possible in summer. As can be seen in Fig. 1, the roof of the house first is slightly inclined, so that the rays of the low winter sun reach far into the interior. Second, it forms a canopy to keep the rays of the high-standing summer sun from the interior. Third the two side walls are not parallel but form a trapezoidal ground plan to widen the opening so that the morning and evening sun gets into the building.

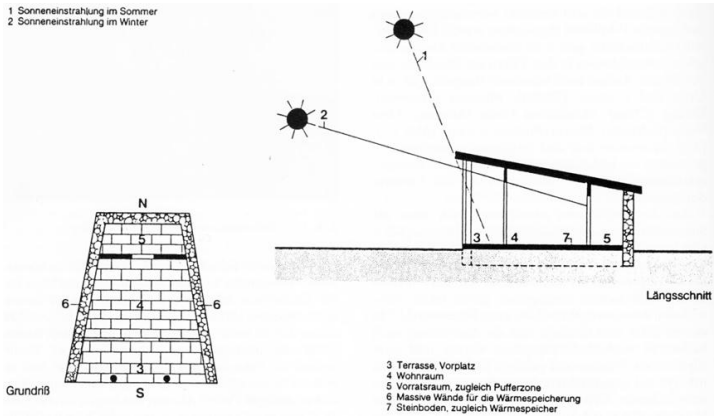


Fig. 1: Socrates House (Image taken from [5]*).*

In our case study we want to test whether solutions can be generated by means of a computer-based optimization strategy, which are similar to the "original" shown in Fig. 1. This study firstly serves the purpose of demonstrating the performance of such a strategy and second we want to draw attention to critical factors in computational modelling of such optimization or design problems. As an optimization method, we use an evolutionary strategy. This is very well suited for our purposes because for optimization, a priori, very few details are given about how a solution should be improved [6]. This is particularly important because we want to investigate the influence of the performance criteria on the geometry of the building.

2.1 Modelling

Modelling is an essential step in the application of optimization methods. This step always preceded the actual optimization and is needed to represent the optimization problem in a mathematical model readable by the computer [7]. Stachowiak [8] distinguishes three essential attributes of models: transformation, abbreviation and pragmatism. The former means that a model is always an image of something, a representation of natural or artificial originals that can itself be models. With second is meant that not all attributes of the original must be mapped in a model, but only those that are relevant for the particular problem. For this, the third feature of pragmatism is especially taken into account, which means that the model must be based on practicality. A model is not associated with an original by itself. A model is used by the model-makers within a certain period of time and for a specific purpose for an original. In our case, it should be noted that the original is not referring to a real existing building, but merely a building design whose attributes are not known at the time of modelling.

For the problem at hand, the optimization of building geometry using evolutionary algorithms, a model is needed for the representation of geometric variations, and for the performance evaluation of these variations. Models to generate geometric variants comprise algorithms that describe the properties of and the relationship between geometrical elements. These models are also referred to as Generative Models (GM). They can be controlled by parameters, whereby a change of one or more parameters results in a new geometric variant. To arrive at an optimal solution, these parameters are varied until a variant fulfils the performance criteria best as possible. The

parameters can be distinguished into those that change the metric and those that change the topological properties of the geometric model. Metric properties define the size and position of elements (e.g. a wall has a start coordinate P1 and an end coordinate P2 and a height h). Topological properties describe the relationships among the elements (ceiling X lies on wall Y and wall Y touches wall Z with their starting coordinates).
The Socrates House can be described by a simple generative model. The essential elements of the house are the three outer walls, the floor and the roof. The three walls include the rear wall of the building connected with the two side walls. The definition of the parameters for the generation of variants can be implemented in different ways. In the following two variants are presented to show different ways to create generative models and on the other hand to check whether the results differ depending on the model used. The two models are shown in Fig. 2. In model A only three parameters for the generation of variants are used: the height and the displacement of the front roof edge and the width of the opening of the house. The height of the back wall, or the depth of the interior are fixed. In model B all vertices of the house can be varied within a certain range.

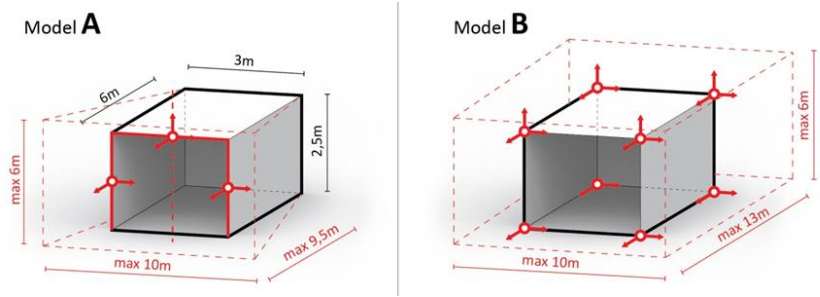


Fig. 2: Schematic of the two models.

For the evaluation of the variants generated by one the two GM the direct solar gains on the interior surfaces of the building are calculated. The performance criteria are to maximize solar gains (*Sg*) in winter and minimize them in summer. The result is a multi-criteria optimization problem with two conflicting criteria. Since the tool used for optimization (Galapagos, a plugin for Grasshopper for Rhino), does not allow systematic multi-objective optimization, the two performance criteria were combined into a single objective criterion as follows:

$$f(x) = Sg_{Winter} - Sg_{Summer} \qquad f(x) \rightarrow max$$

Sg_{Winter} and Sg_{Summer} are calculated from the amount of direct sunlight on all interior surfaces of the building on a winter day (21.12.) resp. on a summer day (21.06.). For this purpose, the corresponding areas were divided evenly and checked whether and at what angle the sun's rays for different time levels meet the respective grid cells. Fig. 3 shows the result of such an analysis on an exemplary model. The amount of solar gain is colour coded. Red cells indicate high, blue cells very low values.

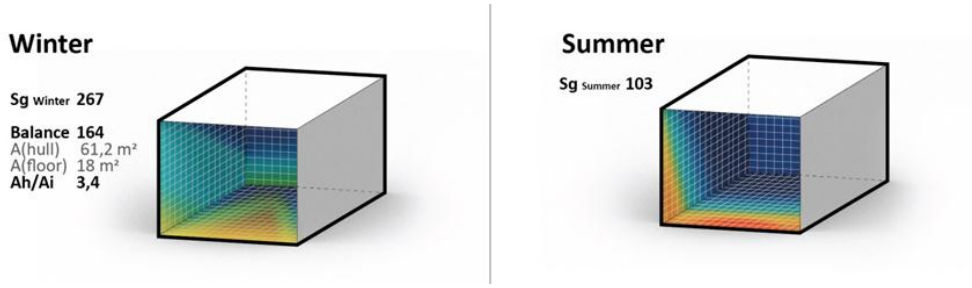


Fig. 3: Performance analysis (left: Solar Gains on a winter day, right: Solar Gains on a summer day).

2.2 Discussion of Results

For each of the two GM described above multiple optimization runs were made. A representative selection of the results is shown in Fig. 4. In the left column optimized solutions based on the model A, in the right column optimized solutions based on the model B are shown.

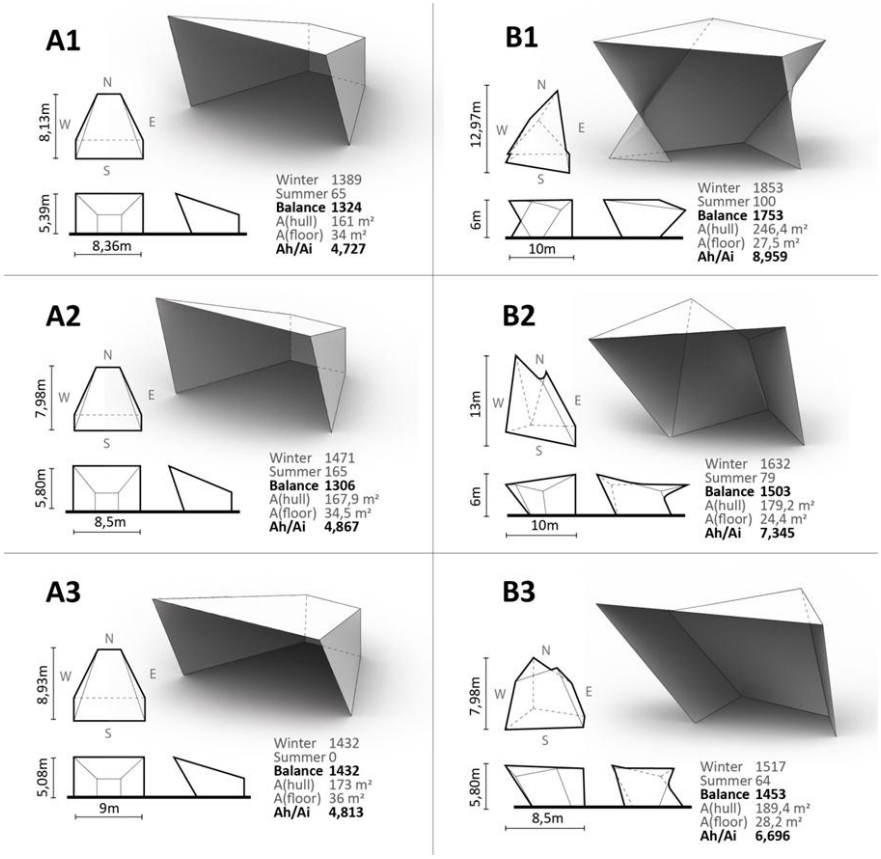


Fig. 4: Different optimal solutions resulting from the two different GM (left: Model A, right: Model B).

The results arising from the optimization using both GM show the essential characteristics of the solar house. Thus the sloping roof and the trapezoidal floor plan can be found in all solutions. It can also be noted that all the variants achieve the performance criteria. Compared with the not-optimized variant shown in Fig. 3, the balance (the difference between winter and summer) is up to 10 times higher. Large differences between the solutions derived from the two GM can be observed in the exact shape of the building, and in the ratio between floor and envelope. Using GM A, the forms are very similar to the original shown in Fig. 1. However, the results of GM B have a highly asymmetric and skewed shape. In addition, they have a much worse ratio of floor area to envelope (A_H / A_F). This is due to the fact that in models with a large envelope and the solar gains are higher since there is a larger surface to be shone on. Accordingly, such variants were favoured in the selection process of the optimization. A bad A_H / A_F ratio has a negative effect on the energy balance of the building, thus although the results of GM B have a slightly better winter-summer-balance compared to the ones of GM A their energy performance is significantly worse.

The similarities of the optimal solutions generated (high performance, essential shape features of the Socrates house) show that optimization methods in the design of buildings are effective in principle. However, the differences between the results of the two GM shows that creating a GM is an essential step in the application of optimization strategies: Depending on how the model is designed not only the range of variants, but also the solutions resulting from the optimization process changes. In the following two critical factors for creating a GM are discussed and implications for the use of optimization techniques in the design process are drawn.

3. Knowledge mapping in generative models

When creating generative models always a certain amount of knowledge about the problem and about possible solutions flows in. By knowledge all information is meant used for the description of

the model. This includes e.g. the information that a wall Y is connected to wall Z or that a certain minimum ceiling height should not be undercut. The amount of knowledge used is a useful criterion for distinguishing between generative models. If much knowledge is used to build in a model, one can speak of well structured models, if little knowledge is used, one can speak of weakly structured models.
The advantage of well structured models is that by a large number of constraints (restrictions), the generation of many unusable variants (e.g. buildings with a floor area of 5m², a triangular ground plan or a ceiling height of 1m) is avoided a priori. To search for an optimal solution in such a case only a few criteria are needed, since it is assumed that many other criteria are met by the introduction of restrictions. In weakly structured models, however, only a few constraints are defined, thus a greater range of variants can be generated. The advantage of such models is that they are able to generate solutions that have not already been covered by the foreknowledge of a model maker (designer). However, numerous useless variants are possible, which conflict with criteria, which were not defined as performance criteria. To find reasonable solutions in this extended range of variants, additional evaluation criteria are required.
The GM described in 2.1 fall into the above two categories: Model A (Fig. 2, left) can be regarded as a well structured model since many constraints were used for the description of variants (only the shape and size of the opening can be changed with three parameters). The solutions generated by optimization of the model only show few differences compared to each other and are similar to the original Socrates House. Model B (Fig. 2, right) can be described as a weak structured model. All points in the model can be moved. There are no dependencies between the points. The solutions obtained have large differences compared to each other and are only partially similar to the original. They also reveal a bad energy performance due to their high A_H/A_F ratio.
Considering the fact that due to the extended variant spectrum in weakly structured models the many unusable solutions need to be sorted out by additional evaluation criteria, the poor results of the second model are reasonable. In the following the weakly structured Model B is extended for one further evaluation criterion, the ratio of floor area to envelope area. The aim is to check whether it is possible if by this Model C solutions can be generated which have an improved energetic performance. The three performance criteria can be summarized as follows:

$$f(x) = Sg_{Winter} - Sg_{Summer} - (\mathrm{A_H}/\mathrm{A_F})\mathrm{w} \qquad f(x) \rightarrow max$$

A_H/A_F is the ratio of base to the envelope surface and a factor *w* is introduced to compensate the size differences of the values of *Sg*. Again several optimization runs were performed for this extended model. A representative selection of the results is shown in Fig. 5.

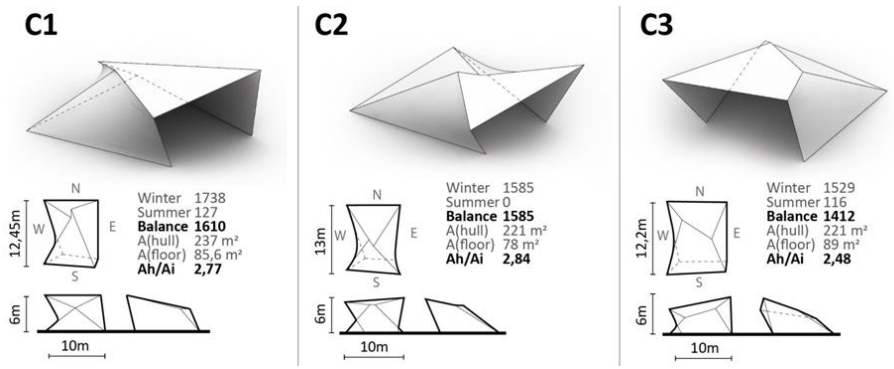


Fig. 5: Different optimized variants of the Socrates House resulting from an extended weakly structured model (Model C).

As can be seen in Fig. 5, all solutions show very good values in both the winter-summer balance, as well as in A_H/A_F ratio. The energy performance of these solutions is thus even significantly higher than those of Model A. This was achieved by not only inclining the side walls forward (to keep the summer sun from the interior), but also slightly outwards, thus in winter more sun rays meet the wall surface at right angles. Is noted as negative, that all variants have, compared to Model A, a large floor area, which due to the steeply sloping walls can not be used completely. This

problem could be avoided in principle by extending the model to other performance criteria.
If all evaluation criteria are known weakly structured models offer one main advantages. First, because the solution space is less restricted than in well structured models, the chance is higher to find innovative solutions. Thus for design problems in principle weakly structured models are preferable to well structured models. For a better understanding of this thesis a distinction of design problems into well-defined (tame) and ill-defined (wicked) problems [9] is helpful. Well-defined problems are problems that can be completely described and thus be easily converted into a problem-solving mechanism (in our case an optimization method). In ill-defined (or wicked) problems, the solution method, the elements, and the design goals are only incompletely known. These are defined through numerous iterations in the design process, where the objectives and the elements are changed frequently. This makes well structured models only partially suitable for such problems, since for any changes, the generative model must be adapted, which is both time consuming and knowledge-intensive. However mapping too much fore-knowledge about possible solutions in optimization models for solving ill-defined problems is unavailing, since the *"lack of knowledge is precisely what makes a problem a problem"* [5, p. 218].

4. Metric and topological properties of geometric models

Another critical factor for using optimization approaches for design problems are the parameters for describing the geometric variations in a GM. As described in Section 2.1 one can distinguish between metric and topological parameters. In the case study on the reproduction of the Socrates house, the topological properties were set fixed (side walls touching the rear wall, the roof lies on walls, etc.) and the metric properties were set variable (position of the start and end points of the walls, length of the roof, etc.). Thus the spectrum of variants include buildings with three connected walls and a roof, wherein the position of the walls, as well as the inclination and length of the roof is variable. Only within this spectrum (also called search space), an optimal solution can be found. Solutions which have, for example, a window in one of the two side walls are excluded a priori. However, making such decisions (e.g. whether and how many windows are placed in a building envelope) is an important step in the design of buildings. These decisions are made by defining the topological properties of the geometric model.
Limiting GM on the variation of metric properties is typical for many projects on optimizing the building form (e.g. [10–12]). Exemplarily for such an approach the work of Caldas [10] is briefly described: Caldas developed a system called GENE_ARCH, which allows to optimize building designs with respect to heating/cooling demand and the available amount of daylight in the interior. The performance of the variants was calculated using a special framework for energy and lighting simulation (DOE2.1E). The optimization algorithm tries to find solutions lying on the so-called Pareto front, which represent the best compromise between the different criteria. The system was in a case study, shown in Fig. 6. It shows very clearly the changes in the shape of the building, depending on whether the minimization of heat loss or maximizing the light entry has priority in the optimization: The best solution for minimal heat losses is a compact building form, while the best solutions for light interior result in buildings with a large envelope surface.

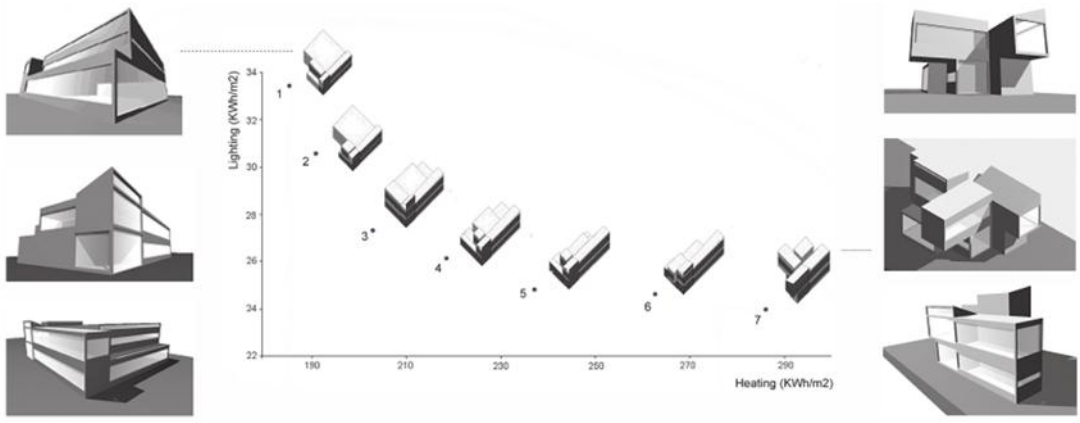


Fig. 6: Variations of building form, optimized for light entry and heating (image taken from [10]*).*

Regarding the modelling of the problem, it is easy to see in this example that the variation spectrum of the GM is highly restricted. The model describes eight cubes, each four are distributed on two floors. The cubes are joined in one point and can be varied in length, width and height. Variants, for example, which have a central courtyard, are not included in the model. The windows are located on two sides of each cube and can only be changed in their height. The width of the window is determined by the length of the respective wall. Placing multiple smaller windows is therefore excluded a priori. Similar to the case study presented in section 2 it can be noted that in models in which topological properties are fixed, and only metric properties can be varied, the search space is highly restricted. More generally one can also say that although numerous variations of a concept can be tested and optimized the creation of new concepts (which have the potential to be more optimal) is not possible. Assuming that important decisions of a building design are defined by its topological properties, then GMs are need to allow the variation of topological properties.
In the works of Watanabe [13] and Dillenburger et al [14] an interesting approach can be found in which only the topological properties of the building geometry are varied. Therefore a GM is used based on a three-dimensional grid. The points of this grid (also called voxels) represent spatial units (e.g. rooms or apartments). The GM generates variants by switching these units in the grid active (available) or inactive (not available). Dillenburger et al [14] showed that different building types can be generated through optimization of different performance criteria (Fig. 7). For example, minimizing the facade area and maximizing the light entry results is a compact building structure with numerous courtyards (Fig. 7, left). If only the amount of daylight in the interior shall be maximized solutions with several tall buildings occur (Fig. 7, middle). Between these two extremes numerous mixed solutions can be generated (Fig. 7, right).



Fig. 7: Different variants of an office building resulting from optimization (image taken from [14]*).*

With respect to the model used it can be considered as advantageous that a priori no information on the relations between the elements is needed. Thus solutions can arise, which consist of many individual buildings or even with connected volume. However, the voxel-model is based on elements with fixed positions and dimensions, thus only the existence of elements is variable. A precise tuning of e.g. distance between elements is not possible.
To summarize it can be stated that by defining the rules for generating variants also the range of optimal solutions is set. This issue was brought to the point by Gero & Radford [15] who compared the use of optimization methods for design with George Bernard Shaw's short story of a man who *"having lost his keys one night, searches under the lamp post, not necessarily because that was where he lost his keys but because that is where the light is"*. To find innovative solutions for a variety of performance criteria with the help of a computational optimization method the GM needs to cover the widest possible variant spectrum and thus must be able to change both topological metric properties. Such models are not yet known to the authors.

5. Form follows the computational model

Performance based architectural design is an interesting approach to meet the diverse needs of the building. Using computer-based methods, this approach can be supported usefully. The case study on the reproducibility of the Socrates House demonstrated on the one hand the potential of optimization methods in designing. On the other hand, it made clear that the extent a form can actually be derived from a desired performance depends on the model used to represent the optimization problem. This model consists of a generative model (GM) for the generation of geometric variants and an evaluation model (EM) in which the evaluation criteria and their weighting is determined.

Setting the GM is a crucial step, because a building can only be optimized within the spectrum of variants which can be generated with this model. When describing this model, a differentiation between metric and topological properties is necessary. It can be noted that, although important information for variation of the building geometry is defined by the topological properties, most models for performance-based form-optimization only vary the metric properties. In these models, the variation-spectrum is severely limited. Such models are only suitable for solving problems in which many decisions have already been made.
Defining the EM depends on the amount of knowledge used for defining the GM. Here, a distinction was made between weakly and well structured models. Generalizing, we can conclude that in well structured models, the solution of a problem is mostly included in the specifications and in weakly structured models, the solution of a problem is defined by the evaluation criteria. Although weakly structured models require many criteria, they are regarded as more suitable for solving design problems, because the variant-spectrum is not too narrowed in advance.
Concluding one can say that how to build a computational model for performance-based design optimization needs to be decided anew in each particular case, but on thorough considerations of the critical factors described in the article. To what extent a general model for design optimization can be built needs to be investigated in further research.

Acknowledgements:
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6. References

[1] CODY A. "*Form follows Energy*". GAM, Volume 2, 2005,
[2] ECKERT C, KELLY I, STACEY M. "Interactive generative systems for conceptual design: An empirical perspective". Artificial Intelligence in Engineering Design, Analysis and Manufacturing (AIEDAM), Volume 13/4, pp 303–320, 1999,
[3] OXMAN R. "*Performance-based Design: Current Practices and Research Issues*" International Journal of Architectural Computing (IJAC), Volume 6/1, pp 1–17, 2008,
[4] HENSEL M, MENGES A. "*Form Follows Performance: Zur Wechselwirkung von Material, Struktur, Umwelt*". ArchPlus, Volume 188, 2008,
[5] TREBERSPURG M. „*Neues Bauen mit der Sonne: Ansätze zu einer klimagerechten Architektur*". Springer, 1999,
[6] RECHENBERG I. „*Evolutionsstrategie '94*". frommann-holzboog, Stuttgart, 1994,
[7] PAPALAMBROS P Y, WILDE D J. "*Principles of Optimal Design: Modeling and Computation*". Cambridge University Press, Cambridge, 2000,
[8] STACHOWIAK H. "*Allgemeine Modelltheorie*". Springer, 1973,
[9] RITTEL H W J, WEBBER M M. "*Dilemmas in a General Theory of Planning*". Policy Sciences, vol. 4, pp. 155–169, 1973.
[10] CALDAS L. "*Generation of energy-efficient architecture solutions applying GENE_ARCH: An evolution-based generative design system*". Advanced Engineering Informatics, Elsevier, DOI: 10.1016/j.aei.2007.08.012; 2008, Volume 22, pp 59–70,
[11] GERBER D J, LIN S H, PAN B. "*Design Optionieering: Variation - Exploration - Correlation*". Technical Report, Autodesk, Los Angeles, 2012,
[12] KÄMPF J H, ROBINSON D. "*Optimisation of building form for solar energy utilisation using constrained evolutionary algorithms*". Energy and Buildings, Elsevier, DOI: 10.1016/j.enbuild.2009.11.019; 2010, Volume 42/6, pp 807–814,
[13] WATANABE M S. "*Induction Design: A Method for Evolutionary Design*". Birkhäuser, 2002,
[14] DILLENBURGER B, BRAACH M HOVESTADT L. "*Building Design as a compromise between qualities and costs*". Proceedings of CAAD Futures, 2009, pp 458–471,
[15] RADFORD A D, GERO J S. "*Multicriteria optimization for architectural design*". Design Optimization. Academic Press, New York, 1985, pp 229–258.

Comparative study of energy performance of an institutional building for different façade configurations in Saudi Arabia



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Short Summary

This paper aims to examine the energy performance of multi- story buildings by changing the settings on available building façade keeping other parameters constant at standardized values (such as orientation, illumination load, type of HVAC system etc.) in Saudi Arabia. Simulations were carried out for different types of facades. The DesignBuilder 3.0 software was used as a simulation tool for calculating energy consumption of the analyzed building. This paper shows the annual energy performance of the building for typical Saudi Arabian climate. Six different economically available building façade are compared. It is shown that there is a significant effect on energy consumption and cooling load on the change of façade as a result of which utility operational costs are reduced. The result of the paper enables to select the optimum alternative of façade configuration; to help decision makers reduce the energy consumption of commercial buildings.

Keywords: Energy performance, Building facades, operating costs, Energy consumption,

Simulation, optimum alternatives

1. Introduction

Façades not only shape the appearance of building, they also determined the indoor climate, energy consumption and operating costs of a building. They directly influence the heating and cooling loads, and also indirectly influence on lighting loads when day lighting is considered. In addition to being a major determinant of annual energy use, they can have significant impacts on the cooling system and electrical demand. However, they are prominent architectural and design elements and they responsible of occupant's performance, satisfaction and comfort.

Air conditioning systems is buildings in Saudi Arabia are responsible for about 70% of their energy consumption [1]. Whereas the electric consumption for air-conditioning in United Kingdom and United States is 22% and 21% respectively as the analysis provided by Saudi Electric Company. Also, according to the same analysis the average electricity consumption of an apartment in Dammam is 20,000 kWh/year, while the average consumption of areas of similar climates in the United States is 8000-10,000 kWh/yr. From this we conclude that buildings are large consumers of energy in Saudi Arabia and therefore prime candidates for energy conservation activities. Since they are replaced very slowly and most of the existing buildings do not meet energy efficient standards, retrofitting would be essential to minimize energy usage. At least cost energy strategy conservation should be supported in the energy future. For every unit of energy saved by a given

measure of technology, resources will be saved, and the annual maintenance costs of producing the unit of energy will be eliminated [1-3]. Therefore, considerable attention is currently been paid on reducing the energy demand for cooling purposes in buildings. Ways to monitor energy consumption of buildings and the prospects of energy saving in residential space cooling have been widely discussed [4–8]. Methods for predicting the annual building cooling energy demand have also been presented in a variety of studies [9, 10]. The demand for energy efficient buildings has made the application of building simulation a must, rather than a need.

Because of the increasing amount of new residential and commercial construction using building facade technologies, it is very important to examine the energy consumption for the building by selecting the effective façade system considering the availability of material in Saudi Arabia. This study aims to examine design factors that could contribute to greater reductions of energy consumption and CO_2 emissions. In comparing several facade with the different U-value, it can be observed that some facade configurations are more thermally effective than others (Table 2).

2. Methodology

The test building analyzed in this paper is constructed in a moderately exposed parking area within the compound of University of Dammam and are constructed in such a way that they shield another building from the outdoor winds.

DesignBuilder 3.0 was used to fully integrate the various aforementioned factors (see considerations on the program [11]), to determine hourly building energy loads and specific loads for end users, such as external lights and others. This made it possible to simulate many architectural designs with the aim of obtaining better solutions for the project within the analyzed context. DesignBuilder 3.0 is a computer simulation program used to explore the electrical energy consumption pattern of a typical building, simulating its dynamic thermal performance.

At first, several technical visits, followed by surveys were carried out to collect information about the existing building. The following items were taken into consideration:

- Built volume with internal partitions and outside openings, described in terms of materials as well as its thermal characteristics, use (office, toilet, etc.) and dimensions.
- Existing façade configuration of the building
- Geographic orientation of the construction
- Timetable of working hours, usage intensity of equipment and air conditioning system data.
- Hourly meteorological data for Dammam.

Through the use of simulation software, a building model was created; based on this model, architectonical modifications were simulated. This building energy-use simulation software uses its own climate data file. Building description for the the simulation of program is mentioned in Table1.

Table 1: Building description for the simulation program

Parameter	Value
No. of floor	3
Total area	4394 m^2
Floor height	3.7 m
Orientation	North to South
Infiltration rate	5.0 m^3/h/ m^2
Ventilation rat	7.5 L/s/person
Thermal zones	Multi-zones
Equipment	20 W/m^2
Lighting	18 W/m^2
HVAC	Central System
Occupancy	4.5 m^2/person
Set point	(22–24 ◦ C) summer, (20–22 ◦ C) winter

The methodology used to study the building consisted in checking the existing façade configuration and comparing it with other alternatives based on locally available economical façade materials.

Six scenarios were developed by façade alteration in the existing building which effect in reducing cooling loads and hence energy. The results of these alterations were shown in Table 3 that provided input for a critical analysis of these parameters.

3. Data description

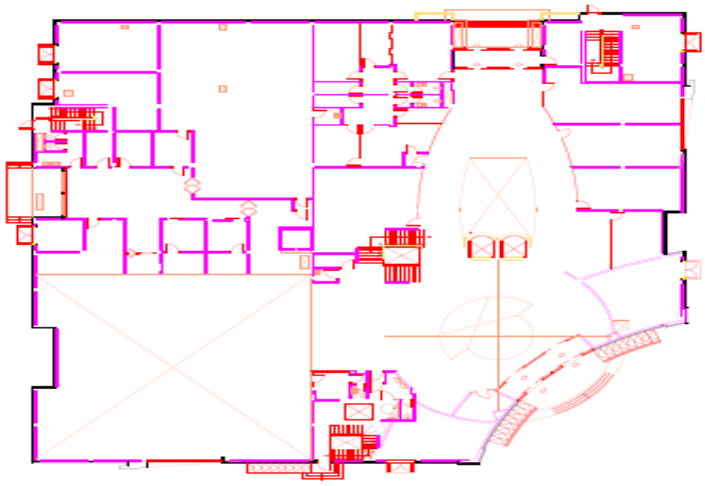
The analysis focus on an institutional building, located in a North Zone of the city of Dammam, Kingdom of Saudi Arabia at latitude 26˚23´N and longitude 50˚11´E, and temperatures varying from 15.3℃ to 45 ℃ on average. The building is in an urban area, with medium density occupation. The orientation of its frontal facade is 58˚ east of North. Construction of the building ended in 2012. The plans of a typical floor of the building under consideration and its elevations and location of Dammam city on Saudi Arabia map are shown in Figs. 1 and 2 respectively.



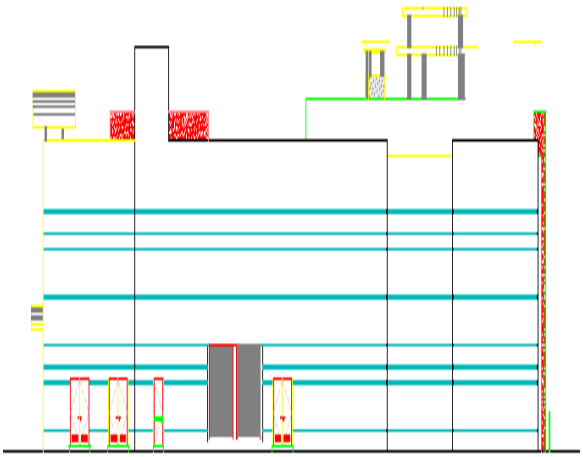
Fig. 1: Location of Dammam city on KSA map

4. Simulation data

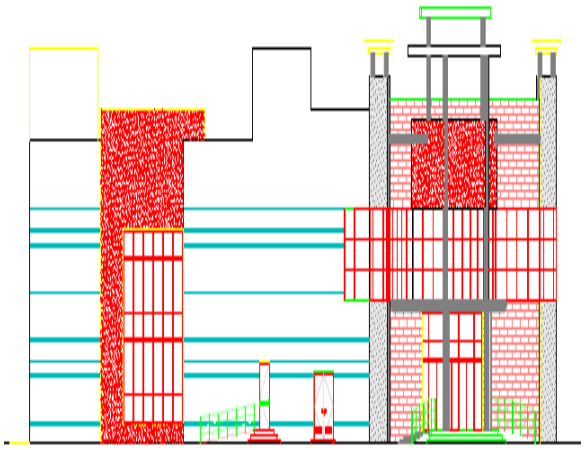
A total of six façade configurations have been analyzed including the base case i.e. Façade-I. Wall conductance and resistance values have been computed for all the six cases as shown in Table 2. The values obtained are then used for the simulation of program.



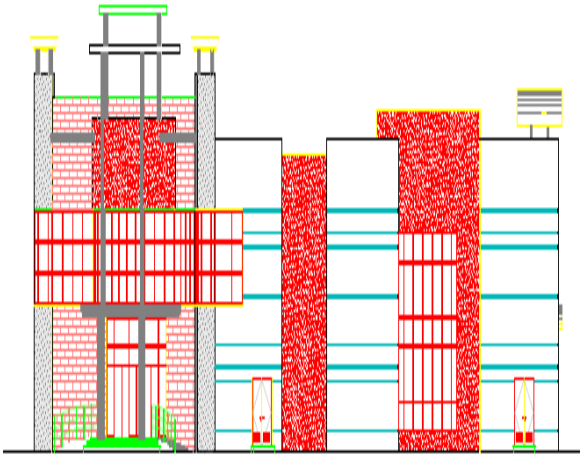
Floor Plan



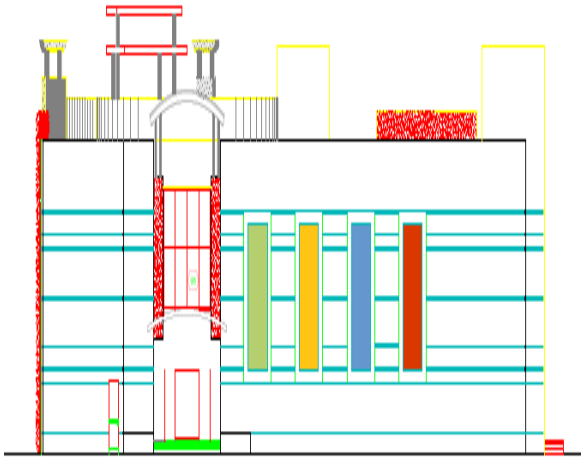
North Elevation



West Elevation



East Elevation



South Elevation

Fig. 2: Plan and elevations and of the case study building

5. Results and discussions

The properties of the material are inserted into the programme such as specific heat, conductivity, density, thermal absorptance values etc. software which computed the cooling loads and total energy consumption for all six cases of facades. The results are shown in Fig. 3 and 4. It is clear from the results that Façade-II configuration has minimum values of annual energy consumption and cooling load.

Based on these values the cost of annual energy consumption and annual cooling load has also been evaluated. The results are shown in Fig. 5 and 6.

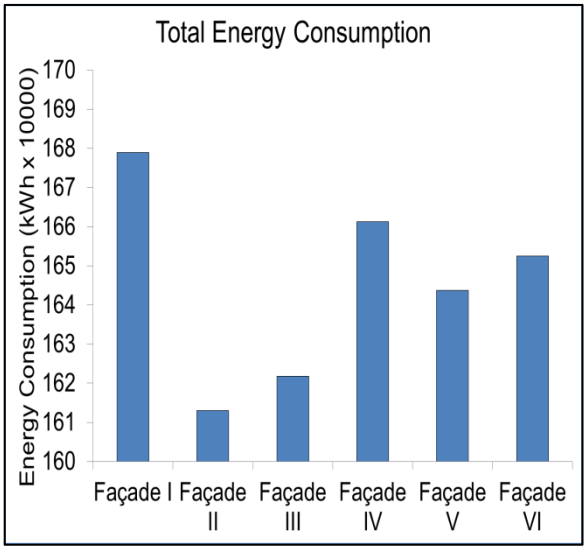


Fig. 3: Annual total energy consumption

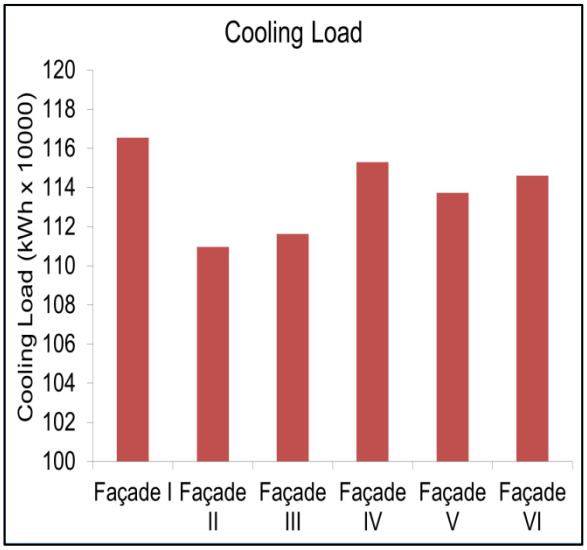


Fig. 4: Annual cooling load

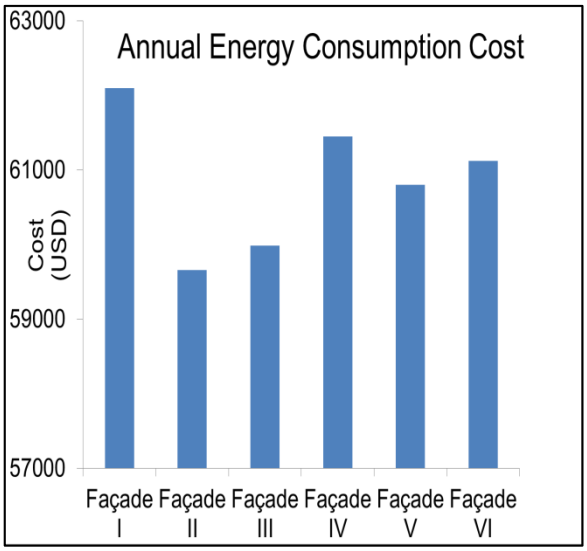


Fig. 5: Annual energy consumption cost

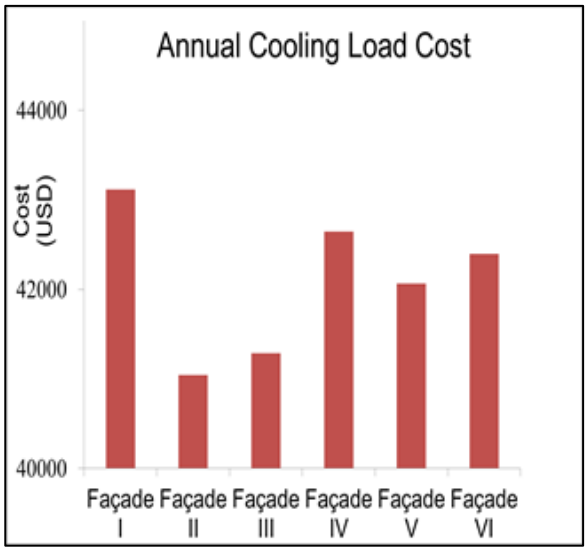


Fig. 6: Annual cooling load cost

Table 2: Structures and thermal characteristics of facades used mostly in Saudi Arabia building

Façade Type	Composition	Thickness of wall components (m)	Thermal conductivity of wall components (W/mK)	Wall Conductance U (W/m^2K)	Wall Resistance (m^2K/W)
Façade-I	Plaster	0.02	1.5	**2.33**	**0.43**
	Concrete Block	0.25	0.62		
	Plaster	0.03	1.5		
Façade-II	Plaster	0.02	1.5	**1.47**	**0.68**
	Concrete Block	0.1	0.51		
	Polystyrene	0.05	0.04		
	Concrete Block	0.1	0.51		
	Plaster	0.03	1.5		
Façade-III	Limestone	0.02	1.8	**1.64**	**0.61**
	Concrete	0.1	0.51		
	Polystyrene	0.05	0.04		
	Concrete	0.1	0.51		
	Plaster	0.03	1.5		
Façade-IV	Limestone	0.02	1.1	**2.13**	**0.47**
	Precast concrete	0.15	1.13		
	Air gap	0.05	0.28		
	Precast concrete	0.1	0.75		
	Plaster	0.03	1.5		
Façade-V	Aluminum	0.01	160	**1.82**	**0.55**
	Air gap	0.015	0.28		
	Concrete block	0.25	0.62		
	Plaster	0.025	1.5		
Façade-VI	Terracotta tile	0.02	1	**1.92**	**0.52**
	Air gap	0.02	0.28		
	Concrete block	0.25	0.62		
	Plaster	0.03	1.5		

Now, it is clear from the results that the façade configuration-II consumes the minimum energy and has minimum cost impact while the existing one consumes the maximum energy and has maximum energy costs. Annual energy consumption per square meter of the area for all the cases has also been simulated and the results are shown in Fig. 7.

The air-conditioning system is responsible for a significant share of total energy consumption of the building, approximately 69% (concluded from Fig. 3 and 4). Fig. 3 and 4 shows the office building total annual electric energy and cooling load consumption. For the purpose of discussion the electric energy and cooling load variation is due to the reason of different U values.

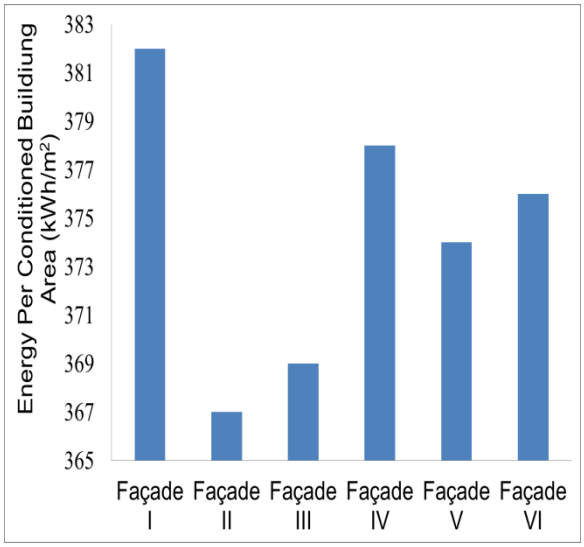


Fig. 7: Energy per conditioned building area

From the Table 2, it is clear that the Façade-I has highest value of thermal wall conductance (U) and hence solar energy transfer rate is maximum or in other words the thermal resistance is lowest among the discussed cases. While Façade-II has the lowest value of U which results in highest thermal resistance and hence the lower energy consumption and cooling load.

It is depicted from Fig. 3 and 4 that by opting Façade-II instead of base case the annual electric energy consumption and cooling load are reduced by 3.92% and 4.80% respectively. Fig. 5 and 6 shows the cost of annual energy consumption and cooling load for different façade configuration. The difference between the annual cost of energy consumption is also significant between the base case (Façade-I) and the best case Façade-II and comes out to be USD 2,439 and USD 2,072 for annual energy and cooling load usage.

6. Final comments and Conclusions

It was confirmed that solar radiation is main source of heat gain in the building. The result shows the importance of façade in preventing solar radiation reaching into the building. Therefore different configuration of facades was developed among the existing economically provided material to minimize the effect. Among them we can cite the use of thermal efficient material with low U factor. The study shows that there is the significant drop of 3.92% and 4.80% in total energy and cooling load consumption respectively by opting the façade-II instead of Façade-I.

Energy conservation and sustainable design in building would make the façade II being the most attractive one among the existing building envelop in Saudi Arabia and should be implemented as it will provide higher rates of comfort accompanied by lower air conditioning energy cost.

7. References

[1] ELECTRICAL AFFAIRS AGENCY (EAA) "*Electricity growth and development in the Kingdom of Saudi Arabia.*" Ministry of Industry and Electricity, 2011, Riyadh, Saudi Arabia.

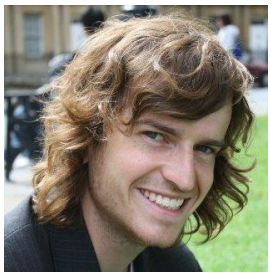
[2] GRONDZIK, W., 1989, "*Architectural applications of thermal insulation*", *Al-Mohandis*, **2**, pp. 2-11.

[3] AL-AHMADI, A. "Thermal performance of insulated layers in buildings subjected to time-dependent and non-linear conditions." *MS Thesis, Mech. Eng. Dept*., 1995, King Saud University.

[4] WESTERGREN K. E., H. HÖGBERG H., NORLEN U. "Monitoring energy consumption in

single-family houses." Energy and Buildings 29, 1999, pp. 247–257.
[5] MIHALAKOKOU G., SANTAMOURIS M., TSANGRASSOULIS A. "*On the energy consumption in residential buildings*." Energy and Buildings 34, 2002, pp. 727–736.
[6] JABER J. "*Prospects of energy savings in residential space heating*." Energy and Buildings 34, 2002, pp. 311–319.
[7] NAGAI T. "*Optimization method for minimizing annual energy, peak energy demand, and annual energy cost through use of building thermal storage*." ASHRAE Transactions 108 (1), 2002, pp. 43–53.
[8] BINAMU A. "*Integrating Building Design Properties 'Air Tightness' and Ventilation Heat Recovery for Minimum Heating Energy in Hot Climates*." Ph.D. Thesis, Tampere University of Technology Publications, 2002, pp. 377.
[9] OLOFSSON T., ANDERSSON S., ÖSTIN R. "*A method for predicting the annual building heating demand based on limited performance Data.* " Energy and Buildings 28, 1998, pp. 101–108.
[10] OLOFSSON T., ANDERSSON S., ÖSTIN R. "*Energy load predictions for buildings based on a total demand perspective*." Energy and Buildings 28, 1998, pp. 109–116.
[11] *DesignBuilder EnergyPlus Simulation documentation*, 2011, pp. 205-319.
[12] HABERL J. S., BRONSON D. J., O'NEAL D. L., "*Impact of using measured weather data vs TMY weather data in DOE-2 simulation*", ASHRAE Transactions 101 (2),1995, pp. 558–576.
[13] AHMAD E. H, "*cost analysis and thickness optimization of Thermal insulation materials used in Residential buildings in Saudi Arabia*", The 6th Saudi Engineering Conference, KFUPM, Dhahran, December, 2002, pp. 21-32.
[14] CARVALHO M. M. Q, ROVERE E.L.E, GONCALVES A.C.M. "*Analysis of variables that influence electric energy consumption in commercial buildings in Brazil*". Renewable and Sustainable Energy Reviews 14, 2010, pp. 3199–3205.

Assessing the severity of workmanship defects using thermography and 2-D and 3-D heat transfer models



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Short Summary

The effectiveness of insulation in reducing heat loss depends to an important extent on the quality of its installation. For new buildings, it is advantageous if the performance of insulation can be checked before construction work is complete. This enables problems to be rectified before the building is occupied. The research presented in this paper is investigating how thermal imaging techniques (thermography) can be used during the construction of new domestic buildings to assess construction quality and the energy efficiency of the building fabric. Thermal imaging surveys are usually conducted post-construction and so this approach to testing constitutes a novel area of practice. Further insights into the results of a thermal imaging survey can be gained from computational models of heat transfer through the building envelope. The particular focus of the paper is how these virtual models and thermography can be used in a complementary way to diagnose and assess the severity of insulation defects in construction work. This idea is explored through three case studies, which illustrate some practical considerations for the application of thermography during the construction process. The research topic will be of interest to built environment professionals, thermographers and researchers interested in methods of investigating the thermal performance of new housing.

Keywords: infrared thermography; construction quality; workmanship defects; low carbon housing; building fabric performance; residential buildings; energy efficiency; thermal bridges

1. Introduction

Thermal imaging (thermography) is held to be “the most powerful technique for determining position and to some extent magnitude of thermal bridges in existing buildings” [1]. In this research project, a testing approach is being developed for conducting thermographic inspections at different stages during the construction of new domestic buildings [2]. The purpose of these inspections is to investigate the quality of workmanship and energy efficiency of low carbon homes as they are being built, and thus increase confidence that design targets for thermal performance will be achieved in practice. This type of testing is motivated by evidence of a “performance gap” in UK housing construction between the energy performance predicted at the design stage and that achieved in completed buildings [3]. Identifying problems at an early stage of construction could help to close this gap, and enables remedial work to be completed before the building is occupied (post occupancy remedies are often much more disruptive and expensive). This could bring significant energy and carbon savings, since heat loss from thermal bridges can be responsible for a large proportion of total fabric heat loss. For example, modelling undertaken by Comiskey [4] found that thermal bridging from poorly designed junctions could account for 31% of the total fabric heat loss in a dwelling. Furthermore, the performance of an energy efficient design detail can still

be compromised by poor execution on site.

If an anomaly is identified in the building fabric using thermography then two questions arise: the cause of the defect and its severity. Two-dimensional (2D) and three-dimensional (3D) heat transfer models can be used to help gain insight into both of these problems. In the paper, three case studies considering the complementary use of heat transfer modelling and thermal imaging are discussed:

- An example of a defect in masonry cavity wall construction (Case Study A);
- A thermography survey of an eaves junction in a timber frame building during the construction process (Case Study B); and
- Tests on a full-scale model of an external wall with deliberate defects (Case Study C).

Together, these case studies explore some practical considerations for the application of thermography during the construction process, including:

- Testing procedures to establish suitable environmental conditions for thermography;
- Assessing the severity of thermal bridges in terms of the effect on building energy performance and also risk of condensation and mould growth; and
- Limitations to the types of defect that can be identified using thermography.

The THERM [5] and HEAT3 [6] software is used for the diagnosis and evaluation of defects in the paper for 2D and 3D modelling respectively. 2D models are generally quicker to define (the geometry) and run and are suitable for assessing linear thermal bridges. However, more complicated geometries may require the use of 3D models, which also have the advantage of being able to generate projections of the temperature field over a surface so that variations in temperature across a structure can be more clearly visualised.

2. Case Study A

2.1 Introduction

An overview of common construction problems observed in UK housing is reported in [7]. An example given is the case of rigid insulation boards in partial-fill masonry cavity construction being cut short of the cavity closer around an opening. This type of defect was documented in a research project carried out by Leeds Metropolitan University which surveyed a number of construction sites in England during 2004 [8]. The problem was observed in 5 out of the 12 sites that used masonry cavity construction, and in one case a 50mm gap was observed between the rigid insulation fitted to the inner leaf and the cavity closer. For this case study, the THERM software has been used to calculate the surface temperatures in the proximity of this type of defect (for a specfic wall construction and under assumed steady-state heat transfer conditions). The additional heat loss resulting from this linear thermal bridge (psi-value) is also calculated using the software.

2.2 Model Description

Three separate models were constructed in THERM:

- A plan section through a partial-fill masonry cavity wall construction (Model A.1)
- A window jamb section, including a cavity closer and window frame (Model A.2)
- A window jamb section as Model A.2, but with a 50mm gap between the cavity insulation and cavity closer (Model A.3)

Model A.1 was used to calculate the modelling U-value of the wall (U'_w). Note this is not a conventional U-value (since it excludes the effect of mortar joints and wall ties on the actual thermal transmittance of the wall) but is used as reference data in Model A.2 and Model A.3 to calculate the installation psi-value for the interface of the window and wall. The external wall construction used in all models is described in Table 1 and Fig. 1.

Table 1: Specification of materials used in THERM model of masonry cavity external wall

Component	Description	Thickness (mm)	Thermal conductivity (W/m.K)	Reference
1	Plasterboard	12.5	0.21	[9]
2	Plaster dabs	15	0.43	[9]
3	15mm airspace	15	0.088	[9]
4	Lightweight blockwork	100	0.11	Manufacturer data
5	PIR insulation	50	0.022	Manufacturer data
6	Unventilated air cavity	50	0.273	[9]
7	Brickwork	103	0.77	[9]

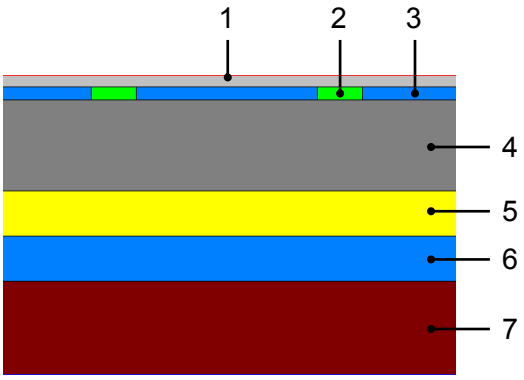


Fig. 1 Masonry cavity wall construction used in THERM model for Case Study A (Model A.1)

Model A.2 and Model A.3 include a 100mm wide cavity closer with the same thermal conductivity as the cavity insulation (based upon manufacturer data) and a window frame. Data for the window frame is based upon THERM modelling reported in [10]. For the purpose of the present work, the modelling of the window frame is simplified by using an equivalent rectangle with the same width and thickness as the actual window frame and with the same heat flow. The two models and boundary conditions used in the THERM model are described in Table 2 and Fig. 2.

Table 2: Components included in non-defective and defective window jamb model

Component	Description	Notes
1	Internal boundary condition (20°C)	Surface resistance = 0.13 m^2K/W
2	External boundary condition (0°C)	Surface resistance = 0.04 m^2K/W
3	Continuous line of dabs at reveal	
4	Cavity closer	Thermal conductivity = 0.022 W/m.K
5	Window frame	Based on Rationel Aldus window frame [10] U_f = 1.162 W/m^2K, frame dimensions: 57mm wide and 115mm thick (in the direction of heat flow), thermal conductivity = 0.1665 W/m.K
6	50mm gap in insulation	Thermal conductivity = 0.405 W/m.K

2.3 Results

The thermal transmittance of the external wall (Model A.1) calculated using THERM is U'_w = 0.259 W/m^2K. The different pattern of heat flow through the non-defective (Model A.2) and defective (Model A.3) wall-window junction is shown in Fig. 3. As would be expected, higher levels of heat flow occur through the break in the insulation layer adjacent to the cavity closer in the defective junction. The temperature profile across the wall-window junction for Model A.2 and Model A.3 (represented by colour isotherms) is shown in Fig. 4. The psi-value for the non-defective wall-window junction calculated using THERM is $\psi_{A.2}$ = 0.013 W/mK and for the defective junction $\psi_{A.3}$ = 0.061 W/mK. This means that the heat loss along the defective junction is almost five times that of

the non-defective junction. Neither of the two junctions would be assessed as being at risk of surface condensation and mould growth according to the calculation procedure defined in [11]. Note that psi-value calculations were performed using a spreadsheet developed by WARM: Low Energy Building Practice [12].

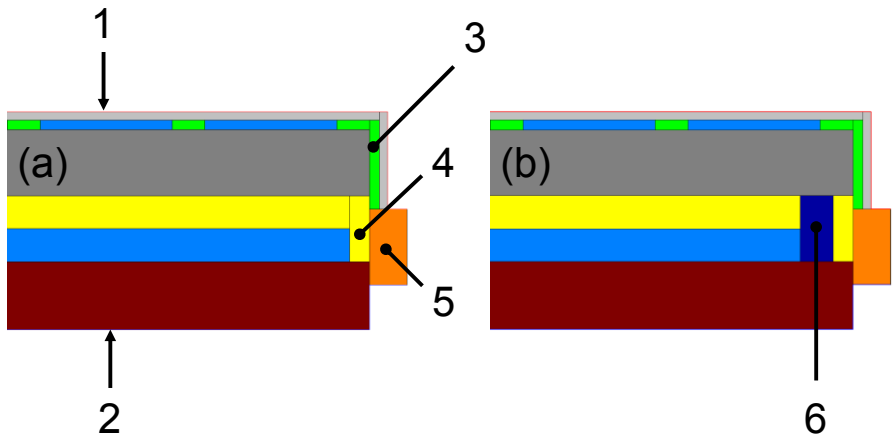


Fig. 2 (a) Model A.2 wall jamb section (b) Model A.3 defective installation of insulation

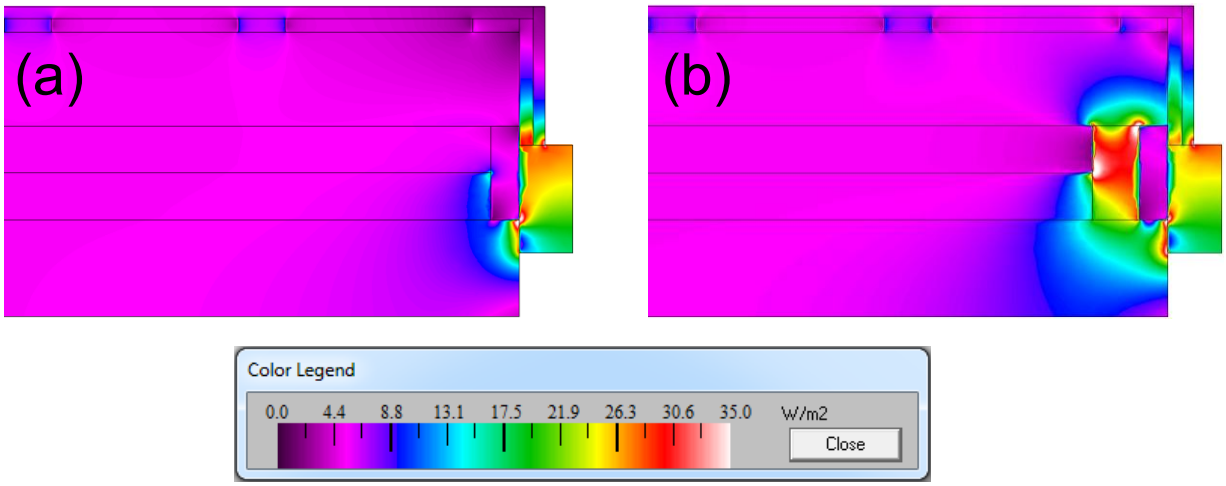


Fig. 3 Heat flux diagram for (a) non-defective and (b) defective junction

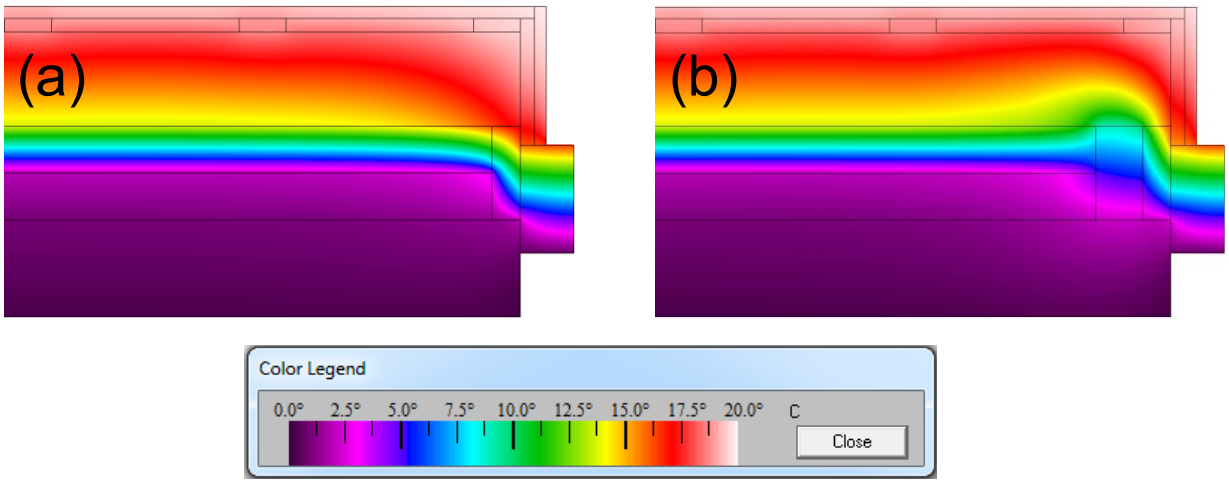


Fig. 4 Temperature profile for (a) non-defective and (b) defective junction

2.4 Discussion

The THERM software has been used to calculate the additional heat loss associated with partial-fill cavity insulation being cut short 50mm from the cavity closer at a window opening (for the particular external wall and window jamb detail modelled above). However, the temperature profile across the junction shown in Fig. 4 suggests that it may not be possible to establish the presence of this defect by a retrospective thermal imaging survey. Although the insulation gap results in a clear discontinuity in the isotherms across the wall, this occurs in the middle of the construction and the effect is diffused through surrounding material. Comparing the non-defective and defective junctions, there is no obvious disruption to the isotherms at the inner or outer surface in Fig. 4(b) that could be clearly related to the presence of a defect below. Although this conclusion is derived from the results of a simplified heat transfer model, it does reinforce a useful caveat to the use of thermography: that the ability to detect a defect depends upon its effect on surface temperatures. In general, this means that the continuity of insulation within a building can be assessed more effectively with thermography when there is less intervening structure between the insulation layer and the internal or external surfaces. This has further implications for the best time to carry out a thermal imaging survey with respect to the sequencing of construction. Modelling may provide a useful predictor of the best stage in the construction sequence at which to survey.

3. Case Study B

3.1 Introduction

In this case study, thermal images obtained from a building survey are compared with THERM modelling data. The case study building comprises a row of terraced houses divided into 12 flats constructed in timber frame. A thermal imaging survey identified lower surface temperatures at the junction between wall and ceiling in the bedroom of one flat, indicating higher levels of heat loss at the eaves. The THERM software is used to predict surface temperatures for the eaves detail as designed and also for poor installation of the loft insulation. Considered together, the thermographic and modelling data provide complementary insights into the performance of the detail.

3.2 Thermography Results

A thermal imaging survey of the building was conducted in April 2013 during the construction phase. Following consultation with the site manager, the main bedroom in the flat at the most advanced stage of completion was selected for testing. The interior finish of the flat had progressed to the stage that the plasterboard had received a skim finish and a base coat of paint. Fig. 5 shows a photograph of the bedroom and a plan layout.

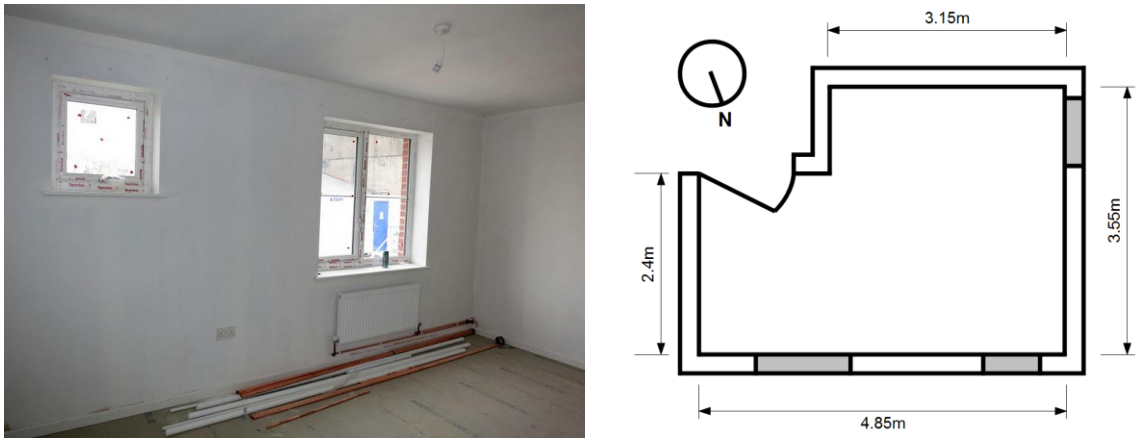


Fig. 5 Photo of north-facing windows and plan layout of test bedroom

A difference of 10°C between internal and external temperatures is often recommended as a “rule

of thumb" for identifying insulation defects using thermography [13]. Establishing these conditions on a construction site can be problematic, particularly since the building heating systems are unlikely to be operational until the building is close to completion. At an intermediate stage of construction, electrical fan heaters can be used to achieve a stable pattern of heat flow through the building envelope (provided that the part of the building under test can be made reasonably airtight). On the morning of the test a 1.5kW electrical fan heater was installed in the bedroom (using a 110V electrical supply compatible with use on a construction site). After a heating period of 4 hours, the air temperature in the bedroom had increased by 9°C resulting in a difference between internal and external air temperatures of 10°C (satisfying the "rule of thumb" criteria). Lower surface temperatures were observed at the junction between the wall and ceiling of the north elevation as shown in Fig. 6.

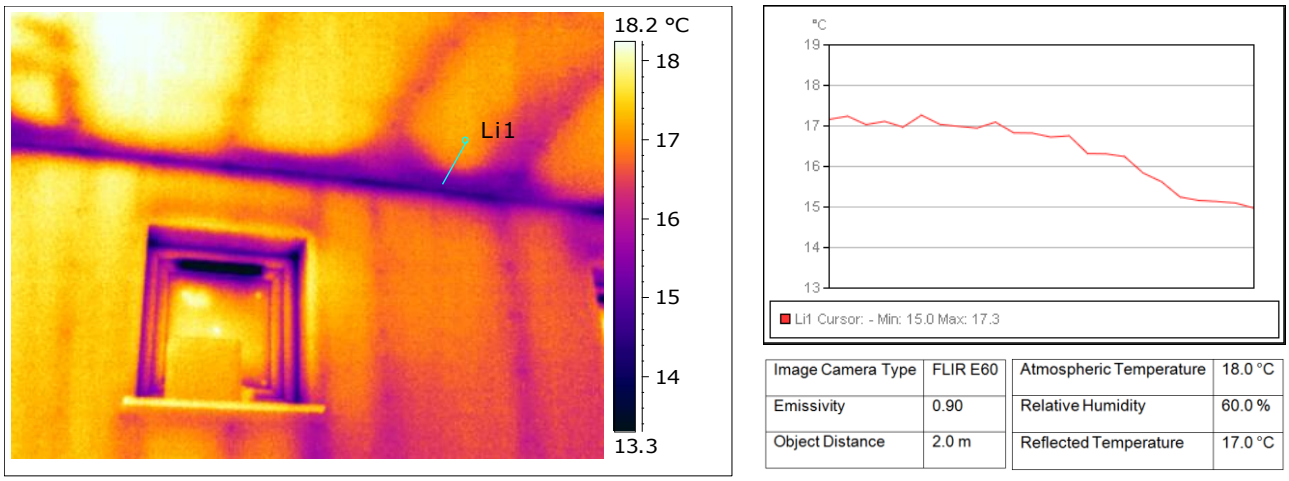


Fig. 6 Thermal image of junction between wall and ceiling at Case Study B

The minimum internal surface temperature (T_{si}) is 15°C. To assess the severity of this defect, the temperature factor (F_{Rsi}) is calculated as follows [11]:

$$F_{Rsi} = \frac{T_{si} - T_e}{T_i - T_e} \quad (1)$$

Where T_i = internal temperature and T_e = external temperature. For this location, F_{Rsi} = 0.7 which is less than the critical temperature factor (F_{CRsi} = 0.75) recommended for dwellings and would therefore be considered at risk of surface condensation and mould growth. Possible causes of lower surface temperatures at this location include: insulation not lapped over top of timber frame wall; insulation not rolled up to eaves; and wind penetration over the brick outer leaf resulting in a thermal bypass [14] over the top of the timber frame wall.

3.3 THERM Modelling Results

To further investigate the issues observed in the thermal imaging survey, two models of the eaves detail were constructed in THERM:

- The "as-designed" detail with insulation installed correctly lapped over the top of the timber frame wall and up to the eaves ventilator (Model B.1)
- A "poor installation" detail with insulation missing above the top of the timber frame wall and not pushed up to the eaves ventilator, and with also higher convective heat loss from the exposed surfaces to approximate the effect of wind penetration (Model B.2)

Drawings of these two models are shown in Fig. 7 and the temperature profiles calculated using the THERM model are shown in Fig. 8. Note the presence of additional timber is included in Fig. 7.b (a ceiling joist and purlin based on site observations) to illustrate where the insulation might stop if poorly installed.

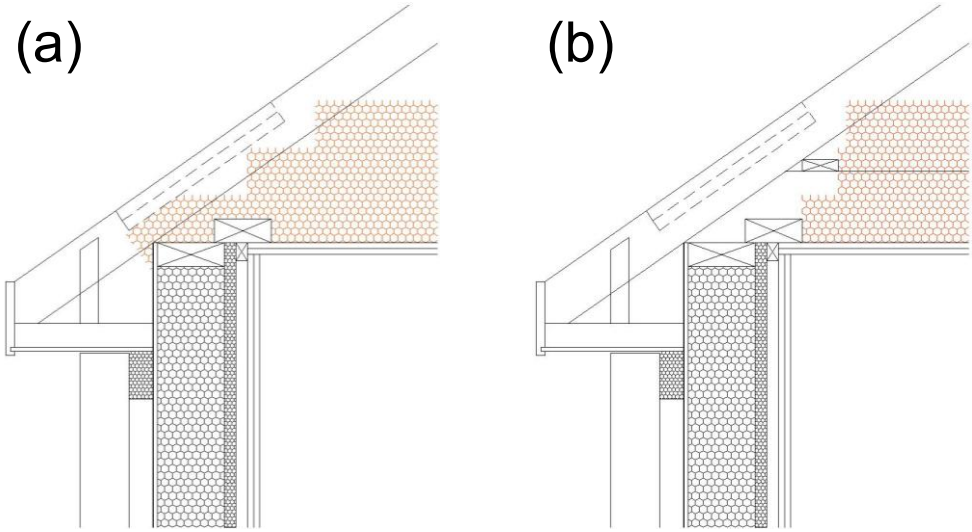


Fig. 7 Eaves detail (a) as-designed and (b) with poor installation of loft insulation

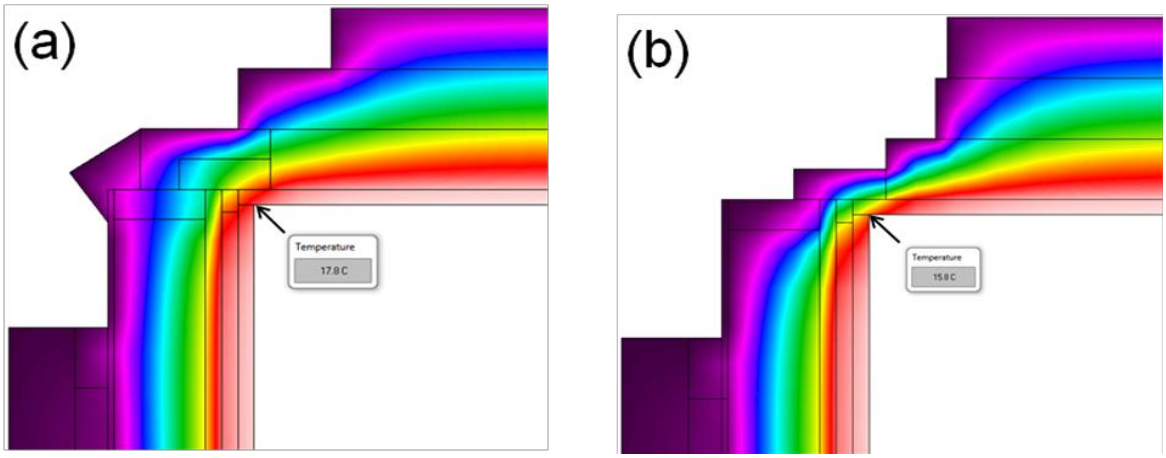


Fig. 8 Temperature profile (a) as-designed and (b) with poor installation of loft insulation

The temperature factor for the as-designed detail (Model B.1) is $F_{Rsi_B.1}$ = 0.89 and for the poor installation detail (Model B.2) is $F_{Rsi_B.2}$ = 0.79. Neither detail would thus be considered at risk of surface condensation and mould growth.

3.4 Discussion

The thermal imaging survey at Case Study B indicated a problem with the loft insulation and possibly also wind penetration at the eaves. This was communicated to the site manager and is to be subject to further investigation. The results of the THERM modelling for the poor installation case (Model B.2) indicates the effect of poorly placed insulation on the surface temperatures at the junction and, to this extent, is consistent with the thermal image data. As a general observation, the comparison between the thermography and THERM modelling is revealing of how the assumptions underlying design calculations of thermal performance (with insulation placed in perfect contact with the surrounding structure) may bear little relationship to the as-built reality encountered on site. This disparity may go some way towards explaining the difference between the modelling results and thermography. An additional advantage of modelling the eaves detail in THERM was that it was possible to calculate the as-designed psi-value for the junction, $\psi_{B.1}$ = 0.077 W/mK. The default psi-value for an “Accredited Construction Detail” [7] at the eaves (with insulation at ceiling

level) is 0.06 W/mK [15]. This suggests the design of the eaves detail could be improved.

4. Case Study C

4.1 Introduction

The previous case study introduced the requirement for a stable pattern of heat flow through the building envelope to obtain reliable results with thermography. Maintaining a sufficient difference between internal and external temperatures can be harder to achieve in buildings at an early stage of construction (e.g. before windows or doors are installed). A solution for early-stage tests being developed in this research project involves the use of electrical radiant heaters to target heat at an area of the building envelope. Since this heating method does not rely on raising the air temperature, suitable conditions for thermography can be established in buildings that are not fully sealed. To investigate the efficacy of the approach, a full-scale physical model of an external wall (referred to here as the *test panel*) has been used to investigate the type of defects that can be identified in timber-frame structures. The results of model testing are compared with predicted surface temperatures calculated using HEAT3.

4.2 Test Panel Results

The design of the test panel comprises 4 layers of construction: a 12.5mm thick plasterboard layer on the “inside” face; a polythene vapour control layer fixed to a 140mm by 38mm timber stud framework filled with mineral wool insulation; and a 9mm OSB “outside” sheathing layer. It aims to represent a section of a timber-frame external wall 2.4m wide (i.e. 5 studs across the width at 600mm centres) prior to the construction of the outer cladding. In preliminary tests a 110V 1.5kW electrical radiant heater has been positioned 3m from the panel. Fig. 9 shows an image of the constructed panel and a plan section.

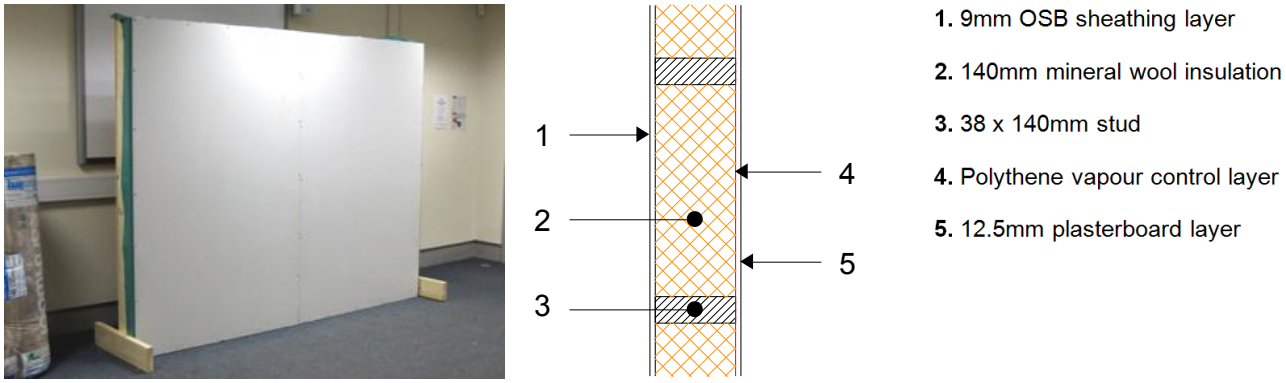


Fig. 9 Test panel design

Preliminary testing has investigated a range of possible workmanship errors in the installation of insulation. This paper considers two specific defect configurations: the replacement of one section of insulation with a section of different thermal performance; and the removal of one section of insulation (i.e. leaving an air void between the studs). The results after 1 hour of heating are shown in Fig. 10.

The difference in surface temperatures between the section of wall missing insulation and the rest of the panel is clearly visible. However, the section with different thermal conductivity is not distinguishable from the adjacent areas of the panel. Note that the two horizontal bands that are warmer in the images are caused by the design of the heater reflector (an uneven heat output).

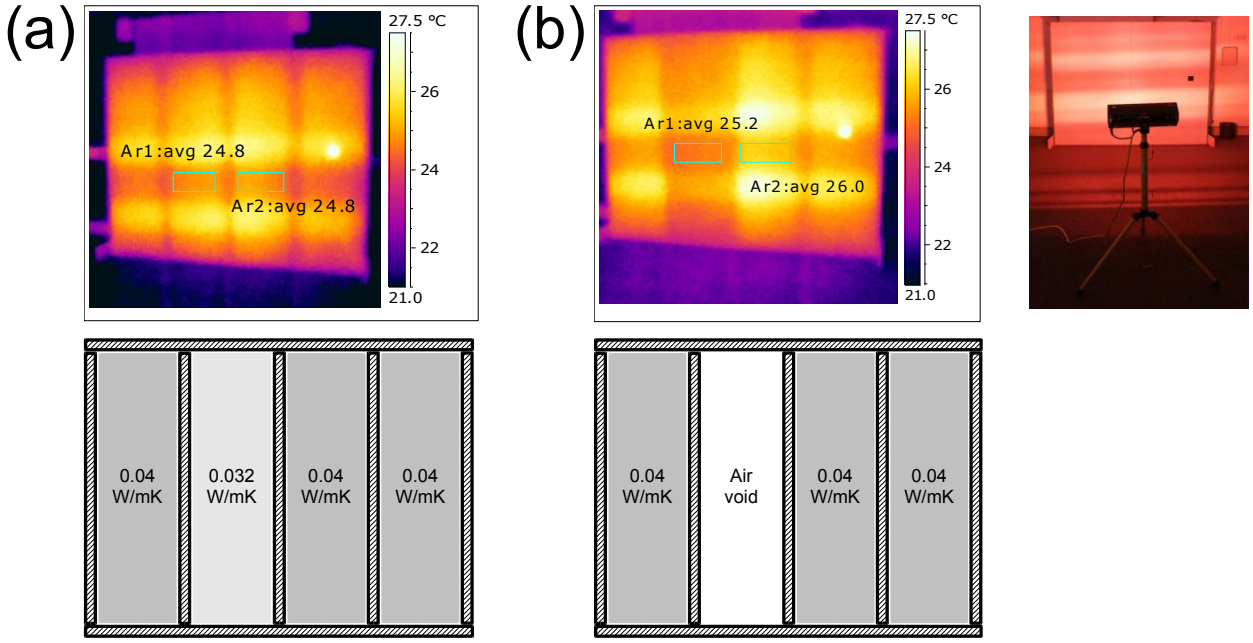


Fig. 10 (a) Section of insulation with different thermal conductivity (b) Section missing insulation

4.3 HEAT3 Modelling Results

For comparison with the results of physical testing, a virtual model of the test panel was created using the HEAT3 software. The use of a 3D model enables a 2D projection of surface temperatures to be generated for the “inside” face. The results for the two defect configurations introduced in the previous section are shown in Fig. 11. This shows the predicted surface temperature distribution under steady-state conditions for constant temperature boundary conditions (inside = 1°C, outside = 0°C). Annex B of ISO 6946:2007 [16] was used to calculate the thermal resistance of the airspace for the missing insulation panel (0.197 m^2K/W).

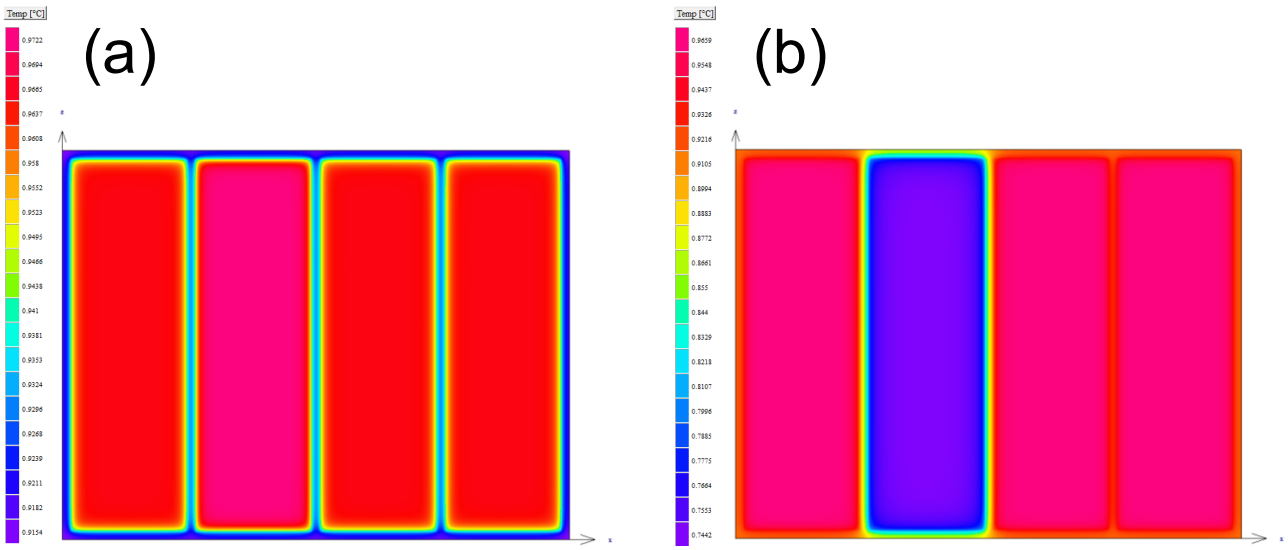


Fig. 11 Surface temperature plots for (a) different thermal conductivity and (b) missing insulation

For the different thermal conductivity case, the difference in surface temperatures between the two standards of insulation is 0.0063°C (for a 1°C difference between boundary temperatures). Whereas the difference between the surface temperature of the area of missing insulation and the insulated area is 0.222°C (or a temperature factor of 0.74 for the missing insulation).

4.4 Discussion

Although the steady-state modelling undertaken in HEAT3 is not directly comparable with the thermal images obtained from model tests, together they support the following two conclusions:

- The use of insulation materials with different thermal conductivity within a wall (i.e. substitution of the specified product by an inferior one) is likely to be difficult to detect using a thermal camera.
- The presence of air voids within a timber frame structure can be determined relatively easily and quickly using a thermal camera and radiant heater.

Thus, the preliminary tests using the radiant heating approach indicate that it can provide useful insights into the quality of installation of insulation in timber-frame construction. Specifically, the approach can identify the presence of air voids within the insulation layer. This could occur if insulation is disturbed by a follow-on trade (e.g. an electrician wiring a power socket) or the insulation is cut short or sags. In addition, it enables the presence of timber to be identified (e.g. studs, noggings etc.).

5. Conclusions

The three case studies presented in the paper provide examples of how thermal imaging and heat transfer modelling software can be used in a complementary way to investigate the thermal performance of buildings. Thermography can be used to obtain feedback from real buildings and improvements in design can be supported by computer modelling, with the lessons from both potentially carried forward to future projects. Some specific ideas explored in the three case studies are summarised below:

- Thermography is a powerful tool for assessing the continuity of insulation in buildings, but there are limitations to the technique related to both the environmental conditions in which a thermal imaging survey is undertaken and the impact of discontinuities in the insulation layer on surface temperatures. The latter point is perhaps not sufficiently acknowledged within existing literature, since it places limitations on the ability to detect certain types of insulation defect.
- The impact of poor design or workmanship on building energy performance can be quantified (e.g. a psi-value for linear thermal bridges) using computational methods provided some basic information about the problem is known. This is a useful complement to thermography, which is primarily a qualitative diagnostic tool.
- Design calculations typically assume perfect placement of insulation to the adjacent structure. This may be an unrealistic assumption, particularly for details that are awkward to build, and may result in actual performance being considerably less than predicted (as may be revealed by thermal imaging).
- 3D heat transfer models can be used to generate 2D projections of surface temperatures. This enables a direct comparison to be made with thermal images, with the potential for a building to be “calibrated” against this expected thermal pattern.

6. Acknowledgements

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7. References

[1] THOMSEN KE, ROSE J. Analysis of Execution Quality Related to Thermal Bridges [Internet]. European Communities; 2009. Available from: http://www.buildup.eu/publications/6292 [Accessed 26 November 2012]

[2] TAYLOR T, COUNSELL J, GEENS A, GILL S, OAKLEY G. Checking ‘fabric-first’ really works: in-construction tests using thermography. In: 33rd AIVC Conference and 2nd TightVent

Conference, 10-11 October 2012, Copenhagen, Denmark. 2012. p. 138–142.
[3] ZERO CARBON HUB. Carbon Compliance for Tomorrow's New Homes - Topic 4: Closing the gap between designed and built performance. London, UK: Zero Carbon Hub; 2010.
[4] COMISKEY DA. Detailing to minimise heat loss at junctions of building elements. In: 9th International Detail Design in Architecture Conference - Innovative Detailing: Materials & Construction Methods for a Low Carbon Future, 4-5 November 2010, Preston, UK. 2010.
[5] http://windows.lbl.gov/software/therm/therm.html [Accessed 13 May 2013]
[6] http://www.buildingphysics.com/index-filer/Page691.htm [Accessed 13 May 2013]
[7] DEPARTMENT FOR COMMUNITIES AND LOCAL GOVERNMENT. Accredited Construction Details. 1st Ed. London, UK: Department for Communities and Local Government; 2007.
[8] BELL M, SMITH M, MILES-SHENTON D. Condensation Risk – Impact of Improvements to Part L And Robust Details On Part C - Interim Report Number 7: Final Report on Project Fieldwork, Report to the ODPM Building Regulations Division under the Building Operational Performance Framework - Project Reference Number CI 71/6/16 (BD2414). Leeds, UK: Leeds Metropolitan University; 2005.
[9] ANDERSON B. Conventions for U-value calculations 2006 edition. Watford, UK: BRE; 2006.
[10] WARM: LOW ENERGY BUILDING PRACTICE. Installation psi-value modelling of Ford Farm Windows St Ives, Cornwall [Internet]. 2011. Available from: http://www.rationel.co.uk/media/17664/full%20report%20rationel%20ford%20farm%2001%2008%2011%20kp.pdf [Accessed 23 April 2013]
[11] WARD T, SANDERS C. Conventions for Calculating Linear Thermal Transmittance and Temperature Factors. Watford, UK: Building Research Establishment; 2007.
[12] http://www.peterwarm.co.uk/resources/downloads/ [Accessed 13 May 2013]
[13] FLIR SYSTEMS AB. Infrared Guidebook for Building Applications [Internet]. Täby, Sweden: Flir Systems AB; 2009. Available from: http://www.getflir.com/green-guidebook-en/ [Accessed 4 December 2012]
[14] SIDDALL M. The Impact of Thermal Bypass [Internet]. *Green Building magazine*. 2009, Vol. 19, No. 1. Available from: http://www.aecb.net/PDFs/Impact_of_thermal_bypass.pdf [Accessed 4 June 2012]
[15] ENERGY SAVING TRUST. CE302 Enhanced Construction Details: thermal bridging and airtightness. London, UK: Energy Saving Trust; 2009.
[16] BRITISH STANDARDS INSTITUTION. BS EN ISO 6946:2007 Building components and building elements - Thermal resistance and thermal transmittance - Calculation method. London, UK: BSI Group; 2007.

Water and Energy recycling in a Residential Passive House



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Summary

Before producing new energy, whether fossil or renewable, or pumping freshwater from groundwater resources, one should look first on how to avoid energy and water consumption and how to optimise the total resource efficiency for both the energy as well as the water sector.

Greywater recycling is one effective tool to improve the efficiency of water use in buildings. Advanced greywater systems have been developed and tested which produce high quality non-potable water (service water) for indoor (toilet flushing, laundry) and outdoor use (gardening, cleaning).

In this paper the treatment of greywater from showers and bathtubs in combination with heat recovery from greywater is presented. Greywater undergoes an advanced mechanical-biological treatment and a final UV disinfection without the use of chemicals, at the same time the heat recovered from greywater is used to pre-heat the drinking water for the building's combined heat and power plant (CHP).

Well planned greywater recycling systems can contribute considerably to water and energy savings in buildings and should therefore be marketed in future urban context as sustainable, environmentally friendly and safe technologies.

Keywords
Greywater recycling, water and energy efficiency, heat recovery, passive house, non-potable water, service water.

Introduction

Water and energy are very much closely linked as water is often needed to generate energy, and vice versa. In order to produce 1 kWh of electrical energy from fossil or nuclear fuel, about 2.7 – 3.2 litres of water will be needed for cooling.

On the other hand, the water supply and wastewater disposal sectors are the largest municipal energy consumers. A city like Berlin with 3.5 million inhabitants and modern conventional water technologies requires for its water sector as much electrical energy as the household electrical energy demand for a city with 280,000 inhabitants [1].

Low-energy houses and passive buildings are milestones when it comes down to reducing the heating demand in a building. What remains ignored is that most of the energy released today into the environment is through wastewater rather than through the building's facade.

In contrast to material recycling of household wastes, which had been reinvented 30 years ago und put into praxis, the value of wastewater had been also long recognised but its realisation compared to waste management lags more than 30 years behind.

Although the first large greywater recycling plant for a 400 bed, four-star hotel is successfully in operation since 1996 [2], many investors and home engineering planners have not yet realised that today water costs in many buildings are significantly higher than the costs for space heating or electrical power and that there exists in buildings a high saving potential, not only for water but also for energy.

Therefore, wastewater should be regarded as a resource and segregating wastewater into its different streams, e.g. blackwater and greywater, can contribute towards a holistic water management strategy. Greywater is the wastewater sourced from bathtubs, showers, washbasins, kitchen and laundry. Greywater is different from blackwater in its composition, and constitutes the largest proportion of wastewater by volume produced in an average household.

Although early efforts to recover heat energy from greywater largely failed mainly due to high maintenance expenditure, low energy yield, low energy prices as well as the lack of legal requirements, there are very promising approaches today that are able to considerably improve sustainable energy and water efficiency in buildings through decentralised systems.

1. Greywater recycling

Greywater is generally classified as low load and high load. Low load greywater usually originates from showers, bathtubs and sometimes hand washbasins, while high load greywater also includes greywater from kitchens and washing machines. Figure 1 shows the average partial water flows in private households in Germany. With greywater recycling, the total drinking water demand can be easily reduced to 45 l/p/d [3].

Greywater recycling in buildings is a sustainable water management approach offering several benefits including economical, environmental and social. Once appropriately treated, greywater is considered suitable for non-potable uses such as toilet flushing, irrigation, laundry and cooling.
In general, greywater recycling systems should fulfil four criteria: hygienic safety, no loss of comfort to the users, environmental tolerance and economic feasibility [4]. The choice of a greywater management strategy is highly dependent on the end use of the effluent produced and should therefore be adapted to a specific application such as for outdoor agricultural reuse (gardening, irrigation), indoor reuse (toilet flushing, laundry) or for safe discharge into surface waters.

In an urban context, the potential for greywater recycling is mainly new-build residential developments, where dual piping can be included during the construction phase. However, greywater recycling is also feasible for already existing buildings within the scope of rehabilitation measures.

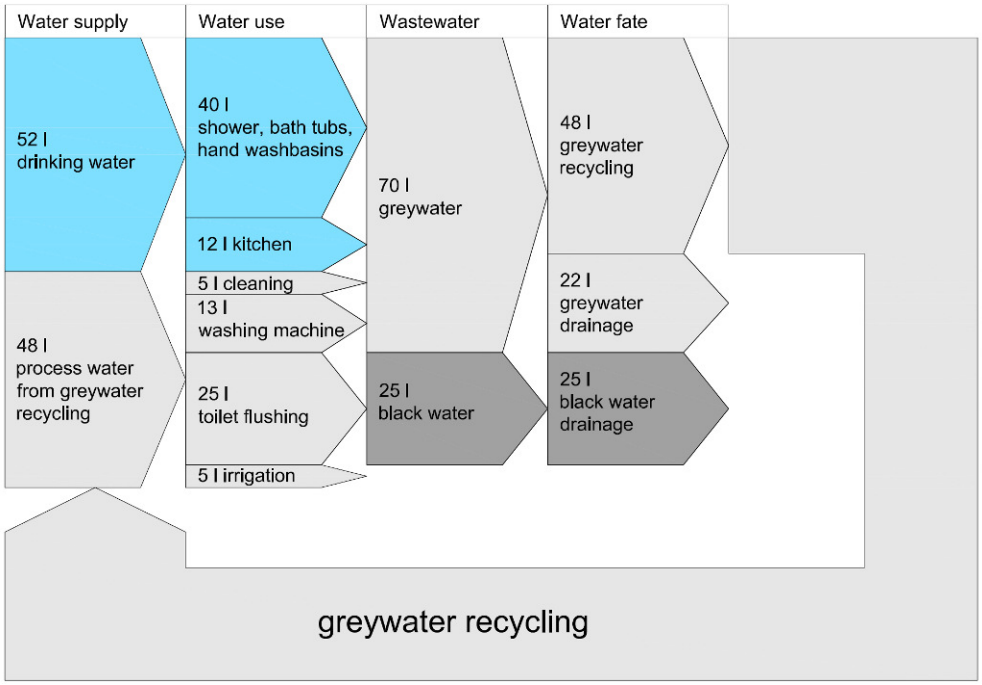


Figure 1: Average partial water flows (litres per inhabitant and day) for private households in new and rehabilitated buildings [Mehlhart, 2001].

Since fresh greywater exhibits relatively high temperatures, the feasibility of energy recovery from greywater is also high, as can be demonstrated in this project. Such an integrated approach would also considerably increase the efficiency of the entire system.

Taking as an example the passive house at Arnimplatz it has been shown that during the winter months heat recovery by means of very low-maintenance heat exchangers can achieve a coefficient of performance (COP) of ≥ 10, producing at the same time high-quality service water (non-potable water). Service water can be used in the building for applications which do not mandatorily require a drinking water quality, whereby further savings can be achieved.

2. Project Arnimplatz

Greywater recycling and heat recovery from greywater can be viewed as an ideal system combination to increase the total efficiency of the system. Fresh greywater has relatively high temperatures (up to 35°C) and therefore a potential for heat recovery already exists in the system.

A greywater recycling plant combined with heat recovery was launched in March 2012 in a multi-storey passive house in Berlin, Germany. For a standard passive house, which has a heat demand for space heating of <15 kWh/m^2/a, about 1.5-fold more energy is needed for hot water generation than for space heating. A total of 41 flats with 123 tenants occupying an area of 4,600 m² and 4 commercial units (600 m²) are connected to the greywater/heat recovery system. About 3,000 litres of low load greywater from showers and bathtubs are treated daily to produce high quality service water which is reused for toilet flushing.

The greywater system including heat recovery is placed in the cellar where the building's heating system is also found, occupying an area of 9 m^2 (ca. 0.1 m^2 per person) (Photo 1).



Photo 1: Greywater recycling combined with heat recovery in a multi-storey passive house in Berlin, Germany (Photos: E. Nolde).

The filtered greywater from showers and bathtubs enters the heat exchanger, where heat is withdrawn by means of a 20-watt circulating pump (Figure 2).

A self-cleaning sieve provides for a very low-maintenance operation of the heat exchanger and the greywater recycling system.

The cooled greywater exiting the heat exchanger enters two aerated buffer tanks acting as a biological pre-treatment stage. Subsequently greywater enters a secondary treatment stage (also a moving bed biofilm reactor (MBBR)) with an integrated particulate removal setup, before it finally passes a UV disinfection unit to enter the service water tank.

The biologically treated greywater (BOD_7 < 3 mg/l; turbidity < 1-2 NTU) is then fed into the service water network by means of a booster pump to serve as non-potable water for toilet flushing. The total electrical demand for heat recovery, greywater treatment and service water distribution is less than 1.5 kWh/m³. Treatment is achieved without the addition of chemicals and at very low maintenance.

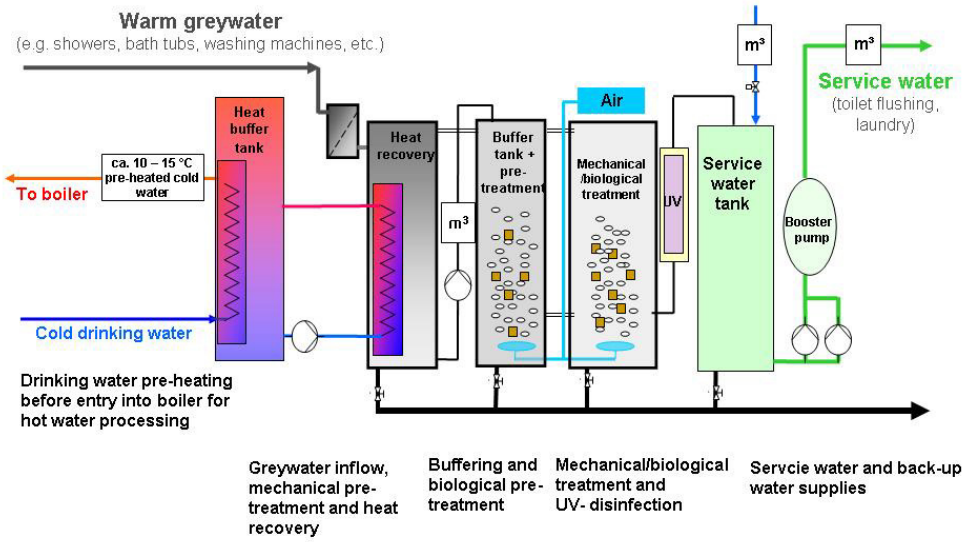


Figure 2: A schematic diagram of the greywater recycling system coupled to heat recovery in a passive residential house in Berlin, Germany.

3. Results and discussion

One essential technical aspect is that the generated greywater is not cooled down strongly before entering the recycling system. For this reason, the use of modern plastic pipes which also possess a good noise insulation is advantageous over conventional cast iron pipes. Even in winter, the mean temperatures of the influent greywater did not drop below 30 °C.

During winter when drinking water temperatures are relatively low (ca. 8.5 °C), it was possible to withdraw over 15 KWh of thermal energy per cubic metre of greywater with the combined system without the use of a heat pump. This energy was used to pre-heat the cold drinking water before it entered the decentralised combined heat and power plant (CHP) to be heated to 60 °C end temperature. During the first summer of operation when higher drinking water temperatures were measured, the recovery potential was only about 10 kWh/m³.

A monitoring study also showed an optimisation potential that would increase the future heat recovery performance of the system.

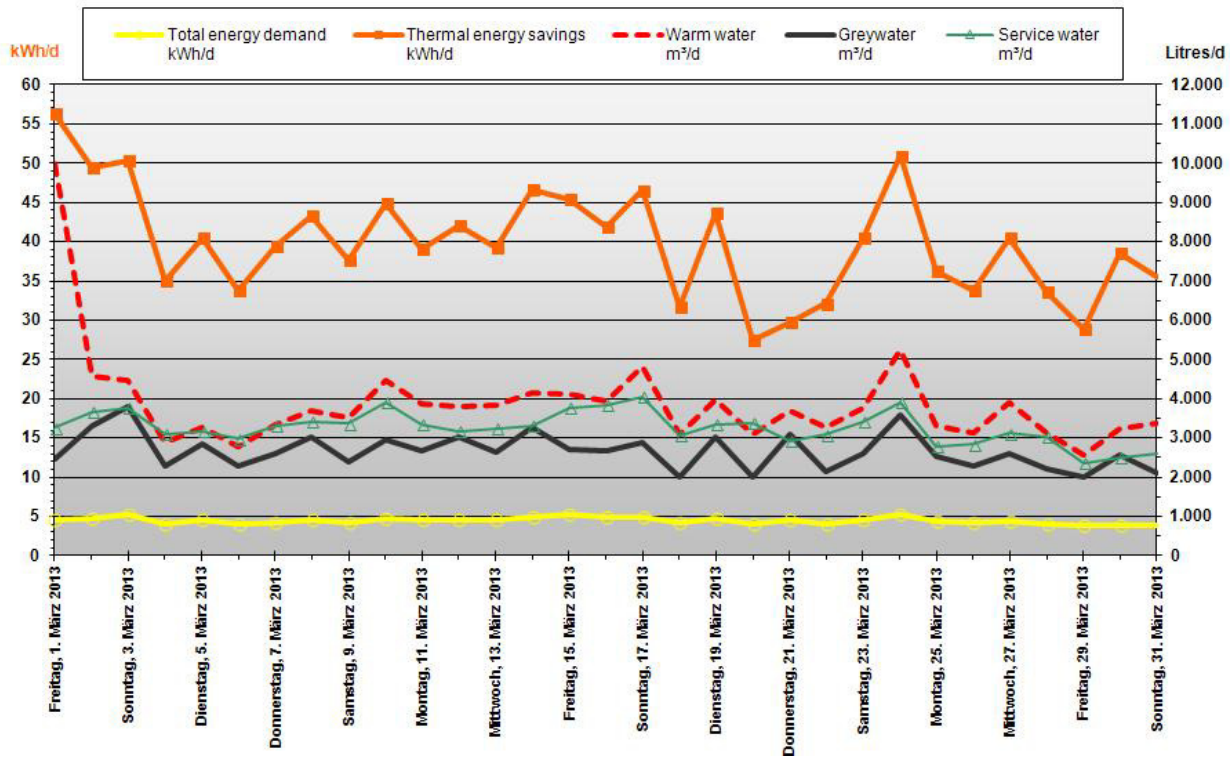


Figure 3: Monitoring results of the water and energy input and output during March 2013 in the greywater recycling plant at Arnimplatz.

Figure 3 shows that dependent on the amount of inflow greywater and freshwater demand more than 40 kWh/d of thermal energy can be often recovered from the system (orange line), compared to the electric energy demand for the entire system which lies constantly around 4 kWh/d (yellow line). Comparing the primary energy gains, this decentralised approach achieves a relatively higher degree of efficiency than centralised systems, where only about 1.5 °C can be withdrawn from municipal wastewater using heat pumps.

The results also show that the amount of greywater (black line), originating in this case only from showers and bathtubs, is not sufficient to cover the demand for toilet flushing (green line). It is therefore recommended to utilise additional greywater sources in buildings, for example, from handwash basins and laundry and even the high load greywater from kitchens (including fats and solids) to increase the availability of greywater and in turn the system's efficiency

Figure 4 shows the measurable benefits of greywater recycling coupled to heat recovery exemplified by the project "Arnimplatz". It is clear from the above results that the benefits of greywater recycling coupled to heat recovery are multiplied exerting eventually a significant positive impact on the greenhouse emissions.

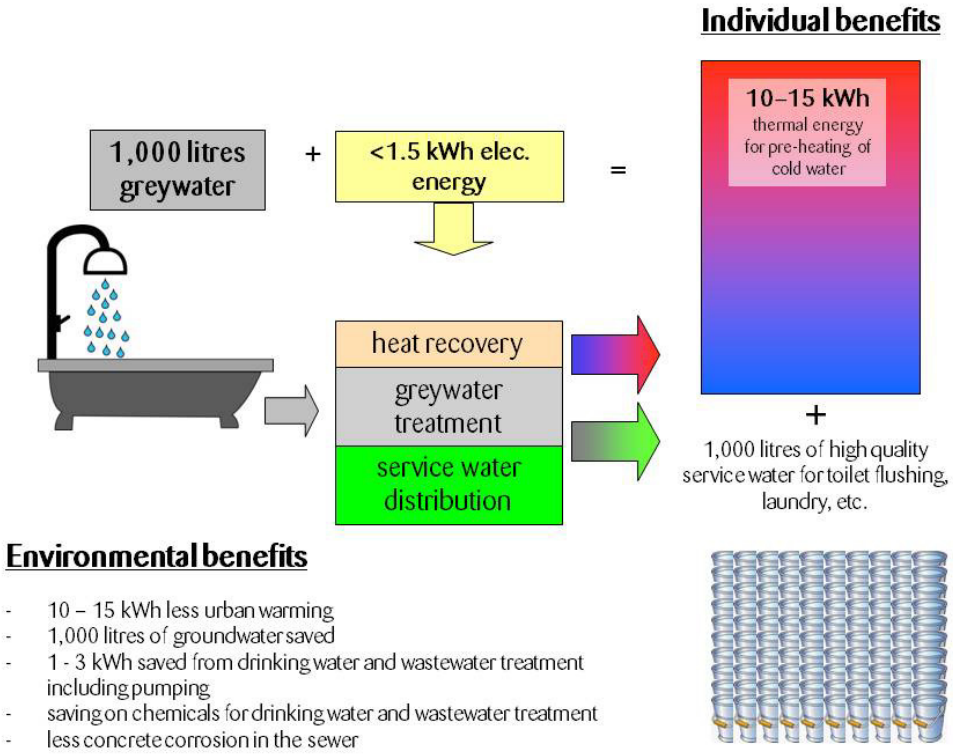


Figure 4: Individual and environmental benefits of greywater recycling combined with heat recovery based on an inflow of 1,000 Litres of raw greywater.

4. Conclusions and recommendations

Greywater recycling and heat recovery from greywater can be viewed as an ideal system combination to increase the total efficiency of the system. Fresh greywater has relatively high temperatures (up to 35°C) and therefore a potential for heat recovery already exists in the system.

Compared to outdoor installation, compact indoor installation systems using the warm heating room has several advantages since no additional insulation of all pipes and the recycling system is necessary and the plant is also more easy to maintain. An advanced monitoring system with access to the internet is very helpful to optimise the system and save operation and maintenance costs.

The additional costs for greywater recycling schemes of 10 €/m² of floor space (excluding second pipe system), compared to the real estate costs (3,500 - 4,000 €/m²), are very low (< 0.3%) and these costs will further decrease if individual plant design and engineering moves on to industrial and modular production. The inclusion of high load greywater, which can be also successfully recycled as had been already shown in a preceding project [6], should be practised at a larger scale in order to increase the efficiency of the system.

Also the increased use of service water for cooling purposes, such as in adiabatic cooling, would result in significant energy savings; about 630 kWh of cooling capacity can be generated from one cubic metre of water [7].

Especially for the area of Berlin the introduced greywater recycling system in combination with heat recovery saves as much energy which is equivalent to a thermal solar energy system of about 35 m² and even exhibiting best performance during the cold winter months.

The separation of blackwater and greywater in buildings should become a standard. Well planned greywater recycling systems can contribute considerably to water and energy savings in buildings and should therefore be marketed in future urban context as sustainable, environmentally friendly and safe technologies.

Therefore, it is essential to establish mandatory guidelines and standards for water and energy efficient systems especially for new buildings. Certification and rating schemes for buildings (e.g. LEED, BREEAM, DGNB, etc.) are only one step in the right direction.

5. References

[1] BWB : Nachhaltigkeitsbericht 2012 der Berliner Wasserbetriebe, S. 24. http://www.bwb.de/content/language1/html/7198.php

[2] Werner, C., Yang, L., Klingel, F., Huelgas, A., Räth, N. and Nolde, E. (2006) Greywater recycling in Hotel ArabellaSheraton am Büsing Palais, Offenbach, Germany. Data Sheets for ecosan projects, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, Germany. http://www.sanimap.net/xoops2/uploads/gnavi/25_2.pdf

[3] fbr (2005) Regulatory Guide H 201 Greywater Recycling: Planning Fundamentals and Operation Information. German Association for Rainwater Harvesting and Water Recycling (fbr), Darmstadt, Germany, [Online], Available: http://www.fbr.de/fileadmin/user_upload/files/Englische_Seite/H201_fbr-Information_Sheet_Greywater-Recycling_neu.pdf

[4] Nolde, E. (1999) Greywater reuse systems for toilet flushing in multi-storey buildings: over ten years experience in Berlin. Urban Water 1999, 275-284.

[5] Mehlhart, G. (2001) Grauwasser weiter auf dem Vormarsch. fbr-Wasserspiegel 2/2001. pp. 14 - 16, Darmstadt.

[6] Berlin Senate for Urban Development (2008) Block 6: Integrated water concept - ecological integrated concept. Department VI, Ministerial Building Affairs, Berlin Senate for Urban Development, Berlin, Germany. http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/download/modellvorhaben/flyer_block6_engl.pdf

[7] Berlin Senate for Urban Development (2010) Rainwater Management Concepts: Greening buildings cooling buildings. Planning, construction, operation and maintenance guidelines. Department VI, Ministerial Building Affairs, Berlin Senate for Urban Development, Berlin, Germany. http://www.stadtentwicklung.berlin.de/bauen/oekologisches_bauen/download/SenStadt_Regenwasser_engl_bfrei_final.pdf

Further Reading

Berlin Senate for Urban Development (2007) Innovative water concepts: service water utilisation in buildings. Ecological urban Planning. Department VI, Ministerial Building Affairs. Berlin Senate for Urban Development, Berlin, Germany. http://www.stadtentwicklung.berlin.de/internationales_eu/stadtplanung/download/betriebswasser_englisch_2007.pdf

SB13 Graz – ELIH-Med Full Paper



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Short Summary

ELIH-Med is a Strategic Project co-financed under the MED Programme, focused on the development of energy efficiency policies in Low Income Housing (LIH) in the Mediterranean area based on sustainable building principles and the involvement of residents in the energy retrofit in order to reach the EU2020 objectives.

The main objective of the project is to identify and test, through large scale actions, the feasibility of cost efficient innovative technical solutions and financial mechanisms backed with ERDF which could then be extended taking into account the specificities of the region.

The target is the low income houses because:

- Represent 30 to 40% of Mediterranean households.
- Have poor thermal performance.
- Is a key segment in order to reach EU2020 objectives.
- Are not a focus of traditional and current EE policies.
- Residents have limited access to credit.

A participative process has been used to organize two groups constituted of the relevant stakeholders at a local level:

A) The Territorial Management Group (TMG): Local stakeholders representing the key institutions that deal with energy efficiency and LIH. In charge of analyzing the innovative financial and technical options and monitoring the implementation of the energy retrofit in the selected dwellings.

B) The Pilot Project Participative Group (PPCG): Residents affected by the pilot projects, social workers, social landlords, local associations etc. which express the real life needs and problems that are experienced in the selected buildings, helping the TMG to develop and adjust the Action Plan to the reality of the situation.

In order to carry out the large scale experimentation of the technical and financial solutions analyzed, a total of 420 dwellings have been selected and divided into 10 pilot projects across 6 partner territories. Furthermore, the promotion of intelligent energy management systems at local and regional level will be carried out through the experimentation of multi-energy smart meters in 135 dwellings.

The objectives established for the pilot projects include:

a) A cut in energy consumption of 40%.

b) A decrease in energy expenditure of 20%.

c) An increase of 2 energy grades.

d) An investment for energy retrofitting of less than 30.000 euro per dwelling.

e) Development of strategies and policies that address EE and sustainable building approaches in LIH.

f) Identification of financial and technical mechanisms adapted to LIH, to be deployed in the Mediterranean area.

g) Improve energy consumption habits and reduce energy bills thanks to smart metering.

The partners involved in the project belong to 7 different countries while the pilots will be realized in Italy, France, Spain, Greece, Cyprus, Malta. Slovenia also participate to experimentation but only for the smart metering part.

The experimentation will produce several guidelines related to technical and financial solutions as well as the awareness campaign.

The project has also produced a policy paper which is still under development and which foresees joint capitalization activity with other two projects, such as MARIE and PROFORBIOMED, which are other two projects of the MED program related to energy efficiency and Renewable energy production by biomass. The final document will be endorsed by all the political stakeholders at European, National and regional level.

All the guidelines and the policy paper, as well as other useful information can be found in the project web site: www.elih-med.eu

Keywords:
Energy Efficiency; Low Income Housing; Mediterranean; Smart Metering

1. Introduction

ELIH-Med Project (Energy Efficiency in Low Income Housing in the Mediterranean) is one of strategy projects supported by the European Commission under the framework of the Med Program – Objective 2.2. The project runs from April 2011 to the end of 2014, with 18 partners from 7 countries (Italy, France, Spain, Greece, Cyprus, Malta and Slovenia) covering the whole Northern Mediterranean seacoast.

ELIH Med main aim is the selection of innovative technical solution and financial mechanisms as well as the implementation of a large scale experimentation, ELIH Med addresses the problem of energy efficiency in Low Income Housing (LIH) in a Mediterranean context.

Economic, social and environmental urgencies are today, maybe more than ever, strongly interrelated. A broad consensus exists on the necessity of developing new economic models and standards of living based on energy efficiency and the European Union adopted common patterns to achieve the ambitious target of an increase in energy efficiency of 20% up to 2020.

This challenge, common to all the European countries, has a specific resonance in the Mediterranean space, where the economic crisis is stronger than elsewhere in Europe with a greater rate of unemployment. Households, enterprises and also public bodies have little solvability and need to reduce substantially their expenses, including the energy bills.

The second common characteristic is the connection between climatic conditions and an important and ancient existing building stock. Energy efficiency renovation of buildings in the Mediterranean face expensive investments in the context of a lower potential of savings (particularly concerning heating), older building stock and poorer population than in Northern Europe. Moreover, the Mediterranean space faces a specific issue, not taken into account till now: the summer comfort challenge.

In this complex Mediterranean framework, it makes sense to test, at a transnational level, new approaches and tools that may contribute to overcome the main barriers that today prevent from a clear improvement of energy efficiency in buildings. It is one of the topics that have achieved legitimacy as an essential axis of the territorial cooperation, because it requires, more than other topics, a multilevel coordination.

The EU Consultation Paper (Financial support for Energy Efficiency in Buildings, released in February 2012) says, “buildings must be central to the EU energy efficiency policies as nearly the 40% of final energy consumption (and 36% of the greenhouse gas emissions) is in houses, offices and shops”. Now, the increase of the global sustainability of building stock and construction sector will depend on the ability of energy efficiency policies to deal with the diversity of the building stock. Furthermore, the ancient building stock in the Mediterranean is characterized by low renovation rates (2-3 times lower than the average energy refurbishment rate in north-western EU countries; BPIE and FI 2011). To transform this energy saving potential in real energy and economic savings, the ancient building stock has to become a priority topic in policies and strategies, which have to target all the relevant public and private stakeholders.

Nowadays, policies mainly impact public social housing, through specific credit lines, ERDF funds and ambitious objectives of renovation. Nevertheless, the low-income housing sector in the MED space is characterized by the importance of the private housing. Now, private owners are “far to reach” by existing policies: a particular effort has to be made, in awareness and financial formulas, as a priority to adapt policies to low-income owners and create innovative incentives.

Apart from the direct impact foreseen in energy and monetary terms for users, large scale energy refurbishment operations should also create positive economic and social externalities. Several studies and analysis from the European Commission and other European institutions have demonstrated the enormous potential of buildings energy efficiency improvement in the MED space economy. The investment needs per year for EU 27 countries, indeed, are valued at 60 billion Euros and the related job creation is estimated at 800.000. However, actually there are important barriers that impede the development of this captive market. The Mediterranean countries should understand how these barriers can be unblocked according to other countries and sectors’ experiences.

Territorial cooperation is a key option to overcome as quickly as possible the enormous barriers that prevent from developing the energy renovation of buildings in MED space. ELIH-Med has therefore concentrated all the efforts to find solution to remove the barriers and promote a policy paper through Europe.

2. The ELIH-Med project

The ELIH Med project has started in December 2011 and it is considered a strategic project because of the large experimentation foreseen on 450 dwellings in six countries. This experimentation will be used to set up guidelines and policy paper for the next programming period of structural and cohesion funds as well as any other action which could influence the development of strategies useful to increase the energy efficiency of low income housing.

2.1 ELIH Med partnership

Eighteen partners from eight countries participate to the project which is coordinated by ENEA, the Italian National Agency on Energy, New Technologies and Economic Sustainable Development

with the support of the French Mediterranean Institute based in Marseilles. The partnership is therefore constituted by the following partners with specific competences:



2.1.1 Italy

a) ENEA.

b) ISNOVA.

c) Genoa Municipality (Liguria Region).

d) Frattamaggiore Municipality (Campania Region).

The countries involved by the HELIH Med partnership

e) LAORE Sardinia.

2.1.2 France

a) Mediterranean Institute (IM).

b) 13 Habitat.

c) CSTB.

d) Languedoc-Roussillon Region.

e) GERES.

2.1.3 Spain

a) The Malaga City Council, through the Municipal Energy Agency, the Urban Environment Observatory (OMAU) and the Local Housing Institute.

b) Valencia Institute of Building-Foundation (IVE), Comunitat Valenciana.

2.1.4 Greece

a) The Centre for Renewable Energy Sources and Saving (CRES).

b) Democritus University of Thrace (DUTH).

2.1.5 Cyprus

a) The Cyprus Energy Agency (CEA).

2.1.6 Malta

a) Malta Intelligent Energy Management Agency (MIEMA).

2.1.7 Slovenia

a) Jozef Stefan Institute, Energy Efficiency Centre, (JSI/EEC).

2.1.8 Belgium

a) The Conference of Peripheral Maritime Regions (CPMR).

2.2 The main objectives

The main objectives of ELIH Med project are:

A. To identify and demonstrate through a large scale experimentation the feasibility of cost efficient innovative technical solutions and financial mechanisms backed with European Regional Development Fund (ERDF).

B. To promote changes in the inhabitants behaviour to reduce energy waste.

C. To experiment the use of smart monitoring systems to rationalize the use of energy.

D. To develop energy efficiency policies in low income households in the Mediterranean area which could, then, be extended to all Mediterranean territories. The policies start from the territory where the experimentation is made.

2.2.1 The pilots

Energy refurbishment of pilot low income households are located in 6 partner countries (Cyprus, France, Greece, Italy, Malta and Spain). The experimentation will bring to the development of concept, approach and policies adapted to low income housing in the Mediterranean area. At the same time the dwellings would achieve the following immediate results:

- A cut in energy consumption of 40%.
- A decrease in energy expenditure of 20%.
- A gain of (at least) 2 energy grades (Example: from class F to class D).
- An investment for energy retrofitting of less than 30,000 euro per dwelling.

To obtain these results the pilots are identifying and experimenting, on a large scale, a set of practical and innovative technical options and financial mechanisms targeted to develop energy efficiency in low income housing. The target includes:



a) Energy performance: theoretical energy characteristics of the building, including heating and cooling system, hot water and lighting.

b) The summer comfort will be considered in order to make the temperature not exceed 28°C more than 10 days per year.

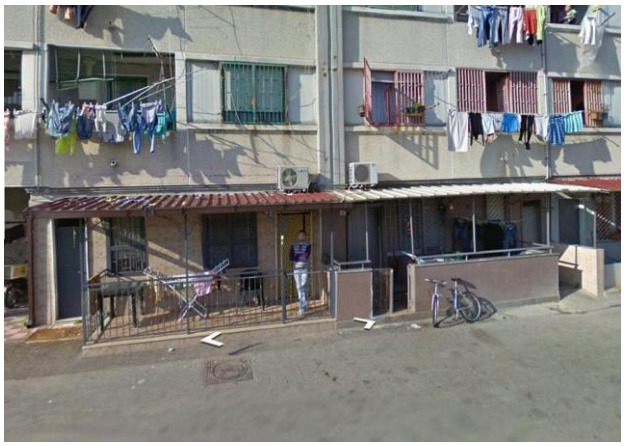
c) Energy charges for heating, cooling and hot water (considering a typical comfort level of19°C in winter, and the summer comfort as described above).

d) Payback period: payback of retrofitting investment by energy charges gain.

The complete set of improvements for sustainable building construction.

In the next two figures there is the representation of low income houses in Frattamaggiore municipality. On the left the situation as it is now and, on the right, the situation after the refurbishment. In this case a small courtyard in front of the house as many objectives: increase safety for children who are now leaving on the ground floor just “on the street” without any protection, increase the shadow in summertime, use the roof for installing photovoltaic and thermo

solar plants for electricity and hot water.

	
Before the refurbishment	After the refurbishment

2.2.2 The guidelines

As the project last step, the results of ELIH-Med large scale experimentation will be analyzed and discussed in various capitalization workshops in order to reach a final set of conclusions and recommendation which could then be extended in the whole Med area.

The results will be collected in different guidelines addressed to different target groups like LIH tenants/owners, building sectorial technicians and other sectorial professionals. It is expected to work out an Operational Plan, giving a visibility at political level as a component of a macro regional strategy for a coordinated use of Structural Funds for the next programming period 2014-2020. The ELIH-Med guidelines which will be widespread in all Med countries are:

a) Guideline on cost-effective refurbishment solutions in Med LIH with the good experimented cost-effective advanced retrofitting solutions in Med LIH.

b) Guideline on innovative financings. The financial guideline contains information on good successful examples of advanced financing schemes and subsidy schemes verified during ELIH-Med pilot actions. The guidebook is addressed to financial institutions and private investors; of course the information will be very useful for housing companies as well as energy agencies, consultants and planners.

c) Guideline on energy efficiency policies in LIH in the Mediterranean. Based on the analysis on current EE polices in ELIH-Med countries made during the first phase of project, in this guideline, ELIH-Med proposes specific EE policies in Med LIH addressed to local and regional authorities.

2.2.3 The smart metering



One of the ELIH Med project aims is to identify the possibilities of energy Smart Metering systems to boost the energy efficiency in LIH, as Smart Metering is a technology where end-use energy efficiency can particularly be encouraged through its impact on tenants' behaviour.

Five partner countries (Cyprus, France, Greece, Malta and Spain) are involved in the pilot experimentation.

The smart metering experimentation

The data will be collected till the end of the project in December 2014 from 765 pilot dwellings selected for the installation of smart meters.

2.2.4 The awareness campaign

For selecting fruitfully pilot dwellings and setting up TMG and PPCG two groups, it is essential to make LIH owners/tenants and the related stakeholders aware of ELIH-Med, of energy efficiency concept/energy saving behaviours and of related technical-financial solutions.



ELIH-Med partners have adopted different methods to implement their awareness raising activities, such as participating social events, organizing technical workshops and making LIH visits. The figure on the right side gives some idea about awareness raising activities carried out by ELIH-Med partners. Especially, Spanish partner IVE has produced a set of Energy Saving tips to change energy consumption behaviours of LIH owners/tenants, which is very appreciated by readers.

Example of “tips” produced by IVE for the awareness campaign

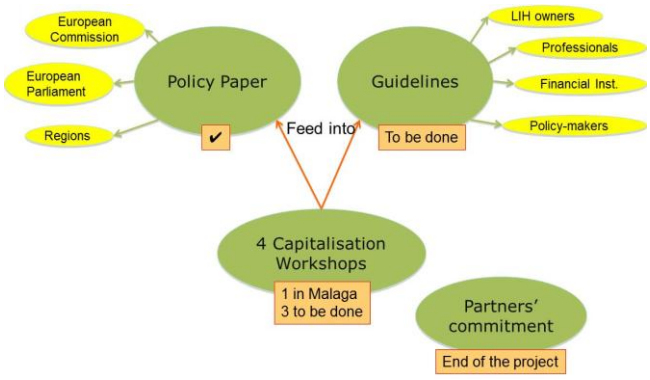
3. The capitalization

The Med program give a large importance to the exploitation of results through capitalization activities which would bring together different project dealing with similar or complementary activity. The result is a common policy paper addressed to all decision makers of Mediterranean area. This policy paper will consider both: energy efficiency policies and territorial cooperation, trying to pave the way for an empowerment of them as central topics at the next programming period operational programs.

It also aims to reinforce the linkage between territorial cooperation initiatives on energy efficiency, public policies and access to new sources of funding. A greater cooperation on energy efficiency issues and specific efforts to test, innovate and fundraise ambitious projects and policies are necessary if we want to make the 20% energy efficiency increase objective more realistic. Currently, the energy renovation of buildings is considered by investors as a difficult question, with unclear profitability and with a long administrative process to reach public subsidies or grants. More than the context of economic crisis and environmental pressure, the EPBD Directives implementation starts nevertheless to open the mind of the main stakeholders in considering energy efficiency improvement of buildings as an important and mandatory challenge.

However, important gaps still remain between countries and regions in the implementation of the European legal framework. And this framework will not be sufficient to compel all the stakeholders to endorse their responsibilities. In this context, transnational cooperation projects could actively contribute to create a local and regional movement towards a better implementation of this framework and an involvement in EE policies, which could encourage investment, and, on the long run, jobs creation. Moreover, cooperation projects should also facilitate citizens’ awareness concerning the importance of energy renovation and buildings opportunities. Territorial Cooperation would facilitate:

a) Benchmark and comparative analysis between different realities. In this sense, territorial cooperation can facilitate the production of more complete analysis and knowledge of reality.
b) Create uniform criteria for assessing the effects of EE measures and evaluation of achieved savings.
c) Share of solutions and measures and integration of the achieved experience based knowledge.
d) Generation and share of common approaches to overcome common barriers.
e) Achievement of economies of scale in investment and efforts development.
f) More dynamic markets in quantitative and qualitative terms.



Energy efficiency in buildings could become a strong pilot sector for transnational cooperation in the Mediterranean. This topic is particularly relevant not only because it is in line with the EU2020 strategy and priorities, but also because experience-sharing opportunities are numerous and policy development in this sector is complex and requires pilot action and innovation. In this domain, multilevel coordination and governance issues are the main barriers and transnational cooperation can facilitate this multilevel dialogue.

The capitalization framework

Nevertheless, transnational cooperation is still a marginal source of funding and projects have difficulties to directly innervate policies at local and regional level. In this sense, preparing, sharing and developing a common MED strategy to improve energy efficiency of buildings is a clear positive example of the usefulness of territorial cooperation approach, even if efforts should be continually done to combine transnational projects with an efficient multilevel governance system able to generate consequent impacts up to the EU2020 objectives. This Policy Paper is a key tool to combine both vertical (multilevel governance) and horizontal (territorial cooperation and policies) approaches and to avoid the usual fragmentation and barriers in EU policies implementation.

As the ongoing programming period for European territorial cooperation is coming to an end, the preparation of the next programming period for 2014-2020 is currently in discussion. Now, ELIH-Med and MARIE are persuaded that both projects, as well as PROFORBIOMED and others belonging to European programs related to these issues, can bring results and lessons of their experiences as a real added value to the next programming period. This is the object of this Policy Paper that aims to propose to the Managing Authority of the MED program a consensus based set of recommendations to contribute to the next programming period preparation, providing answers to the challenges related to energy efficiency in buildings shared by the Northern Med regions and countries. The policy paper of ELIH-Med, which can be downloaded from the web site (www.elih-med.eu) presents a review of the current situation in the Med area, by analyzing the gap between the objectives and the real ongoing investments and mutations. Investigations have allowed MARIE and ELIH-Med partners to agree on strategic lines aiming to improve energy efficiency in buildings that are the skeleton of the shared vision both projects advocate for. In addition, the policy paper proposes recommendations on improving cooperation on energy efficiency issues in the Mediterranean area. PROFORBIOMED, a strategic MED project that pursues the promotion of the residual forest biomass for energy, sustains the same Policy Paper elaborated by ELIH-MED and MARIE projects.

4. EU Directives related to EE of Buildings.

a) The 2002/91/EC introduces an energy certification scheme, a methodology for the calculation of the energy performance, applying in the same time minimum requirements of new buildings.

b) Its recast, directive 2010/31/EU, comes to reduce the large differences between Member States' practices in this sector.

c) The co-generation directive 2004/8/EC establishes a general transparent framework to promote and facilitate the installation of cogeneration facilities.

d) The directive 2006/32/EC on energy end-use efficiency and energy services aims to make the end use of energy more economic and efficient in Member States.

e) The directive 2009/28/EC is a useful instrument for improving energy efficiency in buildings, by promoting the use of energy from renewable sources.

Life Cycle Assessment for sustainable buildings during the planning phase

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Abstract

Since the main efforts in decreasing ecological impact of buildings in the last decades mainly focused on reducing energy demand during operation, used construction materials are receiving more importance in a comprehensive Life cycle assessment (LCA). Decisions about construction materials and systems are often made in an early planning phase regardless of their ecological impact. In analogy to life cycle costing where the influence of decision in the early planning phase has been proven [1], the importance of decisions in an early state of planning influencing the construction and its ecological impact can't be neglected. Regardless its increasing importance, at the moment no tools are available to support such decisions in preliminary planning process. The purpose of this work is to show an approach for estimating the ecological impact of buildings in an early phase (architectural competition or preliminary design phase) in order to support decisions in the design phase.

To do so, the former developed life cycle costing tool "LZK- Tool" [2] has been extended by the possibility of LCA. In the "LZK-Tool" construction elements are used to calculate the costs of an entire building as well as the follow-up-costs during life time. To estimate the ecological impact it was necessary to define more detailed used materials or available products for those elements. Consequently, ecological impacts where estimated either on the basis of available environmental product declarations (EPD) or, for elements with lacking EPDs , with ecological databases. With this approach ecological impacts for about 500 elements were calculated.

To validate the calculations, LCAs calculated by third parties on the basis of drafts have been compared with LCAs calculated by the above described approach. The results show that for a selected group of impact categories adequate results are achieved (a variation of approximately +/- 15% occurs).

It can be concluded that this method successfully manages uncertainty regarding ecological impacts in very early design and concept phases with an established top-down process. On the one hand it can be used to support important decisions concerning the most important elements in a building (facade, primary construction, etc.), and on the other hand it gives the opportunity to compare entries of an architectural competition from ecological point of view besides the already established monetary assessment. Therefore, this approach provides reliable support for decisions in an early planning phase influencing impacts ecologically and monetarily during the lifetime of a building.

Keywords

LCA, sustainable buildings, early planning phase, LZKTool

1. Introduction

Efforts, undertaken after the first energy crises in the late 1970s, in decreasing the ecological impact of buildings have led in the last decades to a tremendous decrease in energy demand of buildings. The main topic of interest was the reduction of energy for heating. While in the 1970's energy demand was around 200-300kWh/m² modern buildings can achieve values below 15kWh/m². A term strongly related to this reduction is "Green Building" which generally describes buildings with low ecological impact considering all phases of a buildings lifetime. As this term not only refers to the energy demand in operation other topics like location in terms of environmental quality, connection to public transport or soft facts like work place quality, acoustic quality in the building etc. are also relevant for green buildings. A topic becoming increasingly important due to the reduced energy demand during operation is the energy demand and ecological impact of the used construction materials. Most of the building certification systems do rate the ecological impact in at least one or sometimes several impact categories of used materials in a building.

The most important certification systems in Austria are the German Sustainable Building Council certification [4] and the so called "Total Quality Building" certification system [5]. In these two certification systems impact categories like Primary energy demand (renewable and non renewable), Global Warming Potential, Acidification Potential and others are part of the evaluation. International certificates like BREEAM or LEED do not take as many impact categories into consideration but limit themselves to Primary Energy Demand and Global Warming Potential.

The importance of these indicators has been shown in "Haus der Zukunft" projects, as it has been calculated that due to the minimization of grey energy (energy needed to produce and provide construction materials till they are on construction site) it is possible to save an amount of CO_2-equivalents which is equal to those of the a heating of a passive house.,. Only in the last 20years research has begun to calculate the values for grey energy for processes and materials and other indicators of interest for ecological impacts.

Nevertheless, even though data is available, the obstacle to overcome is to make decisions, which are influencing the economic, energetic and ecological performance of a future building at an early stage in a planning process.

Also, when an architectural competition is undertaken, decisions about facades and energetic concepts - highly influencing the energetic and consequently the economic performance of a building – have to be made. These decisions are based on the experience of architects and its technical consultants. Because these systems are becoming more complex and, due to the technical innovations in the last decades, the possible solutions are manifold, architectural entries in a competition are difficult to compare. Even after an architectural competition when an architect with its team is chosen, first drafts have to be developed and optimized with regard to economic, energetic and ecologic performance.

As Developers do usually not have the experience to validate proposed technical solutions, important decisions can't be made on the basis of hard facts. This uneasiness in the planning process and the urge to receive high security about construction and operation costs, energetic performance and knowledge about the possibilities for a future building certification during the planning phase, can only be tackled with proper tools. These tools must deliver more or less accurate figures (costs, ecological impact) but work with parsimonious input data as most of the construction and building details are not known by that time.

Unfortunately, most of the available tools to calculate indicators for these issues need detailed information of the future building which can't be provided. As outlined in Hofer et.al 2011 [2] and shown in the figure below there is a lack of tools during the conceptual phase of a building.

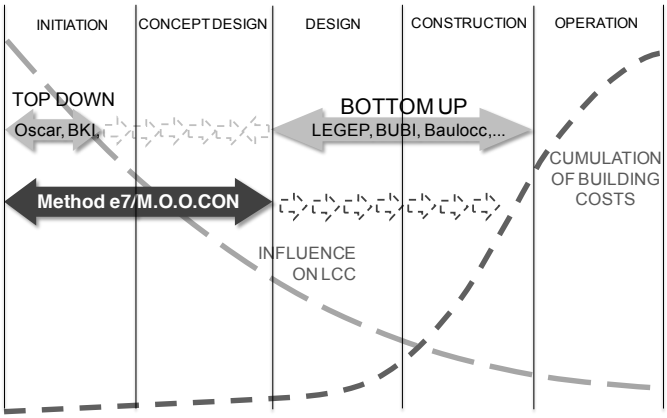


Figure 1. Missing link in models for calculating life cycle costs during the design phase (Source: [2]).

With the growing pressure for buildings being sustainable and growing importance of building certification, not at least to guarantee high marketability as outlined in Fuerst & Allister [3], it has become more important for developers to receive assurance for a high building quality as early as possible in the planning process of a building which in turn increased the need to develop proper tools for this period in planning.

One tool developed in recent years, to make competition entries comparable and to support decision during the early design phase, was the LZK TOOL developed by M.O.O.CON and e7. Till now with the LZK TOOL economic and energetic performance of buildings can be calculated. The main focus of this research project was to extend the LZK TOOL by the possibility to calculate the ecological impact of a building with basically the same method. The first step was to give indications about the ecological impact of the construction materials used in a building and in a next step to calculate the impact of the operational phase of a building. Other indicators like water use and emissions of construction site related transport will be estimated with already calculated output of the LZK TOOL in combination with available emission data.

The following part mainly focuses on the first aim – the calculation of the ecological impact of used construction materials – as this was the main focus of recent research and is most relevant for the use in certification systems and of interest for developers and planers.

2. Method

To calculate the ecological impact in an early planning phase neither a bottom up approach which prerequisites detailed information of a the building nor a top town approach which only can deliver results for the entire building but not parts of it were suitable. Therefore in analogy to the developed "LZK TOOL" described in [2] this approach has been developed.

The Tool described in [2] uses "elements" of constructions which can be aggregated to an entire building. The main advantage of this approach is that with few, known or assumed, parameters in an efficient and time saving way a model of a building can be made. The basic idea is that the sum of elements multiplied by the amount of a related functional unit can be aggregated to a building.

$$building = \sum_{i=1}^{n} element_i * amount\ of\ functional\ unit \qquad (I)$$

In this regard the main focus has to be lied on the definition of elements and a proper functional unit which can be quantified in an easy way.

For example, in the mentioned tool an element is the opaque part of the facade and another one the transparent part of the facade. The related functional units would be one square meter opaque facade and one square meter transparent facade. These two elements together already describe an entire facade. At this point it is clear that an element can have different forms. In case of the transparent facade different types of windows can be used but at least one has to be chosen to fulfil the requirements of the model.

Therefore, functional units can be different for different elements. Functional units in the mentioned tool are for example m² gross floor area, m² facade area or number of workplaces. Not all functional units have to be independent as one can determine another one. For example, a facade usually divides into an opaque and a transparent part. By knowing only the entire facade area and the transparent area the opaque area consequently is a result of the other two areas. Obviously, some functional units can also be input parameters but most are derived from input parameters. Basically, the LZK TOOL works with around 50 input parameters of which some 200 functional units are derived.

In first place the aim of the LZK TOOL was to calculate the construction and operation cost and therefore equation (I) was extended to equation (II)

$$cb = \sum_{i=1}^{n} e_i * \sum fu_e * c_{e,fu} \qquad (II)$$

cb	cost of building
e	element
fu_e	functional unit related to element
$c_{e,fu}$	cost of element based on the functional unit

As the aim of the tool is to estimate the ecological impact of a building, equation (II) had to be altered the following way

$$eib = \sum_{i=1}^{n} e_i * \sum fu_e * ei_{e,fu} \qquad (III)$$

eib	ecological impact of building
e	element
fu_e	functional unit related to element
$ei_{e,fu}$	ecological impact of element based on the functional unit

Whereas impacts of an element could be all known and calculated ecological impacts.

Besides the definition of the element and the functional unit, the system boundary had to be defined. In a first approach it has been decided that in a first step only the construction of the building should be calculated. For validating the tool this was a necessary step because on the one hand the definition of these elements is unique and can't be compared to other systems and calculating the impact over the lifetime of a given building strongly depends on the life time of an element. Therefore, assuming that elements are renewed or at least refurbished several or at least one time, lifetime is a crucial parameter in calculating the economic and ecological impact. As life times differ widely across literature and as already mentioned the used definition of elements in the "LZK TOOL" is unique, it would be nearly

impossible to receive the same results as there is no guideline how to calculate ecological impact of the lifetime of a building. To make the calculations of this method comparable with other tools, first calculation were undertaken without accounting the life cycle impacts of the building. Therefore for the first calculations only the impact of the established building has been considered.

To make this approach operational the database created for the “LZK TOOL” has been further extended. The mentioned database comprises of around 1100 elements of which around 500 elements are used for estimating the ecological impact of the building. Elements concerning the primary construction, the thermal envelope, separating walls and floor constructions are considered within these 500 elements. Elements concerning HVAC (the heating, ventilation and aircondition system) and furniture where not considered.

As the elements have no or only minor information about the used materials and its weights, it was necessary to define all used materials for each element. This was an easy task for the primary construction as the elements are quite simple whereas other elements needed more attention and further research.

After defining used materials the ecological impact of an element related to its functional unit could be calculated. For this purpose mainly data from “ecosoft” (a product of the IBO institute) was used. As ecological impacts are manifold it has been decide to concentrate to only a few of them. In detail for each element the following categories have been chosen:

- Primary energy demand (PE) - because of its overall importance and comparability for buildings
- Global warming potential (GWP) – because of its importance and significance in the global warming discussion
- Acidification potential (AP) – even though this indicator hast lost importance in Europe because most of industry facilities have DeNOx plants, it is still important for mass products like cement which are dealt globally and therefore not necessarily are produced in Europe
- Photochemical Ozone Creation Potential (POCP) – This indicator is especially of importance because it can be highly influenced at the selection of construction products because of the emissions of used solvents

Two often used indicators, Eutrophication Potential and Ozone Depletion Potential, have been discussed but not calculated because of lacking relevance in these days.

For the above mentioned four indicators the impact for an element related to the functional unit has been calculated for the construction and the end of life phase. The distinguishing between these two phases is of major importance as elements have different life times and the ecological impact of a building will be calculated over a predefined building lifetime. Therefore as elements are going to be changed at different times in a building lifetime ecological impacts occur a different time. At the end of the buildings lifetime all ecological impacts are summarized including the demolishing of the building.

3. Preliminary Results

After calculating ecological impacts to 500 elements and importing the data to the database first calculations with the "LZK^{ÖKO} Tool" have been undertaken.

As the input data does not differ from the input data in the LZK TOOL, calculations for several projects could be undertaken. For practical reasons, in a first run only five projects have been calculated which have been chosen by considering the difference in gross floor area and the aim to achieve a certification (either after TQB or DGNB certification system). The projects were proposed by M.O.O.CON and are known under the project titles: WES Smart Campus (Vienna), E+E (upper Austria), Garant (lower Austria), Immorent (Vienna), Windkraft Simonsfeld (lower Austria).

First validation of calculations showed no unreasonable results, afterwards comparisons with calculations based on finished drafts have been done.

	LZK^{ÖKO}	**third party calculation**	**deviation**
Inventory	3756 [t]	3745 [t]	+0,31%
PEnr	2229 [MWh]	2053 [MWh]	+7,88%
Per	332 [MWh]	1083 [MWh]	-225,81%
GWP	574 [t CO2]	255[t CO2]	+55,62%
AP	1774 [kgSO2]	1414 [kg SO2]	+20,30%
POCP	203 [kg C2H4]	163 [kg C2H4]	+19,70%

Table 1: Ecological Impact calculations for a 2100m² GFA building

The figures in table 1 show first results of one of the projects and compared with calculations of third parties. Considering the system boundary it can be said that for the inventory the two approaches deliver approximately the same result. Unfortunately, the different impact categories show results with wider variation. While the results for AP, POCP and PE non renewable show results in an acceptable variation the important indicator for the renewable primary energy demand as well as the global warming potential show substantial variations. As a deeper validation of the data is still in progress only first assumptions about the variations can be made which still have to be validated. Reasons for the variations can be:

- even though the inventory on an overall level shows the same result, shifts between used materials are still possible.
- use of different databases for calculating the ecological impact of the used materials. Whereas for LZK^{ÖKO} Tool mainly Environmental Product Declarations (EPD) were used the calculations of third parties are based on other databases. Differences for the same material can therefore be relevant
- The use of EPD's may cause a general bios as the considered calculation of the third parties do use databases which can better take into account local differences influencing the ecological impact of a relevant product.
- As in the analysed building a substantial amount of renewable materials are used (straw for the insulation, wood for secondary construction, foam glas gravel for perimeter insulation) the fact of using different data sources in this case seems to be predominant

4. Conclusion

Nevertheless, at the given stage of research it can be concluded that the "LZK^{ÖKO} Tool" can be used to calculate the ecological impact in an early planning phase. The inventory shows approximately the same results at a variation below +/- 10%.

As especially the inventory deals as a fundamental prerequisite for calculating the ecological impact, differences in the impact categories can be tackled and brought to an acceptable level. Current differences in some of the chosen impact categories must be further investigated but first insight anticipate that one of the main obstacles is the use of different databases.

The aim of this research, to support decisions for developer in an early planning phase, has been achieved. The first results show, that the chosen method, aggregating ecological impacts of elements to the ecological impact of a building can be used to give a first indication and support developers decisions.

5. Outlook

To assure an accurate calculation, a deeper analysis of used databases must be undertaken. As at the time given only a few buildings could be calculated and compared with third party calculations more calculations have to ensure resilience for the calculated results. Furthermore, one of the main weaknesses of the most tools, regardless of the time used in the planning or construction phase, is the lacking consideration of the HVAC system. Especially in these parts of a building, most of elements are used which usually have high ecological impacts. A focus of future research will be to estimate the relevance of used metals (besides the already calculated reinforcement steel) for the ecological impact of a building.

6. Acknowledgement

The research project to further develop the “LZK TOOL” to the “LZK^{ÖKO} TOOL” was funded by the FFG under the “COIN” program in the field of “Kooperation und Netzwerke”. The authors and the engaged companies bauXund, e7 and M.O.O.CON thank for the financial support.

7. References

[1] M. Pongratz, G.Hofer, The positive impact of Life Cycle Cost Calculations in the early design phase on energy efficient and sustainable buildings, Proceedings of the 7th International Conference on Improving Energy Efficiency in Commercial Buildings, Frankfurt, 2012

[2] G. Hofer, B. Herzog, M. Grim, Calculating life cycle cost in the early design phase to encourage energy efficient and sustainable buildings, SB11 Helsinki World Sustainable Building Conference, 2011

[3] Fuerst, Franz; McAllister, Patrick: Green Noise or Green Value, Measuring the Price Effects of Environmental Certification in Commercial Buildings, Reading, 2008.

[4] DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen e.V.), Deutsches Gütesiegel für Nachhaltiges Bauen, Aufbau – Anwendung – Kriterien. Issue 3/2009. Stuttgart, 2009

[5] Lechner, Robert: TOTAL QUALITY BAUEN: Ergänzung und Erweiterung des bestehenden Gebäudebewertungssystems, Wien, 2009.

In situ U-value measurements for today's Cypriot Houses

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Short Summary

Material thermal properties are essential in calculating thermal energy losses through out a building's shell. Exact values, especially regarding the material thermal transmittance co-efficient, also known as U-value, are critical for the correctness of calculations predicting a building's thermal energy demand, both for heating and cooling, thus enabling engineers in designing, dimensioning and evaluating the building's necessary heating and cooling systems in order to optimize the final building/system integration and maximize efficiency, resulting in decreased consumption. The aim of this study is to establish, under real weather conditions, the thermal characteristics and actual thermal behaviour of typical residential houses in Cyprus.

For this purpose, a wireless web-based monitoring system has been deployed covering 44 different houses, geographically selected all over Cyprus. Construction materials varied amongst each house, resulting in a theoretical U-value range of 0.467 to 1.389 W/m^2K. Calibrated temperature sensors were installed and measurements were conducted at 30-minute intervals for each individual house. The internal house air temperature, the external air temperature, as well as, the internal and external wall surface temperatures, have been continuously monitored for a period of fifteen months.

Processing the above mentioned data has led to the establishment of the mean internal temperature of the typical Cypriot residence and calculation of the U-value for each individual wall, facing north, south, east and west, including the roof, comprising the building envelope. Variations of the calculated U-value of up to 25% for each wall orientation are observed, even though construction materials of each wall remain the same. Furthermore, deviations of up to 30% from the theoretical U-value calculation are also observed.

The utmost aim of this study is to provide experimental evidence and accurate measurements of the thermal characteristics and behaviour of the typical building envelope in Cyprus, providing thus a more accurate tool for the engineering calculations.

Keywords: Heat Losses; Energy; Building Envelope; U-value; Thermal Transmittance co-efficient.

1. Introduction

Energy consumption in buildings accounts for approximately 40% of the total energy consumed in EU annually [1]. Furthermore, it has been established that households, in developed countries, spend slightly more than half (53%) of their total energy needs for space heating and cooling [2]. Taking also into account studies showing that there is major room for improvement on the energy saving of the building sector in general [3], as well as for the residential buildings in Cyprus in particular [4], it is evident that correct analysis of the building envelope and determining the critical sources of thermal losses for a residential building is of great importance. Establishing the actual thermal losses of the typical Cyprus residence, and identifying the dominant mechanisms and elements that contribute the most to the total residential thermal energy demand can become a useful tool in the hands of policy makers, engineers as well as academia involved in the building sector in general. Even though previous studies have been conducted in modelling the Cypriot residence and its energy consumption [4] and also identifying the energy behaviour of the residential buildings stock in Cyprus [5], this is actually the first time that in situ measurements were performed in such a large scale in order to check the accuracy of such theoretical predictions. Theoretical predictions are based on methodologies developed mainly in the US and northern European countries, thus, their direct implementation cannot be fully relied on due to the difference in climatic conditions, building architecture and materials used for construction.

Better knowledge and understanding of the major building elements contributing to the majority of the building's thermal losses, as well as the actual construction materials behaviour and thermal properties, can lead policy makers into improved legislation and EU directives implementation, drafting of measures and targeting government subsidies regarding energy efficiency and saving, thus maximizing the overall used energy reduction in the household sector and the building industry in general. Architects and engineers can also benefit greatly from such knowledge resulting in better building design, more accurate cooling and heating systems design and dimensioning and optimized building/systems interaction resulting in higher efficiencies and energy savings to the benefit of the end user.

In this study, the findings from the collection and analysis of actual in situ measurements in 44 different houses spread all over Cyprus are presented. Specifically, the typical behaviour of the Cypriot user and his habits regarding the use of his residence heating system is identified, the U-value of typical wall structures used in the Cyprus building sector are derived and the actual thermal losses during winter are calculated. Finally, the phenomenon of the radiating roof is presented in detail and its impact in increased energy losses during night time is investigated.

2. Methodology

The methodology followed by the research team participating in this project was based initially on two main axes. At first, a representative sample of houses to be monitored had to be selected based on the following criteria: geographic location and climatic conditions, building type, population density, construction materials and building characteristics. Four major climatic zones are acknowledged in Cyprus; coastal, low-land, semi-mountainous and mountainous. Also, based on population density, three main area categories are distinguished; urban, suburban and rural areas, within the provinces of Nicosia, Limassol, Paphos, Larnaca and Famagusta.

Data acquired from the National Statistical Service of Cyprus [6] regarding the geographical distribution of licensed residential buildings in the above areas for the period of 1991-2006 coupled with identified construction characteristics led to the selection of 44 residential buildings for monitoring, spread all over the island, as shown in Fig. 1. Most of the houses were selected in the Nicosia region since it is the most populated province, followed by Limassol and then Larnaca, Paphos and Famagusta as shown in Fig. 2. Furthermore, as shown in Fig. 3, most of the selected houses have no thermal insulation as this was the common case in Cyprus, before the implementation of the legislation on compulsory thermal insulation in buildings. However, a substantial number of thermally insulated houses were chosen in order to check current construction trends and techniques used in compliance with the recently voted legislation.



Fig. 1: Location of the monitored houses all over Cyprus (marked with red pins)

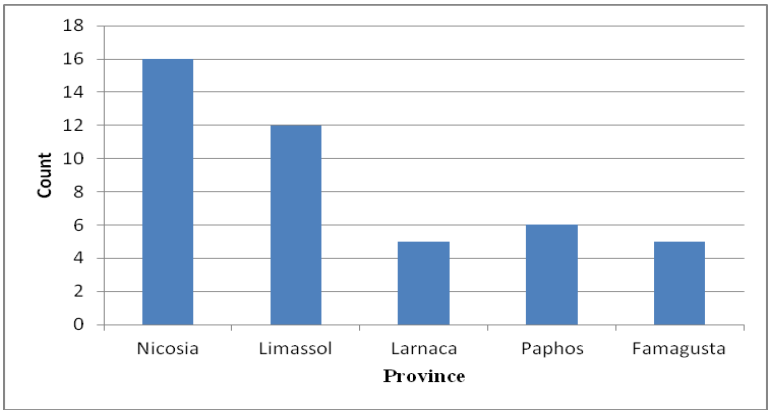


Fig. 2: Geographical distribution of monitored houses

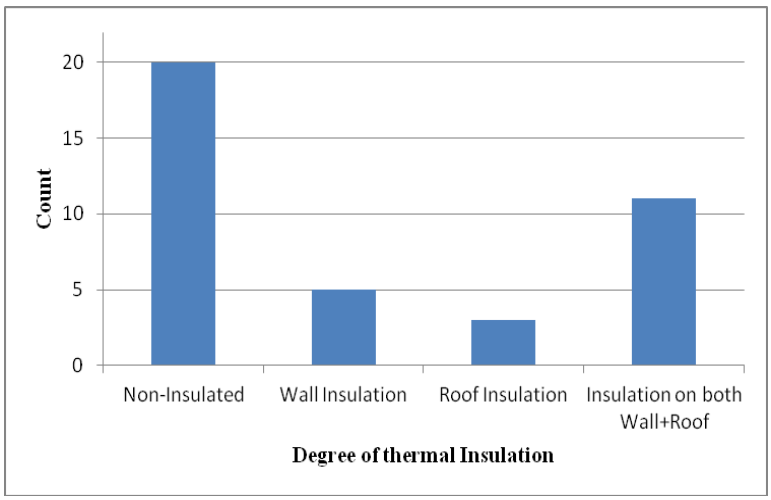


Fig. 3: Degree of thermal insulation of monitored houses

Secondly, a custom temperature monitoring system, mainly due to budget constraints was locally developed for the project's purposes. The temperature sensors consisting of thermistors mounted on wireless and energetically autonomous data acquisition end-notes, were designed, assembled and calibrated at CNE Technology accredited laboratory. The sensors developed were installed in the selected houses, at appropriate surfaces and locations (selected using thermal image photography) in order to monitor the internal and external surface temperatures of the walls and the roofs, as well as the internal room air temperature. Furthermore, air temperature sensors were used for monitoring the outside (ambient) air temperature. Six out of the total 44 selected houses were fully monitored; temperature sensors have been placed on each wall direction (north, south,

east and west), as well as on the roof. The rest of the selected houses were partially monitored; temperature sensors have been placed on walls facing only two directions (e.g. walls facing south and west). Finally, four meteorological stations were installed in order to track local weather conditions and microclimate irregularities as detailed as possible. The meteorological stations were installed in the provinces of Nicosia, Limassol, Paphos and Famagusta where the majority of the monitored houses are situated and their location was carefully selected in order to be as close to the monitored houses of each province as possible.

In addition to the above measurements, a questionnaire was prepared in order to gather further information and details on the selected houses. Information regarding the construction materials of the walls and roof comprising the building envelope, type of windows and glazing, the cooling and heating systems installed as well as the months in use and set temperatures, the number of occupants and the hours that they were absent of the house, electrical appliances and their use and many other that would provide a consumed energy profile, were also gathered.

3. Analysis of Results

3.1 Typical behaviour of the Cypriot resident

The selected buildings have been monitored on a continuous basis and data has been recorded for a period of fifteen months. These data were used to investigate the internal temperature profile of the monitored houses. An example is given in Fig. 4, where the fluctuations of the indoor and outdoor air temperatures of the monitored “House 02” are shown. The study of such graphs provides useful information regarding the usage of the residence’s installed heating system by the occupants. For the given example, it can be noticed that the heating system is turned on twice a day, morning hours and night time, and the set temperature is close to 22 ^{o}C. The above procedure was repeated for every monitored house and the results were summarized as shown in Table 1.

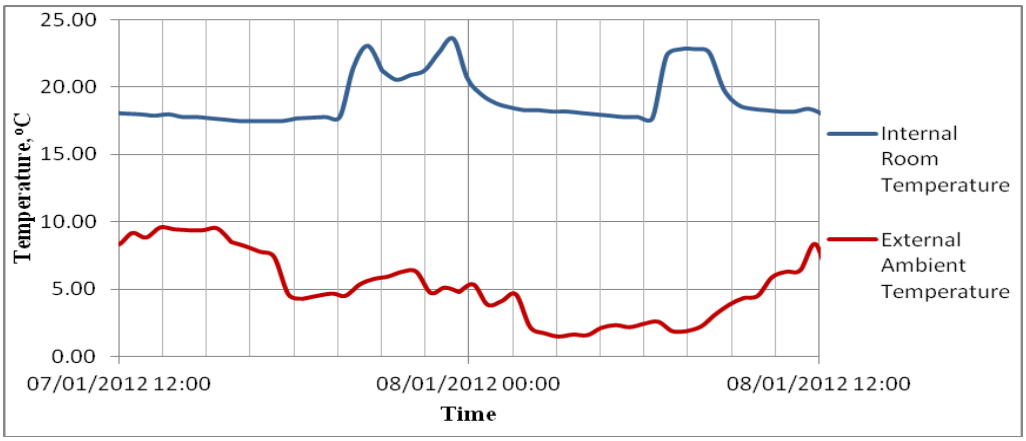


Fig. 4: Air temperature inside and outside of “House 02”

Table 1: Heating hours and room set temperatures at selected houses

House Name	Heating System	Building Use	Heating System Working Hours	Set Temperature
House 01	Boiler	Residential	06:30-08:00, 18:30-21:00	20-21
House 02	Boiler	Residential	05:00-07:00, 18:00-20:30	22
House 05	Boiler	Residential	20:00-08:00	18
House 09	Boiler	Residential	05:00-07:00, 19:00-21:00 (weekdays) 07:00-09:00, 19:00-21:00 (weekends)	21
House 03	Split Units	Residential	07:00-07:30, 21:00-22:00	23
House 07	Split Units	Office Space	09:00-16:00	23

Statistical analysis of the results obtained from all 44 monitored houses, lead to the drafting of the typical behaviour of the Cypriot resident. Most users set their heating systems to run for a short period during the very early morning hours, prior going to work, and then again during late afternoon / evening hours, when they arrive back home and before going to bed. Small variations of the above mentioned working hours and habits can be seen depending the day (weekday, weekend, public holiday, etc). For example, most users shift slightly the working hours of the heating system for the weekends. They set the system to start and stop a bit later during the morning and also to stop at a later hour on Friday and Saturday night. Finally, it can also be observed that they turn off the system in case they are away.

Also, depending on the type of the heating system used, the set temperature that the user considers most appropriate for thermal comfort varies. For boiler based systems, where heat is transferred into the residence using floor heating or radiators/convectors, a set temperature around 18 to 21 ^{o}C is considered as appropriate. An overall average set temperature of 20.5 ^{o}C has been measured in the houses monitored. For heating systems, where heat is transferred into the residence by circulating hot air (e.g. split unit or fan coil systems), a higher temperature of around 23 ^{o}C was noticed.

3.2 U-value measurements

In order to derive the U-values of the monitored houses, the following equation (1) was used:

$$U = \frac{1}{R_{swall}} \frac{T_{si} - T_{so}}{T_i - T_o} \quad (1)$$

deriving from the theory [7] of one-dimensional heat flow, under steady conditions and assuming any heat transmitted through radiation to be negligible.

Knowledge of the wall's construction materials and using the measured temperatures in each monitored house, the U-value of building elements in each house can be calculated. Results for the fully-monitored houses are presented in Table 2, while for the partially-monitored houses are presented in Table 3. The wall thermal resistance co-efficient (R_{swall}) and the theoretical U-value were calculated following the methodology [8] and the Guide [9] issued by the Cyprus Energy Service.

Table 2: Measured U-values at fully-monitored houses

House Name	Theoretical Wall U-value	Theoretical Roof U-value	Calculated U-value through measurements				
			North Wall	West Wall	South Wall	East Wall	Roof
House 01	0.850	0.510	0.615	0.615	0.605	0.755	0.329
House 02	0.516	0.773	0.334	0.375	0.414	-	0.512
House 09	1.389	3.098	0.995	1.253	1.368	1.005	2.887
House 10	0.467	-	0.313	0.313	0.320	0.320	-
House 12	1.111	0.648	0.840	0.855	1.020	0.987	0.476
House 16	0.516	-	0.327	0.320	0.253	0.143	-

Further statistical analysis of the results shows that the measured U-value is on average 20 % lower than the theoretical U-value. The relative standard deviation of these calculations is 12.3%, so it can be safely stated that the current methodology of calculating the U-value of a wall overestimates the actual mean effective value. It is also evident that the U-value varies depending on the wall direction. These are in agreement to the findings of a similar study carried out for historical buildings in Scotland [10].

Table 3: Measured U-values in partially-monitored houses

House Name	Theoretical Wall U-value	R_{wall}	Derived U-value through measurements	Derived /Theoretical U-value Ratio
House 03	0.680	1.302	0.441	0.648
House 04	1.389	0.550	1.318	0.949
House 05	0.398	2.343	0.310	0.779
House 07	0.249	3.851	0.148	0.594
House 08	1.111	0.730	0.794	0.715
House 14	1.389	0.550	1.029	0.740
House 15	1.389	0.550	1.082	0.779
House 17	0.269	3.545	0.184	0.684
House 18	0.515	1.772	0.372	0.722
House 19	0.516	1.950	0.427	0.828
House 20	1.111	0.730	1.011	0.910
House 21	1.389	0.550	1.008	0.726
House 22	1.389	0.550	1.256	0.904
House 23	0.515	1.772	0.378	0.733
House 24	1.156	0.695	0.998	0.863
House 25	0.516	1.770	0.324	0.628
House 27	1.389	0.550	1.302	0.937
House 28	0.516	1.770	0.377	0.731
House 30	1.389	0.550	1.157	0.833
House 31	1.389	0.550	1.208	0.870
House 32	1.389	0.550	1.056	0.760
House 33	1.389	0.550	1.059	0.762
House 34	1.111	0.730	0.870	0.783
House 35	1.389	0.550	1.097	0.790
House 36	1.389	0.550	1.121	0.807
House 37	1.389	0.550	1.146	0.825
House 38	1.111	0.730	1.098	0.988
House 39	1.389	0.550	1.240	0.893
House 40	1.389	0.550	1.288	0.927
House 41	0.249	3.851	0.171	0.687
House 42	1.389	0.550	1.018	0.733
House 43	1.389	0.550	1.246	0.897
House 44	1.389	0.550	1.071	0.771

Average	79.4%
STDEV	0.098
RSD	12.3%

3.3 Thermal Losses & Thermal Gains

Out of the six houses that were fully monitored in all four directions, enough valid data were collected for four of them in order for the thermal losses they sustain during the winter months, as well as any thermal gains, they may have during the same period due to solar radiation, to be calculated. The above mentioned houses are situated in the wider district of Nicosia (House 01, House 02 & House 10) and Limassol (House 09). The results are summarized in Tables 4 & 5.

Table 4: Heat Losses & Heat Gains during February 2012

	House 01	House 02	House 09	House 10
U-value (Measured)	0.648	0.374	1.155	0.317
U-value (Theoretical)	0.85	0.516	1.389	0.467
Total Heat Losses during February 2012 (MJ)	4000	6000	9000	5000
Total Heat Gain during February 2012 (MJ)	500	400	1250	600
Heat Losses during February 2012 (kJ/m2/day)	400	400	900	350
Heat Gain during February 2012 (kJ/m2/day)	50	30	120	50
Energy Gain due to Solar Radiation (% of Losses)	12.7%	6.7%	13.7%	11.4%

An analysis of the results concerning the monitored houses shows that, on average, there is a slightly more than 10% heat gain (see Table 4) from the daily solar radiation. The deviation of “House 02” results from the above percentage is due to severe shading of the south wall of the house due to the neighboring building. Also, paying a closer look to Table 5, it can be observed that the greatest contribution to the above thermal gain, results from the south wall being directly exposed to solar radiation, thus further explaining the deviation in the results obtained from “House 02”.

The actual energy gain or loss for each house depends on the wall structural characteristics and thermal properties (U-value) of each house as well as the use of the heating system (set temperature, hours of operation) but it can be observed that for houses with similar wall structures, it is more or less identical.

Table 5: Heat Losses & Heat Gains during February 2012 for the four basic directions

	House 01	House 02	House 09	House 10
Mean East Wall Energy Losses during February 2012 (kJ/m^2/day)	600	300	570	300
Mean East Wall Energy Gain during February 2012 (kJ/m^2/day)	36	30	165	100
Energy Gains due to East Wall’s Exposure to Solar Radiation during February 2012 (% of Losses)	6.1%	8.7%	30.0%	31.7%
Mean West Wall Energy Losses during February 2012 (kJ/m^2/day)	440	360	900	300
Mean West Wall Energy Gain during February 2012 (kJ/m^2/day)	40	10	40	1
Energy Gains due to West Wall’s Exposure to Solar Radiation during February 2012 (% of Losses)	9.0%	3.0%	4.3%	0.2%
Mean South Wall Energy Losses during February 2012 (kJ/m^2/day)	490	268	990	245
Mean South Wall Energy Gain during February 2012 (kJ/m^2/day)	130	30	200	60
Energy Gains due to South Wall’s Exposure to Solar Radiation during February 2012 (% of Losses)	28.2%	10.9%	19.0%	24.8%

Mean North Wall Energy Losses during February 2012 (kJ/m^2/day)	90	330	550	1100
Mean North Wall Energy Gain during February 2012 (kJ/m^2/day)	0	0	0	0
Energy Gains due to North Wall's Exposure to Solar Radiation during February 2012 (% of Losses)	0.0%	0.0%	0.0%	0.0%
Mean Roof Energy Losses during February 2012 (kJ/m^2/day)	250	600	1200	400
Mean Roof Energy Gain during February 2012 (kJ/m^2/day)	7	55	150	57
Energy Gains due to Roof's Exposure to Solar Radiation during February 2012 (% of Losses)	2.8%	8.6%	12.5%	14.2%

3.4 Radiation of flat Roofs

Analysis of the data collected throughout the test period from the monitoring system in each house and a closer look at the results, led to an overlooked outcome. Specifically, it was noticed that in a considerable number of nights, the roof's external surface temperature dropped considerably below the external ambient temperature in certain houses as can be seen in Fig. 6. This contradicts to the basic heat transfer scenario (mechanism) that is used in calculating heat losses from the interior of a building to the exterior.

In the standard model used today, for a heated room, heat is transferred to the inside surface of the room's external wall through convection from the room air, then to the wall's external surface through conduction, and then again by convection from the outside surface of the wall to the ambient air. This mechanism assumes that the room temperature is higher than the wall's inside surface temperature, which in turn is higher than the wall's outside surface temperature, which is normally higher than the ambient air temperature.

In the monitored cases, this was not the case during nights where there was a clear sky. To quantify this phenomenon, the temperature sensors were re-calibrated and surface thermometers were used to verify their readings. Secondly, a literature search was performed, verifying that flat roofs tend to radiate heat to the sky on sky-clear nights, thus resulting in increased losses through radiation and their surface temperature dropping below the ambient temperature [11]. Another interesting observation was the fact that the above mentioned phenomenon occurred frequently in houses in the Nicosia region, but very rarely in houses in the area of Limassol and Paphos.

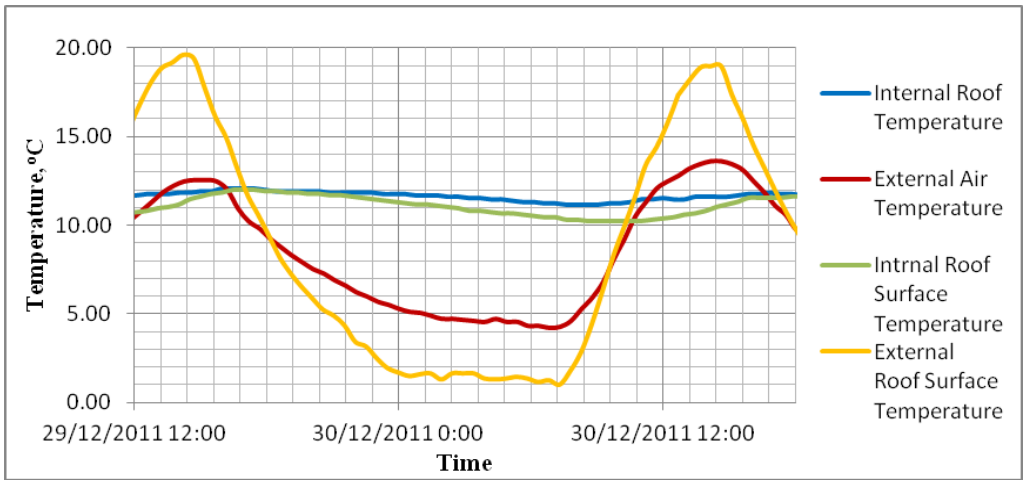


Figure 6: Typical temperature distribution on roof section – "House 01" (Nicosia)

The special climatic characteristics of Limassol and Paphos, with quite high levels of humidity, could be an explanation to the above mentioned observation. On the contrary, Nicosia's climate is much dryer, a fact that increases the possibility of a clear night sky radiation, and thus the occurrence of the flat roof's temperature drop.

Further focus on the houses situated in Nicosia area, where the temperature drop of the radiating roof is much more intense, and detailed data analysis, achieved a quantification of the roof's external surface temperature drop. Statistical analysis of the results shows that there is an average temperature drop of approximately 2.5 ^{o}C as shown in Table 6.

Furthermore, it appears that there is a linear relationship between the ambient air temperature and the external roof surface temperature, since the data are highly correlated (Fig. 7). Establishing a "best-fit" linear curve through the available data (approx. 4000 points), the following linear equation can be derived, which can be used to predict the roof's external surface temperature for a house in Nicosia, for a given external air temperature.

$$T_{roof} = 1.015 T_{air} - 2.786^{o}C \quad (7)$$

where
T_{roof} : is the temperature of the flat roof's external surface.
T_{air} : is the environment ambient temperature.

Table 4: Average temperature drop of flat roof external surface in ^{o}C.

Month	Temperature drop of Roof's External Surface		
	House 01	House 02	House 10
December 2011	2.50	2.90	-
January 2012	2.27	-	-
February 2012	2.46	2.19	2.30
December 2012	-	2.99	2.12
January 2013	-	2.53	-

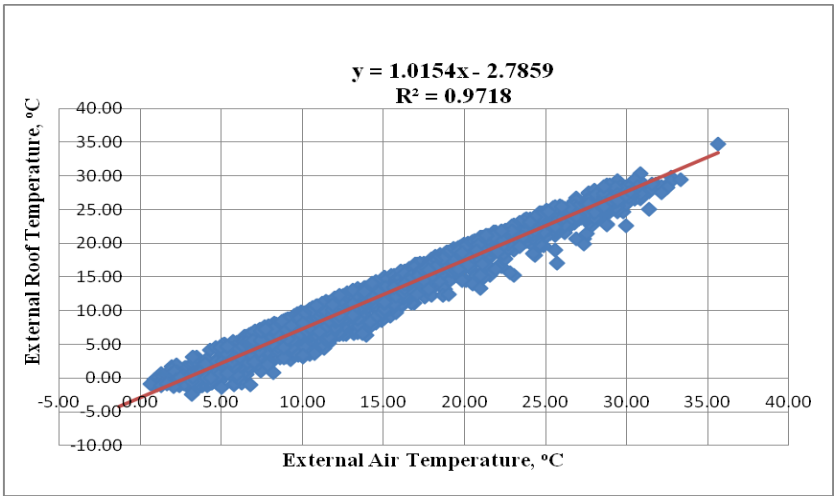


Fig. 7: Correlation between outside (ambient) air temperature and external roof surface temperature for houses with a flat roof in the area of Nicosia

4. Conclusions

In the present study, the outline, methodology, and goals of the corresponding research work have been presented, along with the findings, resulting from the analysis of the collected data, with regards to the typical behaviour of Cypriot resident, the actual U-values of the typical Cypriot houses, the actual thermal losses and gains during the winter season and particular behaviour of the building's flat roof under specific conditions. Also, some critical conclusions regarding the above are presented.

From the analysis of the collected data shown above, it is evident that in the typical Cypriot house the heating system operates at specific periods of the day, in contrast to the northern European countries where heating systems operate for much longer hours. Another interesting result is the fact that users perceive an average temperature of 20.5 ^{o}C as adequate for thermal comfort in water based/radiant heating systems, while a higher temperature of 23 ^{o}C is needed in systems circulating hot air. These findings can prove quite useful for engineers involved in the design of such systems.

Another critical finding of the present work concerns the overestimation of the U-value of a building's envelope that is calculated from current theoretical models. This could be used by the engineering community performing energy simulations and system design in order to decrease the safety factors used in their design calculations.

Furthermore, heat gains due to solar radiation account to approximately 12% of total energy demand for heating during winter. Also, it has been shown that a satisfactory thermal insulation of a building's outer shell results in decreased heat losses of 50 % or more compared to the typical non-insulated house constructed in Cyprus until recently.

Finally, the phenomenon experienced in flat roofs could help policy makers in targeting legislation and possible subsidy schemes in order to countervail the increased energy losses resulting from the above mentioned combined mechanism which amounts to a range of 15-45% of the residentially consumed energy for space heating, depending on house geometry and degree of thermal insulation of the walls and the roof.

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5. References

[1] EUROPEAN COMMISSION. *"Doing more with less, Green Paper on Energy Efficiency"*. 22.06.2005 COM, 2005.

[2] IEA. *"Worldwide Trends in Energy used and Efficiency – Key Insights from IEA Indicator Analysis"*, OECD/IEA, 2008.

[3] EUROPEAN COMMISSION. *"Action plan for energy efficiency: realising the potential"*. Brussels, 19.10.2006 COM (2006) 545.

[4] FLORIDES G, KALOGIROU S, TASSOU S, WROBEL L. *"Modelling of the modern houses of Cyprus and energy consumption analysis"*. International Journal of Energy, 25 (10) (2000) 915-937.

[5] PANAYIOTOU G, KALOGIROU S, FLORIDES G, MAXOULIS C, PAPADOPOULOS A, NEOPHYTOU M, FOKAIDES P, GEORGIOU G, SYMEOU A, GEORGAKIS G. *"The characteristics and the energy behaviour of the residential building stock of Cyprus in view of Directive 2002/91/EC"*. Energy and Buildings 42 (2010) 2083-2089.

[6] *"Statistics of constructions and housing"*. Statistical Service, Republic of Cyprus (2006).
[7] KAKATSIOS X. K. *"Heat Transfer"*. Kleidarithmos, Athens, 2002.
[8] YPRUS ENERGY SERVICE. *"Methodology for assessing the energy performance of buildings"*. August 2009.
[9] CYPRUS ENERGY SERVICE. *"Buildings Insulation Guide, 2nd edition"*. 2010.
[10] BAKER P. "Technical Report 10". BRE, Edinburg, 2011.
[11] NOWAK H. "*The sky temperature in net radiant heat loss calculations from low sloped roofs"*. Infrared Physics 29 (2-4), 231-232 (1989).

Life Cycle Costing of innovative energy storage systems in buildings



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Short Summary

The environmental awareness in politics and society is becoming increasingly important. The reason for this development is on the one hand the awareness of limited resources, but also the potential consequences of the greenhouse effect. In the field of energy efficiency of buildings increasing obligations exist in this context for European countries to construct energy-efficient and environmentally friendly buildings that are implemented by several national policies since the early nineties.

One example is the amended EU directive for energy-efficient buildings (EPBD) of the year 2010. It requires, amongst other things, that the greater use of renewable energy sources and energy storage systems should be promoted. Through the implementation of several directives and the consequent increased use of renewable energy sources, energy storage gains more economic and strategic importance because of the time gap between production and demand of this energy. Through the use of storage systems supply and energy demand can be balanced and power spikes covered.

In the European project MESSIB ("Multi-Source Energy Storage System Integrated in Buildings") exactly these new developments and their effects are investigated. The project focuses on the integration of innovative energy storage systems in buildings, based on the development of new materials and technologies. Objective is to show that energy storage systems can reduce the total energy demand of buildings, whereby end users can reduce their energy consumption and save costs equally. A life cycle cost analysis is necessary to assess this aspect and to take the varied cost savings for the different energy storage systems into account.

The presentation focuses on the Life Cycle Costing of building integrated energy storage systems using the example of a geothermal heat exchanger (thermal storage technology) and a vanadium redox flow battery (electrical store technology). Based on these insights and analysis it can be predicted what kind of storage can be usefully integrated into buildings and to what extent savings of both technologies can be achieved.

Keywords: Life Cycle Costing; Energy Storage; Geothermal Heat Exchanger (GHEX); Vanadium Redox Flow Battery (VRB)

1. Introduction

It is the goal of the European Union to enhance the energy efficiency of buildings until 2020 and to increase the usage of renewable energy sources for heating, warm water supply and air conditioning. The reason therefore is the amended EU directive for energy-efficient buildings of the year 2010 (EPBD) and many European governments have committed to use more renewable energy sources. With a higher share of renewable energy sources in the electrical and thermal energy supply, the significance of storage systems rises accordingly, because the production and use of renewable thermal and electrical energy in the building may be temporally distinct. The integration of energy storage systems in buildings is a necessary step in order to use renewable energy sources in buildings efficiently. [1]

With the help of energy storage systems, it should be possible to reduce the load of peaks and the exchange with the grid. End users can reduce their energy consumption from the grid and costs equally. To consider and to interpret these aspects, it is necessary to perform life cycle cost considerations for energy storage systems.

2. Life Cycle Costing

2.1 General Overview

Life cycle costing analysis is a method to estimate the total costs that occur during the whole lifetime of a product. The costs are considered along the single phases of a product during its life cycle (cradle to grave). That means that all costs of the different life cycle phases, the production stage, the usage and the end-of-life stage are taken into account.

Depending on approach and reasonable detail, each phase has different costs. The initial costs are due at the beginning of the life cycle in the development phase, the running costs and disposal costs incurred as a result of the initial costs. The breakdown of costs is different for each object of observation. Using the LCC, statements can be made about whether to pay off higher investment costs / disposal costs, because they can be reduced by the running costs. It can also be stated that the running costs must be reduced to make it worthwhile. The life cycle costs analysis will identify the parameters that have a great impact on the cost and where optimization potentials are. [2]

The various costs will be most affected at the beginning of the life cycle, especially in the development phase, because at this phase a high percentage of cost assessment and costs incurring are made. In the operating phase, the costs can only slightly or not be affected because there are incurred operating costs, which constitute the largest part of costs.

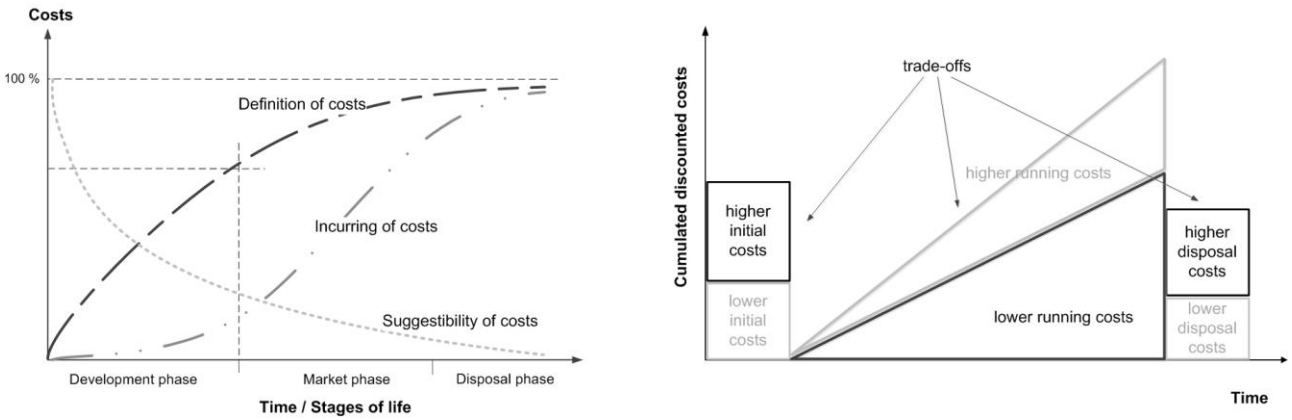


Fig. 1: left – definition, suggestibility and incurring of life cycle costs / right – Trade-offs between initial costs, running costs and disposal costs

In summary it can be said that the goal within the LCC is to identify the utility-maximizing alternative in terms of the maximum economic benefit.

2.2 Approach

Depending on the perspective the life cycle cost analysis is based on two different methodologies. Depending on the available data, life cycle costs can be determined with the support of the Bottom-Up or the Top-Down method. The Bottom-Up method works out the life cycle costs along the life cycle starting with the production to the cost of the usage and the end-of-life. In comparison, the Top-Down method is used when the production costs are unknown.

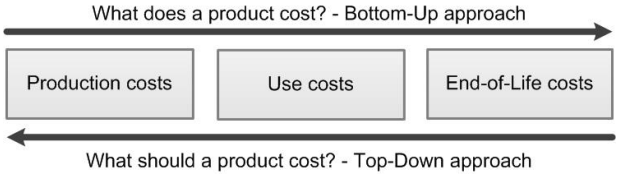


Fig. 2: Different approaches of the analysis of life cycle costs

3. Energy storage technologies

3.1 General Overview

Energy storage systems gain due to the increasing use of renewable energy and the time gap between production and demand this form of energy more and more economic and strategic importance. Through their use, the supply and demand of energy is balanced and power peaks are covered. The different energy storage technologies can be differentiated by their storage time, loading and unloading, saved energy (power) or their size and weight. [3]

The use of renewable energy is always combined with a limited aspect of the storage and any energy conversion is associated with energy loss. Renewable, fluctuating energy sources (solar, wind) are usually only temporary and short-term available in abundance at this moment but not directly stored. For storage and later use it must first be converted into a storable form of energy that is associated with losses.

3.2 Geothermal heat exchanger (thermal storage technology)

Geothermal energy and heat from the earth’s crust means the energy form, which can be used for direct or indirect heat in buildings. In addition, the earth's crust can be used as a cold source and can thus contribute to the cooling of rooms.

To use geothermal energy more effectively, a heat exchanger (Ground Heat Exchanger - GHEX) has been developed which is designed to prevent unwanted heat transfer in the soil to a great extent. This consists of an insulated pipe at the center and four surrounding smaller pipes with the highest heat conductivity as possible. Thereby there is only a low thermal resistance between the fluid flowing through the probe and the surrounding soil.

In order to increase the thermal conductivity between the base and the heat exchanger is introduced into the soil while an inert, conductive liquid material CFM (Conductive fluid material). This will contribute to improved heat storage capacity of the soil.

3.3 Vanadium Redox Flow Battery (electrical storage technology)

Vanadium redox flow batteries are a type of electrochemical storage, which have a high efficiency in a simple and modular construction. The advantage of vanadium redox flow batteries is that a separation of power and amount of energy due to the separation of energy conversion and storage medium takes place. The energy to be stored is determined by the amount of electrolyte, the battery's performance and the size of the active electrode surface. This is the shutdown of the plant instead of practically no self-discharge.

The developments were concentrated in the vanadium redox flow battery on improving the stability of the vanadium and reduction of self-discharge. Furthermore, a compact system for use in buildings is possible.

4. Life Cycle Costing of the storage technologies

Within the EU project MESSIB both GHEX and the VRB were connected or integrated into an existing building. The storage technologies have been studied in terms of energy consumption, the exchange with the grid and its utilization during the use phase. The scenario assessed is based on an office use.

4.1 Life Cycle Costing of the geothermal heat exchanger (thermal storage technology)

Since there are costs data for the GHEX and the conventional borehole (investment and installation) available, the bottom-up approach is applied for the calculation. This means that the life cycle cost analysis can generate a statement, if the higher investment costs of the GHEX can be amortised by lower operating costs over the life cycle.

As yet there are no costs for the CFM available only a statement about the possible investment costs can be made.

The borehole is used in combination with the heat pump as heat and cooling source for the building. For the operation of the heat pump a connection to the grid is necessary. The different scenarios which are considered are shown in table 1. [4]

Table 1: Scenarios of the borehole

Boundary Conditions	Case I	Case II	Case III	Case IV
Thermal Conductivity ground	1 W/(mK)	1 W/(mK)	3 W/(mK)	3 W/(mK)
Thermal Conductivity CFM	No CFM	5 W/(mK)	No CFM	5 W/(mK)

4.1.1 Scenario A

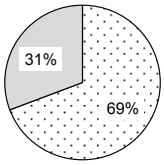
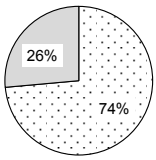
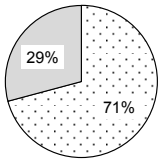
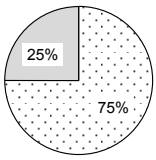
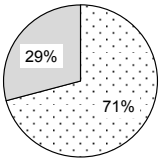
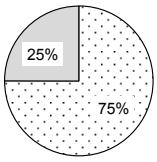
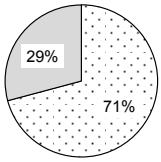
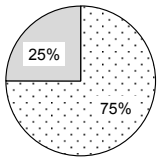
In this scenario the behavior of the two boreholes is investigated at a location with a high heating and low cooling demand. The lengths of the boreholes are 70m and were determined by using an approximation method.

The thermal simulation of the two boreholes has shown that no operating costs can be saved by using the GHEX. Through the introduction of CFM in a ground with low thermal conductivity the operating costs can be reduced by 130 kWh/a. For comparison the costs can be reduced in a ground with good thermal conductivity by introducing CFM only by 11 kWh/a.

The assumed use phase of the scenarios is 20 years. It is furthermore assumed, that the energy costs increase by 4% per year. Capital costs are calculated on a basis of a capitalization interest rate of 5.5%.

The amount of investment and operating costs are depicted in the following table:

Table 2: Scenario A - Life Cycle Costs of the boreholes (amount of investment (grey) and operating (dotted) costs)

Scenario A - Life Cycle Costs			
Case I		Case II	
Convent.	GHEX	Convent.	GHEX
			
18,000 EUR	21,000 EUR	17,600 EUR	20,600 EUR
Case III		Case IV	
Convent.	GHEX	Convent.	GHEX
			
17,600 EUR	20,600 EUR	17,600 EUR	20,600 EUR

The difference of the life cycle costs between the conventional borehole and the GHEX can be explained only by the high investment costs of the GHEX because the operating costs for both are identical.

4.1.2 Scenario B

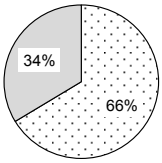
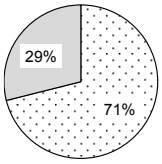
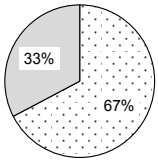
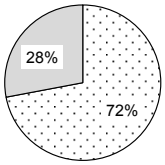
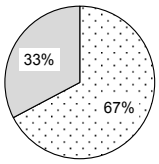
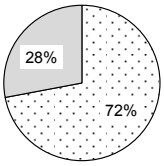
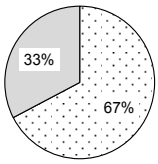
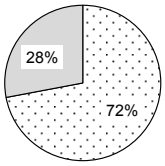
In this scenario the behavior of the two boreholes is investigated at a location with a low heating and high cooling demand. The lengths of the boreholes are 40m and were determined by using an approximation method.

The thermal simulation of the two boreholes has shown that no operating costs can be saved by using the GHEX. Through the introduction of CFM in a ground with low thermal conductivity the operating costs can be reduced by 38 kWh/a. For comparison the costs can be reduced in a ground with good thermal conductivity by introducing CFM only by 6 kWh.

The assumed use phase of the scenarios is 20 years. It is furthermore assumed, that the energy costs increase by 4% per year. Capital costs are calculated on a basis of a capitalization interest rate of 5.5%.

The amount of investment and operating costs are depicted in the following table:

Table 3: Scenario B - Life Cycle Costs of the boreholes (amount of investment (grey) and operating (dotted) costs)

Scenario B - Life Cycle Costs			
Case I		Case II	
Convent.	GHEX	Convent.	GHEX
			
10,400 EUR	12,000 EUR	10,200 EUR	11,900 EUR
Case III		Case IV	
Convent.	GHEX	Convent.	GHEX
			
10,300 EUR	12,000 EUR	10,200 EUR	11,900 EUR

The difference of the life cycle costs between the conventional borehole and the GHEX can be explained only by the high investment costs of the GHEX because the operating costs for both are identical.

4.2 Life Cycle Costing of the Vanadium Redox Flow Battery (electrical storage technology)

The VRB within in the MESSIB project is a prototype and therefor no reliable data for investment costs are available. By using the top-down approach a statement should be generated which level investment and disposal costs can occur. The integrated VRB in the following scenarios has a storage capacity of 6 kWh and an efficiency of 0.7.

The building in which the VRB is integrated is equipped with a PV power plant. As soon as the generation of the electrical energy exceeds the demand, the battery is charged. When the battery has reached its maximum storage capacity and the generation exceeds the demand, the supply of energy is injected in the public grid. If the generation of electrical energy decreases among the necessary demand, the demand will be covered by the battery in a first step. Only when the battery is completely discharged, there is a cover of the demand on the public grid.

The total energy demand of the building is 21,482 kWh/a without battery and 21,794 kWh/a with battery. The amount for covering the demand is shown in table 4. [4]

Table 4: Coverage of the energy demand for scenario I and II

	reference scenario	scenario
PV power		
feed-in	12%	5%
consumption	88%	95%
coverage of demand		
PV power	45%	48%
grid at day	55%	52%

The boundary conditions of the two scenarios are described in the scenarios themselves. Each of those scenarios will be compared to a reference scenario without an electrical storage unit (VRB).

The difference of the reference scenario consist only on the storage technology, which means that even in the reference scenario has got a PV power plant which covers the electrical energy demand and the excess can be feed into the grid.

4.2.1 Scenario I

Table 5: Parameters of scenario I

Feed-in tariff	Power tariff	Efficiency	Storage capacity
44.00 EUR cent	24.34 EUR cent	0.7	6 kWh

In this scenario the energy costs per year are 2,267 EUR/a without battery and 2,496 EUR/a with battery.

The time of consideration for the life cycle calculation is assumed with 20 years. Furthermore a price increasing rate for energy is assumed with 4% per year. Capital costs are calculated on a basis of a capitalization interest rate of 5.5%.

The net present value of the compared scenarios is depicted in the following table:

Table 6: Scenario I – Net present value of the energy costs over the life cycle

Reference Scenario I	Scenario I	Delta costs
39,150 EUR	43,103 EUR	-3,953 EUR

The results of the life cycle cost analysis of scenario I show that the installation of the VRB generates no benefit. Instead the reference scenario generates a benefit of 3,953 EUR. This means that it is not advantageous to integrate a VRB into a building under these boundary conditions.

4.2.2 Scenario II

Table 7: Parameters of scenario II

Feed-in tariff	Power tariff	Efficiency	Storage capacity
0.00 EUR cent	24.34 EUR cent	0.7	6 kWh

In this scenario the energy costs per year are 2,857 EUR/a without battery und 2,744 EUR/a with battery.

The time of consideration for the life cycle calculation is assumed with 20 years. Furthermore a price increasing rate for energy is assumed with 4% per year. Capital costs are calculated on a basis of a capitalization interest rate of 5.5%.

The net present value of the compared scenarios is depicted in the following table:

Table 8: Scenario II – Net present value of the energy costs over the life cycle

Reference Scenario II	Scenario II	Delta costs
49,334 EUR	47,376 EUR	1,958 EUR

The results of the life cycle cost analysis of scenario II show that the installation of the VRB generates a benefit of 1,958 EUR. This means that the investment and disposal costs for the VRB have to be lower than this benefit.

4.3 Comparison of both storage technologies

The innovative developments of the ground heat exchanger in the MESSIB project have not lead to energy savings during the operating phase. However the CFM enables to save energy costs over the life cycle. The comparison of scenario A and B of the boreholes shows that the CFM generates higher savings in a ground with a low thermal conductivity. Furthermore, it can be concluded that CFM at a location with high heating and low cooling demand has a greater impact to reduce operating costs than at a location with high cooling and low heating demand.

The innovative development of the VRB with a storage capacity of 6 kWh which is integrated into an office building could only be analyzed based on the energy costs over the life cycle. The comparison of scenario I and II of the VRB shows that in scenario I no costs can be saved with the integration of the VRB. In scenario II it is possible to save energy costs over the considered life cycle but there are still no investment or disposal costs taken into account. But the saved costs will be not high enough to cover the investment and disposal costs for the VRB. For example a lithium battery, which is already available on the market with a comparable storage capacity has investment costs of 10,000 EUR.

When you compare the two innovative developments of the technologies, it can be seen that it is possible to save the most energy costs under certain boundary conditions (no feed-in tariff) with a VRB. Summarized it can be noted that the boundary conditions (integration and economic parameters) have a great influence on the amount of energy costs savings regardless of the technology.

5. Conclusion

Both technologies allow, under certain conditions, to generate energy costs savings. Decisive boundary conditions are amongst others the political boundary conditions and the setting with the other components of the installation engineering in the building. The feed-in tariff as one political boundary condition has a high impact on how the VRB can generate cost-savings. If the feed-in tariff is too high and the payment of the feed-in electricity makes the integration of a VRB unattractive, this form of energy storage will not be able to enforce in width and apply. Also it is equally important for both technologies to synchronize them on the building, which means that the storage technologies have to be sized in the right way and the other components of the installation engineering (e.g. the PV power plant has to produce enough electricity to charge the battery in all seasons) have to be synchronized with them.

6. References

[1] OERTEL, D. „Energiespeicher - Stand und Perspektive, Sachbestandsbericht zum Monitoring - Nachhaltige Energieversorgung". Büro für Technikfolgen-Abschätzung beim deutschen Bundestag, DOI: http://www.tab-beim-bundestag.de.

[2] HERRMANN, C. „Lebensphasenübergreifende Disziplinen“. Ganzheitliches Life Cycle Management, Nachhaltigkeit und Lebenszyklusorientierung in Unternehmen; Springer Verlag Berlin, Heidelberg, 2010, Seite: 131-234.

[3] RUSS, C. „Thermische Energiespeicherung - mehr Energieeffizienz zum Heizen und Kühlen“. DOI: http://www.enob.info.

[4] BÖTTGE, J. “Lebenszykluskostenbetrachtung von innovativen thermischen und elektrischen Energiespeichersystemen für die Nutzung in Gebäuden”, Diplomarbeit, Universität Stuttgart, Lehrstuhl für Bauphysik, 2012, Stuttgart, Germany.

Real-time Energy Simulation for Advanced Building Control



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Short Summary

In general, current Building Energy Simulation Tools are used for pre-construction design and comparison of designs rather than a full exact varying representation of reality. To provide the best level of detail full CFD analysis for the entire building would be required. However this is currently by far outside the scope of standard computing power and labour efforts for a building energy system. Because these simulation tools are designed for comparison of potential designs and because of the difficulty in predicting occupant behaviour, very often the predicted results do not correlate with the real actual performance when buildings are in operation. Questions arise in relation to occupant comfort when a building space is serviced with a constant level of heating and ventilation. In addition, a cost saving could be realised if intelligent systems know to what level should a building space be heated or cooled.

This paper describes a methodology being developed to combine building energy simulation results with accurate and real sensor and meter data with the purpose of better understanding the relationship between energy simulation and real building operation for better occupant comfort and to guide efficient operation. Real life measured occupancy data from four building spaces in UCC's Civil Engineering Building have been recorded using a novel occupancy system to develop relevant indicators concerning occupancy levels. Two technologies are used to detect occupancy, proximity card access and RFID detection. A contrast of results from both systems is expected while also using both systems to quantify as exact as possible an occupancy level based on scheduled events involving the mentioned rooms.

Results gained from the occupancy detection systems will be utilised as input for commercial building energy simulation tools for the purpose of obtaining a better understanding of real time conditions within the occupied spaces and improving building control of HVAC systems within the experimental building.

Keywords: Simulation; Building Control; Energy Efficiency; RFID; Occupancy.

1. Introduction

As new and retrofitted buildings are developed with more complex monitoring, control and automation systems, vast quantities of data is being produced. A goal of the scientific and engineering community is to provide a holistic and integrated building information solution which can utilise this information and provide value by reducing building energy consumption. Better use and more integrated use of building energy information can contribute to meeting requirements of both the European EPBD and the European 20-20-20 targets which require the EU to reduce Greenhouse Gas levels by 20%, reduce domestic home energy consumption by 20% and increase Renewable Energy by 20%, all by 2020.

A key part of this holistic energy information solution is the integration of building energy simulation tools. Energy analysis plays an important role in developing an optimal HVAC and Architectural design for new buildings and in determining optimal retrofit and commissioning measures for existing buildings [1]. However a barrier to this integration is that the majority of commercial

building simulation tools are developed for design solutions rather than absolute accurate representations of detailed or near real time building performance. Therefore, pre-construction simulations often do not exactly correlate with operating building performance even though building simulation tools operate with accurate physics algorithms [2]. The reason for this mismatch is that detailed input information is required to produce the correct output [3]. To calibrate a dynamic building simulation, measured data from buildings can be used. Calibrating computer models to actual metered data is not a new practice [1]. For over 40 years, recommendations were made to calibrate models based on measured data [4]. Most calibration procedures require months of measured data [1]. Previous studies have developed a calibration procedure based on developing archetypes whereby patterns of similar buildings which operate alike would be developed and used for future similar buildings. This can be used to calibrate buildings to better predict future similar buildings [5].
Comparison of simulated cooling and heating energy simulation against time of day is a very important step in model calibration [5]. Furthermore short term cooling load forecasting with lead times from 1h to 7 days can play a key role in the economic and energy efficient operation of cooling appliances [6]. The study under development presented in this paper is based on calibrating accurate building information models and associated simulation models with real measured sensor data procured from existing buildings.
From previous EU-FP7 project experience a deficit has been encountered whereby the correlation between simulation results and measured data is not entirely accurate. This paper discusses a method of validation, which will provide a means of comparing measured data (e.g. sensors and weather data), and simulated data (e.g. near future simulations).
This method for validation of building simulation results initially involves a comparison of data from building simulation and respective measured sensor readings. From this comparison, value is added from correction of simulation results, and/or input to simulation parameters. Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction and operation. Additional value can also be derived from identifying conditions of poor results and other relevant input factors which can be corrected. Simulation data and actual data is available from various campus buildings of University College Cork, Ireland. Simulations are undertaken using readily available commercial products and use practical and straightforward data analysis methods so that results and further development can be implemented by building engineers who may not have extensive IT or coding experience.

2. Research Building Description

This study focusses on UCC's Civil and Environmental Building (CEE) which is located on the main campus of University College Cork. The CEE Superstructure consists of brick walls, concrete ceilings and wood flooring. The windows are wood-framed single glazing. Efforts to upgrade these windows have been refused due to the semi protected nature of the building on the central Victorian style Campus. The building is approximately 2500m^2 consisting of experimental and IT laboratories, offices, seminar rooms, and lecture theatres. Heat is supplied from the University Combined Heat and Power plant through a connection to Campus Distribution System. Within the building a single pipe heating systems exists with cast-iron type radiators. Thermostatic control valves have been retrofitted in most rooms. The building is naturally ventilated with an air handling system installed to ventilate 2 IT Labs only. Lighting consists of zoned control through presence detection sensors. A moderate upgrade to the building was undertaken in 2009 consisting of:

- Modification of heating system and incorporation of bldg. control systems
- Lighting (fitting replacement, appropriate re-wiring, improved controls)
- Heat recovery ventilation from IT Laboratories

Of particular relevance to this paper is the installation of an occupant tracking system concentrating on 4 key rooms. The occupant tracking includes 2 no. independent systems consisting of;

- "Gate Reader" or RFID solution. This solution works with the readers/antennas fixed to the building. Users and inventory items are "tagged" with different forms of either HF or UHF passive RFID-tags. Tracking will be executed on "item"-level. The emphasis is on the integration of "security data" into Building/Energy Management systems. Additionally, we consider aspects of privacy and security in our research.
- Access Control or Proximity Card solution. This can be considered to be a more active solution whereby close proximity to an access control reader is required to gain access to a

building or room. In the research described here access control was installed in for key rooms within the research building.



Figure 1. Exterior View of CEE Demonstrator Building

The Building Management System installed consists of primarily of monitoring with numerous wireless sensors and heat metering. This data has been recorded for a number of years and is available for research purposes. This provides a concentrated wealth of information relating to building performance in greater detail than typical buildings. The CEE building therefore is an ideal demonstrator to conduct energy simulation study.

3. Demonstrator Building Information Model (BIM)

A detailed BIM model of the Research building has been developed for study within the authors' research group. This model has been independently verified and checked for accuracy of all dimensions, materials, etc. This same BIM is utilised for various research projects and experiments to allow for easy comparison and cross checking of all results. A key part of a holistic energy information solution is the integration of building energy simulation tools. Therefore, rather creating a simulation model within the simulation tool, the calibrated and verified BIM was used. For the research conducted for this paper, the verified BIM model was exported from Autodesk Revit MEP 2012 as gbXML format to be utilised by IES-ve energy simulation software.

The BIM to Simulation Process for this can be summarised as follows;

1. Creation of BIM model with accurate dimensions, geometry, materials, etc.
2. Definition of spaces within model.
3. Definition of type of spaces.
4. Export as gbXML.

As mentioned previously, it is a goal of the scientific community to have seamless interaction between software processes. And indeed, a dedicated import tool to allow easy transfer between the two software modelling packages utilised here. However, a number of time consuming problems occurred which had to be corrected before simulation could occur.

These problems included existence of holes between rooms and external spaces. Whilst not in the BIM model a number of holes appeared only in certain rooms. It is not possible to perform simulations with holes between internal and external spaces. The solution involved checking each individual room/space (44 no.) and deleting any external holes which had appeared. Other problems included;

- Certain building information properties not imported and had to be specified.
- Unusual spaces resulted from non standard building shapes e.g. roof lights.

- Awkward and unnecessary shaped features within rooms.

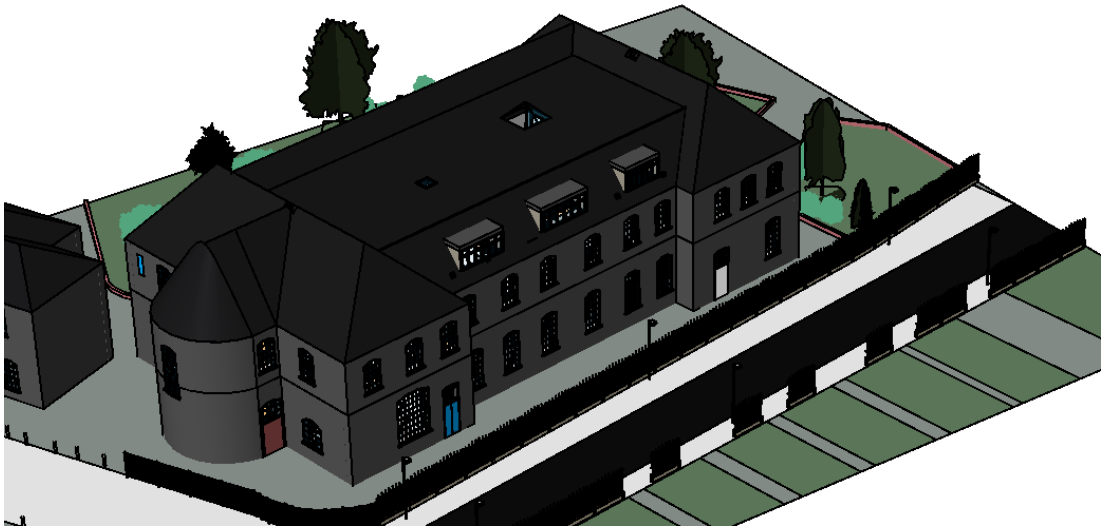


Figure 2. Overview of Detailed BIM Model

Some unnecessarily complex geometry was produced when exporting from BIM as gbXML. This geometry was not altered before simulation to minimise the number of time consuming corrective measures to be undertaken. However it is likely that these anomalies increased the time taken for simulation process to occur. For example what should be a simple 90° angle in a room instead resulted in walls overlapping to produce an unnecessary complex arrangement.
Whilst the BIM should provide geometry, it is likely that when the time taken for corrective measures is taken into account it would have been quicker to recreate the building model for simulation from scratch as the building modelled in this instance is composed of relatively straightforward geometry and materials.
A better solution is more careful creation of BIM solely for the aim of export. The downside of this is that the BIM needs to be utilised for other functions and may be less accurate. The BIM should function as the hub for all information for the project. It cannot be altered to optimise simulation if this interferes with other functions such as construction or facilities management. The original or record BIM needs to be entirely accurate. It therefore would be better if the BIM was modified post export before simulation. This would maintain the central BIM hub method whilst still optimising the simulation process.

4. Building Simulation

After adjustments were made dynamic building energy simulation was carried out using IES-VE (Integrated Environmental Solutions Virtual Environment). This simulation software was chosen as it is commonly utilised in commercial design in the UK and Ireland. Because it is an aim of this researcher not to be confined to a single software product or suite previous research has been carried out using Vabi Simulation, a popular Dutch dynamic building simulation tool and future comparative studies will be carried out using Energy Plus, the comprehensive U.S. simulation software.
A typical simulation procedure was carried out. For this particular simulation software steps taken include, setting correct weather file, running simulation of sun features for building location (Suncast), and adjusting materials schedules (Building Template Manager). Unlike typical preconstruction building simulations whereby building operation schedules, occupancy and timing schedules are estimated based on proposed building usage, this building has the benefit of known and recorded operation schedules and is closely monitored. Therefore efforts were made to match the simulation inputs as best as possible to reality.

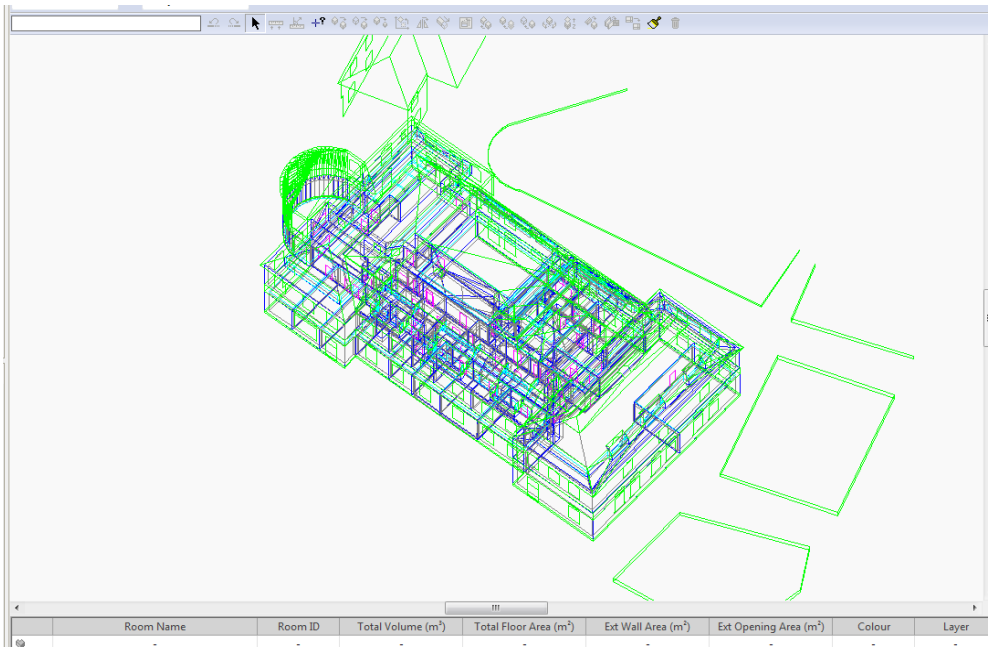


Figure 3. Wireframe View of Simulation Model

Simulations results were undertaken using two of the methods provided by the IES software, ApachSim (Dynamic Simulation) and the CIBSE loads methodology.
Steady state heat loss is the equivalent of running a 24 hour heated building with no internal heat gains for a long period of weather at a constant outside air temperature and no solar income. This process removes the internal heat gains from a Tas dynamic simulation model, runs the model using a weather file with constant outside air temperature and no sunshine and at the end of a 30 day period the simulated heating load is exactly the same as the steady state heat loss calculation. [7]. The steady state method used to design the building analysed is based on the CIBSE admittance method. This method uses idealised (sinusoidal) weather and thermal response factors (admittance, decrement factor and surface factor) that are based on a 24-hour frequency. [8].
Dynamic Simulation Models can be defined as models which are based on first principles and are capable of replicating dynamic heat trans fer in a building, in response to external and internal influences on the time scale of one hour or less [9].
From the simulation process a full and detailled set of results was created which are to be used for comparison to real data as described in the following section.

5. Building Performance Sensor and Meter Data

As mentioned in the Building Description section, a large body of real building sensor and meter readings procured from the CEE building exist for research purposes. These readings are stored on an Oracle data warehouse used for various research purposes within the authors' research group. This data can be accessed using a number of interfaces of varying complexity, from direct data warehouse queries to a web based tool, described below. This web based tool provides intuitive access to data and records from a graphical overview of the CEE building on a floor by floor basis showing where any wired or wireless sensors or meters are located. Overviews of other important areas such as the plantroom are also included in this tool.
Figure 4 shows the view of one floor of the building with the location of all sensors and meters located on that floor. From this view, any of the sensors or meters can be clicked upon to be analysed further. Other floors or areas can be chosen from the drop down menu located on the top left of the screen. When a sensor is chosen, a summary of the previous week is displayed in graphical and tabular form as per Figure 5.

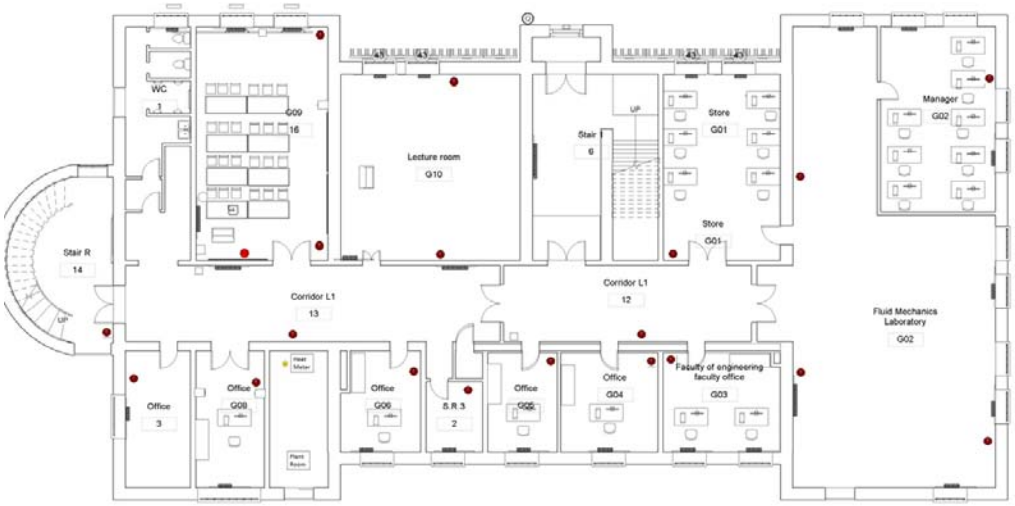


Figure 4. Screenshot of CEE Data Access

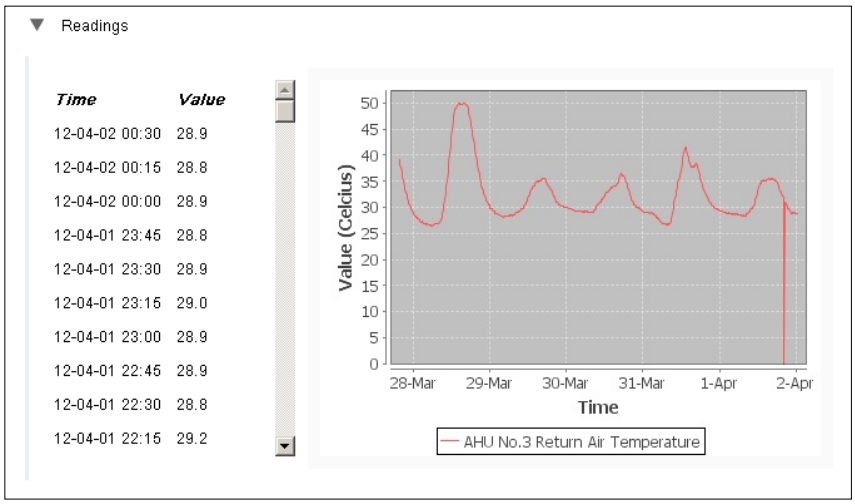


Figure 5. Detail of Temperature Sensor Information interface from the ITOBO Research Project

Furthermore the option is given to download a set of data in excel or csv format. This provides straightforward access to data without knowledge of data warehouse operation.
For more analytical tasks data can be aggregated in the Data Warehouse implementing "Materialised Views". However for the purposes of this research this is not required and the web access tool provides access to all required data.

6. Access Control and Occupancy Monitoring

Modern buildings are built to 'sense' their indoor environments and 'react' accordingly based on various internal factors and the outdoor environment. [10]. However one weakness of building control systems is the ability to capture the precise quantity of human occupation. Typically, human-Sensing is defined as the process of extracting any information on people in an environment in [11]. Many industries, research studies and academic institutes have carried out occupancy monitoring and analysis either based on indoor environmental data [12], post occupancy of a building [13] or through various sensors [14]. For dynamic building energy simulations this is also one of the most difficult parameters to determine and quantify.
As a method of overcoming this deficit a hardware-software platform has been developed at UCC. This consists of two elements a proximity card access control system and a RFID card system.

6.1 Proximity Card Access Control

The University has introduced access control systems using staff/student cards as swipe cards. All access control readers are connected to the Campus' IT-network and data is recorded in a centrally managed IT-system. Client software enables each unit to manage access rights for their

zones in a flexible way. For research and occupancy purposes the advantages of this system are that it is possible to know if a space is occupied (not possible to enter with card) and allows a general idea of occupancy. Negatives are that it cannot measure departure from a space (for fire safety reasons) and could possible underestimate the number of occupants if one occupant used a swipe care and others entered whilst the door remained open.

6.2 RFID Card System

The RFID Card system in operation in the Research Building consists of occupants carrying passive RFID cards in their wallets/purse. Gateways set up at entry and exit points to selected rooms can capture readings with a good degree of success. This is a proven system developed over a period of 4 years of research on now completed research projects. For research and occupancy purposes the advantages of this system over the Access Control system are that it measures both entry and exit quantities. The main disadvantage is that carrying of the RFID cards is entirely voluntary and not essential to gain access to the rooms. Therefore uptake of this system is less than the Proximity Card Access Control system.

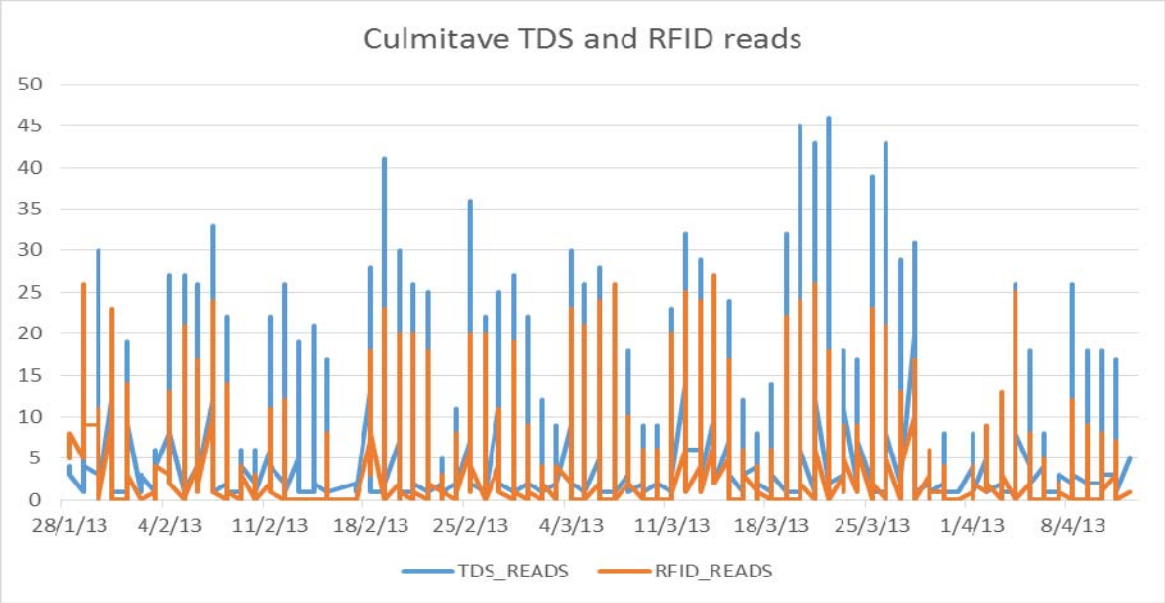


Figure 6. Example of Raw Occupancy Data before Correction

6.3 Further Quality Control of Occupancy detection

Because both methods described above have certain flaws, further quality control was undertaken at certain intervals over the period of research. This involved undertaking physical audits of occupancy in the rooms along with surveys of the percentage of occupants carrying their voluntary RFID cards. Whilst time consuming it allows for statistical adjustments to be made to the results of the occupancy data from both systems to provide a correction for actual occupancy at all times. Furthermore it should be noted that both occupancy detection systems complement each other quite well insofar that the deficits of both described above are somewhat cancelled out by their strengths.

6.4 Value of Occupancy Detection for Dynamic Energy Simulation

Having an accurate and detailed understanding of occupancy in key rooms and spaces in the building over a period of months has allowed the author to produce more accurate input for simulations and to create templates for individual rooms. This overcomes one of the most difficult to quantify inputs of dynamic building energy simulation.

7. Early Findings

Thus far this paper has described a process for providing detailed simulation inputs and results from an accurate and verified BIM model and providing access to a considerable body of building sensor and meter records. The next stage of the process to provide value from comparison and aggregation of this simulated and real data. The comparison concentrated on heating because of the building type and relative cool nature of the Irish climate. The first point of comparison is to determine for which the same simulation results and measured data exists. Next statistically and graphical comparative analysis is conducted.

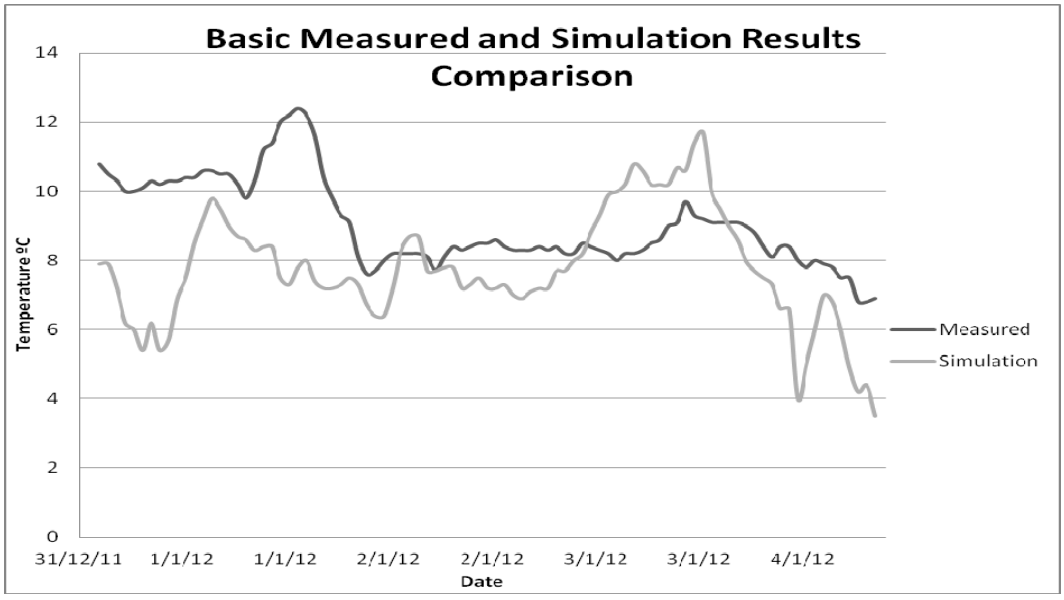


Figure 7. Example of comparison of Measured and Simulation Data

Figure 7 shows an example of a graphical comparison for measured results from one particular temperature sensor and corresponding simulation result. At the time of writing detailed analysis is still being undertaken. However some general trends have been observed to date.
Reasons for differentiation include many of the typical factors for building simulations not exactly adhering, in particular weather conditions. Improvement and validation of these is discussed in the Future Research Section.

8. Future Research & Discussion

The expected result to be derived from this method is to give an indication of quality of simulated data results and provide feedback. If the difference between simulated and real data is too large, steps to improve results will be suggested. In future it is envisioned that automated adjustments may be performed to simulation inputs to correct results.
Live instantaneous simulation can provide benefit from tuning BMS for near future tweaking of BMS/control systems (continuous commissioning), building certification, energy profiles and design performance review.
Possible scenarios which could be implemented include:
Design Review and comparison: During design phase, inputs for Design Simulation Models are estimated future building usage, occupancy density, etc. For Operational Simulation Models, inputs can be real functional data, from BMS and observation. Operational Simulation Models can provide a design check on the Design Simulation allowing feedback to designers for future Design Simulation improvements.
Trend Data Analysis: Trend key system parameters to detect problems early and assess system performance. As above.
Recommissioning or Continuous commissioning: Perform ongoing recommissioning activities to ensure that the building meets its current needs. Identify and correct deviations from “Ideal” initial operating conditions.
Further worth can also be provided by gaining knowledge for creation of simulation profiles which are difficult to predict before construction & operation. Additional value can also be derived from identifying conditions of poor results and relevant factors which can be corrected.
Aside from near future simulation validation, the tool may be able to provide long term commissioning feedback to detect and alert users to long term degradation of systems and possible maintenance or repair remedies. As a distant research goal, it is envisioned that results can be used to provide automated feedback to the Building Management System and further improve control.
Furthermore an explicit process of Knowledge Management has been undertaken by turning data

(simulation results & measured data) into information (basic comparison of key results) and future plans for creating useful knowledge (improve building operation for key results, energy, comfort and CO2). This will ensure that the process can be clearly documented to allow results to be achieved on other buildings in future.

9. Conclusion

Effective building performance simulation can reduce the environmental impact of the built environment, improve indoor quality and productivity, and facilitate future innovation and technological progress in construction [15].
The procedure described in this paper describes a clear methodology for creation of accurate dynamic simulation and comparison with real measured results with the goal of providing better understanding of building operation for the ultimate goal of improving building control. Whilst detailed post occupancy simulations comparisons to building simulations are difficult due to the lack of data, the tools and building being discussed in this paper provide a rare opportunity to do so. Future research to develop this methodology will be undertaken as part of the EU FP7 project Campus21.

10. Acknowledgements

Part of the research discussed in this paper is supported in by a fund from Seventh Framework Programme -ICT "CAMPUS 21" (Project-Nr: 285729). Previous research has been supported by the EU FP7 project “IntUBE” and the Science Foundation Ireland funded “ITOBO” project.

11. References

[1] LIU, G., & LIU, M. *A rapid calibration procedure and case study for simplified simulation models of commonly used HVAC systems*. Building and Environment 46, 409-420. 2011
[2] CLARKE, J. *Energy Simulation in Building Design*. Butterworth-Heinemann. 2001
[3] KUSADA, T. *Comparison of energy calculation procedures*. ASRHAE Journal, 23(8):21-4. 1981
[4] AYRES, M., & STAMPER, E. *Historical Developments of Building Energy Calculations*. ASHRAE Transactions , 101(1):47-55. 1995
[5] FLORES LARSON, S., FILIPPIN, C., BEASCOCHEA, A., & LESINO, G. *An experience on integrating monitoring and simulating tools in the design of energy-saving buildings.* Energy and Buildings , 987-997. 2008
[6] CLARKE, J., & al, *The role of simulation in support of Internet-based energy services*. Energy and Buildings , 837-846. 2004
[7] EDSL. *CIBSE Guide A Environmental Design Calculations*. Retrieved from http://www.edsl.net/main/Software/Designer/CIBSE.aspx. Accessed 2012
[8] CIBSE. *Guide A: Environmental Design*. Chartered Institute of Building Service Engineers. 2006
[9] JANKOVIC, L. *Designing Zero Carbon Buildings Using Dynamic Simulation Methods*. Oxfordshire: Routledge, 2012
[10] MANZOOR, F., *Location Based Sensing and Occupancy Monitoring in Facilities Management Scenarios for Energy Efficient operations using RFID Technology*, PhD Thesis, University College Cork, 2012.
[11] TEIXEIRA, T., DUBLON, G, and SAVVIDES, A. *A Survey of Human-Sensing: Methods for Detecting Pres-nece, Count, Location, Track, and Identity*, ACM Computing Surveys, vol. V, 2010.
[12] MANZOOR, F., HUANG, Y. and MENZEL, K., *Passive RFID-based Indoor Positioning System, An Algorithmic Approach*, IEEE International Conference on RFID-Technology and Applications (RFID-TA), Guangzhou, China, June 2010.
[13] "Building Research and Information," Special Issue on post-occupancy evaluation, vol. 29, no. 2, pp. 158-163, March/April 2001.
[14] GARG, V. and BANSAL, N.K. *Smart occupancy sensors to reduce energy consumption*, Energy and Buildings, vol. 32, no. 1, pp. 81-87, June 2000a
[15] HENSEN, J., & LAMBERTS, R. (2011). *Building Performance Simulation for Design and Operation*. Oxfordshire: Spons Press.

Energy Efficiency Using Integrated ICT Systems: Business Challenges and Opportunities

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Short Summary

This paper focuses on business challenges and opportunities related to the adoption of integrated ICT system that will be developed in the framework of EU-FP7 CAMPUS-21. CAMPUS-21 aims at identifying opportunities for reduced energy consumption in public buildings and spaces through integration of different building automation systems. The integrated ICT platform will optimise renewable energy use, multiple building systems, optimise indoor air quality and consider occupancy of the building. For the purpose of this study a questionnaire has been developed in accordance with the business Model Canvas as suggested by Osterwalder and Pigneur. Business and contracts related data have been collected from the demo-sites, results have been analysed, discussed and conclusions have been drawn.

Keywords: Integrated ICT Systems, Energy Efficiency, Business Models, CAMPUS-21

1. Introduction

Interconnectivity of building automation systems, data collection, data analysis and automated control requires a holistic integrative approach to the management of the energy used by building systems. Integrated ICT Building Automation Systems can extend the functionality of already installed isolated systems and allow the synergistic usage of different data sources. This can result in reduction of life cycle cost by reduction of energy demand (demand-supply improvement) as well as lower maintenance requirements (increased equipment longevity). This poses significant opportunities for service providers and facility managers to create added value for their clients, to contribute to Corporate Social Responsibility and to enter new markets.

Within the framework of the EU-FP7 project CAMPUS-21, an integrated ICT system will be developed in three European public demo-projects. The aim of the integrated ICT platform is to integrate multiple building systems to optimise energy demand-supply, renewable energy use and indoor air quality. This paper analyses business challenges and opportunities related to successfully adoption of this platform in current businesses. Based on the Business Model Generation approach, introduced by Osterwalder and Pigneur, a questionnaire has been designed. Service providers and owners of the demo-projects provided data on used contract, involved partners, existing HVAC systems, energy purchase, energy generation and financial models. Results have been analysed, discussed and recommendations for business improvement have been given.

2. The Business Model Canvas

For a better understanding of existing business models, the business model canvas of Osterwalder and Pigneur [2010] has been used. This framework consists of nine blocks describing business models and introduces five important approaches to build new or to innovate existing business models. These approaches (resources-driven, offer-driven, customer-driven, finance-driven and multi-epicentres) are based on improving one or more blocks and tracing the changes in the other blocks.

3. Methodology

To answer the research question, a case study research has been performed. The Business Model Generation approach, introduced by Osterwalder and Pigneur, has been used to design a questionnaire. Service providers and owners of the demo-projects provided data on used contract, involved partners, existing HVAC systems, energy purchase, energy generation and financial models. Results have been analysed, discussed and recommendations for business improvement have been given.

4. Discussion and conclusions

Existing business models in the three campuses could characterised as very traditional. The three campuses grew in the course of years where buildings have been built or renovated, HVAC systems have been maintained or replaced, business partners have been changed and Energy Management has been implemented. This change process has resulted in segmented business developments and disjointed business models. This segmentation improved business components but mist a holistic improvement. It is also very important to mention that the three existing business models are driven by price instead of added value in terms of thermal comfort, higher productivity of employees, lower environmental impact and corporate social responsibly by greening products and services. Nowadays, governmental bodies, commercial partners and also the society are focusing in adding more value to their business, low price is only one of these added value strategies. Business models have to take into account making their added value or their performance more visible to their customers. This could be achieved by presenting energy savings in the entrance of the swimming pool or the lodges in the football arena or by surveying employees or students satisfaction after implementing new measurements. In order to make achievements and performance more visible, business models have to consider clearly defined key performance indicators in their contracts.

Besides, business models have to consider a life-cycle cost approach instead of initial cost approach. Energy saving measures needs initial costs while gains are can be achieved in also in the use phase yielding lower life-cycle costs. Energy Service Companies have considered this point very well in their business model. They engage with building owners in energy performance contracts that consider a total cost of ownership approach. They pay the initial costs needed to implement energy saving measures and get paid back through the saving they guarantee during the contract. Energy efficiency could be achieved by implementing technical or ICT solutions. However, users' behaviour is a very important factor in realising good energy performance in the use phase. Users have to be taught how to deal with HVAC systems and to be made partners in achieving efficiency. This could be achieved, when possible, by sharing gains from energy saving or by sharing losses that resulted from their behaviour. Suitable business models Energy Service Contracts or Desigh & Build.

5. References

[1] EREC. "*Energy sustainable communities: experience, success factors and opportunities in the EU-25*". European Renewable Energy Council. 2006. Brussels.

[2] Osterwalder, A., & Pigneur, Y. "*Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*". 1st edition. 2010. Wiley.

Comparison of sustainable office façade renovations in the Netherlands



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Short Summary

This paper presents a comparison of different environmental assessment methods in sustainable office façade renovations. The assessment methods applied have both weighted and non-weighted systems to combine energy and material performance. The comparison is based on the south facing facades of three realized office renovations in the Netherlands, and based on the MAXergy method the 'best' renovation project has been further developed to minimize environmental impact. In MAXergy, energy and material performance is calculated to the indicator land-time necessary to create the resources. Based on the comparison of environmental assessment methods in this paper and based on the developed façade renovation version, energy focused optimization of office renovation may result in material performance sub optimization emphasizing the need for a joined and non-weighted assessment of energy and materials.

Keywords

sustainable office façade renovation – environmental assessment methods – building envelope – MAXergy

1. Introduction

Energy consumption is increasing worldwide, mainly based on fossil fuels. As fossil fuels are exhaustible resources, methods to lower fossil fuel consumption are investigated elaborately, amongst others in the built environment. Of all energy consumed worldwide 40% takes place in the built environment. Measures being taken might have a positive effect on the operational energy performance of a building and are often implemented in the building envelope, for instance by adding insulation materials. But these measures have an effect on material performance, which might cause a negative effect on the environmental performance of the building. The material performance can be calculated in embodied energy. With respect to operational and embodied energy, it is possible to calculate an offset between the two, and generate insight in the optimum. But only energy calculations do not offer us the complete picture of combined material and energy impact, as for instance availability and depletion of materials is not incorporated in the calculation. Existing sustainability tools, such as BREEAM and the Dutch GreenCalc+, use weighting factors for combining energy and material performance to arrive at a total score. Currently, methods are investigated to combine material and energy performance on an equal scale without weighting. In this

paper three methods are applied, one based on a weighting of indicators, one based on embodied and operational energy, and one based on land-time impact. The land-time impact might be an useful indicator to generate insight in the combined impact of both materials and energy performance based on the carrier capacity of the system. In this time-space calculation method, called MAXergy, the time and space necessary to fulfill the energy and the material demand for a certain function in a certain environment can be calculated.

Within the Netherlands, approximately 15% of all office buildings are vacant. This leads to a market driven situation in which the demanding party has a wide selection of possibilities. The costs associated with the energy performance is one of the criteria on which potential tenants decide. A better energy performance lead to less vacancy and higher rents. Besides this aspect, the policy of the Dutch government is to only rent high energy performance office buildings. As a third aspect, there is a tendency of commercial and non-commercial organizations to green their real estate to contribute to a positive impression. Currently, numerous assessment methods to calculate the level of sustainability are applied, such as BREEAM, LEED, CASBEE, SBtool, and Greencalc+. These tools have a number of advantages, such as the distinction in the level of sustainability of a building compared to other buildings, providing a communication tool, encouraging stakeholders to define sustainability requirements, and providing a vehicle for policymaking. In this paper, three assessment methods are applied to compare three different office façade renovation projects in the Netherlands. Based on one of the assessment methods, the 'best' office renovation has been further developed to minimize the combined impact of materials and energy.

2. Method

Based on different environmental assessment methods three realized office renovation projects in the Netherlands are compared on their level of sustainability. The assessment methods applied are the Dutch environmental assessment tool Greencalc+, the land impact calculation tool, MAXergy and embodied energy/operational energy calculations based on the program VABI 114 and the ICE database of the University of Bath. The case studies consist of three existing office renovations, where a comparison is made between the situation before and after the renovation related to energy use of the building (operational energy), materials of the facade (embodied energy) and the associated land impact (embodied land).

3. Conclusions and discussion

- The comparison of different assessment methods indicates a large bandwidth of results between the methods and between the projects. In future, a common language should be developed to tackle the difficulties that will arise due to the application of different environmental assessment methods.

- In the Dutch environmental assessment tool Greencalc+ all three renovations score relatively high on sustainability and show comparable total results.

- The embodied energy increased and the operational energy decreased in all three renovations, and in all three cases the cooling load remains the largest energy factor during the technical lifespan of an average office facade (30 years). Based on energy calculations, optimizing energy performance seems logical.

- The embodied land increased in all three renovations, but the results show large differences between the projects. The lowest impact of the WNF building is due to the choices in material application based on renewable materials.

- It can be concluded that material use becomes the determining factor with respect to operational energy in NZEB's.

Comparison of sustainable office façade renovations in the Netherlands



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Keywords

sustainable office façade renovation – environmental assessment methods – building envelope – MAXergy

1. Background

Between 1990 and 2005 global final energy consumption increased by 23%, while the associated CO2 emissions increased with 25% (1). This consumption is expected to grow with another 45% between 2002 and 2025 (2). 20% to 40% of this global energy consumption is consumed in the built environment (3), for more than 86% based on fossil fuels (4). Between 1995 and 2005, extraction of fossil fuels increased with 24% (5). To lower overall energy consumption in the built environment and to lower dependency on fossil fuels, it is agreed within the EU that all new buildings in 2020 have to be (nearly) zero energy buildings (NZEB) (3, 6). A Zero Energy Building produces all necessary operational energy in the building itself during its operational phase. The target of NZEB can be reached by improving the energy efficiency in the operational phase of the building. This requires adding material to the building for thermal insulation, building services and energy generation products. Worldwide, extraction of construction minerals increased between 1995 and 2005 with 30% (5). This underlines that the realization of a less energy consuming built environment is largely depending on an increase of material consumption, and consequently an increasing con-

struction material extraction. Building environmental assessment tools should take both the energy aspect and the material aspect into account.
The Dutch office market, consisting of 52.2 million square meters, had a vacancy percentage of 14.6% in 2012 (7), corresponding with 7.62 million square meters. The average energy label for the Dutch office market is E (8), corresponding with an operational energy performance of 1.49 GJ/m2a for heating and cooling, lighting and hot tap water. To improve the market value of vacant and occupied office buildings, these can be energy efficient renovated, underlining the necessity of an effective building environmental assessment tool.

2. Introduction

As the market situation of office buildings in the Netherlands is not in equilibrium, renters have a wide variety of real estate to choose from, and are in the position to select offices with a high energy performance. Besides this market development, policy of the Dutch government dictates that the Dutch government itself, responsible for around 20% of office space occupation in 2010 (9), only rents offices with minimum energy label C since 2010. Already a number of NGO's and companies have joined this agreement, and it is expected that more organizations will join this government agreements in the framework of Corporate Social Responsibility (CSR). As a result, many offices are renovated to improve their energylabel to a minimum of C, in order be attractive again in the office market. In these renovations, the facade is often replaced to improve the operational energy performance of the building. After the renovation the operational energy consumption of the building is significantly lowered.

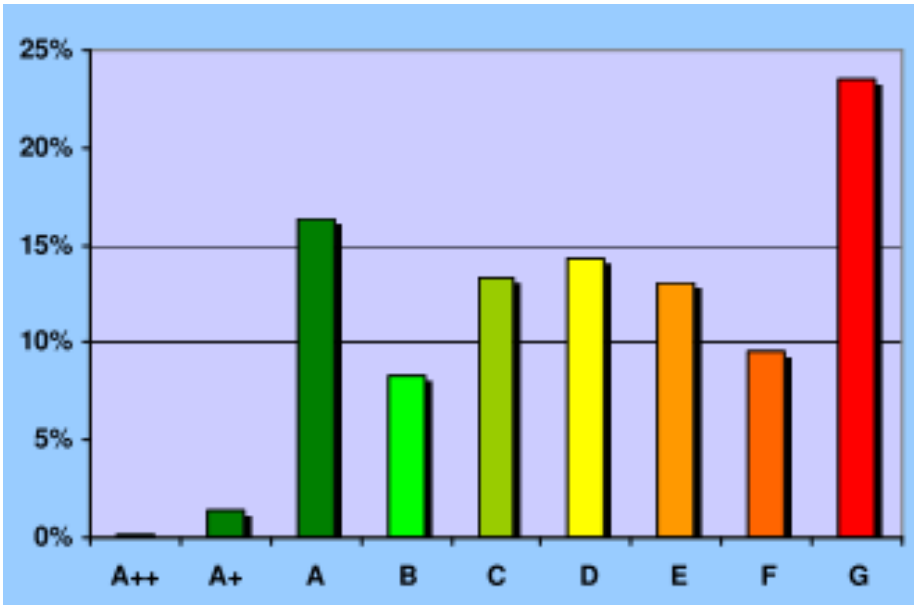


Fig. 1: Energy label distribution Dutch office market 2010 (source: (8)).

Currently, a wide range of tools is available to calculate the operational energy performance of buildings. Frequently, these tools are embedded in building environmental assessment tools. These tools have a number of advantages, such as the distinction in the level of sustainability of a building compared to other buildings, providing a communication tool, encouraging stakeholders to define sustainability requirements, and providing a vehicle for policymaking (10). Increasing requirements, the Dutch government only rents office buildings with an energy label of C or better, contribute to a higher energy efficiency performance of buildings (8). However, the improvement of energy performance may have as a negative effect an increased material consumption. As building are becoming more energy efficient towards the level of zero energy the impact of materials is increasing relative to the energy (11). This indicates the need for an building environmental as-

sessment method in which material performance and energy performance are non-weighted combined assessed.

The material consumption is often only translated in embodied energy: the amount of energy necessary to process raw materials, modify materials and transport materials. The embodied energy in materials can be seen as a 'rebound effect' of energy performance improvement, and has in current practice a negative impact on the calculated operational energy performance improvement of up to 30% in household heating and cooling(12). By calculating material consumption using only the embodied energy, the operational energy aspect and the material aspect are translated in a corresponding quantity; energy. For instance, Belgian residential low energy buildings with a primary energy consumption for heating of ca. 900 MJ/m^3 building volume over 30 years have a total embodied energy of 1400 MJ/m^3 building volume over 30 years, which is higher than the energy consumption for heating (13). For these embodied energy calculations various definitions, methodologies and system boundaries are used (14). An example of the latter is that there is a distinction between methodologies in which only the amount of fossil based energy is part of the calculation as it is 'added' to the product and methodologies in which the total amount of embodied energy, both fossil based and renewable based, which comes from 'natural sources' such as the sun, is calculated. Besides the different calculation methodologies, most results have uncertainties due to temporal, spatial and technical circumstances (location, weather, societal and energy generation), which are in many cases not shown in databases underlying the calculation tools (14). A third aspect of embodied energy calculations is the varying system boundary of the calculation. All these aspects have resulted in databases which face the problem of incomparability and variation (14). Besides these considerations, all embodied energy methods do not take into account the actual availability of resources, both renewable and non-renewable. As the extraction of construction materials increased between 1995 and 2005 with 30%, worldwide (5), it is worth exploring a method to be able to assess energy and materials equally.

Due to the increase of material consumption and due to the associated increase of raw materials extraction more and more land is needed for winning and producing building materials. In addition, raw materials, which are necessary for the production of the building materials, do not have an infinite stock, such as copper. Besides land use required for extracting raw materials, there is also land needed for generating non-renewable and renewable energy. As we have a limited amount of land and also the potential productivity of this land is limited, it seems logical to base our consumption pattern on the land necessary for production and extraction of (building) materials, generation of energy, water production and food production. In future, land necessary to produce renewable energy might compete with land necessary for food production and material production, which may lead to other choices in the design and realization of buildings (15). According to Rovers et al (15), sustainability needs to be based on what can be generated and consumed in equilibrium within the system, implying an indicator based on the carrying capacity necessary to materialize and operate a function, instead of on impact calculations without any relation with the system itself. The carrying capacity is the maximum persistently supportable load of a system (16), and can be indicated by the amount of land necessary to sustain the functioning of the system and the time this land is necessary, embodied land.

In this research the comparison of environmental assessment methods and an improved relationship between the operational energy performance and material performance in office renovation is investigated. Through three case studies, a comparison is made between the situation before and after the renovation related to the energy use of the building (operational energy), materials of the facade (embodied energy) and the related land use (embodied land). The results given here focus on south facing office spaces, and the aim of the research was to generate insight in the effect of embodied land calculations on the environmental performance improvement of office renovations in the Netherlands.

2. Method

In this project, the environmental impact of the south facing façade and the office space behind this façade of three realized sustainable office renovations in the Netherlands was investigated. The situation before and after the renovation was compared, and the results of the three projects were compared. Of the 'best' renovation, the office façade has been further optimized using MAXergy.

The following calculations were made:

- VABI 114 calculation before and after the renovation. VABI 114 is used for the calculation of the operational energy (heating and cooling) for the different buildings before and after the renovation. VABI 114(17) is a building simulation software which can calculate the annual heating and cooling load in MJ.
- Embodied energy of the facade before and after the renovation. The embodied energy refers to the energy, which is necessary for the total life of a material (extraction, production, and transport). In this study, the "Inventory of Carbon & Energy" (ICE) database of the University of Bath(18) is chosen to use for the determination of the embodied energy of the facade. The ICE database is an inventory of the embodied energy of materials data, originating from LCAs, books and papers.
- GreenCalc+ calculation of the buildings after renovation. GreenCalc+(19) expresses the sustainability of a building in an environmental index. The environmental index of the building (Milieu Index Gebouw - MIG) is calculated by the sustainability of the building compared with the sustainability of a standard building realized in 1990. The standard reference building from 1990 has a value of 100 MIG. When a building is more sustainable than the reference building from 1990, then the value becomes above 100 MIG. Buildings with a MIG-value below 100 are less sustainable than a building realized in 1990.
- Embodied land calculation of the facade and space behind the façade before and after the renovation; amount of land and time needed to generate the necessary materials and operational energy, in m^2-year. There are two embodied land calculations made. A calculation, whereby all energy is generated by solar energy (solar panels and solar collectors), and a calculation in which the embodied energy and operational energy is generated by fossil fuels. Calculated with Maxergy(20). Maxergy is a sustainability tool which represents material use and energy use of a building by using the same physical quantity by means of embodied land; time and space necessary to fulfill the energy and the material demand for a certain function in a certain environment. The total Embodied Land (EL) of a product is calculated using several databases as input the amount of new and recycled materials. The total embodied land calculation can be divided into direct embodied land (land and time required for the creation of a raw material), indirect embodied land (embodied energy converted into land and time) and operational energy (converted into land and time).

For the case studies the following projects are chosen:

- DHV office, Amersfoort; renovation during which the façade was totally replaced and the interior was preserved largely.
- WNF office, Zeist; renovation during which the façade was totally replaced and the building was partially demolished, stripped and refurbished.
- Central Post, Rotterdam; renovation of an existing post office, during which the façade was partially replaced.

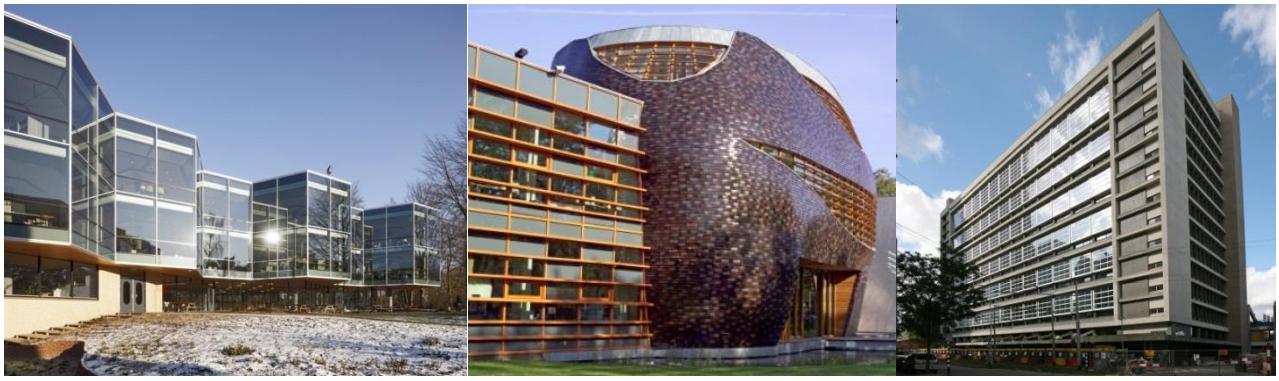


Fig. 2, 3, 4: DHV, WNF and Central Post after renovation (source: vd Meijden).

Of all three renovation projects, in this research project a same south facing part with similar properties of each building was investigated, to generate comparable results. Although the office buildings have the same function and are partly comparable, investigating the complete building is outside the scope of this research. Two office spaces divided over two floors behind the south facing façade are selected for this research, because office spaces are the most relevant spaces in the buildings and the south facade has the biggest effect on the annual cooling and heating load. The selection of two floors is made for a relevant comparison between the three buildings. The facade of the Central Post building in Rotterdam is in fact repeated per two floors and the facades of the other projects are repeated per floor. The simulated space has a width of 8 meters, a length of 8m and a total height of 7m over 2 floors. The length and width of the investigated office space is larger than a standard Dutch office space, because the office lay out of all three projects consists of open office landscapes in this research. For each building the same technical installations are applied, for a relevant comparison of the influence of the façades on the operational energy performance. For all cases, only the material performance of the façade has been taken into account. Installation, lighting, and all other interior building components are out of the scope of this research. For the calculations of the office facades a technical lifetime of 30 years (21) was chosen as reference.

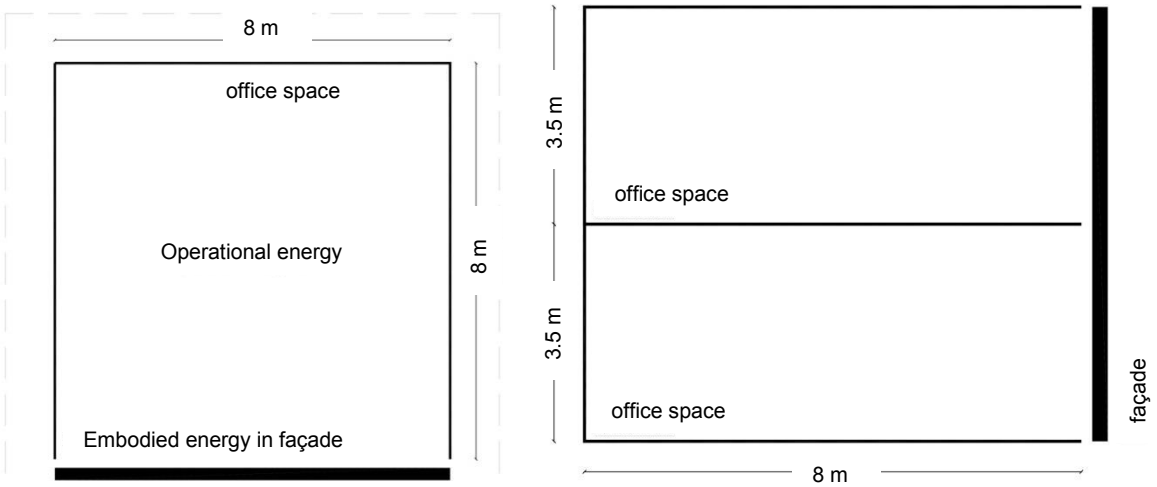


Fig. 5, 6: Floorplan and section of investigated office space.

3. Results

In the following subchapters, the calculated results of the different applied assessment tools, Greencalc+, operational energy, embodied energy and embodied land are presented and combined.

3.1 GreenCalc+

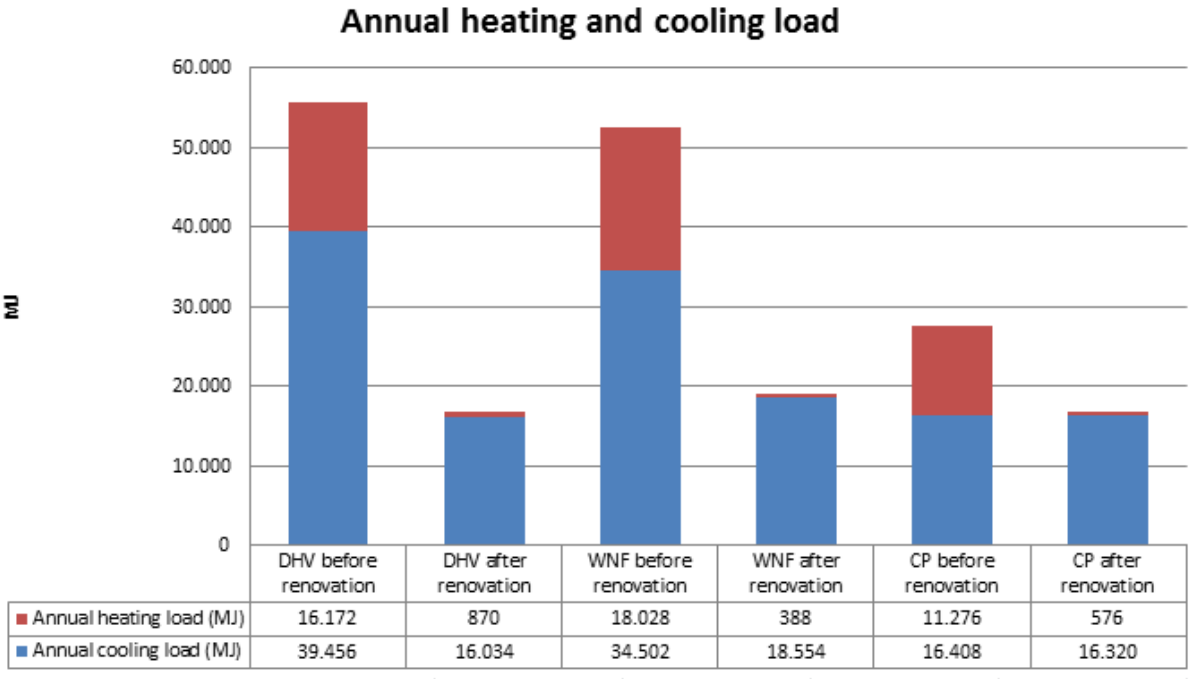
The results of all projects (table 1) show a final score above 200 and all projects score both in the field of energy performance and material consumption an A, which is good. In the results there is no difference between the various projects in the field of energy performance and material consumption. The WNF office has the highest total score, probably because the building generates energy by itself and the other buildings don't.

Table 1: Greencalc+ score of all projects.

	DHV office, Amersfoort	*WNF office, Zeist*	*Central Post, Rotterdam*
Material	A	A	A
Energy	A	A	A
Water	E	F	G
Total	*239*	*269*	*252*

3.2 Operational energy

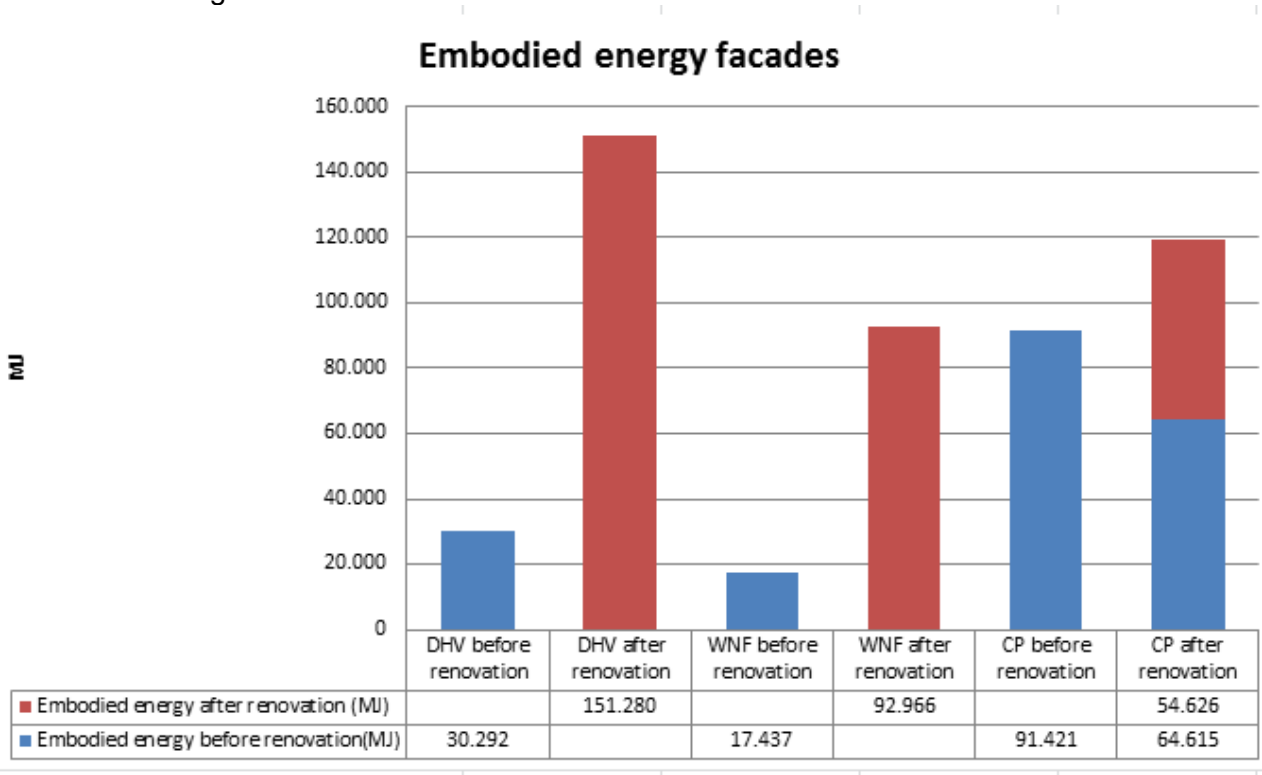
Graph 1 shows the results of the annual cooling and heating load of each project before and after the renovation, calculated with VABI 114. The heating and cooling load of all three buildings after the renovation is almost equal. The cooling load of the investigated south orientated space is in all buildings the largest energy factor both before and after the renovation. The renovation of the façade has mainly impact on the heat load of the building. The heating load is strongly reduced after the renovation. This is achieved mainly by increasing the R value of the façade, applying materials with higher values of thermal insulation, and the application of high insulation HR++ glass.



Graph 2: Annual heating and cooling load.

3.3 Embodied energy

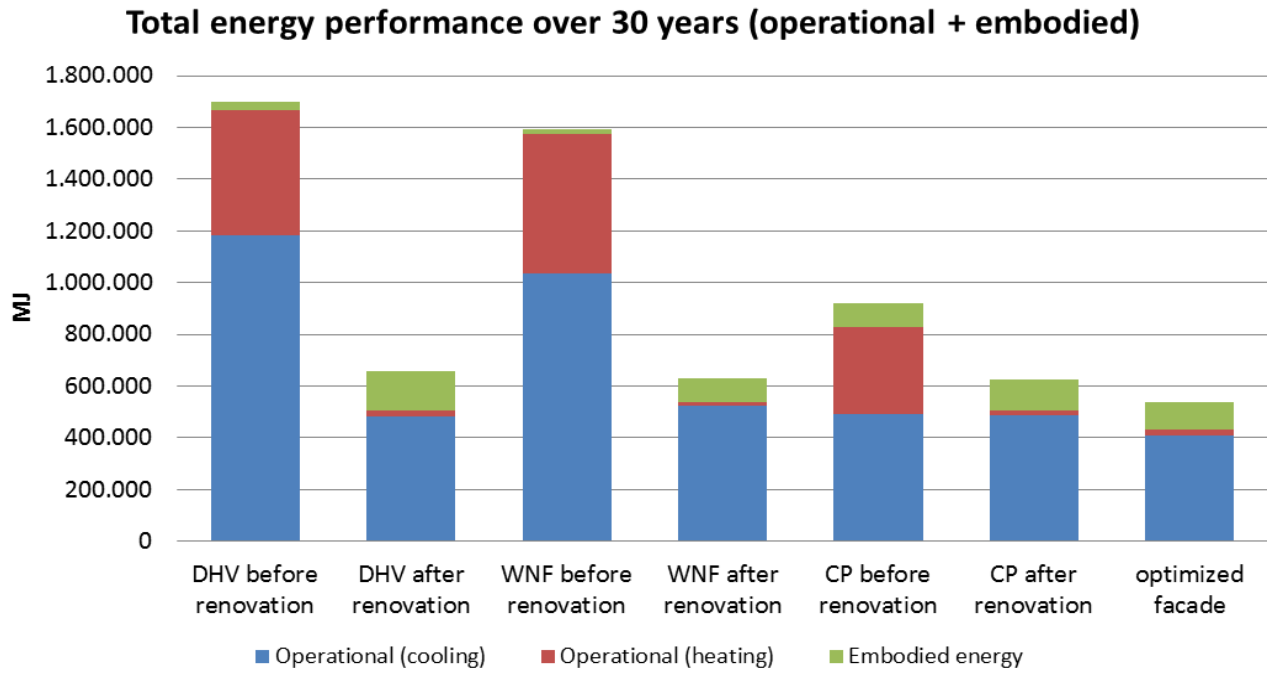
Graph 2 shows the results of all embodied energy values of the facades of the three projects before and after the renovation. The blue columns show the results before renovation and the red columns after renovation. The embodied energy required for the facades of the DHV office and the WNF office after the renovation is many times higher than the embodied energy of the facades before the renovation. After renovation, the DHV office has a new aluminum curtain wall obtained with HR++ double glass and the WNF office has new wooden curtain wall with triple HR+++ glazing filled with krypton gas. The embodied energy required for the new facade of the Central Post building is relatively small compared to that of the other buildings. This is because this façade was only partly replaced and remained largely unchanged. Furthermore, the embodied energy required for the original façade was already very high due to the large amount of the heavy materials concrete and steel. The existing aluminum facade with single glazing is replaced by a new aluminum front with HR + + glass.



Graph 2: Embodied energy before and after the renovation.

3.4 Relation between operational energy and embodied energy

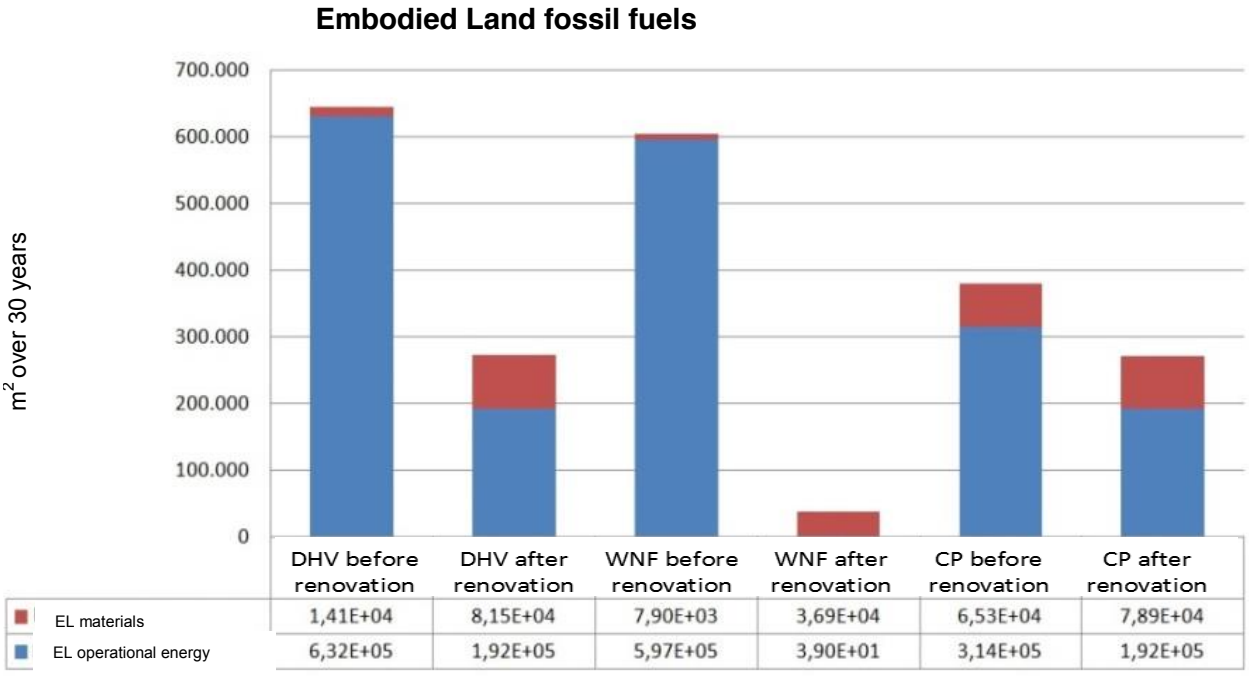
In graph 3 the results of total energy consumption are shown (operational energy of the office and the embodied energy of the façade) before and after the renovation, for a total technical lifetime of 30 years. The results indicate that, for the investigated south facing office space, the cooling load has the largest energy demand, both before and after the renovation. It also shows that the heat load of the office space after the renovation is minimal, which is a result of the improved thermal properties of the facades after the renovation. To achieve these improved thermal properties more embodied energy is required for the facades. In general the embodied energy of the facades increases after renovation, but the cooling load remains the largest energy demand. An exception is the WNF office because this building has become self-sufficient after the renovation. If in this case the operational energy (total heating and cooling load) is not included, the total energy consumption of the building consists of embodied energy so material use will become the determining factor.



Graph 3: Total energy performance over 30 years.

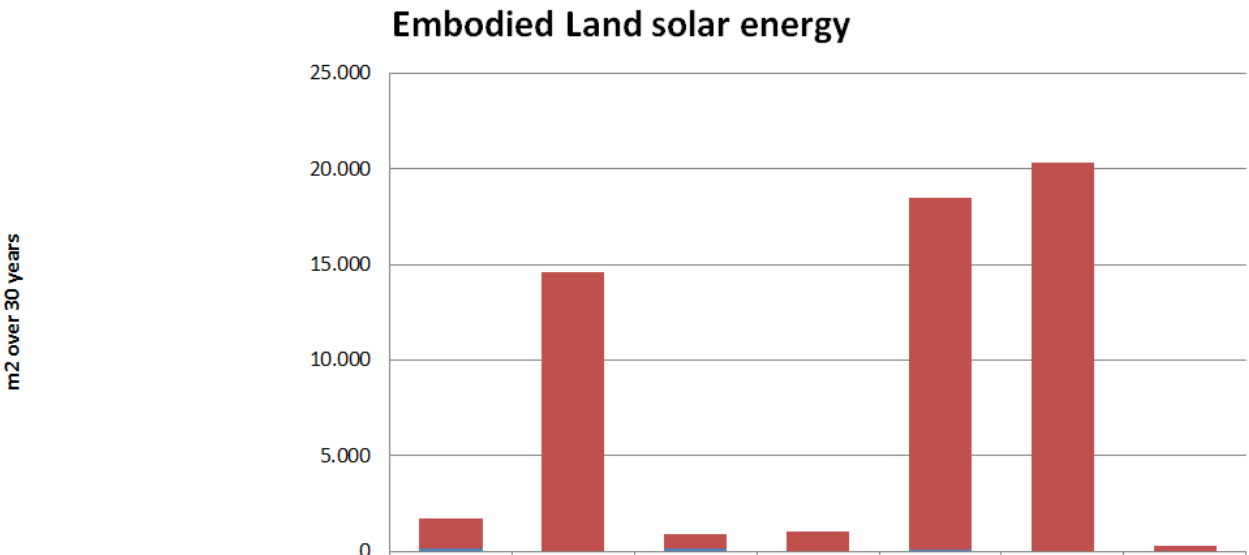
3.5 Embodied land

Graph 4 show the calculated Embodied Land of facade materials and the calculated Embodied Land of operational energy of the office space, when all energy required for the operational energy, is based on fossil fuels. In this case the embodied land of the operational energy is the determining factor with respect to the embodied energy for the materials of the façade. Only the results of the WWF office show a different situation where the material use is the determining factor. This is because after the renovation operational energy in this building is generated by solar energy.



Graph 4: Embodied Land based on fossil fuels over 30 years.

Graph 5 shows the results of the Embodied land, when all energy is generated by solar energy (solar panels and solar collectors). In this calculation, the total embodied land for all projects is much smaller than with a similar calculation using fossil fuels, due to the large time-land impact to generate fossil fuels. Secondly, the embodied land for the façade materials is much greater than the embodied land for the operational energy. The embodied land of the operational energy is in most cases negligible compared to the embodied land for the façade materials.



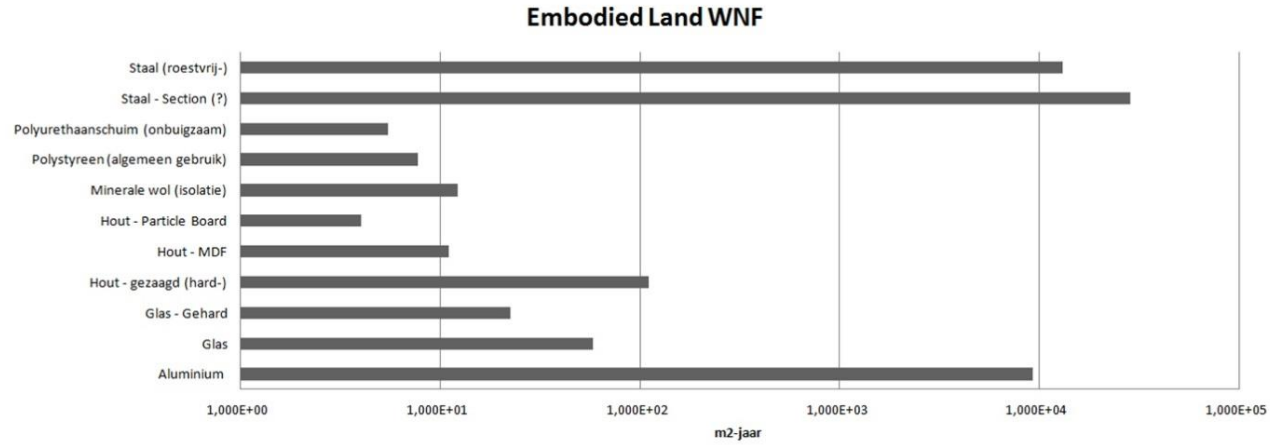
Graph 5: Embodied Land based on solar energy over 30 years.

The results also show that the facade of the WNF office after renovation scores very good in comparison with the other facades in all assessments. The facade of the WNF office consists mainly of wood, a natural material with low embodied energy. Natural (biobased) materials score very well in the embodied land calculation, because these materials can grow back naturally by themselves, so a closed-loop system is created without adding energy.

A closed-loop system for the materials is created when a material that is used as a building product has grown back within the lifetime of the façade, and all energy to realize the building product has been generated. The aluminum, concrete and steel that are used in the facades of the DHV and the Central Post Office are non-biobased and cannot grow back. These materials are however recyclable and partially reusable. The recycling percentages of these materials are not 100%, for aluminum it is 94% (22). According to the MAXergy calculation a lot of energy is needed to win back the non-recycled percentage of these material.

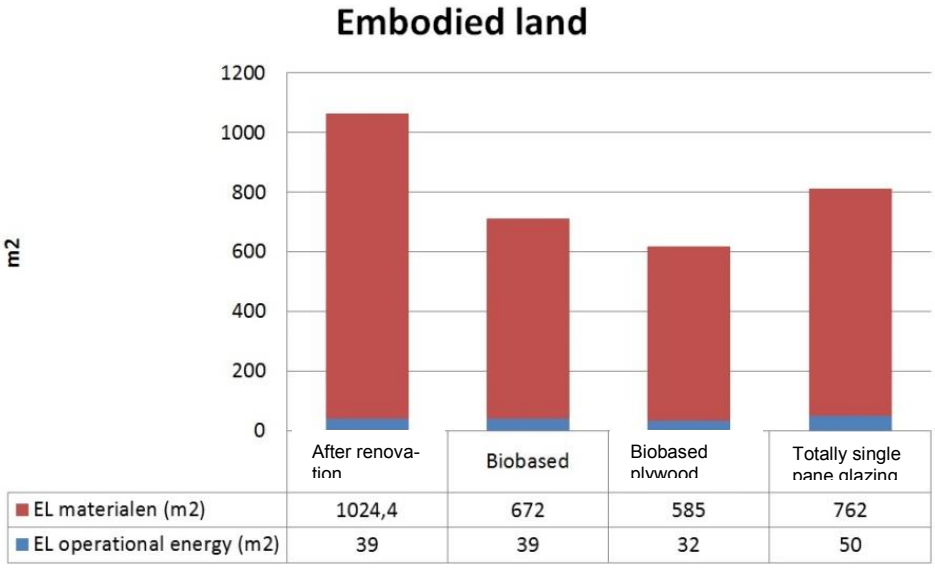
4. Analysis and optimization of the WNF façade

Based on the results presented in chapter 3, the façade of the WNF building has been further investigated and optimized. Analysis on the material consumption (graph 6) in the WNF facade shows that most of the Embodied Land of the facade originates from non-renewable materials. In the first place these are the metals in the facade used for connections, steel profiles, glass profiles, etc. and in the second place the glass and the insulation materials.



Graph 6: Embodied Land of different materials in the WNF façade.

Based on this analysis, a first comparison has been made, in graph 7, between the current façade after renovation; a 100% biobased version of the façade with the current openings; a 100% biobased version of the façade with no openings; and a 100% open version of the façade with single pane glazing, all without external blinds.



Graph 7: Embodied Land of different façade options for the WNF façade.

The Embodied Land of the materials is in all versions still larger than the Embodied Land of the operational energy, indicating the importance of material performance in this assessment method. Even when the facade consists of a minimum amount of biobased materials (only a plywood sheet), the Embodied Land required for the operational energy is small.

Optimized design

To improve the environmental performance of the office façade within the Dutch Building Regulations, the maximum possible use of renewable energy sources should be made for power generation. Optimally would be a maximum energy output with minimal material use. To minimize the embodied land of the facade a maximum use of bio-based materials should be made. The non-biobased materials, like metals, need to be recycled as much as possible. When metals are used, they need to be 100% recycled so it does not need to be recovered.

The optimized façade design of this research aims at minimizing the embodied the land of the façade materials, within the Building Regulations. The façade design consists for 93% of biobased materials, in which most of the metals have been replaced by the fiber-reinforced composites. The facade needs 70% less embodied land than the WNF façade (see graph 3 and 5). In addition, in the design is taken into account that materials are easy to separate.

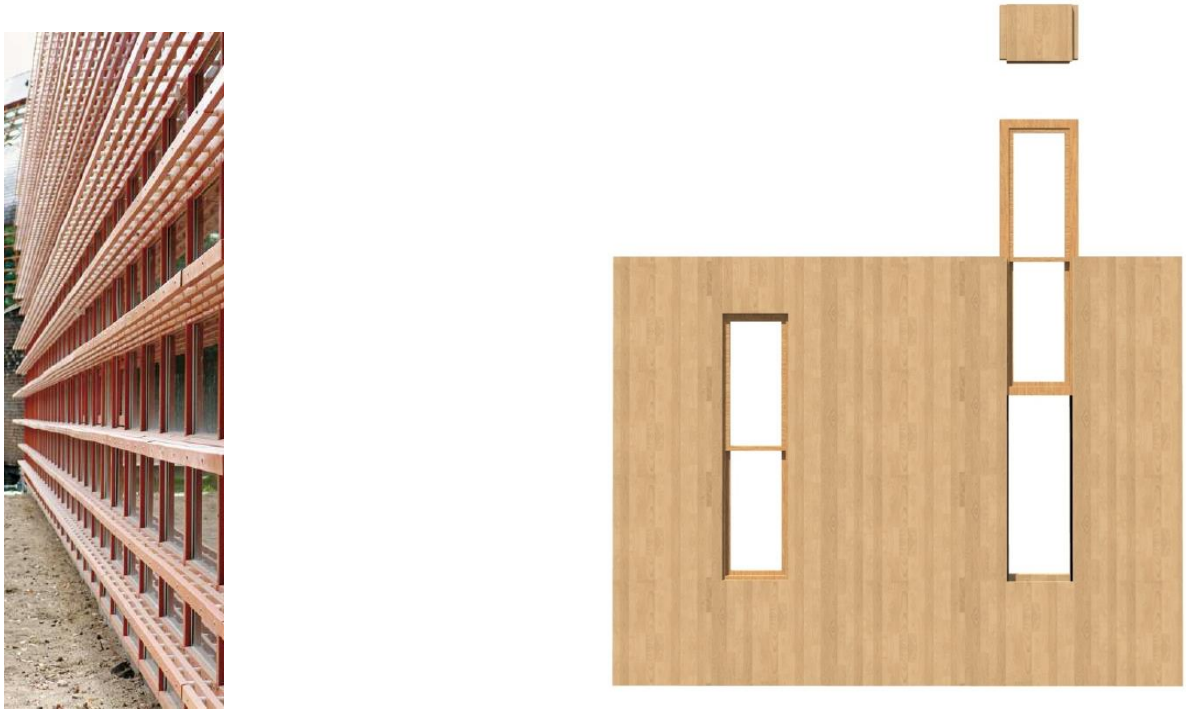


Fig. 7, 8: Picture of the existing renovated WNF façade and optimized design (vd Meijden).

4. Conclusions & discussion

Based on the case studies and on the optimized façade design, the following conclusions concerning operational energy performance, material performance and the related land use are drawn.

- In all projects the embodied energy of the facade after renovation has increased compared with the situation before the renovation. The operational energy performance has improved in all cases.
- Besides the amount of materials also the choice of materials determines the embodied energy of the façade.
- The cooling load is the largest energy part of total energy performance both before and after the renovation and the embodied energy of the facades is a small portion of the total energy demand for a lifetime of 30 years.
- The embodied energy of the building becomes the largest energy aspect, when the operational energy is fully generated by renewable energy sources (e.g. solar and wind) on-site, as at the WNF office after the renovation.
- The Embodied Land calculations indicate that the amount of materials and the choice of materials in nearly all situations determine the land-time impact. Biobased materials like wood score very well in this calculation because the low amount of embodied energy and because these materials are renewable.
- The Embodied Land calculations based on fossil fuels show in almost all cases that the operational energy is the determining factor compared to materials. An exception is the WNF office after the renovation because in this case the operational energy of the building is generated by itself through solar energy. In this situation, only the embodied energy is generated by fossil fuel so the material use becomes the determining factor.

- It can be concluded that material use becomes the determining factor with respect to the operational energy when energy in a building is generated by renewable energy sources. Through the increasing requirements for sustainability of buildings in the future the use of renewable energy sources to generate energy will increase strongly. The materials use and the required land use to create the materials for generating the renewable energy will also increase.

Based on this research project, the following discussions concerning the MAXergy tool are drawn to suggest further research in this direction.

- The embodied land calculation by Maxergy is based on the surface of solar panels and solar collectors, which is necessary for generating electricity and heat. The results of the embodied land calculations are therefore highly dependent on the efficiency of the solar panels and solar boilers used for this.
- The embodied land calculation is realistic if all energy (operational and embodied) is generated by solar energy. This is not always corresponding with the reality. Operational energy is in some cases generated by solar energy, but the majority of embodied energy is not. Therefore, a comparison is made between the land use by means of fossil energy and solar energy. It is interesting to do further research into land use by using the current energy mix (fossil fuels, nuclear and renewable energy). It would also be interesting what the difference is in land use between the current energy mix.
- An important part of the MAXergy calculation is the recovery of raw materials (especially metals). In many cases this is the decisive factor for the final result. For the recovery of metals for example a method is chosen, in which metal particles are filtered from seawater. This includes a number of assumptions. Further research should be done on the recovery of metal particles.

5. References

1. (IEA) IEA. Worldwide trends in energy use and efficiency. report. 2008 2008. Report No.
2. Ko J, Widder L, editors. building envelope assessment tool for system integrated design. PLEA 2011; 2011; Louvain-la-Neuve, Belgium.
3. Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy and Buildings. 2008;40(3):394-8.
4. Administration USEI. International Energy Outlook 2011. U.S. Energy Information Administration, 2011 2011. Report No.
5. Bruckner M, Giljum S, Lutz C, Wiebe KS. Materials embodied in international trade – Global material extraction and consumption between 1995 and 2005. Global Environmental Change. 2012 (0).
6. Frontini F, editor daylight and solar control in building: a new angle selective see-thorough PV-facade for solar control. PLEA 2011; 2011.
7. Zadelhoff D. Nederland compleet; kantoren en bedrijfsruimtemarkt. 2013.
8. AgentschapNL. Onderzoek naar het energie- en CO2-reductiepotentieel. Duurzaam inkopen van gebouwen, de Rijksgebouwendienst als voorbeeld2010.
9. AgentschapNL. Rapport energiecijfers kantoren. 2010.
10. Tran HT, editor measuring sustainability: carbon or land? iNTA-SEGA; 2009.
11. Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy and Buildings. 2010 10//;42(10):1592-600.
12. Herring HS, Steve. Energy Efficiency and Sustainable Consumption. Elliott D, editor. Hampshire, England: Palgrave Macmillan; 2009.
13. Verbeeck G, Hens H. Life cycle inventory of buildings: A contribution analysis. Building and Environment. 2010;45(4):964-7.
14. Dixit MK, Fernández-Solís JL, Lavy S, Culp CH. Need for an embodied energy measurement protocol for buildings: A review paper. Renewable and Sustainable Energy Reviews. 2012;16(6):3730-43.

15. Rovers R, de Flander K, Gommans L, Broers W, editors. designing for only energy: suboptimisation. PLEA 2011; 2011; Louvain-la-Neuve, Belgium.
16. Catton Jr WR. The Gaia atlas of planet management: for today's caretakers of tomorrow's world: N. Myers (general ed.), 272 pp., 1985, Pan, London, £9.95. Journal of Rural Studies. 1986 //;2(2):170-1.
17. website V. 2013. Available from: http://www.vabi.nl/Producten/Vabi-Uniforme-Omgeving/Gebouwsimulatie.
18. Hammond GJ, C. Inventory of Carbon and Energy (ICE). University of Bath, UK. 2008.
19. website G. 2013. Available from: http://www.greencalc.com/.
20. Rovers R. MAXergy and embodied land. In: RiBuilT, editor. 2011.
21. Ebbert TK, U; Eekhout, A.C.J.M. Re-Face: Refurbishment Strategies for the Technical Improvement of Office Facades. Delft: Delft University of Technology; 2010.
22. Haas M. NIBE's basiswerk milieuclassificatie2002.



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The environmental footprint of plastic pipe systems within the built environment

Short Summary

The European Plastics Pipes and Fittings Association (TEPPFA) deems it important to have an insight into the integral environmental burdens encountered during the life-span of particular plastic pipe system applications within the built environment. With this framework in mind, TEPPFA has set up a project with the Flemish Institute for Technological Research (VITO). The aim of this project is to carry out several life cycle assessment (LCA) studies from the cradle to the grave. The LCAs of several plastic pipe systems outline the various environmental aspects which accompany the pipe systems, from the primary extraction of raw materials up to and including the end of life (EoL) treatment after their reference service life time. To get a better view on the advantages and disadvantages from an environmental point of view of a pipe system in plastic compared to its main competing non-plastic material, LCA comparisons were made. The conclusions of the comparative LCA studies show that the average environmental impact of plastic pipe systems in general are lower than the average environmental impact of piping systems made out of traditional materials.
This paper reports on the LCA of some specific plastic pipe systems with the final aim of providing a clear environmental product declaration (EPD), thus raise the awareness amongst developers, installers and users, of the potential environmental impacts and benefits over the complete life cycle. In addition some comparisons for the environmental impact category global warming (CO2 footprint) are presented and discussed.

Keywords

Plastic pipe systems, life cycle assessment (LCA), environmental product declaration (EPD), European sector approach, sustainable construction and housing.

1. About TEPPFA

TEPPFA stands for The European Plastic Pipes and Fittings Association. It is a trade association representing the key manufacturers and national associations of plastic pipe systems. TEPPFA is actively involved in the promotion and acceptance of plastic pipe systems for all applications. It has a

voluntary initiative, commitment to develop EPDs for several types of plastic pipe systems. The EPD initiative of TEPPFA aims to measure the environmental impact of plastic pipe systems throughout their entire life cycle and to communicate about the results by means of EPDs.

2. Life Cycle Assessment (LCA) of plastic pipe systems

LCA is a standardized tool that assesses the environmental impact of products, processes and/or systems throughout their entire life cycle. LCA quantifies the potential environmental effects of a product, a process or a system over its entire life cycle, meaning that the extraction of raw materials, the production of materials and the product, the use and the end-of-life treatment are taken into account.

TEPPFA created cradle-to-grave LCAs consistent with ISO 14040 [2], ISO 14044 [3] and the pre and final EN 15804 [4] and EN 15942 [5].norms. The overall objectives of the TEPPFA LCAs are:

- to analyse the environmental impacts of different applications of plastic pipe systems in selected application groups;
- to investigate the relative performance of various plastic pipe systems at the system level in order to show that material choices cannot be made at the product or material level only;
- to use the results of the LCA-studies of the plastic pipe systems for business-to-business communication by means of EPDs;
- to compare the environmental footprint of the plastic pipe systems with the environmental footprint of non-plastic pipe systems.

Within the TEPPFA framework the environmental impact categories as defined in EN 15804 are considered [4].

Table 1: The environmental impact categories considered in the LCAs

Abiotic depletion:	exhaustion of natural resources
Acidification potential:	emissions from manufacturing processes resulting in acid rain
Eutrophication:	over-fertilisation of water and soil
Global warming:	insulating effect of greenhouse gases, such as CO_2 and methane
Ozone layer depletion:	depletion of the ozone layer in the atmosphere caused by emissions of pollutants
Photochemical oxidation:	photochemical reaction of sunlight with primary air pollutants, that leads to chemical smog

3. Environmental Product Declaration (EPD) of plastic pipe systems

The EPDs for plastic piping systems provide LCA-based information from the cradle to the grave. The EPDs are provided in a standard communication format according to the EN 15942 [5]. The EPDs can be downloaded from the TEPPFA website (http://teppfa.eu/sustainability-a-environment/-epd.html). TEPPFA created the EPD framework. The member companies that produce plastic pipes and fittings provided their life cycle inventory (LCI) data to TEPPFA. Then the LCAs are carried out by VITO, critically reviewed by an external and independent expert from Denkstatt and Third Party Reports and EPDs are created and published on the TEPPFA website. The process reflects a European sector approach for EPDs.

4. Overview of the LCAs and EPDs for plastic pipe system applications

- Sewage and drainage applications (non-pressure):
  - PVC-U solid wall sewer pipe system [12]
  - PVC-U multilayer (foamed core) sewer pipe system [13]
  - PVC-U multilayer (core of foam and recyclates) sewer pipe system [14]
  - PP structured (twin) wall sewer pipe system [15]
  - PP solid wall sewer pipe system [20]**
  - PP structured wall multilayer sewer pipe system [20]**
- Water and gas distribution applications (under pressure):
  - PE water pipe system [8]
  - PVC – U water pipe system [9]
  - PVC – O, MRS 31,5 MPa, water pipe system [10]
  - PVC – O, MRS 45 MPa, water pipe system [11]
  - PE gas pipe system [19]**
  - PE water pipe system installed by directional drilling technology **
- Soil and waste applications in the building (non-pressure):
  - PP pipe system [6]
  - PVC-U pipe system [7]
  - PP low noise pipe system [18]**
  - PVC-U low noise pipe system [18]**
- Plumbing, hot & cold applications in the building (pressure):
  - PEX solid wall pipe system [16]
  - Polymer, aluminium, polymer multilayer pipe system [17]
  - PP-R pipe system [21]
  - PB-1 pipe system**
- Rain gutter applications:
  - PVC-U rain gutter system**

** In preparation

5. Some results for plastic pipe systems

5.1. Sewage and drainage applications

The functional unit of the sewer pipe systems that have been studied has been defined as: “the below ground gravity transportation of sewage over a distance of 100 m by a typical public European plastic pipe system and its alternative concrete pipe system from the entrance of a public sewer system to the entrance of the waste water treatment plant, over their complete reference service life of 100 years, calculated per year”.

PVC-U solid wall sewer pipe system
The environmental impacts of the PVC-U solid wall sewer pipe system is mainly caused by the product stage (raw materials) and the construction process stage (excavation of the). When comparing the PVC-U solid wall sewer pipe system with a concrete sewer pipe system fulfilling the same functional unit, we can conclude that for most environmental impact categories the contribution of the concrete pipe system is relatively lower, although the difference is not significant. Only for global warming of the PVC-U solid wall sewer pipe system has a lower contribution (see Figure 1).

PVC-U multilayer (foamed core) sewer pipe system
The technical possibilities of the plastic pipe systems provide excellent tools to fit these systems to many different requirements. A new product in which a reasonable amount of plastic is replaced by air reduces the environmental impacts dramatically in most environmental categories. When considering a multilayer sewer pipe system instead of a solid wall sewer pipe system, the environmental impacts are reduced significantly. At the same time the environmental impacts of a

PVC multilayer foam core pipe system results in a lower contribution in comparison to the environmental impact of a concrete pipe system and this is valid for all environmental impact categories considered. Figure 2 presents the comparison for global warming.

PVC-U multilayer (core of foam and recyclates) sewer pipe system

In this type of PVC-U multilayer pipe system the virgin PVC material in the core of the pipe wall is replaced partly by foamed virgin PVC and recycled PVC. When considering this multilayer sewer pipe system instead of a solid wall sewer pipe system, the environmental impacts are reduced significantly. At the same time the environmental impacts of this multilayer pipe system with a core of foamed PVC and PVC recyclates results in a lower contribution in comparison to the environmental impact of a concrete pipe and this is valid for all environmental impact categories considered. The use of recyclates further reduces the CO2 equivalent. Figure 3 presents the comparison for global warming.

Figure 1: Comparative environmental profiles: PVC-U solid wall versus concrete sewer pipe systems

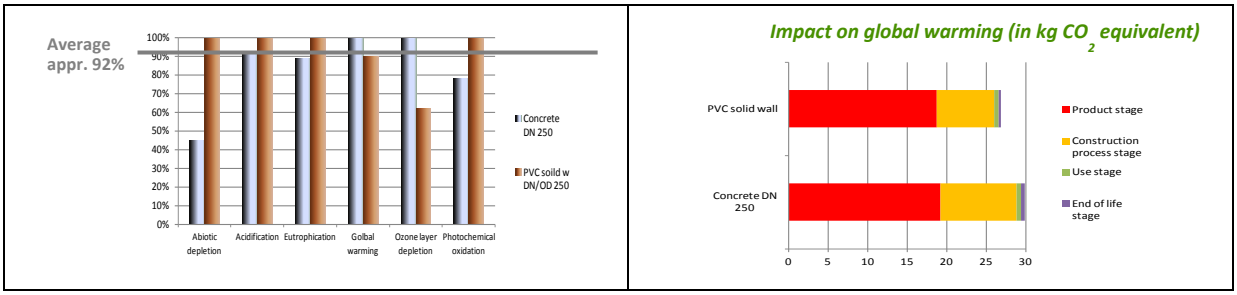


Figure 2: Comparative environmental profiles: PVC-U multilayer (foamed core) versus concrete sewer pipe systems

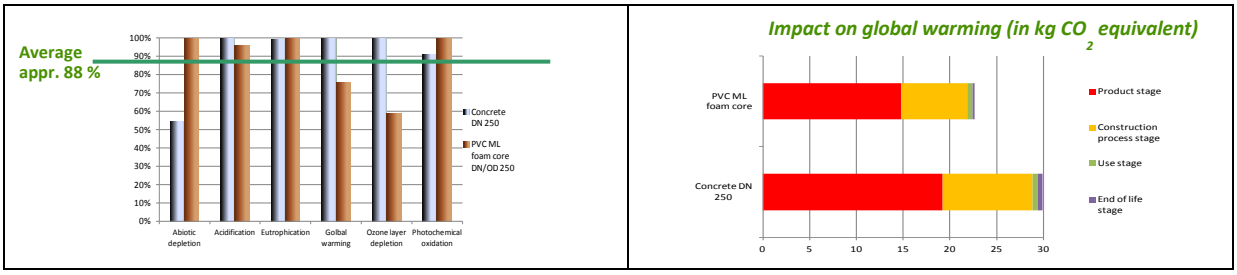
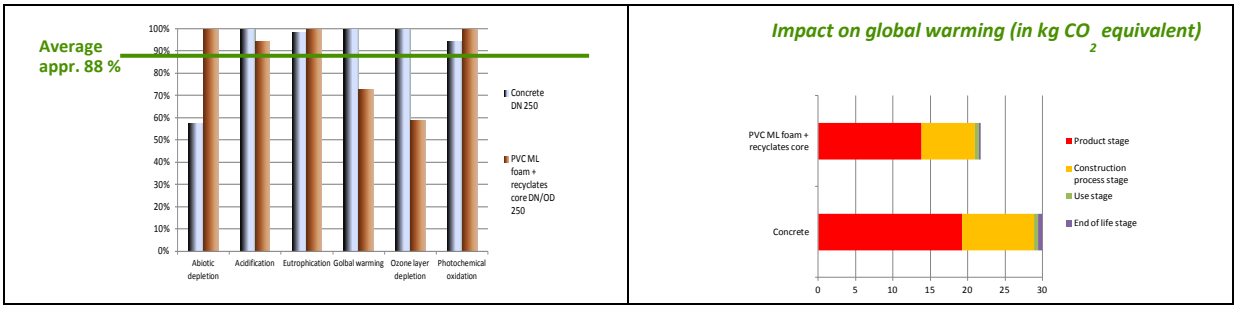


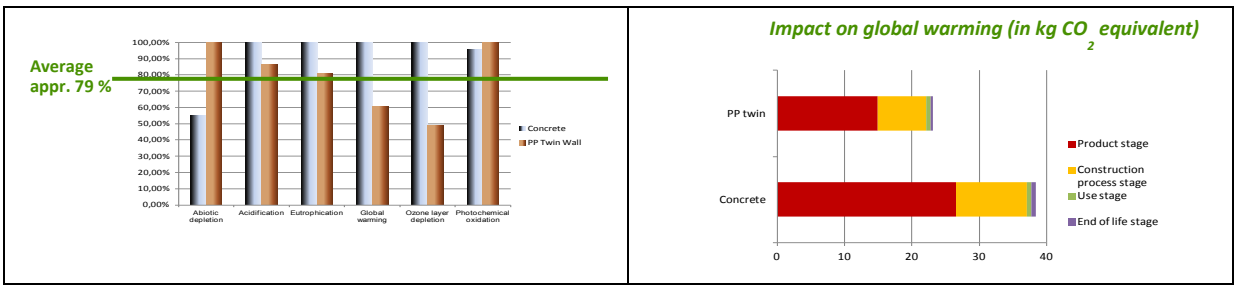
Figure 3: Comparative environmental profiles: PVC-U multilayer (core of foam and recyclates) versus concrete sewer pipe systems



PP structured (twin) wall sewer pipe system

In this LCA study DN/ID 300 PP and DN 300 mm concrete piping systems are compared. When considering a PP sewer pipe system with a structured (twin) wall in comparison to a concrete sewer piping system this results in a relatively lower contribution for all environmental impact categories considered. The excellent environmental behaviour of PP twin wall sewer piping system is again an evidence on the innovative nature of plastics. Figure 4 presents the environmental comparison.

Figure 4: Comparative environmental profiles: PP structured twin wall versus concrete sewer pipe systems



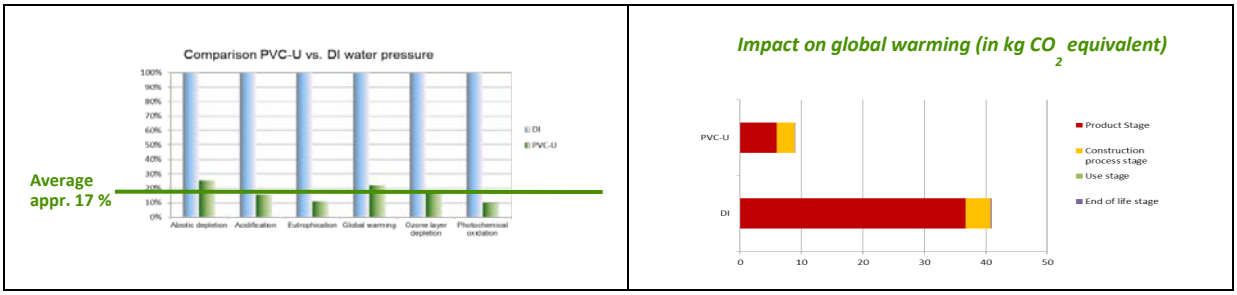
5.2. Water and gas distribution applications

The functional unit of the water and gas distribution pipe systems that have been studied has been defined as: “the below ground transportation of gas/drinking water, over a distance of 100 m (from the exit of the water plant to the water meter of the building), by a typical public European plastic pipe gas/water distribution system and its alternative ductile iron pipe system over their complete reference service life of 100 years, calculated per year.”

PVC-U water pipe system

The environmental profiles of the PVC-U water pressure pipe system is mainly caused the raw materials (PVC) during the product stage and by the construction process stage (mainly due to excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of the PVC-U water distribution pipe system is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 5).

Figure 5: Comparative environmental profiles: PVC-U versus ductile iron water pipe systems



PVC-O water pipe systems (bi-oriented)

Two PVC-O bi-oriented water pipe systems have been assessed: the PVC-O 31,5 MPa pressure and the PVC-O 45 MPa pressure pipe system for water distribution. Both environmental profiles are dominated by the product stage (raw materials production) and by the construction process stage (excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of both PVC-O water distribution pipe systems is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 6 and Figure 7).

Figure 6: Comparative environmental profiles: PVC-O (31,5 MPa) versus ductile iron water pipe systems

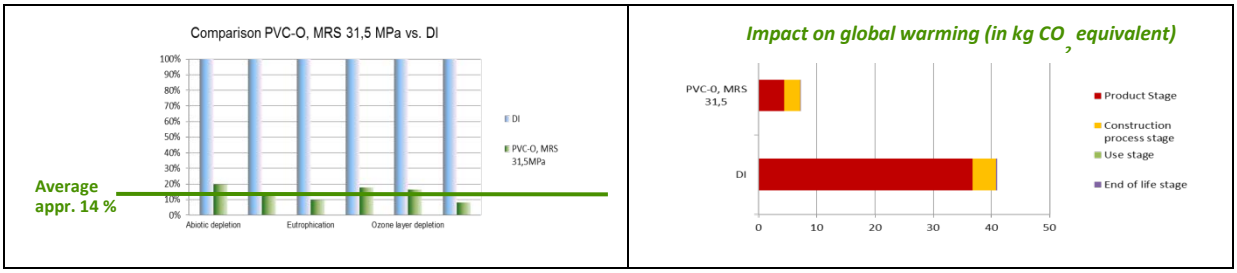
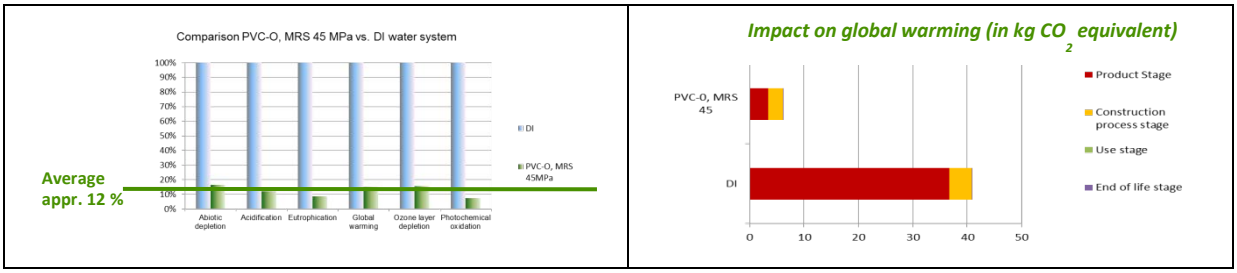


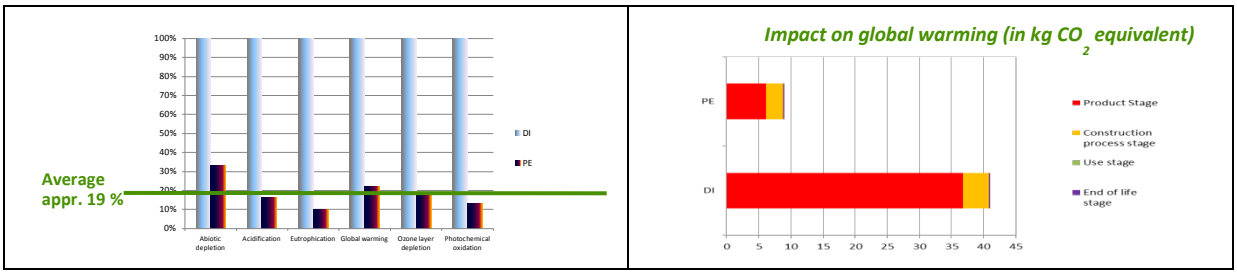
Figure 7: Comparative environmental profiles: PVC-O (45 MPa) versus ductile iron water pipe systems



PE water pipe system

The environmental profiles of the PE water pressure pipe system is mainly caused the raw materials (PE) during the product stage and by the construction process stage (mainly due to excavation operations at the trench). When considering all environmental impact categories of the LCA, we can conclude that the environmental impact of the PE water distribution pipe system is significantly lower than the ductile iron pipe system that is fulfilling the same function (see Figure 8).

Figure 8: Comparative environmental profiles: PE versus ductile iron water pipe systems



5.3. Soil and waste applications in the building

The functional unit of the soil and waste pipe systems that have been studied has been defined as: “the yearly impact of different soil and waste gravity drainage systems’ installation into a typical European 100 m² apartment, incorporating a bathroom, separate WC, kitchen and washroom, considering the reference service life of the pipe systems to be aligned with the 50 year of reference service life of the apartment”.

Plastic soil and waste pipe system

The environmental profile of the PVC-U and PP soil and waste pipe systems is mainly determined by the product stage and more specifically by the production of the different pipe system components. When considering the environmental impact of a PVC-U and the PP soil and waste pipe systems compared to a ductile iron soil and waste piping system it results in a significantly lower contribution for all the environmental impact categories considered (see Figure 9 and Figure 10).

Figure 9: Comparative environmental profiles: PVC-U versus ductile iron soil and waste pipe systems

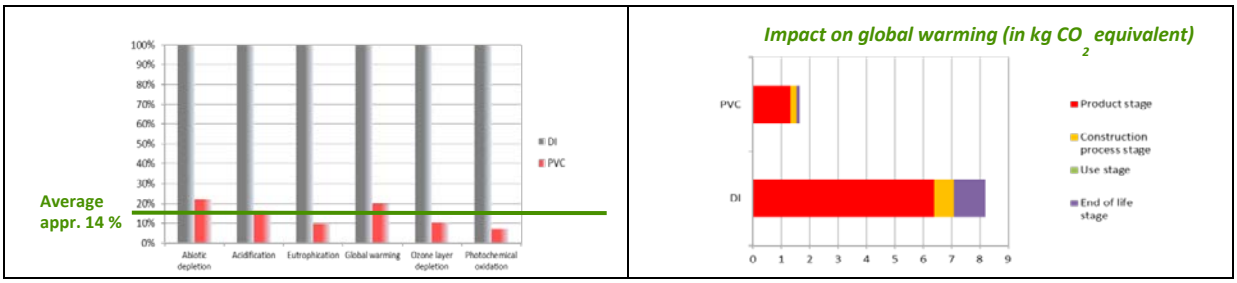
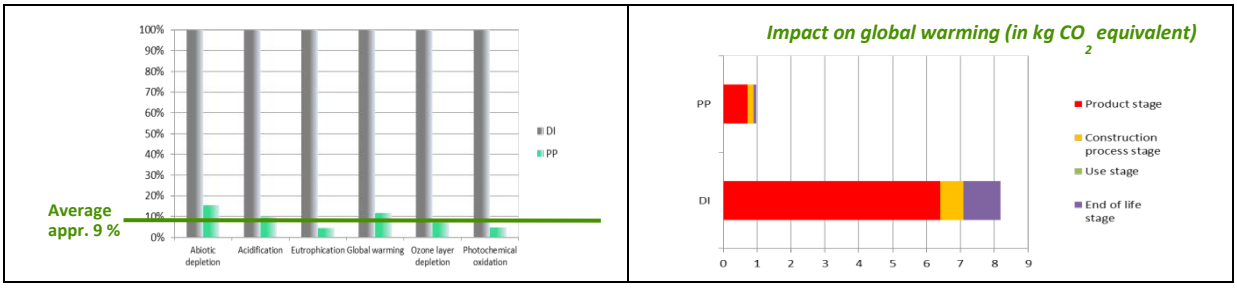


Figure 10: Comparative environmental profiles: PP versus ductile iron soil and waste pipe systems



5.4. Plumbing, hot & cold applications in the building

The functional unit of the hot and cold pipe systems that have been studied has been defined as: “the pressure supply and transport of hot and cold drinking water, from the entrance of a well-defined apartment to the tap, by means of a hot and cold drinking water pipe systems’ installation, supplying a 100 m² apartment, incorporating a bathroom, separate WC, kitchen and washroom, considering the reference service life of the pipe systems to be aligned with the 50 year reference service life of the apartment. The environmental profiles are calculated per year.”

Plastic pipe systems for hot and cold

The environmental profile of the PEX solid wall and the polymer – aluminium – polymer multilayer pipe systems for hot and cold water in the building is mainly determined by the product stage and more specifically by the production of the different pipe system components. When considering the environmental impact of the plastic pipe systems for hot and cold water compared to a copper hot and cold pipe system it results in a significantly lower contribution for all the environmental impact categories considered (see Figure 11 and Figure 12).

Figure 11: Comparative environmental profiles: PEX solid wall versus copper hot and cold pipe systems

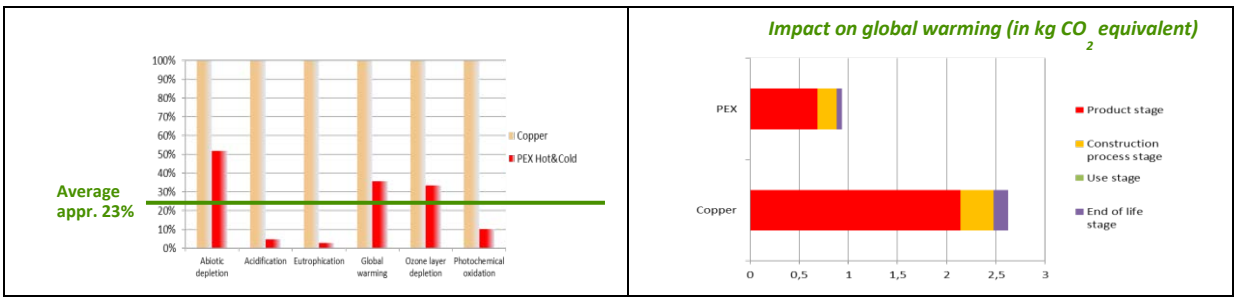
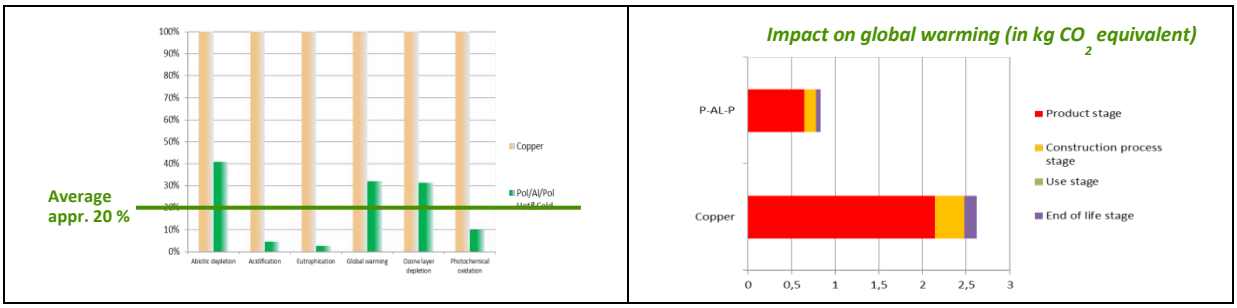


Figure 12: Comparative environmental profiles: Polymer/Al/polymer versus copper hot and cold pipe systems



6. Conclusions

The development of EPDs allows a comprehensive insight in the environmental impact of plastic pipe systems over their entire life cycle.

The results of the LCAs indicate that the impact of plastic pipe systems on the environment is relatively lower compared to the environmental footprint of main non-plastic piping materials.

The contribution of plastic pipe systems to global warming (CO2 footprint) is for all plastic piping systems that have been studied lower in comparison of pipe systems made out of competing materials for the pipes.

TEPPFA is committed to develop new EPDs for other types of plastic pipes and fittings.

TEPPFA members are committed to further reduce the environmental impact of plastic pipe systems.

References

[1] ISO 14025, (2006), Environmental labels and declarations -- General principles.
[2] ISO 14040, (2006), Environmental management – Life cycle assessment – Principles and framework.
[3] ISO 14044, (2006) Environmental management – Life cycle assessment – Requirements and guidelines.
[4] (pr)EN 15804: Sustainability of construction works – Environmental product declarations – core rules for the product category of construction products (draft, 2008);
[5] (pr)EN 15942: Sustainability of construction works – Environmental product declarations – Communication format – Business to Business (draft, April 2009).
[6] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PP pipe system for soil and waste removal in the building (according to EN 1451)” 2010/TEM/R/232
[7] SPIRINCKX CAROLIN, KAROLIEN PEETERS and KATRIEN BOONEN “Life Cycle Assessment of a PVC-U pipe system for soil and waste removal in the building (according to EN 1329)” 2011/TEM/R/114
[8] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PE pipe system for water distribution (according to EN 12201)” 2010/TEM/R/228
[9] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment of PVC-U pipe systems for water distribution (according to EN 1452)” 2010/TEM/R/117
[10] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment a PVC-O (bi-oriented, MRS 31,5 MPa) pipe system for water distribution (according to ISO 16422)” 2010/TEM/R/117
[11] SPIRINCKX CAROLIN, PEETERS KAROLIEN and BOONEN KATRIEN “Life Cycle Assessment a PVC-O (bi-oriented, MRS 45 MPa) pipe system for water distribution (according to ISO 16422)” 2010/TEM/R/117
[12] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U solid wall sewer pipe system (according to EN 1401)” 2010/TEM/R/234
[13] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U multilayer sewer pipe system with a foamed core (according to EN 13476)” 2010/TEM/R/242
[14] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PVC-U multilayer sewer pipe system with a core of foam and recyclates (according to EN 13476)” 2010/TEM/R/244

[15] SPIRINCKX CAROLIN, KATRIEN BOONEN and KAROLIEN PEETERS “Life Cycle Assessment of a PP structured (twin) wall sewer pipe system (according to EN 13476)” 2011/TEM/R/112
[16] SPIRINCKX CAROLIN, IVE VANDERREYDT, AN VERCALSTEREN and KATRIEN BOONEN “Life Cycle Assessment of a PEX pipe system for hot and cold water in the building (according to EN ISO 15875)” 2010/TEM/R/230
[17] SPIRINCKX CAROLIN, KAROLIEN PEETERS and KATRIEN BOONEN “Life Cycle Assessment of a Polymer/Al/Polymer composite pipe system for hot and cold water in the building (according to EN ISO 21003)” 2011/TEM/R/110
[18] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life cycle assessment of a PP and a PVC low noise pipe systems for soil and waste removal in the building)” 2012/TEM/R/12
[19] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a PE pipe system for combustible gas distribution (according to EN 1555)” 2013/TEM/R/14
[20] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a smooth walled polypropylene (PP) mono- and multilayer sewer pipe system” 2012/TEM/R/
[21] PEETERS KAROLIEN and SPIRINCKX CAROLIN “Life Cycle Assessment of a Polypropylene random copolymer (PP-R) pipe system for hot and cold water distribution in the building (according to EN ISO 15874)” 2013/TEM/R/16

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Cooling concept of the new R&D building of the ZAE Bayern using several thermal energy storage (TES) technologies

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Short Summary

The Bavarian Center for Applied Energy Research (ZAE Bayern) is currently raising the new R&D building “Energy Efficiency Center” [1] (EEC) within a public funded research project. The EEC, which will be finished by June 2013, includes offices, laboratories as well as an Info-centre which is open to the public and informs the visitors about the implemented innovative systems and current R&D activities within the funding scheme “Research for Energy Optimized Buildings”.
The overall aim of this project is to demonstrate the compatibility of energy efficiency, user requirements and appealing architecture. The EEC aims to be a technology reference and along with the strong interaction of research, demonstration and dissemination at one place it is supposed to accelerate innovation processes in the field of energy optimized buildings.
Since the EEC is a partial lightweight building with a translucent building envelope and high internal heat gains, an integral, sustainable concept for cooling is required. For this, several new technologies are combined. To minimize energy consumption and to ensure thermal comfort for the employees a highly innovative building automation system will regulate and control the interaction of the single systems.
The centrepieces of the cooling concept are two fire fighting cold water tanks with a volume of 100 m³ each, which are connected to the buildings cooling circuits. While one tank as a backup is cooled by a conventional compression cooler, the second tank is connected to the ZAE-developed “Passive Infrared Night Cooling” (PINC). PINC is an open rainwater circuit using natural re-cooling via infrared heat radiation exchange with the cold night sky on a special area of the roof. It is therefore a highly efficient, energy saving cooling method. The cold water is used for the cooling units in the laboratories as well as for the regeneration of the implemented PCM cooling ceilings in the offices. The PCM cooling ceilings are a new development which improves the thermal connection of the PCM to the room air as well as to the cooling circuit. At daytime the PCM is cooling the room passively while melting. When outside air is too cold or too hot for natural ventilation of the building, tempered air is supplied by a Liquid-Desiccant Cooling System (L-DCS) which uses a concentrated hygroscopic salt solution for dehumidification and evaporative cooler for cooling.
After its completion the building will undergo a comprehensive long-term monitoring and optimization phase.

Keywords: PCM; energy storage; cooling concept; energy efficiency; L-DCS

1. Introduction

Current approaches in reducing CO_2 emissions as part of international and national climate protection policies are based on people's consciousness about the increasing threat of the greenhouse effect. Likewise, ecological and economical consequences, as well as the constantly augmenting costs of fossil fuels have promoted these current policies to significantly reduce CO_2 emissions. In view of plans to increase the energy efficiency by 20% until 2020, turning old buildings into energy efficient ones as well as establishing high standards for energy efficiency of new buildings has become notably important in Germany. Suitable insulation of buildings alone for example may reduce heating demand by 50% while it significantly improves thermal comfort inside buildings. Besides that, with growing insights in the field of energy research several new technologies were developed in the past years which promise more energy efficiency in buildings. Anyhow, in the building sector innovations often take many years until being accepted on the market. This means that a great potential of energy savings is still unused.

Based on these facts the main target of the new R&D building for the Bavarian Center for Applied Energy Research (ZAE Bayern) is to combine cutting edge energy efficient technologies, to optimize their interaction, to identify synergy effects and to accelerate their introduction to the market by demonstration. These ambitious goals are promoted by gathering the know-how of the involved research partners from science and industry and by exchanging experience and ideas. In order to save energy and to provide sustainability and comfort, the main goal is rather to find a reasonable approach to optimize the building’s technology and its innovative envelope than to construct a model for a zero-energy building [1].

Due to the innovative, resource saving lightweight construction of the EEC including a membrane rooftop as well as the highly insulated lightweight facades, the EEC will show a highly dynamic thermal behavior. Because of high internal heat gains from measurement setups, electronic devices, solar gains and occupants high requirements especially for cooling have to be met. As the aim is to minimize the conventional cooling power backup in order to achieve high efficiency, new approaches with innovative technologies and building materials are required to meet the demand. In this paper an overview of the innovative technologies integrated into the EEC and the cooling concept using several energy storage technologies will be presented.

2. Energy Efficiency Center (EEC)

The Energy Efficiency Center (EEC), illustrated in *Figure 1*, is currently under construction and expected to be finished in June 2013. The overall aim of the design of the EEC is to create a reference building which implements innovative techniques, serves demonstrational purposes, and is used for research and development in the field of energy optimized buildings. Hence, the project not only involves integral planning, but also setting up and putting an innovative building into operation. The new research building involves innovative, energy efficient materials, components, and systems, all of which are to demonstrate their applicability for both old and new buildings. The EEC is designed to be easily extendable and is equally devoted to energy efficiency and aesthetically architectural design [2].



Figure 1: Perspective view of the EEC (© Lang Hugger Rampp GmbH).

The EEC includes offices, laboratories and a technical center as well as the corresponding infrastructure for the research activities of the ZAE Bayern in Würzburg. Furthermore, a seminar room, a conference room and a public Information Center are part of the room concept. In the Information Center, the development results of the EnOB-program (Research for Energy Optimized Buildings), funded by the Federal Ministry of Economics and Technology (BMWi), will be presented and explained.
The two-storied building is characterized by a light-weight construction in combination with a highly transparent building envelope with large glass surfaces. It is covered by a translucent roof membrane which serves as weather protection and plays an important role in light and climate management of the building as it creates an intermediate climate zone which acts as a preconditioned heat-insulating layer in the cold season and can be ventilated in summer to prevent overheating. Underneath the roof membrane there is an insulating layer which is carried out partly opaque, partly translucent using highly insulating aerogel modules in order to facilitate optimal daylight conditions for the offices underneath.
The lightweight facades are triple glazed with applied low-e coatings and insulated with vacuum insulation panels in the opaque sections.

Due to its partly translucent roof construction and the large fraction of glass façade the EEC in some parts achieve almost 100% daylight autonomy and no artificial lighting is needed most of the time. A side effect of the partly translucent building envelope is an increased solar heat input. As the outer shell of the building as well as the interior construction is lightweight because of flexibility requirements and resource saving aspects, little heat storage capacity is available to buffer temperature fluctuation. As a result, frequent changes between heating and cooling demand would occur in spring and fall, and elevated temperatures would likely occur in summer. To avoid room climates outside the comfort range without integrating too large conventional cooling power reserves, a combination of several thermal energy storage (TES) technologies is implemented to meet the cooling demand in an energy efficient way. The storage technologies are:

- room integrated phase change materials (PCM) to add additional thermal mass to the building (PCM in wallboards and PCM in cooling ceilings),
- a liquid desiccant cooling system (L-DCS) with a concentrated salt solution as energy storage to supply cool or preheated dehumidified air to the building,
- Passive Infrared Night Cooling (PINC) to provide the cold for appliance cooling and PCM regeneration stored in one of the cold water storages.

These storage technologies will be presented below.

3. Applied TES technologies

The cooling concept of the EEC is based on the integration and interrelation of four different innovative thermal energy storage systems. The implemented passive systems include the integration of PCM in building materials and the ZAE-developed passive infrared night cooling with cold water (PINC), while the active systems include an open cycle liquid desiccant cooling system (L-DCS) as well as an individually optimized cooling ceiling with PCM.

3.1 Passive Infrared Night Cooling (PINC)

The centerpieces of the cooling concept are two fire-fighting cold water tanks with a volume of 100 m³ each, which are connected to the building's cooling circuits via heat exchangers. Whereas one tank is cooled by a conventional compression cooler, the second tank is connected to the ZAE-developed "Passive Infrared Night Cooling" (PINC). A scheme of this system, which is successfully in operation at the existing building of the ZAE Bayern since 2000, can be found in *Figure 2*.

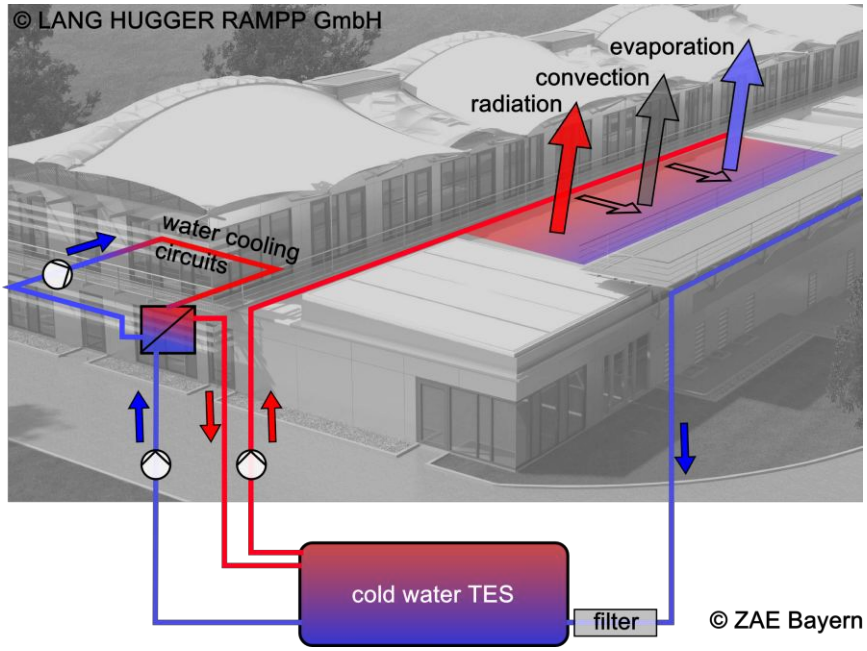


Figure 2: The cooling load is connected to the TES by means of a heat exchanger. The water in the TES is re-cooled on the rooftop, mainly during night time. The cooling effect is caused by infra-red heat radiation exchange as well as convection and evaporation.

PINC is a highly efficient, energy saving cooling method. Cold water is extracted from the bottom of the tank, pumped through a heat exchanger within the building to extract heat from the building, and the resultant warm water is fed back into the tank underneath the surface of the water. This process leads to a pronounced stratification inside the tank with temperature gradients of approx. 1 K/m. In order to re-cool the cold water TES, the stored warm water is pumped up to the roof at night and sprinkled over the sheet metal roof of the building where it runs freely and is cooled down chiefly by the heat radiation exchange with the cold night sky but also by evaporation and convection. The cooled water is fed back into the bottom of the tank. Electrical energy is only used for pumping the rainwater onto the roof. High coefficients of performance (>20) can thus be achieved [3].
As PINC is an open system, water evaporates and the loss has to be compensated which is automatically achieved by additionally collecting rain water from the roof.

3.2 Liquid Desiccant Cooling System (L-DCS)

Apart from the PINC storage system an open cycle liquid desiccant cooling system (L-DCS) is

installed in the EEC. Such a system can reduce ventilation cooling loads of buildings, which often amount to more than 50% of the total cooling load, very efficiently [2]. A scheme of the system as well as an overview of the cooling concept is shown in *Figure 3*. Outside air is dehumidified in an absorber by a concentrated hygroscopic salt solution (lithiumchloride) and subsequently cooled in an air cooler. The conditioned air is then provided to the building. The warmed-up air returning from the building is used in indirect evaporative coolers to produce cooling water by evaporating water from wetted heat exchanger surfaces. The cooling water cools subsequently the supply air cooler and the absorber. The dehumidification process of the outside air is driven by a flow of concentrated salt solution. The solution is diluted in the dehumidification process and has to be regenerated. In a regenerator the solution is re-concentrated by evaporating water at temperatures of 70°C to 80°C with the district heating net acting as heat source. The system of concentrated and diluted salt solution stores driving energy for this process very efficiently. The salt solution can be used as energy storage and transport medium. In winter the heat exchangers installed in the absorber and evaporative coolers can act as a heat recovery system. The open cycle liquid desiccant cooling system (L-DCS) was developed under participation of ZAE Bayern in a BMWi-funded project [4].

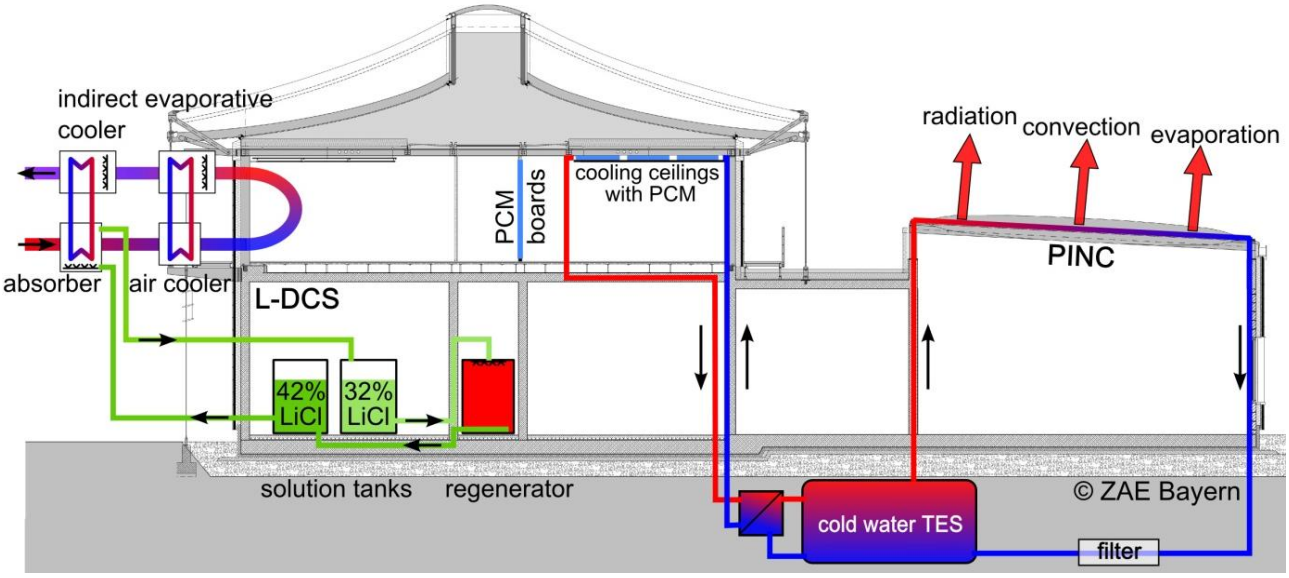


Figure 3: Overview of the implemented innovative TES systems and their interaction. The L-DCS dehumidifies and cools or preheats outside air for additional room temperature regulation. During this process the salt solution dilutes and has to be regenerated.

3.3 PCM in wallboards and cooling ceilings

During the last 15 years, ZAE Bayern has collected extensive experience in the field of Phase change materials (PCM) in buildings in several public funded projects (e.g. [5], [6]). PCM undergo a reversible phase change between the solid and the liquid state in a material specific temperature range. By the phase change PCM are able to store a large amount of heat in a narrow temperature range as all absorbed heat is required to break up the bonds of the crystal lattice. As this happens at a constant temperature level the process is called latent heat storage (*Figure 4*). Therefore the implementation of room-integrated PCM has a temperature stabilization effect and allows the buffering of temperature peaks without the need of energy consuming conventional cooling systems. If the (encapsulated) PCM is completely in its liquid state heat can only be stored as sensible heat and no temperature stabilization effect takes place. Hence, the PCM is regenerated at night to restore its high heat storage capacity. Since the stored heat is again released during the solidification process of the PCM, ways to remove this excess heat from the building has to be considered.

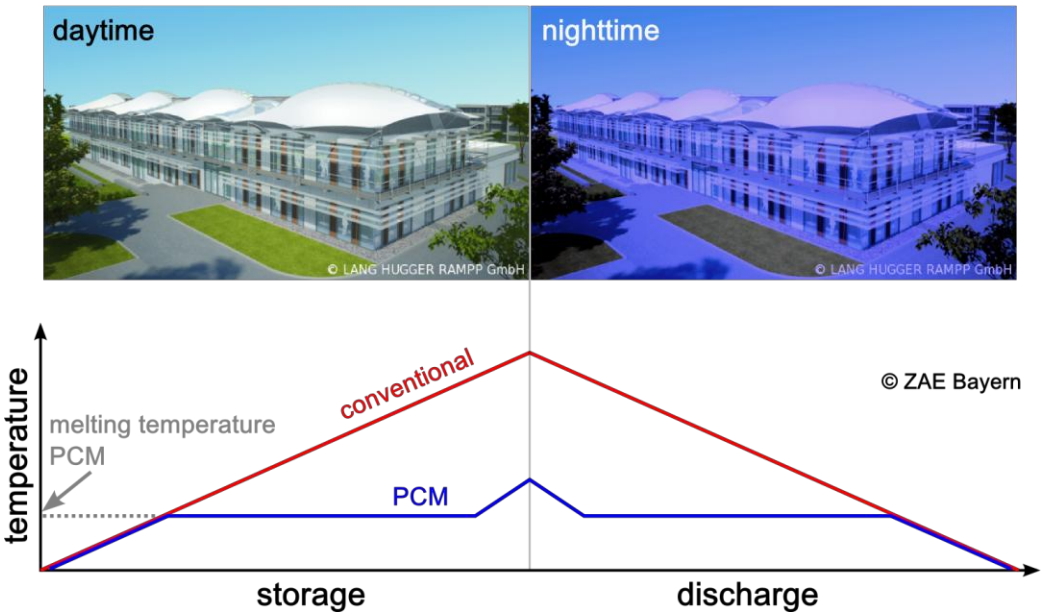


Figure 4: Conventional (sensible) and latent heat storage.

In the EEC, phase change materials melting around 23°C will be incorporated in building wallboards as well as in the cooling ceilings. Experiences show that especially PCM in building materials like wallboards are reacting quite slow to temperature fluctuations of the room air due to low heat transfer coefficients to the room air in the case of free convection. This is problematic during the charging process (passive cooling in daytime) as well as for regeneration of the PCM. In the EEC, natural ventilation will take place during nighttime. If needed, a ventilation system can provide forced convection to overcome the problem of low heat transfer coefficients leading to an acceleration of the charging and discharging process.
The cooling ceilings are individually optimized to reduce the thermal resistances between the PCM and the room air as well as between the PCM and the water cooling circuit. If needed, the stored heat will be removed during nighttime via a cooling water circuit connected to the firefighting water tank which is in turn connected to the PINC system. With the PCM in the ceilings and wallboards and in combination with the supply air of the L-DCS as well as an effective shading regulation no active cooling is needed most of the year. Further optimization of the system is planned during the construction and the operational phase in order to make this application ready for the market.

4. Cooling concept – Integration of TES technologies on EEC

One of the most interesting aspects of the building cooling concept is the integration of both passive and active thermal energy storage systems (see *Figure 3*).

The cold water from PINC is used for the cooling units in the laboratories as well as for the regeneration of the implemented PCM cooling ceilings in the offices. Space cooling in the entrance area, info center and conference rooms is achieved by cold water that is supplied to the heating / cooling floors. Additionally, the equipment in the laboratories is cooled directly by a separate cold water circuit, which is likewise connected to the cold water PINC storage. When the outside air is too cold or too hot for natural ventilation of the building, tempered air is supplied by the Liquid-Desiccant Cooling System (L-DCS).

In daytime, office-cooling at large extend is realized by the PCM incorporated in building materials and the PCM cooling ceilings in passive mode. If the outside air temperature is above 22°C the open cycle L-DCS can support the cooling via cold air supply. Since the PCM melts while absorbing heat, it is of great importance to ensure its regeneration overnight and hence ensure high system efficiency the following day. Specifically, the re-cooling of the PCM at night is required to take full advantage of its latent heat storage capacity. The PCM in the wallboards is regenerated either by natural night ventilation or by forced convection using the ventilation system to enhance

the heat transfer coefficient. The regeneration of the PCM applied to the cooling ceilings can be passively achieved by natural night ventilation or actively by incorporating cold water from the cold water TES. To guarantee the regeneration of the PCM (freezing at about 21°C) overnight, cold water with a temperature between 16°C and 18°C is required to ensure the needed cooling power. This was validated exemplary with a thermal building simulation (ESP-r [7]) for the south-west oriented office (see *Figure 5*) using the test reference year weather data set for Würzburg, Germany, with extreme summer conditions (TRY-Region 13 [8]). The simulation period extends from day 172 to 177 of the year, corresponding to June 21 to June 26. A 14 day forerun was used to initialize the thermal starting condition of the room. In the simulation the room was equipped with 180 kg PCM on a surface of 12.4 m² mounted on the cooling ceiling with an active area of 21 m². The simulated PCM has an assigned specific heat capacity of 72 kJ/kgK in the melting range between 22°C and 24°C. For regeneration of the PCM active cooling with 18°C forerun temperature is applied to the ceiling between 9 pm to 6 am with a volume flow of 316 dm³/h (only weekdays). As it can be seen in *Figure 5* the PCM can be completely regenerated with this cooling strategy. The needed forerun temperatures can be delivered by cold stored in the cold water storage connected to the PINC system and no conventionally generated cooling power is needed most of the time.

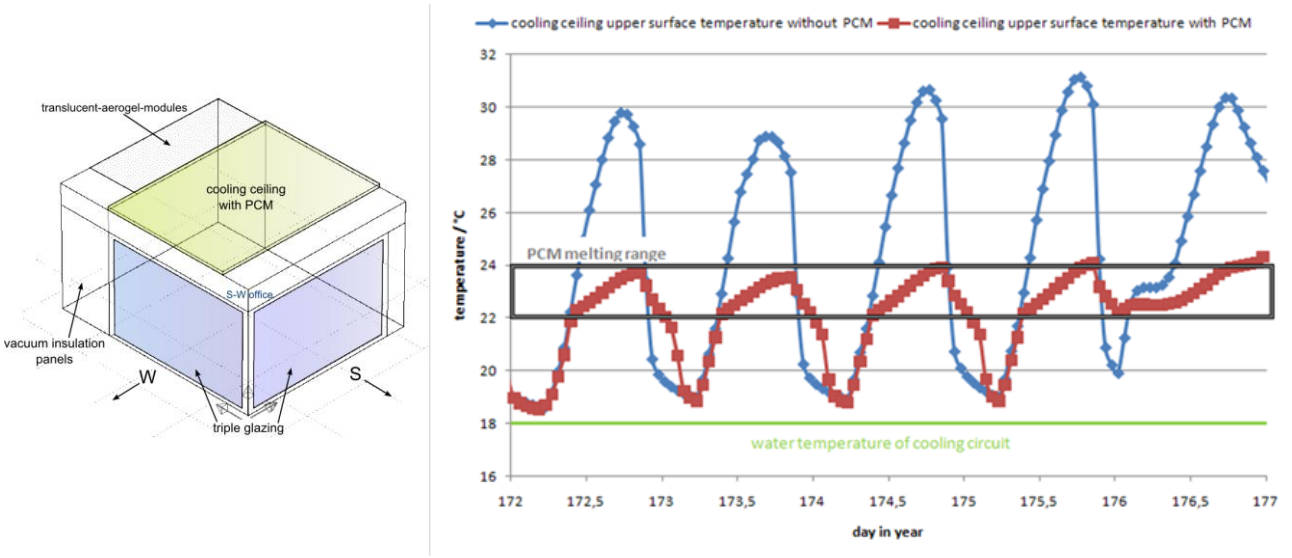


Figure 5: Simulation model used in the ESP-r simulations and temperatures of the upper side of the cooling ceiling without PCM (blue line) and with PCM (red line). The red line corresponds to the PCM-temperature.

The activation of the cooling ceiling may also enhance the regeneration of the PCM-wallboards and therefore leads to a better system performance.
Hence, it is evident that the interrelation of the PCM and PINC systems is important for the overall performance of the cooling concept. The principal aim is to use passive means in order to cover a large fraction of the building cooling loads and consequently use the active L-DCS system when the passive TES systems are not sufficient. During long periods of hot weather the cooling ceilings can also be activated in daytime to meet the comfort requirements. However, to minimize the need of active cooling, the building automation system uses a local weather forecast for a predictive room tempering and a demand-based PCM regeneration by controlling the shading, the night ventilation and the active PCM regeneration.
As there is a differentiation in the energy demand of the various building areas depending on the use of the respective space and the number of occupants, it is important for example to achieve different cooling scenarios for laboratories and offices or conference rooms; constant boundary conditions should be achieved in some laboratories given that constant cooling is often required for some measurement setups connected to the cooling circuit while in offices and seminar rooms there are more fluctuating cooling loads. Therefore, in order to adapt to individual demands and needs, every room has its own intelligent controller to achieve optimal results. Furthermore, energy

inefficient operations such as cooling at a sunny day with open blinds are displayed to the user in the control device and can simply be adjusted on demand by pressing just one button. This generates a user awareness of an energy efficient behavior promoting a positive effect on the overall building performance.
In addition to this building management system, a so called “high level controller” will be available for research purposes. The high level controller interacts with the building management system and allows fast and flexible implementation of control solutions by using the high-performance programming language of Matlab®. Based on a short time weather forecast the “high level controller” decides on the thermal energy storage strategy ("load" or "unload"). The “high level controller" predicts and regulates in real time the optimal control of all thermal storage elements of the building:

- Accessible thermal mass of the building (e.g. by blinds control or passive night ventilation),
- Charge condition of the PCM ceilings,
- Controlling of the Passive Infrared Night Cooling (PINC),
- (Thermal) charge condition of the two cold water TES,
- Charge condition of the solar collector hot water tank.

5. Monitoring

Many developments of the ZAE Bayern in the building sector are demonstrated in buildings, which are distributed over the entire Federal territory. Therefore it is a concern of the ZAE Bayern to bundle several of these newly developed technologies in the EEC and to demonstrate their performance, effective interaction and generated synergy effects in an integral building concept. Since the ZAE Bayern is involved in the development of these technologies, it is an opportunity for optimization und further development of the various innovative systems applied in the building.

Already in the planning and construction phase of the EEC, the monitoring concept as well as the necessary hardware was determined together with the involved project planners in order to create the prerequisite of the intensive monitoring of the building. The second phase of the monitoring concept includes the intensive monitoring of the building where a number of tasks will be fulfilled. Initially, the building energy consumption will be recorded in order to determine the energy consumption characteristics, including the differentiation in various energy consumption data such as auxiliary power for pumps, air support and light. Furthermore, a detailed analysis of all the technical equipment and especially the innovative systems will be performed in order to optimize their operation. After the 2-year intensive monitoring and detailed analysis on energy consumption and user satisfaction, as well as further monitoring on the function and performance of the various systems, the long-term monitoring of the building is being processed. The long-term monitoring lasts at least 3 years and has three objectives; the analysis of the building operation over an extended period, the assurance of a continuous data collection and its delivery to the central database and the possibility of a continuous operation, monitoring and optimization of the various systems.

A significant advantage of the local monitoring and evaluation process is the possibility to directly influence the regulation and performance of single components in a short term. Single components can be removed, modified or changed and then remounted by the scientists. Thereby, an ongoing research and development of the innovative systems can be carried out very efficiently. Also, for selection of the innovative components, neither compromises nor suboptimal solutions have to be taken into account.

6. Discussion / Conclusion

For the first time, the thermal energy storage systems “PCM”, “PINC” and “L-DCS” are combined in one building in order to improve energy efficiency and to use and analyze synergy effects. In cooperation with the building automation system the thermal energy storage systems have an enormous potential to make the use of thermal energy equipment more effective. Subsequently, large scale energy substitutions are reachable which is important from an economic as well as sustainability perspective. Many types of energy storage play an important role in energy

conservation. Thermal storage in a building may be decisive for the reduction of cooling loads and temperature increases, but also the achievement of indoor thermal comfort requirements. In the Energy Efficiency Center the positive effects of energy storage technologies will be proved, the systems and the interaction among themselves will be optimized and verified through a long term monitoring. Therefore this project creates a high attention and has the potential to accelerate the innovation processes in the field of energy optimized buildings.

7. Acknowledgements

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More information is available at http://www.energy-efficiency-center.de/en/Home/.

8. References

[1] *www.energy-efficiency-center.com*
[2] KLINKER F., WEINLAEDER H., MEHLING H., WEISMANN S., ,BUETTNER D., EBERT H-P., LAVEMANN E., EBERT T., JENSCH W. "*Heating and cooling using a combination of several TES technologies in the new R&D building of the ZAE Bayern in Würzburg"* The 12th International Conference on Energy Storage, Innostock 2012
[3] BUETTNER D., HARHAUSEN G., WEINLAEDER H. "*Metal Solar Roof Collectors for Passive Cooling"*, Eurosun 2006
[4] HAUER A. "Raumklimatisierung und Kältespeicherung mit offenen Sorptionssystemen", final report BMWi project (FkZ 0329662C), TIB/UB Hannover, http://edok01.tib.uni-hannover.de/edoks/e01fb07/524751838.pdf
[5] MEHLING H. *"Leitprojekt Innovative PCM-Technologie"*, report BMWA project (FkZ 0327303), TIB/UB Hannover, http://edok01.tib.uni-hannover.de/edoks/e01fb05/503471658.pdf
[6] WEINLÄDER H. *"Entwicklung und praxisnaher Test der Performance von Gebäudekomponenten mit PCM in Demonstrationsobjekten"*, final report BMWi project (FkZ 0327370U), TIB/UB Hannover, http://edok01.tib.uni-hannover.de/edoks/e01fb12/727481797.pdf
[7] HAND J. W., "*THE ESP-r COOKBOOK, Strategies for Deploying Virtual Representations of Built Environment*", Energy Systems Research Unit, Department of Mechanical Engeneering, University of Strathclyde, Glasgow, UK, 2011
[8] CHRISTOFFER J., DEUTSCHLÄNDER T., WEBS M., „*Testreferenzjahre von Deutschland für mittlere und extreme Witterungsverhältnisse TRY*", Selbstverlag Deutscher Wetterdienst, Offenbach, 2004

Refurbishment of a Viennese residential estate to future building standards with a prefabricated façade system and integrated PV



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Short Summary

The recast of the European directive on energy performance of buildings in May 2010 (EPBD, 2010) tightened and added some requirements for new and existing buildings. All member states have to implement national plans to enforce the amount of nearly zero-energy buildings (NZEB) and till 2020 all new buildings have to fulfil this standard [1]. Because of long renovation cycle even existing buildings shall be transformed into nearly zero energy buildings, if major renovation measures are applied.

In the project “B02 enVELOP C - Multifunctional Cover in Refurbishment of Facades and Buildings” a prefabricated renovation system with passive and active modules shall be developed and demonstrated on existing buildings constructed in 1970. Based on an existing passive cardboard insulation system with timber framing, additional active modules with integrated photovoltaic shall be implemented. The photovoltaic cells are integrated into the glass cover of the ventilated façade. A special experimental set-up, developed at the University of Applied Sciences Technikum Wien, should investigate the impact on the natural convective air flow as well as the effect on the insulation properties of the panel.

Keywords: passive house; refurbishment; prefabricated building elements; building integrated renewable energy systems

1. Introduction

The refurbishment of the existing building stock offers high potential for energy savings and contributes a big part to reach the defined climate and energy policy goals for 2020. In Austria the current rate for thermal refurbishment is around 1% [2]. The ambitious goal of the Austrian Climate Strategy of 5% is far away in the medium term [3]. The reasons are quite diverse and relate financial issues, technical requirements, legal regulations and much more.

According to article 9 of the EPBD every member state shall propose measures to increase the number of buildings and encourage best practice transformation of existing buildings into nearly zero-energy buildings [1]. The Austrian implementation of the EPBD is defined in the OIB- Richtlinie 6 [4] supplemented by several standards. The nearly zero-energy building is defined in ÖN-8110-1 depending on the surface to volume ratio. Figure 1 illustrates the current building code and the suggestion of the national plan for 2020, separated for new buildings and retrofit [5]. The horizontal axis is assigned to the surface to volume ratio and the vertical axis to the space heating

demand. As large-volume buildings have a low S/V ratio they are found on the left hand side of figure 1 and single family houses with a high S/V ratio are on the right hand side. Also the standards for low energy house, nearly zero-energy building and passive house are highlighted.

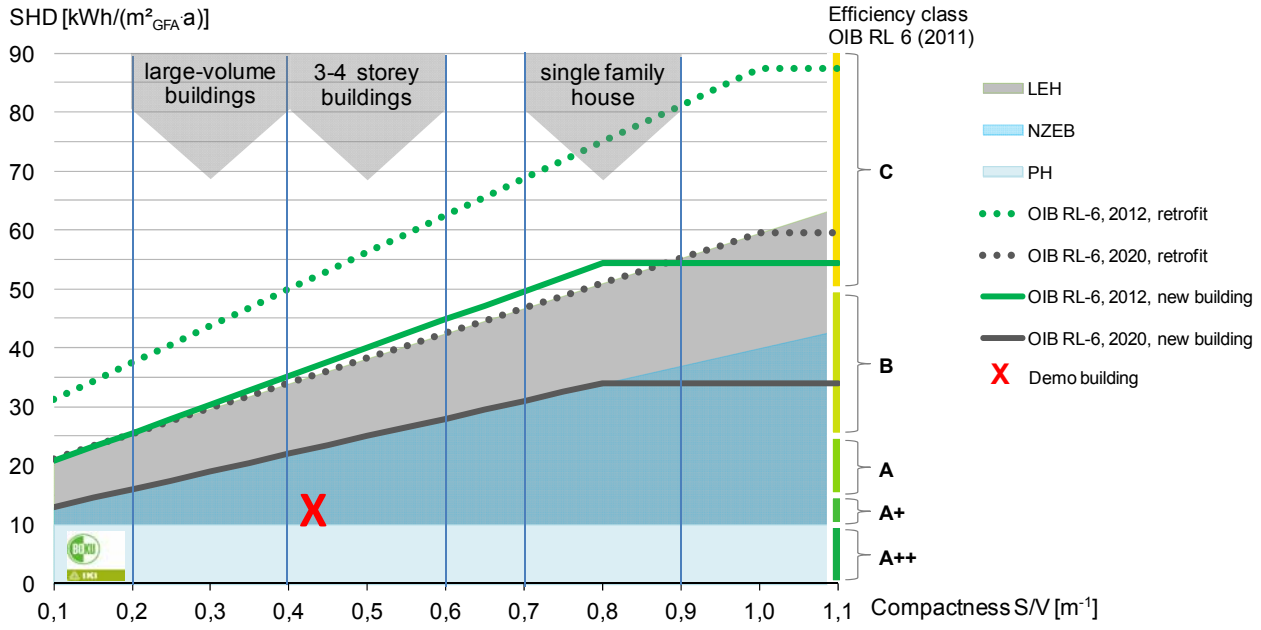


Fig 1: Austrian implementation of the EPBD and national plan till 2020 (SHD: space heating demand, LEH: low energy house, NZEB: nearly zero energy building, PH: passive house) [source: own diagram]

The selected building to be refurbished is a four storey building with a S/V ratio of 0,43 as marked with a red cross in figure 1. The building was constructed in 1970 and has 33 dwelling units for social housing as well as 2 business premises. Because of the hillside situation the basement is separated in dwellings and business premises in the southern half and cellar compartments in the northern half. The current space heating demand (SHD) is about 110 kWh/m^2_{GFA} and shall be reduced to 13 kWh/m^2_{GFA}. All dwellings are inhabited and the refurbishment measures are undertaken during complete inhabitation. To reduce the strain for tenants no floor plan modifications within the dwellings are done. The intervention is basically limited to replace windows and install a decentralised ventilation system. Following constructional measures shall be done:

- **Basement and cellar ceiling:** The southern part of the basement with dwellings and business premises cannot be insulated at the floor slab, as they are inhabited. In the northern part with the cellar compartments the cellar ceiling will be insulated with 8 cm insulation panel as the ceiling height is very low.
- **Exterior walls:** The exterior walls on the south side should be insulated with a novel developed façade system (see chapter 2). The prefabricated façade is based on an existing passive cardboard insulation system with timber framing. In addition active modules with integrated photovoltaic cells shall be implemented. Furthermore the decentralised ventilation system is integrated in the prefabricated panels. On the remaining exterior walls a thermal insulation composite system with 24 cm of EPS F Plus shall be applied.

  The balconies and loggias shall be glazed. Because of their arrangement it is not possible to separate them thermally. The glazing improves their usability as the noise pollution of the street in front is quite high.
- **Top floor ceiling and roof:** The top floor ceiling shall be insulated with 40 cm of insulation and the existing roof cover will be novated. The attic will not be extended.

- **Windows:** All windows will be replaced with triple glazed wood-aluminium windows. The U-value of the new passive house windows is U_w = 0,80 W/(m²K). The windows on the south side will be implemented with integrated sun blinds to protect against overheating in summer season.
- **Thermal bridges:** To reduce thermal bridges the insulation of the exterior walls will be applied below the ground in the area of the unheated cellar. The connection between attic, roof and wall is considered in detail. The window frames will be overlapped with insulation.

2. Façade system

Usual refurbishment actions are based on thermal insulation composite systems on the façade. Beside the southern part a thermal insulation composite system will be applied on the walls of this demonstration building also, because of financial issues. On the southern wall the prefabricated façade described in this chapter will be applied. The system is based on a cardboard insulation panel with timber framing and is distributed by GAP-Solution GmbH. Figure 2 shows the schematic of the panel. The cardboard panel is 29 mm thick and protected by a float glass pane against rain, vermin and other environmental exposures. The special comb structure absorbs solar radiation and heats on the inner wall side. The heat process is dependent on the angle of solar radiation. In winter, when the angle is low, the sunlight gets deep into the comb and heats the underlying wall. The resulting warm zone in the wall reduces the transmission heat loses near zero. In summer, when the angel is high, the sunlight doesn't get into to comb and the heat effect is marginal. The radiation is partly reflected and the combs shade each other. Further information on the cardboard comb panel is found in the technical description, see [6].

Within the project "B02 enVELOP" the gap-solutions system was further developed [7]. In the float glass pane photovoltaic cells were integrated partly. Figure 3 illustrates the integrated PV cells on the first prototype. Because of the dynamic characteristics of the cardboard comb panel the effects of the photovoltaic cells on the thermal behaviour and the rear ventilation of the panel have to be investigated in detail.

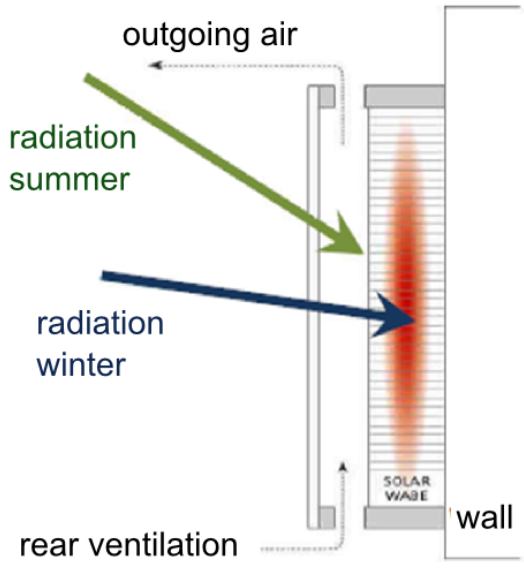


Fig 2: Schematic and function of the gap-solution insulation panel, [6]

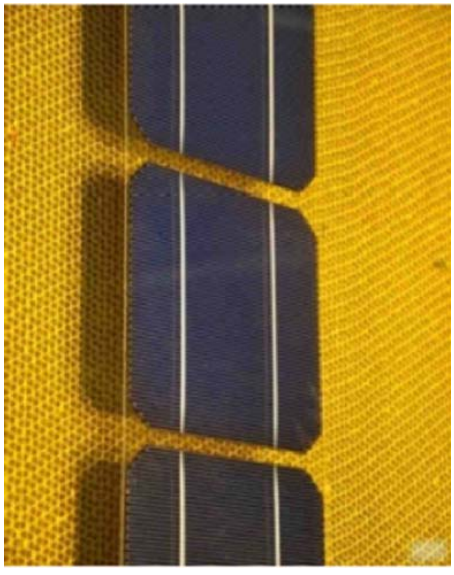


Fig 3: Further development with integrated photovoltaic cells into the glass cover, [8]

3. Experimental set-up

The integrated PV cells provide shading on the façade panel partly. Hence the natural convection flow of the rear ventilation is affected. In addition the solar radiation input is reduced and the warming effect in the combs is influenced.

The goal of the experimental investigations was to identify an appropriate layout for the photovoltaic cells to minimize the effect on the functionality of the façade panel. Furthermore the soiling of the inner glass surface should be assessed as the deposit of aerosols and dust is mainly depending on the convection flow.

The investigations of the effects of PV cell integration were carried out in the laboratories of the University of Applied Sciences Technikum Wien. For this purpose a special experimental set-up was developed. The set-up is based on test facilities of thermal heat panes and was extended for specific measurements.

3.1 Object of investigation

The standard production size of the cardboard comb panel is 1,0 x 1,5 m. The outside dimension of the experimental element was 1,0 x 1,0 m resulting in an aperture area of 0,93 m². The lateral faces were made of acrylic glass to get a visual view inside the rear ventilation layer. The experimental panel was assembled according the actual situation on building sites including cover strips. The underlying wall mounting with insulation and existing wall was not considered.

3.2 Test station

The test station was arranged indoor in the laboratories of Technikum Wien. An artificial light source consisting of six metal halide lamps, each 1.000 W connection power, was used to irradiate the façade panel. A cross-flow radiator fan was used to simulate exterior wind conditions on the glass surface. Below the test panel a reservoir with aerosol-mist was mounted, which could be filled without any pressure. With the reservoir it was possible to visualise the convection flow throughout the entire width of the panel. The panel was equipped with several sensors and measurement devices:

- **Inlet and outlet temperature:** For the measurement commercial PT100 sensing devices were used and calibrated according to DIN EN 60751 [9]. Inlet and outlet temperature were measured with two structurally identical sensing devices each. The results were averaged for interpretation.
- **Temperature in the rear ventilation layer:** The distribution of the temperature in the rear ventilation layer was taken point wise on eleven measurement points. The sensing devices were TESTO thermal flow velocity probes (robust hot bulb). The measured values were logged with the measuring instrument TESTO 480.
- **Velocity of the convection flow:** Similarly the velocity of the convection flow was taken point wise at the same measurement points with TESTO thermal flow velocity probes.
- **Temperature of the outside glass surface:** The temperature on the surface of the glass was taken on the same measurement points and logged with TESTO 435.
- **Thermal flow:** The thermal flow through the panel was measured with two heat flow plates of the company Alhorn and logged with the software LabView.

3.3 General requirements

In Vienna the solar radiation on a vertical and south oriented façade is 811 W/m² at maximum. For the experimental investigations a middling radiation of 508 W/m² was chosen. To align the light sources of the sun simulator to a homogenous distribution of the radiation was a difficult task. Across the entire aperture area the radiation field differed about 13 % and across the defined measurement area about 9%. Figure 4 shows the distribution of the solar radiation on the aperture area of the façade panel. The distribution of solar radiation intensity is according manufacturer certifications similar to the standard spectrum Global AM 1.5 defined in ISO 9845 [10].

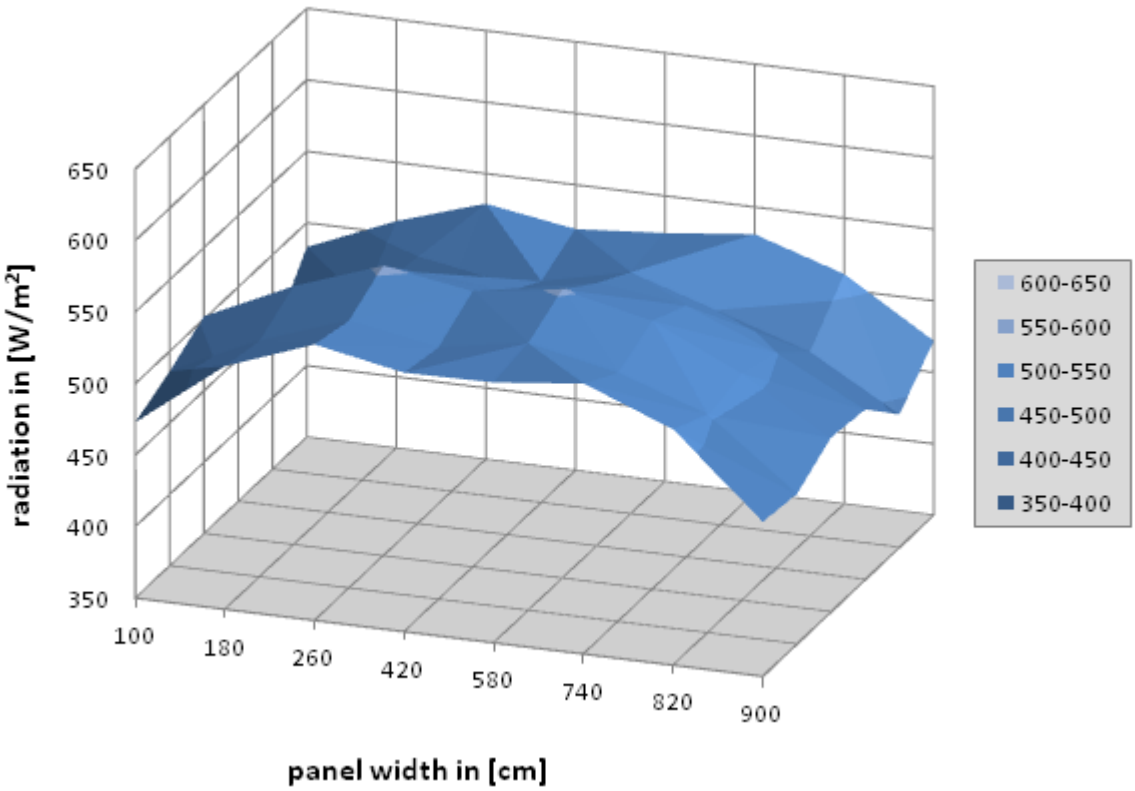


Fig 4: Distribution of the solar radiation on the aperture area of the façade panel, [8]

4. Experimental procedure and results

The main goal was to identify an appropriate layout for the integrated PV cells. Consequently the standard panel has to be investigated at first to define a reference for comparison. The photo-voltaic cells are commercial mono crystalline cells with a dimension of 15 x 15 cm and an electric output of 4,08 W_{PEAK}. For the experimental set-up the integrated PV cells were not connected to each other and have been in a no-load condition. Thus no electrical energy was produced. Four different PV cell layouts were investigated:

- **PV variant 1:** Two columns of vertical aligned PV cells in the middle width of the panel. Each column consisted of six PV cells.
- **PV variant 2:** Two columns of vertical aligned PV cells in the middle width of the panel with a spacing of 20 cm in between. Each column consisted of six PV cells.
- **PV variant 3:** Two rows of horizontal aligned PV cells in the middle height of the panel with a spacing of 20 cm in between. Each row consisted of six PV cells.
- **PV variant 4:** Three rows of horizontal aligned PV cells in the middle height of the panel. Each row consisted of six PV cells.

To generate valid comparisons all measurements were taken in steady state condition, which was achieved after a warm-up period of around 3 hours. The steady state condition was defined by two parameters:

1. the alteration of inlet and outlet temperature was below ± 0,5 °K and
2. the alteration of the thermal flow was below ± 2 W/m².

Each variant was surveyed three times.

4.1 Results on temperatures

In the steady state condition the average inlet temperature was about 24,6 °C for the reference panel. With a middling radiation of 508 W/m² the average outlet temperature was about 44,6 °C. Thus the air was warmed by 20 °K in the panel. The thermal flow through the reference panel is about 96 W/m². In figure 5 the measurement results for the temperature in the rear ventilation layer of the façade panel are illustrated for the reference panel and selected variants with different PV cell layout. PV variant 1 represents the vertical alignment as the results of PV variant 2 are quite similar. PV variant 3 represents the horizontal alignment as the results of PV variant 4 are quite similar. In both variants 1 + 3 the aperture area was shaded by about 30 % and the air was warmed by 17 °K in average. The thermal flow through the panel was reduced across the panel by about 16 % and directly behind the opaque PV cell by about 50 %.

The graphs in figure 5 show an unsymmetrical pattern and a small bias of about 0,5 to 1 °K. A reason for this bias is the laterally arranged cross-flow radiator fan. In addition an outdoor measurement with the same experimental set-up was conducted and resulted in a small bias also, because of outdoor wind conditions.

A first conclusion could be drawn on the measurements about the temperatures: A vertical alignment of the PV cells has a bigger effect as a horizontal alignment. The resulting temperature pattern of PV variant 3 is similar to the reference variant, but the shading of the PV cells causes lower temperatures. The temperature pattern of PV variant 1 differs a lot compared to the reference panel and leads to a very inhomogeneous temperature profile over the panel width.

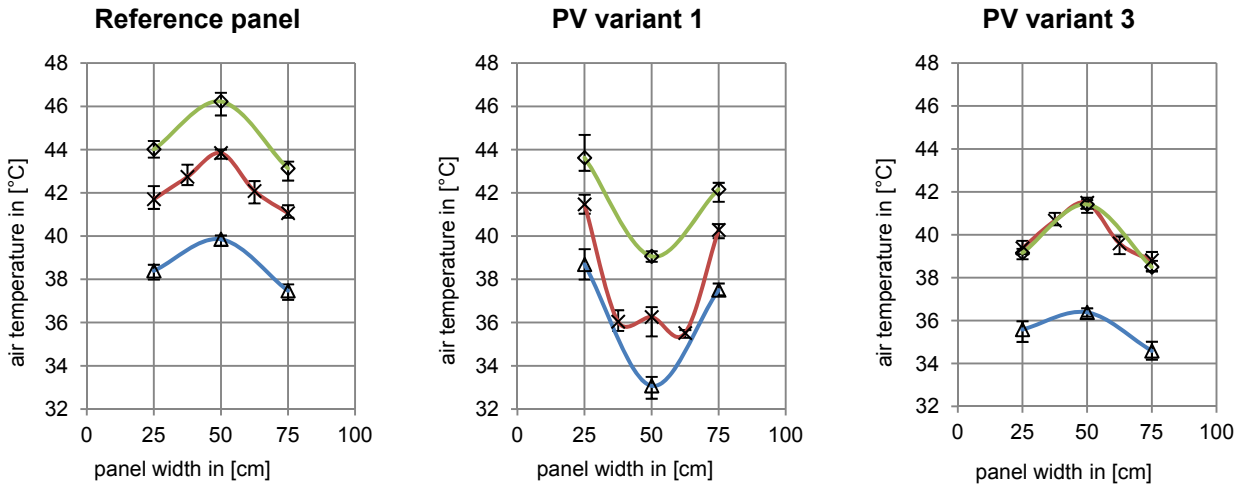


Fig 5: Measurement results for the temperature in the rear ventilation layer of the façade panel for the reference panel and selected variants with different PV cell layout, [8]

4.2 Results on convection flow velocity

The measurement results on the convection flow velocity show similar patterns as the temperatures. The average convection flow velocity of the reference panel is about 0,16 m/s and the emerging volumetric flow is 16,6 m³/h. The highest convection flow was measured in the middle of the panel. Also the small bias and unsymmetrical profile could be explained by the influence of the laterally arranged cross-flow radiator fan.

In PV variant 1 the convection flow behind the vertical aligned PV cells breaks down significantly and leads to a very inhomogeneous profile across the panel width. The average convection flow velocity of PV variant 1 is about 0,13 m/s and the emerging volumetric flow is 13 m³/h. PV variant 3 shows lower alterations and the average convection flow velocity is about 10 % lower compared to the reference panel.

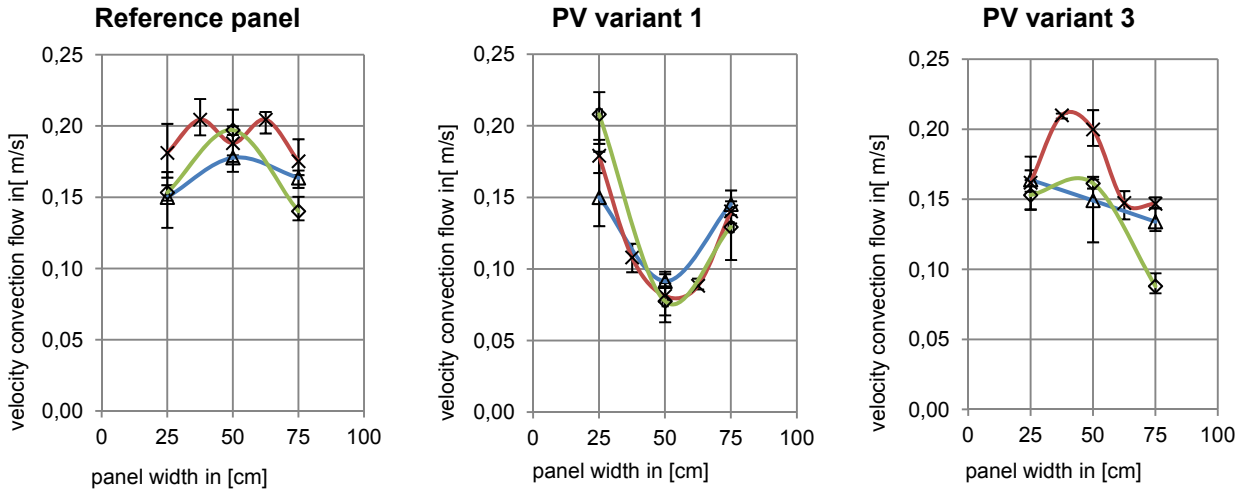


Fig 6: Measurement results for the convection flow velocity in the rear ventilation layer of the façade panel for the reference panel and selected variants with different PV cell layout, [8]

5. Conclusions and outlook

The outdoor measurements under exterior conditions (natural radiation, wind, temperature, etc.) confirm the experimental set-up. The integration of PV cells into the glass cover influences the temperature profile and natural convection flow in the rear ventilation layer to some extend. The lowest influence was observed in PV variant 3. Based on the experimental results the PV cell layout on the façade of the demonstration object should be aligned in horizontal patterns and the density should not exceed one third of the aperture area.

It seems feasibly to recommend an additional investigation and apply semi-transparent PV cells. Thus the shading is lower and the effects on temperature, natural convection and thermal flow through the panel could be reduced further.

For the demonstration object a dynamic building simulation will be carried out. Hereby the focus is on thermal comfort in summer time. The adaption possibilities to climate change issues should be analysed using the climate scenarios and the weather data set of the summer season 2003. The results of the measurements are used to fine tune the previous CFD (Computational Fluid Dynamic) simulation and support the development of a TRNSYS type for building simulation.

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7. References

[1] THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION. *"Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)"*. Brussels, 2010. L153.

[2] AMANN W. *"Quantitative und qualitative Performance der Wohnbauförderung "*. Institut für Immobilien, Bauen und Wohnen GmbH. 2012.

[3] AUSTRIAN FEDERAL MINISTRY OF AGRICULTURE AND FORESTRY, ENVIRONMENT AND WATER. *"Anpassung der Klimastrategie Österreichs zur Erreichung des Kyoto-Ziels 2008-2013"*. Vienna, 2007.

[4] AUSTRIAN INSTITUTE OF CONSTRUCTION ENGINEERING. *"OIB- Richtlinie 6 – Energieeinsparung und Wärmeschutz"*. 2011. OIB-330.6-094/11.

[5] AUSTRIAN INSTITUTE OF CONSTRUCTION ENGINEERING. *"OIB- Dokument zur Definition des Niedrigstenergiegebäudes und zur Festlegung von Zwischenzielen in einem „Nationalen Plan" gemäß Artikel 9 (3) zu 2010/31/EU - Entwurf: 29. August 2012"*. 2012. OIB-330.6-055/12.

[6] GAP SOLUTION. „Gap Fassaden – Technische Unterlagen". Linz, 2012.

[7] ALPS GmbH: *"B02 eNVELOP C - Project Information"*. http://www.alp-s.at/cms/en/climate-change-adaptation/projekte-bio/b02-envelop-c/. accessed 05/08/2013.

[8] KALTENECKER P, STERRER R. "Projekt B02 enVELOP Teil C – Experimentelle Untersuchung der Funktionalität eines solarkativen Fassadenpaneels". University of Applied Sciences Technikum Wien, Department of Renewable Energy. Vienna, 2013

[9] DIN EN 60751:2009-05. *"Industrielle Platin-Widerstandsthermometer und Platin-Temperatursensoren"*. 2009.

[10] ISO 9845-1:1992-10. *„Solarenergie; Referenzwerte für spektrale, solare Bestrahlungsstärke am Boden bei unterschiedlichen Empfangsbedingungen; Teil 1: Direkte Sonnenstrahlung auf normale Empfangsebene und hemisphärische Sonnenstrahlung für Luftmassen 1,5"*. 1992.

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Short Summary

More than 50% of the world's population today lives in cities with more than 1 million inhabitants - and the trend is increasing. 40% of today's energy, CO2 and resource consumption and 40% of waste production are accounted by the global construction industry. In the past, urban architecture has been based predominantly on conventionally produced prototypes with long, complex and resource-intensive construction work. A situation which the Cree GmbH, a subsidiary of the Austrian Rhomberg Group, intends to change with a hybrid construction system for multi-story buildings with up to 100 m height and 30 stories. The project is based predominantly on a renewable raw material - wood.

The goal of the project LifeCycle Tower was to develop a flexible, prefabricated, construction system as a new, independent product, which meets all technical and economical requirements of modern real estate markets. Additional emphasis was placed on the systematically improved resource- and energy efficiency. An integrated planning process was applied to the entire project. This means that representatives of all areas of knowledge (architecture, static, facility management, building technology, etc.) had worked jointly through the essential tasks in their entirety. Another central element was carrying out theoretical simulations, which were checked and confirmed with real trials (e. g. fire tests).

The result of the Project is a flexible “new to the world product”:
- for timber based multi-story buildings up to 100 m and 30 stories
- for multiple uses such as office, apartment and/or hotel
- with a positive energy balance
- with an unmatched ecological footprint
- which is prefabricated and independent from manufacturers or geographical locations

Now, the theoretical development became reality. A prototype, LCT ONE, with eight stories was built in Dornbirn, Austria.

Impact on business & ecological environment
- up to 90% improved CO2 - balance
- 50% improved resource efficiency
- Construction times cut by half
- Regional value added by local production possible
- Flexible usage and conversion of building

Keywords: Cree, life cycle tower, sustainability, hybrid timber, high-rise building, lct one, wood, resources, construction, large volume

1. Global challenge for the building industry

Processes of cultural, ecological and economic change observed around the world are leading to an altered frame of reference for and different demands on the building industry.

1.1 Urban growth

The urbanization of the world presents an enormous challenge to the future of mankind. Even today, 50% of the world's population lives in cities of more than a million inhabitants. Experts believe that this could rise to 75% within 30 years. Over the same period the world's population is expected to rise by 78 million people per year – roughly the population of Germany (United Nations 2008).

The countries that profit from an economic upswing strive to transform their cities into better places to live.

Buildings will have to reach greater heights to keep pace with the rising requirement for space. Accordingly the future activity of the global building industry will become concentrated in urban areas and on the construction of multi-story buildings.

1.2 Scarce resources

If present-day methods of using the world’s resources were maintained, then 2.5 planets would be required to satisfy the future demand for resources. For Europe in particular, where 90% of all raw materials have to be imported, guaranteeing the fulfilment of that need for resources will be an essential precondition for prosperity and social harmony.

Construction worldwide is responsible for around 40% of today's consumption of resources and energy as well as 40% of global CO_2 emissions (United Nations Environment Programme 2009). It is clear that efficient use of resources and energy, and a reduction in CO_2 emissions will be considerable factors in successfully addressing these issues. One of the consequences will be an increase in the statutory provisions and targets relating to energy and resource efficiency applicable in many countries.

1.3 Conventional construction

Up to now, urban development has been based mainly on conventionally built prototypes of complex construction. This entails high construction costs, long erection times and elevated design and construction risks.

Systematization and industrialization of the building production process, such as emerged decades ago in the automotive industry, has so far not been seen in the construction industry.

2. Integrated research – high-rise buildings in wood

The changing global construction scene was the trigger that spawned a research project over several years. An international interdisciplinary team of experts led by Cree GmbH has developed a new type of **wood-hybrid construction system for buildings up to 100 m high** (30 stories). The special feature of the research process was the integrated interplay of knowledge leaders from all the professions in the building industry, such as architecture, structural engineering, building physics, building services, process management, marketing etc.

Three main objectives were pursued:

2.1 Large-volume building

As a result of the global trend towards urbanisation, efforts were made to develop a solution for use in an urban context. The objective was the development of a multi-story building solution capable of reaching up to 30 stories or 100 m in height (Cree GmbH 2010).

2.2 Resource efficiency

The shortage of resources and the associated rising prices of raw materials turn the intelligent use of material goods into an enormous competitive advantage for the building industry. Therefore timber, a renewable and local resource, was chosen as the basis for the development of the new building system. Its reduced "ecological backpack" is only half that of conventional buildings (Manstein C & Reisinger H 2010). Most products we create from the resources of the earth contain far more material by virtue of their extraction, transport and processing than their self-weight alone would suggest. According to the renowned chemist and environmental researcher Prof. Friedrich Schmidt-Bleek all goods have an ecological backpack. To produce a kilogram of steel takes on average 8 kg of mineral ore and fossil fuels, a kilo of copper 348 kg, while a kilo of aluminium "actually" weighs 37 kg. Wood has an ecological rucksack of 1.2 kg. Moreover, wood as a material has the potential to improve the CO_2 balance by 90% (Braune A & Benter M 2010) and reduce the weight of the building by 50 % (Cree GmbH 2010).

2.3 System building

A further objective of the research was to develop a standardised universally usable modular system containing a significant proportion of building technical services (heating, cooling, ventilation,). The individual elements should, as in the automotive industry, be capable of being prefabricated in a factory and modular to the extent required by the client. The concept of serial off-site production was intended to ensure economies of scale, consistently high quality and rapid erection of the building on site.

The **first research project "8+"** investigated the technical feasibility of buildings in wood construction. The results showed that it was technically feasible (from a structural engineering point of view) to erect buildings 80 m or more in height. The research did not consider the commercial marketability or the likelihood of obtaining statutory construction approval of the final concept. It was therefore not possible to construct a building based on principles of the "8+" research project.

The **second "LifeCycle Tower" research project** extended the findings of the "8+" project and developed a new building system modified to suit the requirements of the modern real estate market. Industrial prefabrication and special consideration of fire safety in the design led to the new product becoming ready for the market.

From research project to built property: with the "**LCT ONE"** the developed concept was transformed into reality in the form of an eight-story demonstration building.

3. The LifeCycle Tower – innovative building system for urban, sustainable architecture

3.1 Architecture

The system can be divided into three main components: core, hybrid slab and façade columns.

3.1.1 Access core

For the LifeCycle Tower research project, a rectangular core was adopted as the basic structure to ensure that the nodes in the stiffening components would be as few and as simple as possible and compatibility maintained with every available facade system. The core is erected in two sections,

each 32 m high, in order to maximize stiffness and ductility while being economically competitive with conventional building systems. The reduction to two horizontal interfaces secures not only structural and economic benefits; it also permits a high degree of prefabrication and shortens the construction time. The central core for this project was selected primarily for its structural properties; however this arrangement also has disadvantages when it comes to efficient use of floor area, as incorporating the second escape route inevitably results in a less favourable rentable space ratio. In general, individual stories and their technical services can be accessed via one or several centralized or decentralized be used. The options are available depending on regional building regulations for tall access cores. The cores serve as the stiffening element of the building. While wood is the optimal choice as a material for the access cores, concrete and other non-combustible building materials can also buildings.

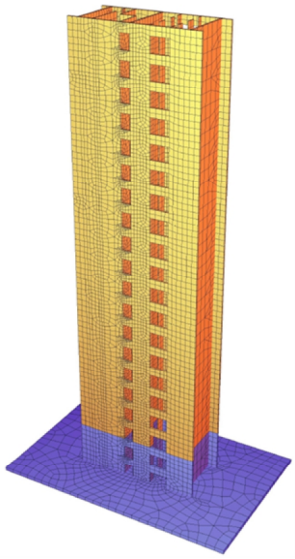


Fig.1: Core

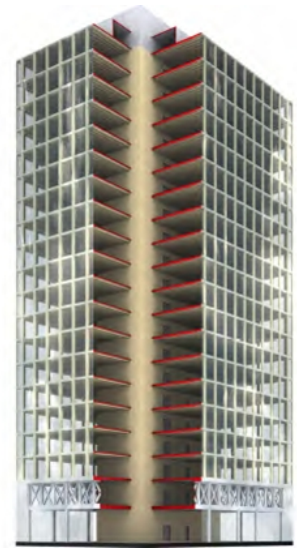


Fig. 2: Shell & Core

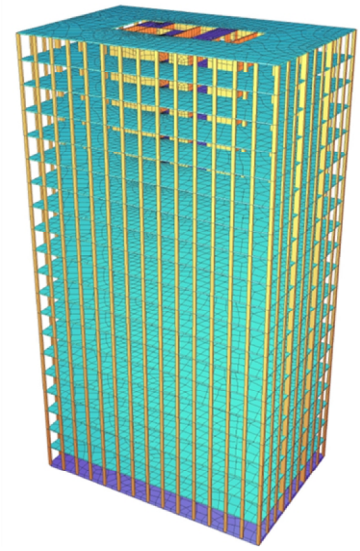


Fig.3: Shell & Core

3.1.2 Hybrid slab

A wood-concrete composite rib construction was chosen for the slab. This fulfils several functions: First, it enables the floor plan to be arranged freely thanks to its long span (<9.45 m) and secondly it guarantees the separation of the stories in the building from each other, as required by fire protection regulations. The space between the ribs allows the building services to be installed within the thickness of the slab. The system also increases the resistance to the spread of fire at the deck soffit. Suspended ceilings are not envisaged. The wood should be left visible for the room users to enjoy, as at the facade supports.



Fig.4: Hybrid slabs

3.1.3 Facade columns

Double columns, designed to provide the required fire resistance, transfer the facade forces directly to the slab, avoiding transverse compressive stresses, and then directly into the column pair

below. The pull out or lateral forces, between the double columns and the hybrid slabs, are prevented from separating by strong, but simple, mortise and tenon joints. Wooden frames link several pairs of columns into one unit that can be installed together with the façade. The combined installation of primary and secondary facade elements allows site work to progress more quickly compared with conventional systems as this is a completely dry method in which no curing times are involved.



Fig.5: Loadbearing system

3.2 Modular construction

Prefabricated construction elements with consistent, standard solutions reduce the need for one-off designs. Construction details have already been incorporated and the components only have to be put together on site. Subsequent work involving non-prefabricated components, such as separate fire protection cladding, is kept to a minimum. The elemental approach avoids the need to construct complex details on site, which is difficult to ensure is done properly in such environments.



Fig.6: Construction phases

3.3 Energy design

A clever, highly energy-efficient building services concept was developed for the LifeCycle Tower, which can be built to low-energy, passive house or plus-energy standard. The qualities of the respective location are utilized optimally for the building. Priority is given to the use of renewable energy sources in the energy planning of the building, sources such as geothermal energy, for example, that can be used for both heating and cooling the building. The distribution and delivery system is adjusted to the respective system temperatures. Combined heating-cooling ceiling elements have been developed for space heating and cooling.

The lighting, a comfort ventilation system as well as smoke detectors and sprinklers are all integrated between the ceiling elements. Other possible elements focusing on the use of regenerative energy include solar thermal systems for hot water, regenerative fuel plants where high water temperatures are required and photovoltaic systems integrated in the facade. Despite sun protection

measures, the demands on room temperatures in summer (comfort criteria and workplace guidelines) make the use of passive cooling ceilings to cool the building inevitable. However, the higher energy expense that this involves can be reduced by an intelligent control concept (exterior shading controls, automatic night cooling, occupancy sensors) and correct user behaviour.

3.4 Fire safety

Fire protection is an important aspect in obtaining approval to construct multi-story buildings. In the last 20 years, modern timber construction has experienced enormous growth both in terms of technology and in economic efficiency, which is also reflected in the continuous amendments to the statutory regulations. Significant differences within national and regional statutory regulations continue to mean that generally applicable statements about the likelihood of construction approval being granted for multi-story buildings cannot be made, all the more so because approval is very dependent on the proposed building use (hotel, office, residential).

A detailed analysis of the possibilities offered by timber construction and consideration of the risk of the spread of fire posed by the combustibility of wood led to the development of a certified fire protection concept. A number of large-scale fire tests have been carried out in Europe for the floor slab elements of the building system. These tests show the technology is able to withstand up to a two hour fire test. Based on the results of these tests, the components have been optimized leading to a reduction in the amount of concrete used, and the granting of the required REI 120 certificate.

4. Commercial considerations

Construction costs for a system-built LifeCycle Tower are fully comparable with those of a conventionally constructed building. A comparative analysis for the two building types found that the additional initial investment cost for the LifeCycle Tower was only 2%. The objective of the further research is to achieve cost leadership in the area of resource & energy-efficient large-volume buildings.

4.1 Industrial series production

Industrial prefabrication of standardized components will exploit the economic advantages of scale and learning curve effects. Factory quality assurance will also lead to minimisation of errors and consistently high quality of construction on site.

4.2 Supply chain management

Cree is not a manufacturer. The independence of contractors and subcontractors means that the best bids out of the local market suppliers can be accepted for production and erection. Capacity bottlenecks or overproduction can be evened out by flexible integration of the producing firms.

4.3 Life cycle-oriented design

The cost of erecting a building is responsible for only 20% of the total cost of the building over its entire life cycle. The concept of the LifeCycle Tower incorporated extensive considerations of cost-effective use, reuse and demolition of the building. One of the consequences of this is the absence of loadbearing partition walls in the structural frame, which allows room sizes to be freely varied in the future. A high energy standard ensures low operating costs and the wood can be used for energy generation following the cascading use principle at the end of the building's life cycle.

5. Implementation concept

5.1 Formation of Cree GmbH

A dedicated company with a present staff of 15 was set up in 2010 to further develop and market the findings of the research. The partners are Rhomberg Holding GmbH, Signa Holding and RIMO Privatstiftung. The development of the LifeCycle Tower and Cree has been met with acclaim and interest from all over the world, presented at international conferences and cited as a pioneering project in innovative timber construction by leading experts.

5.2 Proof of concept

5.2.1 Eight-story prototype LCT ONE

The design conclusions drawn from the research project were implemented in an eight-story (27 m) demonstration building built in Dornbirn, Austria. Based on this prototype, the advantages of the building concept (including resource and energy efficiency, up to 90% improved CO2 balance, 50% shorter construction time, series production) are reported on a public stage. The project serves as an exemplary model for modern sustainable building and point the way ahead for the future development of this sector of the construction industry.



Fig.7: LCT ONE outside

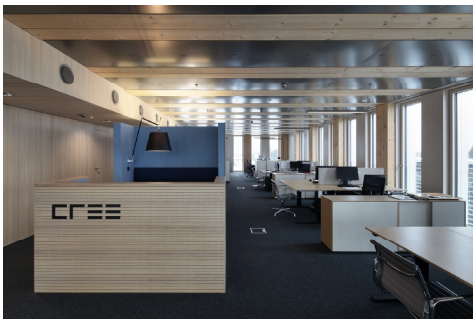


Fig.8: Cree office



Fig.9: LCT ONE at night

5.2.2 First customer project IZM (Illwerke Center Montafon)

The first commissioned project is a large building (120 m) with about 10.000 m² floor area being built in Vandans, Austria. The technical and economic advantages of the proposed LifeCycle Tower wood-hybrid building system were decisive in the commissioning. Verifiable compliance with the fire safety requirements and the ecological advantages of the system were further important factors in the acceptance of the tender by the client.



Fig.10: IZM building phase



Fig.11: IZM

5.3 International marketing

The building system in its finally developed form will be marketed internationally using LCT ONE and IZM as reference projects. Potential target markets will be analysed in parallel with the international positioning of the Cree brand.

5.4 Country-specific construction approval

The engineering feasibility of the tower based on its current stage of development can be confirmed. Construction approval of actual projects still has to be obtained from the competent authorities in each future location. A strategy of sequentially increasing the maximum permissible building height will be adopted to ensure future construction approval. Cumulative experience (construction approvals, fire safety concepts, certifications, testing,) grows with every completed project and serves as the basis of discussions for obtaining approval of the next higher building class.

6. Conclusions

The concept offers enormous opportunities – for the local timber construction industry as well as housing component manufacturers, contractors and suppliers. The uniqueness of using wood as a visible and sensual construction material for high-rise buildings will lead to new modern perception of nature's building material.

In terms of its export potential, the LifeCycle Tower provides an opportunity for local skills to develop international connections and to strengthen the economy and research locations. It allows small and medium enterprises (SMEs) to benefit, above all those which in isolation are considered not to possess the necessary prerequisites for strategic internationalisation. The implementation and international marketing of the developed modular system opens the way for SMEs to international know-how transfer and real export opportunities.

Wood as local renewable construction material will become increasingly important: it secures regional or national independence interms of raw material supplies and protects against high prices.The propagation of the LifeCycle Tower concept in regions in which timber is of high importance therefore strengthens their economies and independence.

7. References

[1] UNITED NATIONS, United Nations World Population Report, 2008.
[2] UNITED NATIONS ENVIRONMENT PROGRAMME, Sustainable buildings & Construction Initiative, 2009.
[3] CREE GMBH, LifeCycle Tower research project, 2010.
[4] MANSTEIN C, REISINGER H, BRIX research project – Rhomberg Bau GmbH, 2010.
[5] BRAUNE A, BENTER M, PE INTERNATIONAL study, Ergebnisse CO_2-Check LifeCycle Tower, 2010.

Concrete Repair Mortar Made of a Waste from Oil Refining Industry



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Short Summary

Awareness that the use of green building materials towards long-term sustainable development includes addressing environmental, performance and economic issues in an integrated way is promoting synergies in waste recycling between different industries. In this regard, the ultimate goal is to turn a polluting waste of one industry into a product with added-value for another industry. Within this scope, this paper addresses the reuse of an oil refining industry waste – the spent fluid catalytic cracking catalysts – in the concrete repair mortars composition.

Keywords: Oil-cracking catalyst; Concrete repair mortars; Waste recycling; Green building materials

1. Introduction

The market demand for concrete repair materials has grown considerably due to: (*i*) deterioration and distress of concrete structures as the age of existing infrastructures is increasing, (*ii*) the understanding that sustainable construction practices includes the ability to extend the structures longevity in order to both continue using embodied energy of construction materials and to reduce demolition wastes, and (*iii*) the need to fulfill mandatory regulations.

Moreover, since cement production is a natural resources, an energy as well as a carbon intensive process, repair practices - particularly using green products - reinforce the aforementioned environmental impact mitigation. In this regard, the production of cement based materials, including concrete repair mortars, with partial replacement of cement with other lower carbon material with cementitious properties has been recognized as a lever for greener products manufacture [1]. In addition, if the surrogate material is an industrial by-product – being recycled in the cement based materials composition – there is also a concomitant decrease in landfill disposal of wastes as well as an increase in profits by adding value to a waste.

In order to improve the yield of more valuable products obtained from crude oil, refineries use currently approximately 500000 metric tons/year of an aluminosilicate catalyst in their fluid catalytic cracking (FCC) units, of which 20% are used in European refineries [2]. When the catalysts no longer exhibit the required catalyst activity must be replaced becoming a waste (wFCC catalyst). Currently, most of the wFCC catalysts generate are disposal of in landfills the environmentally least preferred option.

Although, the exact chemical-mineralogical composition of wFCC catalysts depends on the manufacturer and specific process is going to be used in, their most active phase is the zeolite-Y. This zeolite is an aluminosilicate with a three-dimensional crystalline structure consisting of tunnels

and cages, which produces a high (internal and external) surface area. Previous studies have shown that when wFCC catalyst is incorporated in cement based materials can undergo a pozzolanic reaction with calcium hydroxide ($Ca(OH)_2$) – liberated during cement hydration – producing additional strength-providing reaction products i.e., calcium silicates hydrate (C-S-H) and calcium aluminates hydrate (C-A-H) [3, 4, 5, 6]. The formation of these cementitious products will contribute to the matrix microstructure densification leading to an improvement of both mechanical properties and durability [7, 8, 9] of wFCC catalyst containing cement based materials.

Within this scope, this paper presents results of a study aiming to assess the viability to produce concrete repair mortars incorporating wFCC catalyst. Experimental work was carried out following the test methods prescribed in EN 1504-3 standard since it provides the specifications for structural and non-structural repair products of concrete structures.

2. Experimental program

The raw materials used were: commercial Portland cement type CEM I 42,5R (according to EN 197-1 standard); wFCC catalyst originated in a portuguese refinery plant (PETROGAL S.A. company); sand (according to EN 196-1 standard) and SIKAPlast 898 superplasticizer (SP).

The chemical analysis of wFCC catalyst was performed by X-ray fluorescence spectrometry using a *PANalytical* model *Axios* equipment (Table 1). The loss on ignition and chloride content were evaluated following EN 196-2 and EN 196-21 standards, respectively. The specific gravity of wFCC catalyst was determined by helium pycnometry using an AccuPyc 1330 instrument from Micromeritics and the specific surface areas were determined by nitrogen adsorption at 77 K using a Micromeritics ASAP 2000 apparatus. The bulk chemical composition and physical properties of the wFCC catalyst listed in Table 1 show that the wFCC catalyst present a high content of SiO_2 and Al_2O_3 (representing approximately 92% w/w) typical of the pozzolanic materials and that the catalyst exhibits an extremely high specific surface area.

Table 1: Bulk chemical composition of and physical proportion of wFCC catalyst [10].

Characterization	wFCC catalyst
Chemical composition (% w/w)	
SiO_2	39.59
Al_2O_3	52.81
Fe_2O_3	0.55
CaO	0.09
MgO	0.19
SO_3	0.23
K_2O	0.04
Na_2O	0.68
Ti_2O_3	0.82
P_2O_5	0.06
Cl^-	0.01
Loss by ignition	1.49
TOTAL	**99.56**
Physical properties	
Specific gravity (g/cm^3)	2.71
Specific surface area (m^2/g)	150.07

Repair mortars were prepared using water (w), sand (s), binder (b) and superplasticizer (SP), in a weight ratio (w/s/b/SP) of 0.5/3/1/0.005, respectively. Binders used were plain cement (used as reference) and blended cements formulated by partially replacing cement with wFCC catalyst in the range of 5 to 15% w/w. Notation adopted for the repair mortars is summarised in Table 2.

Table 2: Notation adopted for repair mortars and correspondent binder mixture proportion.

Notation	Binder mixture proportions (% w/w)	
	Cement 42.5 R	wFCC catalyst
C100	100	0
wFCC5	95	5
wFCC10	90	10
wFCC15	85	15

Mortars mixing procedure was performed in accordance with EN 196-1 standard excepted the previous mixture of the superplasticizer in the water. Consistency of fresh mortars was evaluated, immediately after mortars mixing, by flow table test, as prescribed in ASTM C 1437-07. After the flow test, mortars were placed in 40x40x160 mm prismatic steel moulds and cured so that flexural and compressive strengths were able to be assessed at 2, 7 and 28 days of curing ages in accordance with EN 196-1 standard. The flexural strength results are the average of three tests and the compression strength results are the average of six compression tests.

The static modulus of elasticity in compression of mortars was determined following test method 2 described in EN 13412 standard. Testing specimens were prepared using the same prismatic moulds filled with the same mixtures used as in the case of mechanical strengths evaluation and water cured for 28 days. The principle of the test consist in measuring the change in the specimen strain when loaded to produce a stress between 0,5 N/mm^2 and on-third of compressive strength of the specimen measured previously. The modulus of elasticity results are the average of the values obtained with three specimens for each repair mortar composition.

The tendency of repair mortars to imbibe water by capillary action was evaluated as prescribed in EN 13057 standard. In brief, the procedure consists in preparing three cylinder mortar specimens (∅100 × 25 mm) for each of the same mixtures tested to evaluate mechanical strengths. The specimens were water cured for a period of 28 days and thereafter dryed in an oven at 40 ºC until reached a constant mass (defined as a weight change of not greater than 0.2% in 2 hours). The measurements of water capillary absorption were carried out exposing one of cylindrical faces of each specimen to water. During the experiment, the depth of imersion of tested specimens face is 2 mm. The water ingress was calculated by measuring the increase in the mass of a specimen at various testing periods such after 12 min, 30 min, 1 hour, 2 hours, 4 hours and 24 hours from its first contact with water. The amount of water absorbed (kg) was normalized with respect to the cross sectional area of the specimens exposed to water (m^2).

3. Results and discussion

Table 3 presents the consistency results assessed through spread values of the repair mortars, incorporating 0, 5, 10 and 15% w/w of wFCC catalyst, on the flow table. The results show that by increasing the waste FCC catalyst content there is a reduction in the mortars workability. This trend, attributable to the significant water retention by the wFCC catalyst due to its huge specific surface area with affinity for water, has been reported before [10].

Table 3: Spread values on flow table test (mm) of repair mortars with 0, 5, 10 and 15 % (w/w) of cement replacement with wFCC catalyst.

Mortar	Spread values (mm)
C100	223
wFCC5	218
wFCC10	207
wFCC15	188

Fig. 1 and Fig. 2 show, respectively, the flexural and compressive strengths of the repair mortars with 0, 5, 10 and 15% w/w of cement replacement with wFCC catalyst for different curing ages. The results of Fig. 1 show that flexural strengths of wFCC catalyst blended cement mortars are typically lower than those of plain cement mortar at same curing age. However, with a delay in the strength development of 7 and 28 curing days, respectively, for 5 and 10% w/w of cement replacement with wFCC catalyst, the difference between flexural strengths of blended cement mortars and the flexural strength of reference mortar becomes negligible.

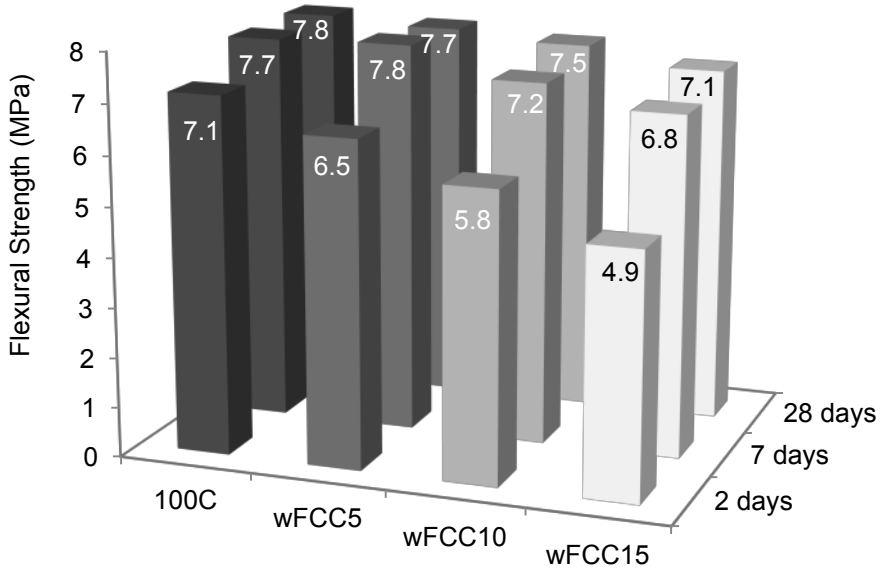


Fig. 1: Flexural strength of repair mortars with 0, 5, 10 and 15 % (w/w) of cement replacement with wFCC catalyst for 2, 7 and 28 days of curing age.

The results present in Fig. 2 show that on the 7th curing day the blended cement repair mortars containing up to 10% w/w of wFCC catalyst already exhibit compressive strength slightly higher than that of the reference mortar. The incorporation of 15 % w/w of wFCC catalyst delays the compressive strength development but from 28 days of curing age the strength is similar to that of plain cement mortar. The improvement in mechanical strengths of the cement repair mortars is likely to be due to the exceptional pozzolanic activity of the wFCC catalyst under study [10].

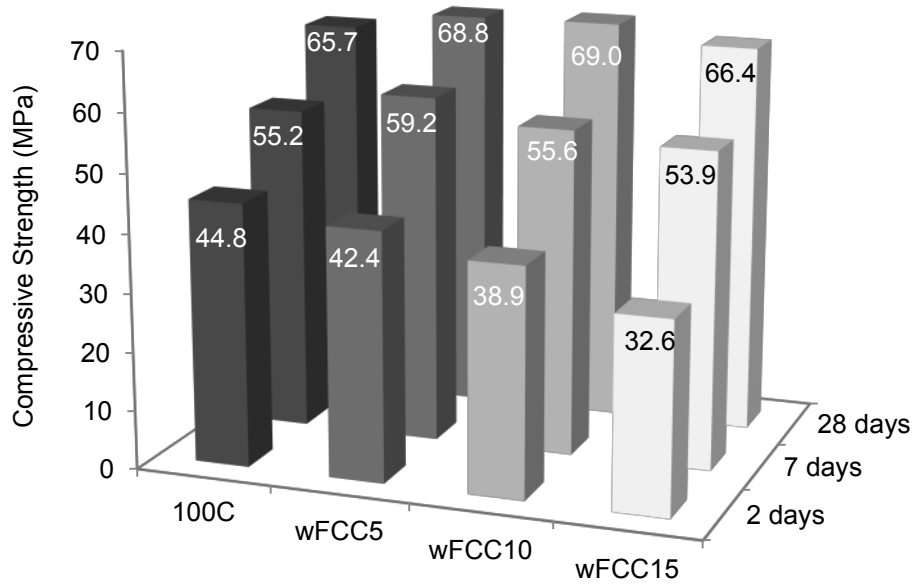


Fig. 2: Compressive strength of repair mortars with 0, 5, 10 and 15 % (w/w) of cement replacement with wFCC catalyst for 2, 7 and 28 days of curing.

Table 4 lists the values of modulus of elasticity in compression of the repair mortars at 28 days of curing age. Cement replacement with up to 10% of wFCC catalyst do not significantly affect the modulus of elasticity in relation to the reference cement mortar. However, increasing incorporation level of wFCC catalyst in the repair mortars composition tends to decrease the modulus of elasticity and, consequently, lower their stiffness.

Table 4: Modulus of elasticity in compression (E) of repair mortars with 0, 5, 10 and 15 % (w/w) of cement replacement with wFCC catalyst.

Mortar	E (GPa)
C100	36.3
wFCC5	36.9
wFCC10	35.9
wFCC15	24.2

Fig. 3 plots the water intake by capillary action on repair mortars against the square root of the time of immersion. The slope of the linear fit of these experimental results, for each mortar composition, provides the capillary absorption coefficient, S (kg/m^2.h$^{0.5}$). All the repair mortars incorporating wFCC catalyst exhibited lower water absorption than the reference plain cement mortar. Moreover, increasing the wFCC content in the mortars composition leads to a reduction in capillary water absorption coefficients i.e., increases the water penetration resistence. These results are in good agreement with previous studies [11] reporting a remarkably lower water absortion in cement based materials incorporating pozzolans than in plain cement based materials. The higher water penetration resistence in pozzolan containing cement based materials – namely in these repair mortars incorporating wFCC catalyst – may be explained as an effect of the pozzolanic activity because the additional forms of C-S-H and C-A-H produced lead both to a reduction in the capillary pores size as well as a decrease in pores interconenctivity [11].

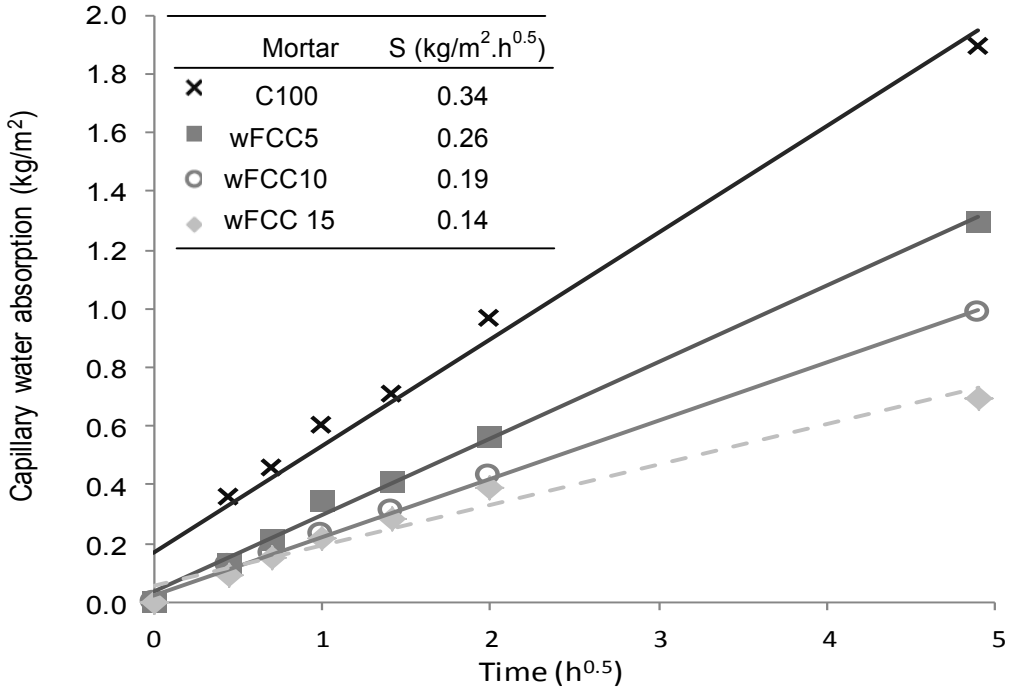


Fig. 3: Water absorption by cappilary action of repair mortars with 0, 5, 10 and 15 % (w/w) of cement replacement with wFCC catalyst.

4. Conclusions

This study aims at contributing to developing concrete repair mortars reusing a waste generated by the oil refining industry. This industrial ecology promotes synergies that are able to generate significant environmental and economical dividends for both the oil and construction materials industries as they become more technologically advanced.

Table 5 presents both:

- the requirements for the properties assessed in the present study towards each of the classes (R1 – R2 Non-Structural; R3 – R4 Structural) of concrete repair mortars as defined by the EN 1504-3 standard;
- a systematization of key experimental results obtained for repair mortars incorporating up to 15% of wFCC catalyst.

It can, therefore, be deduced that mortars with wFCC catalyst incorporation up to 15% w/w complies with the assessed specifications of all classes of concrete repair products set out in EN 1504-3 standard.

Table 5 – Experimental results and requirements laid down in EN 1504-3 standard for classes R1 to R4 of concrete repair mortars.

	EN 1504-3 standard requirements				Experimental results		
	R4	R3	R2	R1	wFCC5	wFCC10	wFCC15
Compressive strength, 28 days (MPa)	≥ 45	≥ 25	≥ 15	≥ 10	70.5	71.4	69.2
Elastic Modulus (GPa)	≥ 20	≥ 15	NR	NR	36.9	35.9	34.1
Capillary absorption coefficient (kg/(m^{2}h$^{0.5}$))	≤ 0.5	≤ 0.5	≤ 0.5	NR	0.26	0.19	0.14

Legend: NR – No requirement.

It should also be taken also in consideration that wFCC catalysts are classifed as non-hazardous solid waste which means that they do not pose a substantial present or potential hazard to human health or the environment [2, 12]. Actually, previous studies on heavy metals leaching from wFCC catalysts containing materials showed that they comply with environmental requirements [13, 14]. Moreoves it is not also antecipated these catalysts to have a negative effect neither on indoor air quality nor on ecotoxicity for soil.

Therefore, major findings in this investigation reveal that there is a large potential to use waste FCC catalyst as a constituent in repair mortars producing novel materials with adequate performance and durability and, concomitantly, making a significant contribution for "greener" construction materials.

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6. References

[1] INTERNATIONAL ENERGY AGENCY, WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT (IEA/WBSC). "*Cement Technology Roadmap: Carbon emissions reductions up to 2050*." 2009.

[2] EUROPEAN CRACKING CATALYSTS PRODUCERS ASSOCIATION, ECCPA."*FCC Equilibrium Catalyst (including FCC catalyst fines) finds safe reuse/rework outlets in Europe*". 2006, http://www.cefic.org/Documents/Other/Ecat_outlets_Europe_04Jan2006%20final%20Dec06.pdf

[3] COSTA C, CARVALHO P A, MARQUES P. "*Relationship between Microstructure and Mechanical Properties of Binary Blended Cement Mortars Containing Waste Oil-Cracking Catalyst*." Proceedings of International Congress on Durability of Concrete, Trondheim, Norway, 2012.

[4] CHEREM DA CUNHA A L, LEMOS M S, METH S, GONÇALVES J P, DWECK J."*A study of the particle size effect on the pozzolanic activity of an equilibrium catalyst".* Journal of Thermal Analysis and Calorimetry 2011, Volume 106(3), pp. 805-809.

[5] PINTO C, BÜCHLER P, DWECK, J. "*Pozzolanic properties of a residual FCC catalyst during the early stages of cement hydration"* Journal of Thermal Analysis and Calorimetry, 200, Volume 87(3), pp. 715-720

[6] GARCÍA DE LOMAS M, SÁNCHEZ DE ROJAS M, FRÍAS M. "*Pozzolanic reaction of a spent fluid catalytic cracking catalyst in FCC-cement mortars".* Journal of Thermal Analysis and Calorimetry, 2007, Volume 90(2), pp. 443-447.

[7] PACEWSKA B, BUKOWSKA M, WILINSKA I., SWAT M. "*Modification of the properties of concrete by a new pozzolan--a waste catalyst from the catalytic process in a fluidized bed"*. Cement and Concrete Research, 2002, Volume 32(1), pp. 145-152.

[8] ZORNOZA E, PAYÁ J, GARCÉS P. "*Chloride-induced corrosion of steel embedded in mortars containing fly ash and spent cracking catalyst*". Corrosion Science, 2008, Volume 50(6), pp. 1567- 1575.

[9] ZORNOZA E, GARCÉS P, BORRACHERO M V, PAYÁ J, "*Durability Properties of Mortars Partially Substituted with Spent Catalytic Cracking Catalyst*", Second International Conference on Sustainable Construction Materials and Technologies, Università Politecnica delle Marche, Ancona, Italy, 2010.

[10] Costa C, MARQUES, P. "*Low-Carbon Cement With Waste Oil-Cracking Catalyst Incorporation"*. Proceedings of *2012 IEEE-IAS/PCA 54th Cement Industry Technical Conference,* San Antonio, USA, 2012.

[11] MASSAZZA, F. "*Pozzolana and Pozzolanic Cements*" in: Lea's Chemistry of Cement and Concrete, 4th ed., ed. P.C. Hewlett, Elsevier Science & Technology Books, 2004, pp. 471-631.

[12] FURIMSKY, E. "*Review of spent refinery catalyst: environment, safety and utilization*".

Catalysis Today, 1996, Volume 30, pp. 223-286.
[13] SU N, FANG H., CHEN Z., LIU, F. "*Reuse of Waste Catalysts from Petrochemical Industries for Cement Substitution"*, Cement and Concrete Research, 2000, Volume 30, pp. 1773-1783.
[14] LIN K-L, WU H-H, CHAO S-J, CHENG A., HWANG C-L. "*Characteristics of waste catalyst reused as latent hydraulic materials*". Environmental Progress & Sustainable Energy, 2013, Volume 32/1, pp. 94–98.

Biobased Sandwich System for Applications in Architecture

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Short Summary

For years polymer foams have posed an excellent „warm shell“ for buildings. Generally the foam is used for external wall insulation and is not employed for additional functions. Yet forming a sandwich from rigid laminates and a quite shear resistant polymer foam core, results in extraordinary stiff elements that provide not only thermal insulation, but form a load carrying structure. The sustainability of the sandwich structure can be raised by combining materials from renewable resources. The sandwich system currently developed in cooperation with our partner from industries C3 House Technologies consists of phenolic foams of varying density and natural fibre reinforced laminates. A phenolic resin matrix provides on the one hand sufficient fire resistance for the entire sandwich itself, and on the other hand a high performance thermal insulation. The material system may be employed for compact construction methods. One may also rely on local resources for the laminates by the selection of fibres and their ratio of mixture in the natural-fibre-fleeces. Additionaly by manipulating the ratio of the various fibres in the fleece one can design the mechanical properties according to use. Depending on the pressing technology, the fibre-resin-ratio and the kind of fleece the elastic modulus of the laminates can be adjusted in a wide range to fit the particular application like external or internal walls.

Keywords: sandwich; biocomposite; lignin; biofoam; bioeconomy; phenolic resin; lignosandwich

1. Introduction

Man has always sought materials to implement his ideas and to meet his requirements. The development of construction engineering is therefore closely linked with the development of construction materials.

Fibre-reinforced plastics were first used in their own right as a class of construction material in the construction industry in the middle of the 20th century. They made it possible to construct plane load-bearing structures and lightweight sandwich structures, dream-like structures with thin walls spanning wide stretches and floral or crystal structures, providing us with a novel type of housing and protection from the environment.

Fibre-reinforced plastics are a multifaceted class of construction materials as the most diverse types of fibres as well as thousands of combinations of plastics together provide high-performance materials. Plastics are currently undergoing a period of transition. Oil is no longer the sole means of producing plastics: natural products are undergoing chemical processes and are being offered as bioplastics. Natural fibres are now fulfilling other roles apart from their traditional use as textile fabrics in the clothing and carpet industries. The construction system being developed is based on the combination of a new composites, existing findings in the field of lightweight construction using sandwich systems, and sustainable resource and energy saving construction methods that are currently in use.

2. Fibre-reinforced plastics

Fibre-reinforced plastics are composite materials comprising a matrix presenting the embedding material and the reinforcing fibres. The fibres transfer forces across the structure. The fibres used are glass, carbon, aramid and natural fibres. The matrix is usually a thermoset, e.g. unsaturated polyester resin or epoxy resin. The matrix forms the construction component, conducts and transmits the forces arising to the fibres and protects them. Essentially, the matrix in combination with additives determines the following characteristics:

- Resistance to chemicals
- Resistance to ageing
- Fire resistance,
- Impact resistance,
- Electrical properties.

The specific density, thermal conductivity and thermal expansion depend on the proportions of the resin, reactants, fibres and fillers.

As the fibres absorb the forces in the structure and as the resin is the most expensive constituent in a composite material component, there is clearly a need to increase the fibre content and to use layers of minimum thicknesses. This enables material costs to be reduced and the load-bearing structure to be more efficiently utilised. A new load-bearing system, a sandwich, is formed by the high-tensile and shear-resistant bond of the composite material formed as thin covering layers around a core of hard foam. Despite their low mass they can support considerable weights and additionally have an integrated thermal insulation effect. Sandwich components are therefore used as well as a spatial partitioning and separately as a load-bearing wall or roof component. Most of the composite structures constructed to date have therefore employed sandwich construction methods.

3. A brief history of the use of fibre-reinforced materials in the construction industry

Plastics served initially at the end of the 19th century as a replacement for rare and therefore expensive natural products. Thanks to the development of numerous different types of plastics, it was not long before plastics were being used in their own right in many sectors, including the construction industry. The thermoplastics and thermosets developed were used in the chemical industry in high quality products produced following quality assurance procedures to enable these products to compete with traditional materials over the long term. The advantages of plastics for consumer goods lay in their low mass and colourability, as well as in the fact that they made less “noise” and did not rust.

An important factor was the development of different petrochemical based wood glues which played an important role in the manufacture of plywood (glued laminated veneers) for the construction of aircraft and airships. In 1933 a polyester resin resistant to water and chemicals was developed by Carleton Ellis in the USA. Glass fibres had been manufactured industrially since 1935. This was followed in 1942 by the development of the glassfibre reinforced polyester by the US Rubber Company. Glassfibre reinforced plastics (GFRPs) had been used in the USA as early as 1943 in aircraft construction for sandwich components with a balsa wood core.

In the 1940s to the 1970s GFRPs underwent a short but very productive phase for a construction material (Voigt, 2007). The chemists, chemical companies, processors, engineers and architects and artists too created a highly developed construction material with a wide range of applications. They proved that GFRPs with their very wide range of forms could be used not only in the sporting goods industry, in the manufacture of boats, motor vehicles and aircrafts but also in the construction industry as self-supporting/load-bearing materials.

Development work in the 1950s initially concentrated on attempts to bring GFRPs up to a standard comparable with other construction materials and to investigate their possible applications, taking into account the material requirements, such as weather resistance and flammability. In carrying out these developments the aim was to develop high-performance and durable materials, to test them, to introduce guidelines and to produce these materials to a consistently high quality standard.

The demand for GFRPs in the military sphere, for example for radar domes (Sonnefeld, 1954, page 159), led to a rapid development and widespread use of this material. The chemical and plastics-processing industry encouraged architects and civil engineers to develop possible applications for the construction industry. Architects and civil engineers had already become aware of this new promising class of material that could be moulded to any shape. The French Snail Shell (1956) developed by the research group led by Ionel Schein and the Monsanto House (1957) developed by the Massachusetts Institute of Technology (MIT) are the most well known research and presentation structures of this period [Genzel & Voigt, 2005, page 39 – 71],[Monsanto, House of the Future, 1954 – 1964].

Most of the composite structures were built between 1960 to 1972 in the industrialised nations (e.g. Fibreglass House Fig.1). The interest, indeed the enthusiasm of the pioneers in the new construction material, is due to the large number of diverse structures which were regarded throughout the world as innovations and as proof of the productivity of this sector of industry and the construction industry, as well as serving as an example for the restructuring of this sector into a construction industry. The concentration on house building was based on the great need for housing after the Second World War and the preference of the modern age for the single family home.



Fig 1: Fibreglass House 1970, development, design and show house: FG Design Wolfgang Feierbach (Wolfgang Feierbach, fg design, 1968, Photo: IBK Archive).

At least 176 different GFRPs structures were built during this twelve year period, 66 of them actually in smaller series. The buildings ranged from very small modules up to blocks of building of 27,000 m2, constructed from hundreds of identical GFRPs components. Apart from structures made of thermally insulated sandwich elements with hard foam core, light plane load-bearing structures were also built which used a small amount of materials and had a large span, such as shells, tiled slabs and hyperbolic surfaces. Examples of successful, economically and technically mature constructions of canopies, building shells or exhibition buildings include the International Airport at Dubai, Arab Emirates (1971), the Olivetti Training Centre in Haslemere, GB (1971), and the public buildings at Iqualuit and Igloolik, Nunavut, CAN (1971), the construction system fg2000 (Fig. 1), FRG (1968/74), and the Futuro, FIN (1968) [Igloolik Research Center,Nunavut, CAN, 1971].

Industrial construction based on prefabrication of highly specialised building units from consistently high quality, great economy, low labour costs and rapid construction, was illustrated and presented by homes prefabricated from glass fibre reinforced composites.

Generally speaking, there was a marked change within the construction industry in the 1970s. Analyses and examinations were carried out of the state of post-war building. For the first time, public concern was expressed about the state of architecture which was in most cases poor – an architecture which was also described as functionalism imposed on building design by economic constraints. This signalled the end of the optimism of the 1960s which was superseded by the general disillusionment of the 1970s.

The economic change was triggered by the oil embargo imposed by the Organisation of the Petroleum Exporting Countries) (OPEC) in autumn 1973. OPEC deliberately reduced the amount of oil produced by about 5% in order to influence the price of oil for its own advantage. Because of the adverse effects due to the economic situation, the rejection by the public of GFRP structures and overly complicated planning and approval procedures, fewer and fewer GFRP projects were carried out. Despite intensive campaigns to publicise the benefits of these materials, it was not possible to dispel people's prejudices, or to request sufficient time to solve all the technical problems. And yet as early as the 1970s construction methods using glass fibre-reinforced plastics had been in terms of their design, features and durability a fully-fledged competitor of construction methods using traditional construction materials.

In the 1990s construction with composites once again attracted the interest of architects and civil engineers. The aim was for architecture to make interior spaces come alive once again by using organic forms and at the same time to use the new possibilities of digital and virtual designing. The pavilions of the Swiss Expo Expo'02(2002), the Light Sculpture ›D-toren‹ in Doetinchen, Netherlands (2004), Chanel Contemporary Art Container (2008) and The Walbrook, London, Great Britain (2009) illustrate this basic principle of an architecture that strikes a vivid response in the mind of the viewer (ForumSoft, Expo'02 Switzerland 2002).

The further development of digital programmes, of PC-based three-dimensional designing and construction, which enable data to be transmitted directly to robots and CNC milling machines, today makes the construction of industrial buildings into a flexible Just-in-Time production process, especially for technically accomplished architects. This enables greater savings to be made for constructions using fibre-reinforced plastics, even for one-off building projects.

4. Design & architecture

A large amount of the heat and energy produced, and thus the consumption of finite gas and oil reserves, goes into heating buildings. The aim of the European Union therefore is to reduce energy consumption by 20% in 2020 by increasing energy efficiency. This shall be achieved by reducing CO_2 emissions, renewable energy sources and last but not least by reducing energy consumption by the consumer (Energy Efficiency Plan of the European Commission, 2011, page 1).

Two-thirds of the energy consumed by buildings during their service life is for heating and ventilation. Efficient thermal insulation and the airtightness of the building shell would result in great savings. The principle of the passive house has attracted interest throughout the world and has served as a shining example in reducing energy consumption. Most of the extremely low heat requirements of such houses are covered by "passive" sources, such as sunlight or ground heat. The main way energy is reduced in the passive house is by reducing energy losses through transmission and ventilation. This is achieved by effective thermal insulation and the airtightness of the entire building shell and a controlled ventilation of living areas with heat recovery from the outgoing air.

Insulated, airtight structures are constructed of many layers which not only exceed the dimensions of the overall structure (overall wall thicknesses of 50 cm), but also lead to sources of defects like thermal bridges and leakages. A compact design in which the load bearing structure simultaneously ensures the building physics and provides protection against weathering (compact system after Deplazes, 2009, page 80), can be achieved by the use of a sandwich system. There are variations in the width of sandwich systems that have already been developed and tested in timber structures, and in structures using composites, as illustrated above. Building on these experiences current research is directed at developing materials for the challenging sector of energy-saving construction.

In the ongoing research projects at the Fraunhofer IWM in Halle experiences in construction and use of composites are linked with current industrial production standards in construction industry and plastics-processing industry. So innovative combinations of renewable raw materials can be employed for sandwich systems, so called Natural Composite Panels (NCP). These are qualified for applications in architecture and construction industry. Apart from the compact solution of load bearing structure, building physics and protection against weathering described previously, NCPs also offer the advantage of savings in material because of thin walls, high quality thanks to the controlled industrial manufacture of the materials, as well as elements with individual design possibilities, a high degree of prefabrication, weight saving thanks to the lightweight design and thus savings in transport costs, good workability and quick installation. Primarily renewable locally available raw materials are used.

5. Materials

The sandwich system (NCP) currently in development with the industrial partner c3house technologies GmbH comprises a phenolic foam core of varying thickness (60- 120 kg/m^3) and top layers from laminates that are reinforced with natural fibres (Fig. 2).



Fig 2: Components of the sandwich system, sandwich element (source: C3 House Technologies GmbH)

The use of a phenolic system as matrix guarantees on the one hand that the fire classification protection [B s1 d0] for the whole sandwich is achieved. On the other hand the phenolic foam offers very good thermal insulation properties which enable the sandwich system to be used for the compact design. By selecting suitable non-woven fabrics (e.g. flax/hemp/sisal/linen) in a varying ratio, it is possible to use local resources and to systematically set the mechanical properties. Depending on the pressing technique, the proportion of the matrix material, the ”prebinding” (e.g. via the degree of needling) and the type of the non-woven fabrics, one can set the laminates modules of elasticity between 6 - 12 GPa and the tensile strength between 50 – 80 MPa and thus tailor the system for the respective use (e.g. as an exterior wall or internal element).

A further advantage is seen in a low thermal expansion α of the upper layers by temperatures between – 40℃ to 100℃. This ranges from – 40℃ to 30℃ for α = (9e – 006 ± 2e – 006)1/K and even less at α = (3e – 006 ± 2e – 07)1/K in the range of 30 ℃ to 100 ℃. This means that laminates reinforced with natural fibres expand only marginally under thermal load and therefore impose only small additional loads upon the structure.

The materials used in NCPs are specified according to the current international requirements for load bearing structures and building physics and are designed on in teamwork with the manufacturer, load bearing structure designer and architect (Fig. 3), taking into account manufacturing requirements and the structural design.

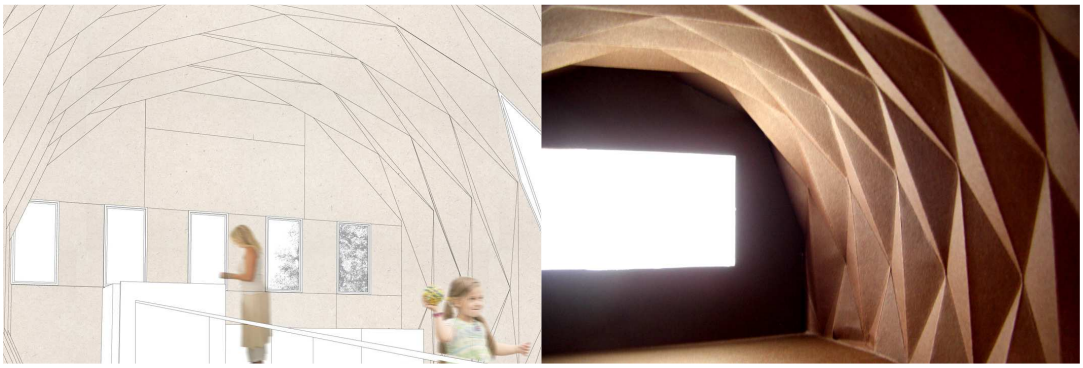


Fig 3: Components of the sandwich system, sandwich element (source: C3 House Technologies GmbH)

Besides the creative flexibility of the NCP construction system, seen on the illustrations, the innovation in structural design is the joining technique – bonding is appropriate for the material involved. Bonding is superior to mechanical joining. Local overloads, that would generally lead to the material being ripped out like in a bolted connection, can not occur. By bonding elements such as windows and doors can easily be integrated.

6. Summary and future prospects

A compact construction method can be implemented by the sandwich system presented which comprises upper layers reinforced by natural fibres and a foam core of phenolic resin. The choice of suitable raw materials and their combination in the sandwich enables the sandwich to be optimally tailored for the respective application. Perspectively, it will be possible to replace part of the petrochemical component (phenolic resin) by lignin as a biobased component, receiving a construction material that consists of 20 – 50% renewable raw materials.

The lignin is produced from beech-wood via the organosolv-process. Then it is chemically integrated into the phenolic resin. The proportion of lignin in the resin can be varied from 5% (P05) to 10% (P10) up to 20% (P20).

This poses an quite prospective idea since using lignin means using natures own synthesis instead of artificial petrochemical processes for resin production and thus reducing the energy needed for resin production. The worldwide availability of lignin is estimated up to about 20 billion tonnes per year - a sufficient raw material base for a prospering lignin based bioeconomy.

This means that up to 80% of the material for the described sandwich elements may be bio-based. In the framework of “LignoSandwich”, a project in the research cluster “Bioeconomy”, the whole value-added chain from the Hardwood to the bio-based sandwich system for constuction (see Fig. 4) is explored.

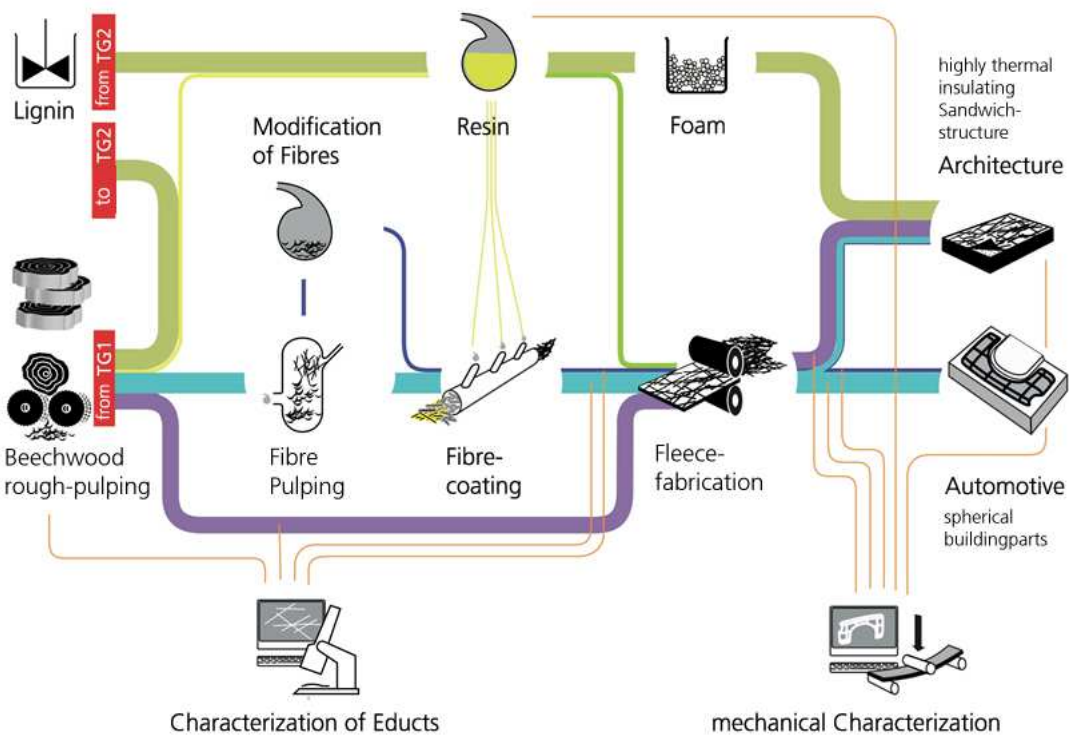


Fig 4: Material flow from beech-wood to a highly thermally insulating bio-sandwich

7. Further resources

Deplazes, Andrea: Architektur Konstruieren. (S. 80).Birkhäuser, Basel, 2009

Genzel, Elke; Voigt, Pamela: Kunststoffbauten. Teil 1: Die Pioniere Universitätsverlag, Weimar, 2005

Koschade, Rolf: Sandwichbauweise. DETAIL, München, 2011

Uffelen, Chris van: Pure plastic: new materials for today's architecture. Braun, Berlin, 2008

Voigt, Pamela: Die Pionierphase des Bauens mit glasfaserverstärkten Kunststoffen (GFK) 1942 bis 1980. Weimar: Universitätsverlag, 2007

Multi-Linear State Space Model Identification for Large Scale Building Systems



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Short Summary

Many Control Design approaches presuppose the knowledge of a state space description of the system. As in many real and large scale systems the construction of a state space model using analytical equations and rough assumptions is a time consuming process leading most of the times to questionable precision. System simulation software has been developed for several applications over the recent past decades. For this purpose a System Identification approach is proposed in the present paper. The idea of the System Identification from a simulation model using statistical measurements from the simulation output data has been of great interested for optimal control schemes which require accurate and furthermore, agile, simple and practical models to handle. In practice real systems and accurate simulation models, show nonlinear dynamic behavior which concludes to linear approximation-identification models being unsuitable for this purpose. The proposed Multi-Linear State Space Model Identification process is using the idea of mixing signals as weighted contribution factors for the final model behavior. A common Least Square error minimization process is used to minimize the model approximation error.

Keywords: Building, Simulation, SSM, Modeling, System Identification

1. Introduction

In control engineering, the field of system identification uses statistical methods to build mathematical models of dynamical systems from measured data. System identification also includes the optimal design of experiments for efficiently generating informative data for fitting such models as well as model reduction.

It must be noted that a white-box model based on first principles could be also build, e.g. a model for a physical process from the Newton equations. In many cases, though, such models are overly complex and possibly even impossible to obtain in reasonable time due to the complex nature of many systems and processes affecting the central model of interest.

A much more common approach is to start from measurements of the behavior of the system and the external influences (inputs to the system) and try to determine a mathematical relation between them without going into details of what is actually happening inside the system. Therefore a black-box (no prior knowledge for the system is available) system identification process is applicable to any measurable system and can be proven as a very efficient scheme for System State Space Model (SSM) realization.

Large scale non-linear systems are usually described in details by very large and complicated differential equations. These equations in order to be analytically complete usually demand the knowledge or the calculation from empirical graphs or tables, of many parameters. In addition, "necessary" physical simplifications and assumptions that conclude to fitting errors, between the constructed model of the system and the actual system, must be considered in order to make feasible the building process of a reliable model. Thus, control schemes, especially, for large scale systems (e.g. buildings, traffic networks) avoid dealing with state space models.

A common strategy is the use of precise and detailed simulation models to simulate systems. Simulation models require several calculations and much execution power. Many applications require fast simulation results due to their nature, thus even online control algorithms using co-simulation schemes can be proven impractical and not efficient at all. In addition a practical drawback in this strategy, is the mobility and compatibility of such model. Generating a precise enough, State Space Model (SSM) bypassing special and usually expensive simulators served by complicated connection interfaces which have to be incorporated in the system simulation scheme can be the only efficient solution to many practical applications.

This paper copes with the idea of approximating a dynamic SSM of a given, either simulation or real, system by using off line measurement data, using a common input-output system measurement database. The main idea is trying to minimize the approximation error of the state space realization matrices, using a simple and convenient way. The proposed strategy introduces state space subdivision and local linearization according to the current system working point - state. Locally referring but globally representative weight functions decide the contribution of each linear subsystem to the final model total dynamic behavior.

2. Transformations and Approximations

Let us consider a general non-linear system which assumes the following dynamics

$$\dot{\chi} = F(\chi, u, w) \tag{1}$$

where $\chi \in \Re^n, u \in \Re^m, w \in \Re^d$ denote the vectors of system states, control inputs and system disturbances, respectively, F is a nonlinear vector function which is assumed to be continuous.

2.1 Multi-Linear Subsystem Mixing Signals

The problem in large scale non-linear systems is the inherent inability of extracting a linear state space realization group of constant matrices in order to be able to design a convenient control system.

Assume that system function F can be approximated using smooth mixing signals membership functions, so as to have smooth switching between the linear subsystems and even more smooth switching between the linear subsystems respective controllers. Also assume as a first step that all states, control inputs and disturbances of the system can be measured or are given:

$$y = Cx = C\left[\chi, u, w, 1\right]^T \tag{2}$$

where matrix C is known and can be considered $C = I$ without loss of generality. Please note that the feedback vector is augmented using an ace at end, due to a constant term considered for all linear subsystems.

Let $\beta_i, i = 1, \ldots, L$ denote a set of smooth *mixing signals* that satisfy the following properties:

$$\beta_i(y) \in [0,1], \quad \sum_{i=1}^{L} \beta_i(y) = 1, \forall y \tag{3}$$

and, moreover,

$$\sum_{i=1}^{L} I\left(\beta_i(y)\right) \le 2 \tag{4}$$

where $I(\beta_i(y))$ denotes the indicator function $I(\beta_i(y))=1$ if $\beta_i(y)>0$ and $I(\beta_i(y))=0$ if $\beta_i(y)=0$.

The activation functions β_i separate the system augmented state space $x\in\Re^{\dim(x)}$, where $\dim(x)=n+m+d+1$, into L overlapping regions, with each of the activation functions assigned to one of these regions. An activation function $\beta_i(y)$ is active [i.e., $\beta_i(y)>0$] whenever y ($y=x$ since $C=I$ is assumed) belongs to the respective region $\beta_i(y)$ has been assigned to. Please note that due to Eq. (4), every time there are maximum 2 activation functions active. We will, moreover, assume that the mixing signals β_i span the whole space y lies on, i.e., we will assume that for each possible y, there exists at least one i such that $I(\beta_i(y))=1$. In order to avoid degenerate cases where two or more mixing signals coincide, we will also assume that $\beta_i(y)\neq\beta_j(y), i\neq j$ holds over a non-negligible subset of $\Re^{\dim(x)}$.

Remark 1: Condition Eq. (4) can be relaxed by requiring – with the exception of at most two mixing signals – all mixing signals take negligible values for each particular y. In such case, the design of mixing signals becomes less complicated by using, e.g. Gaussian functions which show very good fitting properties.

2.2 Multi-Linear State Space Model

Using the above design considerations for the mixing signals β_i we can employ standard function approximation techniques to approximate the system dynamics. Instead of approximating a pure linear model for the specified system, an iterative exploration process decides the number of mixing functions to be used by giving the smallest approximation total error. The idea is to identify many linear subsystems describing the system dynamics in different working areas respectively, where the system behaviour usually changes in a significant manner. At each state the selection of the respective active linear subsystems is decided by the weight factors (mixing functions) and the total system behaviour can be represented analytically by the following equation:

$$\dot{\chi}\approx\sum_{i=1}^{L}S_i\approx\sum_{i=1}^{L}\beta_i(y)\left(\overline{A_i}\chi+\overline{B_i}u+\overline{G_i}w+\overline{F_i}\right) \tag{5}$$

If we group the state space matrices and vectors in one matrix that incorporates them we can write:

$$\dot{\chi}\approx\underbrace{\left([\overline{A}_1\overline{B}_1\overline{G}_1\overline{F}_1][\overline{A}_2\overline{B}_2\overline{G}_2\overline{F}_2]\ldots[\overline{A}_L\overline{B}_L\overline{G}_L\overline{F}_L]\right)}_{=:\Theta}\underbrace{\begin{pmatrix}\beta_1(y)\begin{bmatrix}\chi\\u\\w\\1\end{bmatrix}\\\beta_2(y)\begin{bmatrix}\chi\\u\\w\\1\end{bmatrix}\\\ldots\\\beta_L(y)\begin{bmatrix}\chi\\u\\w\\1\end{bmatrix}\end{pmatrix}}_{=:\Lambda}, \tag{6}$$

and replacing the derivative by the difference quotient the compact form of the equation reads:

$$\frac{\chi_{[new]}-\chi_{[old]}}{\Delta t}=\dot{\chi}\approx\Theta\Lambda \tag{7}$$

2.3 Discrete Time Analysis

To simplify even more Eq. (7) we can use discrete time analysis and assume that the Δt -time step of the generated or measured data is significantly smaller than the time constant values, referring to the dynamics of the system. This assumption is reasonable in large building systems where the time constants have values (depending on the construction) up to 100 hours, compared to the data time step (usually few minutes). Thus alternatively Eq. (7) can then be written as (consider Δt = 1):

$$\chi_{[next]} \approx \chi_{[old]} + \Theta\Lambda \quad . \tag{8}$$

3. Approximation Error Minimization Analysis

After the problem formulation, the main problem is the approximation – calculate Θ matrix which contains all the state space realization constant matrices for every linear approximation member subsystem S_i as described above. In order to form the Least Square problem the following calculations are presented. From Eq. (8) we have:

$$\Lambda^T\Theta^T \approx (\chi_{[z+1]} - \chi_{[z]})^T \quad . \tag{9}$$

The above equation has the general form of the Least Square problem $QX = B$ which is used to minimize the approximation error of X vector. Consider:

$$Q = \Lambda^T,\ X = \Theta^T, B = (\chi_{[next]} - \chi_{[old]})^T \quad . \tag{10}$$

Matrix Λ and tall vectors $\chi_{[next]}, \chi_{[old]}$ include simulation output data or measurement data of the system to be identified. The values of β_i functions (normalised Gaussian functions) are formed using for each data time step the whole or part (C matrix depends on the specific application) of feedback vector y. The kernel functions used in this proposed application are normalised scalar Gaussian functions using the norm of y vector to decide the maximum two active subsets at each given state – working point of the system.

This vector is formed to decide the membership magnitude of the respective linear subsystem. Each row of Θ matrix is approximated using Least Square method with Λ vector and the respective $j-th$ state variable vector $(\chi^{(j)}_{[next]} - \chi^{(j)}_{[old]})$.

In conclusion the problem becomes a regression approximation problem in which we want to minimize the approximation error e using the Least Squares method. The optimization problem becomes:

$$\min \quad T = \sum_{j=1}^{n}\sum_{z=1}^{\mathcal{N}} e_{zj}^2 \tag{13}$$

where $\mathcal{N}$ is the total sample number of the training data set, n is the number of state variables and e_{zj} is the approximation error defined by

$$e_{zj} = (\chi_{[z+1]} - \chi_{[z]})^{(j)} - \Theta^{(j)}_{row}\Lambda_{[z]} \tag{14}$$

where $z = 1, 2, ..., \mathcal{N}$ and $j = 1, 2, ..., n$.

4. Building Model and Zoning Procedure

To test the developed system identification algorithm we use a validated building model generated with TRNSYS [1]. This model has been developed during the project PEBBLE (for details see http://www.pebble-fp7.eu/).

4.1 Center for Sustainable Building (ZUB)

The ZUB building, built in 2001, located at the campus of the University of Kassel, Germany is an exemplary low-energy building. The ZUB has three floors, a basement and an atrium in contact with a nearby building. It is occupied by researchers in the field of building physics, equipped with a significant number of sensors, and used for experimental investigations in the field of energy optimization and building technologies.

The overall volume of the heavy-weight construction is 6882 m³, the net heated floor area is 1332 m^2 and the main floor space is 892 m² [2]. Floor height is close to 4 m and the annual heat demand is between that of a low-energy building and a passive house, approximately 30 kWh/m² or 5.3 kWh/m³; electricity consumption based on the heated net floor area is approximately 20 kWh/m^2 a. More details about the ZUB and its energy concept are given in [3, 2].

Fig. 1a shows the ZUB building model, designed using Google SketchUp, with shading groups in purple. Since the building is equipped with Thermally Activated Building Systems (TABS): independent radiant floors, and radiant ceiling systems in each room, each physical room was defined as a separate thermal zone. In total 26 zones are required to model the whole building. The atrium at the back of the building consists of three thermal (convective) air-nodes, – one per floor, – combined to a single (radiative) zone, for more details on the model and the simplification see [4, 5].

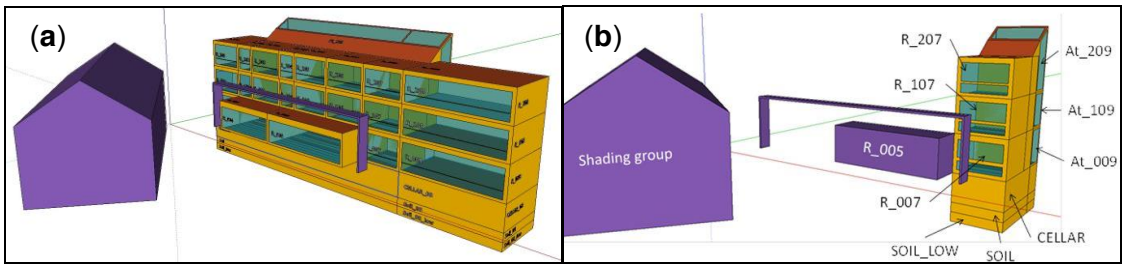


Fig. 1: building model for the ZUB (a) and reduced building model (Tower); designed in Google SketchUp.

For testing the proposed system identification procedure a reduced model the so called Tower is used. This Tower is essentially a cut-out of the building that preserves all relevant characteristics from the whole model, compare Fig. 1b. The implementation approach of SysID, uses TRNSYS simulation output data for system identification. Used weather data are for 2003.

Another major discussion topic of building simulation and control schemes is the zoning procedure. Zoning is defined by simple but often not clear principles. A thermal zone is defined as an individual space or group of neighbouring indoor spaces that is expected to have quite similar thermal loads and behaviour. Zones are defined in thermal building simulation to reduce the number of independent HVAC subsystems. The zone room demarcation in the subject building is done under this simple principle. The three zones due to their orientation and corner position, subject to the whole construction, are expected to have different thermal behaviour depended on unpredictable outdoor environment thermal loads.

A common concept in system identification schemes is the excitation persistency of the system so as the input signal should be such as to excite all the modes of the plant to be identified to assure the convergence of the parameters to their true values. For this reason a simulation schedule is

followed in the building simulations in order to generate proper data for the identification scheme: Every six hours (that is every 24th time step) random control actions were generated and applied to the system to ensure all system dynamics are excited fairly (Fig. 2).

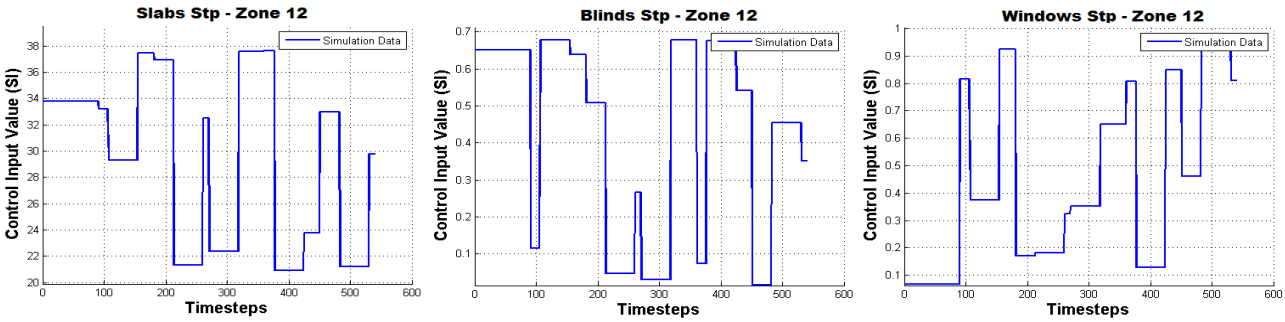


Fig. 2: Simulation random system excitation control signals

5. Parameterization and Identification Results

5.1 Discussion of State-Control-Disturbance Variables

Deciding the proper state and control variables that provide satisfying results with less data complexity and data size is discussed in the present section. In our approach these variables were defined and grouped as:

- Indoor mean air temperature and indoor humidity ratio (consider each zone as a single simulation node – uniform mean temperature and humidity ratio for the whole volume of each zone) were used as state variables (χ vector) because these are the main two physical variables deciding the user comfort level (Fanger [6]).
- Schedule ventilation for openings (windows-doors), schedule for blinds, HVAC temperature set points were considered as the controllable signals for the building model (u vector).
- Outdoor humidity ratio, outdoor temperature, wind speed, wind direction, total solar radiation and office occupancy schedule were considered as uncertain disturbances (w vector).

5.2 Identification Results

Simulation and identification results are depicted below. The simulation data used for the identification process (Training) were chosen during winter period and specifically during the first week of the year i.e. 4th – 12th January 2003 (Fig. 3). The simulation data were divided into two data groups the one used for the model training process (70% of total data) and the other one to validate the identified model with unknown validation data (30% of total data). The sampling frequency was set in the simulation model equal to 15 minutes.
The model was validated using different state resetting frequency (f). In the model integration process three different time horizon scenarios were tested as follows:

- Every validation period time step simulation data were used to integrate the model only to the next time step state variable values (f = 1 step – 15 min).
- Every 25 validation period time steps simulation data were used to integrate the model to the next time step state variable values (f = 25 steps – 6 hours).
- Every 96 validation period time steps simulation data were used to integrate the model to the next time step state variable values (f = 96 steps – 24 hours).

Please note that due to lack of space the results included in the present paper refer only to one thermal zone of the building (Zone R_107). Please also note that the first day of every simulation is used as settling time so as the building reaches a reasonable state – working point.

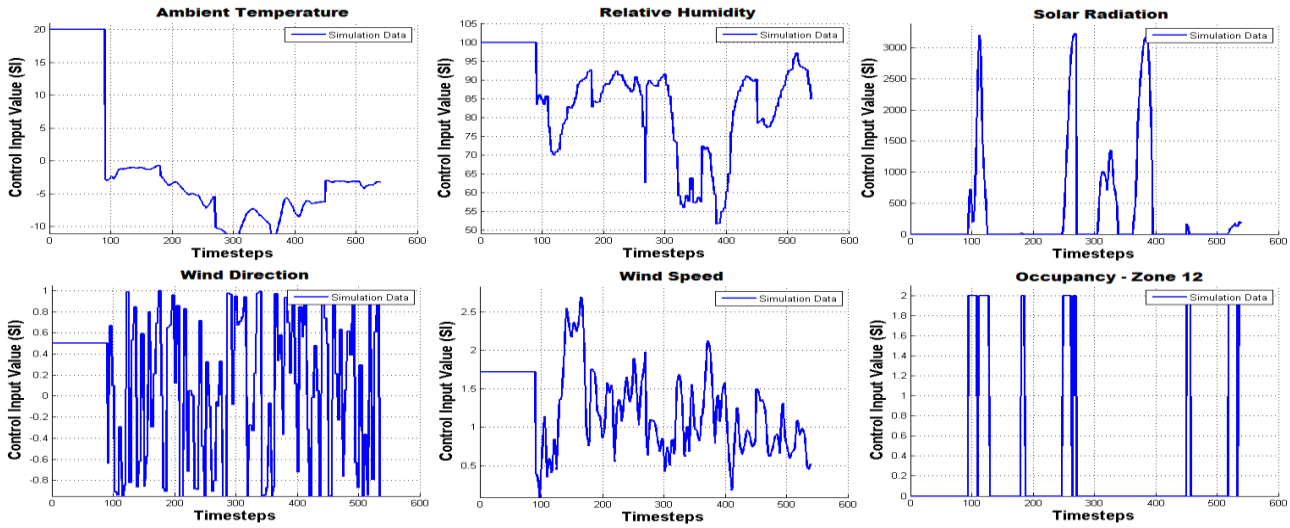


Fig. 3: Simulation Weather Data during the training period which is the first week in January

The summary for the identified model is incorporated in Table 1 below. The respective transients for the validation period are shown in Fig. 4. Note that the blue curves refer to the building simulation results and the green ones to the identified model simulation.

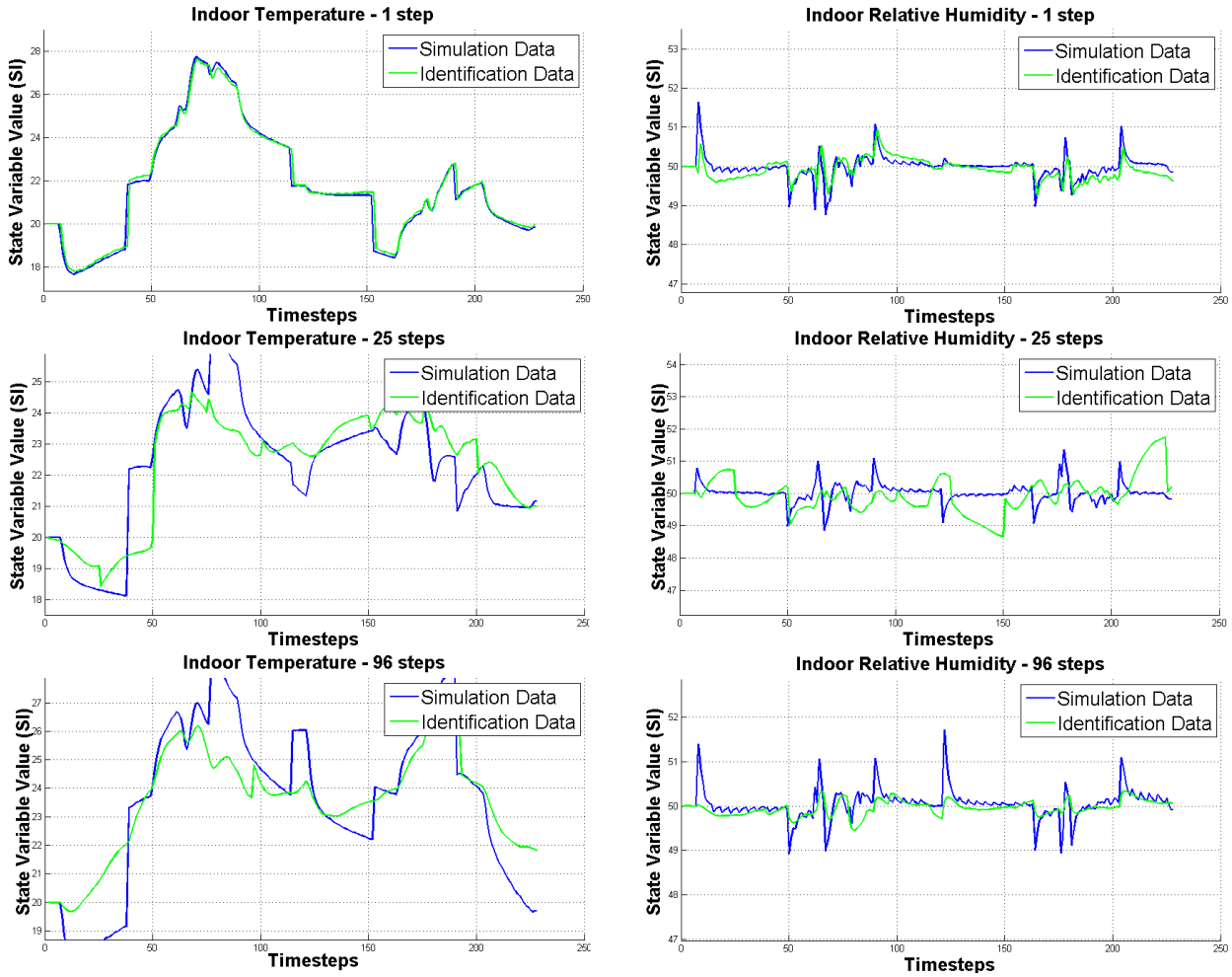


Fig. 4: ID results for indoor temperature in °C (first column) and relative humidity in % (second column) with different state resetting frequency f (different prediction horizon for each row)

Table 1: Identified model summary of results, for three different state resetting frequencies (different prediction horizons)

Steps (1 Step = 0.25 h)	*Prediction Horizon 1*	*Prediction Horizon 25 (6.25 h)*	*Prediction Horizon 96 (24 h)*
Number of mixing functions	2	3	2
Training Period Error (%)	0.9	4.7	6.6
Validation Period Error (%)	1.1	4.5	14.7

6. Conclusion

A system identification approach was proposed in this paper. The identification of a multi-linear state space model which is viable to describe the thermal dynamics of an office building for the near future – based on (simulation) training data from the past – was successfully demonstrated. In this paper simulation data from a validated TRNSYS model of an office building were used for demonstration, but practically these data may stem from measurement data of a real building. Real building data, describing usual operation of the building, however, might not lead to sufficient excitation, which is needed to obtain a "good" model. The idea of mixing signals as weighted factors for the linear sub-models to form the multi-linear state space model proved to work very well if the current state is updated frequently. As the update frequency is increased the modeling error increases significantly for the training period, but especially for the validation period.

Acknowledgements

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7. References

[1] KLEIN, S., BECKMAN, W., MITCHELL, J., DUFFIE, J., DUFFIE, N., FREEMAN, T., MITCHELL, J., BRAUN, J., EVANS, B., KUMMER, J., URBAN, R., FIKSEL, A., THORNTON, J., BLAIR, N., WILLIAMS, P., BRADLEY, D., MCDOWELL, T., KUMMERT, M., ARIAS, D., AND DUFFY, M, "*A TRaNsient SYstems Simulation Program – TRNSYS 17.00.0019",* Manual. Solar Energy Laboratory, University of Wisconsin-Madison, 2010.

[2] SCHLEGEL K.. "*Dokumentation und Analyse eines innovativen Forschungs und Demonstrationsgebäudes"*. Master's thesis, 2001.

[3] HAUSER G., KAISER J. "*Technical Measurement Investigations of an Office Building Characterised by Low Energy Use and High Thermal Comfort*", 7th Nordic Symposium on Building Physics in the Nordic Countries. Proceedings, page 8, 2005.

[4] PICHLER, M., DRÖSCHER, A., SCHRANZHOFER, H. "*Simulation-Assisted Building Energy Performance Improvement Using Sensible Control Decisions",* BuildSys'11 Seattle. 2011.

[5] GIANNAKIS, G., PICHLER, M., KONTES, G., SCHRANZHOFER, H., ROVAS, D. *"Simulation speedup techniques for computationally demanding tasks".* International Building Performance Simulation Association. Building Simulation Conference Paris, 2013.

[6] CEN. "*Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculations of PMV and PPD indices and local thermal comfort criteria".* Österreichisches Normungsinstitut, 2006.

Storepet – European Project of an Innovative Thermal and Acoustic Insulation Solution for Construction Materials



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Short Summary

The Construction Cluster „DUNDJER“ participates together with number of distinguished research and development organizations in EU, in the 7th FP European project entitled STOREPET (FP7-SME-2011-2, Proposal 286730). STOREPET is a project which goal is develop an innovative thermal and acoustic insulation solution based on phase change materials in building sector. StorePET will be especially designed for lightweight and low thermal mass building envelope structures, as well as for any other residential/commercial/governmental new or refurbishing building projects, with extra insulation and heat storage capacities needs. With a project budget of € 2.4 million, it has been estimated that the new product will produce new streams of revenue worth € 170 million in the materials and energy savings worth above € 300 million. The research is at a moment in progress. One of closing meetings, with presentation of final research results will take place in Niš, Serbia, in the year 2013. The Construction Cluster „DUNDJER“ will have all rights and royalties, including regional production and merchendise.

Key words: building materials, thermal insulation, acoustic insulation, light building constructions, energy efficiency, sustainable building.

1. INTRODUCTION

New building strategies addressing climate change effects and reduction of heating/cooling energy are two fundamental issues at EU level. Figures as the 35,000 excess deaths attributed to the last heat wave in the continent in 2003, or 10% of the world’s energy being used just for heating of buildings support European citizen’s concerns and new EU legislation. New national and communitarian stringent directives, together with the economic slump of the construction sector (showing two digit shrinkage rates) have set extremely high challenges to the already weakened companies in the construction sector, especially the SMEs. A market need and a new opportunity for them is researching competitive solutions for thermal and acoustic insulation of light-weighted constructions, a broadly recognized market driver for the next decade. Lightweight constructions represent an economical alternative to traditional buildings, one of whose main drawbacks is the very high energy load needed to keep internal comfort conditions, as they are unable to curb rapid swings of temperature. When compared to heavier weight materials buildings, it’s estimated that to maintain a thermally comfortable temperature range of 18-24°C, low weight materials use between 2 and 3 times the heating and cooling energy needed by a heavy weight material construction.

2. PROJECT DESCRIPTION

The project concept is based upon the fact that outdoor/indoor heat exchanges (which play a significant part of lightweight buildings cooling and heating loads) can be potentially controlled by a new fibre insulation that possesses a thermally active heat storage capacity. During the day, when temperature rises, the peak loads can be largely absorbed by a PCM-enhanced fiber insulation layer, only to be slowly discharged back to the environment later (during the night time, when outside temperature drops), without affecting the interior building energy balance, as it is aided by the presence of an standard low heat transfer fiber insulation layer. This approach will provide a much slower response of the building envelope to daily temperature fluctuations, helping maintaining inside temperature in a comfortable range and thus avoiding the need for extra energy consumptions to accomplish it. Effective levels of indoor comfort will be also guaranteed by the well known fiber materials excellence, when it comes to reduce airborne noise transmission and its superior performance upon controlling the sound resonance in construction cavities.

3. ENVIRONMENTAL CONTEXT

Currently buildings account for 40% of the world‘s energy and almost half of the today‘s Green House gas emissions. This means that buildings contribute more greenhouse gases than traffic, which is estimated at 31%, and industry, estimated at 28%. When we breakdown and analyze buildings‘ energy consumption, the most worrying aspect is that most of this energy used for heating, cooling or ventilation is needlessly wasted or resulting of poor insulation and all the recent projections claims that this consumption will rise considerably on the next years to come. Under this scope, the last Intergovernmental Panel on Climate Change (IPCC) recommendations has stated that worldwide governments, businesses and individuals must aggressively start to reduce energy use in new and existing buildings, in order to reduce the planet‘s energy-related carbon footprint by 77% (against the predicted 2050 baseline), and stabilize CO_2 levels to reach the level called by IPCC. To reach this objective it‘s estimated that global building sector needs to cut energy consumption in buildings 60% by 2050, in order to meet the global climate change targets.

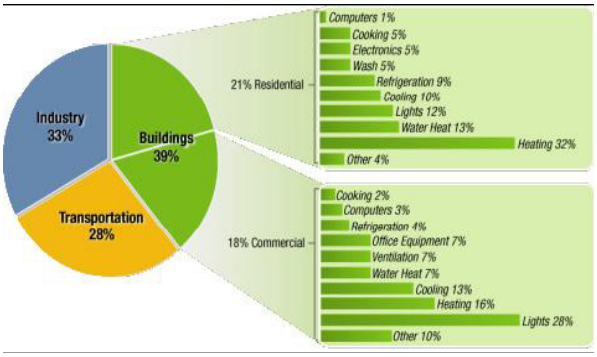


Fig. 1. : Distribution of world energy consumption

With such high levels of energy consumption clouded by severe climate change estimations, the European Community (EC) has triggered a significant number of regulatory and legislative actions. In March 2007, the European Council set clear goals for a reduction of 20% by 2020 in the total energy consumption (below 2005 levels), with a 20% contribution of renewable energies to total energy use and a 20% reduction of greenhouse gas emissions with respect to 1990 figures. In this context, the building sector must assume very ambitious objectives on energy consumption cuts of around 165 Mtoe (millions of tons of oil equivalent) and contribute with 50 Mtoe from renewable energies by 2020. To underline the magnitude of the task, these figures are equivalent to the total joint energy consumption of Spain, Portugal, Greece and Ireland in 2004.
In May of 2010, the new *Energy Performance of Buildings (EPB)* Directive was finally adopted as Directive 2010/31/EU. It calls for improved national regulations upon new and renovated houses energy efficiency, with very ambitious standards and mandatory goals. It also includes a framework for national requirements, related with **heating/cooling** and ventilation systems. In July 2012, the

new directive shall be implemented, though many elements including the regulation of building systems will only be fully enforced by July 2013. By the end of 2020, new buildings in the EU must consume “nearly zero” energy.
With a current stock of around 160 million buildings in the EU, the latest EPB Directive also tack the retrofit of existing buildings, including historic ones towards an effective action against climate change. As for the new buildings, universal trends now show a movement towards lightweight and modular timber or steel constructions (with less site wastes involved and lower embedded energy materials), with global demand for prefabricated housing and elements growing at 3.4 % per year, for a market valued at €51 billion in 2004 for complete buildings alone.

4. THE CONSTRUCTION SECTOR CONTEXT

The construction sector is the one that has suffered most the yet present downturn, partly related to several significant construction bubbles, but also hardly affected by the financial institutions‘ credit crisis.
In particular, focusing on the segment of lightweight prefabricated housing of the building industry, consisting of wood or light steel frame (LSF) and panelized pre-cut structures is expected to show in the next decade the largest growth in terms of novel solutions and production worldwide. Within this segment one of the most important subjects related with building‘s energy efficiency is the use of appropriate insulation materials, both for warm and cold climates (air conditioning is no longer considered an energy-efficient alternative as it accounts for almost 15% of the total energy consumed in Europe). Boosted by present and provisional needs, worldwide consumption of insulation materials is projected to expand 3.8% per year through 2012.. Maintaining the last decade trend, foamed plastic insulation will continue to account for the largest portion of total demand through 2012. Economic expansion in the developing countries of Asia will raise the demand, preferably for foamed plastic, both in building construction and in the production of household appliances. Fiberglass insulation is expected to expand its presence outside of North America (mainly Europe, Asia and all the BRIC - Brazil, Russia, India, and China), while mineral wool will see its share of the market shrink due to the competition of glass wool. Other fiber alternative materials mostly made from recycled materials, like nonwoven technical insulations, will continue to be niche products if they don‘t endorse and push forward their performance.
The increasing demand for energy-saving technologies has contributed to a renewed research for thermal materials that can actively control heat flux environment variations - Phase Change Materials (PCM). The global PCM market is expected to grow from $300.8 million in 2009 to $1,488.1 million in 2015, at an estimated CAGR of 31.7% from 2010 to 2015. The paraffin-based PCM market commands the largest share of the overall PCM market in terms of value, while salt hydrate-based PCMs lead the market in terms of volume. Building and construction currently forms its largest application market, due to the globally increasing demands for indoor temperature control.
European companies in the increasingly knowledge-intensive construction sector need to react quickly to this situation and develop more protectable innovative solutions to remain innovative. In particular, the requirement of higher energy efficiency for buildings has been identified as the primary driver for the construction materials industry. StorePET will provide this EU sector and particularly to the SMEs an excellent knowledge-based competitive tool to ease the recovery and face the near future challenges of our Construction Sector.

5. THE TECHNICAL PROBLEM

Lightweight constructions represent an economical alternative to traditional buildings, one of whose main drawbacks is the very high energy load needed to keep internal comfort conditions, as they are unable to curb rapid swings of temperature. When compared to heavier weight materials buildings, it‘s estimated that to maintain a thermally comfortable temperature range of 18-24°C, low weight materials use between 2 and 3 times the heating and cooling energy needed by a heavy weight material construction.

When comparing the two types of constructions, studies have showed the heavyweight construction could suppress more easily the effects of possible climate change scenario, by maintaining a lower internal temperature than the lightweight construction for most of the time period, with peak temperatures up to 4.5°C cooler. Other studies have revealed that the difference between the peak external and internal temperatures can reach 8º C, when comparing both structures and that a peak temperature delay up to 6 hours can be observed, these delay and amplitude being a complex function of the wall thermal conductivity, the specific heat and several local temperature gradients around wall surfaces. The reason for this huge difference lies on the different thermal mass presented by the two types of constructions. In the case of dwellings for instance, the heat storage and thermal mass properties can vary significantly from 55kJ/m2K for a lightweight timber frame construction to 500kJ/m2K for a solid masonry construction. Thus, thermal mass can be hugely helpful to maintain indoor thermal comfort. Lightweight buildings have a “quick thermal response” and will heat up and cool down over a shorter period than heavyweight building that have a “slow response” (see Fig. 2).

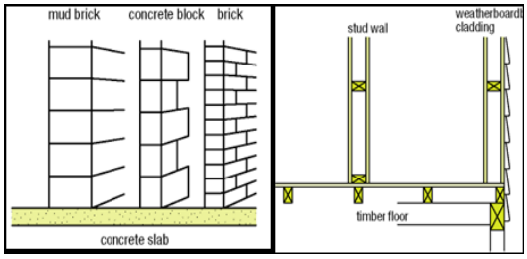


Fig. 2. Materials with high (left) and low (right) thermal mass capacity

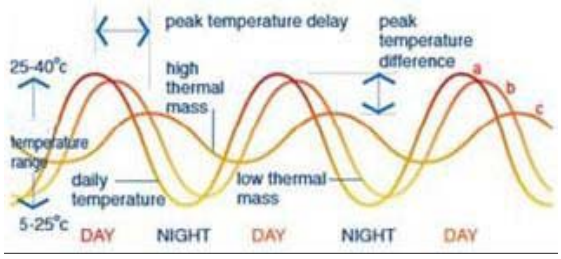


Fig 3. Daily temperature range fluctuations

Thermal mass is most effective in places and in seasons with large daily temperature fluctuations above and below the balance point temperature -BPT- of the building (BPT is the outdoor temperature below which heating will be required in the building because internal heat gains are less than heat loss through envelope and ventilation). In such cases substantially energy is saved by avoiding a significant portion of heat flux being transferred through the envelop backward and forward. Often, the benefits are greatest during summer and fall, when fluctuations above and below the comfort temperature occur. Nevertheless, the same concept can theoretically be used to moderate heat flux under either extreme cold conditions or extreme warm conditions, where outer temperature ranges are well above or below the comfort temperature.

When outdoor temperatures are at their high peak in warm climates, the inside of the building remains cool because the heat penetration through the mass is delayed. If the heat that is stored during the day hours could be evacuated selectively to the exterior at night, the effect of the thermal mass would be very similar to a high performance insulator.

In cold climates requiring intensive heating, thermal mass can be used to effectively collect and store solar gains and to store internal excess heat during the day and selectively release it back inwards. Buildings using electric heating/cooling can simultaneously use off-peak hours enjoying cheaper supply tariffs as daily storing phase. The result will be a substantial net reduction in energy consumption and additional bill cuts due to cheaper electricity.

New European states‘ regulations are more and more concerned about energy efficiency of existent and future buildings and finally looking at **thermal capacity** as a key element for it. For instance, the new UK‘s Building Regulations, recently implemented on the 1st October 2010 refers that thermal capacity of all the internal and external construction elements must play a decisive role on this goal, and used to reduce the heating and cooling demands of a building. Onwards, it will not be enough to consider only the overall heat transfer coefficient (U-Value) of the building elements (level of insulation), but also their related effective thermal capacity per unit area - Thermal Mass Parameter (TMP).

Generally, highly insulated structures cannot efficiently substitute a lack of thermal mass. Thermal mass stores and re-radiates heat, while insulation stops heat flowing into or out of the building. A high thermal mass material is not generally a good thermal insulator and the best insulation material has almost no thermal mass. Thus, in harsh hot climate conditions, the only way to

maintain a comfortable temperature inside a lightweight building on a summer day without installing active air conditioning is to somehow increase its thermal mass. You can do it in traditionally manner with heavy building materials, or by introducing latent heat storage materials in its construction.
Up to now the only solution it's to combine different materials separately for maximum performance. While it is reasonably easy for the heavyweight masonry sector to do this, the quest for thermal mass by lightweight construction builders (that rely almost exclusively upon insulation), it's still seen as a battle that needs urgently to be won in order to stay competitive for the years to come. Although there have been a great deal of resources invested on research (mainly on the US), worldwide construction market is still waiting for economical products that can effectively combine the best of the two worlds (thermal insulation and thermal storage properties), without forgetting the noise insulation ability on a **single, affordable and easy to work product**.
The goal of this project is the development of a new thermally enhanced fiber insulation product solution with the help of phase change materials (PCMs). PCMs are substances with high heat of fusion (high latent heat storage) which, by melting and solidifying at a certain temperature, are **capable of storing and releasing large amounts of energy**. Heat is absorbed or released when the material changes from solid to liquid and vice versa. PCMs are been used for several years as thermal mass components in buildings with some degree of effectiveness upon building energy performance. Today, there are many commercial PCM products available in the market, either in the form of a single material, or in the form of integrated products placed on the interior surfaces of walls, ceilings or floors (such as PCM integrated gypsum wallboards, concrete, plasters, etc). These products are generally used to reduce indoor space day/night temperature swings, due mainly to diurnal solar gains through glazing, by storing autonomously the heat during the day and release it back during the night, providing an extra heat source to keep the inside comfort. To understand the extent of PCM technology upon energy saving possibilities, studies have found that an area of approx. 120 m² using an enhanced plaster with a microencapsulated (thin polymer container) paraffin wax PCM (with a maximum heat storage of 110 J/g), could match up about 40,000 kJ, corresponding to more or less than 11 kWh. This energy consumption is equivalent to the cooling performance of an air-conditioning unit with an input power rating of 4 kW, used at full capacity for 1 hour a day. For a predicted PCM working process for five hours a day during 10 weeks of significant hot weather a year, that would have the same effect as using air conditioning unit for 300 hours, which corresponds to an average saving of 228 €/year, considering the initial equipment investment.
However, none of today's building materials incorporating PCMs in a stand-alone product are designed either to perform as heat flux blockers through the building envelope (external walls and roofs), or as a noise insulator. **The StorePET project intends to overcome this market gap** and act differently from any other PCM available product, **using PCMs fiber incorporation technology to excel the extra advantage of the conventional fiber insulation work**, regarding the large temperature fluctuations that take place in residential attics or at the exterior wall surfaces of lightweight building structures.

6. THE PROJECT CONCEPT

The project concept is based upon the fact that outdoor/indoor heat exchanges (which play a significant role in lightweight buildings cooling and heating loads) can be potentially controlled by a new fiber insulation that possesses a thermally active heat storage capacity. During the day, when temperature rises, the peak loads can be largely absorbed by a PCM-enhanced fiber insulation layer, only to be slowly discharged back to the environment later (during the night time, when outside temperature drops), without affecting the interior building energy balance, as it is aided by the presence of an standard low heat transfer fiber insulation layer. This approach will provide much slower response of the building envelope to daily temperature fluctuations, helping maintaining inside temperature in a comfortable range and thus avoiding the need for extra energy consumptions to accomplish it. Effective levels of indoor comfort will be also guaranteed by the well known fiber materials excellence, when it comes to reduce airborne noise transmission and its superior performance upon controlling the sound resonance in construction cavities.

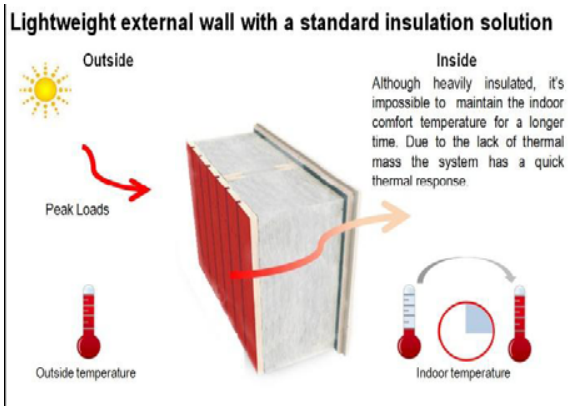


Fig. 4. Standard external insulation solution

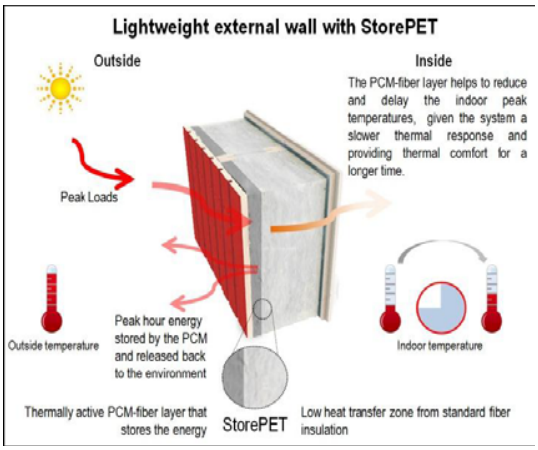


Fig. 5. External insulation with StorePET

From the point of view of energy efficiency design, the added value of the PCMs is its extra ability (on top of the thermal resistance) to reduce energy consumption in the building. The Fig.5. shows how StorePET solution would significantly reduce inside temperature fluctuation and therefore the needed heating/cooling load to keep temperature constant, in a scenario of high fluctuation of outside temperature.

The same conceptual solution when applied to extreme hot or cold temperatures would need different products (PCMs' fusion points, relative concentration and distribution along the matt cross section would be different to avoid external heat than to recover internal heat), and installation layouts (matt allocation, ventilation systems) would as well differ. Maybe the most notable difference is the convenience of an additional ventilation system to take full advantage of the thermal inertia provided by the PCMs.

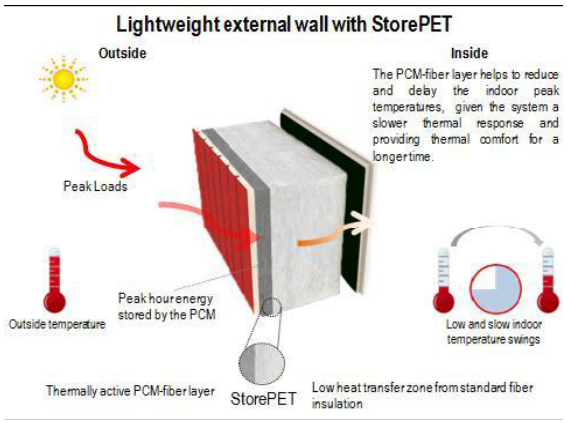


Fig. 6. Extreme high temperatures

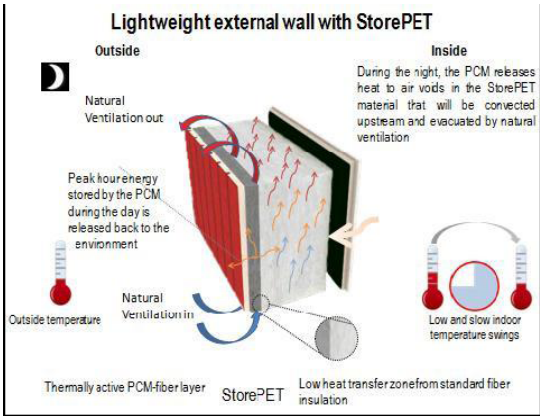


Fig. 7. StorePET with additional ventilation

The above figures (Fig. 6 and Fig. 7) intends to illustrate a scenario of extreme high temperatures. During the day, the PCM acts as a thermal barrier and only a fraction of heat reaches the inside, while the rest is stored in the PCM bat. When temperatures go down in the night (but yet above the comfort temperature), the bat warms up surrounding air. If properly ventilated, natural convection pushes warm air up and then out to the outside, refrigerating the PCM and avoiding storage heat to penetrate the building. An appropriate structure of the bat enabling air mobility in the plane of the facade and restricting the perpendicular direction will favor lateral convection for homogeneous refrigeration and vertical convection for evacuation. The design and manufacture of such a structure through a multilayered approach and other alternatives will be a relevant task of the non-woven panel research.

Although more suitable for warmer climates, while tailoring its composition with different phase change temperature materials and different installation layouts, StorePET will be able to respond to a broad range climate patterns. This will give it a unique and unmatchable versatility amongst other building insulation products. Out of each design temperature season, the product will just act like a normal fiber insulation material, keeping all other thermal and acoustic properties intact.

7. THE SCIENTIFIC, ECONOMIC, AND SOCIAL OBJECTIVES OF THE PROJECT

The main goal of the StorePET project is to develop a new nonwoven technical insulation product that integrates phase change materials for heat storage capacity skills. Maintaining the superior levels of thermal and noise insulation commonly recognized for fiber materials, StorePET will be especially designed for lightweight and low thermal mass building envelope structures, as well as for any other residential/commercial/governmental new or refurbishing building projects, with extra insulation and heat storage capacities needs. Although expected to be more effective in places and seasons with large daily temperature fluctuations, where it‘s possible to take full advantage of its performance abilities, this new product can also be used as standard insulation on any type of climates and a secure choice to counteract global warming rising temperatures.
To ensure that the project is a success we have defined clear objectives that are quantified, measurable and focused during the project‘s work package tasks program and continuing accounted on related deliverables reports.

7.1 SCIENTIFIC OBJECTIVES

- Achieve a clear and extensive understanding of the lightweight building systems currently available, their technical needs and most commonly thermal and noise insulation materials used, its relevant standards and building regulations dealing with the latest energy efficiency requirements;
- Clearly define the theoretical principles evolving thermal conductivity and heat storage and transfer behavior of PCM fiber composite materials, as well as the fundamentals ruling its acoustic absorption and insulation;
- Noticeably identify the best technical fiber characteristics and which PCMs materials and are most likely to be used, based on their thermodynamic, chemical and physics properties, production costs, and technological skills aiming the nonwoven PCM-fiber integration and its end using goals.

7.2 TECHNOLOGICAL OBJECTIVES

- Develop the product‘s design and the technology for its making by building a newly prototype line system for PCM-fiber integration and trial product manufacturing;
- Refine StorePET production technology, aiming to combine the best technical properties with the least embodied energy necessary for its production, using the most cost effective raw materials with the highest recycled content possible and least energy consuming production lines;
- Define the active ventilation systems that should accompany the installation of StorePET insulator, in areas of extreme absolute temperature but low fluctuation;
- Develop a software for thermal and acoustic properties evaluation aiming the design of the optimum StorePET product for a type of installation and a set of variables. It will bring an easy-to-use interface for professionals non highly qualified on the use of sophisticated simulation tools, but will relay on finite elements modeling, properties of raw materials, layer zone designs and climate patterns of the most plausible entrance markets.

7.3 PRODUCT TECHNICAL OBJECTIVES

- Achieve on a lab scale using a guarded hot box facility, reductions in heat flow of about 40% with the new PCM-fiber product, when compared on the equal conditions with the same fiber material produced without the PCM content;

- Achieve by field tests potential and significant cooling load reductions during a spring-summer season period. The fulfillment of this objective will be dependable on the location of these tests. For places with large daily temperature fluctuations during the hot season, peak-hour load reductions higher than 20% and cooling-dominated loads reductions up to 40%, shall be expected (representing real energy savings), when compared to regular fiber insulation materials (mineral wool, glass wool, etc.);
- Secure a thermal conductivity K (W/(mK)) not higher than 0,04 and preferably under this value;
- Accomplish a thermal resistance - RSI value (m²K/W) not less than 2,5 for a nominal thickness of 100mm;
- Achieve a noise transmission insulation (Rw) not less than 55dB for StorePET, when placed between a wall partition made of a double drywall panel, with a 6cm cavity space;
- Guarantee all the other technical requirements to meet the national and communitarian building codes and regulations for each proposed entrance market. Special emphasis shall be given upon moisture and fire resistance, this last one with European fire classification stated not less than Class Bs2d0.

7.4 ECONOMIC OBJECTIVES

- Accomplish significant energy savings concerning the reduction of air-conditioning needs related with the walls/roofs heat exchanges, and a controlled and balanced price for this new product, aiming a reasonable payback time for its end users considering the energy saving possibilities (within a maximum of 5 years).

7.5 SOCIETAL OBJECTIVES

- Increase the consumer (building constructors and home-owners) knowledge and acceptance of this new thermally enhanced insulation product;
- Demonstrate the market demand for a new building insulation material like StorePET;
- Protect/increase the employment in related companies, from raw materials and technical non-woven producers, to PCM suppliers, up to the overall building construction market chain;
- Increase citizen‘s level of indoor comfort and reducing health problems related with thermal and acoustic insulation issues;
- Contribute for the reduction of global CO2 emissions by joining the effort to effectively decrease the building sector account for energy usage.

REFERENCES

[1] EN 15459 *: Energy performance of buildings – Economic evaluation procedure for energy systems in buildings.*

[2] EN ISO 15686-5 : *Buildings and constructed assets — Service life planning - Part 5: Life cycle costing.*

[3] EN ISO 15686-9 – *Buildings and constructed assets – Part 8 Reference service life and service life information.*

[4] *Sustainability and property valuation: a risk-based approach*. Meins, Wallbaum et al. (2010). Building Research & Information 2010, 38(3), 281-301.

[5] Upgrading the flexibility of buildings, Rob P. Geraedts, CIB World Congress, April 2001.

[6] Recommendation SIA 112/1, 2004: Sustainable Building –Building Construction; Swiss Society of Engineers and Architects.

[7] Six steps resulting in a flexibility index of the building. Source: LEnSE: Methodology Development towards a Label for Environmental, Social and Economic Buildings, Indicator: Increase Ease of Building Adaptability.

Implementing dynamic load-bearing structures on a generic case study



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Short Summary

Nowadays most of the buildings cannot respond efficiently to changing needs of users and society due to the way buildings are designed and constructed. Labour-intensive renovation is often necessary; otherwise demolition of the building will follow. In both cases valuable building materials are lost and new raw materials are needed. Partly therefore, the environmental impact of the building sector is significant.
The need for new buildings materials and the production of waste could be minimized by implementing the time dimension in the design phase, in such way a building can change during its life cycle without ever being an end product. Namely by using compatible components and reversible connections, building components can be added and removed to fulfil new requirements. The removed components can be reused later on in a new configuration.

Therefore, in the context of this paper the impediments of implementing dynamic detailing and the dynamic potential of conventional load bearing structures will be explored. It will be examined how a structure constructed by using a conventional building method (masonry, timber skeleton structure, etc.) can pass into various usage scenarios: expansion, reduction, modifications of the skin, etc. This knowledge will be applied to a generic case study.
By doing this, it will become clear which building method can meet the imposed dynamic conditions and which usage scenarios the load bearing structures can fulfil. These results can be extended to other more specific cases.

Keywords: Generic case study; design for disassembly; detailing; load bearing structure; reuse of building components.

1. Introduction

Nowadays most of the buildings cannot respond efficiently to changing needs of users and society due to the way buildings are designed and constructed. Labour-intensive renovation is often necessary; otherwise demolition of the building will follow.
In both cases valuable building materials are lost and new raw materials are needed. Because of this, the building sector is responsible for 50% of the extracted resources [1]; and moreover, for example for Belgium, 30% of all waste is produced by construction and demolishing buildings.
Partly therefore, the environmental impact of the building sector is significant. The main part of construction and demolition waste is indeed recycled, but the recycling process occurs often with a quality descent by mixing different materials [2]. For instance concrete rubble is almost exclusive reused as foundation material for roads and only 5% of the concrete rubble is used again in

concrete applications [3].
The need for new buildings materials and the production of waste could be minimized by implementing the time dimension in the design phase, in such way a building can change during its life cycle without ever being an end product. [4] Namely by using compatible components and reversible connections, building components can be added and removed to fulfil new requirements. The removed components can be reused later on in a new configuration.
The last few decades design strategies and approaches were developed to facilitate change and the reuse of building parts; nevertheless dynamic building is still restricted to a small scale and specific functions, such as temporary / transitional buildings. A frequently cited reason of this restriction is the lack of constructional knowledge.

Therefore, in the context of this paper the dynamic potential of conventional load bearing structures will be explored. Can we use existing building products (perhaps with small adaptations) to build in a more transformable way? Or are there still some specific impediments?
In this paper the research is clearly defined in terms of building layers: only structural components will be taken into account; because this building layer has the biggest environmental cost compared to other building layers (Fig. 1).
If the structure can anticipate changing needs, the structure will last longer and its environmental cost will reduce. If for example, the structure can be removed when there is no demand any more on the initial site for this structure, and it can be reused in another configuration, the cost will diminish too. In a next research phase the building envelope, partitions, etc. can be taking along.

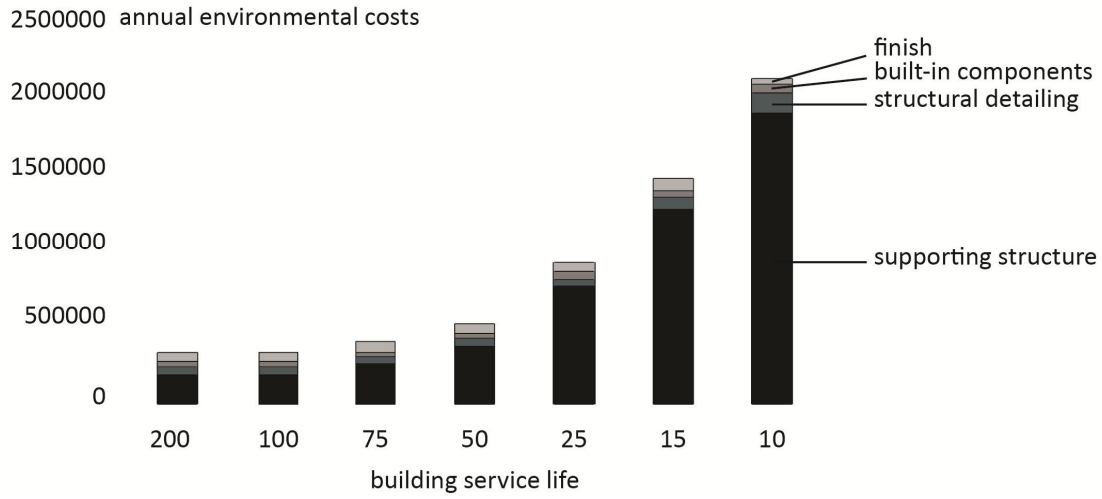


Fig. 1: The environmental load of a building in the case of different building service life scenarios and based on common lifespans of building components. Adapted from [5].

In a previous paper [6] it has been examined how transformable conventional building methods are. There are already adaptable building systems, but they need some adaptations in order to anticipate better changing needs. Those systems will be improved firstly. In a next part it will be explored which scenarios the case should be able to pass into, e.g. expansion and reduction of a basic unit. Finally, those scenarios will be tested on the original and the improved building systems. By doing this, it will become clear which building method can meet the imposed dynamic conditions and which usage scenarios the load bearing structures can fulfil. These results can be extended to other more specific cases.

2. Transformable building systems

2.1 Introduction

Dynamic building systems according to different conventional building methods (masonry, loam structure, etc.) are examined in this section. There will be looked at existing building systems; and if necessary they will be improved.

The characteristics of the components, which will be used to evaluate the transformability are established by literature of Durmisevic [7], Nordby [8], and Paduart [9]; more information can be found in [6].

2.2 Masonry

A large part of the conventional Belgian (new-built) constructions are made of load-bearing masonry with timber beams or concrete floor plates. Most bricks, the components of masonry, are physically suitable to be reused repeatedly. [10] However, when needs change, and therefore renovation or demolition is required, it is difficult to separate the components without damaging them due to the use of cement. The cementitous bricks can be recycled, but this often occurs in an inferior way. It is therefore necessary to examine how bricks can be connected in order to optimize their reuse potential and to respond to changing needs.

A conventional load-bearing masonry has already some good (convertible) properties. For example it is made out of small, light-weight components, namely bricks. This has the advantage that when reusing the components a total different configuration can be made and that the components are easily to handle. Nevertheless, due to the small dimensions, there are a large number of components needed to build for example a wall and by this large number the amount of (dis)assembly sequences on site increases too, which is often a bottleneck for disassembly. [7] Offsite pre-assembly of several building parts provides a possible answer to this problem.
The dimensions of the bricks are standardized according to the method of production, the origin, but the different types of bricks are not mutually compatible. This is unfortunate because compatible bricks could give more architectural flexibility in the reuse phase.
Finally, the influence of a conventional structure on other building layers with different life spans is a major disadvantage. For example the space plan is mainly fixed by the monolithic bearing walls, while according to Brand the space plan changes every 3-30 year and the structure remains sometimes up to 300 years. [11]

SRB-DUP structure (Fig. 2) is an alternative for masonry where building components are unbounded in order to facilitate reuse by using steel plates and bolts. [12] The system consists of a new sort of brick with two holes.
There is another type in the making, namely a smaller variant of Legioblocken®, the Q-bricks (Fig. 3), made of rubble waste. [13] Steel beams transmit the horizontal loads. At the moment, research is going on to use the stones for emergency sheltering. The bricks are held together only by their own weight and can be reused immediately after use. The small, standardized stones could be piled up by one person. Still, the small dimensions cause a large number of components and connections.

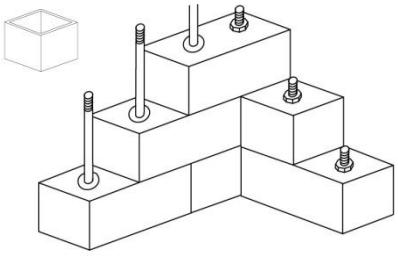


Fig. 2: Existing dynamic alternative for masonry, SRB-DUP structure

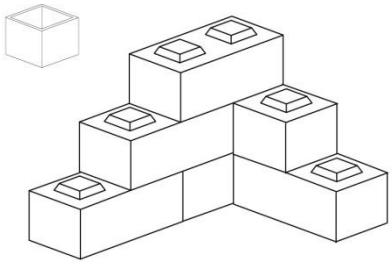


Fig. 3: Dynamic alternative for masonry (in the making), Q-bricks

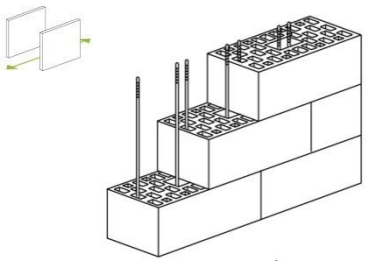


Fig. 4: Improved dynamic alternative for masonry

The influence on the other building layers remains large for both alternatives; and pre-assembly is difficult due to the size of the monolithic entirety. Additionally, for Q-bricks pre-assembly isn't possible due to the way of connecting the bricks.
To propose a possible better alternative there must be worked on the static characteristics of the above mentioned building systems. A boundary condition of the new version is that it should be based on existing products. This ensures an easier application for everyone in the building sector.

The new proposal consists of breeze blocks and steel rods with thread (Fig. 4). The bricks are placed layer by layer over the rods. When an entire wall is built, the stones are tightened with bolts. In this way, a wall can be preassembled. Furthermore, horizontal loads are carried by timber beams. An additional improvement of the SRB-DUP structure could be a single bearing direction. If necessary, small wall elements can be placed to capture forces in the plane of the load-bearing wall, for example, wind loads. This modification reduces the influence of the structure on the other building layers. By making it possible that some parts of the structure can be removed and added independently, this alternative for masonry can be even more easily pre-assembled and adapted.
This proposal should be able to react better on changing needs. Nevertheless, some studies suggest that the environmental costs of using steel bolts will be too high and that historic brickwork with lime mortar could be a better environmental solution with the same salvageability potential. [14] For this reason historic brickwork will be evaluated too in this paper.

2.3 Loam structure

Loam construction is the outsider within stack work. This traditional construction method is rediscovered the last decennia but is still only sporadically used despite of many advantages, e.g. optimal indoor climate and minimal CO_2 emission.
If loam is used as a structural material, a vertical supporting element can be made of loam stones connected with loam mortar (Fig. 5) or of a loam mixture rammed in a formwork (Fig. 6). Those elements can fulfill a supporting function, even up to six storeys high. Horizontal bearing elements can be built out of rammed loam or loam stones sandwiched between wooden lattice beams. [15]
The loam mortar is a reversible connection if moistened. The stones and rammed loam walls can be recycled too if moistened; and they can take a different form. However, there was no evidence found that loam stones may be reused as a new component after use.
The proposed alternative (Fig. 7) is similar to the proposal for masonry; the only difference is the material. The brick itself is comparable to a clay block, proposed in [16] that is optimized in terms of mechanical resistance, weight, economically sensible drying, and thermal capacity. But instead of using loam mortar, bolts and steel rods with thread are used. Horizontal loads are supported by timber beams.

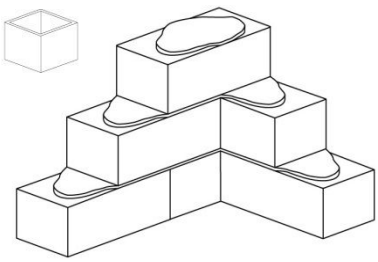


Fig. 5: Loam stones connected with loam mortar

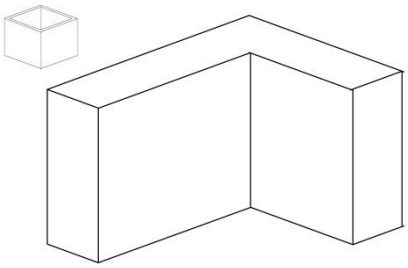


Fig. 6: Monolithic rammed loam wall

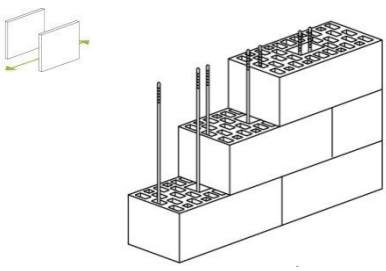


Fig. 7: Dynamic alternative for loam structure

2.4 Massive wood construction

Despite solid wood construction is little used in Western Europe; the opportunities of this construction method are analysed, as it has a great potential reuse without a large footprint.
For example logwork, a traditional solid timber construction, consists of tree trunks, which are cut into equal lengths and stacked without using additions. By lopping the trunks at the ends the different load-bearing walls form a monolithic entirety (Fig. 8). This construction process can be easily executed by two people because the trunks weigh relatively light and are easy to handle. Furthermore, the workforces do not need any special knowledge during the building process.
The components, in this case, the tree trunks, are large, compared to for example components of traditional masonry, which implicate that the number of required components is lower and thus also the number of connections. However, due to the connection method, namely stacking, this building process is difficult to prepare off-site. The connection method is of course completely reversible, so the durable trunks can be reused. The cycle can be simple closed on material level too; since wood can biodegrade safely if no toxic substances were added [17].

A disadvantage of massive timber construction is, as in stack work, that building layers with a different lifetime depend on the structure. For example, openings in the facade should be included in the design of the structure and cannot be made afterwards in a simple way.

A contemporary alternative is Holz100 (Fig. 9). This is a prefabricated building system, which reduces the number of (dis)assembly sequences on site. Wooden planks are joined with dowels into large solid elements; and the different elements are connected to each other on site with nails. Although dowels are a reversible connection, the amount of dowels ensures that the elements are not quite easy to dismantle. Additionally, the Holz100-elements can have all possible dimensions without being based on a generative system, while the trunks used for log work are sawed in more or less standardized dimensions [18]. Finally, one recurring drawback of solid construction is the dependence of building layers with a different lifetime on the structure.
Klimablokken, designed by the architect Berge [19], respond to these disadvantages. He opted for smaller standardized modules that can be concatenated by dowels to major elements (Fig. 10). In this way the blocks can be preassembled, but they can be put together and be taken apart on site too by for example a homebuilder. Timber beams carry the horizontal loads. As the building system can be easily disassembled, the building layers with different lifespans depend less on the structure. The facade could be changed for example, by linking the blocks into another configuration.
As with masonry a single bearing direction of the blocks could be an improvement, wherein the load-bearing walls could be separated into several parts.

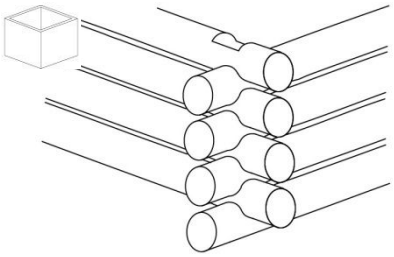


Fig. 8: Traditional building node of massive timber

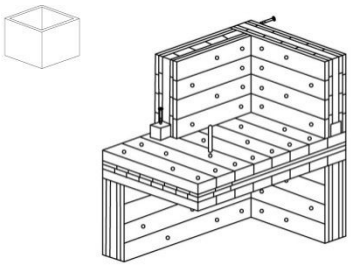


Fig. 9: Existing dynamic alternative for massive timber, Holz100

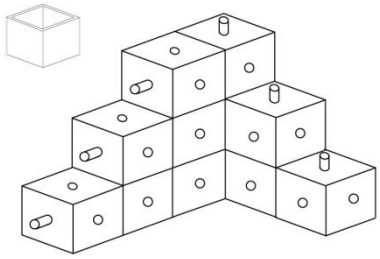


Fig. 10: Existing dynamic alternative for massive timber, Klimablokken

2.5 Skeleton, element and plate structures

Skeleton structures have the advantage that other building layers are little influenced by the structure. For example, the space can be divided and used in freedom, considering only a few columns. Wooden, steel and concrete skeleton structures have this advantage. Moreover, steel can be recycled with the same quality and wood has also the additional benefits mentioned in the preceding section related to the material: a low environmental impact and biodegradable.
Additionally, the components of both building methods can easily be disassembled and reused if the components of the skeleton structure are connected as in Fig. 11 and Fig. 14, namely with bolts. To facilitate disassembly for concrete structures, anchored screws can be used (Fig. 17).

Wooden and concrete components are traditionally not standardized, but rather project dependent. There exist, of course, all ready building systems which have been standardized, such as Lukas Lang® (Fig. 12) and CD20 (Fig. 18). Conventional steel structures are standardized, but the dimensions are not always compatible. Quicon® (Fig. 15) is a possible dynamic alternative for steel skeleton structures.

The components are in all cases larger than brick, which makes the construction process faster, but which will also increase the weight and decrease the ease of handling.

Another wooden building method is timber element construction (Fig. 13). Horizontal laths connected with vertical laths with nails ensure the structural working. As a result, it contains more components than a skeleton structure, but less than a stack work construction. As a result, most

dynamic properties are in between the properties of the two other building methods.
However, if screws are used to connect the vertical and horizontal laths, the elements could be easily disassembled and could give a higher freedom than skeleton structure in the reuse process.
Steel studs are comparable (Fig. 16) to screwed timber element construction.
Another concrete building method is concrete plate structure, but cannot be disassembled in smaller components (Fig. 19).
A single bearing direction of timber element construction, steel studs and concrete plate structure could be an improvement in order to reduce the influence of the structure on the other building layers.

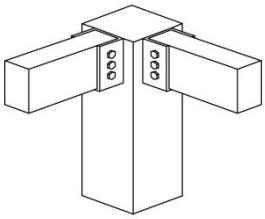


Fig. 11: Bolted building node of timber skeleton

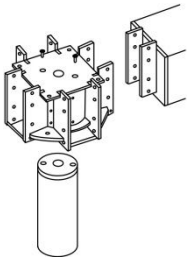


Fig. 12: Dynamic alternative for timber skeleton, Lukaslang®

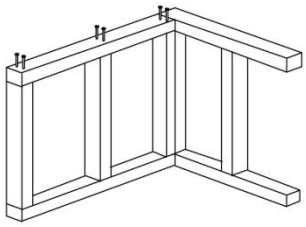


Fig. 13: Timber element construction

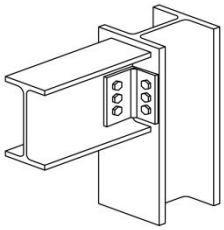


Fig. 14: Bolted building node of steel skeleton construction

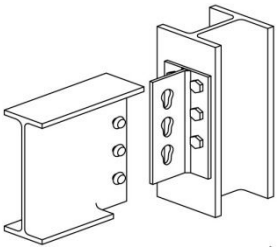


Fig. 15: Existing dynamic alternative for steel skeleton construction, Quicon®

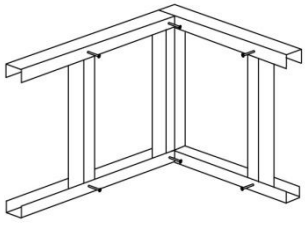


Fig. 16: Steel studs

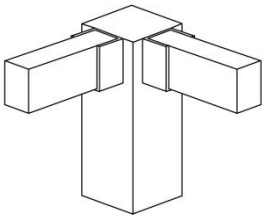


Fig. 17: Anchored screwed concrete skeleton construction

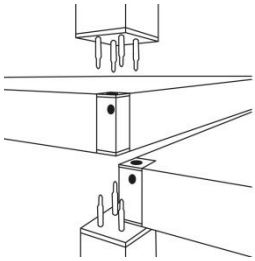


Fig. 18: Existing dynamic alternative for concrete skeleton construction, CD20

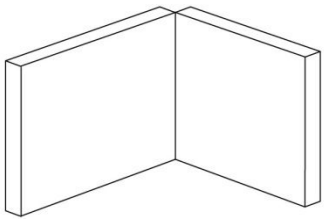


Fig. 19: Anchored screwed concrete plate construction

2.6 Conclusions

In this section most conventional building methods were discussed. A summary was given of the mean dynamic properties of existing building systems. Only some small adjustments were suggested in order to anticipate better changing needs. Solid structures have more freedom if they are single bearing, and all conventional structures would improve their reuse potential by standardizing and making their components compatible. By using steel bolts preassemblies can be made of clay and loam bricks; and they can insure an uncoupling into different building elements.
Those proposals should be further elaborated both theoretical and practical. It should be examined whether there is actually an environmental benefit in applying those construction systems in the short and the long term and compared to existing systems.

3. Determination of possible scenarios

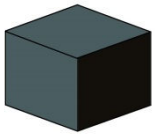


Fig. 20: Volume basic unit

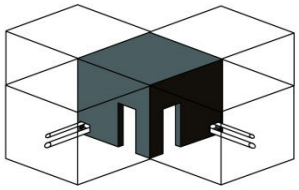


Fig. 21: Horizontal addition to the basic unit

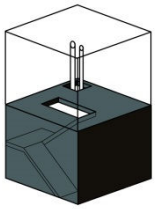


Fig. 22: Vertical addition to the basic unit

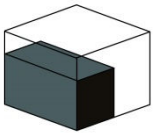


Fig. 23: Reduction

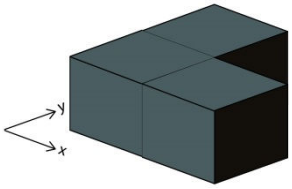


Fig. 24: Joining of two basic units

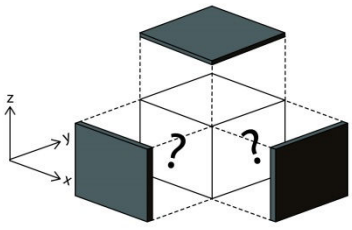


Fig. 25: Modifications of the skin

This section describes some possible usage scenarios for the load bearing structure, on which the abovementioned building systems should be able to anticipate. The scenarios are based on the chapter ‘A manual for flexible housing’ from the book ‘Flexible Housing’ written by Schneider and Till. [20] The included scenarios are the ones where the structure has a major influence on a possible anticipation. For example, if there is need to build an addition on an existing building, accessible from the base unit, there must be enough space in between the structure to build a staircase in order to access the addition. The scenarios were not included if the structure has little effect on a possible anticipation or if there are too many other boundary conditions beside the structure. For instance, a possible anticipation on a change of function (i.e. residential, commercial, office, and retail) depends on many factors, making it little sense to test the scenario on a generic case.

A basic unit consisting of one of the building systems, is the starting point for every scenario. Fig. 20 shows the borders of the structure. The coloured surfaces only indicate the total building volume and do not pass sentence whether it is composed of a skeleton structure or of a solid structure.
The basic unit has unspecified dimensions, because the dimensions depend on the load bearing capacity of the building system and the possible dimensions of the components; it can be considered that the extreme dimensions are approximately 3 by 3 meter.

In the first scenarios, there is a demand for expansion. It examines whether a horizontal and vertical addition is technically possible with the different building systems. (Fig. 21 and Fig. 22) This evaluation considers the connection between the addition and the base unit and doesn’t consider the load-bearing capacity of the base unit, because oversizing the initial structure (foundations included) will make every solution structurally possible.
Additionally, if the addition dependents on the base unit, the addition should be accessible from the base unit; and the services, like water supply, should possibly be extended.

The opposite of addition is a possible scenario too: a reduction in the horizontal and vertical direction of the basic unit (Fig. 23).
Fig. 24 shows how two basic units can potentially transformed into one large space; this scenario is evaluated for the two directions (x- and y-direction).

The following scenarios examine the influence of the structure on the facade (Fig. 25) and on the plan layout (Fig. 26). It is analyzed if the skin can be changed in all directions (x, y and z) without disturbing the structual working; and it must be possible to change the plan layout of the basic unit, whereby the layout is not limited to the boundaries of the building volume in the x- and y-direction.

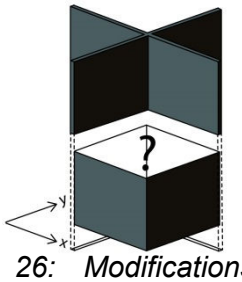


Fig. 26: Modifications of the space plan

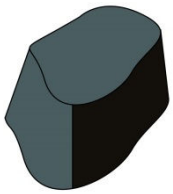


Fig. 27: Dis- and reassembly

The last scenario examines whether the basic unit can be fully disassembled and can be rebuilt in a new configuration () with different dimensions (height, width and length) and a different shape.
Moreover, the possibility of closing the cycle on material level is analysed too. The used materials could be biodegradable or upcyclabe. Upcyclable means that the materials can be recycled with the same quality; and biodegradable means the materials can be given back to nature for biological processes without danger, e.g. no toxic materials.

All other scenarios mentioned in [20] are already contained in another scenario. For example, the extension of the services is included in the scenario where a unit is added.
The described scenarios will be tested in the next section on the different building systems. It will be examined to which extent a particular scenario can occure.

4. Implementing building systems

The different usage scenarios are evaluated for the different building systems in this section. The evaluation is divided in two tables, one for solid structures (Table 1) and another one for other structures (Table 2).

It can be remarked in Table 1 that historic brickwork, Q-bricks, loam stone, rammed loam structure and Holz100 cannot response to various scenarios due to the monolithic volumes of those structures. For instance, a horizontal addition will not easily be accessible nor can services extend. For logwork components it is even impossible to connect a horizontal addition; a second independent structure will be necessary. The other building systems can foresee an access and an extension of the services, because structural elements can be more easily uncoupled.
A vertical addition is easier to implement, especially for the building methods which transfer horizontal loads by beams, because the addition can be accessed and services can extend in between the beams, although the direction of a circulation core is decided beforehand by the beams.
For historic brickwork, Q-bricks, logwork and Klimablokken a vertical reduction can be fulfilled by removing components. For historic brickwork and Klimablokken this is a rather labour intensive process. The SRB-DUP based systems cannot have a vertical reduction, because of the continuous steel rods. As structural elements can be easily uncoupled for SRB-DUP, dynamic loam and Klimablokken, a horizontal reduction can be made for those building methods.
Joining of units is not possible for monolithic building methods nor are changes to the space plan executable. The other single bearing building methods can join units in only one direction, namely the one that isn't supporting the structure; equal for changes to the space plan.
Changes to the skin are comparable too, except the use of beams can facilitate changes to the roof.
Loam stone and rammed loam have reversible connections, but the components will possibly deform during the disassembly process (i.e. humidification of the mortar), so reuse will probably be impossible. The components of the other building methods can be reused. The difference between the reused components lays in the form- and dimensional freedom; namely the smaller the components are the more freedom the new configuration has. Additionally, wooden components can be biodegraded, loam can be upcycled, but backed clay bricks cannot biodegrade or upcycle.
Finally, it can be concluded that the proposed adaptions have indeed a dynamic effect compared to existing dynamic building systems. The modified building systems can give easier access to additions; they can extend services; joining of units and changes in the space plan are now possible in already one direction and reductions and changes to the skin are more easy than before for most adapted systems. Moreover, when reusing the components, they provide more form- and dimensional freedom.

Table 1: Evaluation scenarios solid structures

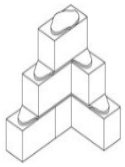
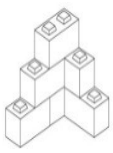
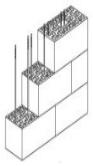
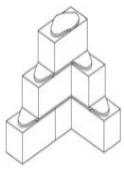
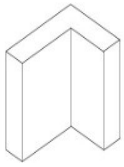
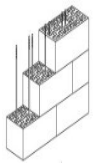
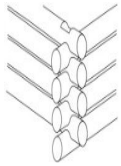
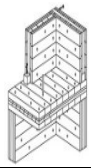
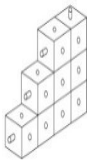
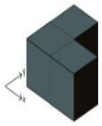
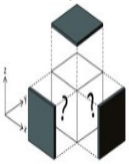
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Hor. addition 	Connect: + Access: - Services: -	Connect: + Access: - Services: -	Connect: + Access: +/- Services: +/-	Connect: + Access: - Services: -	Connect: + Access: - Services: -	Connect: + Access:+/- Services:+/ -	Connect: - Access: - Services: -	Connect: + Access: - Services: -	Connect: + Access: +/- Services: +/-
Vertical addition 	Connect: + Access: +/- Services: +	Connect: + Access: +/- Services: +	Connect: + Access: +/- Services: +	Connect: + Access: - Services: -	Connect: + Access: - Services: -	Connect: + Access: +/- Services: +/-	Connect: + Access: +/- Services: +	Connect: + Access: +/- Services: +/-	Connect: + Access: +/- Services: +
Reduction 	Hor.: - Vert.: +/-	Hor.: - Vert.: +	Hor.: +/- Vert.: -	Hor.: - Vert.: -	Hor.: - Vert.: -	Hor.: +/- Vert.: -	Hor.: - Vert.: +	Hor.: - Vert.: -	Hor.: +/- Vert.: +/-
Joining 	X-dir.: - Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.:+ Y-dir.: -
Change skin 	X-dir.: - Y-dir.: - Z-dir.: +/-	X-dir.: - Y-dir.: - Z-dir.: +/-	X-dir.: + Y-dir.: - Z-dir.: +/-	X-dir.: - Y-dir.: - Z-dir.: -	X-dir.: - Y-dir.: - Z-dir.: -	X-dir.: + Y-dir.: - Z-dir.: +/-	X-dir.: - Y-dir.: - Z-dir.: +/-	X-dir.: + Y-dir.: - Z-dir.: +/-	X-dir.: + Y-dir.: - Z-dir.: +/-
Change plan 	X-dir.: - Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.: - Y-dir.: -	X-dir.: + Y-dir.: -	X-dir.: + Y-dir.: -
Dis- and reassembly 	Reuse: Dim.: + Form: + Upc./bio: -	Reuse: Dim.: + Form: + Upc./bio: -	Reuse: Dim.: + Form: + Upc./bio: -	Reuse: disassembly impossible Upc./bio: +	Reuse: disassembly impossible Upc./bio: +	Reuse: Dim.: + Form: + Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: + Form: + Upc./bio: +

Table 2: Evaluation scenarios skeleton and element structures

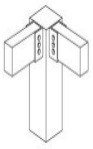
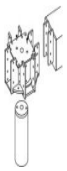
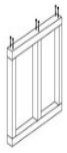
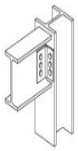
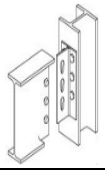
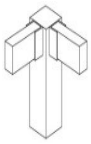
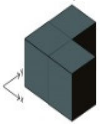
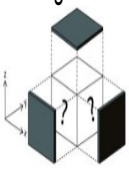
	Wood-frame	Lukas-lang®	Timber element vs.2	Steel skeleton	Quicon®	Steel studs	Concrete skeleton	CD20	Concrete plate
									
Hor. addition 	Connect: + Access: + Services: +	Connect: + Access: + Services: +	Connect: + Access: +/- Services: +	Connect: + Access: + Services: +	Connect: + Access: + Services: +	Connect: + Access: +/- Services: +	Connect: + Access: + Services: +	Connect: + Access: + Services: +	Connect: + Access: +/- Services: +/-
Vertical addition 	Connect: + Access: + Services: +	Connect: + Access: + Services: +	Connect: + Access: +/- Services: +	Connect: + Access: + Services: +	Connect: + Access: + Services: +	Connect: + Access: +/- Services: +	Connect: + Access: + Services: +	Connect: + Access: - Services: -	Connect: + Access: - Services: -
Reduction 	Hor.: - Vert.: -	Hor.: - Vert.: -	Hor.: +/- Vert.: -	Hor.: - Vert.: -	Hor.: - Vert.: -	Hor.: +/- Vert.: -	Hor.: - Vert.: -	Hor.: - Vert.: -	Hor.: - Vert.: -
Joining 	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -
Change skin 	X-dir.: + Y-dir.: + Z-dir.: +	X-dir.: + Y-dir.: + Z-dir.: +	X-dir.: + Y-dir.: +/- Z-dir.: +/-	X-dir.: + Y-dir.: + Z-dir.: +	X-dir.: + Y-dir.: + Z-dir.: +	X-dir.: + Y-dir.: +/- Z-dir.: +/-	X-dir.: + Y-dir.: + Z-dir.: +	X-dir.: + Y-dir.: + Z-dir.: -	X-dir.: + Y-dir.: - Z-dir.: -
Change plan 	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: +	X-dir.: + Y-dir.: -
Dis- and reassembly 	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: +/- Form: +/- Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: +	Reuse: Dim.: +/- Form: +/- Upc./bio: +	Reuse: Dim.: - Form: - Upc./bio: -	Reuse: Dim.: - Form: - Upc./bio: -	Reuse: Dim.: - Form: - Upc./bio: -

Table 2 contains skeleton, element and plate structures. At first sight it can be observed that those structures can, except for concrete plate construction, anticipate much more usage scenarios than the first mentioned structures. For all skeleton structures horizontal and vertical additions are possible; units can be joined; the building skin can be changed without constraints and space plans can be transformed. Timber element structures and steel studs have the same potential, except the freedom is limited in the load-bearing direction. For example an access through a load-bearing element is less obvious.
CD20 and concrete plate constructions are exceptions. Concrete plate structure and CD20 transfer horizontal loads by solid floor plates, which prevent vertical access, services extensions roof changes. Plates restrain for concrete plate structure horizontal freedom too, for example units cannot be joined perpendicular to the load-bearing walls.
For element structures a horizontal reduction can be fulfilled by removing parts of the structure. All other reductions are difficult, especially compared to some solid structures.
All proposed building systems have reversible connections, so all components can be reused. However, compared to solid structures, the components are bigger, which give less form- and dimensional freedom in the new configuration.
Additionally, steel can be upcycled, but concrete cannot biodegrade or upcycle.
For these structures no major adaptations were suggested, because they are already quite dynamic. Compatible components can improve their reuse potential, but the bad points are less easy to change. For instance, making reductions possible for skeleton structure is not easy to do, but the remark can be made that this scenario will less occur.

5. Conclusions

Existing building products only need some small adaptations in order to anticipate better changing needs. Solid structures can provide more freedom if they are single bearing; and all conventional structures would improve their reuse potential by standardizing and making their components compatible. By using steel bolts preassemblies can be made; and they can insure an uncoupling into different building elements. It can be concluded that the proposed adaptions have indeed a dynamic effect compared to existing dynamic building systems. The modified building systems can give easier access to additions; they can extend services; joining of units and changes in the space plan are now possible in already one direction and reductions and changes to the skin are more easy than before for most adapted systems. Moreover, when reusing the components, they provide more form- and dimensional freedom.
However, with or without adjustments, skeleton structures can pass into most usage scenarios more easily than solid structures. But, compared to solid structures, the components are bigger, which give less form- and dimensional freedom in a new configuration.

In this paper some small adjustments to existing building systems were suggested (e.g. single bearing, compatible and standardized dimensions) in order to anticipate better changing needs. However, those proposals should be further elaborated both theoretical and practical. It should be examined whether there is actually an environmental benefit in applying those construction systems in the short and the long term and compared to existing systems. For instance, some studies suggest that the environmental costs of using steel bolts will be too high. However, maybe for some scenarios and building systems this cost will be lower than the environmental gain. Off course those assumptions have to be evaluated more in detail with the aim to improve the suggested building systems.
In addition, the calculated cost of the systems in the short and the long term should be compared to existing systems too; and prototypes should be made and tested in terms of structural behaviour.
The evaluation of the scenarios can be more detailed in further research; for example the load-bearing capacity can be taken into account in order to know how many vertical additions are possible.
The research was in this paper clearly defined in terms of building layers: only structural components were taken into account. In a next research phase the building envelope, partitions, etc. should be taking along.

6. Acknowledgment

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7. References

[1] EUROSTAT. "*Waste statistics - long-term trends"*. 2008. [Online]. Available: http://epp.eurostat.ec.europa.eu/.
[2] OVAM. "*Bouw- en sloopafval: de helft van ons afval"*. 2011. [Online]. Available: http://www.ovam.be.
[3] VRIJDERS J, DESMYTER J. *"Een hoogwaardig gebruik van puingranulaten stimuleren".* OVAM, Mechelen, 2008.
[4] DORSTHORST B J H, KOWALCZYK T. *"Design for Recycling".* Design for Deconstruction and Materials Reuse, Karlsruhe, Germany, 2002, vol. CIB Publication 272, pp. 71–81.
[5] VAN DEN DOBBELSTEEN A. "*The Sustainable Office: an exploration of the potential for factor 20 environmental improvement of office accommodation".* Doctoral Thesis, Technische Universiteit Delft, Delft, Netherlands, 2004.
[6] VANDENBROUCKE M, DEBACKER W, DE TEMMERMAN N. *"Transformability of conventional and dynamic load bearing building nodes".* Proceedings CESB, Prague, 2013.
[7] DURMISEVIC E. *"Transformable building structures: Design for disassembly as a way to introduce sustainable engineering to building design and construction".* Ph.D. Thesis, Technische Universiteit Delft, Delft, 2006.
[8] NORDBY A S, BERGE B, HESTNES A G. *"Salvageability of building materials".* Proceedings SB07 - Sustainable Construction, Materials and Practices, Portugal, 2007.
[9] PADUART A, *"Re-design for change: a 4 dimensional renovation approach towards a dynamic and sustainable building stock"*. Doctoral Thesis, Vrije Universiteit Brussel, Brussel, 2012.
[10] GUY B, CIARIMBOLL N. *"Design for Disassembly in the Built Environment".* Seattle: City of Seattle, King County, WA, and Resource Venture, Inc. by the Hamer Center for Community Design, The Pennsylvania State University, 2006.
[11] BRAND S. *"How buildings learn: what happens after they're built".* Penguin Books, 1994.
[12] YAMAGUCHI K, MATSUFUJI Y, AND KOYAMA T, *"A new structural system: friction-resistant dry-masonry".* Building Research & Information, vol. 35, no. 6, pp. 616–628, 2007.
[13] CROLLA J. *"Van betonpuin tot Legiostenen".* Eindhovens Dagblad, 25-Aug-2012.
[14] NORDBY A S, BERGE B, HAKONSEN F, HESTNES A G. *"Criteria for salvageability: the reuse of bricks".* Building Research & Information, vol. 37, no. 1, pp. 55–67, 2009.
[15] VERSELE A. *"Moderne leembouwtechnieken".* VIBE vzw, KaHo-Sint Lieven, 2004.
[16] KOCH G, KUNZE C, SEIDL J. *"Loam construction - From a niche product to an industrial building system".* Proceedings SB05: Action for Sustainability, Tokyo, 2005.
[17] GELDERMANS R J. *"Cradle-to-Cradibility: Two Material Cycles and the Challenges of Closed Loops in Construction".* Thesis, Technische Universiteit Delft, Delft, Netherlands, 2009.
[18] NORDBY A S, BERGE B, HESTNES A G. *"Reusability of massive wood components".* Proceedings SB07 - Sustainable Construction, Materials and Practices, Portugal, 2007, pp. 600–606.
[19] BERGE B. *"Klimablokken".* Gaia Lista, 2006.
[20] SCHNEIDER T, TILL J. *"Flexible Housing".* Oxford, Elsevier, 2007.

Improving thermal performance of rammed earth walls using expanded clay aggregate



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Summary

The use of earth as a building material dates back to the beginning of our civilization. In the South of Portugal there is still a large number of buildings with rammed earth walls, but this technology has been falling into disuse since the middle of last century. The earth construction is highly sustainable since earth is a local material and is 100% reusable. The buildings with rammed earth walls have a high thermal inertia which, given the climate characteristics Portugal, improves its thermal behaviour. However, it is desirable that the thermal conductivity of the rammed earth were lower. Environmental concerns related to energy consumption associated with comfort in housing and construction, transportation and application of materials used in construction, has led us to seek new solutions in building typologies on earth.

Considering these aspects and improving the energy efficiency in buildings, this paper presents the results of tests performed in the laboratory on building new solutions on earth.

Geotechnical characterization of the soil used was made and various compositions prepared with the incorporation of expanded clay. The expanded clay was chosen as a thermal insulator made from raw materials available in the regions of Alentejo and Algarve (South of Portugal), which are the regions that are famous for using rammed earth in Portugal.

Compositions were considered soil and expanded clay having the following percentages of expanded clay: 0%, 10%, 15%, 20% and 25%. In order to characterize the different compositions from the point of view of mechanical and thermal performance, cubes were produced with 10 cm edge and assayed in order to calculate its compression resistance and its thermal conductivity. The results showed that the use of this type of building typologies on earth with the incorporation of expanded clay allows to increase your performance by making it possible to adapt this typology needs of today, including the demands of the Portuguese legislation. The results of this research can be applied, with the appropriate adaptations, both in buildings in rammed earth and in buildings in adobe.

Through the testing conducted, the value of the thermal conductivity of the soil sample was obtained and it equals to 1.08 W/m.°C. To a mixture of soil and expanded clay containing 25% expanded clay 2-4, we obtained thermal conductivity of 0.79 W/m.°C.

Keywords: Rammed earth walls, Energy efficiency, Expanded clay aggregate.

1. Introduction

Earth has been used as a construction material ever since the rise of sedentary human civilization based on agriculture. Its qualities are notable, particularly its durability: some existing earth buildings are over 3,000 years old. With the principles of sustainability now established in the mainstream, earth is of great importance as a building material: it is 100% reusable, requires a low level of energy input, is extremely durable, and can be locally sourced, while it does not require any form of industrial processing. Moreover, given its high thermal mass, it offers a high level of thermal inertia for buildings, and thus is particularly suited to climates characterised by large variations in temperature.

In Portugal, earth construction, and in particular building incorporating rammed earth or *taipa* walls is common in the Alentejo and Algarve regions. However, the use of this construction technique has gradually fallen into disuse, especially since the mid-20th century. As masters of the art disappear, we risk losing a fund of specialised knowledge required for selecting soil, determining optimum moisture content and implementing the technique itself: the placement and compression of the earth between wooden formworks.

Portuguese regulations governing the thermal performance of buildings (RCCTE – Regulation of Characteristics of Thermal Behaviour of Buildings*,* the provisions of which are contained in statute law: Decreto-Lei no. 80/2006 [1]) set out requirements regarding limits on the nominal consumption of energy during the cool season that are not easy to comply with when using the rammed earth technique.

The aim of this paper is to provide a contribution towards the improvement of the thermal performance of rammed-earth walls by examining techniques for reducing thermal conductivity. This study involved the use of expanded clay aggregate, which was mixed in different proportions with soil in order to gauge how thermal conductivity could be reduced without decreasing too much the compressive strength of the mixture.

2. Geotechnical and physical characterization

In order to determine the suitability of soil for rammed-earth construction, the physical and geotechnical properties of soil were determined and the soil characterized in accordance with Portuguese standards and LNEC - National Civil Engineering Laboratory specifications, as well as the information contained in the work entitled "*Construção em terra*" (Earth buidlings) [2]. Water content in soil was determined at the collection site, as well as organic matter content, particle size, and liquidity and consistency ranges; the Proctor test was carried out in order to determine optimum water content.

2.1 Geotechnical soil properties

Besides geotechnical and physical tests, Houben and Hubert [3] present a number of traditional tests. A visual assessment of soil colour is made to determine the quantity of organic matter in soil, and the presence of feldspar sand and quartz sand, as well as that of iron oxides in clays. A test of smell enables the identification of the existence of organic matter, for example compost, which promotes a rise in temperature and leads to soil humidification. A touch test determines whether a particular soil is sandy or whether it is a plastic or viscous, in accordance with the amount of clay which gives the sample surface its stickiness. Finally, a brightness test enables an assessment as to whether the soil is clay: a cut sample of moist soil will present a bright aspect if there is a predominance of clay. Similarly, there are other tests that were traditionally carried out by masters of construction using earth, as, in the past, laboratory soil analysis was not feasible prior to construction for the assessment of soil quality in terms of consistency after compacting and drying. In this paper,this type of analysis was not

performed, as physical and geotechnical tests were carried out to characterize the soil and had a low margin of error.

Some authors use Feret's triangle, which takes into account the proportions of sand, silt and clay in soil in order to determine a point in the triangle which characterises the soil. An assessment can be made as to whether soil is suitable for earth building, in the present case using rammed earth, according to whether the point lies within a predefined area [4], as shown in Figure 1.

In this study, the soil contained 58% gravel, 18% sand, 14% silt and 10% clay. Ignoring the gravel content and considering the remaining 42% of sand, silt and clay content as 100% of content, we have 18% sand corresponding to 43% of content, 14% silt corresponding to 33% of content and 10% clay corresponding to 24% of content in the triangle (Figure 1). These percentages enable a soil intersection point to be found, which in this case falls within the predefined area for rammed earth [4], as can be seen in Figure 1.

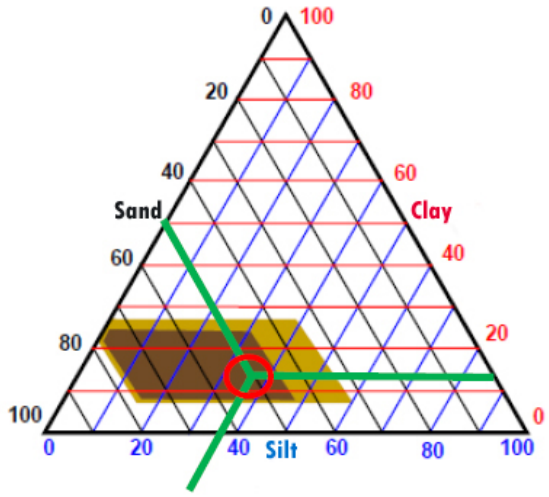


Figure 1 – Feret's Triangle: zone for the use of adobe bricks (dark area) and zone for the use of rammed earth (light area, which includes the dark area)

2.2 Mechanical soil properties (compressive strength)

As regards tests for the uni-axial compressive strength of samples, standard ASTM D 1633 - 00 was applied so that the periodicity used in tests would be adjusted for the time intervals between readings. Tests were performed after 21 days and after 28 days in order to gauge whether there were significant changes in strength. An increase in mechanical strength was shown to have occurred. In this paper, only the results of the tests performed after 28 days are presented, which are compared with samples of 100% soil (rammed earth) and soil with various mixtures and different types of material. Figure 2 shows that the compressive strength of samples of soil containing different percentages of expanded clay is not at all less, and by contrast there is a higher level of strength than for samples comprising only soil, with mixtures containing 10%, 15% and 20% of expanded clay.

Table 1: Strengths for rammed earth NZS 4297 [5]

Strength parameter	Stress (MPa)
Compressive strength (bending or simple compression)	0.50
Earth's shear strength	0.08
Tension strength due to bending	0.10

Table 2: Compressive strength for adobe and rammed earth according to type of stabilization [6]

Type of stabilization		Rammed earth (MPa)	Adobe (MPa)
No stabilization	Low resistance	0.60	0.75
	Average resistance	1.20	1.50
	High resistance	1.80	2.25
Stabilization with Portland cement	Low dose	3.00	3.75
	Average dose	4.80	6.00
	High dose	6.60	8.25
Stabilization with whitewash and Portland cement	Low dose	2.40	3.00
	Average dose	3.50	4.40
	High dose	4.80	6.00
Stabilization with whitewash	Low dose	1.80	2.25
	Average dose	2.40	3.00
	High dose	3.60	4.50

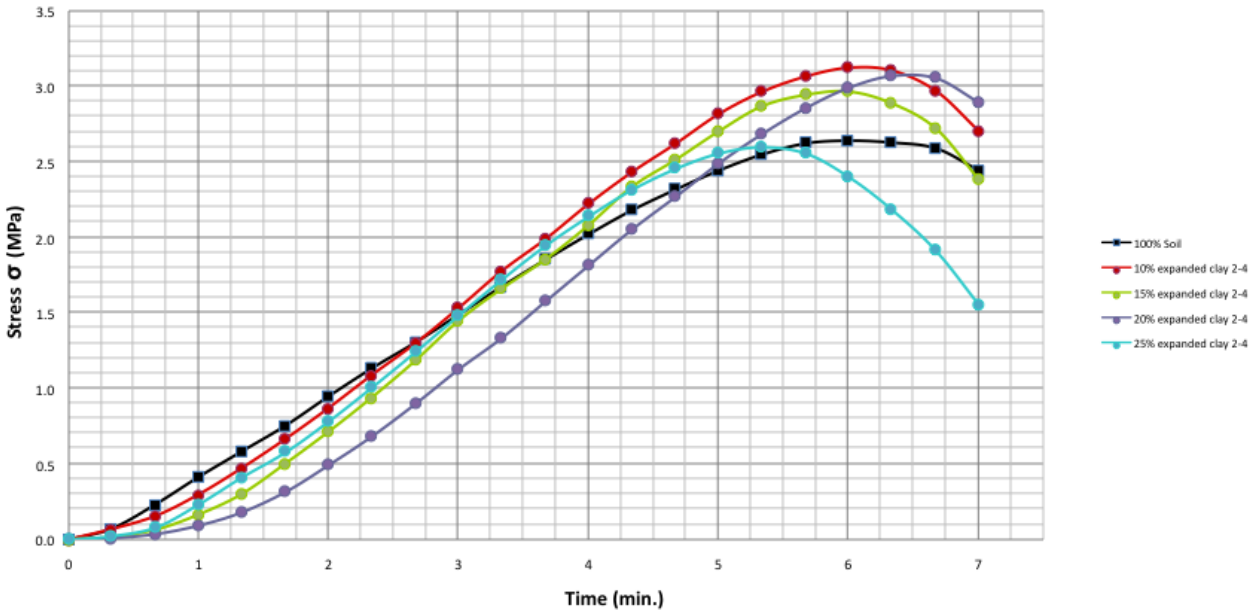


Figure 2 – Uni-axial compression tests for samples of soil with expanded clay 2-4

2.3 Thermal behaviour

The thermal conductivity (λ) of a material is a property which is essential for the characterization of its thermal behaviour and can be measured *in situ* or in the laboratory. There are several methods for measuring thermal conductivity in the laboratory. In this study, the thermal conductivity of samples which were identical to those used in tests to determine compressive strength was measured.

Thermal conductivity was measured using an ISOMET 2104 device (Figure 3), made by Applied Precision. Besides thermal conductivity, this device can be used to measure thermal diffusivity and volumetric thermal capacity, but in this study only the thermal conductivity of samples was measured. The ISOMET 2104 device allows for the use of various types of probes with different reading ranges. All readings were taken using an API 210412 surface thermal conductivity probe. Probes can be recalibrated using a standard method and each thermal conductivity measurement takes approximately 15 minutes to complete. Readings are

stored in the device memory and can be transferred to a computer by means of an RS 232 lead.



Figure 3 - ISOMET 2104 measuring device.

The cylindrical surface probe used for gauging the thermal conductibility of samples had a diameter of 60 mm (Figure 5), which means that the samples had to be bigger than this.

Thermal conductivity measurements were taken on the three sides of sample cubes which corresponded to one of three axes: X, Y and Z. Readings recorded on Side A correspond to the Y axis (Figures 4 and 5). This is the side on which readings are taken perpendicular to compression layers. Sides B and C correspond to the X and Z axes respectively, as shown in Figure 4, and are both perpendicular to compression layers. Of the sides perpendicular to the compression layers, the most regular sides were defined as B because they presented fewer cavities. Three readings were taken for each side of samples.

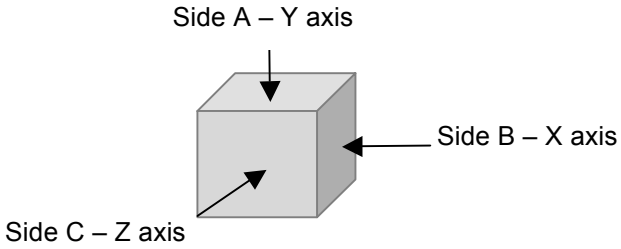


Figure 4 – Configuration of sample readings



Figure 5 – Determining conductibility on the different sides of a sample.

As thermal conductivity may vary from sample to sample of the same material (due to heterogeneity, degree of compaction, particle size) several readings were taken for the various soil samples. Thus, in addition to physical and geological characterization, it was felt that there was a need for characterizing the thermal conductivity of soil samples, which enables a reference value for thermal conductivity to be established for samples where other materials

are added to soil, that is, mixtures of soil and expanded clay aggregate. This allowed for the evaluation of the improvement of the thermal behaviour of samples through the addition of other materials, in accordance with the aim of this study: to find whether the thermal characteristics of samples can be improved in order to achieve a lower thermal transfer coefficient (U value). On the basis of the various measurements, an average thermal conductivity value – X axis – of 1.08 W/m.° C was obtained, with a standard deviation of 0.11.

In a rammed-earth wall, thermal flux occurs horizontally, hence perpendicularly to the direction in which compression occurs. Thus, the values of thermal conductivity obtained for the X or Z axes that are perpendicular to the direction of compression must be considered. Thermal conductivity values obtained for these two axes are analogous, thus X axis values were considered as this axis corresponds to B sides, which provide a greater level of reliability as they present fewer heterogeneities.

Values recorded for the thermal conductivity of samples containing different percentages of expanded clay of particle size 2-4 are presented. Thermal conductivity tests were performed on samples, as was done previously with samples comprising 100% soil (rammed earth), corresponding to the three axes: X, Y and Z. The conclusion was drawn that the findings that should be considered are those which relate to the X axis. X axis measurements are similar to the direction of the thermal flux of a wall.

Table 3: Thermal conductivity for samples of soil with expanded clay 2-4 (mean values and standard deviations)

Samples	λ (W/m.ºC)
100% soil	1.08 ± 0.11
Soil + 10 % Expanded Clay 2-4	1.04 ± 0.66
Soil + 15 % Expanded Clay 2-4	0.93 ± 0.15
Soil + 20 % Expanded Clay 2-4	0.94 ± 0.08
Soil + 25 % Expanded Clay 2-4	0.79 ± 0.15

As a result of the addition to soil of different percentages of expanded clay, a significant decrease in thermal conductivity was recorded, from 1.08 W/m.ºC to 0.79 W/m.ºC, as shown in Table 3.

3. Conclusion

According to the Portuguese Regulation on Thermal Performance of Buildings (RCCTE, Decreto-Lei n.º 80/2006 [1]), the reference value of the thermal transfer coefficient (U value) of the opaque and vertical elements of the exterior envelope in Climatic Zone I_1 (nearly the South of Portugal) is 0.70 W/m^2.°C. Let us compare this with the values obtained as a result of the tests carried out. In order to make this comparison let us determine the thermal transfer coefficient (U value) of a rammed earth wall with a thickness of 0.60 m covered with plaster with a thickness of 0.02 m on the inside and outside.

It should be noted that, as a result of the tests performed, a value was obtained for the thermal conductivity of the soil sample equal to 1.08 W/m.°C. In accordance with the methodology described by Santos and Matias [7], for the rammed-earth wall consisting only of soil and plaster the value U = 1.29 W/m^2.°C was obtained.

With regard to compressive strength, all the solutions tested would show a satisfactory level of compressive strength [5,6] which means soil with 25% expanded clay 2-4 is the best option. The thermal conductivity measured was: λ=0.79 W/m.°C, and the U value of the described wall is: U=1.02 W/m^2.°C. Comparing this with the sample consisting of soil without a thermal insulator, it was found that the thermal transfer coefficient of the option consisting of soil expanded clay aggregate is equal to 79% of the thermal transfer coefficient of the soil sample, thus, a substantial reduction was achieved.

4. References

[1] DECRETO-LEI N.º 80/2006. "*Regulamento das Características de Comportamento Térmico dos Edifícios (RCCTE)"*, Lisboa, Diário da República, I Série A, n.º 67, 2006.
[2] TORGAL F, EIRES R, JALALI S. "*Construção em terra".* Guimarães, Universidade do Minho, 2009.
[3] HOUBEN H, GUILLAUD H. *"Traité de construction en terre".* Marseille, Editions Parenthèses, 2006.
[4] MORAN E. *"Uso del terrocemento en la construcción de vivienda de bajo costo".* Quito, Facultad de Ingeniería Civil, Pontificia Universidad Católica del Ecuador, 1984.
[5] NZS4297. *"Engineering Design of Earth Building".* New Zealand, Earth Building Association of New Zealand, 1998.
[6] DELGADO M, GUERRERO I. *"Earth building in Spain"*. Departamiento de Construcción y Vias Rurales, Escuela Técnica Superior de Ingenieros Agrónomos, Universidad Politécnica de Madrid, 2006.
[7] SANTOS C, MATIAS L. *"ITE50 - Coeficientes de transmissão térmica de elementos da envolvente dos edifícios".* Lisboa, LNEC, 2006.

Future Building Performance Factors towards Energy Efficient Travel Plan in Regional Development

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Abstract

Preliminary research shows short coming of Building Performance field of research to measure outdoor performance of building manly EETP factors. Accordingly, this research aimed to Proposing future building performance toward Energy Efficient Travel Plan based on user friendly EETP factors. The research methodology engaged three research phase. 'Phase I' was to identify user friendly EETP factors. In this phase after a literature review, fix-format self reporting interview survey was conducted among experts in Travel Plan implementation in Malaysia. 'Phase II' was to investigate effective Building performance factors on user friendly EETP, within which literature review conducted on building performances followed by brainstorming with 5 experts in building management field of research. Final phase was to validate purposed building performance towards EETP in a futuristic cross-impact scenario study. In summary, research is concluded to introduce three main out comes, first: list user friendly EETP factors, second: EETP building performance factors and Third: future Building performance factors towards EETP based on futuristic cross-impact analysis. In conclusion, study introduced list of new innovative future building performances including; BCS (Building communication system), BEEM (Building Energy Education Management), EETP (Energy Efficient Travel Plan), BRc.S (Building recycling system), and BAgr. (Building agriculture) investigated as future building performance factors.

1. Introduction to Energy Efficiency Travel Plan

The idea of Energy Efficient Travel Plan (EETP) is under the umbrella of Travel Plan (TP) introduced science late 90's. Traditionally, TP provides policy planning to reduce transportation impact. Enoch and Ison (2010) defines TP as "a long-term management strategy for an organisation and its various sites or business park that seeks to deliver transport objectives through positive action and is articulated by a document that is regularly reviewed".

Wake et al. (2010) defines TP as "… is a package of actions implemented to manage travel generated by a workplace. Primarily, travel plans seek to reduce car trips and encourage the use of lower impact alternatives, such as walking, cycling, public transport and telecommunications."

Rye (2002) sates TP in UK is known as company (workplace) travel plan, while in Europe is known as mobility management, and in US is known as transportation demand management (TDM). Albeit, the three concepts are addressing one issue, this study used TP and EETP as refereed in report. Table 1.1 addresses some of measures in TP Adopted from Rye (2002).

In TP mostly the main concern is measuring, monitoring and reducing Carbon Foot Print of all the residents under issue of TP. TP is proposed normally in 'organizational bases'. Tyler et al. (2006) sates "….Initially, travel plans were required by regulation in the US. The 1990 Clean Air Act Amendment required employers with 100 or more employees to implement trip reduction".

The travel sector is a large and diverse issue, which is encompassing travel by land and the movement of both passengers and vehicles. But passenger vehicles, used for the daily travel of households, are the primary source of CO2 emissions within the travel sector. The controversial argument is that many technological innovations with the potential to reduce transportation emissions from passenger vehicles are possible but it needs more research and investigations. However, consensus is growing that technological innovations alone will not be enough to reach targeted reductions in CO2 emissions: changes in human behaviour are also essential (Rajan 2006; Lutsey and Sperling 2009). TP address this aim in principles.

Table1.1: Travel plan measures (Adopted from Rye, 2002)

Mode	Measure
Overall for whole plan	–Travel coordinator (member of staff) –Promotion and publicity –Implementation process, e.g. steering group
Walking	–Improved lighting and walkways –Incentives for walkers –Crossings in/adjacent to site –Changing/shower facilities
Cycling	–Pool cycles –Bicycle loan scheme –Good, secure parking provision –Discount purchases of cycles and equipment –Provision of PT information at workplace
Public transport	–Access to rail planner –Discounted season tickets, paid for by operator –Liaise with local operators to operate new services –Pay for new services –Pay for subsidies for fares on existing bus services –Staff travel survey to identify potential sharers –Priority parking spaces for car sharers –Guaranteed ride home (taxi)
Car share	–Reduce parking supply –Ration parking through permit allocation –Charge for parking –Flexi-time –Telecommuting/working
Parking	–Company car initiatives (phased out/ altered

2.0 Problem Statement

This section to explain the rational to study is divided to twofold; Gap in research on building performance factors to consider EETP, Need in practice for EETP.

2.1 Gap in Research on Building Performance Factors to consider EETP

This research tries to introduce consequences of Energy Efficient Travel Plan (EETP) on Building Performance factors, as Future Building performance factors. Mohammad (2012) states totally there are 15 building performance criteria to be considered as Building Performance Factors. He reviewed on POE (Preiser, 2008), POE (Minnesota Univ., 2004), Building Quality Assessment (BQA), ISO 6241 Performance standards for buildings, Orbit 2.1, Facilities Performance Evaluation (FPE) and some other researchers efforts and concludes in total 15 different evaluation criteria. Including; Health, Safety, Security, Functionality, Efficiency, Social, Environmental Psychology, Aesthetics, Operations, Comfort, Durability, Economic, Flexibility and culture. Study observes that all the mentioned performance factors are related to the building indoor and close out door of building, and no one is to consider performance of building in area, specially, with the responsibility of EETP. Besides, Intelligent Building concept for more than thirty years has been change the building performance criteria, but with the direction of Energy Efficient Travel Plan (EETP) seems that it can play more to help the travel behavior, and it can introduce new performance criteria to its designers and users.

2.2 Need in Malaysia to consider EETP

It is a common importance among all countries to improve Human development Index (HDI) as a measure of human Quality of Life. The increase in HDI will effect on higher energy consumption. Figure 1 is highlights correlation between HDI and Energy consumption contrast within various countries and shows the critical position of Malaysia. This confirms Malaysia has to foresee the future energy consumption and optimize its energy consumption in sustainable building design framework towards improving quality of life.

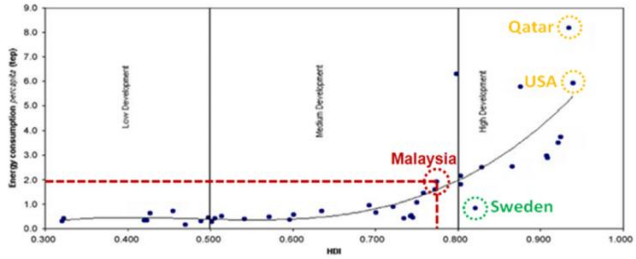


Fig.1: HDI versus Energy consumption within various countries (Adopted from Dias et al., 2006)

This momentum is obvious by Malaysian governments. The key Malaysian ministry and agency involved are the Ministry of Energy, Green Technology and Water, Energy Unit of Economic Planning Unit of Prime Minister's office, The Energy Commission of Malaysia, and Persatuan Tadika Malaysia (PTM). Furthermore, agendas have been sets for the different mentioned Malaysian ministry and agency by five year bases Malaysian plans. The Malaysian government in Ninth Malaysia Plan concerns strongly on Energy efficiency programs while, sustaining the quality of life for the needs of the population and at the same time to manage Malaysia's resources (Ninth Malaysia Plan 2006-2010). Furthermore, greater emphasis has been considered on energy efficiency under the Tenth Malaysia Plan (2011-2015).

In Malaysian building construction industry; environmental concerns, energy crisis, and technology advances, have brought up Energy Efficiency as the agenda for building performances since 80's. In 1989, the Malaysian Ministry of Energy, Water and Communication (MEWC) had introduced the Guidelines for Energy Efficiency in Non-Domestic Buildings. The guidelines were revised as the Malaysian Standard MS 1525:2001 which aimed to encourage the application of energy efficiency in new and existing buildings whist maintaining comfort, health and safety of the building-users. Best practices as stipulated in the Malaysian Standard MS 1525:2007 "Code of

Practice on Energy Efficiency and the Use of Renewable Energy for Non-Residential Buildings" have been adopted as guiding principles.

However, MS 1525:2007 in line with some internationally well-known standards (such as ASHRAE standard 55-2010, and ISO 7730:2005) does not support all requirement of building user in the energy efficiency. Indeed, updating and improving MS 1525:2007, with existence of complimentary tools and framework is considerably needed that ensures continues 'moving forwards' in energy efficiency standards of buildings in Malaysia.

Building based TP has potential towards energy efficiency. The behaviours underlying transportation foot print are complex. Vehicle-Miles-Travelled (VMT) is the direct result of a series of behavioural choices shaped by the physical environment and policy context over different time frames. The rate of emissions per mile is also fundamentally a function of behaviour, both the choice of vehicle type and the style of driving. As obviously location and function of building have direct effect on this CO2 emission.

Therefore, with investigating effect of Building Performance on Sustainable Travel Plan in future urban mobility, we will have new feature in term of opportunity of building to be part of EETP to eliminate and minimize the travel. Relatively, the research question is as followed:

"What would be the future of Building performance factors towards enhancing Energy Efficient Travel Plan?"

3. Aim, Objectives and Scope of Study

This research project aims to propose future building performance factors toward Energy Efficient Travel Plan. To address this aim, the following objectives were defined; First: To identify user friendly EETP factors, Second: To investigate effective Building performances (BP) towards user friendly EETP, and Third: To establish future Building performances (BP) factors towards user friendly EETP. Several area were investigated as scope in this study, including; building functionality, which was limited to cover only office buildings, Malaysia from other possible regions, and the building performance investigated was limited to those with direct effect on EETP.

4. Significant of Study

This study has been formulated the relation of BPs from EETP perspective. This investigation is fundamental for futures buildings to be more Green and Sustainable. Currently, construction building industry is practicing sustainable building assessment (SBA) tools to benchmark sustainability in building. One of key shortcoming of SBA stated by Lützkendorf and Lorenz (2005) "… it must be noted that social aspects and considerations related to sustainable buildings are not yet fully explored due to the complexity of the issue. For example, social aspects also include the interrelation between single buildings and community-level issues like urban design quality, social segregation, urban sprawl, etc." Significance of the current research is to propose future BPs in EEB. Indeed, such BPs will open insight in building construction R&D also towards building sustainable development. Introduction of BPs in this study is fundamental for R&D sector for further development of means to apply the BPs.

5. Research Methodology

This study was developed three research phases corresponding to the three objectives of study. In total, this study is to conduct using four steps. Which first step conducted prior to step 2, 3, and 4. The list below describes each step.

Phase I: (to fulfill requirement of first Objective)
Step 1: Literature review: A review of relevant literature was conducted by focusing on the following key words: EETP factors, user friendly EETP factors, Energy efficient Life styles.
Step 2: Expert input (data collection and data analysis): To validate the results of the literature

review an expert input session implementing Delphi close group discussion.

Phase II: (to fulfill requirement of second objective)
Step 3: Brainstorming (data collection and data analysis): To investigate effective BPs towards user friendly EETP factors in a Synectics session.

Phase III: (to fulfill requirement of third objective)
Step 4: Close Group discussion-CGD (data collection and data analysis): To implement futuristic study method on finding of second objective in an expert CGD session, implementing Delphi close group discussion.

6. Data Analysis

This section is to brief data analysis and discussion on first, second, and third objective. Mainly data analysis was conducted based on three answer presented for three questions corresponding to each objective in different interviews. Questions include;

Q1) It is a as user friendly EETP factor.
Q2) What you can propose as Effective BP to consider this factor?
Q3) There is a need in future on proposed BP based on the four mentioned scenarios.

For question 1 and 3, the research conducted expert input session by means of Delphi structured close group discussions. Thus study used five-point rating scale based on 1 for 'unacceptable' to 5 for 'Acceptable'. Respondent(s) perception collected based on each life style or TP measure, where investigated in literature review. Further explanation on data collection is presented in chapter 3.

As data analysis method WSM is used in this study. The formula (1) applied for each validation aspect. And formula (2) applied for validation conclusion. Table 1 indicates a sample-result of WSM.

$$\boldsymbol{WSM(a_i)} = \left(\sum_{j=1}^{n} \boldsymbol{w_j}\right) \boldsymbol{a_i}, \quad for\ i = 1,2,3,\dots,m \qquad (1)$$

Where,
'w_j', *referred to assigned weight by decision maker in close group discussion for sub-issue of discussion by participants number 'j'*
' a_i', *is sub-issue of discussion with the given ordering number of 'i',*

$$\boldsymbol{WSM(a_i)\ /\ WSM(a)_{max}} \textbf{ = Consensus in \%} \qquad (2)$$

Where,
$WSM(a)_{max}$ *, refers to maximum sum of possible weight can be given for one sub-issue*

Formula (4) indicts the consensus calculation. Albeit, consensus where accepted if more than % 70 consensuses were observed. One example is presented to calculate consensus using WSM (Table 2).

Table 2: Example of WSM process in the clacualtion of concenses

Validation Aspects	w_1	w_2	w_3	w_4	w_5	w_6	w_7	$WSM(a_i)$	$WSM(a)_{max}$	Cons. %
factor 1	3	4	5	5	5	np	5	27	30	90

Note . **np:** refers to cases where participants didn't assigned the weight to the sub-issue, **Cons.:** refers to consensus calculated based on furmula (4).

Question 2 is to address finding of 2nd objective. And Question 3 is based on futuristic analysis on final finding of question 2. The amount of production in supply side has correlation with demand. Thus, to conduct the futuristic study we must consider this correlation. It is to insure the common acceptable finding. It is a common trend in futuristic study to consider restrictions in study. Thus to consider clean Electricity& clean fuel as restriction there are four possible scenarios (in timely manner):

1st scenario: Current Electricity& fuel (not enough not clean)

2nd scenario: Production of Energy (in the form of clean electricity) will cover the needs and also more

3rd scenario: Production of fuel (in the form of clean fuel) will cover the needs and also more

4th scenario: Production of Energy (in the form of clean Electricity& fuel) will cover the need

In summary of data analysis applied in all three phase of research Table 3 is presenting the result. According to results of Table 3, BCS (Building communication system), BEEM (Building Energy Education Management), EETP (Energy Efficient Travel Plan), BRc.S (Building recycling system), and BAgr. (Building agriculture) were investigated as future building performance factors.

Table 3: Content analysis to identify 'user friendly EETP' based on adopted list of life styles from Leonard-Barton (1981)

Life styles and TP measures		Q1	Q2	Q3
Life style	Bike for exercise	61		
	Bike on errands	33		
	Bike on retail purpose	24		
	Change oil in car	60		
	Get instruction to increase self-reliance	72	**BEEM**	78
	Exchange goods or services	40		
	Grow vegetables	78	**BAgr**.	87
	Recycle paper	75	**BRcS**	87
	Recycle glass	34		
	Recycle cans	46		
	Buy second-hand clothes	24		
	Buy at garage sales	65		
	Make gifts	78	**EETP**	74
	Make clothes/furniture	73	**BES**	64
	Plan meatless meals	67		
	Have compost pile	63		
	Contribute to ecology organizations	85	**BEEM**	78
	Belong to a cooperative	83	**BEEM**	78
Plan	Travel coordinator	74	**BEEM**	78
	Promotion and publicity	65		
	Implementation process	73	**BEEM**	78
Walking	Improved lighting and walkways	56		
	Incentives for walkers	74	**BEEM**	78
	Crossings in/adjacent to site	56		
	Changing/shower facilities	36		
Cycling	Pool cycles	56		
	Bicycle loan scheme	62		
	Good, secure parking provision	75		
	Discount for purchasing and equipment	68		
	Provision of PT information at workplace	75	**EETP**	74
Public transport	Access to rail planner	32		
	Discounted tickets	45		
	Liaise with local operators for new service	74	**BEEM**	78
	Pay for new services	54		
	Pay for subsidies of existing bus services	83	**BEEM**	78
	Staff travel survey	74	**BEEM**	78
	Priority parking spaces for car sharers	79	**BEEM**	78
	Guaranteed ride home (taxi)	90	**EETP**	74
Car share	Reduce parking supply	87	**EETP**	74
	Ration parking through permit allocation	93	**BEEM**	78
	Charge for parking	93	**BEEM**	78
	Flexi-time	-		
	Telecommuting/working	98	**BCS**	95
Parking	Company car initiatives	78		

7.Discussion

This section is to briefly discuss findings of each objective in this study. First is to present finding of the first objective. Next is to discuss findings of second objective and finally it will address findings of the third objective.

Findings on first objective: The first objective of this study was to identify user friendly EETP factors. Based on literature review 'life style and TP measures' presented to the expert to validate acceptability of them as user friendly EETP. The data analysis of expert input conducted using WSM. Based % 70 saturation study resulted in list of user friendly EETP criteria as presented in Table 2.

Findings on second objective: The second objective of this study was to investigate effective Building performances (BP) towards user friendly EETP. Thus, based on findings of fist objective, user friendly EETP factors presented to the expert in a brain storming session. It was to propose the effective BPs. The data analysis of expert input conducted using WSM. Based % 70 saturation study resulted to list of effective TPs towards EETP as presented in Table 2.

Findings on third objective: The third objective of this study was to validate findings of second objective in a futuristic study. Thus, based on findings of second objective, BPs presented to the expert in a futuristic cross-impact analysis having four scenarios. The data analysis of expert input conducted using WSM. Based % 70 saturation study resulted to list of future effective TPs towards EETP as presented in Table 2.

8. Conclusion

In reference to Table 3 BCS (Building communication system), BEEM (Building Energy Education Management), EETP (Energy Efficient Travel Plan), BRc.S (Building recycling system), and BAgr. (Building agriculture) investigated as future building performance factors.

Acknowledgement

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References

[1] David Wake, Amy Thom, Rick Cummings, Evaluating workplace travel plans, Australasian Transport Research Forum 2010 Proceedings 29 September – 1 October 2010, Canberra, Australia Publication website: .http://www.patrec.org.atrf.aspx

[2] Dias R.A., Mattos C.R., Balestieri J.A.P. (2006).The limits of human development and the use of energy and natural resources Energy Policy, Vol. 34 (9), pp. 1026-1031

[3] Energy Information Bureau (EIB) 2011 report, /www.eib.org.my/index.php, access in April 2011

[4] Hannu, Numi , (1980). Approaches to collective decision making with Fuzzy preferences relations, Fuzzy Sets and System, Vol. 6, pp. 249-259

[5] Institute of Environmental and Water Resource Management –IPASA- 2009, www.utm.my/IPASA/, access in June 2011

[6] ISO 6241 (1984). Performance Standards in Building - Principles for Their Preparation and Factors to be Considered. International Organisation for Standardisation.

[7] Kaplan, R. (1992). Urban forestry and the workplace. In P. H. Gobster (Ed), Managing urban and high-use recreation settings. Chicago, IL: North Central Forest Experiment Station.

[8] Marcus Enoch and Stephen Ison , (2008), Expert Perspectives on the Past, Present and Future of Travel Plans in the UK, Research Report to the Department for Transport and the National Business Travel Network, Loughborough's Institutional Repository, access at (https://dspace.lboro.ac.uk/)

[9] MS 1525:2007 Code of Practice on Energy Efficiency and the Use of Renewable Energy for Non-Residential Buildings.

[10] Noorfariha Dorasol, Izran Sarrazin Mohammad, Abdul Hakim Mohammed, Norazela Hamadan, Nik Mohd Iezuan Nik Lah, Post Occupancy Evaluation Performance Criteria and Parameters for Hospital Building in Malaysia, Proceedings of 3rd ICBER 2012, 12-13 March 2012 ISBN:978-967-5705-05-2

[11] Patton, M. Q. (2002). Qualitative research and evaluation methods: Sage Publications, Inc.

[12] Preiser, W. F. E., & Nasar, J. (2008). Assessing Building Performance: Its Evolution from Post-Occupancy Evaluation. ArchNet - IJAR: International journal of architectural research. 2(1).

[13] Public Work Department (JKR) of Malaysia, www.JKR.gov.my, access in February 2012

[14] Sophie Tyler, Marcus Enoch and Lian Zhang, Setting up Local Travel Plan Groups: the future of workplace travel planning in urban conurbations? Examples from London, UK.

Loughborough's Institutional Repository,2006, access at (https://dspace.lboro.ac.uk/)
[15] Tom Rye, Travel Plan: Do they work?, Transport policy Vol. 9 (2002) pp. 287-298.
[16] Yearbook Statistics Malaysia 2010, Department of statistic Malaysia, 2011

Keywords: Building Performance Factors, Energy Efficient Travel Plan, Regional Development

Climate:active renewable raw materials (k:a NAWARO)

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Short Summary

Keywords: ecological building materials, renewable resources, natural building materials, insulation, refurbishment, environmental and health impact

1. What are RRMs?

Renewable raw materials (RRMs) are agricultural and forestry-produced materials and biogenic rest or waste materials which are not used as food or feeding materials, but are used as raw materials in the industry or as energy sources. Unlike fossil fuels, they renew annually or in a reasonable timeframe. During combustion or composting, RRMs only set free the quantity of CO_2 that they have absorbed from the atmosphere during their growth period. Unlike fossil fuels, they are therefore largely CO_2 neutral under certain conditions. This CO_2-neutrality, however, is at risk, if the current CO_2 storage is affected by the expansion of cultivable acreage for renewable resources, or other greenhouse gases are released into the atmosphere, or the use of artificial fertilizers increases. The sustainability of products from renewable materials is ensured when regional cycles arise with ecologically compatible cultivation.

2. What is the objective of the k:a RRM programme?

The national awareness program climate:active promotes the material use of renewable raw materials in products, to achieve a better market penetration and acceptance by consumers and users.
The objective of this program is to support the sustainable use of renewable raw materials in Austria and to actively push the material use of RRMs. This will be done particularly in the following product areas:

- RRM biopolymer materials
- RRM insulation
- RRM oils, varnishes, paints, binders and
- RRM regional products

Since the project is integrated in the climate:active program, the overall goal is the reduction of greenhouse gas (GHG) emissions through substitution of fossil fuels by renewable raw materials in Austria. Assuming that the full market potential of RRM material use can be achieved, the technical CO_2-eq. saving potential is estimated at 326,000 t/a in Austria. To be able to fully exploit this potential, the mere focus on the CO_2-factor is insufficient. Therefore a holistic sustainability assessment of the entire production chain (including sustainable produced raw materials) forms a central point in the argumentation chain.

3. Climate:active RRM programme in the construction sector

Direct regional chains from the raw material to the end product are a realistically implementable target mainly in the building construction area. Analogous to regionally produced foods, a regional building culture (i.e. preferring construction materials from regional processing) would be part of the added value directly related to the use of renewable materials and to the creation of "green jobs".

The objectives in view of the renewable raw materials are the following:

- Definition of quantitative and qualitative criteria for the efficient use of RRMs for concrete applications – especially in the field of construction materials for the raw materials sheep wool, hemp, flax, miscanthus, straw and wood residues.
- Identification of utilization cascades (optimized material and energetic value added from the cultivation of a plant or material or rather material use and subsequent energetic use of the product as an end-of-life option)
- Demonstration of the added value potential in the regional context and communication to regional decision makers

With regard to the markets, the objectives are aligned as follows:

- Strengthening of regional implementation networks eg. craftsman and salesman associations and refurbishment networks for the use of RRM construction materials
- Acquisition of a larger market share of RRMs in the insulation sector of thermal refurbishments
- Increase of the awareness of already successful products
- Influence over the development of the framework for the use of renewable raw materials (building guidelines, standards ...)
- Initiation of innovative product developments among manufacturers – even cross-industry collaborations are requested
- Initiation of research projects and information about adequate funding opportunities (eco innovation, FFG)
- Establishment of quality assurance as part of the climate:active program (product label / Eco-label)

4. RRM suitcase

The already provided **RRM suitcase** demonstrates the versatility of renewable materials and products in the construction sector. It contains a multitude of construction product samples made of renewable raw materials and gives explanations of its ecological assessment, it´s manufacture, use and characteristics.
Accordingly, the information and illustration samples serve for energy advice, training, education and public relation. Goal of the composition of the suitcase was to integrate some unconventional products to demonstrate the wide range of application possibilities of RRMs. The compilation of the information and documents primarily based on the construction materials are declared on the web platform www.baubook.at. On the website, in-depth information, technical parameters as well as manufacturer and salesman can be found.

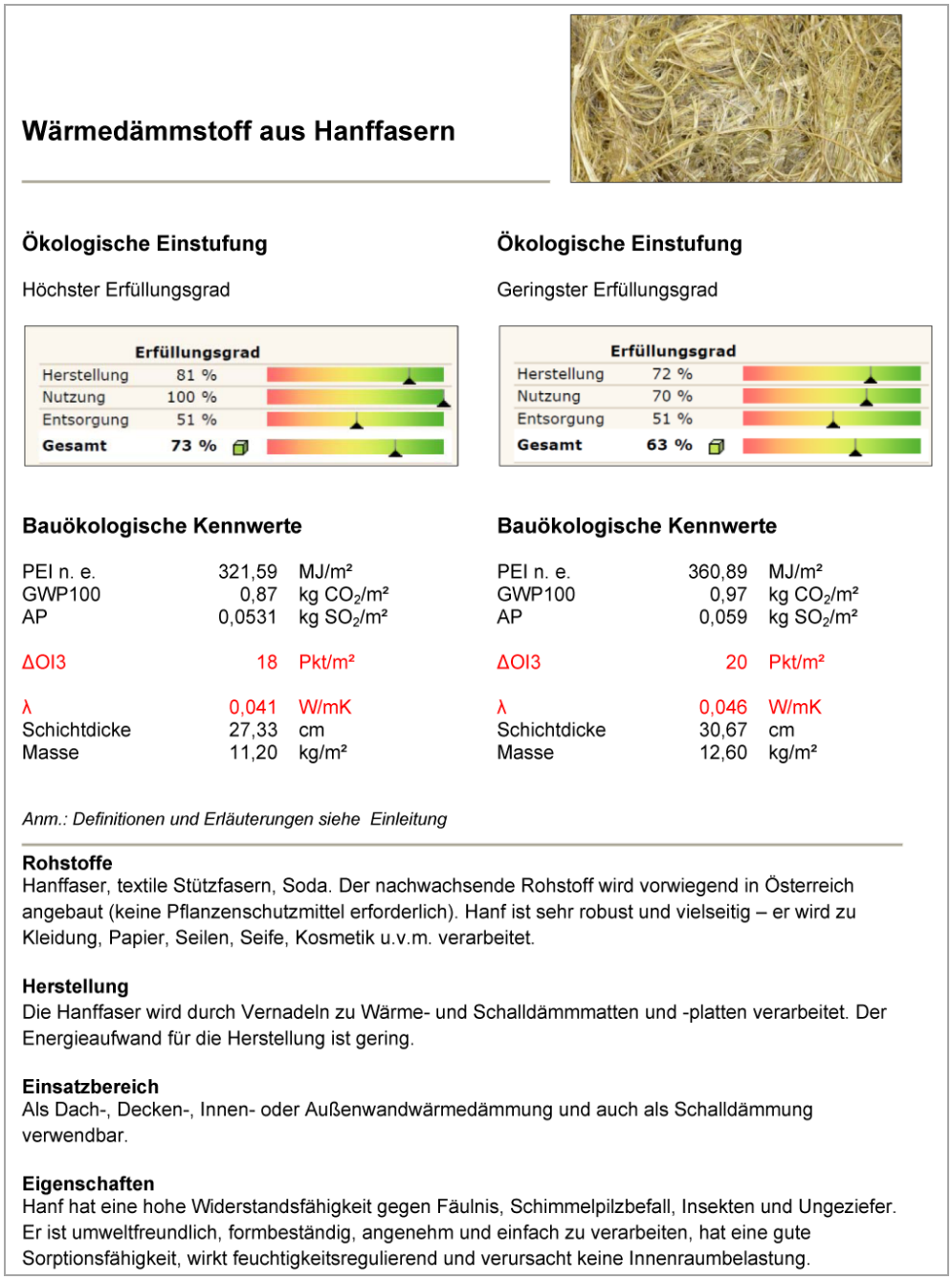
The following contents are available in three different tools:

Information documents (wooden case) with an:

- Overview of the products and samples
- Detailed information about the products and hand patterns
- Ecological Construction Manual – Guide for cost-conscious builders with general information for building and construction products
- Product Information

Product samples (aluminum case) with detailed information about the products and hand patterns

Detailed information (web platform www.baubook.at) with:
- Technical principles and indicators
- Information technology applications, health and environment of construction
- Product Database (with retailers and manufacturers)
- Online computer component
- Ecological tender criteria



Wärmedämmstoff aus Hanffasern

Ökologische Einstufung

Höchster Erfüllungsgrad

Erfüllungsgrad	
Herstellung	81 %
Nutzung	100 %
Entsorgung	51 %
Gesamt	**73 %**

Ökologische Einstufung

Geringster Erfüllungsgrad

Erfüllungsgrad	
Herstellung	72 %
Nutzung	70 %
Entsorgung	51 %
Gesamt	**63 %**

Bauökologische Kennwerte

PEI n. e.	321,59	MJ/m²
GWP100	0,87	kg CO_2/m²
AP	0,0531	kg SO_2/m²
ΔOI3	18	Pkt/m²
λ	0,041	W/mK
Schichtdicke	27,33	cm
Masse	11,20	kg/m²

Bauökologische Kennwerte

PEI n. e.	360,89	MJ/m²
GWP100	0,97	kg CO_2/m²
AP	0,059	kg SO_2/m²
ΔOI3	20	Pkt/m²
λ	0,046	W/mK
Schichtdicke	30,67	cm
Masse	12,60	kg/m²

Anm.: Definitionen und Erläuterungen siehe Einleitung

Rohstoffe
Hanffaser, textile Stützfasern, Soda. Der nachwachsende Rohstoff wird vorwiegend in Österreich angebaut (keine Pflanzenschutzmittel erforderlich). Hanf ist sehr robust und vielseitig – er wird zu Kleidung, Papier, Seilen, Seife, Kosmetik u.v.m. verarbeitet.

Herstellung
Die Hanffaser wird durch Vernadeln zu Wärme- und Schalldämmmatten und -platten verarbeitet. Der Energieaufwand für die Herstellung ist gering.

Einsatzbereich
Als Dach-, Decken-, Innen- oder Außenwandwärmedämmung und auch als Schalldämmung verwendbar.

Eigenschaften
Hanf hat eine hohe Widerstandsfähigkeit gegen Fäulnis, Schimmelpilzbefall, Insekten und Ungeziefer. Er ist umweltfreundlich, formbeständig, angenehm und einfach zu verarbeiten, hat eine gute Sorptionsfähigkeit, wirkt feuchtigkeitsregulierend und verursacht keine Innenraumbelastung.

Fig. 1: Example product description of hemp insulation

5. RRM Best practice examples

To raise acceptance and awareness of construction projects with RRMs among planners,

architects, building owners and promoters, the aim of climate:active RRM program is to evaluate and disseminate best-practice examples. Already successfully implemented construction projects, in which construction materials were used in large measure, will be presented on the climate:active webpage. For the project description special emphasis is made on the specifications of the construction materials used in the projects and particularities, such as the health aspects, in comparison to commonly used products.

The information about the selected construction projects in the areas of public and corporate buildings will be available online: http://www.klimaaktiv.at/erneuerbare/nawaro_markt.html

klima:aktiv

Die Klimaschutz-Initiative

1. Grunddaten

Standort	Merian Gärten, Basel, Schweiz
Gebäudetyp	Schulgebäude
Bautyp	Neubau
Fertigstellung	2012
Bauherr	Christoph Merian Stiftung
Architektur	Barcelo Baumann Architekten GmbH
Konzeption	Lehm Ton Erde Baukunst GmbH und Architekten BB A
Ausführung	Erden Lehmbau GmbH

2. Gebäudedaten

Nutzfläche in m²	367	
Anzahl der Geschosse	1	
U Werte (W/m²K)		
Außenwand	**Dach/Oberste Geschossdecke**	**Fußboden**
0,16	0,16	0,17
Heizwärmebedarf (kWh/m²a)	53	
Gebäudetechnik	Geheizt wird mit Fernwärme der Holzschnitzelheizung der Merian Gärten. Die Beleuchtung funktioniert mit stromsparenden LED-Leuchten, und die großen Fenster bringen viel Licht ins Gebäudeinnere.	

3. Baustoffe und Konstruktion

Alle Bauteile können nach ihrer Lebensdauer einfach getrennt und weiterbearbeitet werden. Lehm benötigt als natürlicher Baustoff für die Verarbeitung fast keine Energie und schafft ein ideales Raumklima. Das verwendete Holz trägt das Schweizer FSC-Label.

Verbaute Dämmstoffe	**Masse [kg]**	**Volumen [m³]**
Thermofloc (Zellulose)	**65**	**105**
Steico Universal / Special Dry	**140**	**93**
Gutex Ultratherm	**180**	**80**

4. Foto

@ Tom Baumann, Katrin Schulthess, Christoph Merian Stiftung)



Fig. 2: Best-practice example Merian Gärten, Schweiz, Barcelo Baumann Architekten GmbH

6. Meetings and Conferences

Two conferences focusing on renewable raw materials construction materials and best practice experiences are planned for 2013:

- On the 17 October 2013 the conference "Regional renewable building materials in the context of healthy and ecological hotels" is planned in Vienna. Especially in the tourism sector, ecological solutions are increasingly in demand. The use of renewable raw materials affects both, new buildings and renovations focusing on sustainability and healthy living. The planned conference will give experts and hotel keepers the chance to share experiences in the planning process of ecological of best practice examples.
- In collaboration with the project partner Vorarlberg Energy Institute, the conference "Implementation of RRMs in refurbishment strategies" will be organized in the framework of the conference “Win 13 – Wirtschaften mit neuen Energien und Ressourcen” in Bregenz on the 28–30 November. The congress with nationally and internationally accepted speakers, provides perspectives for successful economic development and shows new cross-industry concepts, practical solutions and innovative examples of best practice in the areas of construction, trade, industry, tourism and communities. In addition a one half day excursion is planned.

More information on the programs is available under: http://www.klimaaktiv.at/erneuerbare/nawaro_markt/Aktuelles.html

HOMETAINER



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Short Summary

The Hometainer project set itself the aim to make sustainability, ecological thinking and resource-efficient construction to the basic module on the subject of living. In order to highlight this focus the draft has been specifically designed for developing and emerging countries. The Hometainer units should also feature the topic of a sustainable environment on a low expenditure and budget. The goal is the implementation of a prototype.

Keywords: sustainable development; lifecycle; developing countries; urban poor; ecological thinking, common property.

1. Introduction

„According to estimates of the United Nations Human Settlements Programme (UN-Habitat) in 2030, nearly two billion people worldwide must live under intolerable conditions in poor and overcrowded homes, often under the threat of expulsion, flood or crime.“

This quote and a comprehensive research were the starting point for the development of the Hometainer project.

The generated living space will be planned, built, maintained and exploited by the residents themselves. The support of the planning team should be lowered to a minimum.
The entire project is not only designed to educate people about ecology and sustainability. Instead they should live it. The building and the cycle of land use will contribute to a sustainable environment. Working together towards a sustainable future can open new perspectives to the residents.

2. Project development

The Hometainer project was developed in front of a realistic background and can be realized location-independent. The basic unit of the project are used 20’ and 40’ feet shipping container units. Therefore the entire system is extremely flexible and can be adapted to almost any size and condition.

2.1 Implementation – and the promotion of the natural cycle

Before starting the project a demand analysis of the existing social and economic structures should be made. The earlier local population is involved in the project the more likely will later campaign for it.

As possible building sites unappealing properties in slums or in its vicinity should be selected. The background of this plot choice is the earliest possible introduction of a working infrastructure.

Because of the operating lifetime the future use of the Plot has to support functions for the public use. E.g. like buildings of education, aid or administration. Also the restoration of the natural environment is desirable and should be seen as a sustainable upgrading of living space.

With the support and their personal contribution it is able to provide a most favorable living space for future residents. During the construction period the inhabitants also have the chance to join a career training e.g. as a construction worker, carpenter or metal worker.

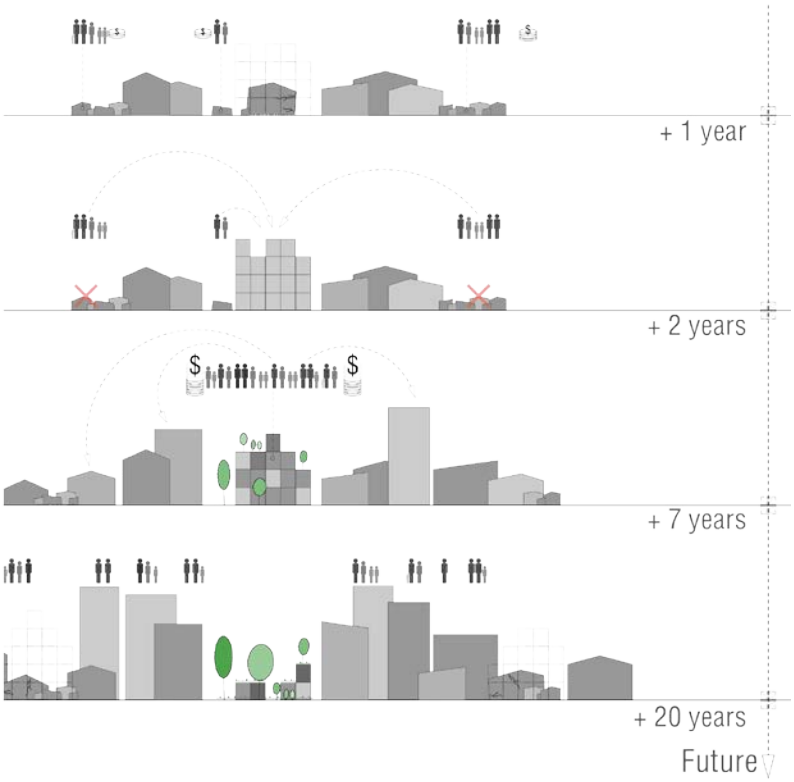


Fig. 1 Timeline of the Hometainer implementation

2.2 Structure - The variety of simplicity

A few basic rules, the standardized dimensions and couplings of the container, allow a simple implementation.

- A grid of 8 to 20 feet either set in length or width determines the positioning of the container. The rotation of the entire grid can accommodate the existing environment such as roads and buildings but is not bound to follow them.

- A Hometainer unit consists out of three up to six levels. One level is composed out of five times two 20 foot containers. This results in a square floor plan with 40 * 40 feet. Through the square ground plan of a Hometainer a rotation in 90 degree steps is possible.

- Due to the connection possibilities and an economic infrastructure a rotating stacking of the different levels by 90 degrees is not possible.

- Because containers are available in different heights it is important not to switch the heights within the container floors.

- If an existing Hometainer gets enlarged by another block the staircase of the new

Hometainer will be eliminated and will be replaced by an atrium. This serves ventilation and lighting by daylight. The accessibility of the new apartments is provided through a simple and slender extension from the existing staircase.

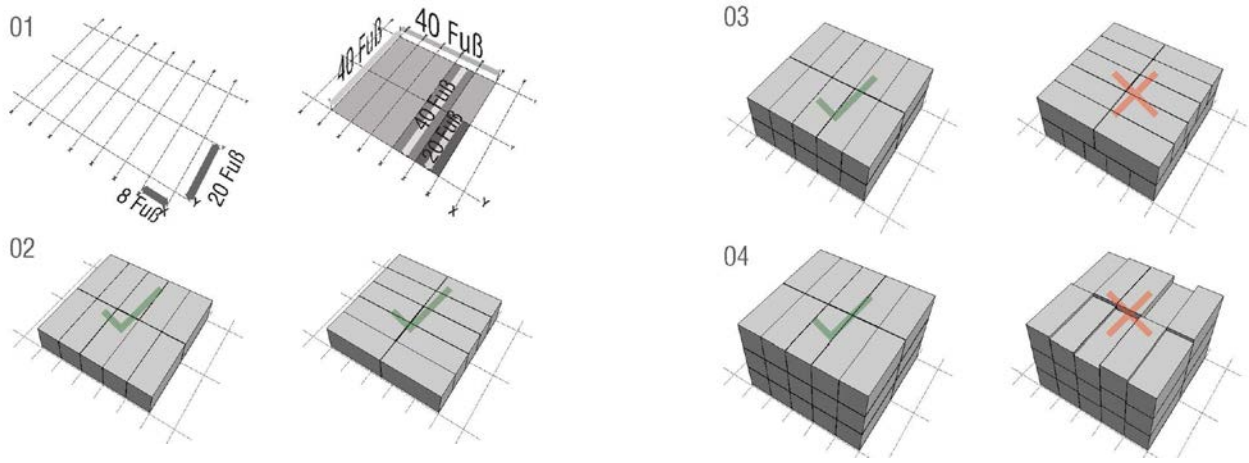


Fig. 2: Basic Guidelines for the container construction

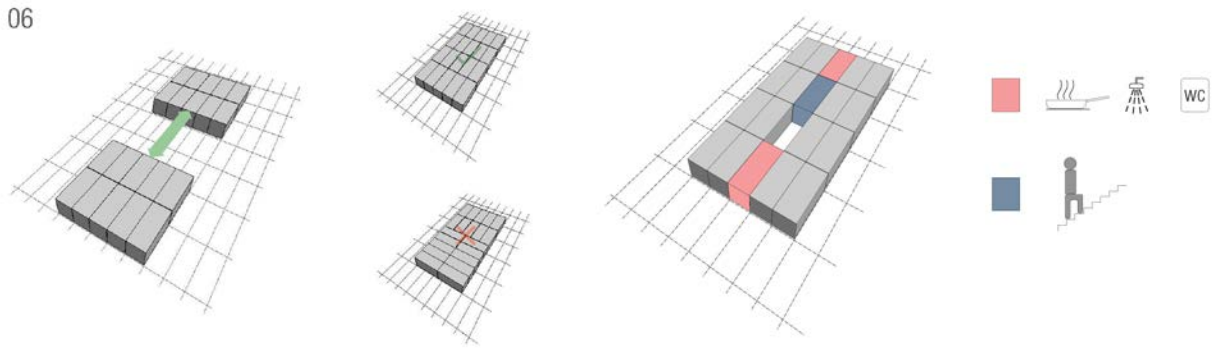


Fig. 3: Expansion of the Hometainer and distribution of infrastructure and stairwell

2.2.1 The Zoning

Through the vertical access and infrastructure in the middle the building is divided into two halves, each with two flats per level. All units consist out of a 40-foot and two 20 foot containers. The combination of the three modules provides an optimum solution for every requirement.

One half of the infrastructure module is assigned to an apartment. Depending on the size of the family and its needs a floor space of 47- 60 m² is available.
The decision to entrust the layout of the rooms and the choice of the façade to the resident is based on the fact that a high percentage of the poor population has good technical skills. The freedom of an autonomous decision and the opportunity to contribute their part will be encouraged.

The ground floor is used as a business, and community area. The roof areas are freely available to the residents. The usage should be referred to the Community, e.g.: for urban gardening, Rainwater harvesting or power generation.

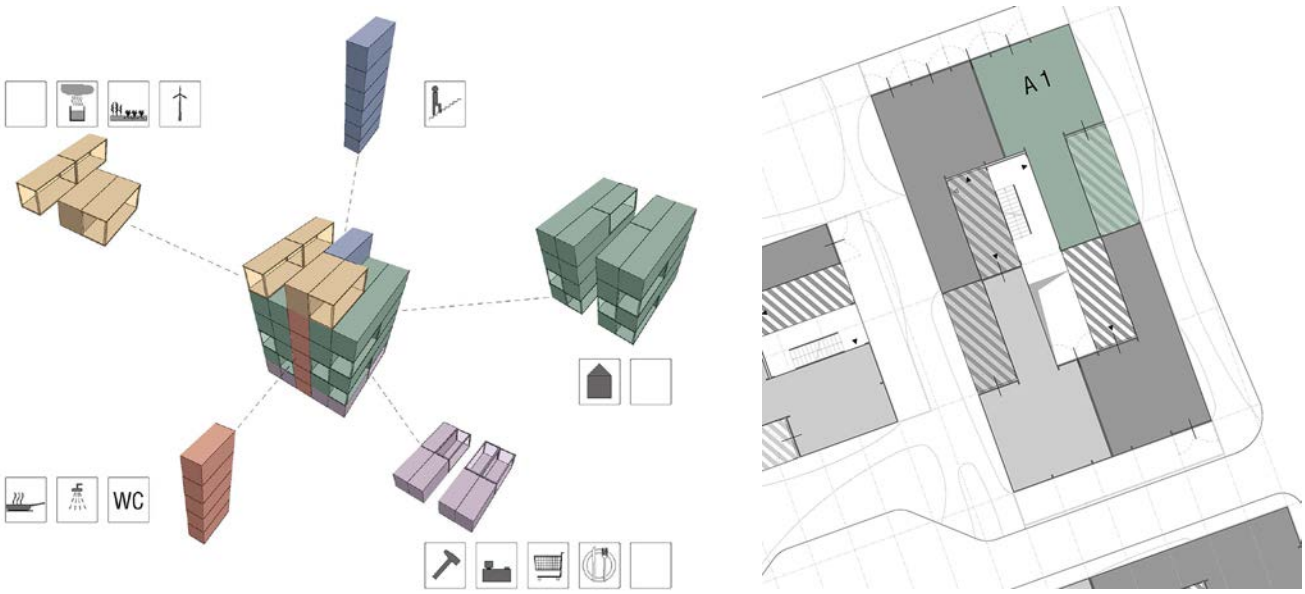


Fig. 4: Components of the Hometainer / exemplary site plan

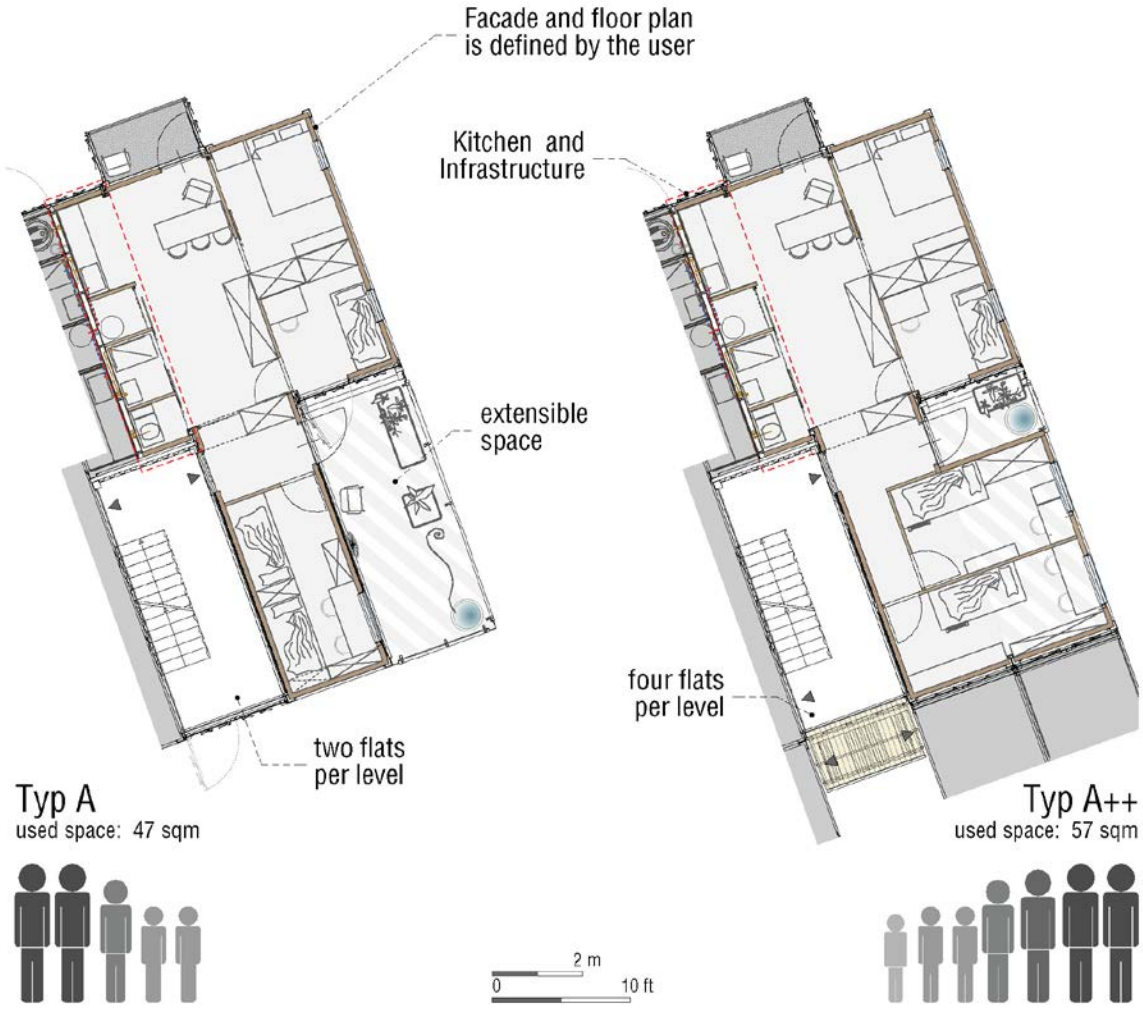


Fig. 5: Exemplary floor plan

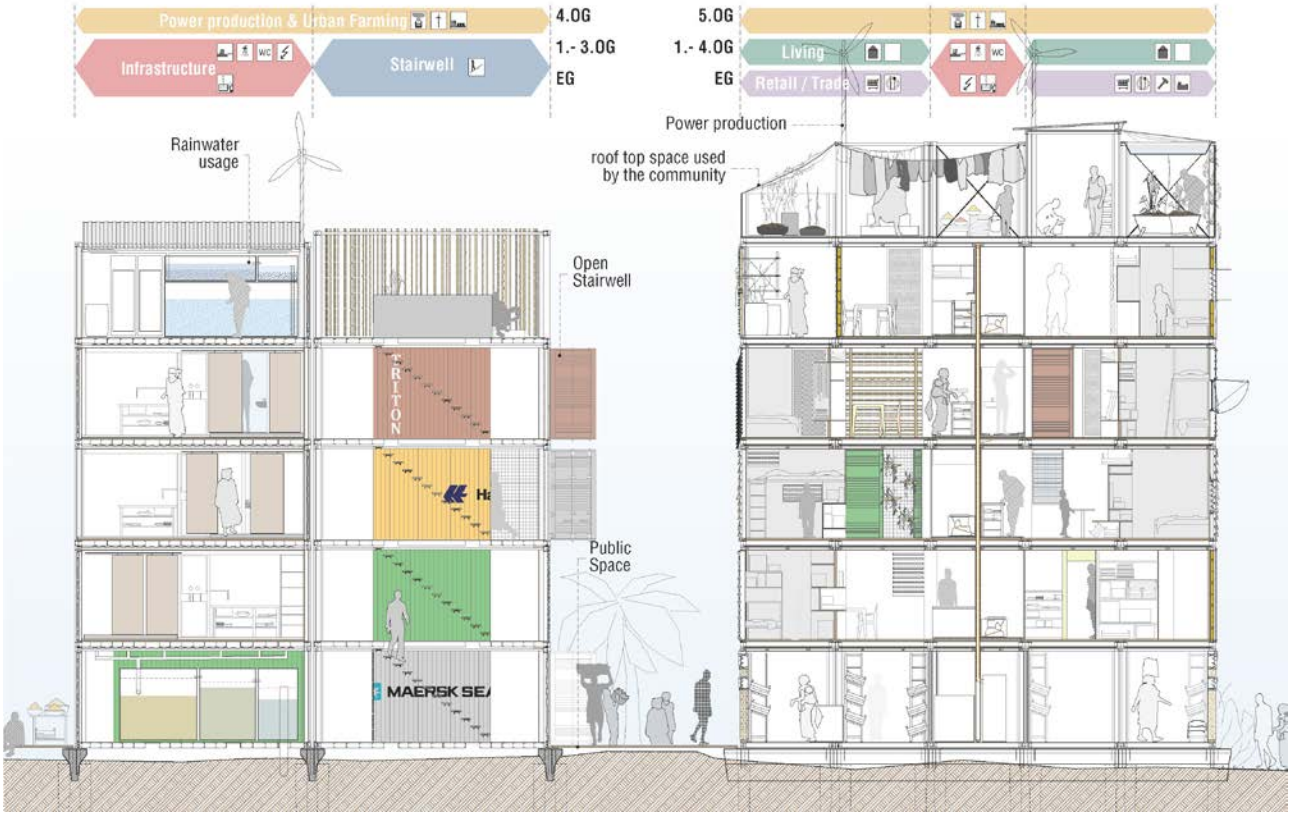


Fig. 6: A section through two Hometainer

2.3 Building materials

The Hometainer structure consists 100% out of used containers and represents the first major contribution to a sustainable cycle of use. In order to make the container habitable most parts of the steel walls will be removed. These parts can be reused on the building or sold as a recyclable commodity.

Instead of an expensive high-tech – façade solutions it will be set to local and freely available or repurposed materials that are joined to an inexpensive but effective solution. The variants range from single facade such as packed mud to multilayer components made out of wood, reeds, textiles and scrap. This diversity of outward appearance should reflect the freedom, self-determination and the participatory planning process of the Hometainer user and should show how to use resources sustainable and meaningful.

Behind all developed façades, the thought is that it can be built, maintained and adapted by the users themselves. In addition care was taken to use as often as possible materials which are natural products, ready-mades or simply to machine.

A wooden frame substructure that will be double planked from the inside with chipboards of agricultural waste constitutes the common basis of all variants.

2.3.1 Inner walls / Floor / Roof / Furniture

For the interior work Chipboards made from agricultural residuals will be used. The building board was developed by the Bern University of Applied Sciences and is 100% organic and contributes to a sustainable environment. Swarfs from corn cobs, peanut shells, and all types of cereals, rice and

bamboo can be used. In Africa, Asia and South America, these raw materials mostly grow all year round and the residual materials remain almost wasted. Here is an immense potential and a building material of this type could contribute significantly to a more sustainable environment.
A process for the preparation of these plates was developed by the Bern FH and is freely available (no patents).

2.3.2 Mud

Mud is one of the most natural building materials. It's easy processing and has temperature regulating properties. A long architectural tradition makes it an outstanding material. It is mainly used at the ground floor and in easily accessible locations.



Fig. 7: Façade section through an exterior wall made out of mud

2.3.3 Textiles / Bamboo

Textile fabrics or used Tilt Trucks with 600g / m² or more can be tensioned directly on the wooden frame or be cross threaded through a bamboo substructure. It also serves as a sunscreen. An open bamboo braid can be used in the areas of the enlarged housing.

2.3.4 rush / Grass Mats

This ecological natural material with a long tradition can be mounted as facade from the inside. The material appears as good as in all coastal regions and will continue and support local building traditions.

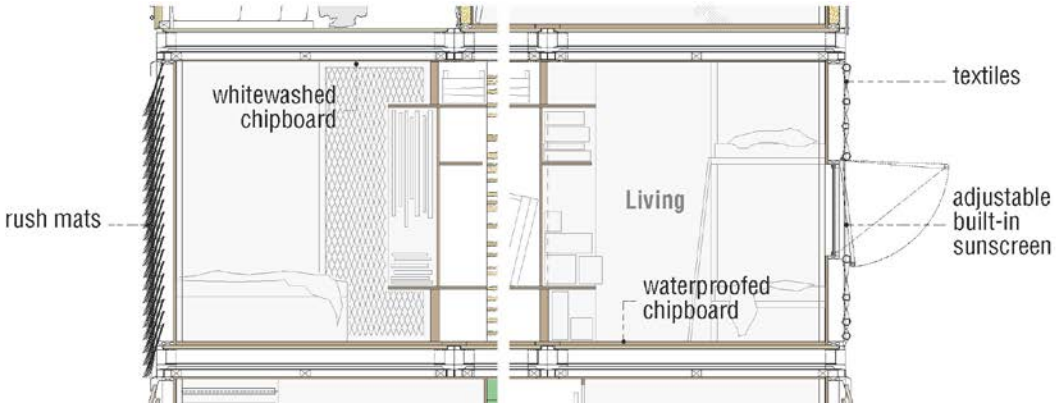


Fig. 8: Façade modification with textiles / bamboo and rush mats

2.3.5 Wood

Untreated boards in the shape of a horizontal shuttering provide a weather-protective level. Generous rear ventilation will keep the wood dry. It can also be mounted in front of windows as a permanent shade.

2.3.6 Structural steel / PET bottles

PET bottles filled with plastic waste (A substitute for thermal insulation) can be arbitrated in the wooden frame and planked on both sides. An exterior structural steel mesh can be covered with found materials and forms the outer protective sleeve. The structural steel mesh can be cut in front of the windows and bent outwards to serve as a sunscreen.

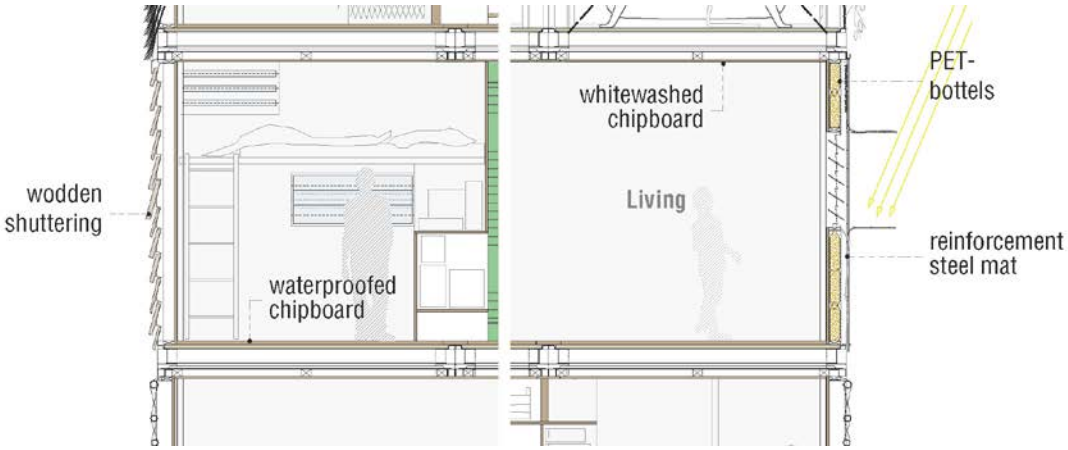


Fig. 9: alternative façade made out of wood respectively of structural steel and used PET bottles

2.3.7 Roof surfaces

The roof surfaces are used for the cultivation and sustainable building operations. (Rainwater harvesting, wind generators, hot water generators) The arising plants will help to improve the microclimate and replace a part of the lost ground surface.

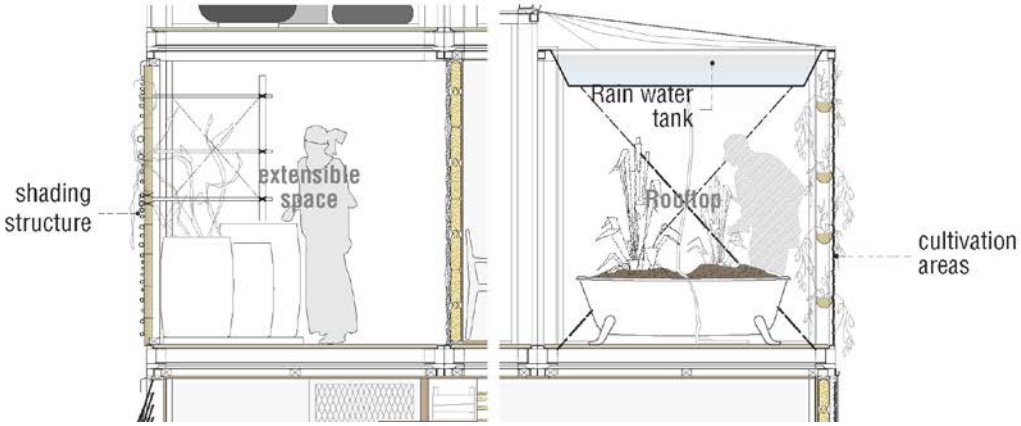


Fig. 10 possible usages of the rooftop and extensible space of the flats

3. Conclusion an future development

The Hometainer project includes three ideas.

- Every person should have a right to an appropriate accommodation. As mentioned in the introduction, more than two billion people live in the worst conditions. A further development with appropriate means is essential for reducing this grievance.

- To ensure a permanently development and progress a careful use of the available resources is necessary. To develop housing in forms of already used materials is actually just a sustainable continuation of the product lifecycle.

- The equitable use of common property (land) and the promotion of communal thought. Thus, the project will encourage users to see the progress from a new side, to create synergies and to work cooperatively towards a better future.

In further consequence of the development phase the implementation of a Hometainer prototype is desired. This allows checking the system for its suitability and effectiveness. In none of these steps the benefits for the project and people must not be neglected.

4. References

[1] STUBITSCH G. “Hometainer - Das Recht auf Wohnen und Entwicklung”. Diplomarbeit / Graz 2012

ELAS – Assessing the energy aspects of settlements



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Short Summary

ELAS is the abbreviation of the research project “Energetic Long-term Analysis of Settlement structures” [1], in which the interrelations between spatial aspects as well as technical aspects of residential settlements and energy aspects were modelled. The results were transferred in a freely available online calculator for settlements, the ELAS-calculator: www.elas-calculator.eu.

Keywords: Energy calculator; sustainable urban planning; energy efficiency, renewable energy supply; sustainability assessment.

1. Introduction

Energy consumption linked to settlements is a major factor within the energy balance of society. In the European case much of the 27 % share of the energy consumption of households is defined by the infra-structure of settlements. This also holds true for a considerable part of the 33 % share of the energy consumed by transport, given that the location of settlements determines the mobility of their inhabitants to a large part; on top of the mobility of individuals, building houses and infra-structure such as roads, sewage systems and energy distribution grids also cause transport of goods, thus adding to the transport impact of settlements. Finally production of all these goods again requires energy in the industrial sector, appropriating a substantial part of the 24 % share of the industrial sector within Europe’s energy balance [2]. Therefore spatial planners need to be aware of the linkage between energy production/consumption and settlement structures. Beside legal conditions which need to be addressed [3], adequate tools will help planners and decision makers during the development process of construction sites. Decisions taken regarding site, structure and operation of buildings and settlements have a strong impact on energy consumption of society and all related environmental impacts. These decisions affect all sectors of life and may not be reduced to just the impact of household energy consumption. As these decisions tend to define energy consumption patterns of society in the long term they must be based on solid strategic evaluation of all available alternatives if sustainable development shall be achieved.
Any sustainability oriented energy strategy from the supranational to the local level rests on three pillows: energy saving, energy efficiency and renewable energy supply. This is also true for the European Energy Strategy as laid down in the Energy Roadmap 2050 [4]. The environmental overshoot of the current energy systems are caused by high energy intensity of society as well as the predominant reliance on fossil and/or nuclear based energy provision [5]. Housing and settlement infra-structure as well as the operation of buildings and the mobility of citizens living in them constitute a pivot for turning the energy system towards sustainability.
This pivot function can however only be realized when all actors in the field take informed decisions. Therefore tools are required that offer evaluation of impacts incurred by those decisions from all aspects of sustainability. If decision takers have a holistic view on the consequences of

their actions, including all ecological impacts along the life cycle of buildings and settlements, the life cycle costs and social implications the chance that they may opt for sustainable development pathways increases considerably. There is no shortage on evaluation tools regarding buildings and their impacts on the economy and environment. All these tools are useful and may help decision takers in their task to cut through the intricacies of finding the optimal solution for housing development. They offer however only partial information that has to be put together to obtain a comprehensive sustainability evaluation of decisions related to housing. This paper introduces a holistic decision making tool (The ELAS Calculator, www.elas-calculator.eu) that models complex systems of energy demand and supply of residential settlement structures and provides a basic sustainability appraisal considering

- energy demand and supply for
  - construction of buildings
  - construction of public infrastructure
  - operation of buildings including room heating, warm water and electricity
  - operation of public infrastructures as well as
  - mobility of residents depending of the demographic structure of the inhabitants as well as the location of the settlement and
- impact on regional economic turn over, revenue and labor market

The model can be applied to existing settlements as well as to planned projects spanning from

- new settlements as greenfield developments
- renewal and renovation of existing settlements with/without expanding them
- tearing down and reconstructing settlements on the same site or on a different site.

2. ELAS - Calculator

Basic decision like the site chosen for a building and the technical standard of building will have profound impact on the energy consumption during its whole life cycle. This has to be reflected in any reliable decision support tool. The life cycle in this case therefore more resembles a “life cycle-network” with the provision of housing at its center. It combines the life cycle of buildings, including the provision of building materials, transport of material, construction, renovation and up-grading as well as demolition and final disposal (or recycling) of building material with the life cycle of infra-structure (roads, sewage systems, energy provision grids) including their operation and maintenance with the life cycle associated with mobility of residents and the life cycles of energy provision to operate the buildings (including heating, cooling and electricity).
The concept realized in the ELAS Calculator is to evaluate the impact of a building or settlement as well as any planned changes to a building or a settlement (including radical changes such as demolition and construction at a different site with a different technological standard) on this “life cycle-network”. That means that all impacts generated along the life cycles constituting this network will be calculated and made transparent, not only in ecological but also in economic and social terms. This applies to current operation as well as all planned changes in to the existing structure as the status quo of buildings and infra-structure will not be rated according to their ecological, economic and social impacts. By this approach the users of the calculator can assess not only the direct impacts of their decisions but may also gain a comprehensive view on the consequences of their action on nature, economy and society.
The ELAS Calculator is designed to support informed decisions about design and operation of buildings and settlements by all relevant actors. It therefore addresses different audiences in order to provide actors on different levels of decision taking with coherent information thus enabling a discourse within as well as across different levels of actors. In particular the ELAS Calculator is designed to be used by

- *Single households* - to assess their individual decisions regarding design, operation and maintenance of their houses and flats, also including the impact their behavior has on construction, operation and maintenance of infrastructure supporting their buildings and mobility induced by their choices

- *Municipal administrators* - to assess impacts the ecological, economic and social impact of existing settlements
- *Planners* - to assess consequences of their activity regarding design and changes in settlements (enlargement, change of technical standards, changes regarding supporting infrastructure and measures concerning energy efficiency and energy provision systems, etc.), including impacts generated by necessary supporting infrastructure and induced mobility by residents.

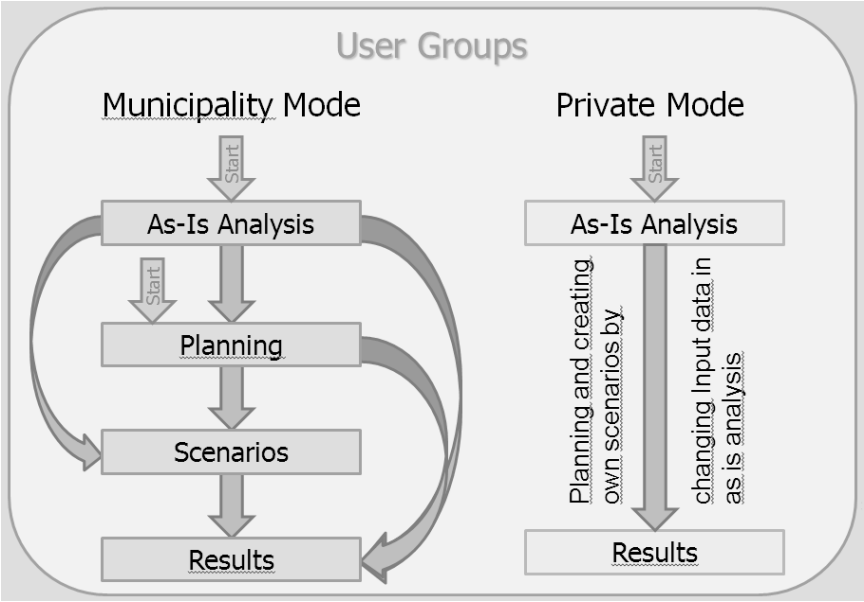


Fig. 1: ELAS-Calculator modes

This requires that the necessary data as well as representation of results must be adapted to the needs of these actor groups. Fig. *1* shows the overall architecture of the calculator. The two principal modes, the “private mode” and the “municipal mode” refer to the two main user groups, private households and professional users, respectively. Within the “municipal mode” the separation of assessment of an existing settlement (As-Is-Analysis) and planning of a new settlement (planning mode) represents the realization of the two tasks, analysis of impacts of existing settlements and planning of new settlements. It is however possible to change from the analysis of an existing settlement to the planning mode and thus assess changes for an existing settlement. Using this option municipal administrators as well as planners can evaluate not only direct impacts of enlargement of settlements and/or up-grading of technical standards of buildings and infrastructure but also impacts of measures of spatial planning and zoning.
Besides the assessment of the impacts of housing under current conditions, the ELAS Calculator offers the option to calculate these impacts under future scenarios (with a time horizon of 2050):

- Trend scenario: in this scenario total traveled distance for individual mobility increases by 25 %, 10 % of the fleet will be operated by biogas and 15 % by electricity, electricity demand it increases at a rate of 2.2 % p.a. This scenario follows projections by Kratena & Schleicher [6] and Friedl & Steiniger [7].
- Green Scenario: in this scenario energy demand of the settlement will decrease by 33 %, electricity will be provided entirely by renewable resources. Increase in traveled distance will again be 25 % however 70 % of cars will be operated on biogas and 30 % on electricity. Several studies were included to justify corrections made to the Trend scenario, including [8] [9] and the instructive analysis of the economic effects of energy price shocks. [10]

These scenarios enable the user to estimate the bandwidth of impacts of the settlement in future within reasonable boundaries.

Any evaluation regarding the sustainability of a settlement has to take the spatial situation in relation to locations providing all necessary functions for residents living in it into account. Construction and maintenance of infrastructure as well as mobility requirements for residents depend critically on the distance between settlement and the provision of functions such as retail stores, educational institutions, health provision, administrative centers, etc. The ELAS Calculator meets the challenge of systematizing this fundamental factor for the evaluation of settlements by defining different "levels of centrality" that define what services are provided in the community the settlement is located in (see *Fig. 2*).

Dependent variable of reachability **Route duration in minutes**				**higher-ranking levels of centrality are already including services of lower-ranking levels infrastructure**		
car	public transport			**Supply** (products = goods and services)	**Social Infrastructure**	**Spare time, Regeneration and Sports**
walking distance		Centrality	**Village without Centrality and Local Supply** Level 1	no supply of goods and services	***Public Administration and Security***	***Earmarked Public Space:*** e.g. graveyard
≤ 10	*≤ 15*		**Village without Centrality but with Local Supply** **Level 2**	***Convenience Goods***	***Educational Institution*** level 0 and 1 according to ISCED-97: ***Health Care-, Long Term Care - and Child Care Facilities:*** ***Cultural-Religious Facilities:*** ***Public Administration and Security:***	
≤ 20	≤ 30		**Center - Village** **Level 3**	***Convenience Goods with slighlty more specialised Character:*** drugstore barber financial institution post office or post partner	***Educational Institution*** level 2 according to ISCED-97: ***Educational Establishment (out-of-school):*** ***Health Care-, Long Term Care - and Child Care Facilities:*** dentist, drugstore, home forthe elderly ***Public Administration and Security:*** police station	***Earmarked Public Space:*** open air pool indoor swimming pool *gastronomy* café restaurant bar
≤ 30	≤ 45		**Regional Center** **Level 4**	***Shopping Goods:*** health food store, toys clothing, footwear bookshop, stationery sound carrier florist, gas station sport goods watchmaker, jeweller electric shop movie, picture, data processing, telecommunications dinnerware, household goods	***Educational Institution*** level 3, 4 and 5 according to ISCED-97: ***Educational Establishment (out-of-school):*** e.g. adult education center, language school ***Health Care-, Long Term Care - and Child Care Facilities:*** e.g. medical specialist, hospital, hospice service, migrants facilities ***Cultural-Religious Facilities:*** museums, galleries event center ***Public Administration and Security:*** district administration facilities chambers of social partners (labour-, economic- and agriculture chamber; federation of trade unions) court	***Public Space:*** spots ***Service Facilities:*** sauna solarium gym cinema club
≤ 60	≤ 90		**National or Supra-Regional Center** **Level 5**	***Special Shopping Goods and not frequently consumed Products:*** furniture, furnishing domestic appliance do-it-yourself store tools and gardening tool specialist shop musical instruments, sheet music other one-line shops (e.g. art trade, weaponry)	***Educational Institution*** level 5 and 6 according to ISCED-97 ***Educational Establishment (out-of-school):*** archive ***Cultural-Religious Facilities:*** theater, cabaret opera, concert hall ***Public Administration and Security:*** facilities of regional government authority	***Public Space:*** parks and green areas ***Earmarked Public Space:*** botanical and zoological gardens allotments, stadiums ***Semi-Public, useable Public and Green Space:*** inner courtyards, community area ***Provision of Service Facilities:*** e.g. amusement and theme parks

Fig. 2: Degree of centrality definition (compressed version) (Source: [11])

Higher levels of centrality refer to communities offering a broader spectrum of functions. The calculator offers a step-by-step help function to support the user in defining this fundamental set of data. Using the distances to the different locations providing basic functions for residents (and using demographic information and modal split information explained later) the ELAS Calculator is able to evaluate the part of the impact of settlements and buildings related to their location.

3. Results of the ELAS Calculator

The ELAS-Calculator offers a holistic numerical evaluation of buildings and settlements from a

sustainability perspective based on a coherent data base. This requires providing a comprehensive ecological assessment, an evaluation of the economic impact of the settlement on the regional economy and insight into its influence on the job market. The ELAS Calculator does not evaluate issues that are less amenable to numerical assessment but are no less important to sustainability such as the impact on biodiversity and landscape and the impact of settlements on social equality, gender issues and inter-generational equity.

3.1 Holistic environmental Appraisal

A holistic environmental appraisal requires looking at the ecological impact of the life cycle network providing housing from perspectives. The ELAS Calculator meets this challenge by offering different ecological measures based on the same data base. By this approach the ELAS Calculator provides a comprehensive, multidimensional picture of the ecological pressures exerted by a certain building, settlement or development project from different angles without requiring the user to care about coherence of life cycle limits or data as the use of the calculator intrinsically guarantees congruence of these critical foundations of evaluation.
In this approach a fine line has to be treaded between providing a comprehensive picture of ecological impacts and deluging the user by information overload that hinders taking clear decisions. Choice of ecological measures represented in the calculator therefore becomes critical.
In the ELAS Calculator the following ecological evaluation methods are implemented:
Cumulative energy demand: this measure was chosen to provide insight into the energy flows (grey energy from construction, renovation and infra-structure provision, energy for operation of the building or settlement, mobility of residents) caused by the life cycle network providing housing, accepting the fact that energy use is responsible for a considerable share of ecological pressures across many impact categories. This measure also provides clear indication of the consequences of energy efficiency measures.
Life cycle CO_2 emissions: This measure corresponds to a particularly important ecological pressure, the emission of CO_2 and the subsequent impact on global warming. This measure also captures the efficiency of the energy provision system regarding global warming and hence may be used to compare different alternatives for providing energy to the building or settlement.
The ecological footprint, calculated according to the Sustainable Process Index (SPI) method: this measure allows the inclusion of the impact of nuclear energy but also the evaluation of all relevant ecological pressures linked to provision of resources and the generation of emissions and wastes (also including greenhouse gases) from the life cycle network. This measure therefore can be used to compare different alternatives regarding their overall ecological impact.
The three methods are described in more detail below.

3.1.1 Life cycle wide energy demand

Energy is a major factor in the ecological pressure exerted by a building or settlement. The ELAS Calculator accounts for all energy flows generated by the whole life cycle network. This includes the energy to operate the buildings (heating, cooling, electricity demand of appliances), the necessary supporting infrastructure (energy to operate sewage systems, street lighting, road service, etc.) and mobility of residents. The calculator however also includes all “grey energy” that is necessary to provide the materials of construction for buildings and infrastructure or used in construction, renovation or demolition and disposal (when appropriate) for any planned changes to the current structure. This grey energy is calculated using the methodology of the “Kumulierter Energieaufwand – KEA” [12]. Grey energy input will be related to one year by taking lifetimes of buildings and infrastructures (66 years) into account.

3.1.2 Life cycle wide CO_2 emissions

The calculation of CO_2 emissions is directly coupled with the calculation of the ecological footprint (see below). All fossil carbon inputs across the whole life cycle network are the base of the CO_2 calculation. This includes also CO_2 emissions from synthetic materials used in construction of new buildings and infra-structure as well as in renovation, depreciated over the life time of the building and the renovation interval respectively.

3.1.3 Ecological footprint according to the Sustainable Process Index (SPI) method

The SPI is a method to calculate ecological footprints that emissions to air, water and soil besides resource provision into account [13]. The method compares anthropogenic and natural flows according to the following sustainability critera [14]:

- Principle 1: Anthropogenic mass flows must not alter global material cycles;
- Principle 2: Anthropogenic mass flows must not alter the quality of local environmental compartments.

The results of the footprint calculations are broken down into partial footprints for direct area consumption, fossil resource consumption, renewable resource consumption and emissions to air, water and soil.

3.2 Socio-economic Appraisal

Socio-economic impacts are calculated using the economic input-output analysis [15]. This method calculates the impact of particular economic activities throughout the whole economic system by modelling the interaction of the sectors of the economy, using appropriate input-output coefficients linking the activities of different sectors. The sectors in this analysis were defined following the NACE-systematic of economic sectors [16] however splitting the sector E “Electricity, Gas and Water Supply” into non-renewable energy, renewable energy and water supply. Activities evaluated with the ELAS Calculator are supposed to provide products summarised in building construction, building operation, municipal services construction and operation and external effects (mainly concerning transportation).
The ELAS Calculator will evaluate socio-economic impacts regarding the concrete region the settlement is located in. This requires regionalisation of the input-output coefficients, starting from national data provided by Eurostat [17] and using regionalisation techniques according to [18][19]. This method counters the main drawback of mainstream regionalization techniques, i.e. the overestimation of multipliers and transformators.
Using this model the ELAS Calculator will provide an evaluation of regional and national turnover, value added and jobs induced by the operation of the existing building or settlement and the planned changes to the settlement respectively.

4. Conclusions

Decisions concerning construction and operation of buildings and settlements are pivotal to achieving sustainability and in particular to arrive at a sustainable energy system of society. This is due on the one hand to the large fraction of energy used in buildings (in particular in Europe) and on the other hand to the considerable influence the way settlements are situated has on other energy uses, in particular by shaping mobility requirements of residents and modal split of travels. As such decisions, due to the longevity of buildings, have long ranging consequences thorough and reliable decision support is necessary.
Providing such comprehensive decision support for individual house owners as well as for municipal administrations and planners was the goal of the “energetic long term analysis of settlement structures” (ELAS) study that forms the background to this article. Based on a thorough analysis of ten settlements in different spatial situations and featuring a variety of building types and demographical set-ups of residents, a web based calculator was developed that evaluates buildings and settlements from the point of view of their sustainability.
The major challenges addressed with the ELAS Calculator were on the one hand the complexity of the ecological impacts of buildings and settlements and on the other hand the necessity to provide ecological and socio-economic valuation on the base of a coherent data set. Regarding the complexity of ecological impacts housing was represented as a “life cycle network”, combining the life cycles of energy provision as well as buildings and infra-structure. Comprehensive inventories for these different aspects were included in the ELAS Calculator. They were then used to evaluate the whole system of activity linked to buildings and settlements with three different ecological valuation methods, namely the total energy consumption, the life cycle CO_2 emissions and the ecological footprint using the SPI calculation method to provide a comprehensive picture of the ecological impact of buildings and settlements.

These same inventories were then coupled with economic input-output analysis with regionalized technology coefficients. This evaluation renders a comprehensive picture of the socio-economic impact of buildings and settlements, providing information about turn over, value added imports and jobs created by operating building and settlements or by renovation of buildings or changing settlement structures.
Within the research carried out it became obvious that infra-structure construction and maintenance as well as site-induced mobility are crucial for the sustainability of settlements. For both the site of the settlement is a defining factor. The ELAS approach addressed this by introducing different levels of centrality, differentiated according to the services available in the town the settlement belongs to. Thorough studies linking these levels of centrality and the demographic set-up of residents with daily and leisure mobility allow the evaluation of these factors within the ELAS Calculator without requiring excessive data acquisition from the user.
The ELAS Calculator offers free accessible evaluation for stakeholders involved in long ranging decisions regarding buildings and settlements. With this tool stakeholder can readily integrate aspects of sustainability in their decisions, both regarding the operation of buildings and settlements as well as in planning renovations, enlargements or even relocation of settlements.

5. Acknowledgements

The model was developed by the team of authors in an interdisciplinary research project named “ELAS – energetic long-term analysis of settlement structures” co-funded by the Austrian Climate and Energy Fund, the Provinces Upper Austria and Lower Austria as well as the Town of Freistadt. Therefore, we will further refer to the model as ELAS-model. The ELAS-model was transferred to an open-access internet tool, the ELAS-calculator, available on www.elas-calculator.eu. This paper reveals the ELAS-concept, the main approaches to calculating the outcomes and the way the database for the calculation was created.

References

[1] STOEGLEHNER G, MITTER H, WEISS M, NEUGEBAUER G, NARODOSLAWSKY M, NIEMETZ N, KETTL K-H, BAASKE W, LANCASTER B. (2011): ELAS - Energetische Langzeitanalyse von Siedlungsstrukturen. Projekt gefördert aus Mitteln des Klima- und Energiefonds, der Länder Oberösterreich und Niederösterreich sowie der Stadt Freistadt. www.elas-calculator.eu. [last access: 05 March 2013].
[2] EUROSTAT, 2011. ESA 95 Supply Use Input Tables, http://epp.eurostat.ec.europa.eu/portal/page/portal/esa95_supply_use_input_tables/data/workbooks [December 2012]
[3] STÖGLEHNER G, NIEMETZ N, KETTL K-H, (2011) Spatial dimension of sustainable energy systems: new visions for integrated spatial and energy planning, Energy, Sustainability and Society, 1, DOI: 10.1186/2192-0567-1-2
[4] EUROPEAN COMISSION, 2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee Of The Regions: Energy Roadmap 2050, /* COM/2011/0885 final */
[5] NARODOSLAWSKY M and STOEGLEHNER G (2010) Planning for local and regional energy strategies with the ecological footprint. J. of Environmental Policy & Planning 12/4 pp 363–379
[6] KRATENA K and SCHLEICHER St 2001. Energieszenarien bis 2020. WIFO, Wien.
[7] FRIEDL B and STEININGER K, 2002. Environmentally Sustainable Transport: Definition and Long-Term Economic Impacts for Austria, Empirica 29 (2002): 163-180.
[8] POLASEK W and Berrer H, 2005. Regional Growth in Central Europe, Long-term Effects of Population and Traffic Structure. Reihe Ökonomie / Economics Series. No. 172, IHS, Wien.
[9] Arpaia A and Turrini A, 2008. Government expenditure and economic growth in the EU: long-run tendencies and short-term adjustment. European Economy – Economic Papers 300, Directorate General Economic and Monetary Affairs, European Commission
[10] Kilian L, 2007. The Economic Effects of Energy Price Shocks. CEPR Discussion Papers 6559, published as: L. Kilian, 2008, The Economic Effects of Energy Price Shocks, Journal of Economic Literature, American Economic Association, vol. 46(4), 871-909
[11] *RIN 2008, Zielgrößen für die Erreichbarkeit zentraler Orte von Wohnstandorten,*

Ministerkonferenz für Raumordnung MKRO

[12] Öko-Institut e.V., 1999. Erarbeitung von Basisdaten zum Energieaufwand und der Umweltbelastung von energieintensiven Produkten und Dienstleistungen für Ökobilanzen und Öko-Audits; i.A. des Umweltbundesamtes. Berlin. Darmstadt. Freiburg.
KROTSCHEK Ch and NARODOSLAWSKY M, 1996. The Sustainable Process Index - A new Dimension in Ecological Evaluation. Ecological Engineering 6/4 (1996) pp. 241-258.

[13] NARODOSLAWSKY M and KROTSCHEK Ch, 2000. Integrated ecological optimization of processes with the sustainable process index. Waste Management 20:599-603.

[14] MILLER R.E. and BLAIR P.D., 2009. Input-Output Analysis. Foundations and Extensions. 2nd Edition, Cambridge

[15] EUROPEAN COMISSION, 2002. Commission Regulation (EC) No 29/2002 of 19 December 2001 amending Council Regulation (EEC) No 3037/90 on the statistical classification of economic activities in the European Community

[16] EUROSTAT, 2007. Energy, transport and environment indicators, Eurostat pocketbooks, accessed through http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-DK-11-001/EN/KS-DK-11-001-EN.PDF [December 2012]

[17] CLIJSTERS G.M.J., OUDE WANSINK M.J., PEETERS L.M.K., BAASKE W.E., 2003. Adapting QFD for evaluating employment initiatives, Transactions from Int. Symp. on QFD 2003, 15th Symp. on Quality Function Deployment, Orlando/USA, ISBN 1-889477-15X, p183–199.

[18] BAASKE W.E. and LANCASTER B, 2004. Evaluating Local Commitment for Employment – Towards a realisation of the European Employment Strategy, Trauner, Linz, ISBN 3-85487-573-8.

GUGLE – A smart urban quarter model for the building stock in Vienna



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Short Summary

Cities like Vienna are obliged to achieving energy policy targets. The GUGLE – master plan originates from the need of collective actions at regional, national and EU levels, while considering user needs in an urban area and incorporating sustainable technologies and actions. Although a transition to a more sustainable path is commonly acknowledged, it has been proven to be rather difficult to change the incumbent system. In order to implement appropriate concepts and strategies for achieving sustainability and for assessing the potential impact of novel clean technologies and measures, GUGLE serves as a gate towards advanced regional, national and EU demonstrations, by building upon Bottom-Up-Approaches.

The comprehensive integration approach used in GUGLE aims at drawing a technical feasibilty study (TFS) for two Viennese districts, Penzing and Alsergrund, considering within their borders every aspect of a smart city life and energy services. The TFS serves as a gate towards advanced regional, national & EU demonstrations by designing, implementing and validating a plausible scientific framework for proper actions and co-operation towards future sustainable energy policies in end-use sectors for the EU-targets 2020 / 2050.

The objective of this scientific study relies on developing a comprehensive interdisciplinary urban quarter concept as a trendsetting business model in close co-operation with related envisaged investors and industrial partners. Based on selected lighthouse projects and on related promotion activities of empirical results the wishful market extension will be pushed on mid-term. Proposed future scenarios and measures of the GUGLE Master plan are not new, but have been intensively discussed with all relevant stakeholders within project meetings and workshops and are specified for extended deployment at district level.

Keywords: urban quarter concept, smart city development, sustainable energy policies, future scenarios

1. Introduction Smart Cities

1.1 Background of Smart City Initiatives

In one decade about two thirds of the world's population will live in urban areas. Only cities with a functional ecology can offer the prospects of saving natural landscapes from urbanization in order to secure high quality of life for its inhabitants [1].
This is the background of many so called „smart city" initiatives - they pursue the goal of creating more attractive and liveable cities, which have the highest potential for energy-efficient way of live, because of their density.
Some of the most effective instruments of smart city projects are ambitious refurbishments of the existing building stock, the creation of new highly energy-efficient living quarters, the switch from fossil energy sources to renewable energies and the development of intelligent traffic and transport solutions.

1.2 National and European initiatives on smart cities

In 2010 the EU enacted the so called „Strategic Energy Technology Plan" („SET-Plan"), which was designed to function as a steering tool for the strategic collaboration of European Nations in order to fundamentally transform today's energy system and to reach the European 2020 energy targets (reduction of greenhouse gas emissions by 20% compared to 1990 levels, increase of the share of renewable energies of 20% and the increase of the overall energy efficiency of 20%).
The Seventh Framework Programme (FP7) issued by the European Commission currently grants subsidies to innovative projects promoting sustainable developments – including smart city initiatives as one main emphasis.

In Austria the national programme „Smart Energy Demo - FIT for SET" was issued by the Austrian Climate and Energy Fund, which emphasizes on the establishments of Austrian smart city initiatives. The aim is to accompany and support cities, as well as companies and research institutes implementing smart city measures.
The programme was received with great interest, during the starting phase in March 2011 a total of 20 projects from different cities across Austria were granted subsidies. Among these was the research project "GUGLE" (Green Urban Gate towards Leadership in sustainable Energy), which focuses on the energy-efficient refurbishment of two Viennese districts, Alsergrund (9th district) representing the inner city and Penzing (14th district) representing suburban settlements, which contains very opposite types of existing building developments.

2. GUGLE

2.1 Initial situation

The research project GUGLE - Green Urban Gate towards Leadership in sustainable Energy was initiated by the workgroup Sustainable Constructions at the University of Live Sciences and Natural Ressources (BOKU), Department of Structural Engineering and Natural Hazards, Institute of Structural Engineering under the scientific leadership of Univ. Prof. Arch. DI Dr. Martin Treberspurg.

GUGLE builds on the objectives of the previous „Smart City Wien" project, which was striving for solutions for an overall smarter Vienna. In its course a roadmap addressing several areas of activity was developed in order to ensure ambitious targets related to energy and climate protection. Those goals should be achieved at city level by 2020 and 2050. The „Smart City Wien" project-team has identified various areas of activities, comprising the topics of urban extension, mobility, new construction and renovation of buildings, utilisation of various types of energy and energy related user behavior.
The comprehensive approach used in GUGLE is in line with these smart city actions and aims at drawing an energetic master plan for the two Viennese districts Penzing and Alsergrund. This

master plan addresses every necessary aspect for a smart district life and also covers the topic of energy services and supply. The aim of the project is to find intelligent and innovative ways at district level which eventually can be applied to full city scale, based on a bottom up approach.
The objective of this scientific study based on the thematic fields presented in fig.1 relies on developing a comprehensive interdisciplinary city quarter concept as a trendsetting business model in close co-operation with related envisaged investors and industrial partners. The goal was to use and integrate existing Viennese strategies like the climate protection program (KLIP Klimaschutzprogramm der Stadt Wien) and the city development plan (Stadtentwicklungsplan) as well as other programs.

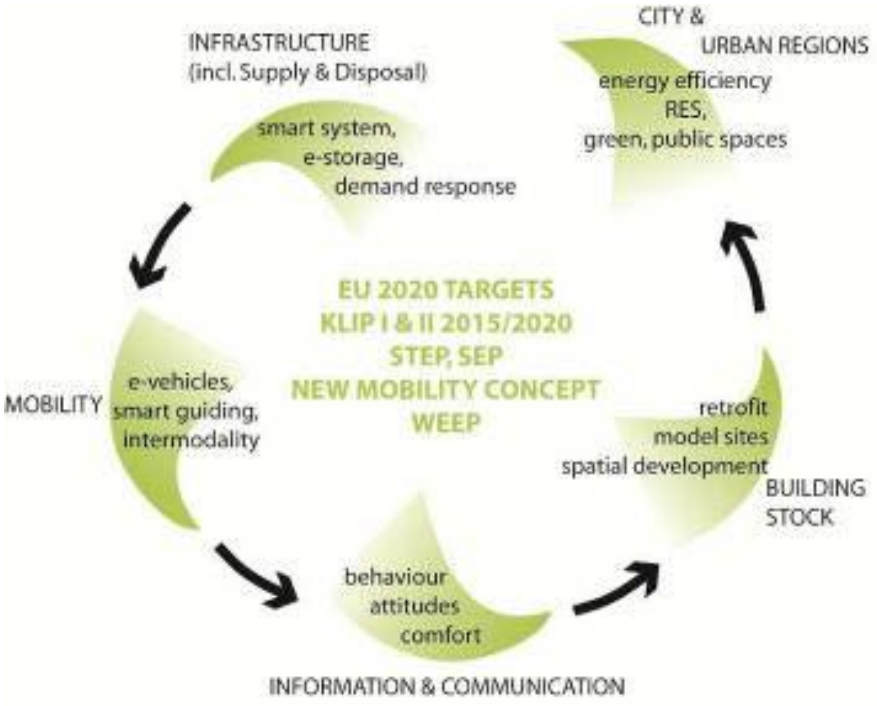


Fig. 1: Relationship between the thematic fields of GUGLE and the energy-political frame of Vienna [Source: BOKU Vienna].

2.2 The historical development of the Viennese districts Alsergrund and Penzing

The spatial development of the city of Vienna can be retraced by looking at its different urban patterns. Originally Vienna consisted of an inner core (today's first district), which was protected by a city wall (which was replaced by the "Ringstraße" - boulevard during the historic period).
Starting off in the 15th century, the first medieval suburbs were formed outside the city wall ("Vorstädte"). Until the 19th century they remained sparsely populated, which abruptly changed in 1850, when they were affiliated to Vienna as its new settlement areas because the inner city was already over-crowded.
The Viennese district Alsergrund represents one of these former suburbs, which are still characterized by the buildings and typical urban patterns stemming from the period of promoterism (Wiener Gründerzeit, 1840-1918). Some characteristics the former suburbs all have in common are: a high percentage of historic buildings and a very central location around Vienna's old town with an optimal access to public transport. The lack of green spaces and a high heat-energy demand of the historic buildings, which results in an overall reduced living comfort can be identified as their main disadvantages.

Penzing on the contrary represents one of the early settlements which existed in the form of a rural-urban fringe around Vienna ("Vororte", today's 10th – 19th district). These settlements developed as autonomous towns around the previously mentioned new suburbs and were incorporated to the city of Vienna under the regiment of Austrian emperor Franz Joseph in 1892.

Because of their distinguished settlement history, their urban structure differs from those districts located around Vienna's city center.
Today, the district of Penzing contains former working-class quarters constructed during the later period of promoterism and a large building stock of multiple dwelling units from the 1950-70ies.

2.3 Energy Scenarios developed in the GUGLE – master plan for Penzing and Alsergrund

Beside urban layout, mobility and energy supply a special focus was on the building stock within the master plan. Based on the actual building stock, different scenarios were developed to show possible optimizations. These scenarios will be exemplified in the following section.

2.3.1 Data

In the course of the development of a GUGLE-master plan the heat demands of Viennese districts Alsergrund and Penzing were analysed closely. Based on the actual consumption data, four scenarios of future energy consumption were calculated based on the simulation model Invert/EE-Lab (based on Kranzl et al., 2011) [2]. These scenarios simulate the building related final energy demand for space heating and hot water of Alsergrund and Penzing until the year 2030. The considered buildings are residential and service buildings and exclude buildings for industrial purposes. Invert/EE-Lab is a dynamic bottom-up simulation tool which uses disaggregated data for the building stock, such as available roof area and currently existing heating systems. The model simulates different scenarios (price scenarios, insulation scenarios, different consumer behaviors, etc.) and their respective impact on future trends of renewable as well as conventional energy sources on a national and regional level. Beside that the model evaluates effects of different promotion schemes (different settings of economic and regulatory incentives) on the energy carrier mix, CO2 reduction and costs. The Vienna University of Technology/EEG worked out these scenarios with the Invert simulation tool.

In order to apply the Invert/EE-Lab model for the Penzing and Alsergrund, data of the district's building stock, as well as their heating supply (by fuels used and by system type) were required. This data has been derived through calibration of data from Vienna (Statistic Austria (2011)) [3] to the districts data from Statistic Austria (2004) [4]. However it must be kept in mind that this approach is associated with a certain level of uncertainty as the latest data concerning heating systems reflects the status as of 2001. For the future development of building stocks, future expectations from ÖROK (2011) [5] have been taken into account.

2.3.2 Description of Scenarios

In order to pre-estimate the final heat energy demand development up to 2030 under the aspect of different levels of refurbishment four scenarios have been conducted. The key characteristics of these scenarios are the quality as well as the quantity of the thermal refurbishments conducted in the scenarios. The following four scenarios were identified:

- Business as Usual - "BAU Scenario":
This scenario reflects the current trends of refurbishments in Austria based on given information in Tabula Brochure [6] . This scenario includes entire building renovations (i.e. renovation of all building elements), however, due to the lack of information or economic support instruments, it is estimates that a considerable number of buildings will be refurbished without thermal improvement. The BAU scenario also assumes that, to certain extend, the NRfNB (National Regulation for New Building) standards will be disregarded.
This scenario results in a low rate of thermal building refurbishment of less than 1% per year.

- “Alternative Scenario_1”:
This scenario assumes that all new buildings will be built based on NRfNB Standards. It is also assumed that until 2020 refurbishments will be conducted based on current trends, but from 2020 on, refurbishments will be based on NRfNB standards. Again, due to economic conditions or a lack of information, there is a considerable share of buildings renovated without improving their thermal standard. Furthermore it is assumed that all heating systems will be replaced by high efficient heating systems (e.g. high efficiency boilers) after 2020.
The resulting thermal refurbishment rate of Alternative Scenario_1 is slightly higher than of BAU-Scenario.

- “Alternative Scenario_2” (“Gugle_Penzing” and “Gugle_Alsergrund”):
The difference between this scenario and Alternative Scenario_1 is the assumption that refurbishments as well as new constructions starting from 2020 on are based on NZE (Nearly Zero Energy) standards. This scenario is therefore called “Gugle_Penzing” and “Gugle_Alsergrund” Scenario, as the intended demonstration projects within the Gugle Project for these districts are incorporated in the scenario development. More precisely, the assumption is taken that these refurbishments will be based on NZE isolations standards.
In this scenario the thermal refurbishment rate of buildings is slightly higher than in Alternative Scenario_1, but still a number of buildings are renovated on low-level thermal insulation standard.

- “Potential”:
The fourth scenario “Potential” indicates the possible heat energy demand reduction of Penzing up to 2030 under the assumption that all building refurbishments will be based on NZE standard and that no building renovation activities will be conducted without thermal improvements or with lower standard than NZE. Thus, we assume that for those buildings renovated, there are no extra costs for renovating to NZE standard. However, it is assumed that there will be no advanced investments in building renovations, such as investments in integrated thermal refurbishments of buildings ahead of the end of lifetime of building components.
Therefore, the overall resulting thermal building renovation rate is still moderate (yearly average rate up to 2030: 1.5% for Penzing, 1.75% for Alsergrund), though it would mean more than a doubling of the current renovation rate. More ambitious scenarios would only be possible with a higher share of advanced investments in building renovation.

2.3.3 Total final heat demand – Penzing

The development of Penzing's total final heat demand is shown in fig.2. Choosing 2006 as the starting year with a total building related heat demand of 912 GWh in Penzing, it shows the estimated heat demand reduction until 2030 based on the four calculated scenarios.

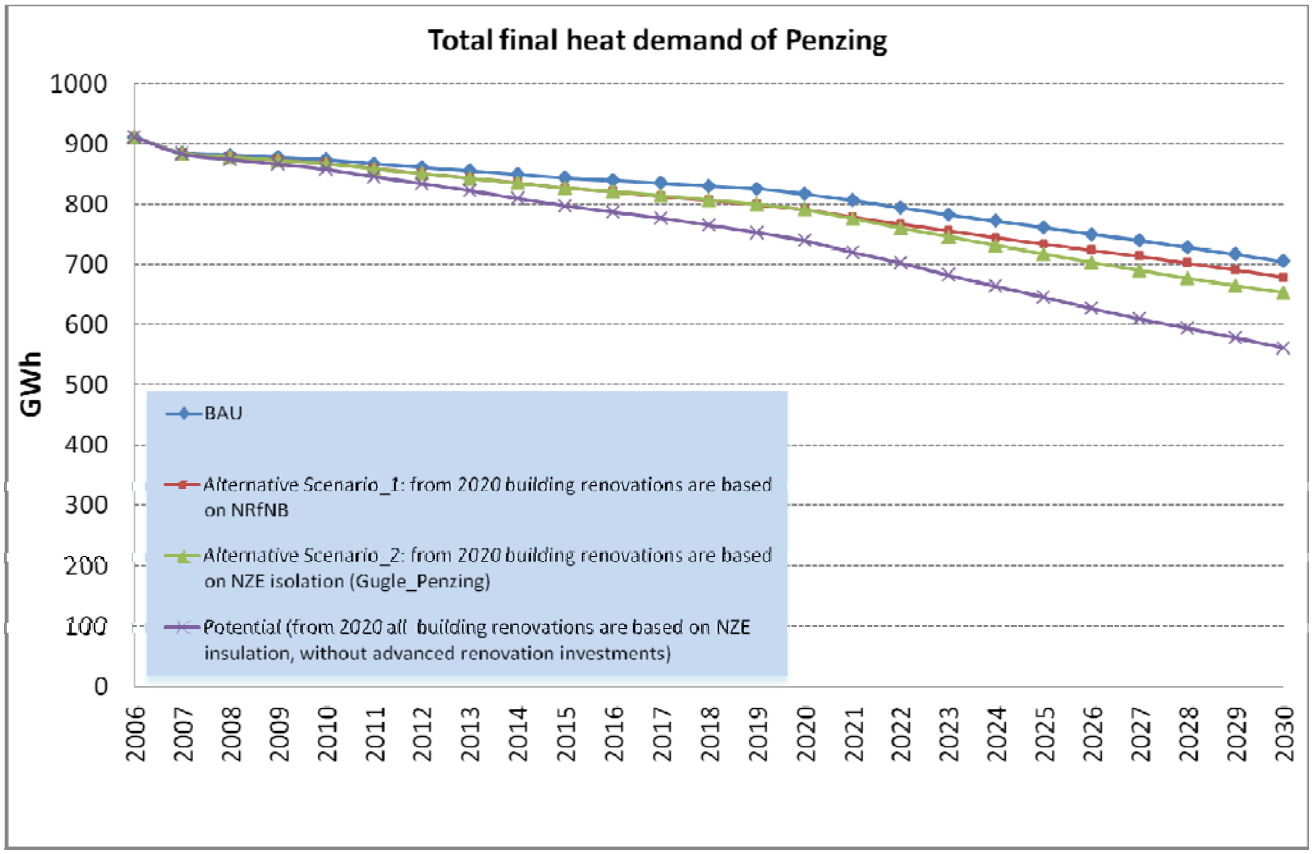


Fig. 2: Development of final heat demand (space and water heating) of Penzing up to 2030 [Source: TU Vienna/EEG 2012]..

According to the simulation based on:

- "BAU Scenario", the heat demand will decrease by 23% to 705 GWh.
- "Alternative Scenario_1", setting standards from 2020 on, the heat demand of buildings in Penzing can be reduced by 26% to 679 GWh.
- "Alternative Scenario_2", the heat demand can be decreased by two more percent to 653 GWh, if buildings are thermally renovated based on NZE standards (intention of GUGLE demo projects).
- "Potential Scenario", a maximum 38% reduction of Penzing's heat demand is possible.

2.3.4 Total final heat demand – Alsergrund

The development of the total final heat demand of Alsergrund is shown in fig.3. Setting 2006 as the starting year with a total building related heat demand of 376 GWh, it shows the estimated heat demand reduction until 2030 based on the four calculated scenarios.
Within the simulation of the ninth district, the heat consumption of Vienna's General Hospital (AKH) located in Alsergrund is not represented in the Invert/EE-lab model.

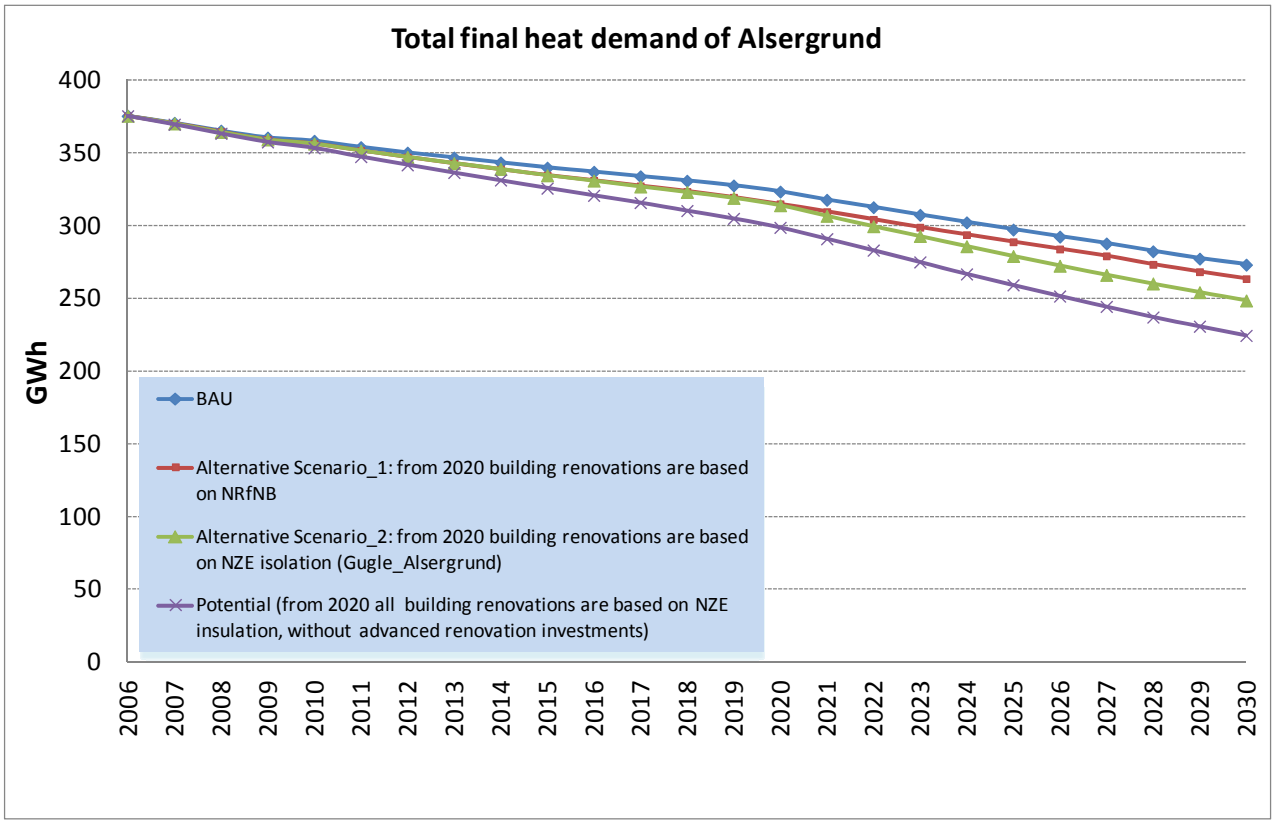


Fig. 3: Development of final heat demand (space and water heating) of Alsergrund up to 2030 [Source: TU Vienna/EEG 2012]..

According to the simulation based on:

- "BAU Scenario", the heat demand will decrease by 27% to 273 GWh.
- "Alternative Scenario_1", setting standards from 2020 on, the heat demand of buildings in Alsergrund can be reduced by 30% to 264 GWh.
- "Alternative Scenario_2", the heat demand can be decreased by four more percent to 249 GWh, if buildings are thermally renovated based on NZE standards (intention of GUGLE demo projects).
- "Potential Scenario", a maximum 40% reduction of Penzing's heat demand is possible.

2.4 Results Roadmap

As the main result of GUGLE a master plan for the future development of Alsergrund and Penzing was created, which suggests measures in various fields:
One focus is the development of strategies for improving the performance of the building stock. For this purpose smart refurbishment solutions for different representative buildings were developed by the GUGLE team. As an important additional measure, an evaluation sheet was designed, to give residents of newly refurbished buildings the chance to feedback the measures taken on their building. This sheet can contribute to highering the acceptance of refurbishment measures overall by portraying the individual needs of users in the district and learning from individual problems of users.

2.4.1 Building Stock and City Planning

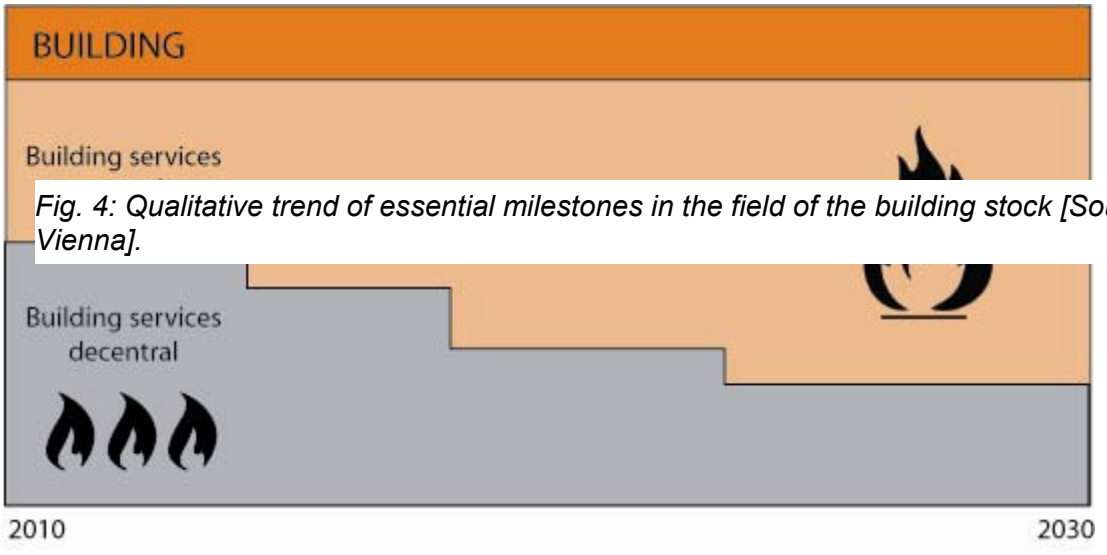


Fig. 4: Qualitative trend of essential milestones in the field of the building stock [Source: BOKU Vienna].

- Finding cost-optimized solutions for refurbishments under the aspect of lifecyclecost according to the European Buildingcode
- Increase of refurbishment activities by pushing towards the creation of new attractive subsidy schemes adjusted to the legal situation (e.g. tenancy law/property law)
- Continuous increase of energy efficiency in order to bring refurbishments to NZE standard until 2020.
- Switch from decentralized to centralized building equipment solutions as a necessary precondition for the widespread implementation of renewable energies.

Influence of different regulations – right of abode

The three individual Austrian laws, regulating the right of abode - the “Mietrechtsgesetz MRG” (tenancy law), the “Wohnungsgemeinnützigkeitsgesetz WGG” (for housing corporations) and the “Wohnungseigentumsgesetz WEG” (for property owners) - play an important role in the context of executing refurbishments.
In case of the MRG, reduced consumptions and consewquently cost reductions must be confered directly to the tenant and only actual investments can be accounted by the owner. The bypassing of cost by interposing service providers with flat charges is invalid. Tenants must recieve compensation for the phase of refurbishment according to the principle “acceptance in return for money or another type of benefit”. Rent must be used for repairing measures and a balance must be accounted for the period of ten years. If the owner does not meet his obligations of maintenance, tenants can file a suit for renovation. (This is the reason why apartment buildings are regularily put up for auction.) A switch to renewable energies during the contract period involving higher cost cannot be transmitted to the tenant, unless it represents the cheapest option. Momentarily, despite all substitutions, renewable energies are more expensive than other energy sources and therefore the status quo is obtained. At the moment, only the most cost effective option can be inflicted on the tenant – therefore it is nearly impossible to implement renewable

energies in the course of a refurbishment against the will of tenants.
The WGG adresses non-profit housing corporations which can also be corporate entities. It allows the installation of technically adequate shared equipment in order to reduce the building's energy consumption. The housing coorporation can decide on any building measures, if the tenants demand them during a residents meeting and if there are sufficient reserve funds of the object.
The WEG foresees that under certain circumstances appartment owners are authorized to conduct renovations, if all cost is covered by the initiator.

Generally it must be stated that all three laws of abode in their current way are prejudicial to the introduction of renewable energies in the course of refurbishments of residential buildings. The WGG offers the widest scope for tenant-contracting models and further measures.
Furthermore the law regarding heat cost billing has a large influence on refurbishments - it states that measures replacing existing systems, which are undertaken in the interest of reducing energy consumption and are justified by a cost-benefit equation can be equated to maintainance measures.

2.4.2 Mobility

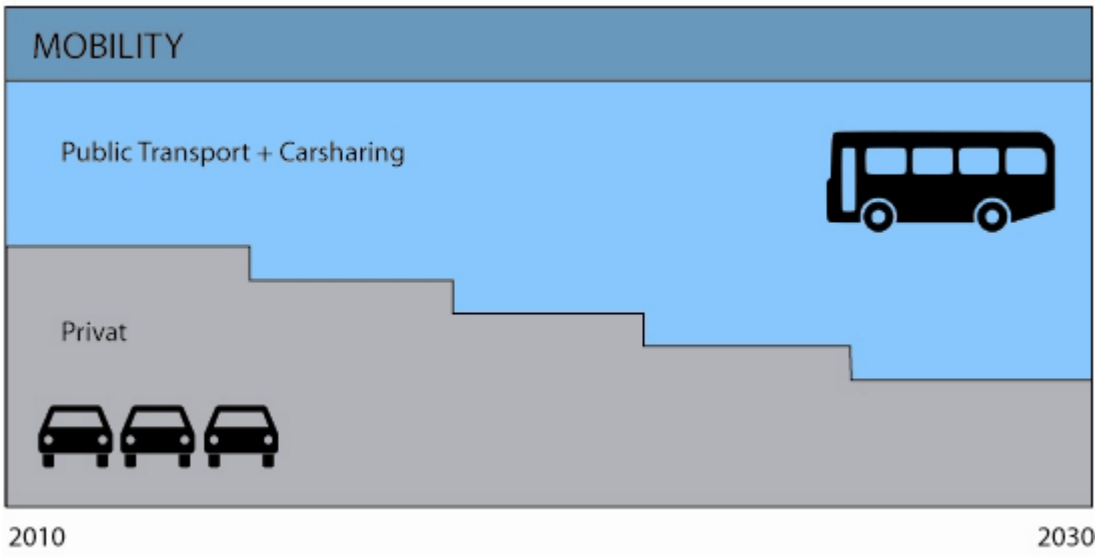


Fig. 5: Qualitative trend of essential milestones in the field of the mobility [Source: BOKU Vienna].

Milestones

- Mobility management strategies for urban settings:
  - "car-reduced living" – apartments are sold together with a parking spot and a five year ticket for the public transport.
  - Integration of information and service: delivery service for groceries and laundry service in cooperation with local amenities, installation of delivery boxes in designated spaces of apartment buildings
  - Car sharing – widespread provision of car sharing facilities, reserved parking space, special packages for first-time users such as free memberships or reduced fees for a certain amount of time
  - Bicycle facilities: sufficient bike parking spaces inside and outside of residential buildings, as well as public buildings and local amenities. bike-service-stations
- Implementation of new mobile information technologies
- Management of the stationary traffic
- Provision of infrastructure for e-mobility

Shaping of „Smart City Consumers" - quality of live and prosperity through a sustainable consumerism and lifestyle (2010 – 2030)

Through mobility-management measures in the area of housing, the resident's choice of transportation can be influenced positively:

- Regular information packages matched to conditions regarding location - focus group: new residents
- Special classes for the use of public transportation (e.g. how to use ticket vending machines, how to read timetables) – focus group: elderly people
- Coaching by specialized "mobility-trainers" for local residents: workshops about personal cost saving strategies through change of means of transportation
- Activities at local schools with a playful character: workshops about mobility, experiments and competitions for classes (e.g. prize for the class with the lowest individual traffic volume)
- Promotion of communal traffic solutions such as "bike & ride" facilities including e-bike stations with the possibility of reserving filling stations. Securing of connection to public transportation.
- Expansion of the Citybike system (free/very cheap public bike rental with dozens of rental/return stations) with a focus on highly-frequented locations in the city)
- Stimulation of e-mobility: by integrating electric cars to the vehicle fleet of car sharing providers, by providing exception regulations for e-vehicles (e.g. parking time, financial amenities for parking), by changing building codes by establishing the right to provide electricity filling stations in private or public garages

2.4.3 Communication

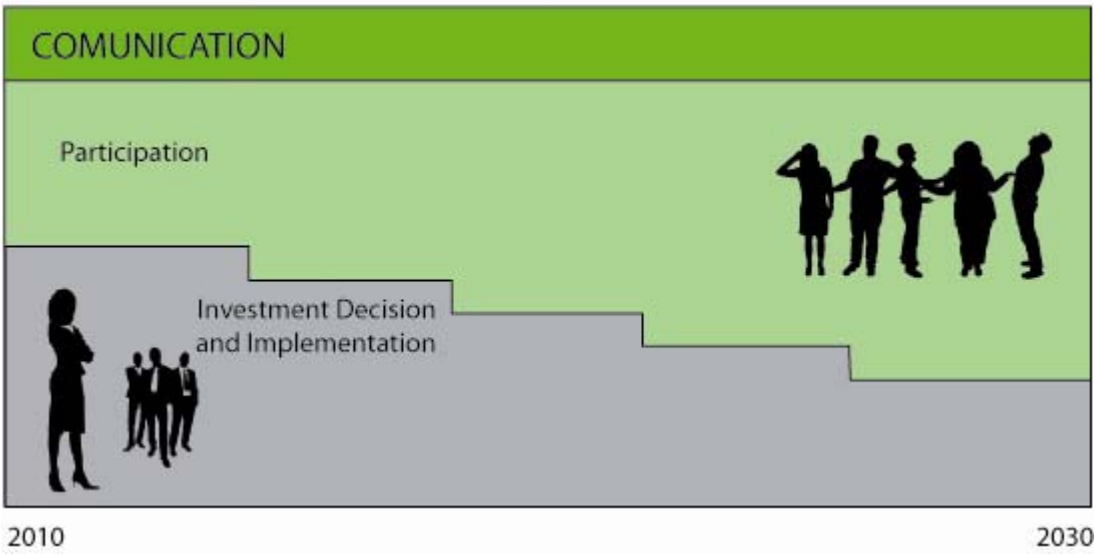


Fig. 6: Qualitative trend of essential milestones in the field of communication [Source: BOKU Vienna].

- Active PR for GUGLE
- Establishing networks between local groups and initiatives in Alsergrund and Penzing and creation of an active GUGLE-Platform (2013 – 2015)
- Raising awareness for future landmark projects and accompanying bottom-up initiatives (2016 – 2030)
- Observation of participation and knowledge transfer (2020 – 2030)

2.5 Local Networks

2.5.1 “Wiener Gebietsbetreuung Stadterneuerung”

One focus of urban redevelopment in Vienna since the foundation of its urban development plan in the 1970ies has been the modernization of its large building stock from the period of promoterism. Ever since then refurbishments have been accompanied by special funds and a variety of consultation opportunities with a focus on the needs of the local residents. Through these actions, the amount of substandard apartments in Vienna could effectively be reduced from 300.000 during the 1970ies to around 50.000, without banishing the local population.
The “Gebietsbetreuung Stadterneuerung” is a Viennese institution actively involved in these “gentle” urban redevelopment projects.
Recent goal of the urban development in Vienna is the improvement of the quality of life in densely populated city quarters. This goal is currently targeted by refurbishments, which are the main focus, the provision and strengthening of local amenities, the boost of local cultural activities and the enhancement of the design and layout of public spaces.
The Gebietsbetreuung Stadterneuerung works on behalf of MA 25 and is lead by private contractors under the business group of living, housing and urban redevelopment (Geschäftsgruppe Wohnen, Wohnbau und Stadterneuerung).
http://www.gbstern.at/teams/gb14-15/

2.5.2 Local Agenda 21 Plus (LA21+)

Local Agenda 21 Plus was created in 2002 in order to boost public participation on district or city level in Vienna. The task of Local Agenda 21 Plus is the support of citizens who actively want to get involved in actions towards more sustainability and quality of life for their neighbourhood. Local Agenda stands in direct contact with local authorities such as the district administratian, politicians and city planners. http://la21wien.at/

2.5.3 Wohnpartner

“Wohnpartner” is a service institution for the residents of appartment buildings owned by the city of Vienna.
There is a total of nine “Wohnpartner” service centers in Vienna, which take care of residential buildings all over the city. They offer multifaceted activities to boost the community inside these buildings in order to improve the overall quality of life for the residents.
http://www.wohnpartner-wien.at

3. Outlook

For the GUGLE-master plan the interdisciplinary consortium identified the most important measures for the upgrading of urban sites towards sustainability and in particular for the two Viennese districts Penzing and Alsergrund. These consist of:

- The renovation of existing buildings,
- the integration of renewable energies and
- a sustainable design of urban mobility.

These actions will help to tackle national and European CO_2 reduction targets at district level. Based on selected lighthouse projects and on related promotion activities of empirical results, the market extension will be pushed on mid-term.
The proposed future scenarios and measures of the GUGLE Master plan have not been implemented yet, but were intensively discussed with all relevant stakeholders during several project workshops and were specified for extended deployment at district level.

4. Acknowledgement

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- ENERGIECOMFORT Energie- und Gebäudemanagement GmbH
- 4ward Energy Research GmbH
- iC consulenten Ziviltechniker GesmbH
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- Technische Universität Wien, Institut für Energiesysteme und Elektrische Antriebe
- Wiener Linien GmbH & Co KG
- Wien Energie Fernwärme GmbH
- Wien Energie Gasnetz GmbH
- Wien Energie Stromnetz GmbH

And the cooperation with participatory networks in the districts providing local knowledge
- GB* 6/14/15
- Lokale Agenda 21 Plus

5. References

[1] TREBERSPURG M, *“Ökologischer Stadtbau.”* Bauwelt 1995, Book 24.

[2] KRANZL L., MÜLLER A., HUMMEL M., BEURSKENS L., DALLA LONGA F. *“Assessment of the effectiveness and economic efficiency of selected sup-port options for Austria”.* D13 of WP4 from the RES-H Policy project, A Working Document prepared as part of the IEE project, "Policy development for improving RES-H/C penetration in European Member States (RES-H Policy)", Draft 2.0 – April 2011

[3] STATISTIK AUSTRIA *„Wohnen Ergebnisse der Wohnungserhebung im Mikrozensus Jahresdurchschnitt 2010.“* Wien, 2011

[4] STATISTIK AUSTRIA *„Gebäude- und Wohnungszählungen 2001, Hauptergebnisse von Statistik Austria.”* Wien, 2004

[5] ÖROK *„ÖROK-Regionalprognosen 2010, Anhangstabellen im Excel Format.“* http://www.oerok.gv.at/r

[6] TABULA, AUSTRIAN ENERGY AGENCY *„Eine Typologie Österreichischer Wohngebäude, Ein Nachschlagewerk mit charakteristischen, energierelevanten Merkmalen von 28 Modellgebäuden – im Bestand und für jeweils zwei Sanierungsvarianten.“* Wien, Mai 2011

Review of LCA for concrete and its applicability to Austria



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Short Summary

The construction sector has a large share on the global warming potential. Concrete generates a substantial part of the environmental impact especially due to its content of Portland cement clinker. To quantify the ecological effects, concrete has to be assessed over his whole life cycle.
The method of Life Cycle Assessment (LCA) [1,3] helps to identify opportunities to improve the environmental performance and provides informations for a strategic business planning.
The literature review in the presented paper provides a survey of the state of the art in the D-A-CH (Germany – Austria – Switzerland) countries. An analysis of the regional concrete constituents is the background for the comparison with typical types of Austrian concrete.
Based on these results the optimization potential for concrete is addressed.

Keywords:Life Cycle Assessment (LCA); global warming potential (GWP); concrete

1. Introduction

The majority of their time (90%) people spend in buildings or use infrastructure. This fact points to the importance of the construction sector. It generates about 10% of the global warming potential in the European Union [2]. Buildings and infrastructure have the highest product lifetimes (decades, often centuries).
On the other hand, the construction sector also causes huge mass flows. Concerning the large amount of concrete which is used for those constructions, the environmental effects have to be investigated in detail.
To provide a basis for research, an evaluation of the current situation is necessary.

2. Methodology

The literature survey is mainly focused on results from the D-A-CH countries. Databases and research findings were screened for results for the environmental performance of concrete.

Method of Life Cycle Assessment (LCA)

The requirements for the creation of an LCA are shown in ÖNORM EN ISO 14044 [3] and ÖNORM EN ISO 14040 [1] in detail. The LCA refers to the environmental aspects and potential environmental impacts during the life cycle of a product from raw material acquisition through production, use, waste treatment, recycling and final disposal (i.e. from “cradle to grave”). Usually, economic or social aspects in Life Cycle Assessment of a product will not be considered.

The scope of an LCA study consists of Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment and Analysis (Figure 1).
The scope, inclusively the system boundary and the level of detail, depends on the object of investigation and the intended application of the study.
A Life Cycle Inventory (LCI) is the inventory of input and output data, which refer to the considered system. An impact assessment is used to provide additional information to support the assessment of the LCI of a product system for a better understanding of its environmental relevance.
As part of the analysis the results of LCI or Life Cycle Inventory Analysis (LCIA) or both are discussed and summarized as a basis for conclusions and recommendations.

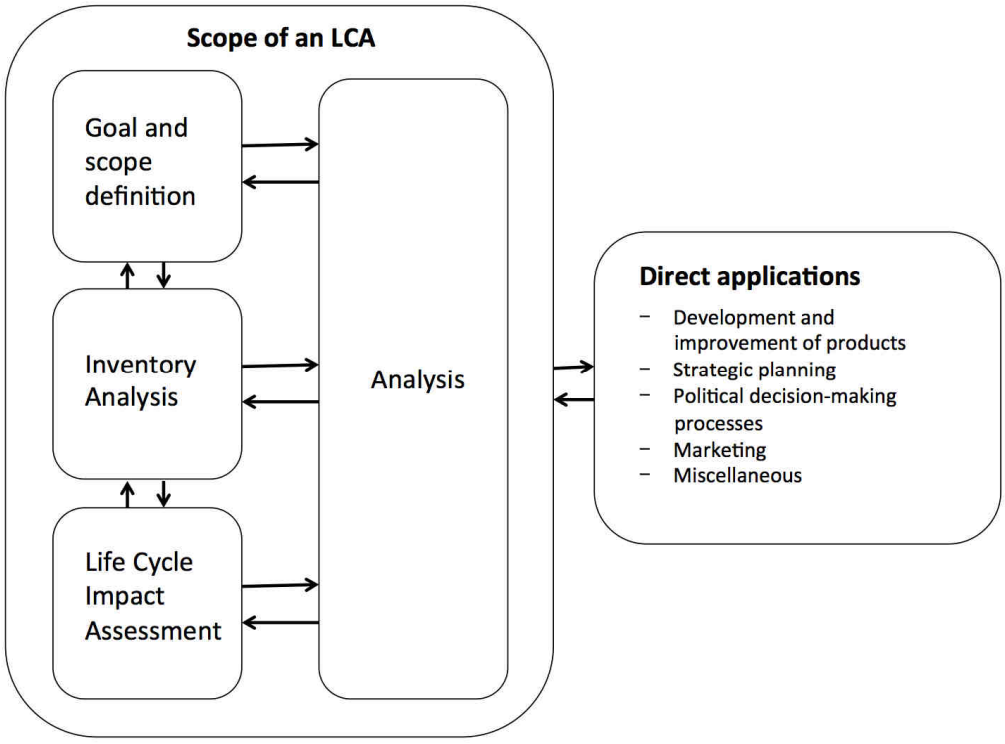


Figure 1: Scope of an LCA according to EN ISO 14040:2006

An LCA can help:

- in identifying opportunities to improve the environmental performance of products in various stages of their life cycle;
- to provide information for decision-makers in industry, government or non-governmental organizations
- in selecting relevant indicators of environmental performance, including the associated, measurement methods,
- with marketing (eg. when implementing an environmental label, making an environmental statement or creating an environmental declaration for a product).

Characterisation factors according to ÖN EN 15804

Indicatores, which are essential for a Life Cycle Assessment and the corresponding impact assessment, are described below, cf. [4].

Global Warming Potential (GWP), [kg CO_2-equivalent]
The global warming potential describes the contribution of a certain amount of greenhouse gas to the greenhouse effect. Carbon dioxide (CO_2) is used as a reference gas for an assessment of the GWP. Greenhouse gases also include methane (CH_4) and nitrious oxide (N_2O). The global warming potential is an essential feature for the environmental assessment of concrete. The main

part of the GWP of the concrete is caused by its content of portland cement clinker.

Ozone Depletion Potential (ODP), [kg R11- equivalent]
This indicator discribes that amount of ozone, which can be completely reduced by a given amount of a chemical product. Trichlorofluoromethane is used as a reference substance for the ODP.

Acidification Potential (AP), [kg SO_2- equivalent]
The adification potential describes the influence of certain substances on the pH-value of air, water and soil. Here SO_2 is used as a reference substance.

Eutrophication Potential (EP), [kg PO_4- equivalent]
The eutrophication potential shows the risk of an possible eutrophication of an ecosystem as a result of emissions from product manufacturing and the product itself. This indicator is estimated using an equivalent amount of phosphate PO_4.

Photo Optical Ozone Depletion Potential (POCP), [kg C_2H_4- equivalent]
The accumulation of ground-level ozone is based on a reaction of certain trace gases in cojunction with UV radiation. As an equivalent value ethene (C_2H_4) is used.

Primary Energy (PE), [J or MJ]
Primary energy is that quantity of energy which is required to produce a given amount of a product. The dimension unit is Joule per kg or m^3. A determination between renewable and non-renewable energy has to be done.

Cumulative Energy Demand (CED), [MJ/kg]
This energy expenditure represents the sum of the primary energy input for the production, use and disposal of the product. It is used for comparative analysis of primary energy demand of technical processes and product systems [13].

3. Results

Table 1 shows the GWP-100 for different kinds of cement based on literature and databases. Out of this it is easy to see that there is a difference between CEM I and CEM II caused by the different amount of cement clinker. For the “average cement” no specification about its amount of cement clinker is given. This table also shows the need for a more detailed analysis of cement GWP due to the big variation of the results.

Table 1: GWP-100 values of different types of cement

CEM I 42,5		CEM II 42,5	CEM II /A - L 32,5	CEM II /A-S 42,5
Müller (GER) [4]	*SimaPro (CH) [7]*	*SimaPro (CH) [7]*	*SimaPro (CH) [7]*	*SimaPro (CH) [7]*
956,0	902,6	820,7	718,0	704,0

"Average cement"		
Krispel (AT) [8]	*ökobau.dat (GER) [5]*	*Ecosoft (AT) [9]*
796,0	738,0	673,0

GWP 100 [kg CO_2-eq./m^3]

The GWP-100 values for cement are a basis for the results for concrete as described below.

Germany:
In Germany there are results for specific types of concrete and also for average concrete available. The german database “ökobau.dat” [5] provides datasets only for concrete with average cement. The example for “ökobau.dat” in Figure 3 shows the GWP-100 value for a transport concrete C25/30 with a mass of 2365kg/m^3 (Reference Year 2011). There is no information about the amount of cement available. The LCA was calculated “cradle to gate”, the deliverable product at gate frames the system boundary. The source for “ökobau.dat” is the software “GaBi 4” [10]

database 2006. The GWP-100 value is 240 kg CO_2 equ./m^3 .
More specific values are listed by Proske [2,11]. As a reference concrete a “DIN C25/30 XC4/XF1” is listed. The amount of cement (CEM II/A-LL 42,5R) is 275kg, which corresponds to the minimum cement content required in DIN standard, the water-binder ratio is 0,63. The estimated GWP value is 220 kg CO_2 equ./m^3.

Austria:
An example for an average Austrian concrete is the result by “Ecosoft v5” [9]. The chosen “Füllbeton” (id 570,kat.ID 1) is listed with a density of 2300 kg/m^3. The source for this dataset is “IBO” [12]. The GWP-100 value is 218 kg CO_2 equ./m^3 .
According to ÖN B 4710-1:2007 [15] own calculations were made. In “simapro” [7], which refers to the datasets of „ecoinvent“ [14], the basis was the suisse dataset for a transport concrete B35/25, which is comparable to Eurocode 2 - C25/30. According to the exposition classes B1 to B12, which refer to the required performance against environmental attacs (from low to high exposure)- in ÖN B 4710 the amount of cement was varied from 280 kg to 375 kg. Furthermore the water-binder ratio and the gravel changed with each calculation. An other adaptation was the use of the austrian electricity mix. The calculations were made for CEM I 42,5 and CEM II 42,5 seperately with the appropriate values shown in Table 1.
As shown in Figure 2 the result for GWP-100 is in a range of 268 to 353 kg CO_2 equ./m^3 for CEM I and between 245 and 322 kg CO_2 equ./m^3 for CEM II. These values refer to the minimum required amount of cement for a specific exposition class. In praxis often higher amounts are used, in Austria 400 kg/m^3 (376 kg CO_2 equ./m^3 for CEM I and 343 kg CO_2 equ./m^3 for CEM II) are plausibel as a practical value.
Switzerland:
In Switzerland the results bases on “simapro” and accordingly “ecoinvent”. The calculation, done with the original dataset as described above (with 300 kg CEM I 42,5), leads to a GWB-100 value of 285,6 kg CO_2 equ./m^3 .

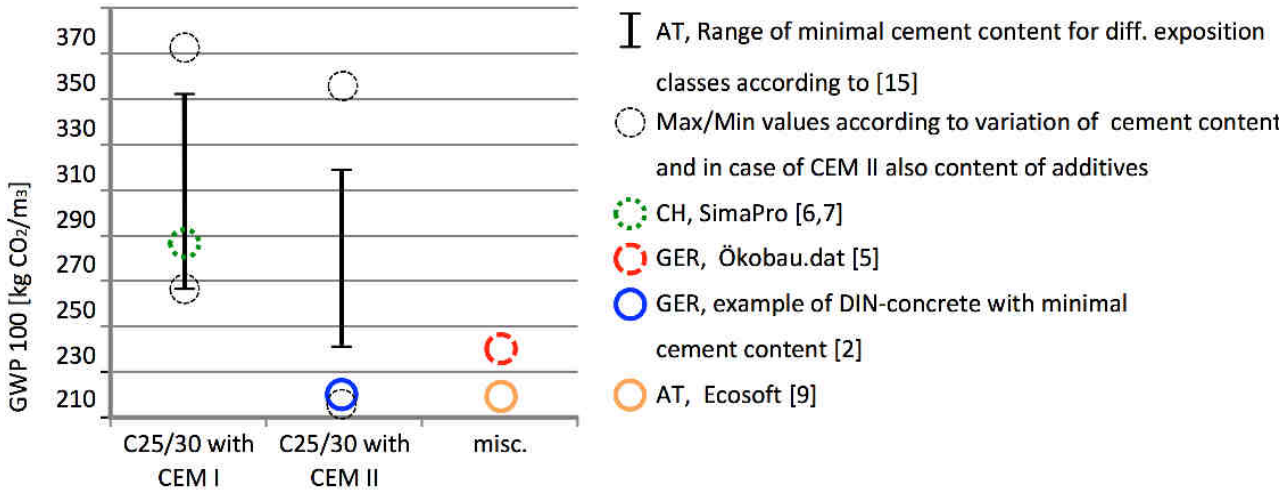


Figure 2: GWP-100 values of different types of concrete

Environmental performance of an average Austian concrete
Based on an ecoinvent dataset a calculation for all characterization factors for an idealized average Austrian concrete was made (Figure 2). The amount of cement was defined with 300kg/m^3 of CEM II/A 42,5 and the Austrian electricity mix was considered. There were four sectors differentiated, Portland cement, gravel, production & transport and miscellaneous. Other constituent parts of concrete were merged due to their low influence on the calculation.
The figure shows relatively the high influence of cement clinker on the environmental performance of concrete.

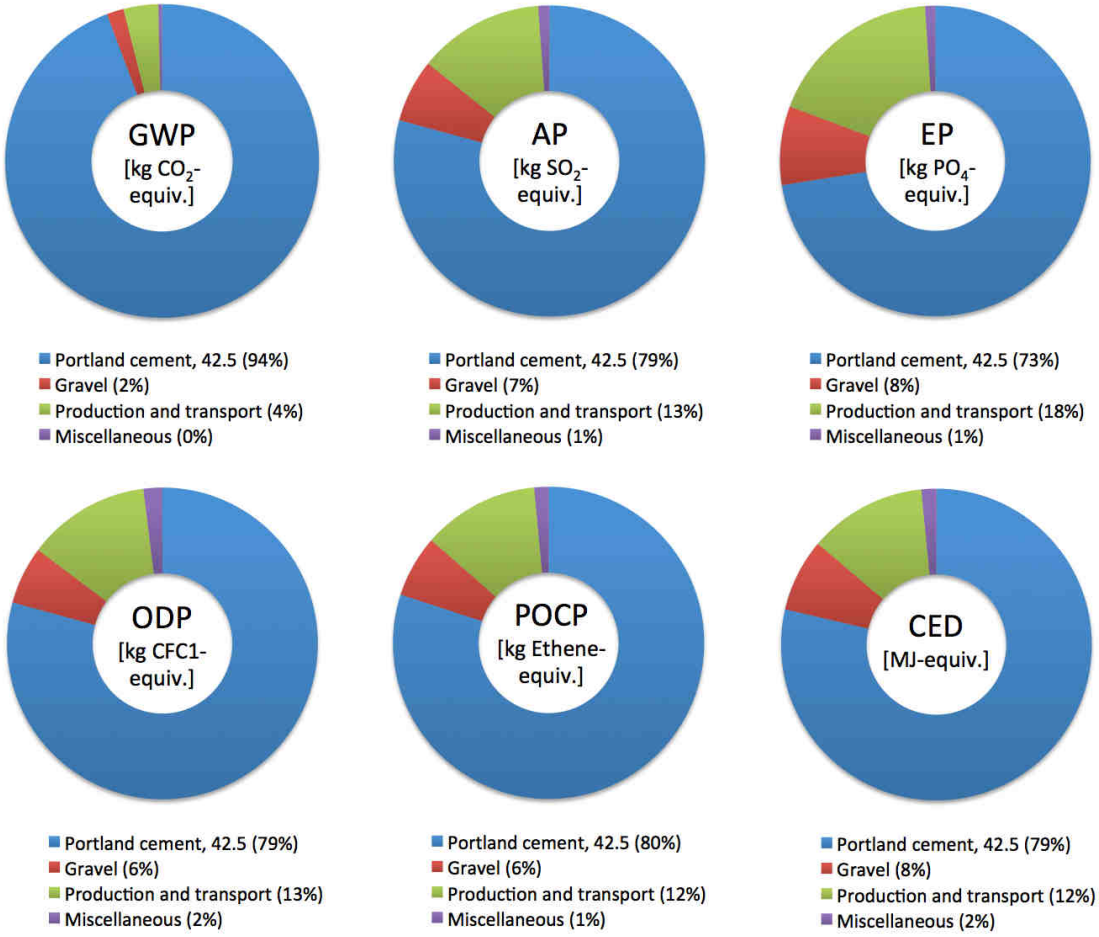


Figure 3: Environmental performance of an average Austrian concrete

4. Discussion and Conclusion

The result shows a wide range of the GWP depending on the amount of cement and country-specific conditions. Another point is the share of cement on the GWP of concrete, which is up to 94%. In actual literature data for different concrete mixtures are given without taking into account the same functional requirements (class of strength resistance, cement ratio, exposition class etc.). Due to this reasons, it is indispensable to take into account national requirements, specifications and standards as a basis for a LCA of concrete and to differentiate between concrete types according to their performance requirements.
In an on-going research project carried out at the Institute concrete for precast application is optimized technologically with the aim to reduce its environmental impact while ensuring identical technical performance.

5. References

[1] ÖNORM EN ISO 14040, Environmental management - Life cycle assessment - Principles and framework vol. 2006 (2006)
[2] Tilo Proske, Carl-Alexander Graubner, Stefan Hainer: Ökobetone zur Herstellung von Betonfertigteilen In: Darmstädter Betonfertigteiltage 2012, S.24ff
[3] ÖNORM EN ISO 14044, Environmental management - Life cycle assessment - Principles and guidelines vol. 2006 (2006)
[4] Haist, M., Müller, H.: *Nachhaltiger Beton - Betontechnologie im Spannungsfeld zwischen Ökobilanz und Leistungsfähigkeit*, in: Nachhaltiger Beton - Werkstoff, Konstruktion und Nutzung, Scientific Publishing, Karlsruhe, 2012, pp. 29–52.
[5] Baustoffdatenbank “ökobau.dat” http://www.nachhaltigesbauen.de/oekobaudat/ (Stand 05.04.2013)

[6] Frischknecht R, Jungbluth N, Althaus H-J, Doka G, Heck T, Hellweg S, Hischier R, Nemecek T, Rebitzer G, Spielmann M, Wernet G Overview and methodology, ecoinvent report No. 1, Swiss Centre for Life Cycle Inventories, Dübendorf
[7] Software für Ökobilanzierung “simapro”, http://www.simapro.de, (Stand 05.04.2013)
[8] S.Krispel, P.Nischer,M.Peyerl,J.Macht: *Ein neuer Zement als Win-win-Situation sowohl für Zement- und Betonhersteller als auch für Konsumenten und Umwelt*, in:zement&beton 5_11 (2011) p.34ff
[9] Software „Ecosoft“, V 5.0, Österreichisches Institut für Bauen und Ökologie GmbH 2013
[10] Software für Ökobilanzierung „GaBi Software“, Version 4; http://www.gabi-software.com, (Stand 10.7.2013)
[11] Tilo Proske, Stefan Hainer, Moien Rezvani, Carl-Alexander Graubner: *Eco-friendly concretes with reduced water and cement contents — Mix design principles and laboratory tests*. In: Cement and Concrete Research 51 (2013), p. 38-46
[12] IBO – Österreichisches Institut für Bauen und Ökologie, www.ibo.at (Stand 10.5.2013)
[13] Walter Klöpffer und Birgit Grahl: *Ökobilanz (LCA) – Ein Leitfaden für Ausbildung und Beruf*, WILEY-VCH Verlag, Weinheim 2009, S. 78.
[14] Software für Ökobilanzierung „ecoinvent“, http://www.ecoinvent.ch, (Stand 10.5.2013)
[15] ÖNORM B 4710-1:2007, Beton Teil 1: Festlegung, Herstellung, Verwendung und Konformitätsnachweis (2007), S.60f

Legal and economic prerequisites for sustainable refurbishment of housing companies in Finland



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Summary

The Finnish building stock is young in a European perspective, and was rapidly built. Suburbs consisting of mainly concrete apartment buildings were built with a foreseen life-span of approximately 40 years. Now we are encountering the need for comprehensive refurbishments on large scale.

The need and demand exists, but the refurbishment of residential buildings in Finland faces particular legal and economic challenges, due to the ownership of homes, challenging decision making processes of housing companies, building permit processes allowing for local interpretations and new regulations for energy efficiency improvements, a lack of financial incentives and support.

Case Virkakatu 8, the second energy retrofit in Finland realized with the TES Energy Facade method, revealed economic incentives and advantages but also shortcomings in current building regulations and decision making processes with regard to deep retrofits. The case shows the interests of an institutional owner of a building complex in comparison to the interests of owner-occupied housing cooperatives.

The case study additionally showed that there is a lack of know-how and competition with regard to deep retrofits of existing buildings. The demand exists but there is a lack of supply. The question remains: How to achieve a competitive edge, and foster cost efficient deep retrofits in cold climates?

Keywords: refurbishment, housing company, energy efficiency regulations, TES Energy Façade, E2ReBuild

1. Introduction

The Finnish building stock is young in a European perspective, and was rapidly built during the reconstruction era and as to satisfy the needs of rapid urbanization. Suburbs consisting of mainly concrete apartment buildings were built with a foreseen life-span of approximately 40 years. Now we are encountering the need for comprehensive refurbishments: the total Finnish renovation debt has in 2013 been estimated to between 30 and 50 milliard euros [1].

Regardless of the identified need, the refurbishment of residential buildings in Finland faces particular legal and economic challenges, due to the ownership of homes, challenging decision making processes of housing companies, building permit processes allowing for local interpretations and new regulations for energy efficiency improvements of existing buildings, lack of financial support.

2. The Finnish context

2.1 Finnish residential building stock

The Finnish building stock derives mainly from the Post War Era, with 75% built after 1960 [2]. An increasing urbanization lead to a rapid extension of urban settlements in the late 1960´s and early 1970´s. Today, every fifth Finnish apartment is in a suburban, multi-storey residential building from this time. These buildings are typically 3 or 4 storeys high concrete apartment buildings with a load bearing frame of concrete and facades in concrete sandwich elements. Many of them represent early prefabrication and element technology using standardized, precast elements and joint details, the so called “BES-system”, developed in Finland in the late 1960´s. The buildings are in the need of major renovations including improved indoor air quality, renewed facades and building services, improved energy efficiency, and in the need of elevators for improved accessibility. [3]

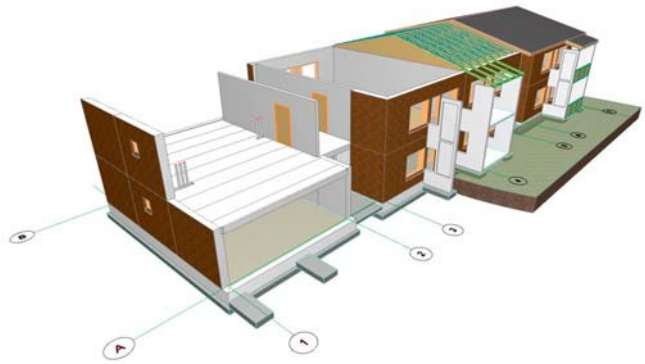


Fig. 1: The BES system as exemplified by case Virkakatu 8, Oulu.

2.2 Ownership of dwellings in Finland

The majority of Finnish homes are owner-occupied, single family homes. In 2011 44% of all homes were situated in multi-storey houses, 29% of the Finnish homes were rentals, and most rented dwellings were situated in multi-residential buildings. [4]

The majority of multi-residential buildings in Finland are owned and controlled as Limited Liability Housing Companies, occupied by housing company shareholders. Shares confer the right of possession to apartments, and all shares carry equal rights in the company. The housing company is responsible for utilities and the building facade. Shareholders pay for common expenses used for acquisition, construction, use, maintenance, renovation, expansion and modernization.

Modernization is decided by majority vote if the obligation to pay does not reach an unreasonable level and buildings are modernized to current standard requirements, and may not violate the equal treatment of the shareholders. The expenses to undertake modernization that exceeds current standard level shall be collected from shareholders that consent. [5]

Conflicts in interests within the decision process are resolved in favor of the majority, and investments typically reflect conservative consensus. A shareholder majority may prevent renovations with long payback periods, or a minority may be obliged to pay for renovations not in their personal interest. Shareholder demographics are decisive. Owners faced with the prospect of a massive energy retrofit, may opt to neglect or postpone the renovation, in fear of high investment costs related to energy efficiency targets.

Institutional owners of rental residential buildings are more likely to make proactive long term investments in high quality refurbishments, while housing companies with resident shareholders postpone investment decisions and accumulate maintenance burdens until major repairs are unavoidable.

2.3 National building regulations

In Finland the development of the national building code towards targets set by the recast Directive 2010/31/EU on the energy performance of buildings [6] and the Commission Delegated Regulation (EU) no 244/2012 supplementing the Directive [7], started in 2010 by establishing a group of experts to develop a roadmap, the ERA17 Energy-Smart Built Environment 2017 action plan. The target is to position Finland as the leader in energy-efficient building [8].One outcome is a roadmap for the development of the National Building Code of Finland, including the establishment of regulations for existing buildings undergoing renovations and alteration works.

As a result the first Finnish statutory regulation regarding renovations and alteration works on existing buildings was published on 27.02.2013 [9]. It is applied to public authority buildings starting 01.06.2013 and all buildings from 01.09.2013 onwards [10]. The regulation is applicable to buildings in which is done renovation or alteration works requiring a building permit. [11] The emphasis is on measures to improve the energy efficiency of existing buildings with an overarching target impact by 2050 of 25% estimated decrease of total energy consumption, and 45% decrease of carbon dioxide emissions caused by existing buildings. [12]

The regulation does not imply any comprehensive interpretation or definition of renovation and alteration works. It suggests alternative solutions for improving and proving an increased energy efficiency of the building. According to existing practice, regulations for new buildings are applied when a building is renovated to such an extent that it is comparable to new building. What differentiates a refurbishment comparable to new building from a deep retrofit including the target of improved energy efficiency? Practice will show, through case by case interpretation, whether the new regulation will be applied to cases of deep retrofit or if they will be compared to new building.

2.4 Economic prerequisites

Estimated costs by 2050 for implementing the new regulations are, based on a typical yearly refurbishment rate of 2.5% of buildings built before 1980, between 10 and 25 milliard euros. Savings as a result of decreased energy consumption are estimated to 0.5 – 2.4 milliard euros yearly. [13]

However, according to the Finnish statutory regulation regarding renovations and alteration works, the obligation for building owners to improve energy efficiency is bound to such measures that are subject to building permit. [14] Owners faced with the prospect of a massive energy retrofit, may opt to neglect or postpone the renovation, in fear of high investment costs related to energy efficiency targets and regulatory requirements. The possibility to influence investment decisions and decisions related to energy efficiency is additionally limited by the Finnish building permit process, where designs are brought to building inspectors at a late state when all the main decisions have already been made.

Solutions and strategies proposed to achieve sustainable high quality refurbishments require a detailed analysis in order to meet goals for economic efficiency, anticipate risks, and satisfy shareholders' perceived values. Good communication to include residents' values for social sustainability, careful project planning and a flexible legal framework are essential to the broader implementation of ecological high quality refurbishments. An effective adoption and implementation of the new regulation would require economic incentives, financial support for housing companies.

3. Deep retrofit, case Virkakatu 8

3.1 Framework for the retrofit

Case Virkakatu 8 in Oulu, Finland is an example of a deep retrofit of an institutionally owned rental apartment housing block. It is a small student apartment building with 8 flats, part of a housing cooperative of five buildings and communal facilities, owned by PSOAS Student Housing Foundation of Northern Finland [15]. The building was completed in 1985 and has now been refurbished completely including the upgrading and makeover of student flats according to today´s standards. Construction works on site started in August 2012 and were finished by the end of February 2013. The

building is one of seven demonstrations throughout Europe within the framework of project E2ReBuild *Industrialised energy efficient retrofitting of resident buildings in cold climates* [16].

Aims for the retrofit included a reduction of the building´s energy use for heating, as occupied, to 30 KWh/m^2/y through a facade retrofit using prefabricated timber facade elements and standardized retrofit measures with high replication potential, including new ventilation with high efficiency rotating heat recovery ventilation units, LED lightning, energy efficient appliances and building automation that tracks energy performance, indoor air quality, and monitors the building physics. The heating is based on an existing district heating system, but with retrofit flow control (valve actuator) based on real time supply and return temperature monitoring and outdoor temperatures controlled by new building automation to optimise the heating supply. [17] The Oulu demonstration is the second retrofit in Finland realized with the TES Energy Facade - method [18].





Fig. 2 and 3: Case Virkakatu 8, Oulu: during and after retrofit.

3.2 Relation to building regulations

The building works in Oulu took place before the publication of the new Finnish statutory regulation on the improvement of energy efficiency of buildings during renovation and alteration works. Hence, in the Oulu project, decisions made by local building inspectors were steered by existing practice and based on existing regulations for new buildings. Regulations for new building were applied to the project due to the extent of the retrofit including a complete reskinning of the building envelope, a new floor slab, new building services and new interiors. The energy efficiency target was set to the Finnish VTT passive house recommendation [19] and went up to and above current new building regulations. The EnerPHit Certificate for Energy Retrofits with Passive house Components [20] is currently being considered.

The deep retrofit resulted i.e. in assumptions regarding the renewed useful life of the building, its fire safety classification, stretching of the regulations for sound insulation of party walls, the addition of sound insulation to floors.

The case revealed that to a large degree current Finnish building regulations do not anticipate the real risks of deep retrofits and requirements for new built are not directly applicable. Regulations for new buildings are focused on fire risks, concrete construction and safety. However, the case shows that when using i.e. TES elements, there is a need for inspection of repair tolerances, sealing for airtightness, differential structural movements, and quality control of timber structures.

3.3 Incentives for refurbishment

Drivers for the retrofit in case Virkakatu 8 included social values in the form of upgraded living spaces for students, economic values based on market positioning with desirable student housing, market segmentation through the change from shared flats to family apartments and the desire to pilot deep refurbishment with the energy efficiency target of passive house using the TES Energy Façade method, an industrialized retrofit method based on the use of timber construction. These drivers highlight the interests of an institutional owner.

The refurbishment was realized with PSOAS own funding and supported by EU Fp7 project funding. The EU funding was critical for research and development work, and follow-up monitoring of the project. However, the total refurbishment was expensive, with one third of the costs caused by energy retrofit and total construction costs comparable to new building at passive house level.

The project showed that contractors are interested in and prepared to take on extensive and deep retrofits. It also shows that ambitious energy efficiency targets for the retrofit of existing buildings in cold climates demand investments. Regarding the construction works, it became clear that there exists little supply and competition in the prefabrication of TES timber based façade elements.

4. Discussion, conclusions and acknowledgements

4.1 Discussion and conclusions

In the Finnish context, there is a growing need for refurbishment and deep retrofits. Until recently, the National Building Code of Finland has only recognized new building. However, starting June 2013 the first regulations with regard to the upgrading of existing buildings came into force.

Case Virkakatu 8 revealed shortcomings in new building regulations when it comes to the implementation of them to deep retrofits, especially with regard to renovation related risk scenarios, air tightness and detail solutions. The new statutory regulation with regard to renovation and alteration works of existing buildings does to some extent include additional requirements on the building envelope and technical systems. According to § 10: in connection to measures improving the energy efficiency of the building envelope a sufficient airtightness of the building envelope, window and door connections to surrounding structures must be ensured, as to protect thermal insulation layers from the performance-degrading effect of air flows. When designing and realizing retrofits of the building envelope and technical systems measures should be taken as to ensure correct levels of thermal and sound insulation, hygrothermal performance and fire protection. [21] However, practice will show what these measures should be and how they should be proven. Due to the nature of deep rerurbishments, they cannot be regulated as clearly and unambiguously as for new building. However, problems of interpretation which repeat and which are replicable could be considered for specific instructions for retrofits.

The Finnish building stock forms slightly over half of our national capital stock and 60% of this is based on the value of our residential building stock [22]. It should be a national interest to care for this capital and ensure the future condition of our buildings. Yet currently there exists no financial incentive or support to refurbish buildings, and hence the renewal process and decrease of energy consumption of the built environment are prone to progress slowly and are, due to the Finnish ownership structure of residential buildings, dependent of individual investment interests. Such interests seem to occur more likely among institutional owners.

The case study also revealed that there is a lack of know-how and competition with regard to deep retrofits of existing buildings. The demand exists but there is a lack of supply. The question remains: How to achieve a competitive edge, and foster cost efficient retrofits in cold climates?

4.2 Acknowledgements

The paper is based on research and development support for the passive house demonstration in Oulu, Finland, realized within the EU Fp7 funded project E2ReBuild *Industrialised energy efficient retrofitting of resident buildings in cold climates*, coordinated by Christina Claeason-Jonsson, NCC AB. The project started in January 2011 and ends in June 2014. Partners from Finland include the Aalto University, NCC Rakennus Oy and PSOAS.

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5. References

[1] VEHMASKOSKI T, PESONEN R, LEMETTINEN S, VILJANEN J, SOLASAARI R.,"*Rakennetun omaisuuden tila 2013*", Suomen Rakennusinsinöörien Liitto RIL, Helsinki, 2013, pp. 6.

[2] www.korjaustieto.fi/component/content/article/51-tiedotteet/828-ympaeristoeministerioe-avasi-uuden-verkkopalvelun.html [accessed 21.05.2013]

[3] NORDBERG K. "*Puurakenteisten lisäkerrosten toteuttaminen betonielementtirunkoiseen asuinkerostaloon*". Master Thesis, Aalto University School of Engineering, 29.04.2013, pp 15.

[4] *Official Statistics of Finland (OSF): Dwellings and housing conditions* [e-publication]. ISSN=1798-6761. Overview 2011. Helsinki: Statistics Finland [accessed: 20.5.2013]. www.stat.fi/til/asas/2011/01/asas_2011_01_2012-10-24_tie_002_en.html.

[5] *"Asunto-osakeyhtiölaki"*, Oikeusministeriö, Helsinki, 22.12.2009.

[6] "*Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)*", Official Journal of the European Union, 18.06.2010, L 153/13 - 153/35.

[7] "*Commission delegated regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements*", Official Journal of the European Union, 21.03.2012, L 81/18 – 81/36.

[8] *"ERA 17 For an energy-smart built environment 2017"*, Ministry of the Environment, SITRA, TEKES, Erweko 2010, pp. 3.

[9] KAUPPINEN J. "*Ympäristöministeriön asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöissä "*, Helsinki, 27.02.2013.

[10] Ibidem, § 14.

[11] Ibidem, § 1.

[12] KAUPPINEN J. "*Ympäristöministeriön asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöissä tekninen perustelumuistio*", Ympäristöministeriö, Helsinki, 4.6.2012, pp. 1.

[13] VEHVILÄINEN I, VANHANEN J, ILLMAN J. "*ERA17-toimintaohjelman alustavat vaikutus- ja kustannusarviot"*, Gaia Consulting Oy, 12.11.2010, pp. 18.

[14] KAUPPINEN J. "*Ympäristöministeriön asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöissä "*, Helsinki, 27.02.2013, § 1.

[15] www.psoas.fi/en/locations/apartment-agent/location.php [accessed 20.05.2013]

[16] www.e2rebuild.eu/ [accessed 20.05.2013]

[17] www.e2rebuild.eu/en/demos/oulu/Sidor/default.aspx [accessed 20.05.2013]

[18] tesenergyfacade.com/ [accessed 20.05.2013]

[19] NIEMINEN J, LYLYKANGAS K. "*Passiivitalon määritelmä. Ohjeita passiivitalon arkkitehti-suunnitteluun*", 2009, pp.9. www.passiivi.info [accessed 20.05.2013]

[20] "*EnerPHit and EnerPHit+i Certification Criteria for Energy Retrofits with Passive house Components*", Passive house Institute, 2012. www.passiv.de/downloads/03_enerphit_criteria_en.pdf [accessed 20.05.2013]

[21] KAUPPINEN J. "*Ympäristöministeriön asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöissä "*, Helsinki, 27.02.2013, § 10.

[22] www.korjaustieto.fi/component/content/article/51-tiedotteet/828-ympaeristoeministerioe-avasi-uuden-verkkopalvelun.html [accessed 21.05.2013]

Monitoring of Land Use Development and Building Stocks in Germany – Methodology and Results



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Short Summary

Spatial data on land use, buildings and their development is of importance for sustainable planning approaches on all planning levels and the development of smart concepts. The monitoring system “Monitor of settlement and open space development” (www.ioer-monitor.de) of the Leibniz Institute of Ecological Urban and Regional Development (IOER) describes the state and the development of land use for the entire Federal Republic of Germany. On its basis different indicators with focus on settlement, open space, nature reserves, population and traffic can be derived automatically. In addition, official building footprint data are integrated. It has now become possible to quantify the amount of buildings in Germany on a very detailed level for the first time. The calculated indicators are stored in a database and can be visualised in thematic maps via a WebGIS-based internet platform. In addition to administrative spatial units (federal state, region, district, municipality), indicators are also visualised in regular raster maps with different cell sizes. This allows spatial and temporal comparisons based on constant reference areas. In addition, we give an insight into tools and developments which are useful for data acquisition. Firstly, the technology of the tool SEMENTA® is presented, which is based on an automated analysis of analogue topographic maps at scale 1: 25.000 (TK25 and DTK25(-V)) and which has recently been further developed. By means of digital image analysis building footprints are extracted, vectorised and classified according to a pre-defined building typology. On the basis of the building footprints, various indicators (e.g. building density, floor space ratio, building volume, no. of housing units, households and inhabitants) are derived to describe the settlement structure on a very detailed level. The development of the module SEMENTA®-CHANGE allows to measure settlement dynamics on building level. Another tool for automatic georeferencing of scanned topographic maps supports the data preparation and makes it more efficient.

Keywords: Monitoring Technology, Spatial Analysis, Land Use Development, Building Stock Analysis, Building Footprints, Geographic Information System (GIS)

1. Introduction

Creating smart built environments entails making the best of new technologies available in order to optimise municipal services (for further Information on Smart Cities see Deakin et al., [1]. The optimisation of built environment resources provides welfare and sustainable development. Spatial data on land use, buildings and their development is of importance for sustainable planning approaches on all planning levels and the development of smart concepts. Despite their significance for both researchers and planners, area-wide statistical data with high resolution is sparse. In

Germany official statistical data are currently only available on municipality or on districts level. For research and planning issues spatial data with higher resolution are therefore necessarily needed. Information and communication technology has made a large contribution in supporting planning and management of the built environment. Against this background the article gives insights into the research unit “Monitoring of settlement and open space development” of the Leibniz Institute of Ecological Urban and Regional Development (IOER).

2. Monitor of settlement and open space development

2.1 WebGIS-based internet platform

Within the context of achieving long term sustainability the IOER established a monitoring system focusing on the computation and visualisation of land use indicators for Germany [2]. The concept of the “Monitor for Settlement and Open Space Development” (IOER Monitor) sets up on the nation-wide Digital Basic Landscape Model (ATKIS® Basic DLM) which is available for all federal states in homogeneous quality [3]. It is a product of the Authoritative Topographic-Cartographic Information System (ATKIS) and serves as the basis for the authoritative topographical map production at scales of 1:10 000 to 1:25 000.

Due to the following facts the Basic DLM is a suitable data source for land use analysis:

- The data is defined to be a topographical description of the current state of land use.
- The data is based on standardisations of detailed object catalogues.
- The mapping authorities of the federal states ensure regular updating of the data regardless to economical conditions of certain areas. Thus, the data quality is homogeneous throughout all regions.
- The object based data model enables an automatic analyses by means of a script-based geo-processing.
- The data enables to derive land use indicators with high spatial resolution ranging from 100 m raster data to whole-country statistics.

To gain a proper land use calculation the Basic DLM data has to be examined according to a defined land-use typology (Fig. 1). To ensure unambiguity it was necessary to define rules to assign certain topographical objects to specific land-use types. Thus, it is possible to summing up the categories to the whole reference area.

The results of the nation-wide analyses are presented to the public free of charge via internet on the online platform of the IOER Monitor accessible at www.ioer-monitor.de. The user is able to browse through a categorised list of indicators which are available for four two-year time periods beginning in 2006 and (for the present) ending in 2012. Thus, for each administrative unit including municipalities (ca. 12 000), districts (ca. 400), federal states (16), and the whole country as well as for regular rasters with a cell size ranging from 100 m to 10 km a number of more than 50 indicators can be visualised as maps. The maps in Fig. 2 show examples for raster maps of 5 km cell size showing typical land-use patterns for Germany.

Furthermore, a tabulation tool enables the exploration of histograms and the comparison of values of several time steps. Both map and table views can be exported and downloaded for an offline usage and further statistical analysis.

2.2 Land Use Indicators

Based on the established official indicator set used for land-use reports we defined a hierarchal land use typology to provide a detailed landscape structure description. In few cases the IOER Monitor land use scheme typology differs in the assignment of land use categories to upper classes from the approach used by the authoritative statistical reports. Thus, mining areas are considered to belong to open space rather than being settlement sites (Fig. 1).

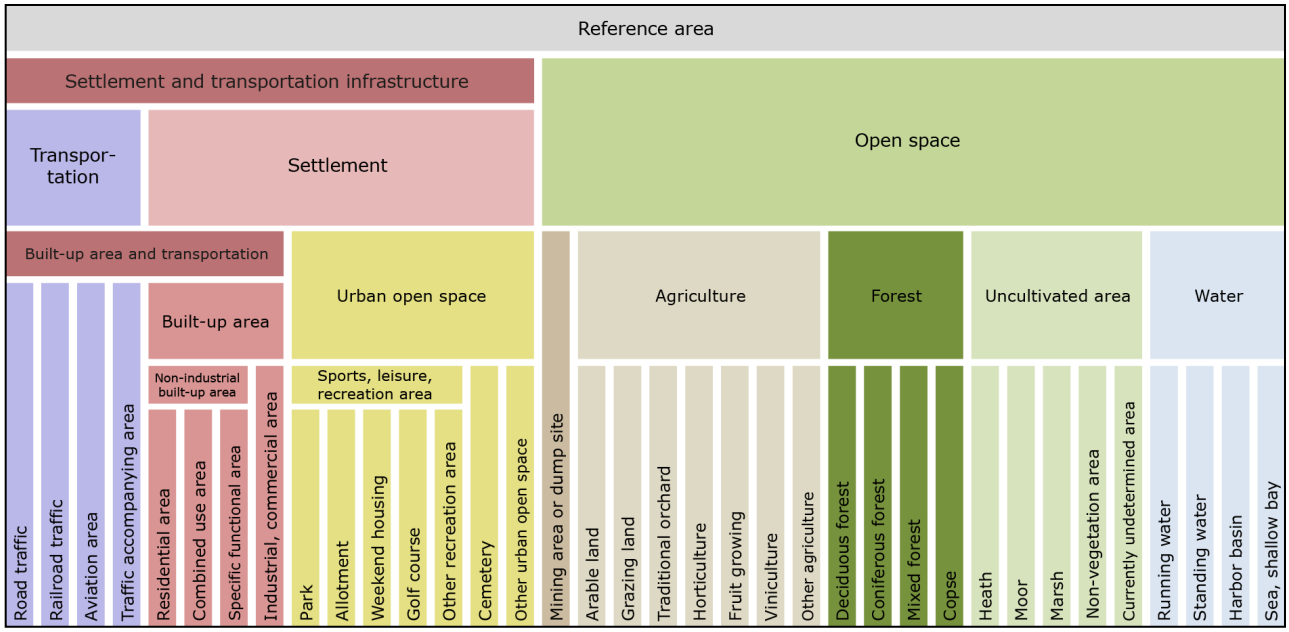


Figure 1: Land-use typology of the IOER Monitor. (Source: own editing)

Land use is generally divided into the three main categories of settlements, transportation, and open space. The transportation category comprises all kinds of infrastructure for individual, public and goods transport. This includes roads, railway lines, airports and all functionally accompanying areas. Due to the fact that roads and railways are provided as linear objects by the Basic DLM it is necessary to buffer these features to gain their real dimension. This is realised by extensive geo-processing of the data since the buffered features cause overlaps with adjacent polygons which are to be dissolved. The linear features are additionally used to calculate transportation network indicators which do not actually fit into the land-use typology but give important information on the infrastructural development level. Shipping transportation is not being considered, since ports are defined as economical sites, whereas harbour basins and water surfaces used for shipping routes are assigned to the stretches of waters category. Transportation routes like road and railway networks do not fit into the land-use typology. Nevertheless, network lengths are provided alongside the transportation areas indicators.

Settlement areas include built-up residential, mixed use, and industrial areas as well as urban open space facilities such as parks, allotments, recreational areas, and cemeteries. Thus, an appropriate differentiation between several types of settlement structures is made possible which was called by the ministerial conference on spatial planning in 2010 [4].

Open space category is, generally spoken, the sum of all land uses which are not assigned to settlement or transportation. Yet this does not necessarily mean that these areas are anthropogenically unaffected, since they include mininig sites, agricultural areas, forests as well as uncultivated sites like heath, bog, and all kinds of natural and artificial water surfaces.

Further indicators which do not fit into the hierarchal typology focus on qualitative aspects of land use such as effective mesh sizes [5] and hemeroby index values [6]. The latter is calculated by use of a more extensive set of attributes available in the Basic DLM [7]. Additionally, indicators referred to the population of administrative units relating the amount of certain land-use classes to the number of inhabitants are provided. Hence, in connection with area related indicators the effectivity of land use can be explored by the users.

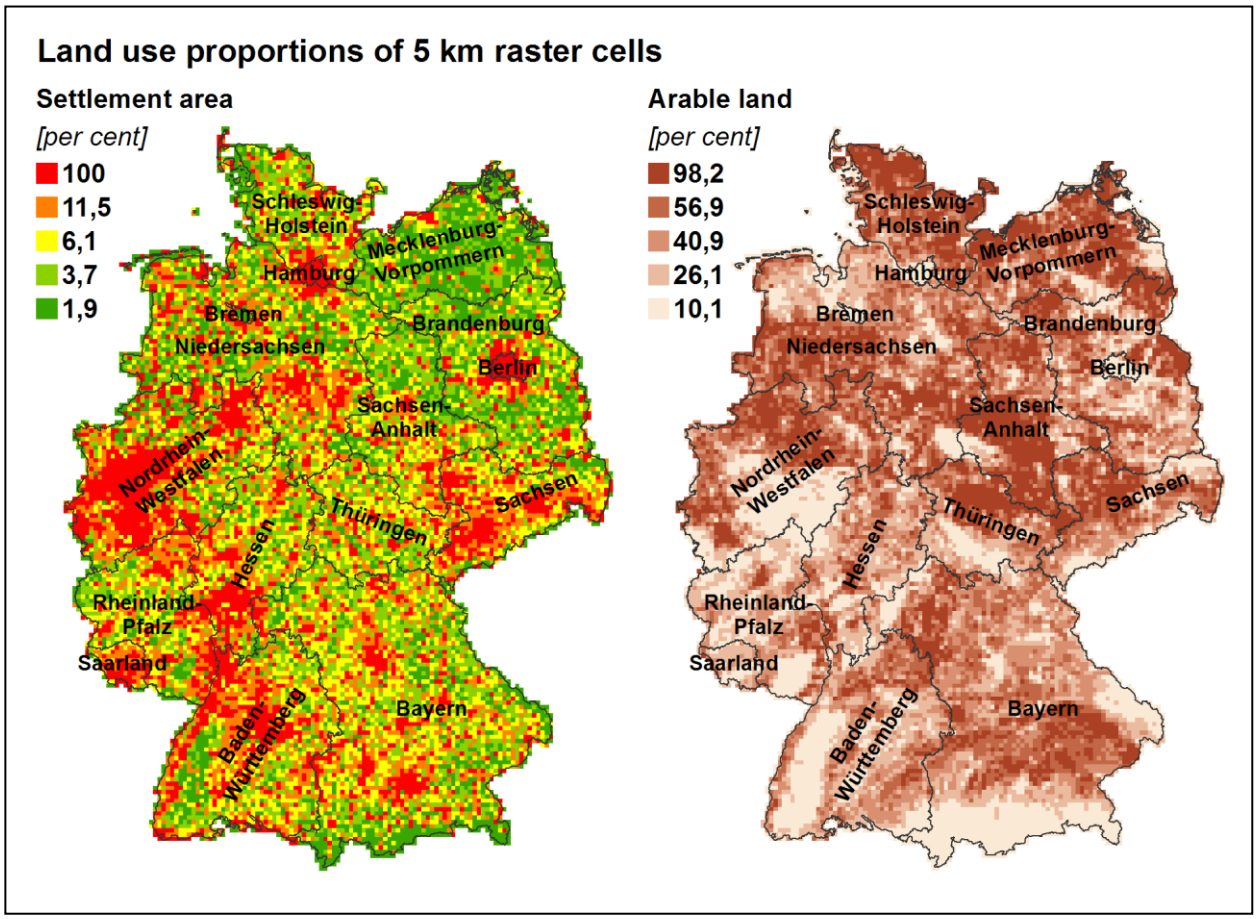


Fig. 2: Land use indicators calculated for 5 km raster cells showing typical spatial patterns for settlement and agriculture in Germany (Source: Own editing).

2.3 Building Indicators

In Germany several institutions record different kind of data about buildings. Unfortunately there are just a few basic statistics about the current number of buildings. Collection of data is very complicated, often expensive and the handling of missing data is one of the biggest handicaps. Recently the combination of new digital geodata sets is suitable to quantify the whole German building stock and later on to study its spatial distribution and patterns. The building stock is covered by the data set of the official building polygons of Germany (GeoBasis-DE, 2010/BKG 2011). This data set consists of a two-dimensional geometry (building footprints), which are introduced from the cadastral data. Unfortunately the only attribute per building is the official municipal code AGS (in German: Amtlicher Gemeindeschlüssel) which is to identify German administrative units by an 8-digits number code. Nevertheless the official building polygons allow easy combinations with other (statistical) data sets as well as visualisation and analysis on a finer level.

To improve the quality of the data set and the information content of the buildings some data enhancement was needed. In the case of one federal state of Saxony, the building footprint data was not complete. Hence, missing buildings were substituted with the buildings from the ATKIS data set. In another case, adjacent buildings (e.g. terraced houses, building blocks) are not consistently modelled. These buildings can be either modelled as multiple building footprints or these are modelled as one huge polygon representing two or more buildings. In the latter case, the polygons need to be divided into single buildings by making use of the official postal address coordinates data set (in German: Georeferenzierte Adressdaten Bund). In addition, all buildings were allocated

to a specific land use class. Such classification is based on the official topographic and cartographic information system, ATKIS Basic DLM. Depending on the building location and the ATKIS land-use class, the buildings were classified as follows: industrial building, building with special functions, residential, and other buildings. In addition, some other attributes were given (e.g. label of the federal state, label of the municipality, building's centre point, etc.). The applied procedure of the processing of the German building stock is illustrated in Figure 3.

The resulting data base contains nearly 50 million objects. Figure 4 shows the German building stock in a grid representation. The grid is specified by the directive INSPIRE (infrastructure for spatial information in Europe) which regulates the establishment of EU-wide data infrastructure and spatial data harmonisation with the background of environmental policies that should be implemented by 2019. The raster values represent the number of buildings having their geometric centre points (centroids) inside the grid cells. A majority of the buildings are located in Nordrhein-Westfalen. The conurbations in Germany are easily seen. For example, Berlin, Hamburg, the Rhein-Ruhr, and Rhein-Main regions are characterised by a large amount of buildings. As indicators on buildings are calculated for Germany as a whole, they are also publicly available via the IOER Monitor described above.

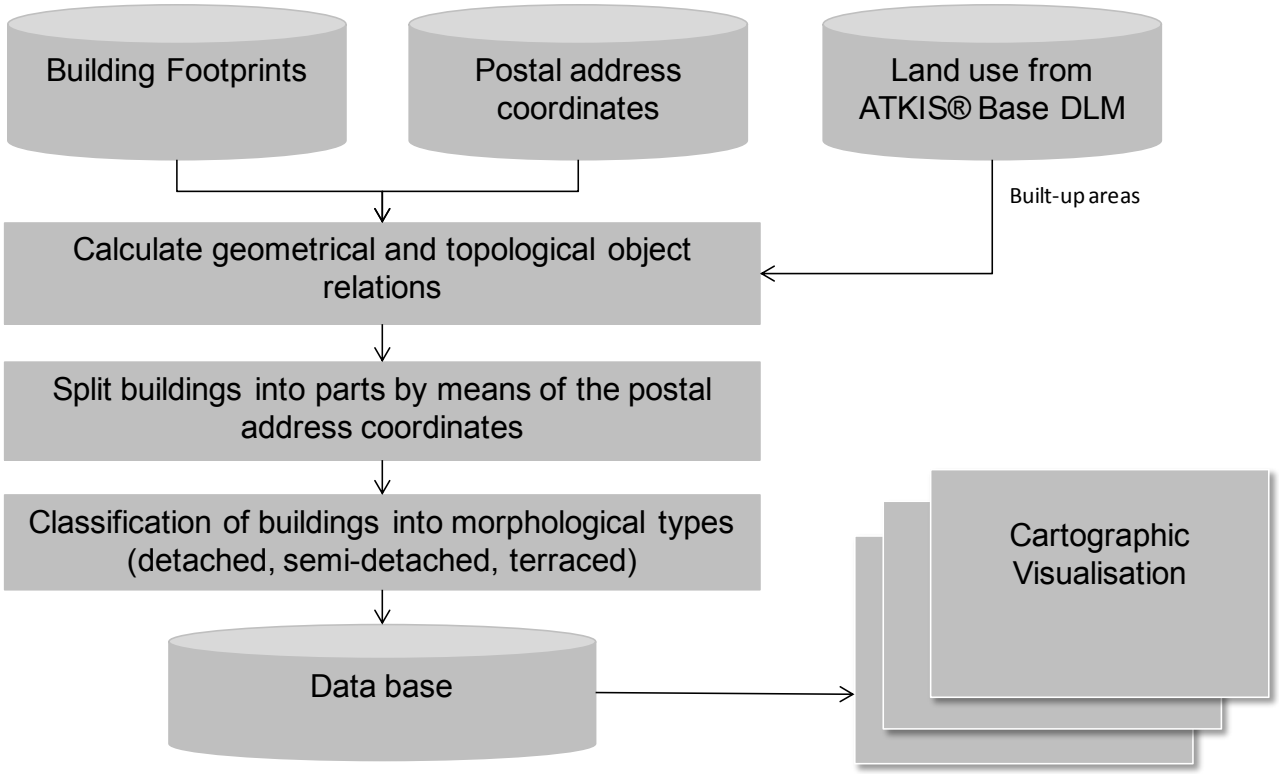


Fig. 3: Procedure of the building data processing (see also [9]).

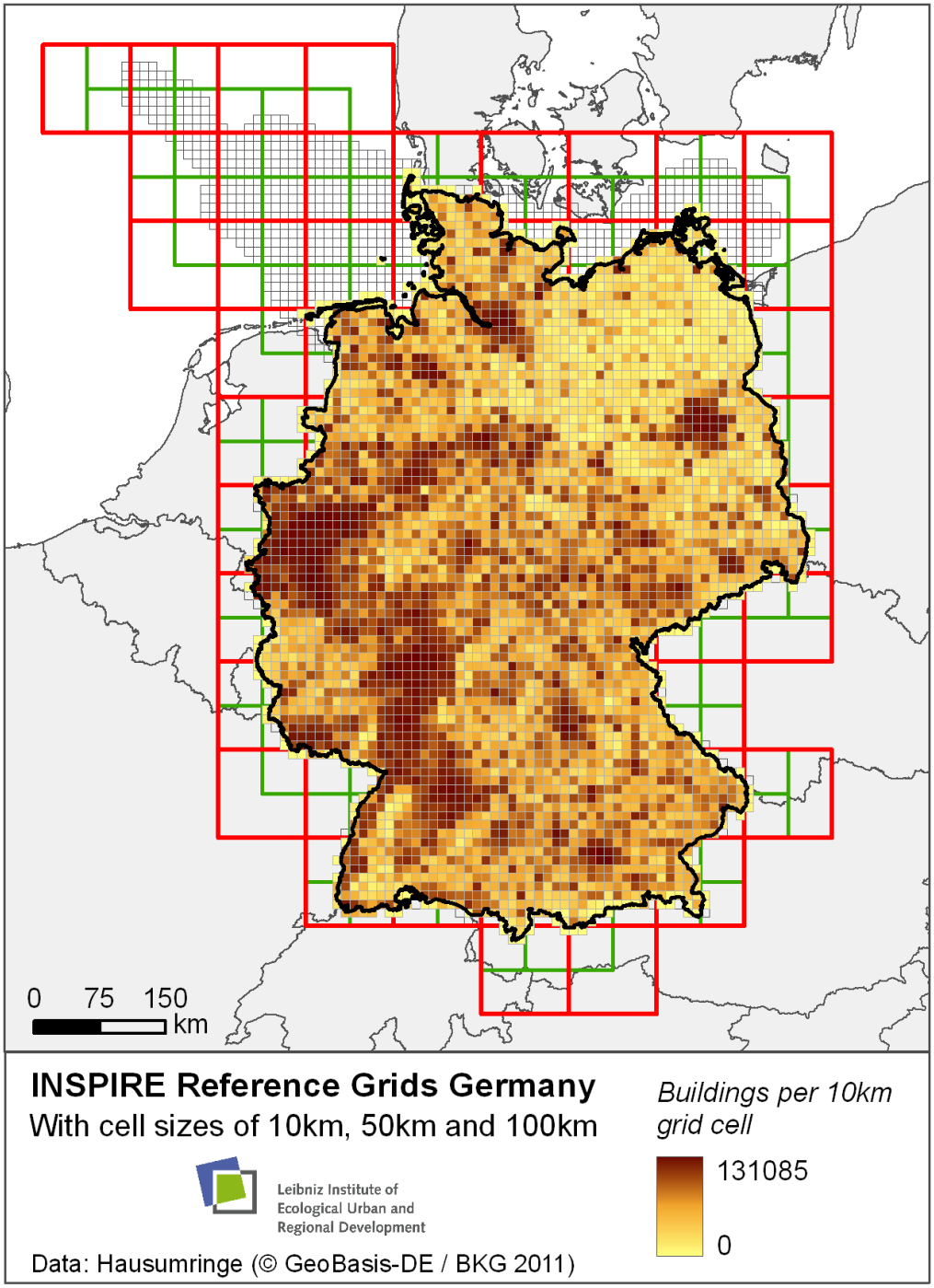


Fig. 4: Building Density per 10 km grid cell (Source: [10])

3. Tools for the small-scale description of settlement structures

Spatial analysis techniques and Geographic Information Systems (GIS) help to describe the settlement structure. In this section we give an overview about some developments at the Leibniz Institute of Ecological Urban and Regional Development (IOER), especially a tool for the automatic derivation of settlement indicators, current developments to measure dynamics and a tool for automatic map georeferencing.

3.1 Settlement Structure Analysis with SEMENTA®

Small-scale information on functional, morphological and socio-economic structure is an important component to solve research and planning issues in urban and rural areas. Buildings are of key importance here, since they determine the morphological structure of a settlement and there usage defines functional and socio-economic patterns.

With the help of spatial analysis and GIS it is possible to describe and analyse the settlement structure. One example is the SettlementAnalyzer (SEMENTA®), which is a tool for the automatic extraction and classification of building footprints from scanned paper maps or digital topographical data and to derive various indicators to describe the physical structure in detail. By combining the building stock model with official statistical data it becomes possible to estimate distribution patterns of dwellings and the residents. In the following, the basic processes are described briefly. For a detailed description of the method see [11] and [12].

The method sets up on topographic maps at scale 1:25.000 (e.g. German TK25, DTK25-V or DTK25) and the land-use information of the Basic DLM [3]. Topographic maps are usually available as a raster scan with an image resolution of 508 dpi (1.25 by 1.25 m in nature). The black layer of the map shows the buildings almost completely and only slightly generalised. One challenge is to extract the buildings from the binary raster image, in which they are merged with other elements such as traffic, vegetation symbols and lettering elements. By means of image processing techniques like morphological operations (opening) thin elements (traffic and block boundary lines) can be eliminated at first. In a second step the buildings are separated from lettering and symbols using various object features like compactness, convexity, anisometry, and orientation.

After building extraction, the building footprints are classified according to a given building typology. The typology differentiates 7 residential and 2 non-residential building types. For the classification a knowledge-based rule set has been developed, which sets up on derived building features (e.g. building area, circumference, compactness, distance from neighboring buildings, distance from block boundary). The rules consist of comprising conditions (premises) and actions (conclusions) and the buildings are classified by means of ‘if-then’ rules in combination with defined threshold values.

The classified building footprints are the basis for the derivation of various indicators to describe the settlement structure. With the help of assumptions (e.g. typical number of floors, dwellings and residents) further socio-economic indicators can be estimated. The following indicators can be calculated per spatial unit (regular raster cell or urban block unit):

- Urban structure type (7 residential and 2 non-residential types)
- Number of buildings and building density
- Sum of building footprint area and building coverage
- Average number of floors (weighted average of the number of floors of all buildings in a block)
- Floor area and floor area ratio (sum of all building footprint area multiplied by the average number of floors)
- Building volume and density of building volumes
- Number of dwellings and dwelling density
- Number of residents and density of population.

Figure 5 shows the automatically derived foor area ratio map for a section of Dresden, Germany.



Fig. 5: Map of the foor area ratio for a section of Dresden (Source: [12])

All the procedures for pre-processing, image processing for building extraction, feature extraction, classification and spatial analysis to derive settlement structure indicators have been implemented in the Esri ArcGis Desktop environment, which is widely used by planning and regional administrations. SEMENTA® was initially designed for users who do not have access to spatial building databases. If users have access to building footprints from digital cadastral vector maps, the building extraction procedure can be skipped.

Small-scale information on the settlement structure can be useful in a wide spectrum of applications. It mainly improves the information base used in planning and decision-making processes.

3.2 Spatio-temporal modelling of dynamics with SEMENTA®-CHANGE

Capturing the land use dynamics by visual interpretation based on historical maps and aerial photography is a common but time-consuming process. Therefore, since many years the development of methods for automatic urban change detection by remote sensing techniques is a research focus for the scientific community exploring spatio-temporal settlement dynamics. Previous approaches focus on the detection of land use changes and are only suitable for applications addressing large and medium scales. Measuring the dynamics on building level is a relatively new field. Despite the availability of very high-resolution (VHR), hyperspectral remote sensing imagery and LiDAR techniques, the acquisition of spatio-temporal information from multisource and heterogeneous data still remains a challenging task.

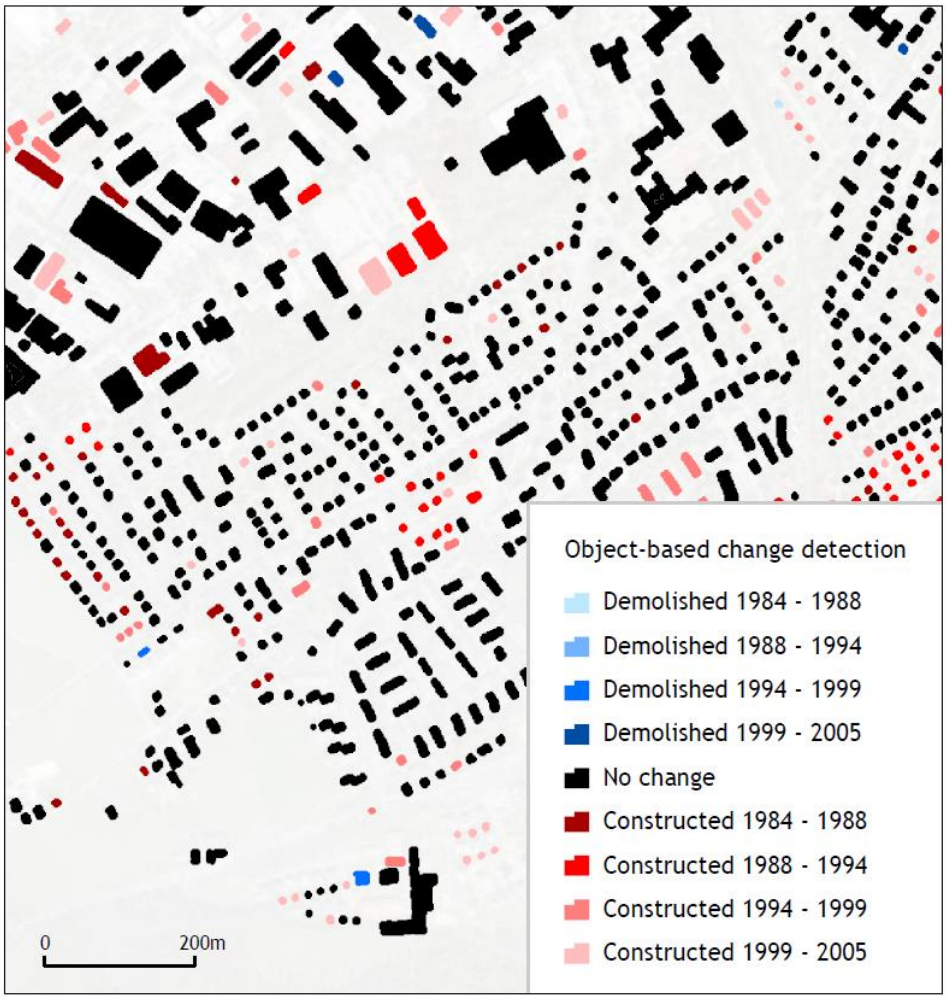


Fig. 7: Sample result of building-based change detection (Source: [13])

Here, the focus is set to the automated analysis of topographic maps. Compared to the multitemporal analysis of satellite data, the data availability is not limited to the last few decades. Topographic paper maps and plans have been existing for centuries. At the latest since the standardisations during the land surveying inititatives in the 18th and 19th century, these maps are relatively homogeneous in terms of map layout and symbolisation.

The methodological approach builds on two major steps [13]: Firstly, an object-based segmentation and classification of each of the multitemporal maps is applied in order to extract the building footprints (see section 3.1). In this process the buildings of each time period are extracted and stored in a spatio-temporal database. Secondly, a change detection algorithm based on the retrieved objects in different points in time is employed. Starting from each building object in the most recent data set, its existence in the older data sets is examined. The automated procedure follows the concept of backward editing in manual digitisation of multitemporal data sets. The temporal information on the construction period of newly constructed buildings is inferred by operational object-based comparison of segmented footprints from the historic maps (see Figure 7).

The methodology has been implemented and tested using the machine vision and image analysis software MVTec HALCON and the geoprocessing scripting engine in Esri ArcGIS. Currently, the approach is limited to the proof of object existence in old data sets. Structural changes of buildings are not yet considered. The spatio-temporal database allows the monitoring of the above mentioned (see section 3.1.1) settlement indicators such as the change of building density over time.

3.3 Automatic Map Georeferencing

The methodology described above bases on land-use information that is retrieved from recent and historic topographic maps. Recent maps are usually available as georeferenced data sets and thus are ready-to-use for building extraction. Historic topographic maps are by nature available as printed hardcopies. Thus, these paper maps have to be scanned and geocoded in order to use the automatically extracted information for spatial analyses within GIS. Considering an application on a national level, thousands of maps have to be manually georeferenced. This is an extremely time-consuming and hardly feasible task. Therefore, we have developed an automatic procedure [14]. In contrast to previous approaches (see [15] and [16]) we aimed for handling and processing maps with varying layouts over time. For this reason our approach is based on the least common features for referencing: the map margins and the map identifier comprising sheet number and name. The recognition of the former is achieved by means of a sequence of morphological filtering operations and a best-fit linear regression estimator. This procedure yields the image coordinates of four map corners. The latter is achieved by applying an optical character recognition (OCR) algorithm to the map number. The corresponding real world coordinates of the map corners are inferred from the national map sheet line systems and are subsequently assigned to the corresponding image coordinates. As in our approach only four points of each map are used for referencing, the method only allows affine image corrections. Figure 8 shows the general principle of the procedure.

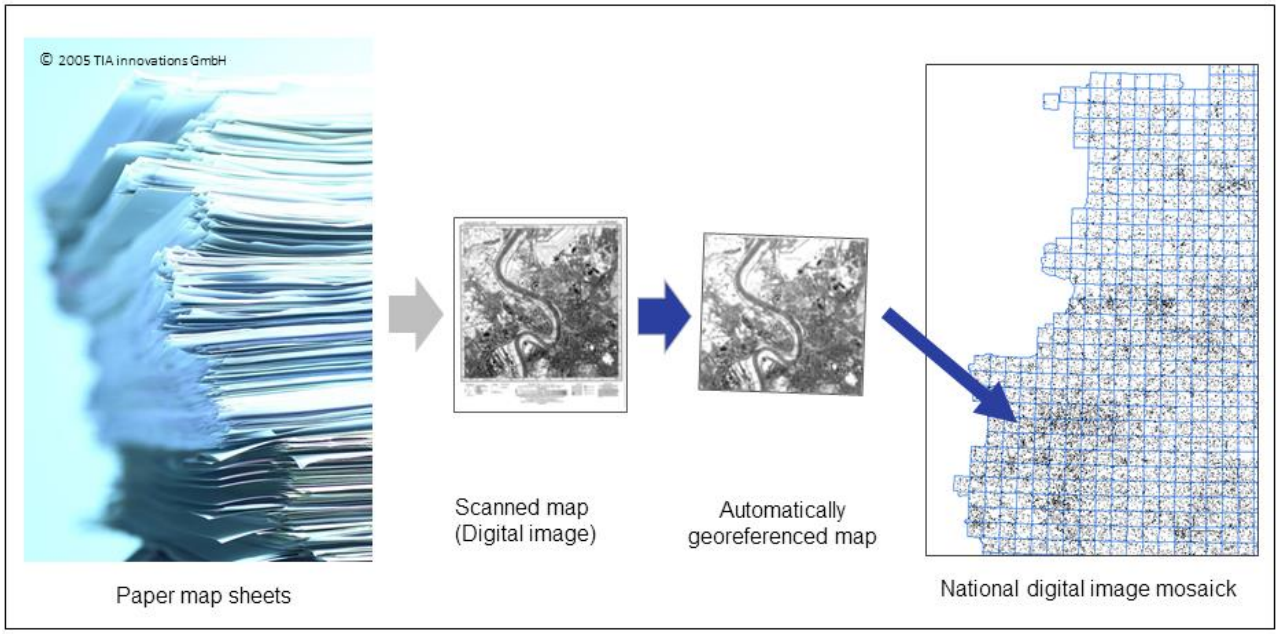


Fig. 8: Map georeferencing procedure.

4. Conclusions & Future Work

The presented methods could be of particular interest for spatial sciences as well as planning. Currently, different machine-learning techniques are tested in order to enhance accuracy, efficiency and the flexibility of the classification process [17]. We have also developed a tool to detect the changes in urban areas on building level by use of historical maps. The findings and the achieved automation enable micro-scale retrospective analyses of urban land-use dynamics on regional and national levels. Thus developments may support the nationwide land-use monitoring system for Germany, proposed in [2] and [8]. Current developments are merely based on the data availability in Germany, but the methods can be transferred to data of other countries, too. In this context, the standardisation and harmonisation of national spatial data sets, which is induced by INSPIRE, becomes very important for a cross-border monitoring.

5. References

[1] DEAKIN M, WAER HUSAM AL, eds. *"From Intelligent to Smart Cities"*. Journal of Intelligent Building International, Vol. 3, pp. 1-17.

[2] MEINEL G. *"Monitoring of Settlement and Open Space Development on the Basis of Topographical Spatial Data - Concept, Realization and first Results",* In: Core Spatial Databases - Updating, Maintenance and Services - from Theory to Practice, Haifa, Israel, 2010, ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences; Vol. XXXVIII, Part 4-8-2-W9), pp.132-137

[3] ADV, *"Aktuelle Dokumente der GeoInfoDok"* AdV, available at http://www.adv-online.de/icc/extdeu/broker.jsp?uCon=68470b36-de06-8a01-e1f3-351ec0023010 (last visited 01.05.2013)

[4] MKRO. Beschluss der 37. Ministerkonferenz für Raumordnung am 19. Mai 2010 in Berlin „*Flächensparen als Aufgabe der Raumordnung*". http://www.bmvbs.de/cae/servlet/contentblob/58510/publicationFile/29423/ministerkonferenz-mkro-2010-beschluss-4.pdf (last visited 01.05.2013)

[5] MOSER B, JAEGER J A G, TAPPEINER U, TASSER E, EISELT B. "*Modification of the effective mesh size for measuring landscape fragmentation to solve the boundary problem*" Landscape Ecology, 22 (3), 2007, pp. 447-459. doi:10.1007/s10980-006-9023-0

[6] STEINHARDT U, HERZOG F, LAUSCH A, MÜLLER E, LEHMANN S. "*The Hemeroby Index for Landscape Monitoring and Evaluation"*. In: Hyatt, D. E.; Lenz, R.; Pykh YA, Hyatt E, Lenz RJM [eds.]: Environmental Indices. Systems Analysis Approach. Oxford (EOLSS), 1999, pp. 237-257.

[7] STEIN C, WALZ U. *"Hemerobie als Indikator für das Flächenmonitoring. Methodenentwicklung am Beispiel von Sachsen*". Naturschutz und Landschaftsplanung, 2012, Volume 44/9, pp. 261-266.

[8] KRUEGER T, MEINEL G, SCHUMACHER U: *"Land use monitoring by topographical data analysis"*. Cartography and Geographic Information Science (in press, to be published in 2013)

[9] MEINEL G, BEHNISCH M, DIESSELMANN M, BURCKHARDT M *„Deutschlandweite Analysen der Flächennutzungsentwicklung und des Gebäudebestands auf Grundlage von Geobasisdaten*", GIS.Science, 2012, Nr. 4, pp.131-139.

[10] BEHNISCH M, MEINEL G, TRAMSEN S, DIESSELMANN M „*Using Quadtree Representations in Building Stock Visualisation and Analysis* ", Erdkunde (accepted publication), 2013.

[11] MEINEL G, HECHT R, HEROLD H, SCHILLER G. "*Automatische Ableitung von stadtstrukturellen Grundlagendaten und Integration in einem Geographischen Informationssystem*". Berlin; Bonn: BMVBS; BBR, 2008.

[12] MEINEL G, HECHT R, HEROLD H. *"Analyzing building stock using topographic maps and GIS"* Building Research & Information, vol. 37, no. 5–6, 2009, pp. 468–482.

[13] HEROLD H, MEINEL G, HECHT R, CSAPLOVICS E. "*A GEOBIA approach to map interpretation – Multitemporal building footprint retrieval for high resolution monitoring of spatial urban dynamics*", in Proceedings of the 4th GEOBIA, Rio de Janeiro, 2012, pp. 252–256.

[14] HEROLD H, RÖHM P, HECHT R, MEINEL G *"Automatically Georeferenced Maps as a Source for High Resolution Urban Growth Analyses"*, Proceedings of the ICA 25th International Cartographic Conference, July 3 - 8, Paris, France. Paris, 2011, pp. 1-5

[15] RUS I, BALINT C, CRACIUNESCU V, CONSTANTINESCU S, OVEJANU I, BARTOS-ELEKES Z. "*Automated georeference of the 1: 20,000 Romanian maps under Lambert-Cholesky (1916-1959) projection system"*. Acta Geodaetica et Geophysica Hungarica, 45(1), 2010, pp. 105-111.

[16] TITOVA O A, and CHERNOV A V. "*Method for the automatic georeferencing and calibration of cartographic images. Applied Problems",* Pattern Recognition and Image Analysis, 19(1), 2009, pp. 193-196.

[17] HECHT R. *"Classification of Building Footprints*" in Wallgrün JO, Lautenschütz A-K (eds.): Proceedings of the GIScience 2010 Doctoral Colloquium, IfGI prints 38, AKA, 2010, pp. 35-40, 2010.

Orona IDeO – innovation city

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Creating an Ecosystem of Innovation

Orona IDeO – innovation city is the flagship design of the new extension of San Sebastian's Technology Park that frames in public-private collaboration between ORONA and the Technology Park. ORONA's activity centres on the design, manufacturing, installation, maintenance and modernisation of mobility solutions, such as lifts, escalators and moving walkways.

The project is an answer to the need of common networking space of an international company, creating a place that is both a flagship and a common home for its more than 4,000 employees and a hub for researchers and students on elevation, urban mobility, energy and eco-technology branches.

The purpose of this project is to house ORONA's Innovation Ecosystem, which stands out as it brings together different synergetic activities –business, technology canters and university- and it will be a laboratory where leading-edge technologies in sustainability and energy management in buildings will be applied.

Orona IDeO is overtaking the future with the cutting edge bioclimatic design of its buildings and urban spaces, a district heating cooling system using 100% renewable energy sources and a perfectly integrated photovoltaic roof aimed at its own consumption as well as for research on electricity storage linked to elevator systems. The construction started in mid 2011 and is under way at this moment. Its opening in 2014 will coincide with the company´s 50th anniversary.

Keywords: bioclimatic architecture, solar roofing, District Heating-Cooling, sustainability certification, Urban Cell, Leed & Breeam, biomass, geothermal, cantilever

1. A project for innovation must be innovative in itself

The company and the architects stated that a Project for Innovation had to be Innovative in itself, which includes a range of aspects where the project incorporates cutting edge solutions that will help evolve a new common corporate culture for Orona IDeO - innovation city, i.e.:

-Urban design: integrative, environmentally friendly and open to citizens.
-Architecture: mixed-use, innovative, and high identity design.
-Mobility and accessibility showroom of ORONA's cutting edge technology.
-Sustainability: to be certified simultaneously both in LEED Gold and BREEAM excellent.
-Energy Lab: onsite 100% green thermal energy production and integrated PV design managed by an ESCO.
- Orona Foundation's activities will strengthen the local knowledge network.



Figure 1. Aerial view showing the cladding works of the buildings.

2. Master planning a 21st Century Knowledge Park

Donostia-San Sebastian is a medium size city located in the Basque Country, in the north of Spain. The city and its metropolitan area have been highly dynamic attracting innovative activities in recent years with the aim to diversify cities activity into a more knowledge-oriented economy.

The project incorporates the asset of being located within the extension of the Technology Park of San Sebastian and offers a mixed-use environment that will attract people of the neighbor companies. The location permits easy public transport and is next to the urban tissue where you can find dwellings, sports facilities, urban services and easy accessibility to bicycle and pedestrian network. By means of the hybrid building approach of the Orona Foundation, Orona IDeO will offer a cafeteria, a library and a kindergarten to the local community. The outer public space will be open to citizens and will be suitable to house open activities related to technology, culture and leisure using the Orona Gallery building as an attractor.

Master planning a 21st century Technology Park requires a design that takes into account the uses in the neighbor urban tissue, accessibility to public transport and landscape integration among others. In this respect, the project updates the concept of the city as something that agglutinates and acts as a meeting point for activities in its streets, squares and public spaces and in the care of its landscape.

The EcoBoulevard is the linear park shaping the backbone of the Technology Park's new extension. This space is an image and reference point for the whole of the Park, and is characterized by its rich vegetation and careful landscaping in the recreation areas where pedestrians will have preference over cars. The EcoBoulevard ends in a sculptural observation point that offers a view of the landscape and connects with the city. The inside of Orona IDeO – innovation city is structured around a pedestrian axis which will join the public entrance area around the existing roundabout with the EcoBoulevard.



Figure 2. View of the EcoBoulevard on foreground and the Orona IDeO buildings in the background.

3. Buildings and connectors

Orona IDeO - innovation city is made up of different buildings and the connection spaces among them:

3.1. Orona Zero

Orona Zero is a highly iconic building of ca. 11,000m2 that will house ORONA's corporate headquarters and Orona eic (Elevator innovation Centre). Its design is based on a circular shape, which has always accompanied the Orona brand image. The idea of ascent (positive and dynamic), is transferred to the final design via an even more sophisticated idea than elevation per se, via a suspended 90 m diameter and 16 m high cylindrical shape which creates a large entrance projection. This structure is inclined 15º horizontally to create a door effect and provide access to the inside of the building. This inclination provides the façade with a good orientation for solar energy collection, and presents a friendly façade towards the square.

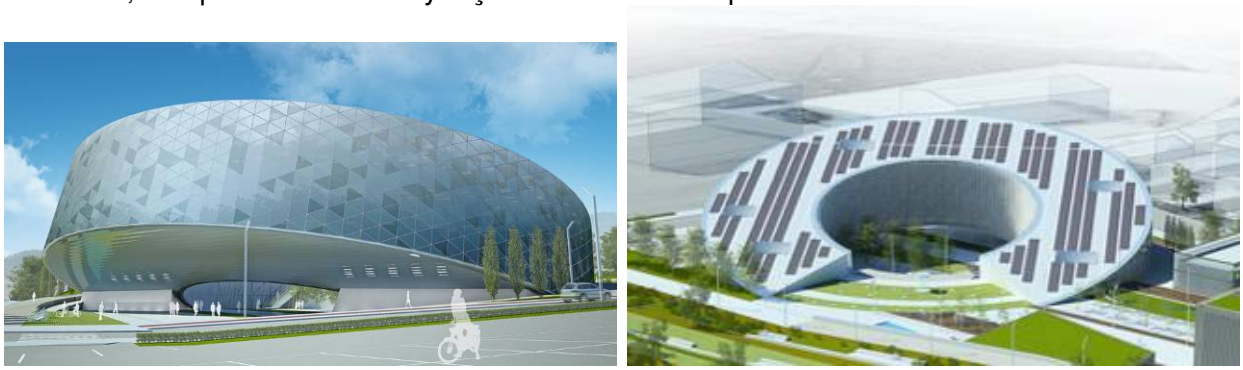


Figure 3. Front and rear view of the Orona Zero building.

3.2. Orona Foundation

This building is a "collage" facility of around 10,500m2. The two lower floors are for common and shared facilities such as the canteen, auditorium, library and crèche. Its façade onto the plaza acts as a backdrop for the public space and aims at being permeable and polyvalent.

This building will host the Orona Corporate University and the Mondragon University. The two upper floors are for use as teaching facilities at graduate and post-graduate level in energy-related subjects like two new Eco-engineering bachelor degrees.

3.3. Orona A3 research

This building encompasses two prismatic volumes holding office space and laboratories aimed at research on advanced applications on electrical storage systems. The purpose of this research is to develop technology for its application to elevation systems and in energy management in buildings. The laboratory building has a glowing U-glass façade, whereas the office building of the researchers has a more light-hearted, brightly-colored façade that helps provide diversity to the architectural ensemble.

3.4. Orona Gallery

This building will be a museum and a pavilion for visitors and its purpose will be to teach and transmit the Orona IDeO philosophy. It will contain a Showroom for demonstrating the monitoring of energy in the buildings in real time and will be the access point for visitors to the facilities for producing energy from renewable sources: biomass, solar thermal, geothermal and photovoltaic.

3.5. Orona IDeO Plaza

The Plaza will describe an urban hall with a series of pedestrian areas welcoming researchers, workers and students who will share these spaces aimed at encouraging relationships and the exchange of ideas. The design of this urban space seeks to afford all of Orona IDeO's building a recognizable character on the pavement through a striped design that raises the idea of the geological strata and the rich landscape of its setting.

4. Ecodesign and bioclimatic architecture

To achieve efficient energy performance in the buildings, the bioclimatic design and the environmental issues must be present from the initial architectural design. The Architects' objective is to fully profit from the passive measures applied and to choose the most suitable energy generation and consumption systems for this specific project.

Every building has integrated bioclimatic measures from the early design phase, but the conception, orientation and diversity of users of each one of the building has led to radically different solutions. The Orona A3 research building, for example, has three patios that flank the lab and office volumes and permit the entry of natural light to the basement labs. The Orona Foundation building, meanwhile, is clad in a perforated folded sheet to protect the building from the heat gain that comes from the rising and setting sun.

The Orona Zero building stands out for its singular design and its rich architectural composition. It is mainly devoted to office space that has large internal loads due to its occupants and to the density of the electronic equipment which dissipates heat and, at the same time, requires diffused light to avoid glare. The ground plan places the workplace near the outer façade which is mainly north facing, whereas the south-facing ring-shaped gallery distributes the flow of people and overlooks the building's central void. This is a space of a more social nature where sun capture is welcome and does not interfere with the work space. The service ring with stairs, lifts, toilets, utility shafts, etc. acts as a buffer between the two areas and structures the depth of the bay, creating different spatial situations due to the building's inclined geometry.

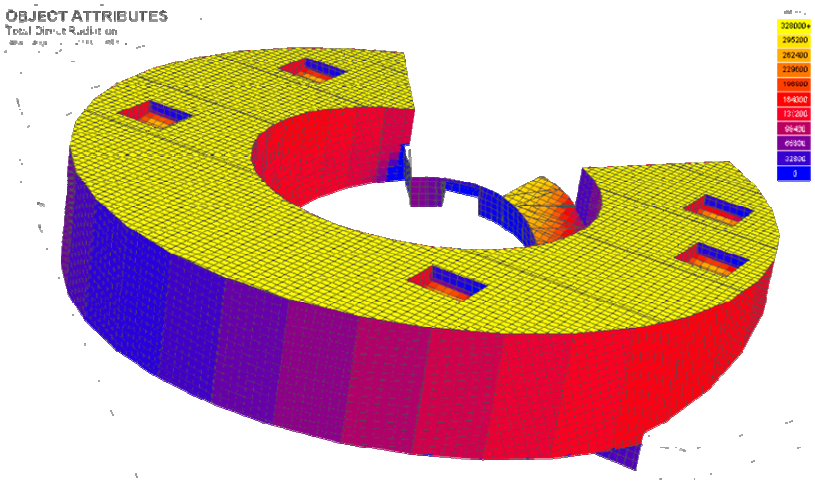


Figure 5. Simulation of accumulated radiation on the different façades of the Orona Zero building during the summer months.

The cylinder façade is made up of a curtain wall with a skin composed of triangular pixels which change from: opaque, translucent and transparent, depending on their position and the different circumstances regarding exposition to solar radiation, access to views, the relation with the use of internal space, etc.

With the aid of the superposition of these variations on the façade development, and taking into account the overall transmittance and a reference threshold for heat loss, the solutions for the outer and inner façades are designed, each with a different ratio of openings and opaque areas.

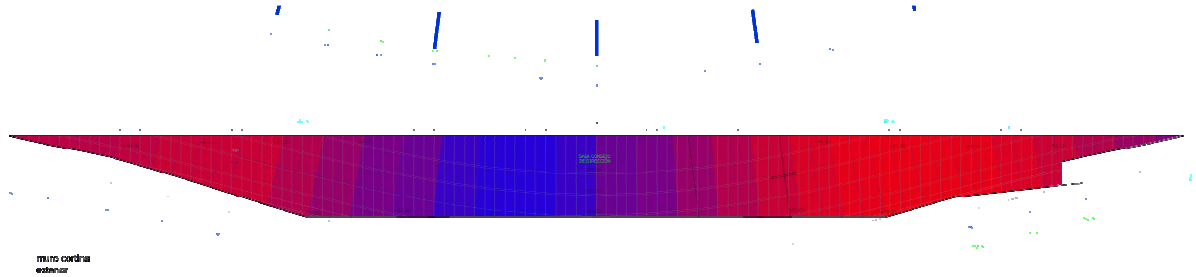


Figure 6. Studies on the façade of the Orona Zero building

5. Energy concept

The energy use in the buildings is based on the premise of making the most of the District Heating-Cooling system of the whole. This system is powered on 100% renewable energy sources: biomass, thermal solar and geothermal. The water that is heated or cooled using the District Heating-Cooling system is distributed to the substations located in each of the buildings, and, at these points, the flow of energy is adapted to the different conditioning systems.



Figure 7. The energy distributed by means of the District Heating-Cooling system is shown, in blue for electrical energy and orange, for thermal energy.

Heating and cooling are carried out using a radiant flooring system. Its distribution was designed in line with the climate-adjusted areas programmed for the building, so that the system allows for the distribution of heat and cold at the same time.

More than 1,000 polycrystalline photovoltaic modules are integrated on the inclined rooftop of the Orona Zero building that will have an annual electricity output of 220,000 Kwh, similar to the consumption of 100 average flats. This energy will be both used for self consumption as well as to investigate on new Net Zero Energy Lifts and new battery technologies at real time balance.

In short, energy production from renewable sources is highly competitive when properly calculated to meet the expected consumption over a large number of hours a year, with the result that the installation is cost-effective. Within the design's global energy scheme more conventional systems occasionally cover energy consumption peaks, thus ensuring that the best is made of each installation. The existence of an ESCO aimed at the sale of energy in Orona IDeO is an asset for the optimum performance of the renewable energy installation.

It is important to underline the fact that this experience will be viewable inside Orona IDeO itself, as the Orona Gallery will offer tours of the District Heating-Cooling facilities, and real-time energy performance together with the adjustment and control system for the buildings will likewise be visible.

6. Sustainability Certification

Orona IDeO – innovation city is the first project in Spain that is being certified simultaneously both in Leadership in Energy and Environmental Design (LEED®) and Building Research Establishment Environmental Assessment Method (BREEAM®). The fact that the project has a common design and share centralized facilities is a very interesting feature of the project that benefits the overall sustainable design approach.

It is important to underline that Orona Zero has been awarded the First Extraordinary Point for Innovation ever awarded by BREEAM ES. At Orona Zero, the point of innovation has been achieved in the field of energy efficiency and more specifically the requirement ENE 8 related to Lifts.

ORONA's innovation is a practical contribution towards giving shape to the Nearly Zero Energy Buildings standard that will be implemented throughout whole Europe by 2020. Orona IDeO is a step forward towards this goal and a Living Lab where these future technologies are being tested.



Figure 8. Current works at Orona IDeO – innovation city.

7. Facts Chart

7.1. Location

Donostia-San Sebastian, Basque Country, Spain
Latitude: 43.275987
Longitude: -1.986938

7.2. Team

The project is signed off by the architects:
Xabier Barrutieta (ORONA)
Eneko Goikoetxea (ORONA)
Javier de la Fuente (LKS)
Santiago Pérez (LKS)
ORONA, LKS ingeniería, Cenit Solar, Cener, MC2 ingeniería and Garrigues have all been involved in drawing-up, construction and managing of the project.

7.3. Data

Total built surface area above ground: 23,000 m2
Corporate use: 4,000 m2
Orona Elevator Innovation Centre: 4,800 m2
Technology center and laboratories: 3,000 m2
Shared use: 6,000 m2
Teaching use: 5,200 m2
Total built surface area below ground: 27,000 m2
Budget: 70M€
Completion: 12/2013

website: www.orona-ideo.com

2012 Austrian State Prize for Architecture and Sustainability



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Short Summary

The Austrian State Award for Architecture and Sustainability is conferred under the auspices of klima:aktiv, the Austrian Ministry for Agriculture, Forestry, Environment and Water Management's climate change initiative. The prize is significant because it provides definitive proof that architectural and aesthetic needs can be combined seamlessly with ecological, social and economic responsibility. The special feature of this award is that a building is eligible only if it can show both excellent architecture and outstanding sustainable construction

Keywords: architecture, energy efficiency, ecology, sustainability, award, lighthouse projects

1. Background, purpose, and goal

When traveling through cities, villages, and rural areas with our eyes wide open, we immediately evaluate what we see. We spontaneously judge the buildings we cast our eyes over as beautiful, ugly, fascinating, boring, bizarre or pretentious regardless of their energy credentials.
Energy-efficient construction, Passive House, Solar House and Plus Energy House buildings often do not stand up well to architectural critique. The print media loves to publish attention-grabbing quotes by architects in keeping with the premise that bad news is good news, such as: "Thermal insulation - the burka for the home" (Frankfurter Allgemeine Zeitung, November 14, 2010).
"Every building represents destruction. Destroy intelligently" (Architect Luigi Snozzi). Architecture does not take place in a vacuum. Just as a sculptor can create a piece of art from lump of stone, an architect can also create beautiful buildings with low energy demand

2. Method, evaluation, and judging

Professor and architect Roland Gnaiger and Wolfgang Neumann, the creator of the Energy Conservation Trade Show and the initiator of the Energy Globe Award, sat down together in around 2002. The result of this meeting was the Great Austrian Solar Architecture Award in 2003.
The Austrian Ministry of Agriculture, Forestry, Environment and Water Management is conferring the Austrian State Award for Architecture and Sustainability for the third time. The award recognizes projects with both excellent architectural value and outstanding ecological, energy, social and economic sustainability. Roland Gnaiger from the University of Art and Design Linz, who oversees the prize, developed the first state award in 2006 on behalf of the Ministry and then

worked with ÖGUT to organize its creation. Robert Lechner, the managing director of the Austrian Ecology Institute, then came on board to help develop the parameters for this prize.
Roland Gnaiger stresses that he felt it particularly important that the prize contain the word “and”. In other words, it should be called the State Award for Architecture and Sustainability rather than the State Award for Sustainable Architecture. This means that a building must have exceptional architecture and sustainability to be eligible for the prize.

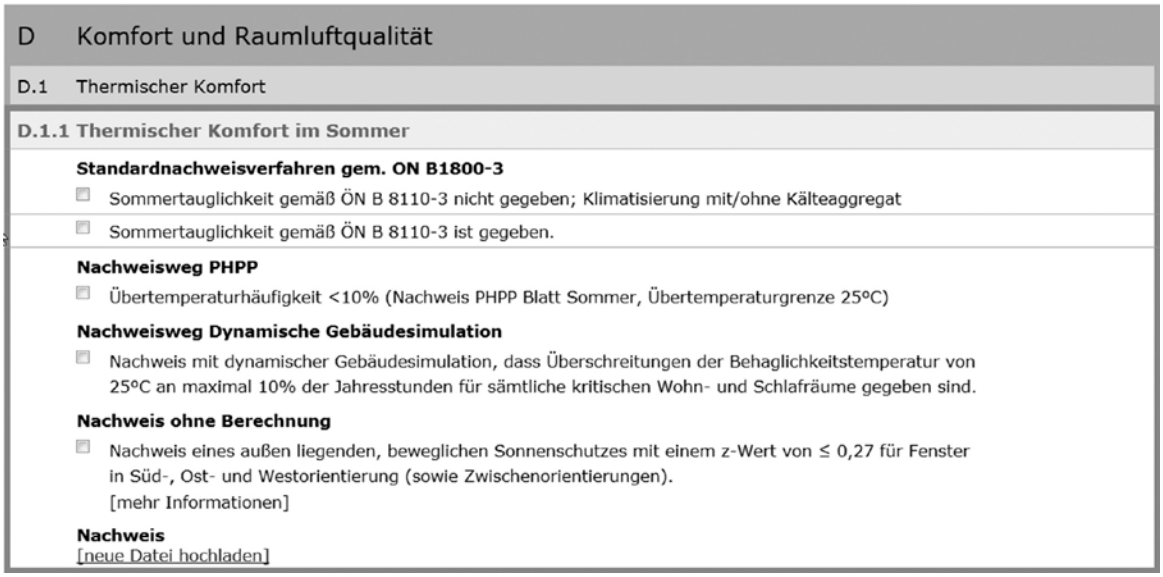
Method, evaluation, and judging

Jury decisions had to be unanimous to ensure assessment of equivalence. A building cannot receive the prize if it is a real treat architecturally speaking, but its sustainability, its ability to benefit future generations, is anything short of excellent. The opposite is also true: a building with all of the energy-efficiency and environmental credentials in the world cannot receive a state award if the jury deems its architectural features to be average. This is the first special element of the prize.

The process has three stages: an invitation for submissions, an initial round and judging. While the preliminary review of architectural features can focus solely on whether formal criteria have been met, buildings undergo rigorous scrutiny of their sustainability credentials at this stage. A web portal set up for the State Award for Architecture and Sustainability documented the entries. The content of this web portal leans heavily on klima:aktiv’s evaluation structure:

- Building data and general information
- A Planning and implementation (max. 130 points)
- B Energy and supply (max. 600 points)
- C Building materials and construction (max. 150 points)
- D Comfort and indoor air quality (max. 120 points)

Buildings can achieve up to a maximum of 1,000 points from all four categories. Each category or sector is subdivided into up to three levels, for example:



The preliminary review entails the labor-intensive task of checking that the information contained in all entries is complete and accurate.

A total of 99 buildings were put forward for the prize. The caliber of entries for the 2012 State Award for Architecture and Sustainability was much higher than in years past. At its first meeting, the jury narrowed the field down from 99 entries to 14 buildings that members visited in person during a three-day trip. This elaborate trip is needed because the jury is sometimes only able to confirm the building's quality by looking at it in person from the inside and out.
Another meeting at the end of the trip selected the five award recipients from the nine buildings nominated for the prize.

The results of the jury trip were stunning. All projects were of the highest quality, yet a decision still had to be made. In his summary, Roland Gnaiger writes: "This group's contributions are so important because they provide definitive proof that architectural and aesthetic needs can be integrated seamlessly with ecological, social and economic responsibility. Paul Valéry got to the heart of the matter in his wonderful dialog "Eupalinos or the Architect". His Socrates says, "This type of artist has no need for modesty. They have discovered the means to mix necessity and artifice inextricably.""

While few and no famous prize-winning architects had designed buildings put forward for the award just a few years ago, a surprisingly large number were in the running for the 2012 State Award for Architecture and Sustainability. This a good sign that excellent architecture does not fly in the face of sustainability, ecology and solar power. In this vein, Otto Kapfinger, one of Austria's most well-known and acclaimed architecture critics, remarked that "the three school projects in the final round by themselves are far superior to what we normally see in branding architecture in terms of their functionality, room quality and detail while meeting the highest ecological and energy standards." When analyzing a building's architecture and sustainability, a choice does not have to be made between one or the other; a building can perform well in both areas.
Another interesting feature is that several solid-construction buildings (of course, with highly efficient insulation and other Passive House Standard elements) were among the entries, unlike in years past.

The winners of the State Award for Architecture and Sustainability are outlined over the next few pages.



Figure 1: Salzkammergut Agricultural Education Center, Altmünster - STATE AWARD WINNER

This education center including a boarding school is a new build extension including an existing wood-framed wing with a usable area of around 10,000 m².
Key figures: 3.7 kWh/(m²a) (Austrian Institute for Building Technology, national calculation method)
Building owner: Landes-Immobilien GmbH Oberösterreich
Architect: Fink Thurnher Architekten
Professional planning: DI Dr. Lothar Künz ZT GmbH (construction physics); E-Plus GmbH (building services)
Special features: untreated wood used in the interior, which accommodates 250 students Redesigning, retrofitting, and adding a floor to a 50-year-old school building



Figure 2: Linz General Special School – STATE AWARD WINNER

Key figures: Heating demand: 3.12 kWh/(m²a) (Austrian Institute for Building Technology)
Building owner: Immobilien Linz GmbH & Co KG
Architect: grundstein Architektur
Professional planning: IBO (construction physics); Ing. Grillberger GmbH & Co KG (building systems)
Special features: Fully accessible to the disabled; solid construction with wood elements and a wood-concrete composite ceiling system; made entirely out of CFC-free and PVC-free materials




Figures 3 and 4: NÖ Haus Office Building in Krems - STATE AWARD WINNER

10,000 m² usable area, solid construction with insulation composite system built to Passive House Standard
Key figures: 2.6 kWh/(m²a) (Austrian Institute for Building Technology)
Building owner: NÖ Landesimmobilien GmbH
Architects: ARGE NÖHK: AllesWirdGut Architektur ZT GmbH, feld72 Architekten ZT GmbH, FCP – Fritsch, Chiari & Partner ZT GmbH
Professional planning: DI Walter Prause (construction physics), TB ZFG-Projekt GmbH (building services) and bauXund Forschung und Beratung GmbH (building ecology)
Special features: A redensification project in the historic town center, PVC-free, bicycle racks and showers, extensive green roofs, use of ground water to flush toilets



Figure 5: Wohnhaus U31 - STATE AWARD WINNER

New residential build with solid construction containing 46 apartments and commercial space
Key figures: 6.0 kWh/(m²a) (Austrian Institute for Building Technology); 14.2 kWh/(m²a) (PHPP)
Building owner: Heindl Holding GmbH
Architect: querkraft Architects ZT GmbH
Professional planning: Schöberl&Pöll GmbH (construction physics); BPS Engineering (building services)
Special features: Community rooms





Figures 6 and 7: Residential complex in Graz's trade fair district - STATE AWARD WINNER

A solid-construction residential building with 196 apartments and commercial space in the first floor
Key figures: Heating demand: 9.0 kWh/(m²a) (Austrian Institute for Building Technology)
Building owner: ENW – Gemeinnützige Wohnungsgesellschaft mbH
Architects: DI Markus Pernthaler Architekt ZT GmbH
Professional planning: Vatter & Partner ZT GmbH (construction physics), RFG Engineering GmbH (building services), and bauXund Forschung und Beratung GmbH (building ecology)
Special features: Stands to hold 547 bicycles, swimming pool and sauna on the roof, and 700 m² solar array

3. Outlook

The 2012 Austrian State Award for Architecture and Sustainability demonstrates that architecture can go hand in hand with sustainability. But opponents still argue that this is not the case, as changing direction is inherently difficult, especially in a sector dealing with immobile goods. Understandably, architects lament the increasing burden they face when planning buildings. New and sometimes incomprehensible standards and laws are coming to bear, along with more and more building contractors who are no longer tradespeople and cannot be due to massive pressure on prices.
Despite all of these hurdles, the buildings recognized with the State Award for Architecture and Sustainability show that we can achieve and build what is desirable. These architectural lighthouses can no longer be ignored; they serve as benchmarks for other projects. As a result, they will also influence everyday architecture, which shapes our perception of building culture.

4. More information

There are all projects presented with detailed explanations on the website:
www.staatspreis.klimaaktiv.at >> http://www.klimaaktiv.at/bauen-sanieren/staatspreis

Österreichische Gesellschaft für Umwelt und Technik (ÖGUT), Hollandstrasse 10/46, A-1020 Vienna, Tel.: +43.1.315 63 93; Email: klimaaktiv@oegut.at; Website: www.oegut.at

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klima:aktiv

Die Klimaschutzinitiative
des Lebensministeriums

klima:aktiv Bauen und Sanieren

behaglich, gesund und energiebewusst!

klima:aktiv Bauen und Sanieren steht für
Energieeffizienz, ökologische Qualität, Komfort und Ausführungsqualität. Egal ob Neubau oder Gebäudesanierung, klima:aktiv Bauen und Sanieren hilft Ihnen, die richtigen Entscheidungen zu treffen. Welche Maßnahmen lohnen sich? Welcher Energieträger ist in welcher Situation sinnvoll? Welche Förderungen gibt es?

Gebäude in klima:aktiv Qualität garantieren Ihnen

- niedrigen Energieverbrauch und niedrigste CO_2-Emissionen
- beste Raumluftqualität
- optimalen Nutzungskomfort und eine ökologische Bauweise
- hohe Planungs- und Ausführungsqualität
- Wirtschaftlichkeit und hohen Wiederverkaufswert der Immobilie

„klima:aktiv Bauen und Sanieren" ist Teil der Klimaschutzinitiative klima:aktiv des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.







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Weitere Infos auf:
www.bauen-sanieren.klimaaktiv.at

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klima:aktiv

Building and Refurbishment

Comfortable, healthy and energy-conscious

klima:aktiv Building and Refurbishment stands for energy efficiency, ecological quality, comfort and high quality of execution. No matter, whether we are talking about a newly constructed building or the renovation of a building, **klima:**aktiv Building and Refurbishment helps you to take the right decisions. Which measures are worthwhile? Which energy source is useful in which situation? Which funding schemes are available?

klima:aktiv Building and Refurbishment is part of the climate protection initiative of the Federal Ministry of Agriculture, Forestry, Environment and Water Management.

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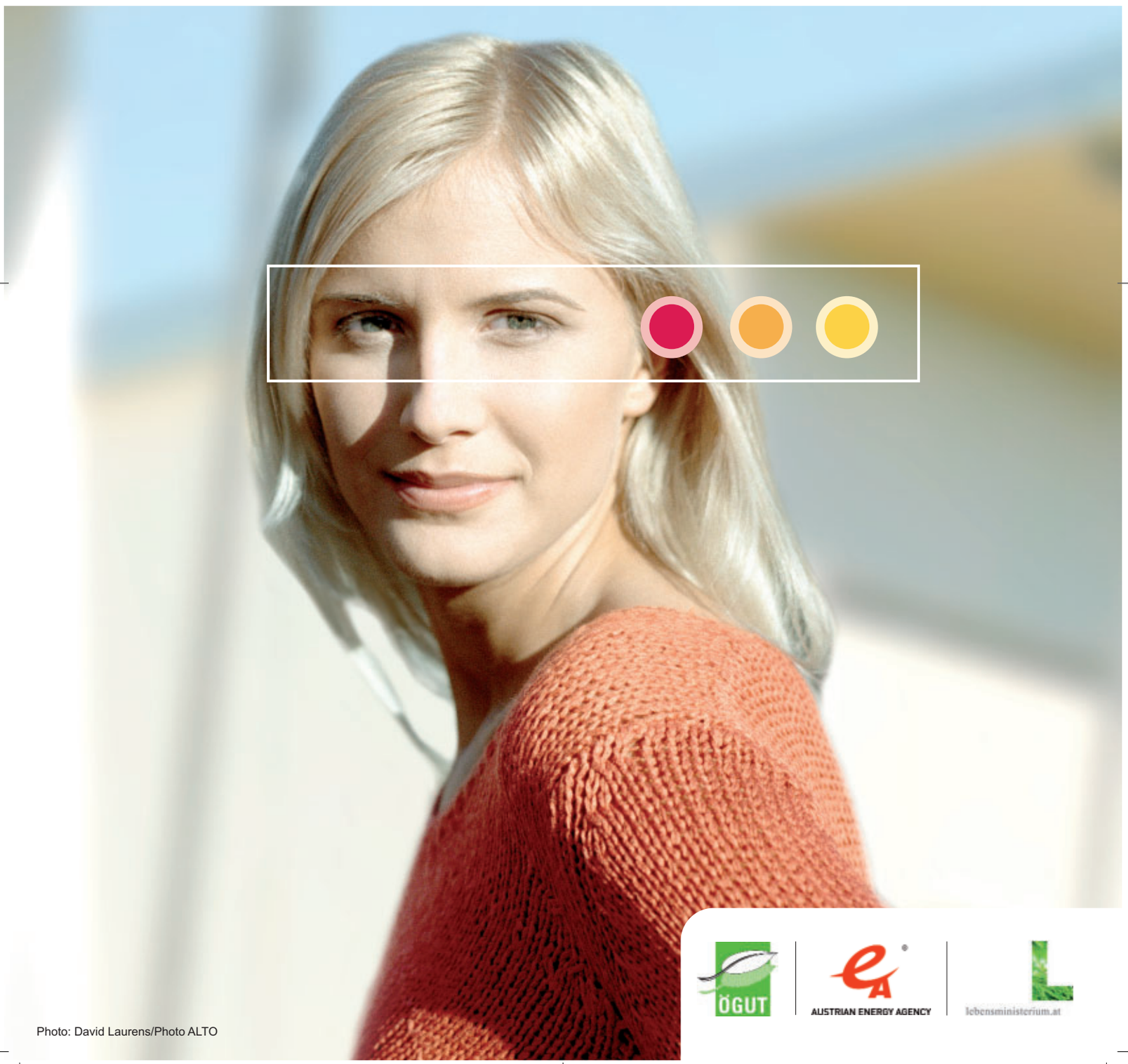


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Wienerberger
Building Material Solutions



We won't live to see our greatest achievements.

Sustainability Report 2012

What we strive for

Sustainability Goals

Employees	Deadline	Performance 2012	2011	Remarks
Reduce the frequency of accidents to < 10 per million hours worked by 2015	2015	**12**	17	We have made substantial progress in this area since the implementation of the safety initiative in 2010
Increase the data collection on respirable crystalline silica to > 95% of all ceramic plants by 2020	2020	**84%**	na	We will continuously expand data collection on respirable crystalline silica
Increase the share of women in senior management to 20% by 2020	2020	**8%**	8%	Preferential treatment of women when qualifications are equal; low number of new appointments in 2012 due to restructuring measures
Increase the share of women in administration to > 45% by 2020	2020	**44.3%**	43.7%	
Increase the share of women in sales to 30% by 2020	2020	**24.3%**	24.2%	
Environmental Protection in Production				
Reduce specific energy consumption in ceramic production 20% below 2010 level by 2020	2020	**-9%**	-5%	The Environmental Action Plan defines measures to reach our goals in the ceramic production; however, the targets are very ambitious, since we have already reduced these figures significantly during the past 10 to 15 years
Reduce specific CO_2 emissions from ceramic production 20% below 2010 level by 2020	2020	**-1%**	0%	
Reduce the share of water drawn from public supply networks to 40% by 2020	2020	**45%**	48%	We have already reduced the share of water drawn from public supply networks in 2012 and are confident to reach this goal
Sustainable Products				
Increase the share of revenues generated by innovative products to 30% in 2015	2015	**23.4%**	23.3%	We have set an ambitious goal and are constantly working to bring innovative products to our markets
Corporate Social Responsibility				
Expand WISBA to 12 countries by 2015	2015	**na**	na	We created WISBA in 2012; four countries will participate in 2013; the concept will be rolled out step by step
Stakeholder Management				
Introduce a stakeholder dialogue in 90% of our ceramic production network by 2020	2020	**na**	na	We set this goal in 2012 and will start to implement measures in 2013

WISBA … Wienerberger Sustainable Building Academy
na … not available (data has not been collected)

Key Data

Sustainability Data by Product Group

Bricks & Tiles		2010	2011	2012	Chg. in %
Employees at year-end		9,792	10,014	9,414	-6
Accident frequency		20	17	13	-22
Share of women	*in %*	13	12	13	-
Employee turnover rate [2)]	*in %*	12	7	10	-
Specific energy consumption					
Wall	*Index*	100	95	89	-6
Roof	*Index*	100	93	84	-9
Facade	*Index*	100	96	98	+2
Specific CO_2 emissions					
Wall	*Index*	100	101	101	0
Roof	*Index*	100	95	85	-10
Facade	*Index*	100	100	102	+1
Specific water consumption	*m³/to*	0.163	0.183	0.180	-2

Ceramic Pipes		2010	2011	2012	Chg. in %
Employees at year-end		na	570	561	-2
Accident frequency		na	29	36	+24
Share of women	*in %*	na	10	9	-
Employee turnover rate	*in %*	na	1	7	-
Specific energy consumption	*Index*	100	90	82	-9
Specific CO_2 emissions	*Index*	100	91	87	-4
Specific water consumption	*m³/to*	0.225	0.241	0.242	0

Plastic Pipes		2010	2011	2012	Chg. in %
Employees at year-end		2,292	2,571	2,509	-2
Accident frequency		2	4	4	-7
Share of women	*in %*	16	15	15	-
Employee turnover rate	*in %*	16	15	10	-
Specific energy consumption	*Index*	100	100	98	-2
Specific water consumption	*m³/to*	4.830	4.673	4.476	-4

Concrete Pavers		2010	2011	2012	Chg. in %
Employees at year-end		985	1,015	936	-8
Accident frequency		20	13	17	+31
Share of women	*in %*	16	16	17	-
Employee turnover rate	*in %*	15	17	17	-
Specific energy consumption	*Index*	100	108	96	-12
Specific water consumption	*m³/to*	0.056	0.057	0.047	-17

Explanatory notes to the report:

- *Operating EBITDA is adjusted for non-recurring income and expenses.*
- *Free cash flow equals cash flow from operating activities minus cash flow from investing activities plus growth capex.*
- *2011 data were adjusted to reflect the initial consolidation of Steinzeug-Keramo.*
- *The calculation methods are explained in the respective chapters of the report.*
  Information on the reporting threshold can be found in the chapter "About this Report".
- *Rounding differences may arise from the automatic processing of data.*

Wienerberger Products: Production 2012



Homes built:
140,000



Roofs covered:
180,000



km pipes installed:
280,000



m² pavers layed:
11,600,000

Wienerberger Group

Corporate Data		2010 [1]	2011 [1]	2012	Chg. in %
Revenues	*in € mill.*	1,663.6	1,915.4	2,355.5	+23
Operating EBITDA	*in € mill.*	198.3	240.4	245.5	+2
EBIT	*in € mill.*	4.6	37.5	-21.7	<-100
Profit after tax	*in € mill.*	-35.4	39.4	-40.5	<-100
Free cash flow	*in € mill.*	170.5	135.0	163.6	+21
Net debt	*in € mill.*	362.3	358.8	602.0	+68
Gearing	*in %*	14.5	14.8	25.5	-
Ø Employees		11,296	11,893	13,060	+10

Employees		2010	2011	2012	Chg. in %
Accident frequency		20	17	12	-29
Training hours / employee		12	16	13	-20
Ø Training costs / employee	*in €*	214	285	257	-10
Share of women	*in %*	13	13	14	-
Share of women in senior management	*in %*	5	8	8	-
Share of women in administration	*in %*	47	44	44	-
Share of women in sales	*in %*	24	24	24	-
Turnover rate [2]	*in %*	12	8	11	-

Environmental Protection in Production		2010	2011	2012	Chg. in %
Energy consumption	*in MWh*	7,280,997	7,727,106	6,744,796	-13
Specific energy consumption	*Index*	100	97	92	-5
CO_2 emissions	*in to*	1,901,727	2,110,033	1,834,073	-13
Specific CO_2 emissions	*Index*	100	100	99	-1
Waste	*in to*	116,894	132,433	133,600	+1
Water consumption	*in mill. m³*	2.2	2.7	3.2	+21
Water from public supply networks	*in %*	54	48	45	-

Sustainable Products		2010	2011	2012	Chg. in %
Revenues generated by innovative products	*in %*	20	23	23	-

Corporate Social Responsibility		2010	2011	2012	Chg. in %
Strike days	*in man-days*	na	na	402	na
WISBA countries		na	na	na	na

Stakeholder Management		2010	2011	2012	Chg. in %
Ceramic plants that have a stakeholder dialogue in place	*in %*	na	na	na	-

1) The data were adjusted to reflect a change in accounting policies.
2) excluding North America (analysis limited by special local legal regulations)
na … not available (data has not been collected)

We have set goals for these key data that we want to reach by 2015 or 2020.
A summary of all goals can be found on the previous page.
The individual goals are described in detail in the respective chapter of the report.

Because coming generations will benefit even more from our sustainable business approach.



A good working environment is the foundation for our future.

We challenge and encourage our employees. To make sure we can expect top performance, we invest in a safe and motivating working environment. We have significantly reduced the number of work accidents since 2010 and, with 12 accidents per million hours worked in 2012, moved closer to our goal of less than 10 accidents by 2015.

As an employer in many, in part structurally weak regions, we want to offer stable employment relationships. The long service length of 12.9 years and a low number of days lost through work stoppages speak a clear language.



A long life requires amazingly little energy.

A house made of Wienerberger building materials is an investment for coming generations. The core of our sustainability strategy is the long service life of our products. At the same time, we implement measures to reduce the environmental impact of our production processes. Our activities are focused not only on reducing energy consumption, but also on improving our ecological footprint by using fewer raw materials and increasing the use of recycled products.



We don't think about tomorrow.
We're already there.

The sustainability of our products is underscored by their long service life. Outstanding technical properties are another exceptional feature: ceramic building materials are free of pollutants. They not only provide good thermal insulation, but also protection against noise and fire, and create a healthy, comfortable indoor climate. With continuous innovation, we make sure our pipes can meet any challenge – above all in the areas of health and supply security.



Success can't always be measured in numbers.

We believe we can help best in areas related to our core expertise. That's why we are active, above all, in two main areas. First, in the construction of housing for the needy and help in the event of disasters near our plants. And second, in cooperation with the Vienna University of Economics and Business, we give young, talented men and women an opportunity to obtain additional technical training in sustainable construction.



Every bridge we build brings us closer together.

We are convinced that sustainable management creates added value for all our stakeholders. In order to establish and maintain positive relations with our investors, the media, suppliers and other stakeholders, we follow a policy of transparent communications and active dialogue. Invitations to our plants and the regular exchange of information provide a platform for interaction with neighboring residents in many countries. We want to be a fair neighbor who not only meets but also exceeds legal regulations to provide quality living for local residents.

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Quick Response (QR) Codes

You will find QR codes at selected points in this sustainability report. Scan the codes with your smartphone and visit the linked websites for more detailed information.

www.wienerberger.com

Introduction by the Chief Executive Officer

Dear Ladies and Gentlemen,

The mega-challenges of the future require responsible action

Climate change, limited resources, population growth, rising poverty, migration, demographic change, urbanization, the loss of biodiversity – the list of global, often interconnected challenges is long.

Climate protection and climate change as central concerns

The frequently discussed climate change is attributable primarily to the sharp rise in CO_2 emissions from the burning of fossil fuels such as crude oil and natural gas. In order to limit global warming to a tolerable level, we must reduce CO_2 emissions, use energy more efficiently and convert to non-fossil energy sources – and all that as quickly and completely as possible.

Nearly zero-energy standard mandatory in the EU starting in 2021

The energy consumption of buildings plays a major role in this process. The building sector in the EU is currently responsible for roughly 40% of total energy consumption. As a result, the EU issued a directive that requires all buildings built after January 1, 2021 to meet "nearly zero-energy" standards [1)].

e4-Brickhouse 2020 already meets this standard today

Our e4-Brickhouse 2020 already meets these requirements today. It can save 4,200 tons of CO_2 per year compared with a conventional single family house because it produces more energy than it uses. In order to verify this claim, the Austrian Institute of Technology (AIT) will monitor the first e4-Brickhouse 2020 up to 2014. This house was built in the Lower Austrian town of Zwettl by a family of four, who moved in during the past year.

Healthy living (e.g. interior air) as a key issue for the future of housing

In addition to the energy efficiency of buildings, I see healthy living as one of the most important issues for the future of modern housing. People in the western industrial countries spend roughly 90% of their time indoors – and the quality of the interior air generally leaves a lot to be desired: pollutants, dry air, dust and mold not only have a negative influence on the indoor climate, but also represent a major health risk. Today, asthma is the most frequently diagnosed disease among children in Europe. It is no coincidence that bricks have been used as a building material for thousands of years – their outstanding properties create an optimal quality of living for residents. Bricks are absolutely free of pollutants. They are also permeable, which means they equalize the humidity in the room and, in this way, create a healthy indoor climate. Bricks also help to save energy, both in heating and cooling, because of their natural air conditioning properties. The accumulation capacity of bricks evens out temperature fluctuations by absorbing heat during the daytime and releasing it in the night, or vice versa. Bricks are therefore one of the best building materials for the creation of a pleasant and comfortable atmosphere.

1) Directive 2010/31/EU from May 19, 2010 on the energy performance of buildings



Heimo Scheuch, Chief Executive Officer of Wienerberger AG

Special pipe system to prevent flooding in cities

The consequences of climate change and the resulting heavier rainfall over shorter periods of time represent a new challenge, above all for urban areas. Flooding has become a growing problem because sufficient drainage areas are frequently not available and sewage systems are not designed to handle the higher water volumes. With our innovative Raineo^{TM} pipe system, we have developed a solution for this problem.

Long service life of our products brings responsibility for continued development and innovation

Our products have a proven service life of more than 100 years. This creates value for generations, but also brings a great deal of responsibility. Therefore, one of our main goals is to anticipate trends and developments to offer our customers innovative and affordable solutions for residential construction, infrastructure and renovation that guarantee long-term comfort, health and security. Innovation is one of the guiding principles of our strategy to generate organic growth and create maximum value for all our stakeholders, above all our customers. This is our course for the future. Our goal is to increase the share of innovative products from the current level of 23% to 30% of revenues by 2015.

First-time announcement of sustainability goals in this report to improve transparency

Sustainable management has been a key part of the Wienerberger corporate culture for many years and is integrated in all areas of the company. In order to make our activities even more transparent, we have decided to announce our sustainability goals for various areas for the first time in this report and will report to you on our progress in the future. I invite you to form your own opinion of our efforts in sustainability management and to join us on a sustainable course into the future.

Yours

Wienerberger at a Glance

The Wienerberger History

From an Austrian brick manufacturer …

Wienerberger was founded in 1819 by Alois Miesbach on the Wienerberg in Vienna. This Austrian brick manufacturer became one of the first companies to trade on the Vienna Stock Exchange with its initial public offering in 1869. In spite of this listing, Wienerberger remained a local company for over one hundred years. The first internationalization step was taken in 1986 with the acquisition of the German Oltmanns Group and continued with successful expansion into Eastern Europe, France and the Benelux countries during the 1990s. The ***founding of Pipelife*** (plastic pipes) as joint venture with a Belgian partner and the development of the Group's ceramic pipe and concrete paver activities also occurred during this time.

… through a number of expansion steps …

Further growth steps in Europe were followed by Wienerberger's development into a ***global player*** with the takeover of General Shale in the USA during 1999. Another key strategic milestone was set in 2003 with the Group's ***entry into the roofing systems market through the acquisition of Koramic*** and the steady expansion of this business in the following years.

… and restructuring measures …

After many years of strong, expansive growth, Wienerberger was hit hard by the global economic crisis in 2009 because of its heavy dependence on cyclical new residential construction. ***Heimo Scheuch*** took over as ***chief executive officer*** of the Wienerberger Group in summer 2009 and implemented an extensive restructuring program through the end of 2010 that adjusted corporate structures to reflect the difficult market conditions. The end of the restructuring process was followed by a strategic reorientation, which focused the company on financial discipline and organic growth through innovative and premium products. The expansion steps after 2009 were directed, above all, to less cyclical business areas like roof tiles and pipe systems in order to ensure the sustainable generation of stable earnings.

Company Profile

… to an international system provider of building materials

With the full takeover of the plastic pipe producer Pipelife in 2012, Wienerberger completed its transformation into an international supplier of building material systems. Business activities are now aggregated in two divisions: Bricks & Tiles and Pipes & Pavers. The Bricks & Tiles Division covers the clay block, facing brick and clay roof tile product groups. Wienerberger is the world's largest producer of clay blocks, number one in facing bricks in Europe and the USA and the market leader for clay roof tiles in Europe. The Pipes & Pavers Division includes our activities in the areas of plastic pipes, ceramic pipes and concrete pavers. Wienerberger is one of the leading suppliers of plastic pipes, ceramic pipes and concrete pavers (only in Central-East Europe) in Europe.

Clay blocks:	**No. 1 worldwide**
Facing bricks:	**No. 1 in Europe, co-leader in the USA**
Clay roof tiles:	**No. 1 in Europe**
Plastic pipes:	**Leading position in Europe**
Ceramic pipes:	**No. 1 in Europe**
Concrete pavers:	**No. 1 in Central-East Europe**

Strategy and Business Model

Sustainable creation of added value as top corporate goal

The goal of our business model is to create and maintain a sustainable increase in the value of the company in accordance with ecological, social and economic principles. Accordingly, we want to create added value for all our stakeholders.

Completion of strategic reorientation from an expansion-driven to a market-oriented company

For Wienerberger, the years since the crisis have been characterized, above all, by a difficult new residential construction market and an internal focus on cash generation. Extensive restructuring measures were implemented in 2009 as a reaction to the global financial crisis, which cut fixed costs by approx. € 200 million, substantially reduced working capital and gradually decreased the company's debt. The restructuring phase was followed by a strategic reorientation from a primarily expansion-driven to a market-oriented company with a focus on organic growth. Our customers are the focal point of our actions – we want to create added value for them with innovative, high-quality and application-oriented system solutions. Comprehensive advising and service for our customers, starting with the project planning stage, are an important part of our improved sales activities. The strategy for our core business is designed to establish and extend leading positions in all markets in which we are present.

Strategic expansion through development of pipe systems

In order to reduce Wienerberger's dependence on new residential construction over the medium-term, we have been working for several years to expand the core business through a stronger concentration on renovation and infrastructure. Our activities in the area of pipe systems should be seen in this connection. We acquired Steinzeug-Keramo, the market leader for ceramic pipes in Europe, during 2010. In 2012 the Wienerberger Group completed its transformation to an international system provider of building materials with the full takeover of Pipelife, one of the leading European producers of plastic pipes. Both companies were acquired at comparatively low multiples and create substantial added value with a CFROI that clearly exceeds the internal hurdle rate of 11.5%. The expansion of the core business has reduced the dependence on cyclical new residential construction from approx. 70% to roughly 60% of revenues. It has also broadened Wienerberger's strategic base and extended the potential for sustainable growth over the medium- and long-term.

Financial discipline is a top strategic priority for Wienerberger

Our strategic focus will remain on financial discipline as well as the protection of a strong capital structure based on our internal goal to hold the ratio of net debt to operating EBITDA below 2.5 years. The issue of an additional bond in April 2013 with a volume of € 300 million increased our liquidity reserves and further optimized the term structure of liabilities. The maintenance and protection of a strong capital structure remains a central goal for Wienerberger, which we will continue to pursue through the proactive management of liquidity and the term structure of liabilities.

Wienerberger Group: EBITDA potential of € 600 million

Wienerberger's activities cover ***solutions for walls and roofs*** (clay blocks, facing bricks and clay roof tiles) as well as ***pipe systems & paver solutions*** (plastic pipes, ceramic pipes and concrete pavers). These businesses are managed by region based on the following divisions: ***Bricks & Tiles Europe***, ***Pipes & Pavers Europe*** and ***North America***. The Wienerberger Group has a medium- to long-term EBITDA potential of approx. € 600 million across all divisions, once the new residential construction market recovers.

The Year 2012 in Review

Increase in operating results through expansion of pipe operations in a difficult market environment

Wienerberger increased revenues by 23% and operating EBITDA by 2% during 2012 in a difficult market environment. The Group's results were influenced by three major developments: an earnings decline in the European brick business due to weaker residential construction across Europe, a substantial positive contribution from the acquisition of Pipelife in May 2012 and moderate recovery on the US new residential construction market with a resulting improvement in revenues and earnings in the North America Division. The Bricks & Tiles Europe Division recorded a decline in revenues and earnings for the year because the European construction industry was again faced with the negative effects of the euro and sovereign debt crisis and new residential construction subsequently fell below the 2009 crisis year in a number of key markets. These developments were met with a restructuring program that involves non-recurring costs of approx. € 43 million, but will bring sustainable costs savings of € 50 million by year-end 2014. The costs for the restructuring program and other non-cash effective one-time expenses resulted in a loss of € 40.5 million for the year.

Return of 20% on free cash flow

Wienerberger again demonstrated its cash flow-generating strength in 2012, despite the difficult market environment, and increased free cash flow by 21% to € 164 million. That represents a free cash flow return of 20% at year-end. The Group's strong capital structure was underscored by a ratio of net debt to operating EBITDA that equaled 2.2 years at year-end 2012. As a result a € 0.12 dividend per share for the 2012 financial year was paid to shareholders.

Pipelife acquisition main reason for increase in workforce

The average number of employees in the Wienerberger Group rose to 13,060 during the reporting year. This development resulted, above all, from the initial consolidation of Pipelife as of May 31, 2012. The Pipelife acquisition and compensation increases explain the rise in wages, salaries and employee benefits.

Dividend and coupon on hybrid bond lead to payments of € 46.3 million

A dividend of € 0.12 per share, or a total of € 13.8 million, was paid in 2012 from profit recorded for the 2011 financial year. As in the previous years, the payment of the hybrid coupon amounted to € 32.5 million. Net debt rose from € 358.8 million at year-end 2011 to € 602.0 million as of December 31, 2012, in particular due to the Pipelife acquisition, but gearing equaled a comparatively low 26% at the end of 2012.

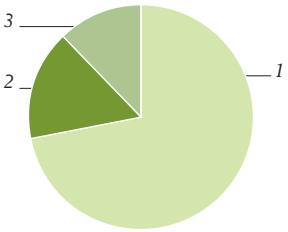
Payments of € 33.7 million to the public sector

Payments to the public sector, which represent taxes on income and other taxes (excluding deferred taxes) fell slightly to € 33.7 million in 2012 due to the decline in earnings and the resulting lower tax expense.

Cash flows to stakeholders *in € mill.*	2010 [1]	2011 [1]	2012	Change in %
Revenues and other operating income	1,731.3	1,971.8	2,407.3	+22
Operating costs [2]	-1,040.1	-1,179.0	-1,518.7	+29
Employee wages, salaries and benefits [3]	-469.4	-525.4	-592.5	+13
Payments to providers of capital (owners) [4]	-32.5	-44.2	-46.3	+5
Payments to providers of capital (creditors)	-43.8	-39.5	-52.1	+32
Payments to public authorities [5]	-24.4	-35.7	-33.7	-6

1) The data were adjusted to reflect a change in accounting policies
2) Production costs plus selling, administrative and other operating expenses; excluding wages, salaries, benefits, depreciation and amortization as well as non-income based taxes
3) Excluding temporary personnel and company automobiles; including employee-related restructuring costs
4) The hybrid coupon and dividend are shown in the year in which payment was made
5) Excluding deferred taxes

Public financial subsidies
in %



1 Investments in environmental protection and occupational safety 72%
2 Product research and development 16%
3 Other 12%

The Wienerberger Group received public financial subsidies of € 3.2 million in 2012 (individual amounts over € 50,000 are recorded). The major payments represent investments in environmental protection and occupational safety (€ 2.3 million), product research and development (€ 0.5 million) and other financial subsidies (€ 0.4 million).

Corporate Governance at Wienerberger

Implementation of strict principles for good management and transparency

For many years Wienerberger has followed a strategy that is designed to maximize cash flows in order to create and maintain a sustainable increase in shareholder value. Strict principles of good management and transparency as well as the continuous development of an efficient control system form the basis for meeting this goal.

Compliance code to prevent insider trading and code of conduct for lobbying activities

We give the highest priority to providing all shareholders with the same comprehensive information. To prevent insider trading, we have released a compliance guideline that implements the provisions of the Issuer Compliance Code published by the Austrian Financial Market Authority. A compliance officer monitors the observance of these rules. A code of conduct based on the Austrian Lobbying Act covers all corporate bodies and the employees of Austrian companies in which Wienerberger AG holds a controlling interest. This code defines the principles for lobbying activities and can be reviewed on the Wienerberger website (www.wienerberger.com).

Wienerberger is the leader for transparency

Wienerberger was one of the first companies in Austria to announce its support for this code and to commit to compliance with its rules. Wienerberger met all rules and recommendations of the code (in the version dated July 2012) in 2012. The corporate governance report is integrated in the 2012 annual report (pages 20 to 37).

Additional information on corporate governance at Wienerberger is provided in the 2012 annual report, which is also published on the company's website (annualreport.wienerberger.com).

Sustainable Development at Wienerberger

Wienerberger Principles of Sustainability

Business as an integral part of society

Wienerberger views business as an integral part of society. Its duty is to serve people and create value for everyone. Wienerberger takes its role as a responsible member of society seriously. We define responsibility as ethical actions, honest communications, active participation in the transparent development of our economic environment, personal accountability and actions that confirm our standing as a reliable and valuable member of society.

Sustainable products are the focal point of the sustainability strategy

Sustainability represents an integral part of the Wienerberger corporate culture and the corporate strategy. We view sustainable management as a process that creates lasting added value for all our stakeholders. Our sustainable products and system solutions form the focal point of our sustainability strategy. Wienerberger produces and sells a wide variety of building material products and solutions that are used for very different applications. One of our most important goals is to create added value for our customers with our products and solutions with their long service life, technical properties, low impact on the environment over the entire lifecycle and economy. In general, we see sustainability as a function between the service life of a product and its impact on the environment during production, transport, installation, use and disposal:



The sustainability of a product increases with its service life. Increasing the service life of a product reduces the use of resources and the effects on the environment over the entire lifecycle. In this same way, a reduction in the use of resources based on a constant lifecycle makes products more sustainable.

The Sustainable Management Cycle

Sustainability is an integrated process

At Wienerberger, sustainability is embedded in all stages of the value creation process. We see sustainability as an integrated process that creates lasting value for all our stakeholders.



Sustainability begins with our ***employees***. We place high value on their health, advancement and development because our success is based on the commitment of a workforce that believes in sustainability and acts as entrepreneurs. Our focus for ***production*** lies on the best possible conservation of resources and the recycling of materials. We produce innovative, long-lasting ***products and system solutions*** for residential construction and infrastructure that create sustainable value for the people who use them every day. In accordance with our donation guideline, we provide in-kind support for the needy with our products and also give young people an opportunity for training in sustainable construction. These measures demonstrate our commitment to sustainability and to ***society*** and, in the end, create sustainable added value for our ***stakeholders*** – which completes the cycle.

1. Development of employees

Employees are the basis of our success

Our employees are the basis of our future success. We therefore place a special focus on these men and women, and encourage the creation of internal networks and cooperation throughout the Wienerberger Group. In accordance with our corporate values, we offer a healthy, safe and motivating working environment. Our goal is to develop the potential of our employees

and, subsequently, to fill most of our management positions internally. A corporate culture that encourages openness and respectful interaction serves as a reference point for our employees, also with respect to their targeted personal development.

2. Environmental protection in production

Resource conservation and recycling as central principles for production

Environmental protection in production is a top priority for Wienerberger. The use of reusable raw materials and recycling are the central principles of our sustainable production. Another important focal point of our activities is the greatest possible conservation of resources. That means improving the energy and resource efficiency of production processes through optimized technologies and, in that way, and through the use of renewable energy carriers reducing CO_2 emissions. We are also working to reduce the weight of our products and evaluating the use of secondary raw materials.

3. Sustainable products

Long-lasting and innovative products create sustainable value

The value of a building or a pipe system is dependent on numerous factors, not least on the products used. A central principle of product development at Wienerberger is the creation of sustainable value for people with long-lasting and innovative system solutions. Wienerberger brick products form an integral part of sustainable building concepts. They guarantee a high quality of living and make an active contribution to climate protection. In the area of pipes and pavers we offer system solutions for today's challenges, including the demands on water management resulting from climate change and increasing urbanization.

4. Responsibility for society

We are committed to social responsibility

"Building with a clear conscience" – Our belief in sustainability is also reflected in our goal to accept responsibility for society. The protection of human rights and compliance with all relevant national and international legal regulations as well as open and transparent communications with politics and public authorities also represent an integral part of our commitment to social responsibility. Our donation guideline provides a framework for the targeted, in-kind support we provide to the needy in the form of products or training programs. We believe we can help best in areas related to our core expertise, namely in the provision of building material solutions and know-how for sustainable construction.

5. Added value for our stakeholders

Our most important goal: the creation of added value for all our stakeholders

Our foremost goal is to generate added value for all our stakeholders through future-oriented, proactive behavior. We create a healthy living environment and provide security of supply for our customers with our long-lasting and innovative products, a solid investment for our shareholders and an attractive workplace for our employees. Wienerberger engages in an active dialogue with all its stakeholders and is well aware of its responsibility to shareholders.

Processes and Instruments of Sustainable Development

Sustainability report as part of a continuous process

The Wienerberger sustainability report transforms our commitment into an obligation. It is based on the standards defined by the Global Reporting Initiative (GRI) and represents an integral part of a continuous process. All levels of management and our employees have taken on shared responsibility for the implementation of measures to support a continuous improvement in sustainability at Wienerberger. This sustainability report provides information on the current status and further measures in the areas of employees, environmental protection in production, sustainable products, social responsibility and stakeholder management. It not only represents a collection of interesting facts and figures, but also serves as an instrument to monitor the progress of our sustainable development.

Transparent communication of goals for the first time

The Sustainable Development Steering Committee (SDSC) was founded in 2009 to define Wienerberger's sustainability strategy, key indicators according to GRI and goals for sustainable development. The SDSC meets regularly or as required to discuss progress on the sustainability process and options for further actions. It also defines goals and measures for implementation throughout the Group. In order to make our commitment to these goals transparent, we are publishing them for the first time in this sustainability report. The following chapters provide information on our goals in the respective areas.

CEO monitors sustainable development

This sustainability report was released by the SDSC. The Chief Executive Officer of Wienerberger AG, Heimo Scheuch, is a member of the Sustainable Development Steering Committee. He monitors the company's sustainable development on a regular basis and ensures that sustainability always has top priority for the company.

Sustainability management is anchored in the organization

In recent years our approach to sustainability management has become substantially more professional and more firmly anchored in the company. Responsibilities for sustainability have also been clearly defined. In addition to a Group-wide sustainability officer who reports directly to the Chief Executive Officer of Wienerberger AG, each of our country organizations and subsidiaries has designated a person who is responsible for sustainability and the implementation of the respective Group guidelines and programs.

Internal audit as control function

The SDSC uses Wienerberger's internal audit department to review major aspects of the sustainability program. This department, which reports directly to the Managing Board, evaluates the company's operating processes each year based on an audit plan and a risk assessment. Monitoring the internal control system in the accounting process is one of the most important responsibilities of internal audit. Another duty is the review of compliance with legal regulations and internal guidelines, for example the guidelines on business gifts and competition law. Internal audit also evaluates compliance with Wienerberger safety standards for employees and with selected areas of the Austrian Corporate Governance Code, whereby the latter is mainly a focus of activities by the external auditor.



2001

Commitment to a Social Charter for compliance with the applicable agreements and recommendations of the International Labor Organization (ILO) in Geneva

2003

Commitment to the UN Global Compact – a United Nations initiative established in 1999 to promote ethical behavior among companies (good corporate citizenship)

2004

Extensive discussions of sustainability by Wienerberger management together with external advisors; definition of the Wienerberger mission statement by 80 managers from all country organizations

2005

Communication of the Wienerberger mission statement to all employees and implementation in all country organizations

2006

Wienerberger is a founding member of the Austrian UN Global Compact network respACT Austria

2009

Founding of the Wienerberger Sustainable Development Steering Committee to define Wienerberger's sustainability strategy, key indicators and targeted goals for sustainable development

2010

Publication of the first Wienerberger Sustainability Report and implementation of the defined measures, for example the Environmental Action Plan and Safety Initiative 2010

2011

Integration of local sustainability managers into a network to better anchor sustainability issues in the Wienerberger country organizations

2012

Communication of goals for defined sustainability indicators

Employees

Principles of Sustainable Human Resources Management

Sustainable human resources management for diversity and equal opportunity, safety and health, training and a motivating working environment

Our employees are the basis of our success and a key factor for the successful development of our company. Wienerberger is well aware of its responsibility to its employees and takes this responsibility seriously. We are committed to sustainable human resources management that creates the necessary requirements and conditions for our employees in the areas of diversity and equal opportunity, occupational safety and health, training and a motivating working environment. Our human resources management is based on the following sustainability principles, which apply without limitation throughout the entire Group:

– *Equal opportunity independent of age, gender, culture, religion and origin*
– *Healthy and safe workplaces*
– *Advancement and development of each employee*
– *High readiness to act and personal responsibility*
– *Entrepreneurial thinking and actions*

Wienerberger Social Charter guarantees fair working conditions

With the signing of a social charter in 2001, Wienerberger formally confirmed its intention to work toward employment and working conditions in all Group companies that meet or exceed national law or collective bargaining agreements. The company is also committed to compliance with the recommendations of the International Labor Organization (ILO), which include the prohibition of child labor and discrimination, respect for the freedom of association and the right to collective negotiations as well as the provision of safe working conditions.

Corporate culture as success factor

The Wienerberger corporate culture influences the actions and behavior of our employees. Our common goal is to provide people with a better quality of life through our outstanding, sustainable building material and infrastructure solutions. Expertise, passion, integrity and respect, customer orientation, entrepreneurship, quality and responsibility are the seven key factors for Wienerberger's business success.

"ideas & more" to better utilize our employees' potential

We see the know-how of our employees as one of the most important sources of innovation and the further development of existing products. In order to better utilize this potential, we have anchored the subject in business and work processes. The "ideas & more" internet platform was launched to give employees an opportunity to support the development process by submitting their suggestions for improvement and their ideas for innovation.

Processes and Instruments for Sustainable Human Resources Management

Employee development and support as central responsibility of human resources

The focal point of human resources management at Wienerberger is the support and development of all employees in line with the Group's strategic goals. The responsibilities of human resources include employee recruiting, international know-how transfer and exchange, talent management and succession planning, training and education platforms, appropriate compensation and bonus systems, occupational safety, internal communication and industrial relations as well as the socially responsible reduction of jobs in connection with restructuring programs. In all these areas, human resources also serves as a contact partner and advisor for employees.

Succession planning as part of annual management review

Strategic succession planning represents a central challenge for sustainable human resources management. An annual management review focuses on the evaluation of senior managers and succession planning for senior management positions. Wienerberger maintains a management database to provide fast access to records on the training, professional experience, salary structure and service contracts of the respective employees. This database, which covered roughly 90 men and women in 2012, supports structured and transparent career planning.

SHE reporting

The Safety, Health & Education (SHE) reporting system was introduced throughout the Group in 2007. This system collects quarterly data from all local Wienerberger companies on the size of the workforce, occupational safety, days lost through illness as well as training and development. The resulting indicators provide management with the necessary tools for analysis and the development of appropriate measures in the areas of occupational safety, health and training.

Wienerberger safety standards

The improvement of workplace safety in all its plants is an important goal for Wienerberger. In this connection, the following safety standards were implemented in 2009:

1. *Introductory safety training program for all employees*
2. *Appointment of an occupational safety officer*
3. *Increased awareness for occupational safety*
4. *Personal protective equipment for each employee*
5. *Safety introduction and protective equipment for visitors*
6. *Regular safety training programs*
7. *Establishment of a working group in each plant and quarterly safety meetings*
8. *Plant safety audits*
9. *Monitoring of workplace conduct*
10. *Mandatory accident reporting*

Implementation through safety initiative

Wienerberger's safety initiative provides the framework for realizing these goals. The related investments, i.e. the purchase of protection equipment, have already been completed. Employees are now receiving special training to increase their awareness of occupational safety and change their behavior over the long-term to prevent accidents. These training programs are organized by the local companies. Progress in the area of occupational safety is monitored by SHE reporting at the Group level, which allows for the identification and implementation of additional measures as needed.

The following statistics include Steinzeug-Keramo beginning in 2011 and Pipelife for the full 12 months of 2012. A different method was used to calculate the number of employees, and explanations are provided in footnotes at the relevant sections.

Employment Trends

Number of Employees

10% workforce increase in 2012 due to initial consolidation of Pipelife

The average number of employees in the Wienerberger Group rose by 10% year-on-year to 13,060 in 2012. The Bricks & Tiles Europe and North America Divisions reported workforce reductions due to the weaker development of business and resulting restructuring measures, while the number of employees doubled in the Pipes & Pavers Europe Division. This strong increase is explained, above all, by the takeover of Pipelife during the reporting period.

Ø Employees by operating segment

Full-time equivalent	2010 [1]	2011	2012 [2]	Chg. in %
Bricks & Tiles Western Europe	6,130	6,420	6,227	-3
Bricks & Tiles Eastern Europe	2,747	2,618	2,516	-4
Bricks & Tiles Europe	8,878	9,038	8,743	-3
Pipes & Pavers Western Europe	33	470	1,604	>100
Pipes & Pavers Eastern Europe	1,029	1,052	1,440	+37
Pipes & Pavers Europe	1,062	1,522	3,044	+100
North America	1,104	1,127	1,064	-6
Holding & Others	252	206	209	+1
Wienerberger Group	**11,296**	**11,893**	**13,060**	**+10**

1) Steinzeug-Keramo is included in the Pipes & Pavers Western Europe Segment beginning in December 2010.
2) Pipelife is included as of June 2012.

Higher number of employees in all functional areas

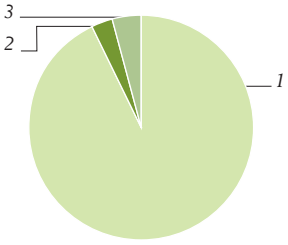
The Pipelife consolidation led to an increase in the number of employees in all functional areas during 2012. This development was evident, above all, in administration and sales because Pipelife operates through direct sales organizations in a number of countries.

Ø Employees by functional area

Full-time equivalent	2010 [1]	2011	2012 [2]	Chg. in %
Production	7,604	8,048	8,673	+8
Administration	946	980	1,142	+17
Sales [3]	2,746	2,865	3,245	+13
Total	**11,296**	**11,893**	**13,060**	**+10**

1) Steinzeug-Keramo is included in the Pipes & Pavers Western Europe Segment beginning in December 2010.
2) Pipelife is included as of June 2012.
3) Employees in sales, marketing and warehousing

Classification of employees by type of employment *in %*



1 Full-time 93%
2 Part-time 3%
3 Temporary (incl. limited contracts) 4%

Of the total workforce employed by the Wienerberger Group as of December 31, 2012, 93% were full-time and 3% part-time. Temporary employees and persons with limited employment contracts therefore represented 4% of the total.

Employee Turnover

Employee turnover



The restructuring programs implemented in recent years in the Bricks & Tiles segment as a reaction to the difficult market environment have led to repeated, substantial increases in employee turnover. The conclusion of the first measures at year-end 2010 was followed by brief stabilization in the workforce, but the necessary implementation of further restructuring measures in 2012 caused another rise in turnover. In spite of this development, the average length of service equals a relatively long 12.9 years and represents a clear vote of confidence by employees in favor of their employer.

A detailed analysis of employee turnover shows the different effects of the restructuring programs on the individual divisions. The Bricks & Tiles Europe Division reported the largest increase, with turnover rising from 6.6% in 2011 to 10.3% in 2012. This development is explained, above all, by the higher number of employees leaving companies in the Bricks & Tiles Europe Division as a result of the increased restructuring measures. The Pipes & Pavers Europe Division remained stable in year-on-year comparison. The Holding and Others Division was the only segment to report a sharp drop in turnover of 5 percentage points to 9.3% in 2012, which reflected the lack of involvement in restructuring measures. The employee turnover rate for the Wienerberger Group rose from 7.5% to 10.6% in 2012, above all due to the higher turnover in the Bricks & Tiles Europe Division.

Turnover rate by operating segment [1] *in %*	**2010**	**2011**	**2012**
Bricks & Tiles Western Europe	8.1	5.5	7.8
Bricks & Tiles Eastern Europe	20.9	9.1	16.3
Bricks & Tiles Europe	12.0	6.6	10.3
Pipes & Pavers Western Europe	-	1.4	7.5
Pipes & Pavers Eastern Europe	15.2	17.4	14.5
Pipes & Pavers Europe	15.2	11.6	11.4
Holding & Others	13.8	14.3	9.3
Total, excluding North America	**12.3**	**7.5**	**10.6**
North America [2]	16.3	26.7	26.1

1) Turnover rate: ratio of persons leaving the Wienerberger Group (termination by the employee or employer as well as mutually agreed terminations) to the average number of employees in permanent employment; excluding temporary workers as well as workers with limited contracts; persons who retire or are on official leave are not included.
2) Analysis limited by special local legal regulations

1,295 employees left the company in 2012

A total of 1,295 employees left the Wienerberger Group in 2012, whereby the restructuring program led to the reduction of 492 jobs. The remaining 803 employees included 669 men and 134 women (excl. the North America Division). A classification by age shows the following results: 180 of these employees were under 30 years of age; the largest decline (-454) was recorded in the age group of 30 to 50 years; and 169 employees over 50 years left the company.

Diversity and Equal Opportunity

The principles of sustainable human resources management at Wienerberger ensure that all employees have the same rights and opportunities independent of age, gender, culture, religion, origin and political views. Wienerberger does not tolerate any form of discrimination whatsoever. Since the start of data collection by HR local management on possible discrimination, no such incidents were reported.

No reports of discrimination since start of data collection

Gender

Wienerberger traditionally has a high share of male employees because of its concentration on production (heavy industry). Special efforts are therefore in progress to increase the share of women, above all in non-production areas, e.g. administration, sales and management. One of the implemented measures involves preferential treatment for women in new appointments when candidates' qualifications are identical. The share of women in **senior management** for the Wienerberger Group currently equals 8%, and **the goal is to increase this indicator to 20% by 2020.** The share of women rose slightly in all functions during 2012 to 13.7% at year-end (2011: 12.6%). **We want to increase the share of women to more than 45% in administrative functions and to 30% in sales functions by 2020.**

Share of women rose slightly in 2012





Share of women by function [1] *in %*	**31.12.2010**	**31.12.2011**	**31.12.2012**
Production	4.5	4.1	4.3
Administration	47.4	43.7	44.3
Sales [2]	24.2	24.2	24.3
Total	**13.3**	**12.6**	**13.7**

1) Temporary employees and persons with limited employment contracts are not included.
2) Employees in sales, marketing and warehousing

Age

The long average length of service with the company is also reflected in the age structure of our workforce. In 2012 58% of the employees were between 30 and 50 years old, 11% were younger than 30 years and 31% over 50 years. These indicators have not changed significantly in recent years. We are particularly interested in the training and education of young people. In Bricks & Tiles Germany we increased the number of apprenticeships by nearly 20% in 2012 and are planning a further increase in 2013.

58% of employees are between 30 and 50 years old

Cultural Diversity

Corporate cultural identity strengthened by regional appointments

As a multinational corporation, Wienerberger believes in respect for local cultures and the support of diversity. We see regionally recruited teams as an important success factor, not least because of the local nature of our products and markets. Our human resources planning is therefore directed to the employment of local workers, plant supervisors and managers to ensure that the Group viewpoint also includes a focus on the local markets and regions. Job rotations strengthen the internationality of Group management and allow for better insight and new perspectives in many areas. This cultural diversity and these decentralized structures have a positive influence on Wienerberger's corporate cultural identity.

Occupational Safety and Health

Safety initiative focused on increased awareness and change in behavior

Wienerberger acknowledges its responsibility to provide safe working conditions and to protect the health of employees. A safety initiative was launched in 2010 to ensure the implementation of uniform safety standards throughout the Group in order to significantly reduce the number of accidents. In a number of companies, the program was initially connected with investments in protective equipment. The completion of this first important step has been followed by measures to create a greater awareness for safety among all employees and, through a change in working habits over the long-term, prevent accidents. As part of this process, the safety targets defined by the Group were broken down to the plant level in the individual regions. Specific safety targets are defined for each plant and must be reached within a defined time period. These goals are set in agreement with the respective plant managers and represent an element of variable remuneration. In addition to the legal regulations applicable in some countries, the Wienerberger safety standards call for the installation of an occupational safety committee, the assignment of responsibilities and the introduction of comprehensive training. A toolbox of successfully implemented, best practice examples is available to help the plant managers select the optimal measures to reach their goals.



Occupational safety has top priority for Wienerberger. As part of our safety initiative, we continuously train our employees to create a greater awareness for this important issue.

CHRISTOF DOMENIG *(Deputy CEO Bricks & Tiles Europe Division)*

SHE reporting records all accidents that lead to the loss of at least one working day. The most common cause of accidents is carelessness. Since the issue of safety was handled differently throughout the Group prior to the start of the safety initiative, activities were initially directed to the countries and regions with the greatest potential for improvement. The commitment of local management supported the fast implementation of recommended measures and led, in part, to a significant reduction in accidents, especially in Italy, Bulgaria and Romania. Both the frequency and severity of accidents have declined significantly in all divisions since 2010. We have made substantial progress in the area of occupational safety over recent years, but have still not reached our goal to completely avoid accidents. **In a first step, we want to reduce the frequency of accidents to less than 10 per million hours worked by 2015.**

Decline in accident frequency from 20 in 2010 to 12 incidents per million hours worked in 2012



Accident frequency by operating segment [1]	2010	2011	2012
Bricks & Tiles Western Europe	27	22	17
Bricks & Tiles Eastern Europe	15	11	8
Bricks & Tiles Europe	23	19	14
Pipes & Pavers Western Europe	-	29	17
Pipes & Pavers Eastern Europe	20	13	7
Pipes & Pavers Europe	20	17	10
North America	4	4	3
Holding & Others	8	10	4
Wienerberger Group	**20**	**17**	**12**

1) Accident frequency: number of work accidents / number of hours worked x 1,000,000; including temporary employees and persons with limited employment contracts

The Bricks & Tiles operations in Italy reduced the accident frequency from 52 in 2011 to 9 for the reporting year. This outstanding development resulted from the implementation of a strict safety management system. After an in-depth risk assessment, the initial problems were solved with safety investments, the posting of safety instructions in all production areas and intensive training courses on occupational safety. All Italian plants received the internationally recognized OHSAS 18001 certification in May 2012. Plans call for the immediate analysis of all future accidents in a personal discussion to prevent further incidents.

Bricks & Tiles Italy cuts accident frequency from 52 to 9

The severity of accidents, which is measured as the number of days lost per million hours worked, fell sharply from 470 in 2011 to 308 in 2012 for the entire Wienerberger Group. Only the North America Division recorded a slight year-on-year increase due to two severe accidents that resulted from carelessness. Despite these positive developments at the Group level, two tragic fatal accidents unfortunately occurred during the reporting year. Industrial accidents at a brick plant in Belgium and a concrete paver plant in Romania resulted in the death of two employees. We immediately investigated the reasons and made the information available to all plants to prevent similar accidents in the future.

Decline in accident-related days lost from 470 to 308 per million hours worked

Accident severity by operating segment [1]	2010	2011	2012
Bricks & Tiles Western Europe	555	472	396
Bricks & Tiles Eastern Europe	588	584	385
Bricks & Tiles Europe	566	507	393
Pipes & Pavers Western Europe	-	427	402
Pipes & Pavers Eastern Europe	481	699	148
Pipes & Pavers Europe	481	632	240
North America	95	76	100
Holding & Others	330	103	4
Wienerberger Group	**496**	**470**	**308**

1) Severity of accidents: accident-related days lost / number of hours worked x 1,000,000; including temporary employees and persons with limited employment contracts

STOP™, an accident prevention instrument for Pipelife plants

Pipelife has followed a zero accident strategy for many years. One of the most important measures to reach this goal is STOP™ (Safety Training Observation Program), a program that supports accident prevention. Employees use STOP cards to identify hazards and report occupational safety issues to the responsible managers. The entire workforce is therefore actively involved in eliminating potential dangers. These measures are intended to sustainably improve working conditions and reduce the frequency of accidents, while also creating a better awareness among employees for safe behavior.

Future project "Safety at Semmelrock"

Semmelrock announced plans to launch a new safety program "Safety at Semmelrock" in mid-2013. Work on the first goals started before the official kick-off and includes, above all, the implementation of the AIRS reporting system ("Accident Investigation Report Semmelrock") to centrally document, analyze and administer all accidents and incidents in the future.

Annual safety coaching and training at Steinzeug-Keramo

Steinzeug-Keramo has reduced accidents with annual safety training programs that are specifically designed for each workplace as well as an additional offering of courses on occupational safety and accident prevention.

Health protection measures

The Wienerberger Group offers regular physical examinations and vaccination campaigns to prevent illness. Employees can call on company medical staff and arrange for ergonomic workplace analyses. Support for fitness is also important. For example, events and outings for employees in Austria are frequently connected with sporting activities. Other measures include reduced fees for health club memberships and special exercise courses to prevent vertebral problems.

Average of 10.6 sick-leave days per employee

The average number of sick-leave days equaled 10.6 days per employee in 2012. This indicator remained within the range of 9.9 and 11.4 days that is based on the data collected since 2007.

Sick-leave days per employee by operating segment [1]	2010	2011	2012
Bricks & Tiles Western Europe	10.3	10.9	11.2
Bricks & Tiles Eastern Europe	10.1	9.0	9.2
Bricks & Tiles Europe	10.3	10.3	10.6
Pipes & Pavers Western Europe	-	9.4	10.0
Pipes & Pavers Eastern Europe	8.0	10.5	11.9
Pipes & Pavers Europe	8.0	10.1	11.0
Holding & Others	3.8	3.8	3.6
Total, excluding North America	**9.9**	**10.1**	**10.6**
North America [2]	2.2	2.6	3.0

1) Including temporary employees as well as persons with limited employment contracts
2) Analysis limited by special local legal regulations (on sick-leave days)

Protection against Respirable Crystalline Silica

Protection against respirable crystalline silica

In the Wienerberger Group, only the employees in the ceramic plants are exposed to respirable crystalline silica. The protection of these employees has top priority, whereby our goals are to minimize the respirable crystalline silica emissions from brick production and create an increased awareness of the need for careful handling. The central office at the EU level is the European social dialogue between employees and employers under the direction of the European Commission, in which Wienerberger has been active for many years.

NEPSI (Negotiation Platform on Silica) used for EU surveys

The EU has collected comprehensive data on respirable crystalline silica from the involved branches in all member states since 2008. This survey is conducted every two years through NEPSI (Negotiation Platform on Silica), a shared online platform. There was no survey conducted in 2012, but the results of the latest survey can be found in our 2011 sustainability update, which is available for download on our homepage. The NEPSI system collects data, among others, on potential dangers to employees, health controls, training, the implementation of organizational measures, the distribution and use of protective equipment (e.g. the mandatory use of protective equipment) and technical measures such as the enclosure of involved production lines. Wienerberger collects relevant data on all involved Group plants that are located in the EU.

Annual internal survey planned in future

The issue of **respirable crystalline silica** emissions not only concerns our plants in the EU but all our production facilities, and we have consequently started to implement the NEPSI standard at other plant locations. Data has been collected to date from 84% of the Wienerberger plants, and **the goal is to reach a coverage rate of over 95% by 2020.** Future plans include the collection of data for the NEPSI survey as well as annual internal surveys through a separate query system. This should further improve transparency at the Group level. As announced in the previous year, the data in next year's sustainability report will also cover Norway, the plants in the USA and Steinzeug-Keramo.



Training and Personnel Development

Training

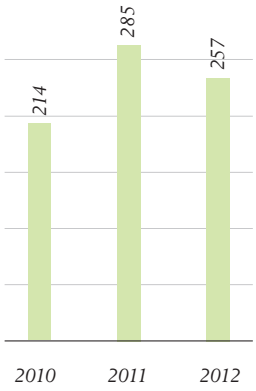
12.8 training hours per employee

At Wienerberger, we believe in advancing and supporting our employees as well as creating a climate that encourages the cross-border exchange of knowledge. An average of 12.8 hours per employee was spent on training in 2012. This indicator includes both internal and external programs, but excludes on-the-job training. The number of training hours per employee declined in the Bricks & Tiles Europe Division due to the end of the Sales Academy program. In the Holding & Others Division, cost reduction measures led to a decline in the number of training hours. In particular, the use of external training courses was substantially reduced during the reporting year. This cutback is also reflected in the total number of training hours for the Group.

Average training costs of € 257 per employee

The average training costs per employee equaled € 257 in 2012, compared with € 285 in 2011. The decline in this indicator resulted from an increase in the internal training offering as well as a reduction in the total training hours per employee.

Average training costs per employee *in €*



Training hours per employee and operating segment [1]	2010	2011	2012
Bricks & Tiles Western Europe	12.0	18.4	17.6
Bricks & Tiles Eastern Europe	19.2	16.8	14.4
Bricks & Tiles Europe	13.6	17.6	16.8
Pipes & Pavers Western Europe	-	4.8	8.0
Pipes & Pavers Eastern Europe	4.0	7.2	4.8
Pipes & Pavers Europe	4.0	6.4	6.4
North America	2.4	11.2	11.2
Holding & Others	23.2	36.8	14.4
Wienerberger Group	**12.0**	**16.0**	**12.8**

1) Including internal and external training programs; based on headcount

Sales Academy to professionalize marketing and sales activities

In the Bricks & Tiles Division, Wienerberger has developed from an expansion-driven to a market-oriented company in recent years. One of our key corporate goals is to intensify our marketing and sales activities, and thereby strengthen our customer ties. In order to provide the best possible support for making this goal reality, the Sales Academy training offensive was launched in 2010. The program is designed to strengthen and improve selling activities in the local organizations through the creation of a know-how network and the international exchange of ideas.

Engineering Academy: training and international exchange of know-how by engineering personnel

The Bricks & Tiles Division also offers other internal and external training programs that give employees an opportunity to continue their professional and personal development. Of special note is the Wienerberger Engineering Academy, which was established as a permanent facility to provide internal training in various technical areas and thereby create a sustainable competitive advantage in production. The academy offers different programs: basic modules, the Engineering Academy Advanced and the Plant Manager Course. In the basic modules, our experts transfer their international know-how on raw materials, processing, drying and firing technology as well as quality analysis to engineering employees. The Engineering Academy Advanced was developed in 2010 as a platform for the exchange of information between experienced and younger engineers on strategic issues such as plant and process optimization as well as energy and cost efficiency. In the Plant Manager Course, key employees from the production area are provided with general training. The main focal points include process optimization, basic financial management and personal development. The design of the modules for the plant manager course is also based on international know-how exchange and networking.

We believe in the development and advancement of our employees. Through specially designed programs and individual measures, we support targeted development steps.

MAREN FELLNER *(Corporate HR Manager)*



Ready4Excellence: training and international know-how transfer

A number of cross-divisional training measures were also implemented in recent years. Together with parts of the Pipes & Pavers Division, a four-module Ready4Excellence program for international key people was launched in May 2012 with 22 colleagues from 12 Wienerberger countries. This program is designed to communicate content and instruments based on Wienerberger's requirements. Its objective is to support international professionalization – above all with respect to instruments and processes – and ensure targeted support for the implementation of the Wienerberger strategy. Other topics include communications and familiarization with our feedback philosophy to support personal growth and the continuous development of the corporate culture. The knowledge transfer from these modules is not only interesting for Wienerberger employees, but also for non-company persons. For this reason, Wienerberger allocated three places in last year's program to the aid organization Concordia, which provides shelter for homeless children in Romania, Bulgaria and the Republic of Moldavia.

Pipelife Business School, Pipelife University and Pipeschool

The Pipes & Pavers Division also offers training programs that concentrate on specific problems related to plastic pipes. The Pipelife Business School is a one-year training program that covers modules on management, communications, project management, self-management and finance. Selected Pipelife employees are given an opportunity to expand their knowledge in these areas and to apply this know-how in specific projects. In addition, the Pipelife University L6S and the Pipelife Pipeschool are open to all employees. L6S is a training course for employees who are involved in the implementation of Lean Six Sigma. This well-known management system is focused on the delivery of qualitatively faultless products and services that completely and profitably meet customers' needs. The Pipelife Pipeschool is an online learning platform that offers lessons on general Pipelife subjects, Pipelife products, 5S and visual management.

Personnel Development and Succession Planning

Talent management to identify and advance future managers

The structures and processes for professional talent management in the Wienerberger Group were defined during 2012, and the first specific measures have already been implemented. The goal of this program is to identify and develop qualified men and women for positions in key management functions. In this way motivated employees with suitable potential receive an opportunity for further development, while Wienerberger is able to fill management positions internally and also maintain its high management standards. In recent years, many graduates of the previous Ambassador Program have assumed managerial roles or key positions in local companies.

Annual assessment of all employees and support for international mobility

Personnel development also includes annual appraisals of all employees as well as the annual management review. The latter serves to evaluate senior management and supports strategic succession planning for positions at this level. International mobility is promoted by means of corresponding expatriate packages and comprehensive support on relevant issues by the local HR departments and corporate HR.

Satisfied employees as key success factor

The wide range of measures implemented in the areas of training and personnel development plays an important role in establishing and maintaining employee satisfaction. Well-trained and satisfied employees are a key success factor for Wienerberger. Employee satisfaction is also reflected in the relatively high average length of service – 12.9 years – which represents a clear vote of confidence by employees in favor of their employer.

Remuneration

Income that provides a secure livelihood

The Wienerberger Social Charter states that employees are entitled to receive wages, salaries and benefits in line with the normal payment for similar jobs in similar branches or industrial sectors in the region where the work is performed and that this remuneration should be sufficient to provide for a secure livelihood. Our employees are paid at or above the legal minimum wage or the minimum income defined by applicable collective bargaining agreements.

Long-term remuneration model for top management

Management compensation at Wienerberger includes both a fixed and a variable component to increase motivation and strengthen identification with corporate goals. The variable component is based on short-term remuneration as well as medium- to long-term remuneration within the framework defined by the long-term incentive (LTI) program. The short-term variable component for 2013 will be paid out over two years, whereby the second payment is dependent on the attainment of an additional goal. This modus strengthens the link between the short-term bonus and sustainable management. Additional information on the remuneration model is provided in our 2012 annual report (annualreport.wienerberger.com).

Group-wide guideline for design of local incentive systems

A group-wide guideline forms the basis for local incentive systems. Local circumstances (e.g. government minimum support programs) are taken into account and the rules are adapted to meet the respective market conditions. In addition to company pension plans, disability insurance and health insurance, the Wienerberger employees and managers are also covered by travel insurance.

Industrial Relations

Wienerberger Social Charter

The Wienerberger Social Charter was signed in 2001 by the Managing Board of Wienerberger AG and the chairman of the European Employees' Council in Strasburg to formally confirm the company's intent to comply with the relevant agreements and recommendations of the International Labor Organization (ILO). With this charter, Wienerberger demonstrates its global commitment, among others, to human rights, to sufficient remuneration, against excessive working hours, to permanent employment and to respect for the freedom of association and the right to collective negotiations.

Installation of European Employees' Council in 2011

The European Employees' Council was founded in 2011 on the basis of the European Forum, a social partnership board. It addresses European issues such as strategy, investments, reorganization and rationalization measures. The goals of the European Employees' Council are constructive social dialogue and the creation of networks for employees' representation committees. Currently, 10 countries are represented by 26 delegates. The steering committee of the European Employees' Council is headed by Karl Sauer and includes five elected delegates from Austria, the Netherlands, Germany and Poland. The European Employees' Council meets twice and its managing board at least twice per year. Appropriate adjustments to the European Employees' Council are planned to reflect the acquisition of Pipelife.

Improvement of workplaces and health protection

The most important objectives of the European Employees' Council are to improve workplace conditions and health protection. Another concern is to reduce the physical burden for older employees as a result of the increasing retirement age by providing jobs that require less physical labor. This has already been realized at some Wienerberger locations. The European Employees' Council also works to achieve fair and just remuneration.

National employees' councils based on Austrian example

In Austria, for example, employees' councils have been installed at all locations. There are 54 employee representatives. These representatives elect a central council, which consists of four persons and is headed by Karl Sauer. Elections for the employee representatives and the central council are held every four years. The employee representatives hold one conference each year, while the central council meets at least four times or more often as needed. Similar structures can be found in other European countries.

Company agreements, collective agreements or at least legal requirements

Different regulations apply to employees in Europe, including collective bargaining agreements, laws and directives, union contracts and company or individual employment agreements. All employee representatives of Wienerberger AG are located in countries that recognize the right of employees to free assembly and collective negotiations.

Future Measures

Implementation of Group-wide HR standards

Group-wide HR standards will be introduced in order to ensure uniform practices. In addition, talent management and the training programs for sales management will be expanded.

Respirable crystalline silica: internal survey system in addition to NEPSI and integration of further plants

Plans for 2013 include the annual collection of relevant data on respirable crystalline silica with a separate query system to further increase transparency at the Group level. Additionally, as announced in the previous year, the survey on respirable crystalline silica will be expanded for the 2013 sustainability report to cover the plants in Norway and the USA as well as Steinzeug-Keramo.

Further measures to improve workplace safety

Additional measures will also be implemented to improve workplace health and safety. Among others, Semmelrock is expected to launch its new program "Safety at Semmelrock" in mid-2013. Data collection in the plants will then be used to design future measures and start specially designed safety programs.

Specific long-term goals for the future

Wienerberger has set a number of long-term goals in the area of human resources: to increase the share of women by 2020 to 20% in the Group's senior management, to more than 45% in administrative functions and to 30% in sales functions, to reduce the accident frequency to less than 10 per million hours worked by 2015 and to expand data collection on respirable crystalline silica to cover more than 95% of the relevant Group plants by 2020.

Environmental Protection in Production

Principles of Sustainable Production

Production in harmony with the environment

Environmental protection in production is a matter of great importance to Wienerberger. We are well aware that industrial production processes always involve a certain degree of interference with the natural environment. Our goal is to minimize the environmental impact of our production processes. The responsible interaction with clay extraction sites, the best possible conservation of resources and an increase in the share of recycling materials are the central principles of our sustainable production.

Responsible clay extraction and professional restoration of mining sites

The use of recyclable raw materials and ***the responsible interaction with clay extraction sites*:** The methods used by Wienerberger to extract and process clay, the recyclable raw material that is used for our ceramic products, are designed to minimize the impact on the environment and to conserve resources. Responsible interaction with clay mining sites means preventing negative effects on neighboring residents during extraction (in the form of noise or dust) as well as protecting the environment (e.g. by maintaining local biodiversity). The clay reserves in our extraction sites are used to the greatest extent possible. Responsible interaction with clay extraction sites at the end of their useful life means professional restoration – often in cooperation with environmental NGOs like the WWF – or transfer to another use. Specifically designed restoration concepts allow for the ecologically friendly utilization of exhausted clay pits and often help to increase biodiversity.

Resource conservation in the production of ceramic products ...

Greatest possible conservation of resources: The conservation of resources starts at the beginning of the production chain. Our ceramic plants generally process local raw materials like clay, loam and sand. Since the clay pits are usually located close to our production facilities, transport routes tend to be short. The use of these resources is optimized continuously, while product quality is maintained or improved at the same time. These results are achieved, for example, with the use of recycled ceramic materials. Another important resource for the ceramic production process is energy, which generates the high temperatures required for drying and firing. We work to make these processes as environmentally compatible as possible by optimizing our production technology and using renewable energy sources.

... as well as plastic pipes

Resource conservation is also a focal point in the production of our plastic pipes. We work to reduce product weight and increase the share of recycling materials in the mix, while maintaining the same high level of quality. Energy consumption plays a less important role in the production of plastic pipes than in our ceramic business. However, a comparatively large amount of water is required to cool this production machinery. Our goal is to minimize water consumption, above all the amount of water drawn from public supply networks.

Processes and Instruments for Sustainable Production

Research and development

R&D in production is a focus of strategic planning

Research and development (R&D) form an integral part of strategic planning at Wienerberger and represent key activities for the Group. In these areas we work to optimize production processes and to continuously improve and develop our products and system solutions. R&D at Wienerberger is managed centrally in the individual business units, but implemented locally based on close cooperation between the various R&D departments and on-site management and engineers. This ensures the fast and efficient rollout of successful developments throughout the Group. In 2012 R&D expenditures in the Wienerberger Group amounted to € 9.0 million.

Process optimization to improve sustainability of ceramic products

The improvement of production processes represents the main focus of research for our ceramic products. A central engineering department is working, above all, on projects to reduce energy consumption. Drying and firing comprise a significant amount of the energy requirements for our production, and many assignments therefore concentrate on optimization in this area. Other research projects involve resource conservation in production, the responsible processing of raw materials and the use of recycled materials.

Use of recycling materials and reduction in weight of plastic pipes

R&D activities for plastic pipes are located at our research center in the Netherlands, which works together with universities and external experts from various disciplines. Research is concentrated on the refinement of formulas for the raw material mix and the optimization of the production process. Our production-related projects target the increased use of recycled products as raw materials and the reduction of product weight.

Research projects for our concrete pavers are focused on the composition of raw material mixtures and, above all, on the reduction of the cement content.

Environmental Management

Ecologically relevant aspects in QMS

The environmentally relevant aspects of our workplaces, e.g. the management of waste and residual materials or the prevention of noise and dust emissions, were integrated in the existing quality management systems (QMS). The QMSs in nearly all plants are certified according to ISO 9001. The criteria defined in the QMS form the starting point for the demands on production and the related processes. Environmental officers ensure the implementation of the relevant standards. A number of plants have been certified according to ISO 14001, but there are no plans for additional Group-wide certification under ISO 14001 or EMAS. Wienerberger believes the current QMS provides appropriate control and management for processes and their environmental impact.

Technical Controlling System

Production data collected by technical controlling system

A technical controlling system has been implemented in all production areas of the Wienerberger Group. This system collects the production-related data required for controlling activities and internal benchmarking among the plants. Statistics are compiled on production volumes, product quality, machine efficiency, energy consumption and, if relevant, CO_2 emissions. The resulting analyses indicate the effectiveness of measures implemented to reduce the environmental impact of our production processes.

Key Data on Sustainable Production

Energy Consumption

The key data presented in this sustainability report were adjusted to reflect the new corporate structure. The following statistics therefore cover the entire Wienerberger Group, including our pipe activities. This data includes our ceramic pipe activities starting in 2011 and our plastic pipe activities beginning in June 2012.

Energy consumption *in MWh*	**2010**	**2011**	**2012**	**Chg. in %**
Natural gas	6,062,614	6,457,081	5,541,640	-14
Coal	234,629	248,541	186,663	-25
Heating oil	112,178	104,529	90,783	-13
Liquid gas	70,591	75,715	62,338	-18
Electricity	800,985	841,240	863,372	+3
Wienerberger Group	**7,280,997**	**7,727,106**	**6,744,796**	**-13**

Energy consumption declined by 13%

Energy consumption in the Wienerberger Group declined by 13% year-on-year in 2012, despite the initial consolidation of the Pipelife Group. This development resulted, above all, from a decline in natural gas consumption. Natural gas is used primarily in ceramic production to generate the high temperatures required for the firing process. The decline in the use of natural gas during 2012 can be explained by a 9% volume decrease in the Bricks & Tiles Europe Division and an improvement in specific energy consumption in the clay block, clay roof tile and ceramic pipe product groups. We are currently working on projects to identify other energy sources as substitutes for coal and heating oil in order to reduce CO_2 emissions and costs. The slight rise in electricity consumption resulted from the initial consolidation of Pipelife, where the production process is driven almost entirely by electrical energy. Renewable energy sources as a share of total electricity consumption declined from 43% in the prior year to 31% in 2012 due to the inclusion of the pipe business.

Index of specific energy consumption	**2010**	**2011**	**2012**	**Chg. 2011 in %**	**Chg. 2010 in %**
Wall	100	95	89	-6	-11
Roof	100	93	84	-9	-16
Facade	100	96	98	+2	-2
Ceramic pipes	100	90	82	-9	-18
Ceramic Segments	**100**	**95**	**91**	**-4**	**-9**
Plastic pipes	100	100	98	-2	-2
Concrete pavers	100	108	96	-12	-4
Wienerberger Group	**100**	**97**	**92**	**-5**	**-8**

The specific energy consumption in the above table represents a historical comparison of the individual product groups and therefore differs from the consolidation range of the Wienerberger Group. This sustainability report uses 2010 as the basis for the specific energy consumption index (based on kWh/ton), which forms the starting point for the following goal.



By 2020 we want to reduce the specific energy consumption in ceramic production by 20% below the 2010 level. This is a very ambitious target, since we have already reduced energy consumption significantly during the past 10 to 15 years. We have made sound progress in clay block, roof tile and ceramic pipe production in recent years, but our efforts in the facade brick area are just beginning.

CO_2 Emissions

Data collection on CO_2 emissions is based on the method defined by the European Union Emissions Trading Scheme (ETS system), which only records direct CO_2 emissions. Accordingly, only the CO_2 emissions from our ceramic production (bricks and ceramic pipes) are relevant. The CO_2 emissions from primary energy sources change in line with energy consumption, while the emissions from the production process result from raw materials and in the case of clay blocks from the use of pore-forming agents. Electrical energy is used in the production of plastic pipes and concrete pavers, and the related CO_2 emissions are attributable to the electric power producer.

CO_2 emissions *in tons*	**2010**	**2011**	**2012**	**Chg. in %**
From primary energy sources	939,826	960,269	829,176	-14
From the production process	561,545	688,421	562,455	-18
Total – within the ETS [1)]	**1,501,371**	**1,648,690**	**1,391,631**	**-16**
Plants outside the ETS [2)]	**400,356**	**461,343**	**442,442**	**-4**
From biogenic added materials [3)]	305,870	310,492	280,098	-10

1) Source: Community Independent Transaction Log (CITL)
2) Calculated in accordance with national rules (Switzerland) or based on EU standard emission factors. Only the CO_2 emissions from the firing of primary energy sources are included for the plants in the USA.
3) Volumes from Wienerberger CO_2 monitoring in accordance with national rules

The following data on specific CO_2 emissions (based on kg CO_2/ton) represents a historical comparison of the individual product groups. The slight increase in CO_2 emissions for clay blocks is related to raw material process emissions, which are nearly impossible to reduce, and to a shift in the product mix to high thermal insulating blocks, which require more pore-forming agents.



However, our goal is to reduce the specific CO_2 emissions from ceramic production 20% below the 2010 level by 2020. This is also a very ambitious target because we have already reduced CO_2 emissions significantly during the past 10 to 15 years.

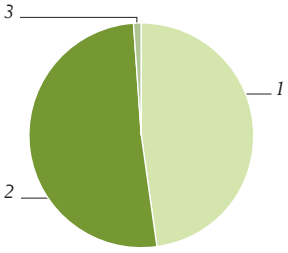
Index of specific CO_2 emissions	2010	2011	2012	Chg. 2011 in %	Chg. 2010 in %
Wall	100	101	101	0	+1
Roof	100	95	85	-10	-15
Facade	100	100	102	+1	+2
Ceramic pipes	100	91	87	-4	-13
Wienerberger Group	**100**	**100**	**99**	**-1**	**-1**

Waste

Statistics for 2012 show 133,600 tons of waste for Wienerberger. The year-on-year increase (the prior year data were adjusted to reflect the inclusion of Steinzeug-Keramo) is attributable to the initial consolidation of Pipelife. Most of this (nearly 100 %) is non-hazardous waste that is collected and recycled or disposed. The only hazardous waste includes relatively small amounts of workshop waste (oily rags) and oil separator contents (from refueling stations).

Waste *in tons*	2010	2011	2012
Wienerberger Group	116,894	132,433	133,600

Total waste 2012
in %



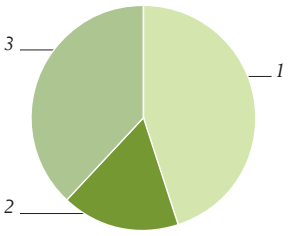
1 Non-hazardous, recyclable 48%
2 Non-hazardous, deposited 51%
3 Hazardous 1%

Water Consumption

Statistics on the specific water consumption in m³/ton for each product group are presented for the first time in this sustainability report. Water consumption plays a limited role in the production of ceramic products, but comparatively large amounts of water are required to cool plastic pipes after extrusion. The specific water consumption was reduced substantially in 2012, above all for plastic pipes and concrete pavers.

Specific water consumption *in m³/ton*	2010	2011	2012	Chg. in %
Brick products	0.163	0.183	0.180	-2
Ceramic pipes	0.225	0.241	0.242	0
Plastic pipes	4.830	4.673	4.476	-4
Concrete pavers	0.056	0.057	0.047	-17

Water usage by source
in %



1 Water from public networks 45%
2 Water from plant wells 17%
3 Water from ponds (rainwater) 38%

The total water consumption in the Wienerberger Group rose by 21% to 3.2 million m³ in 2012 due to the initial consolidation of Pipelife. We attempt to use water that comes primarily from our own wells or ponds (rainwater). In 2012 the volume of water drawn from public supply networks decreased to 45% due to the initial consolidation of plastic pipe activities. **In order to make our efforts measurable, our goal is to reduce the share of water drawn from public supply networks to 40% by 2020.**



Water consumption		2010	2011	2012	Chg. in %
Wienerberger Group	*in mill. m³*	2.2	2.7	3.2	+21
From public supply networks	*in %*	54	48	45	-

Ceramic Production

Responsible clay extraction and professional restoration of mining sites

Resource conservation starts at the beginning of the ceramic production chain. The most important raw material for our ceramic products (clay blocks, facing bricks, roof tiles and ceramic pipes) is the recyclable raw material clay. Wienerberger places high value on protecting endangered animal and plant species as well as rare, sensible ecosystems. The greatest possible conservation of resources in clay extraction is just as important as the expert restoration of former clay mining sites. There are generally several possible alternatives for the restoration of clay pits, e.g. conversion for agricultural use, residential or commercial construction, nature conservation or use as recreational areas. Wienerberger works to return former clay mining sites to nature wherever possible, since these restored areas often become substitute habitats for protected animal and plant species that would otherwise be lost.

Short transport routes from clay pits to plants

Since the clay pits are usually located close to our production facilities, transport routes tend to be short. After extraction, the clay is prepared through a grinding and milling process. Water, sand and, for some products, pore-forming agents (e.g. sawdust, paper fiber) are then added. Wienerberger has issued a group-wide guideline for the use of additives. It ensures that our plants only use additives that meet local environmental requirements and applicable health and legal regulations.

Drying and firing process

After brief storage in a mud house, the clay is ready for shaping. It is pressed through dies into the desired shape by extruders or compressed into forms. The cut products are then transported on palettes to the dryer. The drying process removes the moisture from the soft products and prepares them for firing. Depending on the type of the product, the drying period lasts between four and 45 hours. The moisture content drops to below 2% during this time. After drying the products are transferred to a kiln, where they are fired at a temperature of 800 to 1,200°C over a period of six to 36 hours. The drying and firing time can be longer for technically demanding products. Firing gives the products a permanent strength and makes them permanently nonflammable and fire-safe. In packaging our products, we use particularly thin foils. Transport routes to our customers are short because of our regional, decentralized plant network, which also reduces the impact of our business on the environment.

Energy Consumption and CO_2 Emissions

Thermal energy is used for drying and firing

Most of the energy used in ceramic production is thermal energy (natural and liquid gas, oil or coal). This energy is used mainly to heat the tunnel kilns, whereby the heat released during the cooling process is recovered and returned to the drying process. Electrical energy plays only a limited role in ceramic production (e.g. to mix and prepare the raw materials, for extrusion and grinding and in transportation).

Pilot projects for substitution of fossil energy sources

Energy consumption was lower in 2012, in part because of the decline in production volumes. However, we also implemented a number of measures to optimize the dryer-kiln-heat system and thereby reduced the specific energy consumption for clay block, roof tile and ceramic pipe production. We are also working to substitute alternative fuels for fossil energy sources. A biogas plant was built near one of our ceramic pipe plants, which is fueled with biomass from the surrounding area. This biogas is used to operate a combined heat and power station, and the residual heat is used to dry the clay pipes. At our plant in India, we converted part of our energy sources to biomass during the reporting year, and in Italy and Germany we are using electrical energy generated by our own photovoltaic equipment. In Switzerland and the USA we are gradually replacing heating oil and coal with natural gas, which produces significantly lower CO_2 emissions and is also less expensive.

Environmental Action Plan defines measures to reduce energy consumption

We have defined our goals for energy-efficient, environmentally compatible and resource-conserving production in an Environmental Action Plan (EAP). In particular, it includes our goal to achieve a 20% reduction in specific energy consumption and specific CO_2 emissions in ceramic production by 2020. The core of the EAP is formed by a package of measures to optimize the drying and firing process, optimize the dryer-kiln-heat system, recover heat through the installation of heat exchangers, improve and target thermal insulation, reduce the water content of clay, cut production weight, optimize the raw material mixture, increase the use of biogenic fuels and use stretch foils in packaging. A program to implement these measures was launched at nine plants in Belgium, Germany, the Netherlands and Poland during 2010. The EAP has since been rolled out to 51 plants and will be introduced at other Wienerberger locations in the future. We also invest continuously in technological optimization measures to make our production process as environmentally compatible as possible, above all through the use of renewable energy.

> Our measures to reduce the use of energy in ceramic production, above all through the optimization of the dryer-kiln-heat system, have already produced the first positive results and we now intend to implement this program at other plants in the future.
>
> **JOSEF BIRNGRUBER** *(Head of Process Technology in the Bricks & Tiles Europe Division)*



Goal: 20% reduction in indicators by 2020

Over the coming years these measures should help us to reach our ambitious goals – to achieve a 20% reduction in specific energy consumption and specific CO_2 emissions in ceramic production below the 2010 level by 2020.

Waste and Recycling

Nearly all ceramic production waste is non-hazardous

Nearly all the waste resulting from ceramic production is non-hazardous. It is separated, collected and recycled or disposed. Hazardous waste appears in only very small quantities, e.g. as workshop waste (oily rags).

Recycling materials are added to raw materials mixture

Internal production scrap such as broken or imperfect products can be reprocessed and recycled and is therefore not classified as waste. External recycling materials are used as additives for certain product groups and are generally processed together with the raw material mixture during preparation. Typical recycling materials from biogenic sources include sawdust, hay, sunflower seed shells and paper fiber, which are used to create the pores in clay blocks. In the production of ceramic pipes, we also use rock grain from gravel production and ceramic scrap from the production of clinkers, roof tiles, tiles and other ceramic products that cannot be recycled in these areas.



We now use up to 40% ceramic recycling products in our raw material mixture for specific ceramic pipes. That makes an important contribution to resource efficiency.

GERNOT SCHÖBITZ *(CEO Steinzeug-Keramo)*

Clean separation of materials and awareness in construction industry are required for recycling

External recycling materials can only be used if they are separated correctly when buildings are demolished. Wienerberger works to increase the awareness of construction personnel for recycling and plays an active role in designing a legal and normative framework that will make the use of recycled building materials easier and more economically feasible in the future. Our work is also focused on the recycling of construction rubble as an input for brick production, but also to develop new opportunities for its use (e.g. in landscaping).

Water Consumption

Recycling of water

The use of fresh water and wastewater plays a limited role in the production of ceramic products – clay blocks, roof tiles, facing bricks and ceramic pipes. Many of the Wienerberger plants recycle their process wastewater. This water drains into a collecting tank, is subsequently processed and then reused for clay preparation. Evaporation loss is replaced from public water lines or plant wells. In 2012 the specific water consumption declined slightly in brick production and remained constant for ceramic pipes.

Plastic Pipe Production

PVC, PP and PE as raw material granulates

In the plastic pipe business, our most important raw materials include PVC, PP and PE granulates. We only use materials that do not represent a risk for the environment during the production, use or disposal of the pipes. No plasticizers are used. As a member of local initiatives like Responsible Care in Austria, we regularly evaluate the health, environmental and safety impact of our raw materials and products.

Materials are heated, then shaped with an extruder

The plastic raw materials are first mixed together to create the properties for a specific product group and then heated. The melting process requires a temperature of approx. 200°C, depending on the raw material mixture. The heating takes place directly in an extruder, which presses the hot moldable plastic mass through a die to shape the pipes. In the so-called casing head, a calibrator ensures the desired diameter, which can range from several millimeters up to 2.5 meters. The accessories for our pipes are shaped in forms after the raw materials are heated.

Cooling in water bath and final cutting of pipes

After shaping, the pipes are cooled and hardened in a water bath. The continuous pipe string is then cut to the desired length, whereby a length of up to 600 meters can be produced for certain applications. The pipes are then packed and delivered to the customer. A decentralized network of 27 plastic pipe plants in 27 countries positions us close to our customers and normally provides for short transport routes.

Energy Consumption and CO_2 Emissions

No direct CO_2 emissions from plastic pipe production

Electricity is the main energy source for the production of plastic pipes. It is used to operate the machinery and equipment and heat the granulates. There are no direct CO_2 emissions from plastic pipe production, which is the reason our plastic pipe activities are not registered in the European Emissions Trading System. In 2012 we reduced the specific energy consumption in plastic pipes by 2% with the regular monitoring of energy consumption and optimization measures. At our plant in Turkey, transparent spaces were installed in the roof of the production hall. The resulting inflow of daylight generally eliminates the need for artificial light during the daytime.

Waste and Recycling

Waste plays only a limited role

Waste plays only a limited role in the production of plastic pipes. More than 50% of this waste is recyclable, and is collected and reused.

Goal: Increase in the share of recycling materials

A major goal in the plastic pipe area is to increase the share of recycling products in the raw materials mix. Our research center in the Netherlands is working on projects to increase the use of secondary raw materials, while maintaining the same high product quality. The share of recycling materials per produced ton rose by 11% to approx. 60 kg in 2012.

Pipelife is collection point for recycling materials in Austria

Recycling materials from external sources must first be collected and prepared. Through its membership in national associations, Pipelife plays an active role in creating a greater awareness for the importance of recycling. The Pipelife plants in Austria, for example, serve as collecting points for used pipes and fittings. The Austrian plastic pipe industry set a new record by collecting approx. 1,500 tons of used pipes. That represents CO_2 savings of roughly 9.2 million automobile kilometers.

Water Consumption

Cooling in closed water cycles

Water plays an important role in the production of plastic pipes because it is used to cool the hot extruded products. Our plants generally use closed water cycles and heat exchangers, which prevent the cooling water from becoming contaminated. At a plant in Ireland, our location allows us to use river water in a closed cycle to cool the pipes. This water is returned to the river after the cooling process without any problem.

Water is sourced mainly from company wells and ponds

Pipelife uses water from its own wells or ponds (rainwater) whenever possible. Roughly 80% of the water used in production comes from these sources. In 2012 continuous optimization measures in the water cycle supported a 4% reduction in specific water consumption.



We monitor our water consumption continuously and took a number of steps in 2012 to further reduce the use of external water supplies.

ZORAN DAVIDOVSKI *(Vice President Marketing, Innovation & Sustainability at Pipelife)*

Concrete Paver Production

Cement, sand, rock grain and water are most important raw materials

Concrete is a moldable building product that is made of several basic natural raw materials: cement, sand, rock grain and water. Semmelrock purchases these raw materials from local producers based on pre-defined quality standards.

Pavers are dried at room temperature

The first step in the production of concrete pavers is the mixing of the raw materials. Our research and development activities for the production area are focused on reducing the cement content. After mixing, the concrete is shaped by pressing or pouring. The products are then dried at room temperature over a period of roughly 24 hours. Certain products receive special surface treatment before or after the drying process, such as washing, grinding, sanding or sealing. The finished products are then packaged and delivered to our customers.

Energy Consumption and CO_2 Emissions

No direct CO_2 emissions

The production process for our concrete pavers requires comparatively low amounts of energy to drive the machinery. Electricity, which does not cause any direct CO_2 emissions, is the only energy source used.

Waste and Recycling

Most waste is non-hazardous

Scrap from the production of concrete pavers is returned to production. Broken or imperfect items can normally not be recycled. However, nearly all the waste from concrete paver production is non-hazardous and can be recycled or disposed.

Water Consumption

Water used as raw material and for surface treatment

In the production of concrete pavers, water is used as a raw material and in special surface treatments (e.g. the washing of slabs). Semmelrock recycles part of the washing water into production to minimize wastewater. Most of the plants have implemented a water management system, and our plans call for the step-by-step implementation of water management systems in all plants.

Future Measures

Stronger integration of energy reporting

Plans for 2013 call for the even stronger integration of energy reporting in the SAP system to increase the automated collection of data.

Continued roll-out of measures to improve energy efficiency in ceramic production

In the ceramics area, we will continue to roll out the measures defined in the Environmental Action Plan to reduce energy consumption and CO_2 emissions. The facing brick product group will represent a special focal point for the coming years. We want to make our production processes even more energy-efficient and increase resource conservation in the future.

Cradle to cradle certification for ceramic pipes

All ceramic pipe products will be certified according to the cradle to cradle concept in 2013. This underscores the continuous improvement of our production processes in the interest of sustainability.

Numerous smaller measures for plastic pipes

Numerous smaller measures will be implemented in the plastic pipe area over the coming years, for example to gradually reduce energy consumption by insulating casing heads and thereby preventing heat loss. We will also continue to invest in technological improvements that lead to an increase in energy efficiency.

Sustainable Products

Principles of Sustainable Products

Creation of sustainable value with high-quality building material solutions

A central principle of product development at Wienerberger is the creation of sustainable value for our customers with long-lasting and innovative system solutions. We view sustainability as a function of the service life of a product and its impact on the environment during production, transport, installation, use and disposal. Wienerberger brick products form an integral part of sustainable building concepts. They guarantee a high quality of living and make an active contribution to climate protection. In the area of pipes and pavers we offer system solutions for today's challenges, including the demands on water management resulting from climate change or increasing urbanization.

Energy efficiency and climate protection, raw material efficiency, healthy living, safety and economy as central demands on modern brick construction

Wienerberger's innovative products and system solutions for bricks meet the wide variety of challenges presented by modern, sustainable construction. As a recyclable product made of clay and based on its long service life of up to 100 years, the brick – whether in the form of clay blocks, roof tiles or facing bricks – meets today's demands for ecological, economical and social sustainability like no other building product. In the area of energy efficiency and climate protection, our high thermal insulating clay blocks help building users to reduce energy costs and CO_2 emissions. Complete housing concepts also optimize energy efficiency over the entire product life cycle. Our high thermal insulating clay blocks filled with mineral wool or perlite already meet all EU requirements for 2020. We are continuously increasing the raw material efficiency of our products by optimizing their design to reduce the weight and the amount of materials required, while maintaining or improving the static and thermal insulating properties. Another focal point in this respect is the reduction of energy consumption in production. The high accumulation capacity of brick walls keeps rooms cool in the summer and pleasantly warm in the winter. Our bricks attain excellent values for interior air quality and a healthy room climate, and create lasting value in the form of high-quality, healthy homes. Another closely related subject is safety, an area where our products stand out by providing high protection against fire and earthquakes. In order to combine maximum quality and affordability, a special focus of our efforts is continuous improvement in the economy of our brick solutions. We work to reduce laying time and simplify construction with product innovation and systems. For example, our Dryfix® aerosol glue reduces construction time by up to 50% compared with conventional masonry methods.



Housing is a very long-term investment. For that reason, we should base construction on building materials with a long service life like our ceramic products. An analysis of housing in Belgium shows that over 20% of all brick homes are more than 100 years old.

ANITA ORY *(Sustainability Manager in Belgium)*

Outstanding mechanical properties, high resistance to chemicals and protection against corrosion make plastic pipes long-lasting and economical

At Pipelife, our specialist for plastic pipe systems, the R&D and marketing departments work closely together to meet customers' needs with fast reaction times and short development periods. Our lightweight, flexible and easy to install pipes can be used in a wide variety of solutions for fresh water and wastewater management, residential construction, industrial facilities and public supply infrastructure. Outstanding mechanical properties like high pressure resistance, particularly smooth surfaces and high resistance to many chemicals make these products especially long-lasting and economical. They are also absolutely corrosion-free. With solutions for water management (fresh water, wastewater and irrigation systems), energy supply, electrical wiring and telecommunications, Pipelife products and system solutions represent an integral part of the answers to the megatrends of the coming decades.

Sustainable concrete paver products

Concrete pavers made by Semmelrock create lasting value with their variety, high resistance, durability and wide range of applications. Concrete is a moldable building material that is made of natural raw materials – cement, sand, rock grain and water.

Ceramic pipe systems are suitable for trenchless installation and environmentally friendly

Steinzeug-Keramo ceramic pipes also meet important demands for ecological and economical sustainability. Vitrified clay pipes have a service life of more than 100 years, are virtually maintenance-free, retain their shape and are highly resistant to corrosive chemicals because of their glaze. Vitrified clay pipes do not cause any reaction between the building section and the surrounding earth or ground water, can be installed in an environmentally-friendly manner without trenches and are completely recyclable. Therefore, the use of ceramic pipe systems is extremely eco-friendly and economical.

System solutions for energy-efficient construction as competitive advantage



The many diverse demands on modern buildings from users, developers and regulatory requirements such as the Energy Performance of Buildings Directive (EPBD) have made the systems approach a key focal point of construction. Integrated system solutions can optimally combine and utilize the outstanding properties of individual products in the Wienerberger portfolio with products from partners in building technology. **Our goal is to increase the share of Group revenues generated by innovative and sustainable products from 20% in 2010 to 30% in 2015.** The share of revenues from the sale of premium products increased slightly in the Bricks & Tiles segment in 2012. On the Group level this key figure remained constant at 23.4% due to the initial consolidation of Pipelife, which shows a long-time share of revenue by innovative products of 20%.

Processes and Instruments for Sustainable Product Development

Research & Development

Market-oriented product development is focus of R&D

Research and development (R&D) form an integral part of strategic planning at Wienerberger and represent key activities for the Group. In these areas we work to continuously improve and develop our products and system solutions in all our application areas – from energy-efficient building concepts to environmentally compatible pavers and supply and sewerage systems. We want to protect and further expand our market positions through product innovation and move closer to the decision-makers in the construction process to support the timely exchange of information. Our research centers maintain an ongoing dialogue with universities and experts in various disciplines. Product development at Wienerberger is managed centrally in the individual business units, but is always market-oriented and therefore implemented in the individual countries. In addition to legal requirements and standards at the European or national level, a new product must harmonize with local building traditions. Product development must recognize cultural factors as well as the local cost structure of comparable construction methods and systems.

Innovation as Result of Research and Development

Product development and innovations for bricks

Wienerberger operates three research centers for Bricks & Tiles that are specialized by product group: clay blocks, facing bricks and clay roof tiles. Our product management experts work closely with the various marketing and sales departments to ensure that new developments always meet the needs of our customers. One of the R&D focal points in 2012 was to minimize thermal conductivity and optimize the thermal insulating properties of clay blocks. These activities led to the creation of the new mineral wool-filled PTH 30 W.i. Objekt, which was developed especially for multi-story buildings. It combines low wall thickness to maximize usable space and high compressive strength with excellent thermal insulation. Wienerberger is also pursuing a “light brick” strategy for infill masonry. These clay blocks have 25% less weight, which reduces raw material, transport and energy costs and also increases the living space. Light bricks are used to fill the space between the load-bearing sections of a building and create a pleasant and healthy interior room climate.

Goal for new roof tiles: optimal resource efficiency

Resource efficiency represents the focus of product development for roof tiles. In 2012 Wienerberger introduced a so-called FEM (finite element method) calculation for the optimization of the geometry of roof tiles. Two models were successfully used in Switzerland during 2012, and a third model is currently being implemented. The goal is a 10% reduction in the weight of the roof tile with constant bending load bearing capacity, which will decrease raw material requirements and energy consumption and also optimize the transport weight.

Facade developments focused on solutions for renovation and space optimization

Development projects for TERCA facade solutions were concentrated primarily on renovation in 2012. The responsible revitalization of existing buildings and the optimization of energy efficiency are two important goals in this area. The development of the Eco-brick® or SlimBrick® product lines provides two-layer wall systems with higher thermal insulation and a maintenance-free service life for the facade over many decades. Ceramic facade boards for rear-ventilated facades from the ArGeTon® product line can be combined with a variety of other building materials and are particularly well-suited for multi-story residential construction. The special development ArGeLite® saves space and reduces the use of raw materials.

Product development and innovation for plastic pipes

R&D activities for plastic pipes are located at our research center in the Netherlands, which works together with universities and external experts from various disciplines. Research is concentrated on the development of new products as well as the refinement of formulas for the raw material mix. One recent development by Pipelife is the Halovolt Low Friction EMC, an electrical installation pipe that minimizes electromagnetic radiation in the immediate surroundings. This solution sets a new environmentally friendly and healthy standard for public and private buildings. Pipelife is also a leader in the development and production of oversized pipes (LLLD pipes) with a length of up to 600 meters and a diameter of up to 2.5 meters for industrial applications. Special products in the Soluforce Heavy line are used in high pressure applications by the oil and gas industry. Steel wire reinforcement and high corrosion resistance make these pipes long-lasting, more resource-efficient and economical. The special plastic liner can also withstand a wide variety of aggressive chemicals and handle the safe collection and drainage of toxic waste water.

Ceramic jacking pipes allow for trenchless installation

The optimization of technical properties represents the focal point of R&D for ceramic pipes. One result is the development of ceramic jacking pipes that are suitable for trenchless installation. The pipes are inserted into a starting shaft and then pushed to the target shaft by means of a tunneling machine. This procedure allows the pipes to be installed with only minimal earth movements and without disturbing the existing infrastructure. Steinzeug-Keramo set a milestone in 2012 by installing the first ceramic jacking pipe in a curve drive for a project in Singapore. This technique can also be used to replace existing pipelines without digging new trenches.

Development of surface structures to extend service life and improve economy

Research projects for concrete pavers are directed to improving the surface designs and developing new technologies for the surface structure to extend the service life and increase product economy. Semmelrock Premium Protect®, a special surface shield, seals the stones and thereby provides for long-lasting color protection and easy maintenance, even on areas that are exposed to heavy soiling. Einstein®, an innovative jointing system, was developed to meet the high demands on heavily trafficked areas. This fully interlocking system with integrated protection against shifting prevents the paved areas from displacing, tilting or warping, even under high stress.



Our innovative surface treatments create modern and attractive paver solutions, and also extend the service life of our products.

ROBERT F. HOLZER *(CEO Semmelrock)*

Wienerberger System Solutions

Combining the outstanding properties of individual products into specially designed system solutions for the many diverse demands on modern construction is one of the central challenges for Wienerberger as an application-oriented and innovative building materials producer.

e4-Brickhouse 2020

The e4-Brickhouse: a leading and comprehensive concept for the affordable home of the future

The building concept for the e4-Brickhouse 2020, which includes all Wienerberger product groups, illustrates the principle of a complete system solution. In the Lower Austrian town of Zwettl, Wienerberger is demonstrating this principle in practice. A family of four moved into the first e4-Brickhouse 2020 during 2012 – a home that already meets all requirements of the Energy Performance of Buildings Directive 2020, which requires all buildings constructed after 2020 to have a positive energy balance.

The e4-Brickhouse has a positive CO_2 and energy balance

The e4-Brickhouse 2020 produces more energy than it uses during a year, which results in a positive CO_2 and energy balance. Experts have calculated that 33,600 kg of CO_2 can be saved with this house by 2020. The heart of the e4-Brickhouse 2020 is a thermal building shell made of high thermal insulating POROTHERM W.i. bricks that are filled with mineral wool and, in monolithic construction, can reach a U-value of ≤ 0.13 W/m^{2}K on the exterior wall (including plaster). The plane ground bricks are laid with the time-saving Dryfix® system, an aerosol masonry glue that makes fast masonry work possible at temperatures down to -5°C. The wall temperation heating system developed together with Pipelife creates a pleasant room climate and leads to lower energy consumption by reducing heating requirements (see below). The exterior walls are covered with TERCA facade bricks and ArGeTon® brick slabs. Semmelrock supplied the concrete pavers for the outside areas. The products from our Koramic line create a long-lasting, attractive appearance of the roof and additionally cover more than 100% of the electricity requirements with photovoltaic equipment from our offering of complete solutions.

Brick Wall Temperation

Energy savings and a healthier room climate with brick wall temperation

The high accumulation capacity of brick walls keeps rooms cool in the summer and pleasantly warm in the winter. As a system solution combining plastic pipes and clay blocks the brick wall temperation manages and increases this effect. The brick wall is thermally activated by an integrated pipe system. The air temperature can be reduced by increasing the surface temperature of the wall, without impairing the perceived room temperature. This can result in energy savings of up to 20% compared with convector heating. The lower interior air temperature increases the humidity in the room and reduces dust convection, which has a positive influence on the health of the building users. Three pilot projects were realized with this newly developed wall heating system in 2012, one of which is the e4-Brickhouse 2020.

Raineo™ ends Flooding in Inner City Areas

System solution to prevent flooding in inner city areas

Climate change and the increasing development of green areas have led to a growing incidence of flooding in inner city areas. With Raineo™, Pipelife has developed an extremely efficient system to solve this problem. It is installed underground and creates the necessary space for rainwater to drain off quickly. The system covers collection, preparation, storage and recycling or the diversion and disposal of the water. The heart of the system is the so-called "Stormbox", a large plastic box that is installed under built-up areas to collect excess water. When the rain is heavy, the water overload flows into the box and, in this way, the system prevents flooding.

Our Raineo™ water management system provides solutions to meet the challenges of climate change and helps to mitigate and prevent flooding in urban areas.

NIELS RUNE SOLGAARD-NIELSEN *(CEO Pipelife)*



The Energy-Independent House



Prof. Timo Leukefeld
on the energy-independent house
made of Wienerberger bricks:

"The Helma energy-independent house is a possible answer to the question of how we want to live in the future. It uses the free, crisis-proof 'raw material sun' to generate electricity and heat and also support our mobility. The result is complete energy independence – with no need for fossil fuels or electricity from public supply networks. That is what I call modern high-tech."



Technical concept:

The energy-independent house with monolithic brick walls by Wienerberger provides a possible answer to the future of housing design and concepts that include complete energy self-sufficiency (i.e. no connections to the public supply network are required). These energy-efficient houses use solar energy to generate electricity and heat and power motor vehicles. Although the amount of available solar energy can fluctuate considerably from day to day, this energy (solar electricity and solar heat) can be stored to ensure long-term supplies. That provides sufficient energy for heating, household electricity and powering an e-car over an entire year, which also leads to a substantial reduction in costs.

The brick is a proven, successful wall building material for energy-independent houses. This is demonstrated by various features, above all thermal storage capacity. Since temperature fluctuations are only transferred to the living areas over a longer period of time, a brick wall is a natural balancing accumulator and therefore the ideal building material for an energy-independent house. In addition, a modern brick provides perfect insulation. The need for heating is reduced considerably: the house stays warm in the winter and cool in the summer. The remaining energy requirements are minimal and can be covered by solar equipment combined with a long-term heat storage system. Solar heat and bricks in this combination produce the most effective houses currently on the market in Europe and could serve as a guiding vision for the European homes of 2020. These energy-independent buildings achieve ratings nearly 80% below the standard passive house for primary energy consumption, CO_2 emissions and annual heating costs.

Koramic Complete Solutions for Roofs

Koramic complete solutions for roofs

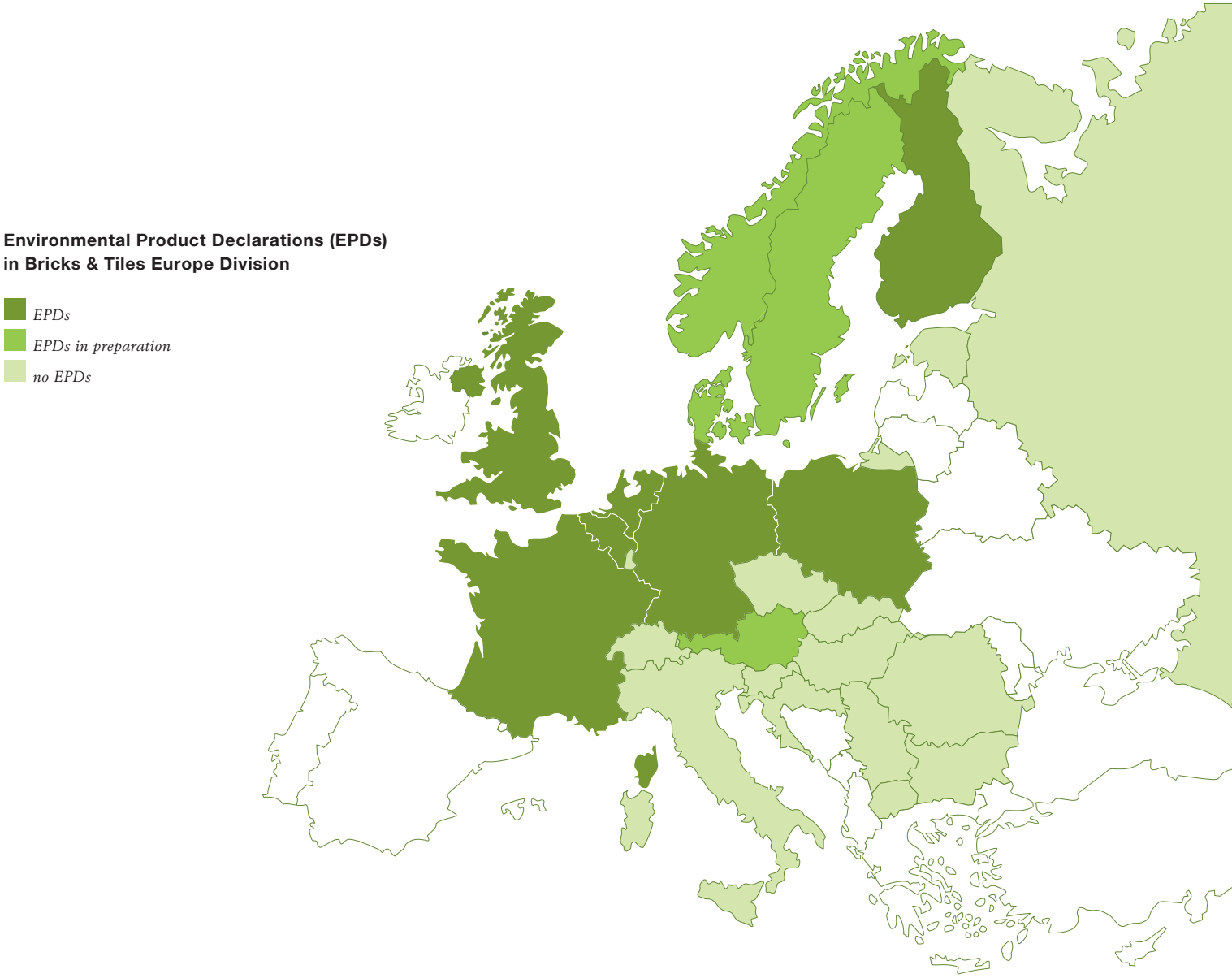
The system approach represents the focal point for R&D on roof tiles. Together with our durable, colorfast and stable clay roof tiles, we also offer a complete line of accessories. This underscores Wienerberger's positioning as a complete supplier for roofs and a competent partner for the planning phase. Wienerberger expanded its product line in 2012 to include a Koramic system solution with optimized thermal insulation that is marketed together with the necessary components such as insulation elements and coordinated accessories. We also expanded our offering as a one-stop shop with a service to calculate the energy performance of our roof solutions. Starting in Germany, this service will be successively rolled out in other Wienerberger countries. Climate change and the resulting extreme weather conditions have also led to increasing demands on the resistance of roofs. Wienerberger has met this challenge with the patented *sturm*FIX system, which uses special fixation hooks to protect roof tiles from even the strongest storms.

Ecobalance and Development of Environmental Product Declarations

Long-standing, active role in preparation of ecobalances and EPDs, and European harmonization of standards

The preparation of ecobalances and environmental product declarations (EPDs) for all product lines has been a focus of activities at Wienerberger for many years. The European Construction Products Directive (CPR) and the work of the European Committee for Standardization (CEN TC 350) will make these declarations mandatory for all building materials producers over the coming years. In Belgium, the respective regulations will take effect on January 1, 2014. EPDs from a number of brick producers have been published in recent years. This generally took place at the association level in France, Germany, Belgium and England. The Belgian brick industry developed an EPD system as part of a research project, which defines the criteria for EPDs, and EPDs for all product lines have been issued in the Belgian product line. The brick industry in Austria decided to prepare differentiated branch EPDs by product category, i.e. for clay blocks, facing bricks and roof tiles. This project will be completed in the near future. With these measures, a large part of Wienerberger's brick product line is directly covered by EPDs or included in branch solutions. Wienerberger is a leader on this issue in the above-mentioned countries and, through the positions of the Wienerberger Managing Board and employees in the Tiles and Bricks Europe association (TBE), works actively on the preparation of ecobalances and EPDs as well as the harmonization of national rules throughout Europe.

Environmental Product Declarations (EPDs) in Bricks & Tiles Europe Division



Project to develop ecobalance database for all plants launched in 2012

Wienerberger started a pilot project in 2010 to collect ecobalance data on all its roof tile plants and completed this work in 2011. These ecobalances form the basis for the preparation of EPDs. In 2012 we started a project to create a Wienerberger database for the collection of ecobalance data in all our plants. This will move us closer to meeting our goal – the preparation of EPDs for all product groups – and we can then use this comprehensive database to demonstrate our compliance with national or European regulations.

Cradle to cradle certification

The cradle to cradle concept (C2C) is modeled on nature's processes. It is designed to create waste-free systems by not disposing of products as waste after their use, but returning them to continuous production cycles for new products. This concept is also based on the use of renewable energy and the support of diversity. Certification and the related continuous development of products and production processes in the sense of sustainable environmental protection anchor the cradle to cradle principle in companies. Steinzeug-Keramo has already received C2C certification for part of its product line and is now working to achieve certification for the remaining

products. In the Bricks & Tiles Europe Division, all clay block products in Belgium have been certified under C2C since 2012, and preparations are now in progress for the certification of selected roof tile and facing brick products.

TEPPFA leader in the preparation of EPDs for functional areas

In the plastic pipe industry, the focus is on the preparation of environmental product declarations by the producers' association. The European Plastic Pipes and Fittings Association (TEPPFA) is using life cycle assessments (LCAs) to develop environmental product declarations for functional areas based on ISO 14025. One example of a functional area for heating is the total amount of plastic pipes and fittings required to heat a 100 m² housing unit. TEPPFA members can reference the EPDs for these functional areas. Nineteen environmental product declarations have been completed and the preparation of further EPDs is scheduled for 2013. Niels Rune Solgaard-Nielsen, the CEO of Pipelife, is actively involved in the rapid, goal-oriented implementation in his role as president of TEPPFA.

Future Measures

Our future measures for sustainable products are focused on the (further) development of system solutions, including an improvement in economy and efficiency, as well as the development of solutions for modern, energy-efficient and urbane construction. Wienerberger will also collect ecobalance data from all its plants and work on the preparation of EPDs for the entire product line, and make an important contribution to the harmonization of standards throughout Europe.

Expansion of one-stop shop concept and development of solutions for multi-story housing

In our brick business, we want to further expand the one-stop shop approach that has already proven successful in the roof segment. We will also continue our work on projects that combine the outstanding properties of Wienerberger products into system solutions with concepts like the e4-Brickhouse, also with the inclusion of external partners from branches such as heating and ventilation technology. Our goal is to provide solutions from a single hand that not only comply with all relevant building regulations, but also meet our customers' demands for healthy living, comfort and affordability in construction and use. We are therefore focusing on system solutions that help to reduce construction time and optimize construction logistics. Another central objective is the expansion of our offering for multi-story residential construction. Our efforts in this area will concentrate on our slim infill clay blocks for load-bearing exterior walls and our special lightweight bricks for infill masonry and innovative facade solutions.

Product certification and improvement in economy and service life as focus for Pipes & Pavers

Steinzeug-Keramo will complete the certification of its ceramic products according to the cradle to cradle principle in 2013. In addition to ongoing R&D projects to further generate 20% of revenues from innovative products, Pipelife is working on the collection of ecobalance data and the preparation of EPDs. Activities at Semmelrock involve the improvement of economy through innovative laying systems as well as the extension of the product lifecycle through an increase in durability, color retention and surface stability.

Goal: 30% of revenues from innovative products by 2015

In 2012 23.4% of Group revenues were generated by innovative products and system solutions. Our goal is to increase this indicator to 30% by 2015.

Corporate Social Responsibility

Wienerberger Principles of Corporate Social Responsibility

The economy as an integral part of society

Wienerberger views the economy as an integral part of society. Its duty is to serve people and create value for all. Wienerberger takes its role as a responsible member of society seriously. We define responsibility as ethical actions, honest communications, active participation in the transparent development of our economic environment, personal accountability and actions that confirm our standing as a reliable and valuable member of society.

Defense of human rights

Within its respective sphere of influence, Wienerberger guarantees ***protection for basic human rights***. The company has signed a social charter in which it commits, among others, to supporting the freedom of association and collective negotiations at all locations as well as preventing child labor and forced labor. Our corporate guidelines call for sanctions in the event of violations.

Support for social institutions

Support for social organizations on a local basis is a central principle of corporate social responsibility for Wienerberger. Our donation guideline confirms our intention to provide targeted, in-kind support to the needy in the form of our products and to help young people through training programs in sustainable construction.

Compliance with all applicable national and international laws

A commitment to ***compliance with all applicable national and international legal regulations*** is also an important part of corporate social responsibility at Wienerberger. Legal compliance at all organizational levels creates the basis for good management. Wienerberger ensures that both international and national laws and standards are followed in all its business operations and places a special focus on the prevention of illegal and anti-competitive behavior.

Active participation in political decision-making

As a member of numerous national and European platforms and technical committees, Wienerberger plays an active role in the political decision-making process. Wienerberger is an established, reliable stakeholder and building materials expert that views ***open and transparent communications with politics and public authorities*** as part of its corporate social responsibility. The company works to create a sustainable economic environment that unifies economic, ecological and social interests.

Energy Efficiency and Climate Protection

Climate change as a central challenge for society

The man-made climate change has already started and will represent one of the central social challenges of the future. The creation of a competitive, resource- and energy-efficient economy is one of Wienerberger's stated goals. With our energy-saving building material and infrastructure solutions and our energy-efficient building concepts, we are supporting the transition to a low carbon society. We believe future-oriented building materials must make an important contribution to slowing climate change.

Wienerberger products support climate protection

"Building with a clear conscience" is one of our guiding principles and underscores our commitment to sustainability. We want to create the greatest possible benefits for society with our building material solutions and our expertise. Our long-lasting, resource-conserving building materials help our customers make a contribution to environmental protection. Wienerberger is also committed to the development of energy-efficient house concepts. In these projects, we always consider the total energy efficiency of a building – from production to construction, use and recycling. Our e4-Brickhouse 2020 has both a positive energy and a positive CO_2 balance and, in this way, makes an active contribution to climate protection.

Our innovative pipe systems are an integral part of future-oriented solutions for water management – they allow for the efficient collection of rainwater and wastewater, and also support water transportation, recycling and disposal. These pipe systems help to optimize the water cycle and improve resource efficiency, while also ensuring long-term security of supply.

Regional Employer

Important employer, also in structurally weak regions

Its large network of local production facilities makes Wienerberger an important employer in many, in part structurally weak, regions. We see the creation and preservation of jobs as an important corporate social function. At our plants we work to develop and maintain the best possible understanding with municipal authorities, interest groups, neighboring residents and NGOs. Our activities are focused on mutual understanding, the regular exchange of ideas and respect. We have installed local steering committees at a number of our plants to help us meet this goal.

With the signing of a social charter, Wienerberger formally confirmed its intention to comply with the recommendations of the International Labor Organization. We are committed to safe and appropriate working conditions, fair compensation and our employees' right to the freedom of association and collective negotiations. Approx. 80% of all Wienerberger employees are covered by a collective agreement. Our efforts to ensure fair working conditions are appreciated by our employees and reflected in a low strike rate. The number of work stoppages totaled 402 man-days in 2012, which represents 0.01% based on the total number of hours worked in the Wienerberger Group. Moreover, most of these strike days were protests against general political decisions at the regional level and not directed against Wienerberger.

Wienerberger Donation Guideline

Our goal: to provide the best possible benefits for society with our products

We want to use our products and expertise as a supplier of building material solutions to create the greatest possible benefits for society in every country where we are present. Our donation guideline provides a framework for the targeted, in-kind support we provide to the needy with our products. We also offer additional training programs in sustainable construction for architecture and civil engineering students. We believe we can help best in areas related to our core expertise, namely in the provision of building material solutions and know-how for sustainable construction.

Cooperation with Habitat for Humanity

In connection with its new donation guideline, Wienerberger entered into a three-year agreement with Habitat for Humanity to support the construction of housing in Romania and Bulgaria. Habitat for Humanity is an international organization that is dedicated to providing poor and disadvantaged people throughout the world with safe and affordable housing. This three-year cooperation program was launched with the "Big Build 2012" in Craiova, Romania, from October 1 to 5, 2012. Together with the involved families, volunteers from all over the world built five brick homes in five days.



We believe affordable housing
is a basic human right.
I am therefore particularly pleased
that we are able to build homes for the needy
together with Habitat for Humanity.

GERHARD KOCH *(Head of European Affairs & Sustainability Management)*

Development of WISBA training program

The principles underlying the donation guideline formed the basis for the development of a specialized training concept in 2012, which led to the creation of the Wienerberger Sustainable Building Academy (WISBA). This European training program is focused on sustainable construction and was created together with Vienna University of Economics and Business and in cooperation with technical colleges. WISBA is directed to master's degree students in architecture or civil engineering, who can demonstrate a significant interest and special achievements in sustainable construction. Wienerberger supports this target group by financing the international training, which can be credited in full to the respective degree program (5 ECTS points). The participants also have an opportunity for practical training at Wienerberger. The first course will start during the autumn semester 2013/14 with students from Austria, Germany and Poland. **Plans call for the expansion of WISBA to 12 countries by 2015.**



Selected Charitable Projects

Unbureaucratic help in disaster situations

We regularly support and promote a variety of social projects in nearly all countries where Wienerberger is present. In addition to the planning and realization of charitable projects together with aid organizations, we believe it is important to provide fast and unbureaucratic relief in emergencies. We help where we can make a real contribution and are certain this help will arrive at the right place.

Pipelife: around the world with 27 aid projects

As part of its long-standing partnership with the Austrian Red Cross, Pipelife launched a new campaign in 2012: for 27 months, the company will support 27 humanitarian projects in the 27 countries where it is active. The kick-off for this campaign was a unique training program carried out in cooperation with the Red Cross in Austria and the UK, which also received financial support from the European Community Humanitarian Office (ECHO). The program's goal is to improve the skills of development aid workers to react quickly and correctly in disaster situations and thereby ensure supply security, above all for water. This project "Prepare to Respond" has held courses in a variety of humanitarian fields, including water, hygiene and sanitation equipment.

Support for young masons' competition in Austria

Wienerberger also supports professional training for young men and women in sustainable construction. We supplied the products for an apprentice masons' competition in Austria, and the winner of the national contest will take part in the World Skills 2013 in Leipzig. This initiative will help make the masonry profession more attractive for future generations.

Affordable housing in India

Affordable housing for the people living near our plant has been an important issue ever since our market entry in India. Together with an external partner, we carried out a study on the needs of the local population in 2012. We then developed a concept for affordable housing that provides sufficient living space for a family. In a next step we want to work together with NGOs to support residents in their search for financing.

Compliance

Measures to ensure legally compliant behavior

The term "compliance", which originated in Anglo-American law, is understood to cover all measures required to ensure adherence to the relevant legal regulations and prohibitions by a company and its employees. A commitment to compliance with all applicable national and international legal standards represents a central principle for the Wienerberger Group. Individual legal issues are so important that Wienerberger has issued separate guidelines in these areas and places a special focus on compliance. These areas include the prevention of corruption and compliance with competition law as well as compliance with national guidelines and regulations, which are described in the following sections.

Prevention of Corruption

Difference between business gifts and corrupt behavior

Wienerberger is committed to free and fair competition, and rejects any form of corruption. However, the differentiation between well-meant business gifts and corrupt behavior is often difficult to determine in individual cases. This applies, above all, to procurement and sales because of the increased contact between the respective staffs and public authorities or private business partners.

Guideline on business gifts

In order to inform employees of legally compliant behavior, Wienerberger issued a group guideline that covers business gifts. This guideline is intended to serve as guidance for employees by defining the cases in which the granting or accepting of business gifts could pose a problem under criminal law. It defines the term "business gifts" and differentiates this term from other types of presents. The guideline also distinguishes between gifts to persons in the public sector and the private sphere, and provides standards for acceptable behavior. In conclusion, the guideline defines cases in which the granting or acceptance of business gifts must be reported to the Managing Board or company management.

Instructions for managing directors

In connection with the implementation of this guideline, the top managers and managing directors of the country organizations (approx. 40 persons) were instructed on the correct procedures for dealing with business gifts. This included instructions to ensure full compliance with the guideline in every company. Local management is responsible for passing this information on to employees through special training courses, which are regularly monitored by the corporate headquarters.

Internal audit as control function

The duties of internal audit also include reviewing compliance with legal regulations and internal guidelines. Audits were conducted in 35 companies during 2012, which focused on organization, procurement, materials management, sales and personnel as well as corruption and antitrust law. The audited companies represent roughly half the operating units in the Wienerberger Group. These reviews confirmed that all internal guidelines had been implemented in all companies and that employees had been instructed accordingly. Any deviations were reported to the Managing Board and the Audit Committee, and appropriate corrective measures, such as the improvement of documentation processes, were developed together with the responsible management.

Dual controls for business transactions

Another important instrument for the prevention of corruption is the principle of dual controls for signatures in business transactions with third parties. This principle calls for signatures by two authorized persons in the local unit when rights and obligations are created, amended or cancelled. Group guidelines also include this rule, which supports the prevention of corruption on an international basis.

Sanctions for violations

Legally compliant behavior is expected from all Wienerberger employees, and any violations represent a breach of the obligations under labor law. If the suspicion of a violation is confirmed, it will lead to consequences under labor and civil law that reflect the scope of damages to the Group. In 2012 no charges were filed against Wienerberger based on a suspicion of corruption and no criminal penalties were paid for related violations.

Prevention of Anti-competitive Behavior

Fair competition as basis for our business

Competition law ensures compliance with free and fair competition. Management is convinced that business policies based on free competition are in the best interest of the company and also in the best interest of shareholders and employees.

Antitrust compliance program

The Wienerberger Group introduced an antitrust compliance program many years ago. This guideline forms the basis for increasing the awareness of our employees for compliance with antitrust regulations. The rules of conduct defined in the guideline provide guidance for dealing with sensitive subjects in the area of competition law and must be strictly observed. Special rules regulate contacts with competitors and deal with issues such as market allocation, the exchange of information, the design of prices and delivery conditions and other possible forms of cooperation. The interaction with customers, sales partner and suppliers is, among others, regulated with respect to the determination of resale prices and related restrictions as well as exclusivity agreements. The guideline also contains regulations concerning intellectual property rights and merger controls.

Control through internal audit

Regular training sessions are scheduled for employees as part of the antitrust compliance program. Local management is responsible for organizing these programs and selecting the employees. The realization of the training sessions and compliance with the guideline are monitored by internal audit.

Pending antitrust proceedings in Germany, searches in the offices of plastic pipe producers

Due to the position of the Wienerberger Group in individual markets, the pricing policies of our subsidiaries are actively monitored by antitrust authorities. Antitrust proceedings are pending in Bricks & Tiles Germany and, in the event of a conviction, could lead to a fine. A provision has already been recognized for a possible antitrust penalty, but we assume Wienerberger was not involved in any illegal actions. In addition, the EU Commission ordered searches at the offices of plastic pipe and fitting producers during June 2012 in connection with alleged agreements in violation of antitrust law, which also included Pipelife. The responsible authorities have not issued any findings to date. It should be noted that price-fixing agreements are not part of Wienerberger business policies; internal guidelines expressly prohibit such activities and call for sanctions in the event of violations.

Compliance with National Guidelines and Regulations

Environmental, health and safety regulations

Wienerberger is subject to extensive and increasingly stringent environmental, health and safety laws in many countries, which can lead to investments for compliance with these regulations. The failure to comply with these regulations could result in administrative fines, the assessment of damages or the suspension of operating permits.

Responsibility with local management

In accordance with the decentralized structure of the Wienerberger Group, local management is responsible for implementing and monitoring the applicable national guidelines and directives. Officers have therefore been appointed at the country level in agreement with the relevant national laws. These persons are responsible for evaluating and reporting on legal compliance to local authorities and to the Wienerberger Managing Board. Internal audit reviews compliance with these processes on a regular basis and reports to the Managing and Supervisory Boards on the results of these audits.

The Political Decision-making Process

Active participation in political decision-making

Wienerberger is a member of numerous European and national professional associations and platforms as well as various technical committees and, in this way, plays an active role in the political decision-making process. One of our most important goals is to address the trends and developments in individual markets, for example growing urbanization, and to provide decision-makers with practicable, sustainable and, above all, affordable solutions for new residential construction, infrastructure and renovation.

Membership in national and European ceramic associations

Through its country organizations in the Bricks & Tiles segment, Wienerberger is a member of numerous national brick associations which, in turn, are organized at the European level into an association called Tiles and Bricks Europe (TBE). Heimo Scheuch serves as president of the TBE, which is located in Brussels, and regularly attends the meetings of the executive committee. In the ceramic pipe segment Gernot Schöbitz, CEO of Steinzeug-Keramo, is president of the European association Feugres. Both TBE and Feugres are active members of the European ceramic association CERAME-UNIE, where Heimo Scheuch serves as vice-president. CERAME-UNIE also organizes the annual European ceramics forum together with representatives of the European Parliament. This forum takes place in the European Parliament and provides a platform for the exchange of information and communication between industry, the European Commission and politics on current economic topics.

Pipelife is a member of the European association TEPPFA

Wienerberger's plastic pipe business is represented in The European Plastic Pipes and Fitting Association (TEPPFA) through Pipelife. In April 2013 Pipelife CEO Niels Rune Solgaard-Nielsen was elected president of TEPPFA. Our membership in this association provides a platform for our active participation in the political decision-making process at the European level, where we support key issues such as recycling, the development of product standards for plastic pipes and the preparation of environmental product declarations.

Semmelrock is represented in VÖB

Semmelrock represents the Wienerberger Group in VÖB, the association of Austrian concrete and prefabricated producers. Semmelrock CEO Robert F. Holzer serves as the vice-president of this organization, which represents the interests of all concrete prefabricated producers in Austria and views itself as a know-how platform and branch speaker. VÖB is a member of the Bureau International du Béton Manufacturé (BIBM), which is active at the European level.

Emission trading system 2013-2020

The most important economic and environmental issues for Wienerberger in 2012 included, among others, the design of the emissions trading system for 2013-2020, the Energy Efficiency Directive and the Construction Products Directive. In 2012 Wienerberger played an active role in the national implementation of the European Energy Performance of Buildings Directive (in particular with regard to the cost optimization of energy-efficient buildings). We are also involved in a number of regional and national construction initiatives.

Future Measures

Continued cooperation with Habitat for Humanity

Wienerberger entered into a three-year cooperation agreement with Habitat for Humanity in connection with our donation guideline. Plans call for the construction of roughly 150 homes for the needy in Romania and Bulgaria during this period.

Start of WISBA in autumn semester 2013/14

The first course of studies in the Wienerberger Sustainability Academy is scheduled to start during the autumn semester 2013/14. It will include 12 students from Austria, Germany and Poland, who will complete an international training program on sustainable construction. We plan to expand WISBA to 12 countries by 2015.

Increase in local steering committees

In order to provide a platform for increased dialogue with the stakeholders near our plants, we want to establish local steering committees at additional locations.

Preparations to preserve carbon leakage status

Through the Tiles and Bricks Europe Association (TBE), the European brick and roof tile industry started preparations at the end of 2012 to preserve carbon leakage status after 2015 and will continue these measures during 2013. Wienerberger also works to standardize the interpretation and implementation of the Construction Products Directive by means of its membership in various European associations.

Stakeholder Management

Principles of Stakeholder Management

Communication is the central principle of responsible interaction with our stakeholders

Creating value in the interest of all stakeholders is one of Wienerberger's central principles. Accordingly, communication forms the focal point of responsible interaction with our stakeholder groups. Our efforts in this area are designed to provide our employees, customers, shareholders, local residents and suppliers as well as politics, the media and NGOs with relevant information, while also maintaining an open, proactive, continuous and transparent dialogue with these groups. This dialogue creates a better mutual understanding for the respective interests, needs and concerns, and creates added value for everyone involved. Our communication instruments include personal meetings as well as regular newsletters, information brochures, internet-based platforms and information events.

Communication with employees

Employees are interested in a motivating, future-oriented and stable employment relationship, opportunities for advancement and active involvement as well as a good working environment that guarantees health, safety, fairness and equal opportunity. These principles and values are an integral element of our corporate culture, which forms the basis for our everyday work. In order to create a motivating environment and encourage individual initiatives, we provide our employees with comprehensive and timely information on corporate goals and strategies as well as important developments and measures. Various internal media are used for this purpose, including a regular CEO letter, iComm (our intranet platform), local employee magazines and internal newsletters from various departments (e.g. engineering and marketing newsletters). Our "ideas & more" innovation platform gives employees an opportunity to contribute ideas and receive a bonus if they are implemented. As part of our health & safety initiative, we also organize regular training courses for employees to further improve occupational safety and promote good health.

Communication with consumers, merchants, developers, planners and masons

Our customers – consumers as well as merchants, building developers, planners and masons – are interested in high-quality, long-lasting and affordable products that provide security and comfort. We maintain a continuous dialogue with our customers to better understand their concerns and develop products that meet their needs. Wienerberger informs customers of the technical, ecological and economic benefits of its products through a wide range of communication measures that include information brochures, presentations at trade fairs, training courses and online tools. Training programs and our service center support our customers in the use of our products and system solutions.

Communication with shareholders, analysts and banks

Capital market participants – shareholders, analysts and banks – are interested, above all, in the sustainable development of the company. Comprehensive and transparent reporting as well as timely communications and regular exchanges with the Managing Board play a central role in supplying the necessary information. The main instruments used for this purpose include the annual and quarterly reports, presentations and press releases on current developments. Road shows, participation in investors' conferences, one-on-one meetings and the annual capital markets day ensure a continuous and active dialogue with all capital market participants.

Fair business relationships with suppliers

Suppliers are interested in fair business relationships. Wienerberger is interested in the long-term, sustainable procurement of the required raw materials, supplies and products. We therefore communicate our expectations for compliance with economic and social standards to our suppliers. Pipelife, for example, has compiled these standards in a code of conduct that must be signed by suppliers before contracts are concluded and followed during the entire business relationship.

Communication with the media

The media expect targeted and up-to-date information on strategic and current issues. Our objective is to achieve fair reporting by the media. In order to ensure optimal cooperation, we provide the media with timely information through press releases and press conferences. Inquiries by journalists are answered as quickly as possible, with personal interviews allowing for the necessary exchange of information.

Communication with politics

Politics establishes the legal framework for society and, as such, defines the general business environment for Wienerberger. The subjects on which the exchange of information with Wienerberger took place in 2012 are described in the section "The Political Decision-making Process" in the chapter "Corporate Social Responsibility" (page 60). Our media contacts include an increasing focus on the need for affordable housing and social housing construction in Europe. We also support public subsidies for renovation and the construction of (water) supply and disposal networks in Western and Eastern Europe.

Communication with other stakeholder groups

Our stakeholders also include local residents, communities and public authorities as well as NGOs. The Bricks & Tiles Europe Division has established local steering committees in several countries, which include Wienerberger management, residents, political representatives and NGOs. Regular meetings allow for the exchange of information and, wherever necessary, the joint development of measures to improve relations. In 2012 we set a goal for our ceramic production network to collect information on current efforts and to **introduce stakeholder dialogues in 90% of our plants by 2020.** Pipelife also places high value on an open and active dialogue with its stakeholder groups. These communications are supported by different types of events, for example family days for the Pipelife Hungary employees and a get-together at the Pipelife Austria plant.



Wienerberger sees these activities not only as a means of creating added value for all stakeholder groups through active dialogue, but also as a win-win situation. Selected examples are provided on the following pages:

Stakeholder Management: Selected Examples



CEO Letter

Heimo Scheuch,
CEO of Wienerberger

I am committed to providing our employees with regular and timely information on the latest developments. During my frequent visits to our Group companies, I try to meet with employees from all areas of the business. Regular emails also give me an opportunity to communicate a wide range of information. Wienerberger was faced with significant challenges in recent years. As a result of the difficult market environment we were forced to implement numerous restructuring measures and make some very hard decisions. However, we attempted to take the necessary personnel steps as carefully and socially responsible as possible. Internal communications were particularly important for me in this situation. I want each of our employees to know the reasons for our decisions as well as the goals we are following and what we want to achieve together during the coming years. Because we can only be successful when we all work together.



Capital Markets Day in Vienna

Willy Van Riet, CFO

This year's capital markets day was held in Vienna. More than 50 investors, analysts and banks used the opportunity to learn about the latest developments at Wienerberger. The focal point for 2012 was the newly created Pipes & Pavers Division, which was introduced by the respective business unit managers. The participants were given an in-depth view of Wienerberger's plastic pipe, ceramic pipe and concrete pavers businesses as well as our corporate strategy. The program closed with a dinner that provided a platform for extensive discussions with our guests as well as a tour of the Pipelife plant on the following day.



Annual summer event at Schlagmann

Johannes Edmüller,
Managing Director of Schlagmann

As thanks for the good cooperation and support, we organize a summer event for our employees and neighbors and highlight a different topic each year. In 2012 we had a particular reason to celebrate: we implemented an energy management system based on DIN EN ISO 50001 standards and received certification during the summer. Martin Zeil, the Economics Minister and Deputy Prime Minister of Bavaria, presented the certificate at the event and, in his speech, praised Schlagmann's efforts as a pioneer in energy policies. The interaction with our guests from politics, the business sector, friends, neighbors and families made this day a real success for me and my staff.



Open house in Hennersdorf

Christian Weinhapl,
Managing Director Austria

The open house at our plant in Hennersdorf on September 22, 2012 drew a large number of guests. Roughly 350 visitors used this invitation to learn more about brick production and our company through various activities. The event provided our employees with an excellent chance to meet different stakeholder groups and give these visitors an overview of their work and production processes. Bricky and Bricka, our mascots, were a particular highlight for the children.

About this Report

Report Profile

Sustainability report on activities in 2012 with three-year statistical trend

This sustainability report covers Wienerberger's activities during 2012, but selected statistics are also provided for 2010 and 2011 to present a three-year trend. The first Wienerberger sustainability report was prepared for 2009. Sustainability reporting at Wienerberger focuses primarily on the ecological and social aspects of the company's activities. Information on Wienerberger's financial development, organizational profile and corporate governance is provided in our 2012 annual report (annualreport.wienerberger.com).

In the future, full report every two years with short report as interim update

Wienerberger also intends to issue regular reports on its sustainable development in the future. However, we have decided to only publish a complete sustainability report every two years because our sustainability principles cover the long-term and therefore generally remain constant. In the interim periods, we will issue an update that presents the latest facts and figures as well as our progress in specific areas.

Reporting threshold: full coverage of investments

The contents of this sustainability report are based on the fully consolidated subsidiaries in the wall, roof, facade, ceramic pipe, plastic pipe and concrete paver product groups. This reporting structure reflects the consolidation range of the Wienerberger Group and therefore includes our pipe activities for the first time (Pipelife plastic pipe and Steinzeug-Keramo ceramic pipes). Steinzeug-Keramo is included beginning in 2011 (the prior year data were adjusted retroactively). Data on Pipelife are presented in the chapter "Environmental Protection in Production" as of June 2012 (for seven months) and in the chapter "Employees" for the full 12 months of 2012. Any deviations from this procedure are explained in the respective sections. The data in the chapter "Environmental Protection in Production" only cover our production facilities, while the remaining statistics relate to all locations in the Wienerberger Group. Detailed information on the consolidation range and the segmentation of the Wienerberger Group is provided in our annual report.

Core issues and key indicators defined by SDSC

Recommendations for the subject areas and indicators to be included in this report were made by the respective Wienerberger working groups and the sustainability officer. The Wienerberger Sustainable Development Steering Committee (SDSC) under the direction of Heimo Scheuch (CEO) was responsible for the final selection. This sustainability report was prepared in agreement with the requirements of the Global Reporting Initiative (GRI).

External validation by independent auditor

The data presented in this report are based primarily on internal statistics. Selected information was validated by an independent external auditor, whereby the 2012 audit concentrated on a review of the content and statistics on energy consumption and emissions as well as occupational safety and health. The integration of data from Pipelife represented a particular focal point in this respect. The audit also covered the underlying sustainability management and the processes used to collect data and implement the sustainability strategy. This sustainability report reaches the GRI B+ level.

GRI Index

GRI Level B+

PwC Wirtschaftsprüfung GmbH evaluated this sustainability report and confirms the GRI B+ level.

No.	Indicator	Page	Level of Fulfillment
General Indicators			
1.1	Statement from the most senior decision-maker	SR 8-9	■
1.2	Description of key impacts, risks and opportunities	SR 10-12 / AR 16-19	■
2.1-2.10	Organizational profile	SR 10-13, 21 / AR 38-39, 40-43, 49-52	■
3.1-3.11	Report parameters	SR 65 / AR 40-43	■
3.12	GRI Content Index	SR 66-67	■
3.13	External assurance	SR 68	■
4.1-4.13	Governance, commitments and engagement	SR 13 / AR 21, 24, 27, 28-30	■
4.14-4.17	Stakeholder engagement	SR 62-63	■
Economic Indicators			
DMA-EC	Management approach: economy	SR 10-12 / AR 16-19	■
EC1	Direct economic value generated and distributed	SR 13 / AR 104	■
EC2	Risks and opportunities due to climate change	SR 16, 54	■
EC4	Significant financial assistance received from the government	SR 13 / AR 127, 151	■
EC7	Procedures for local hiring	SR 21, 24	■
EC8	Services provided primarily for public benefit	SR 55	■
Ecological Indicators			
DMA-EN	Management approach: environment	SR 14, 16, 17, 33	■
EN1	Materials used	SR 33, 38	■
EN2	Percentage of materials that are recycled	SR 40	■
EN3	Direct energy consumption by primary energy source	SR 35	■
EN4	Indirect energy consumption by primary energy source	SR 35	■
EN5	Energy saved	SR 35	■
EN6	Initiatives for energy-efficient and renewable energy-based products	SR 44	■
EN8	Total water withdrawal by source	SR 37, 42	■
EN9	Water sources significantly affected by withdrawal of water	SR 37, 42	■
EN10	Percentage and total volume of water recycled and reused	SR 37, 42	■
EN13	Habitats protected or restored	SR 33, 38	■
EN16	Total direct and indirect greenhouse gas emissions	SR 36	■
EN18	Initiatives to reduce greenhouse gas emissions and reductions achieved	SR 37-39	■
EN22	Total weight of waste by type and disposal method	SR 37	■
EN26	Initiatives to mitigate environmental impacts of products	SR 44-54	■

No.	Indicator	Page	Level of Fulfillment
Social Indicators			
DMA-LA	Management approach: labor practices and decent work	SR 15, 19	■
LA1	Total workforce by employment type, contract and region	SR 21	■
LA2	Total number and rate of employee turnover by age group, gender and region	SR 22, 23	■
LA4	Employees covered by collective bargaining agreements	SR 55	■
LA7	Rates of injury, occupational diseases, lost days and absenteeism	SR 25-27	■
LA8	Risk-control programs regarding serious diseases	SR 26	■
LA10	Average hours of training per year per employee	SR 28	■
LA13	Diversity of employees	SR 23-24	■
Indicators on Human Rights			
DMA-HR	Management approach: human rights	SR 16, 54	■
HR4	Incidents of discrimination	SR 23	■
HR6	Risk for incidents of child labor	SR 54	■
HR7	Significant risk for incidents of forced or compulsory labor	SR 19, 54	■
Indicators on Society			
DMA-SO	Management approach: society	SR 16, 54	■
SO1	Management of impacts of operations on communities	SR 55	■
SO2	Business units analyzed for risks related to corruption	SR 57-58	■
SO4	Anti-corruption measures	SR 57-58	■
SO7	Legal actions for anti-competitive behavior and anti-trust	SR 59 / AR 33, 162	■
SO8	Fines and sanctions for noncompliance with regulations	SR 162	■
Indicators on Products			
DMA-PR	Management approach: product responsibility	SR 16, 44	■
PR1	Assessment of health and safety impacts of products	SR 46-48	■
PR3	Product information requirements	SR 52-53	■

■ *Complete* ■ *Partial* *SR: Sustainability Report 2012* *AR: Annual Report 2012*

Report on the independent limited assurance engagement in accordance with KFS/PG 13

To Wienerberger AG, Austria

In accordance with our agreed terms of engagement, we performed procedures to obtain limited assurance on selected information of the Sustainability-Report 2012 of Wienerberger AG. This engagement is subject to the "General Conditions of Contract for the Public Accounting Professions" (AAB 2011) as amended February 21, 2011, issued by the Austrian Chamber of Public Accountants and Tax Advisors. Our liability towards the Company and also towards third parties is limited in accordance with section 8 of the AAB 2011.

We draw attention to the fact that the English translation of this Report on the independent limited assurance engagement is presented for the convenience of the reader only and that the German wording is the only legally binding version.

Responsibility of the management

The preparation of the Sustainability-Report 2012 in accordance with the criteria set out in the Sustainability Reporting Guidelines Vol. 3 of the Global Reporting Initiative ("GRI criteria")

- Materiality
- Stakeholder inclusiveness
- Sustainability context
- Completeness
- Balance
- Clarity
- Accuracy
- Timeliness
- Comparability
- Reliability

is the responsibility of the management of Wienerberger AG. This responsibility includes the selection and application of appropriate methods for preparing the Sustainability-Report 2012, making assumptions and estimates of individual sustainability disclosures that are plausible under the given circumstances, as well as designing, implementing and maintaining systems and processes where relevant for the preparation of the Sustainability-Report 2012.

Limitation of the scope of the engagement

Our responsibility is to give an assessment, based on our work, on whether anything has come to our attention that causes us to believe that the quantitative disclosures in chapter "Environmental Protection in Production" on the issues of "Energy Consumption and Emissions" (pp. 35 to 37), as well as in chapter "Employees" on the issues "Occupational Safety and Health" (pp. 24 to 27) of the Sustainability-Report 2012 have not been prepared in accordance with the GRI criteria as set out in the Sustainability Reporting Guidelines Vol. 3. Our review was limited to the key performance indicators in the cited areas of focus.

We also performed the Global Reporting Initiative (GRI) Application Level Check to comprehend the application level declared by Wienerberger AG.

Responsibility of the independent auditor

We have performed our engagement in accordance with Expert Opinion KFS/PG 13 for assurance engagements. This standard requires us to comply with our professional standards and to plan and perform the engagement in a way that enables us to draw conclusions in accordance with KFS/PG 13.

Engagement approach

In a limited assurance engagement, the work performed is less extensive than in a reasonable assurance engagement and, therefore, less assurance is obtained. We performed our work, using appropriate random samples, based on our due judgment and to the extent required to obtain limited assurance. In the course of our engagement, we therefore obtained relevant evidence based on risk and materiality assessments in order to obtain this limited assurance on the compliance of the disclosures according to the scope of the engagement with the GRI criteria mentioned above. In doing so, our work performed at the headquarters of Wienerberger AG in Vienna, Austria, particularly included the following:

- Inspection of relevant documentation of the process for preparing the Sustainability-Report 2012, as well as of existing documents and systems on the sustainability management and their sample testing
- Interviewing employees materially involved in the preparation of the report contents from the departments Corporate Controlling, Corporate Engineering, Human Resource Management and European Affairs of Wienerberger AG in Vienna as well as the sustainability coordinators of the entities Pipelife and Steinzeug-Keramo
- Sample comparison for a selection of disclosures included in the Sustainability-Report 2012 according to the scope of the engagement with records provided by country organizations and recorded centrally, as well as any side calculations
- Reviewing the declaration of Wienerberger AG on the compliance with Level B+ of the GRI G3 guidelines

Conclusion

Based on our work, nothing has come to our attention that causes us to believe that the quantitative disclosures in chapter "Environmental Protection in Production" on the issues of "Energy Consumption and Emissions" (pp. 35 to 37), as well as in chapter "Employees" on the issues "Occupational Safety and Health" (pp. 24 to 27) of the Sustainability-Report 2012, in all material respects, have not been prepared in accordance with the criteria materiality, stakeholder inclusiveness, sustainability context, completeness, balance, clarity, accuracy, timeliness, comparability and reliability of the Sustainability Reporting Guidelines Vol. 3 of GRI.

Based on our work, nothing has come to our attention that causes us to believe that the Sustainability-Report 2012 of Wienerberger AG does not meet the requirements according to GRI Application Level B+.

PwC Wirtschaftsprüfung GmbH
Wirtschaftsprüfungs- und Steuerberatungsgesellschaft

Vienna, June 13, 2013



Dr. Aslan Milla
Austrian Certified Public Accountant

Imprint

Note

The Sustainability Report 2012 is available in German and English.
It is available for download from the Wienerberger website (www.wienerberger.com).

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Sustainability
gets everywhere

ÖGNI
AUSTRIAN SUSTAINABLE BUILDING COUNCIL



Sustainability doesn't end in the bank foyer. Austrian banks like ÖGNI members as the Raiffeisen regional bank of Styria and Real Treuhand rely on sustainable construction and management. They take responsibility.

3P.for.happiness

The Austrian Sustainable Building Council (ÖGNI) has been founded in 2009 of 125 founding members, including Prof. Peter Maydl and Alexander Passer of Graz University of Technology.

ÖGNI pursues the aim of a **paradigm shift towards Sustainability** in Austria's building and real estate industry.

ÖGNI develops content such as guidelines or codices, **certifies companies** in their ethical behavior and honors lighthouse projects of sustainable building with the international **DGNB certificate**.

Sustainability is practiced in a comprehensive way, applying the 3-P approach: **persons, processes** and **products** (real estate).

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The Austrian Sustainable Building Council (ÖGNB) was initiated and founded in Austria in January 2009, by a number of renowned and independent institutions in the field of sustainable building.

Membership is open to all who are interested, to institutions and businesses seeking to participate actively in supporting the Austrian building industry in compliance with sustainable building.

Testing the TQB tool

For testing purposes, please find the TQB assessment tool for both residential buildings and office buildings on www.oegnb.net. Please note that buildings cannot be saved on this site.

To make full use of the service including transfer of proof for the building assessment, you need to register as Austrian Sustainable Building Council consultant. Registration is free.

For further information and membership please contact:

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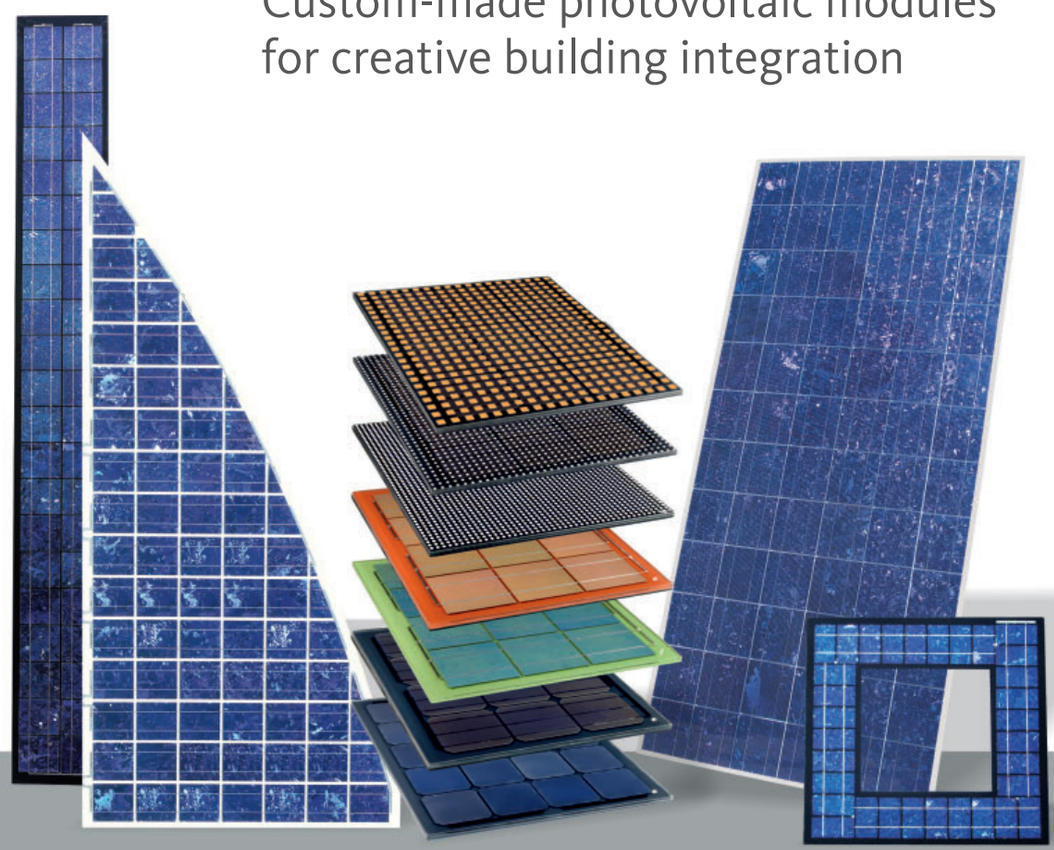
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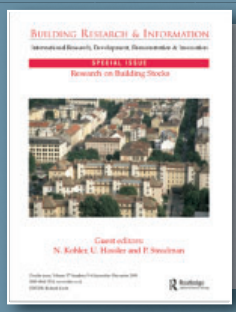
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