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262 Impacts of the level of details, shadowing and thermal zoning on urban building energy modelling (UBEM) on a district scale

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Abstract

In order to address the building sector energy efficiency improvement at the urban scale, a new Urban Building Energy Modelling (UBEM) generation is described, following a bottom-up physical model-based workflow. It is built over a shoebox paradigm to address all kind of buildings with as much data as possible, still complying with high samples of simulation to run. As a first step before calibration and using the UBEM tool for large scale energy conservation measure's impact, this study proposes to address three basic assumptions of the modelling process. The Level of Detail on the geometry side of each building is studied through the impact on the energy heat needs for LOD 1.2 and LOD 1.3, the thermal zoning resolution is compared from coarse assumption of single zone for heated and non-heated volumes up to core and perimeter zones for each floor's building. Finally, the impact of surrounding shadowing environment is computed. Two districts are considered for the three aforementioned points, both in Stockholm County, Sweden. Stockholm typical year weather file is used from IWEC. Analyses are done through the energy needs for heating only. Results show that the scale of analyses makes the differences. At the building scale, all three elements have important impact whereas at the district scale, quite few differences are obtained depending on the thermal zoning resolution or the Level Of Details on the geometry of each building. The surrounding shadowing environment is still important as up to 10% of difference is computed at the district level for on eof the two studied areas.

Keywords: Urban Building Energy Model, UBEM, Level Of Detail, Shadowing, Thermal zoning.

Introduction

The building sector is responsible for one-third of total final energy use and greenhouse gas emissions (IEA, 2016). Hence, it is one of the key areas to be addressed in order to meet 1.5°C scenario. There is a wide range of interventions available, including decarbonisation of supply, renovation of the existing building stock, low-energy requirements to new buildings. However, the current pace of energy transition for buildings is much lower than what is required to meet national and local climate commitments. In order to address the challenge of making the building sector improve its overall efficiency, new paradigm and tools are needed. There is a strong need for integrated models and tools that would allow assessing the benefits and drawbacks of each urban energy intervention in a holistic way to all involved stakeholders. Urban Building Energy Modelling (UBEM) has emerged recently as a bottom-up approach to city-scale building energy modelling (Reinhart and Cerezo Davila, 2016). A number of attempts to address the issue of scale for UBEMs have been done (Ferrando et al., 2020), including different approaches to align the models with measured data at the urban scale through automated calibration (Sokol et al., 2017; Wang et al., 2020). It is different from a simple aggregation of building energy models (BEM) as it imposes automated creation of simulations involving larger amounts of structured data and simplified representation of individual buildings. In the UBEM field, physicssbased, multizone dynamic models, are still required to evaluate detailed urban design scenarios as well as urban scale building rhetoric analyses, even though such models could be seen as too detailed for such scale of analyses, (Reinhart and Cerezo Davila, 2016). However, multizone dynamic thermal simulation can be time-consuming when too high thermal zoning resolution is needed, besides the amount of available data might be a bottleneck for introducing higher spatial resolution in the energy modelling.

Therefore, a balance between required data and model accuracy is a key issue for UBEMs. Many studies utilize archetypes (representative building for a group of similar buildings) to diminish the number of simulations needed on a city scale (Cerezo et al., 2017, 2015; Pasichnyi et al., 2019).

However, quite a few studies investigated the basic assumptions for the mandatory UBEM inputs. Particularly, three aspects are regularly highlighted to have a crucial impact on the quality and applicability of the derived UBEMs, namely a) level of detail (LOD) of buildings' geometry (Biljecki et al., 2016), b) shadowing effect of the surrounding environment (Nikoofard et al., 2011) and lastly, c) the thermal zoning (Chen and Hong, 2018). This study aims to explore the impact of these three factors on the accuracy of district-level UBEMs based on preliminary learnings from modelling two districts in Stockholm, Sweden.

Regarding previous studies, the main novelties given from this new generation UBEM come from 1) the methods used to catch the surroundings shadowing environment for each building and 2) the ability of the workflow to automatically generated Functional Mock-up Unit (FMU) from each building in order to address, at a district scale operation issues on either electrical or heating networks. Co-simulation is mandatory in such cases and FMU is one of the easiest ways to make model communicate at each time step along the simulation period.

Three core steps could be distinguished in the overall process: 1) the data gathering process, 2) the 3D geometry construction, including external shadowing surfaces, its conversion in dedicated file format (GeoJSON) and 3) the energy modelling parts which has to comply with all kinds of building and data embedded in the main input GeoJSON format file. One file is computed for an entire urban area to be modelled.

In the following section, the new generation UBEM workflow is presented in detail, trying to be as close as possible to a shoebox paradigm, to comply with all kinds of building and equipment, followed by the two studied areas to address the three aspects mentioned above. The gathering data process, which is a key part of the UBEM workflow, is presented within these two areas to give insights of different sources used to gather the required data for the energy modelling parts.

UBEM Workflow

Bottom-up physical based UBEM workflow is about how can input data form large open-source database be embedded in a general and common framework to model all buildings in a given urban area. At such scale, the energy modelling of buildings can be subdivided into two levels: the building level and the zone level. The first one requires at least a geometry description, surrounding environment, thermal zoning, and some elements that enable to represent the building envelope performance. The related inputs could be seen as the static ones for the UBEM workflow (like envelope materials, number of floors, surrounding environment, for example). The zone level requires occupancy related inputs and indoor elements that have dynamic impact on the energy needs. In a same way, the related inputs could be seen as the dynamic ones for the UBEM workflow. Considering an entire building, equipment units for heat or cool production are allocated at the zone level, as several types can be present in the same building. Following the same paradigm, envelope leaks are assigned at the zone level as these have time dependent impacts and can be differently addressed depending on the type of zone (heated or non-heated).

The current UBEM workflow is compatible with either building per building simulation approach or archetype from building segmentation approach. In both approaches, a physics-based model needs to be defined with as many elements as possible to represent either the building or the archetype (representation of a sample of buildings). This current UBEM workflow is based on Python 3 and EnergyPlus respectively for the structuring process and the thermal core engine. All processes (input ASCII files and dynamic thermal simulations) take benefit of multiprocessing capacities. The entire process is freely available in https://github.com/KTH-UrbanT/MUBES_UBEM. The UBEM workflow is presented in the following section respectively to the two aforementioned levels – building and thermal zone.

Building Level

This level is about geometry definition, envelope characteristics, thermal zoning and surrounding environment. Each are presented separately in the following sections.

Geometry definition

Buildings are defined though polygons for each external surfaces, these are gathered from photogrammetric point cloud approach. Some filtering processes are done at this stage and two methods can be designed for either making LOD1.2 or 1.3 in the 3D building model considering the classification proposed in (Biljecki et al., 2016).

What is the main pros and cons of making either LOD1.2 and 1.3 (the approaches that we called 2D and 2.5D). it has to be linked to the results section where LOD1.3 can bring valuable aspect on computing the energy needs (shape factor can be strongly affected)

In the results section, the impact of dividing one building into several blocs (LOD1.2 to LOD1.3) is quantified for one specific district.

Envelope characteristics

Building envelope is simplified into two components for the two main thermal effects that are insulation or inertia, respectively. All constructions are supposed to be composed of one or two layers maximum, thus, giving the ability of simulating either lightweight materials or heavy ones and with either external or internal insulation. This simplification is compatible with the UBEM levels as there is no need to get into several layers with small effect. The counter part is that the input database should consider equivalent material for typical constructions methods depending on the year of construction or specific renovation action for each building. The equivalent material definition shall follow the resistance/capacity paradigm from similarities with electricity, for layer in series as 1D conduction is still considered. The layers are thus composed by one single material for which the three main thermal properties, aside from the thickness, are required (density (kg/m3), the thermal conductivity (W/K/m) and the calorific capacity (J/K(kg)). Surface's radiative properties can also be defined at this stage if specific effect is to be considered like special paintings or metallic surface layers. Windows are part of the envelop. The input of windows to wall ratio (wwr) is used to automatically compute the height of windows. Window spreads from both sides, on each external facade.

Thermal zoning

Several options of thermal zoning are proposed form the single zone for heated and non-heated volumes up to the multizone option on each floor, splitting the area into a core zone and as much as perimeter zones as required. In case of single zones for heated and non-heated volumes, the inputs are corrected to still consider the entire heated floor areas using floor-multiplier factor. An automatic algorithm has been developed to ensure the multizone definition. Depending on the perimeter depth, perimeter zone definition is automatically realized starting from each edge delimiting the core zone. A threshold on the resulting edge length, defined by default as half of the perimeter depth, is integrated to the core zone perimeter. This enables to avoid having to too narrowed zone angles or too small zones. Then, triangle zones (having a single vertex on the external polygon) is not allowed except for the last perimeter zone definition, closing the loop over the core's edges. Thus, perimeter zones with more than one edge in common with the core zone are allowed. The perimeter depth starts at 3m by default and is reduced by half if some issue is encountered in the process. Figure 1 present the thermal zoning option and its relation to the perimeter depth on two types of building. The process could be optimized further as non-convex zones are currently allowed (all external non-convex surfaces are still split into convex ones for the sake of shortwave multireflection, see Surrounding environment below). Nevertheless, non-convex zones are mandatory only if internal shortwave multireflection is requested, which are out of UBEM field of interest. Besides and still linked to the building scale, no internal architecture is available in any available database. The core and perimeter zone would be needed only to better catch discrepancies between southern and northern oriented surfaces. In such multizone definition, partition walls shall be defined but without adding any inertia nor limitation in the heat transfers at the floor scale. The current workflow has been developed using EnergyPus 9.1 for which the common definition of partition airwall is done through a thin highly conductive material. A new object is introduced in version 9.2.0 and will be implemented in the following release of the UBEM workflow. Nevertheless, the results with the partition assumption used show very close results for the different thermal zoning option as shown later in the results section.

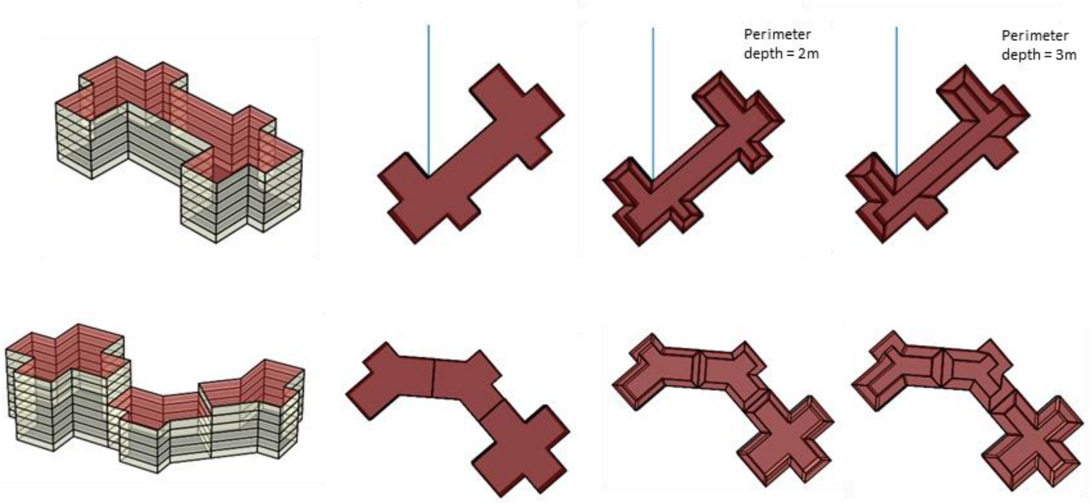


Figure 1. Thermal zoning, single zone and core perimeter zone with 2m and 3m of perimeter's depth. Example for LOD1.2 case (top) and LOD1.3 case (bottom)

Surrounding environment

Even though each building is modelled separately, the surrounding environment is considered through its shadowing impact on each building. The shadowing is automatically dealt in EnergyPlus for external surfaces defined as shadowing elements. External surfaces can receive and reflect shortwave radiation. Long wave radiation is not taken into account as it should require computing the view factors between each surface of the building and the surrounding ones before simulation and then to use an iterative approach to catch the heat fluxes between surfaces at each time step. Some proposal of iterative method have been done by (Luo et al., 2020) and maximum effect of 3.6% of decreasing effect on the heat needs is observed upon different locations in US. In the current UBEM workflow, all external surfaces of each building are considered one after the other and all visible surfaces belonging to other building are reported. Then, depending on a distance's threshold form the building's centroid, all surfaces closer than the limit are kept and modelled as shadowing surfaces in EnergyPlus. Figure 2 illustrate for one random building the effect of the distance threshold on the modelling process.

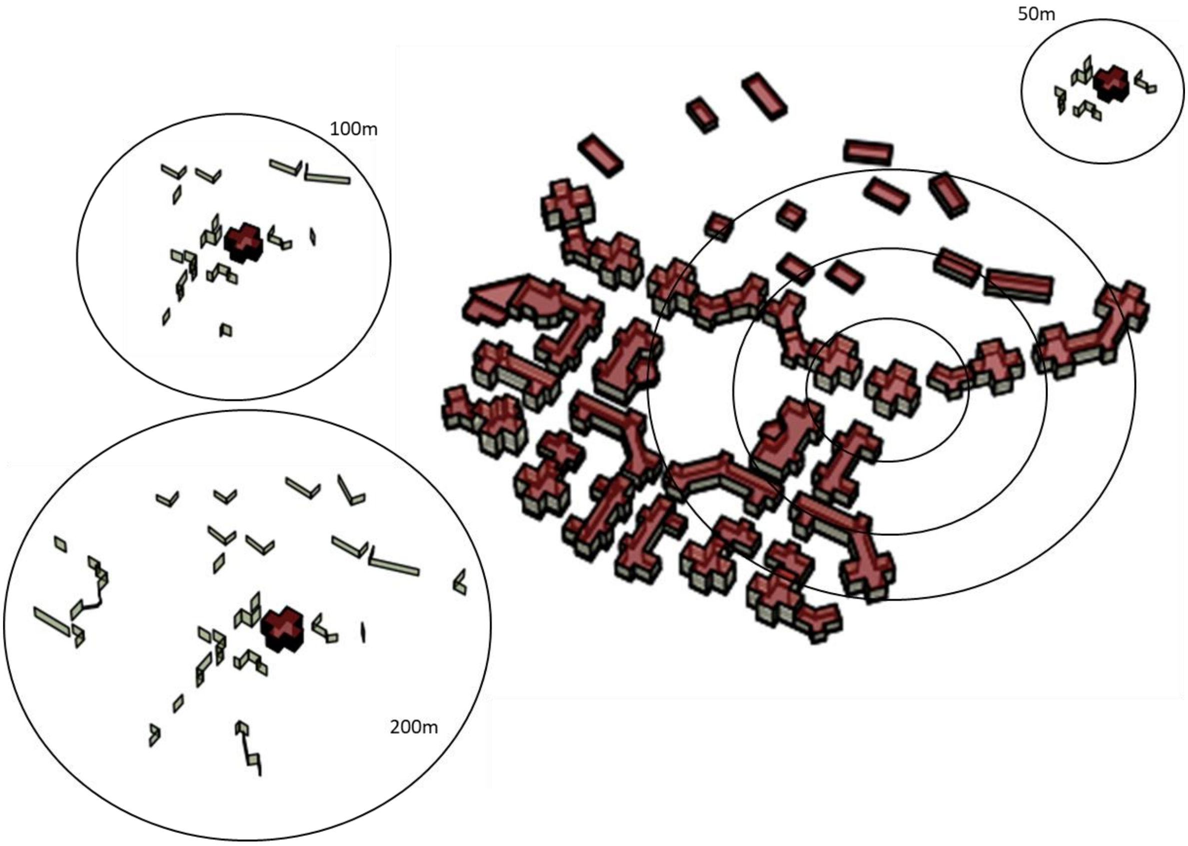


Figure 2. Shadowing effect of the environment based on a distance threshold (50, 100 and 200m around a random building).

At a district scale, the effect of surrounding cannot be estimated for each building thus some systematic threshold should be considered for all buildings. Parametric simulations for two different districts are reported in the results section.

The Zone Level

This level is about all local elements that has impact in the energy balance of each zone, at each time step. Thus, even if some element could be linked to the building, like envelope leakage, these are included here as depending on the over whole external envelope areas of each zone. Figure 3 represents the different required inputs at the zone level. Each of these are presented separately in the following sections.

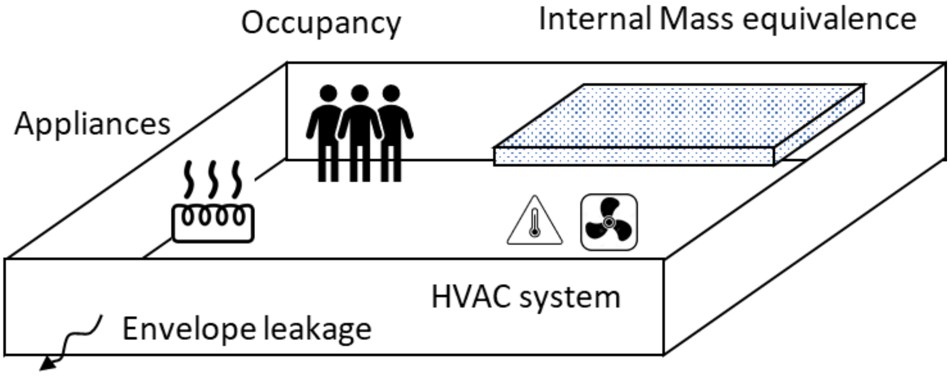


Figure 3. Schematic inputs representation at the zone level

Internal Mass equivalence

Internal mass is the effect of indoor furniture and partition walls on the indoor temperature dynamics. These are of greater importance in UBEM assumptions as internal architecture is not modelled. All floors are fully open spaces in which area-based elements are to be defined. Internal mass is defined through a material with classic thermal properties, a weight per square meter and a surface of exchange with the current zone. The default values used in the current UBEM takes 40kg/m2 of an equivalent material with thermal conductivity of 0.3W/K/m, density of 600kg/m3 and specific heat of 1400 J/kg/K. The surface is automatically computed to be twice the specific area taken form the volume divided by the thickness of the material (taken at 0.1m by default). This definition uses the floor-multiplier in case of single zones for heated and non-heated zones.

Envelope leakage

Envelope leakage is an important parameter, that is influenced by thermal gradient and the zone’s height (hydrostatic pressure gradient, thus considering stack effect). EnergyPlus infiltration model with flow coefficient enables to consider several elements as influenceable factors, such as stairwells, urban area density and building’s height. In the current process, the equivalent value given in l/m2 at 50Pa is converted using a value of 0.667 on pressure exponent value in the power law. The influenceable parameter are given in the EPC’s templates in Sweden.

For non-heated zones, being generally below ground level, an air change rate is defined per volume as no outside boundaries does not refer to external environment (but contact with ground temperature).

HVAC System

The Heating, Ventilation and Air Conditioning (HVAC) system is limited in the UBEM workflow to the used energy. This means that the energy carriers and their production and distribution efficiencies are not taken into account in the zone level, but rather in the post-treatment and calibration process as described further. On the opposite, the different ventilation systems, being either fully exhaust or balanced with heat recovery, are taken into account through the amount of incoming fresh air as these are direct sinks in the energy balance. Thus, the equivalent *shoebox* HVAC model is considered as an Ideal Load Air System that computes, for each zone, the needed energy to matches the internal temperature set point. Figure 4 presents a schematic view of such system. If heat recovery system is to be modelled it will raise the temperature of the incoming fresh air. Thresholds, if available, either in the supplied air temperature or compensation mass flow rates of the overall supplied power, can be given as inputs to better catch the heat needs of each zone. The heating and cooling supply will correspond to the external needed energy, at each time step, for this zone to comply with its temperature set point. The temperature set point can be defined as constant or can follows fixed schedules with day and night times or can be defined through external files on an hourly basis. In the current UBEM workflow, each zone has an HVAC system. The different inputs for the *shoebox* HVAC model are gathered from the database. Heat recovery is only considered through sensible heat exchange.

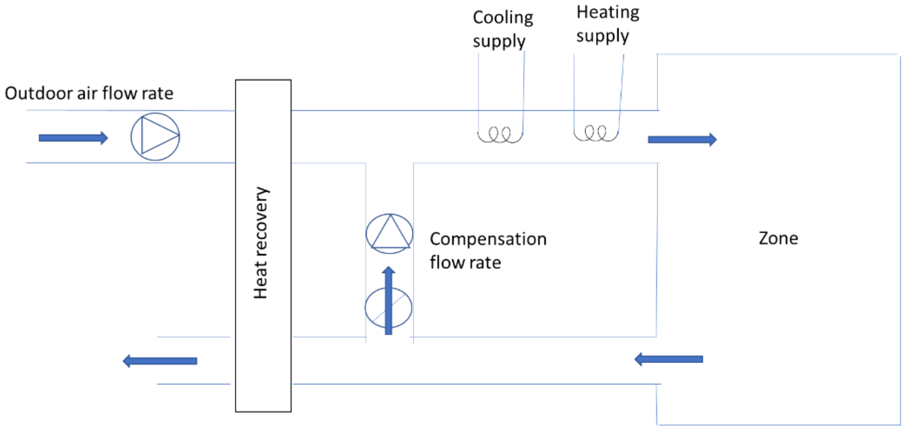


Figure 4. Schematic view of the Ideal Load Air system

Occupancy

In the current UBEM workflow and as domestic hot water needs are considered in the post processing stage (presented in a dedicated section further), occupancy rate usage is limited to non-residential types of buildings. All but residential type of buildings generally has extra air change rates based on the number of occupant and in these, the heat released by occupant (taken constantly at 70W per occupant in the current UBEM) raises above levels that are no more negligible. In residential type of building, occupancy's impact can be embedded in the appliance's energy needs presented further. The number of occupants is based on occupant density defined for the different occupancy types (except residential). Two options are available using either the maximum density or an hourly random beta distribution-based number of occupants. Time schedules are also implemented for all but residential occupancy types. Opening hours are defined as inputs to compute the number of occupants.

Appliances

The energy needs and thus released by internal appliances is of great importance to compute the building heating and cooling needs. On a yearly basis, these can be defined as internal loads in W/m2 but as energy needs are dynamically computed, there is a need to define a higher resolution for internal loads. Several options are available to define either constant needs (the loads will remain the same for each time step for the entire simulation period), or seasonal based needs with variable slope possibilities. The appliances energy consumption is modelled as fully electric equipment and thus all the loads are injected as internal heat gains in the different zones. Figure 5 presents the different profiles computed form the year basis consumption. Depending on the input database, yearly electric consumption can be gathered. In such case, internal load profiles are computed with respect to this yearly data.

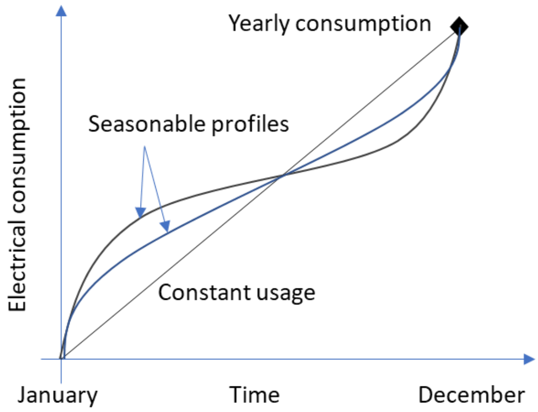


Figure 5. Internal appliances profiles

Domestic Hot water

The current UBEM workflow assumes no strong coupling between the domestic hot water (DHW) network and the building energy balance. Thus, the requirement for modelling DHW is given by potential available measured data, that would embed DHW needs with heating needs, for calibration. In such case, the related energy needs for DHW are modelled through a simple water use equipment. The hot water temperature supply is fixed to 55degC (can be define in the database), incoming cold district water temperature is still given as a time series input (or taken constantly) as well as the water taps resulting in the energy needs for DHW. As DHW might me considered only for the calibration stage, the FMU's option (see co-simulation environment section further) of the current UBEM could be worth of interest to compute the water taps the diminish the discrepancies between measured and simulated energy needs in non-heating periods.

Calibration

Even if UBEM is not a simple aggregation of BEM, the calibration process remains mandatory. The calibration process that bests fit with UBEM constraints might be the probabilistic calibration. Indeed, even though simplifications are realized compared to BEM, many inputs are still needed and with higher uncertainties than for BEM. The UBEM process needs to address all the different buildings with the same process. Even though missing inputs could be more or less the same for a full sample of building, the calibrated inputs will definitely be different. Among the probabilistic calibration, the Bayesian iterative process is promising as it can automatically adjust the exploring ranges of missing inputs to each building.

The UBEM workflow described above is fully compatible with probabilistic calibration. It offers the option of making numerous of simulation with Latin Hypercube Sampling (LHS) of any input parameter for the sake of either sensitivity analyses or calibration process. Such a calibration method has been applied for Hammarby district with hourly measured data. Nine parameters from both static and dynamics inputs were considered.

Co-simulation environment

The current UBEM workflow is aimed to be used either for making district-city energy analyses of current state, retrofitting actions, generating sample of simulations for the sake of calibration but also to analyses, at a district level option, different operation strategies on either the electric or heating network. In order to make co-simulation, functional moke-up unit (FMU) are to be built and used in a dedicated environment. The FMU toolkit for Energy plus is embedded in the UBEM workflow and enables to automatically create FMUs of each building in the input file. Of course, as specific inputs / outputs will have to be defined in the process that matches with the controlled parameters ones want in the co-simulation. Two examples of co-simulation process are proposed in the UBEM workflow using the indoor temperature set point and the DHW taps as inputs at each time step. The environment used to make the co-simulation is FMI++.

In the following sections, parametric simulations, using the above described UBEM workflow, are presented to highlight the impact of the level of detail in the geometry process, the thermal zoning impact and the shadowing impact of the surrounding environment. Two different districts in Stockholm County are taken for the sake of illustration. A first sections section presents the two districts, followed by the database construction process to gather as much element as available for these two districts. The results from the simulation are presented in a last section.

Case study

Two different districts of considered in the following to make the parametric simulation. Both districts are mainly residential but most of the building include some small percentage of non-residential occupancy type. After a brief description of the two districts, the data gathering is presented. Results from parametric simulation are finally presented.

District's presentation

Minneberg district and a part of Hammarby Sjöstad are composed of 33 and 45 buildings, respectively. Figure 6 Presents the two districts used as studied cases with current the UBEM workflow. Only Minneberg is used for the impact of level of details while both are used for the thermal zoning impact and the surrounding shadowing impact on the energy heating needs (EHN). For both districts, the same database workflow is used to gather the available information needed to build the cases in the UBEM workflow.

After presenting the data gathering process, the results are presented and discussed.

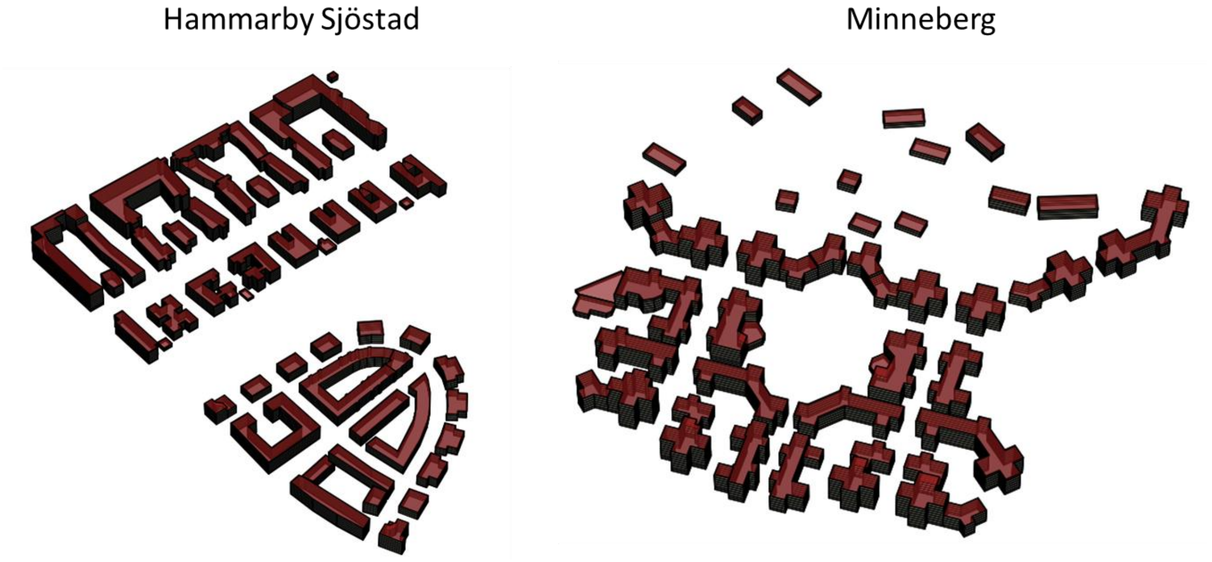


Figure 6. Districts considered in the parametric simulations.

Data Gathering process

As said earlier, data scarcity remains the most difficult part of any UBEM tools. The most related database to UBEM remains the energy performance certificate. Being mandatory since a few decades now, the amount of available data continuously growth among years. Different levels of information are available in EPCs for different countries. In Sweden, EPCs are required every 10 years with one full year of measured data on the energy consumption for the different needs (heating, cooling, domestic hot water, electricity, subdivided into collective and private areas). These are generally obtained by installed meters for the purpose of the EPCs while some other could be done using the yearly purchased energy through invoices analyses from the energy suppliers. Thus, EPCs include measured energy consumption and some details on the geometry, the occupancy type, the installed equipment and the energy carriers. A counterpart is small renovation either in the building envelope, or its equipment might create discrepancies between the available information and the real situation of each building.

This main database, from EPCs is cross checked and enriched by other sources. Building and property cadastres, 3D city models and national climate database are also considered in the overall input database for the current UBEM workflow.

The urban area of interest, including geometry and all gathered properties, are compiled into GoeJson files. Python is used for the building process of the input files and launch Energy Plus for each building defined in the GeoJson file. Both input file and simulation processes are using the multiprocessing capacities of python.

Level of detail impact

In this section, Minneberg district is particularly used to illustrate the impact of level of detail in the building geometry. The climate of Stokholm, Arlanda airport is used from IWEC typical year database form ASHARE. Level of detail LOD 1.2 and LOD 1.3 are considered. These two require different point cloud approaches and cleanings before being able to be integrated in the UBEM workflow. Figure 7 presents two examples to illustrate the differences between LOD1.2 and LOD 1.3. Even though EHN are generally divided by the heated area, the external envelope's surface and the solar gains are different in the two assumptions leading to different heat gains and losses.

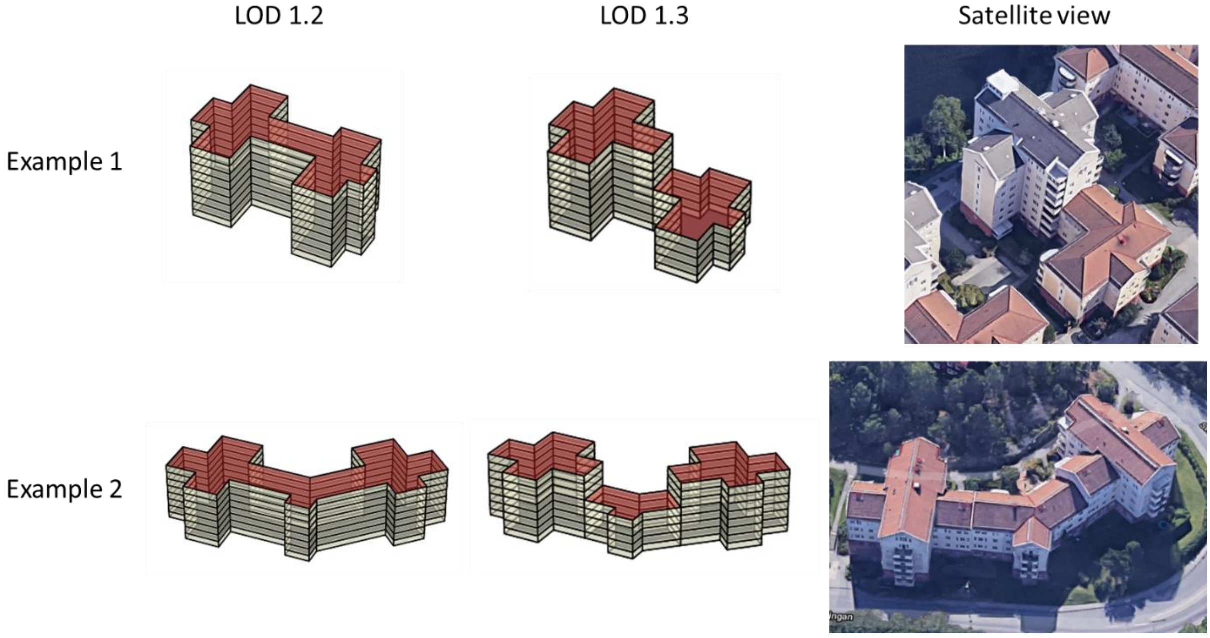


Figure 7. Examples of LOD 1.2 and LOD 1.3 models compared to satellite views.

Figure 8 presents the relative error between LOD1.2 and LOD 1.3 for Minneberg district (LOD 1.2 being the reference). Only 23 buildings are present in the comparison as some were not available in the LOD1.2 format. Nevertheless, results show that even though the majority of discrepancies remain below 4%, some specific buildings show up to 10% higher heat needs with LOD1.3 than for LOD1.2 (buildings 8 and 9 in Figure 8). The two highest differences are observed with around 20% higher shape factor for the same buildings (**Figure 9**). Thus, at the UBEM scale, keeping LOD1.2 could lead to 10% extra discrepancies in the EHN of some buildings. But the on the overall district, the difference remains below 1% (0.76%). Thus, the level of details might be irrelevant at the UBEM scale. But the extra effort catching LOD1.3 is worth of interest in the context of computing impact of ECMs or in the calibration steps as these 10% of extra EHN should have been compensate by wrong calibrated inputs.

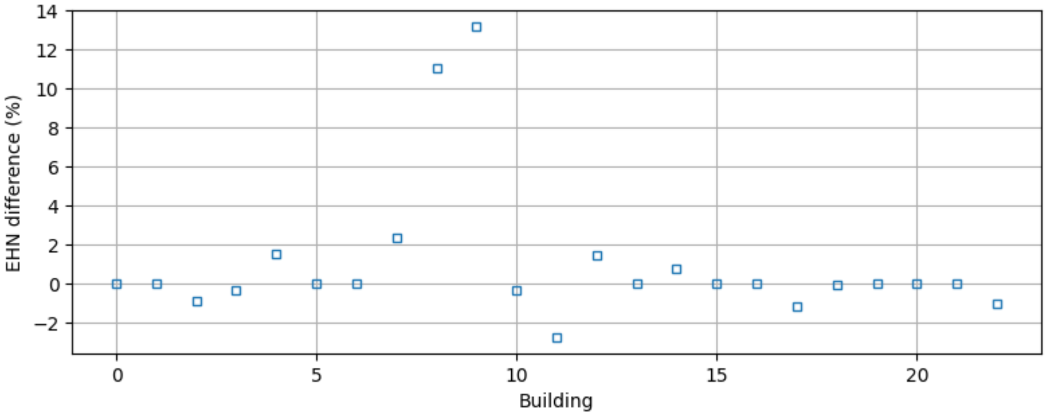


Figure 8. EHN differences between LOD 1.2 and LOD1.3 taking LOD 1.2 as a reference.

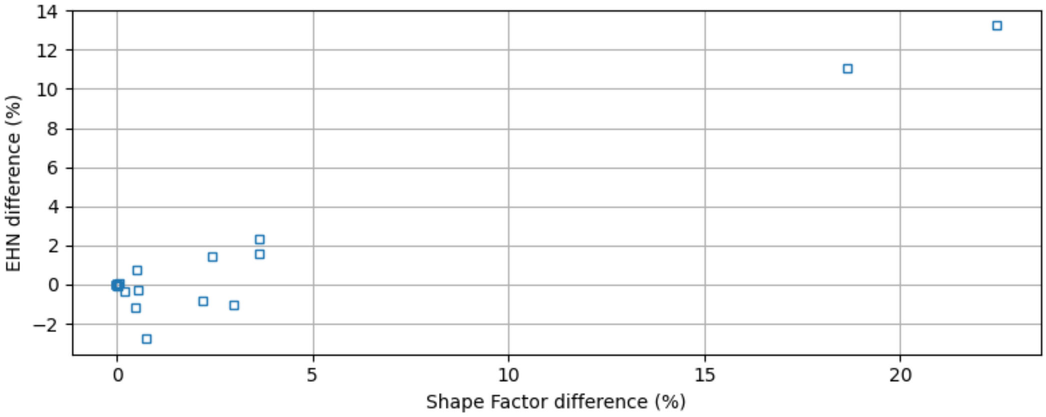
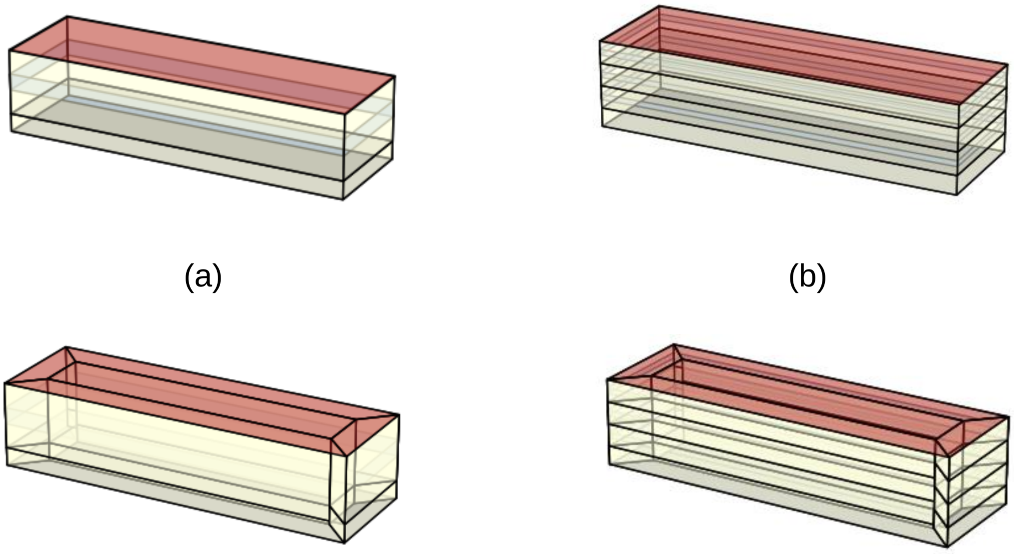


Figure 9. EHN differences between versus shape factor difference of LOD 1.3 versus LOD 1.2 taking LOD 1.2 as a reference.

Thermal zoning impact

This section present, for the two districts described above, the impact of different thermal zoning resolutions. For illustration, Figure 10 present the different options available in the UBEM workflow on a simple building.



(a) (b)

(c) (d)

Figure 10. Four thermal zoning option, applied on a simple building with 3 storey and 1 floor basement: (a) Single zone for heated and non-heated volumes (b) single zone per floor (c) Core and perimeter zones on (a) configuration and (d) core and perimeter zones on (b) configuration.

The same paradigm of floor multiplier is applied as in (Chen and Hong, 2018) for option (a) and (c). The core and perimeter zone definition follows the algorithm presented above. All element but the thermal zoning remains the same among the different simulations presented below. Impact of thermal zoning is illustrated regarding the EHN.

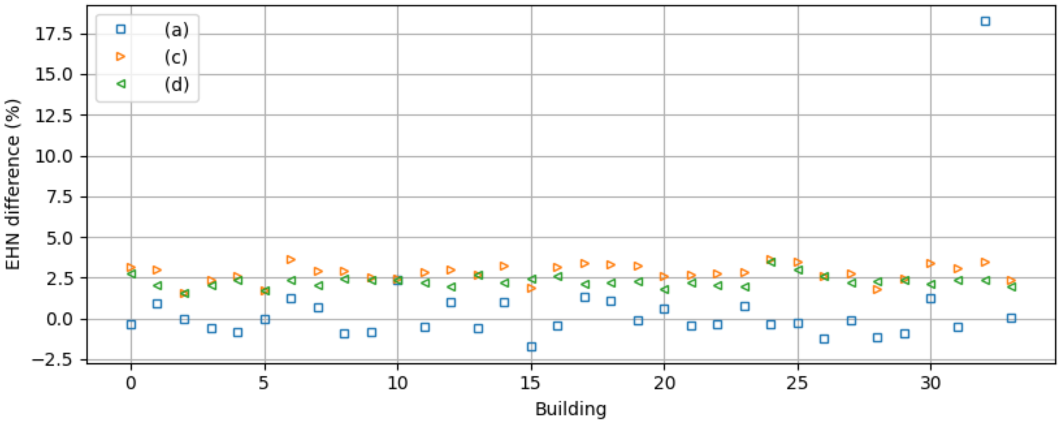


Figure 11. EHN differences based on thermal zoning option (b) and for Minneberg district in LOD1.3 geometry modelling option.

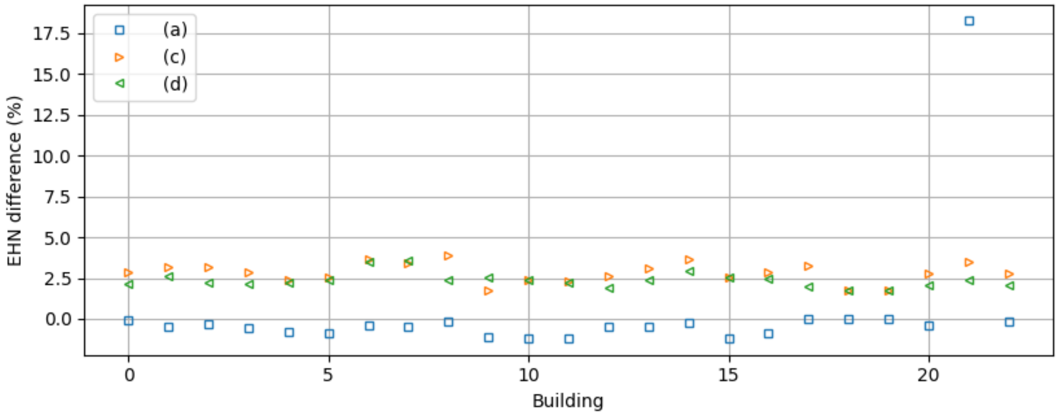


Figure 12. EHN differences based on thermal zoning option (b) and for Minneberg district in LOD1.2 geometry modelling option.

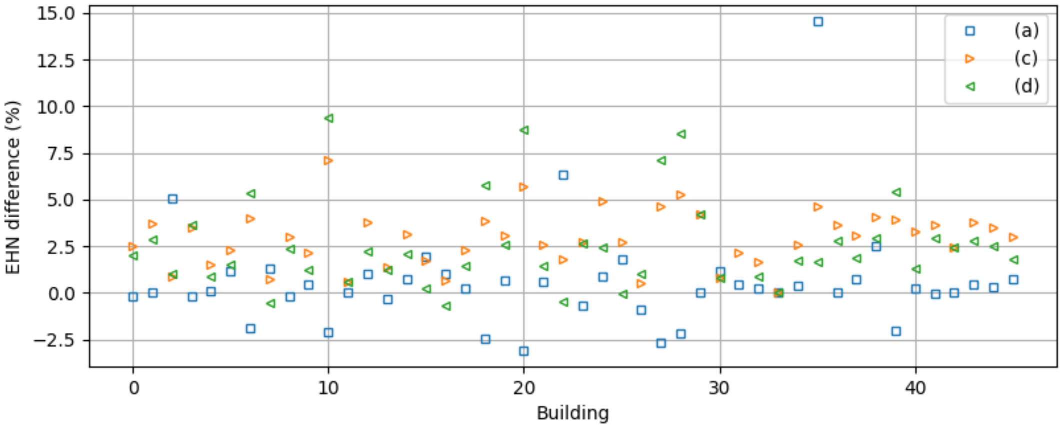


Figure 13. EHN differences based on thermal zoning option (b) and for Hammarby district in LOD1.3 geometry modelling option.

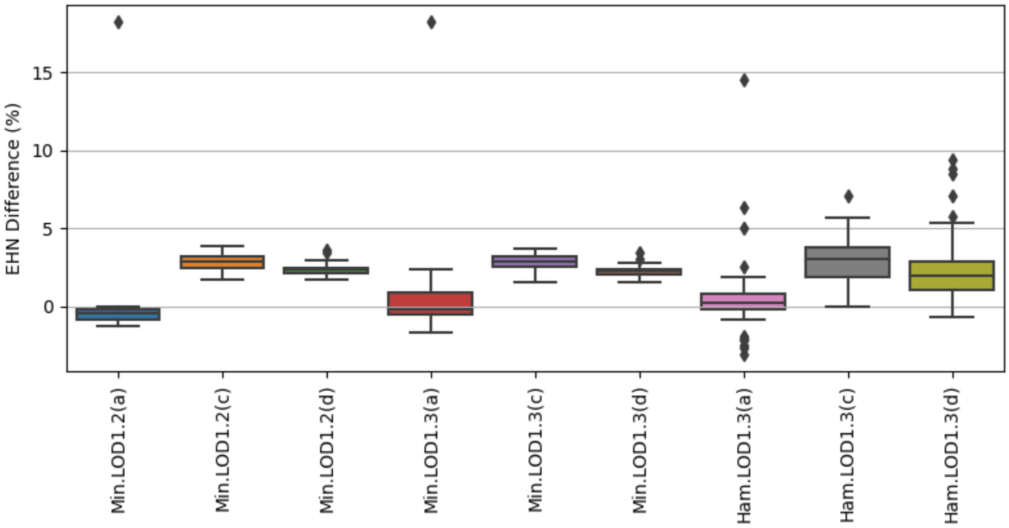


Figure 14. Box plots of the EHN difference for the three cases

Table 1: EHN difference on the cumulative demand at the district scale

	Min. LOD 1.2 (a)	Min. LOD 1.2 (c)	Min. LOD 1.2 (d)	Min. LOD 1.3 (a)	Min. LOD 1.3 (c)	Min. LOD 1.3 (d)	Ham. LOD 1.3 (a)	Ham. LOD 1.3 (c)	Ham. LOD 1.3 (d)
Total EHN differences (%)	0.5	2.7	2.3	0.7	2.8	2.2	0.9	2.7	2.0

The different figures, for the three cases (two districts and LOD1.2 and LOD 1.3) shows the same trends. The configuration with single zones for heated and non-heated volumes remains to the configuration with one zone per floor configuration, the core and perimeter zone raises the EHN by a small amount. These results match with earlier obtained results for similar studies (Chen and Hong, 2018).

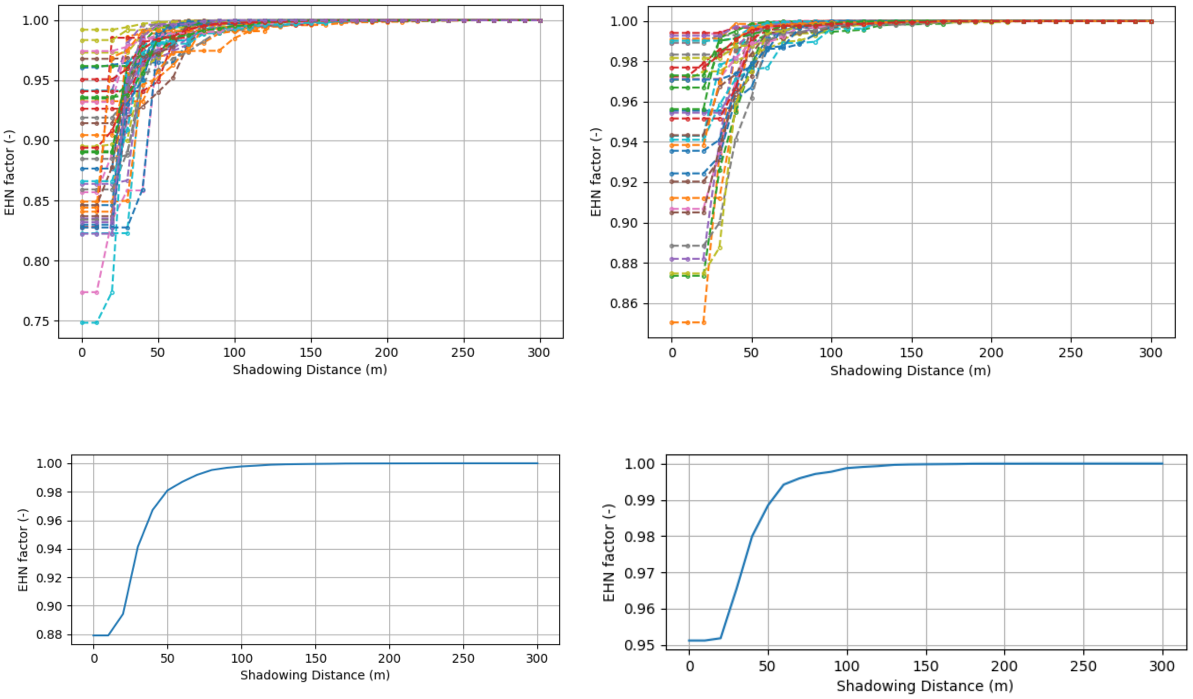
Here again, at the district level, considering the different option might be strictly equivalent and not worth of interest. But the strong discrepancy that remain for some building is still of concerns for either catching retrofitting aspect or just calibrating missing inputs for these specific buildings. While large extra time were required for the core and perimeter zone on each floor, the one zone per floor or the core and perimeter zone with the floor-multiplier are suggested for UBEM studies.

This particularity on specific buildings has not been explained from now, why this building especially was different from the others…

Surrounding shadowing environment

As presented in the building level's presentation section above, a threshold can be defined above which surrounding building are no more taken into account. For the two described districts with LOD 1.3 and one zone per floor configuration (option (b)), parametric simulations are realized for all the buildings in each district.

Results on EHN are presented for each building and aggregated at the district scale. The EHN factor represents the ratio of the EHN for each shadowing distance over the maximum EHN computed for all shadowing distances. As expected, as more shadowing impact are considered as more EHN is computed. From **Figure 15**, even though for both districts, some building shows an important dependency on shadowing effect of surrounding environment, aggregated results at the district level are quite different. 5% of difference can be found for Minneberg while 12% of EHN difference is computed for Hammarby at the district scale. Some threshold for both districts could be held form those results. Difference below 2% could be computed with all shadowing surfaces within 50m from building's centroid while all surfaces farer than 150m does not seem to have any effect on the district level, at the building level a threshold of 200m could be kept.



(a) (b)

Figure 15. Shadowing distance threshold impact for each building in the 2 considered districts (a) Hammarby, (b) Minneberg and all building (top) entire district (bottom)

Conclusion and discussion

A new generation UBEM workflow has been presented. It has been developed under python environment for the management process and uses EnergyPlus as the thermal core engine. The gathering data process includes the geometry photogrammetric point cloud methods. The UBEM process undertake physical building energy modelling, thus, following a building per building approach at the district scale. Data are organized into a GeoJson structure file with polygons for all building's external surfaces and different properties gathered from several database. It tries to follow as much as possible a shoebox model all along the process as shown for the HVAC system, in order to comply further with other format of data file. The UBEM workflow has been used to highlight the importance of level of details on the geometry side, the impact of thermal zoning and shadowing effect of surrounding environment. From the two districts considered in this study, the following conclusions can be held:

On the level of details: the LOD 1.2 and LOAD 1.3 can lead to quite different shape factors for each building and might be worth of interest as its impact on the EHN might be not negligible on the building level. On the district level, and depending on some district typology, LOD1.3 might not be required. For the specific studied district, the overall difference at the district level remains below 1% even though up to 10% could be computed for some specific buildings. As extra effort to compute LOD1.3 might not be important, the authors would still advice to keep as much as possible this level of modelling geometries.

On the thermal zoning: As shown also by earlier studies, the thermal zoning effect at the district level remains below 5% of difference despite some strong effect for some specific buildings. The single zone option for heated and non-heated volumes is still to avoid as is not recommended by any standard. Applying a core and perimeter zone can lead to closest results to a classic one zone per floors option.

On the surrounding shadowing environment: for two districts with quite different types of building geometries, up to 12% of EHN differences could be computed, with the lowest EHN the lowest shadowing distance threshold. At the district scale, EHN difference below 2% were observed for shadowing environment up to 50m to the building's centroid and surfaces farer than 100m does not seem to have any effect at the district scale on both studied areas. At the building's scale, this threshold is raised to 200m. As extra computing time is negligible, the authors would advice to keep 200m for all simulation.

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