SUSTAINABLE ENERGY CONSUMPTION

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ABSTRACT

This paper discusses the importance of implementing photovoltaic systems in tunnels to reduce operating costs and contribute to global climate targets. The amount of electricity consumed in a tunnel depends on various factors, with energy requirements typically highest during the day. Different options for installing PV modules are explored, considering factors such as orientation, sizing, and dimensions. A case study of the Schönberg noise protection gallery in Austria demonstrates how a photovoltaic system can help cover a tunnel's consumption needs and even generate surplus energy.

Furthermore, the paper explores sustainable cooling methods for electrical rooms in the North Operations Building of the Kramer tunnel in Germany. By utilizing fire water and groundwater as cooling sources, the study aims to enhance energy efficiency and reduce operating costs. The design includes a detailed analysis of cooling load calculations, investment costs, and amortization times for the proposed systems. Results indicate that while initial investment costs for groundwater cooling may be higher, the long-term operational savings make it a more cost-effective and environmentally friendly option. This research contributes to the development of sustainable cooling technologies for electronic infrastructures, with potential applications across various industries.

Keywords: Renewable Energy Sources, Sustainability, Photovoltaic Systems, Cooling Systems

1. INTRODUCTION

In the current period of energy transition, there is great interest in finding ways to sustainably generate electricity from renewable energy sources, especially for public infrastructure. In this context, the use of solar energy to supply tunnel systems, especially enclosures, with electricity, makes a valuable contribution. Another example of how available resources in the vicinity of tunnels can be optimally used, is the use of fire water and groundwater (water from inside the mountain) to cool the electrical equipment in operations buildings.

2. PHOTOVOLTAIC SYSTEMS

The amount of electricity consumed in a tunnel has a major impact on its annual operating costs, not only because of ever-increasing energy prices. Electricity consumption generally represents a high proportion of tunnel operating costs. In order to reduce these costs and also contribute to global climate targets, it is necessary for tunnels to be as self-sufficient as possible in terms of their electricity consumption to cover their own electricity consumption needs as best as possible. There are often many areas around tunnels where it is suitable to install photovoltaic (PV) systems to cover the respective tunnel's own consumption needs. This paper explains the different options for installing PV modules and the influence of the orientation as well as sizing and dimensions of photovoltaic systems.

2.1. Typical Tunnel Load Profile

The amount of electricity consumed in a tunnel depends on many factors, such as the length of the tunnel, the ventilation concept, traffic monitoring and control, and other technical components. Typically, the amount of energy required is highest during the day and reaches a minimum at night. The amount of energy required for lighting at the tunnel entrance depends in particular on the amount of solar radiation. The higher the level of solar radiation, the more powerful the lighting needs to be in order to maximise the ability of our eyes to adapt to the lighting conditions in the tunnel.

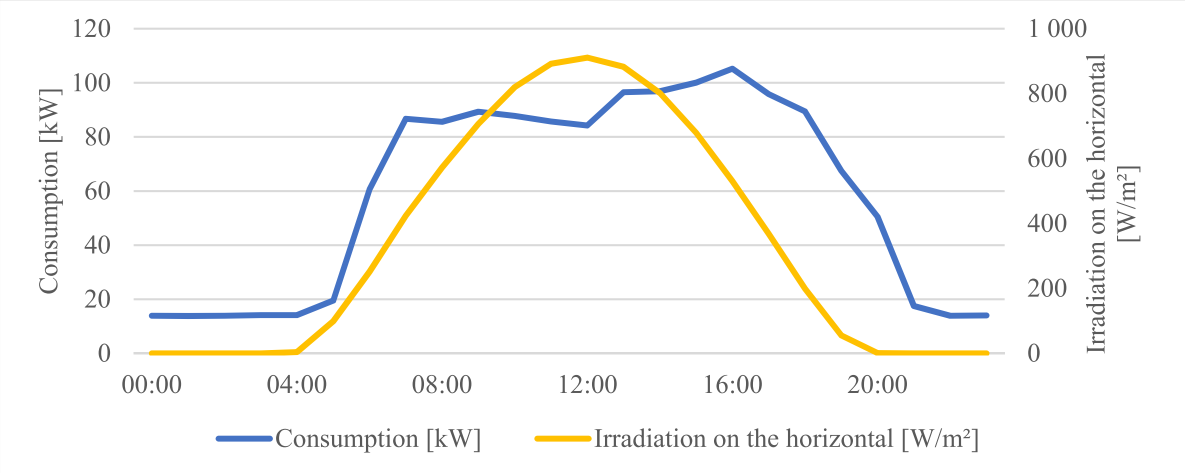


Figure 1: Typical Tunnel Load Profile on a sunny day in June

2.2. PV Module Installation Options for Tunnels

There are a variety of options for installing PV modules in the vicinity of tunnels, a description of which is given in the table below. The options are defined on a project-specific basis according to the local conditions and from an economic, operational and maintenance point of view.

Table 1: Photovoltaic substructures for open spaces

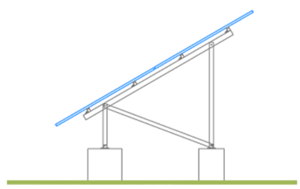
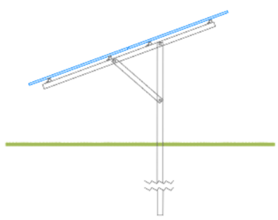
Open Spaces	
	Installation on Concrete Foundations Used in open spaces where there is insufficient cover/overburden to use a rammed system; the substructure is ballasted with concrete foundations. E.g. Cut-and-cover tunnels and galleries
	Rammed Systems Used in open spaces with an inclination of up to 20°, where posts can be driven into the ground. E.g. Areas on top of or in front of tunnels

Table 2: Photovoltaic substructure for slopes and anchor walls

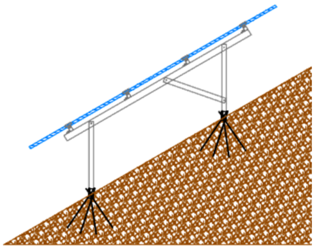
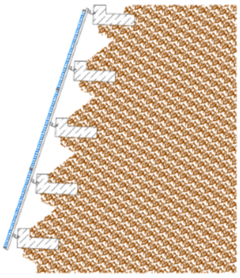
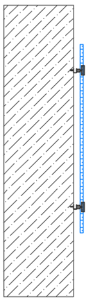
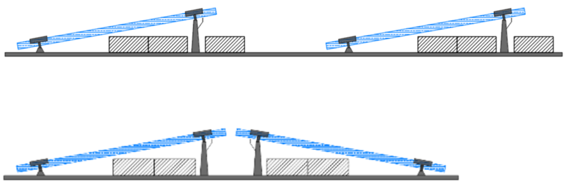
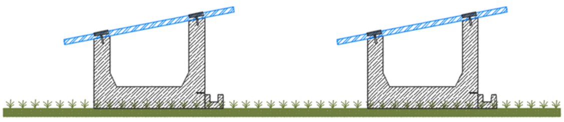
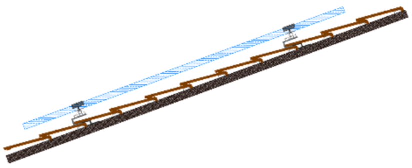
	System with Bored Piles A two-column system with bored piles can be used in open spaces with an inclination of 20° to 40°. This system can also be used in flat areas with difficult ground conditions. E.g. Embankments, slopes
	Installation on Anchor Walls To attach the PV modules to an anchor wall, mounting brackets can be screwed onto the concrete blocks on which a crossbar system is installed for mounting the PV modules.

Table 3: Photovoltaic Substructures for Buildings and Façades

Buildings and Façades	
	Installation on Façades, Noise Barriers, etc. Depending on the type of façade, the substructure is hung, clamped or screwed on. In addition, the PV modules can be mounted either parallel to the building or on top of it (tilted at an angle). E.g. Portal entrances, noise barriers, façades of operations buildings
	Installation on Flat Roofs Modules mounted on top of the building, tilted towards the South or South-East using a ballasted substructure. No roof penetration required.
	Installation on Green Flat Roofs On green roofs, a substructure can be used at a greater distance from the ground to prevent the PV modules from being shaded by vegetation.
	Pitched Roofs Depending on the type of roof covering, pitched roofs can be fitted with roof hooks or clamps; a mounting profile can then be attached to these hooks or clamps.

2.3. Dimensioning and Optimising PV Module Installation

The sizing, dimensions and installation of a photovoltaic system can be planned and designed according to the intended use of the system and the amount of space available. If the load profile is such that more electricity is consumed in the afternoon, the PV modules can be oriented towards the West to better utilize the PV energy, especially in the afternoon. To maximise the specific annual yield, the modules should ideally be tilted directly towards the South.

In order to achieve the most consistent electricity generation possible throughout the year using photovoltaics, PV modules should ideally be installed in a near vertical position. However, this reduces the specific annual yield. When aligning and installing the modules, consideration must be given to neighbouring buildings and resulting possible shadowing.

To determine and implement the best economic option, it is therefore necessary to evaluate all available areas at the site, taking into account the orientation, installation options, size of the available area(s), distance to the feed-in point and possible shadowing. A simulation program can be used to overlay the tunnel's PV generation and load profile to determine the tunnel's own consumption, degree of self-sufficiency and amount of surplus energy.

2.4. Example Project

The Schönberg noise protection gallery on the A 13 Brenner motorway in Tyrol, Austria, is 884 m long and approximately 25 m wide. On top of this gallery, a photovoltaic system will be installed to help cover the gallery's consumption needs. Surplus energy will be fed into the public electricity grid.

The gallery currently uses 503,000 kWh of electricity per year. The gallery roof has been filled with soil and substrate, and grassed. The backfill has been adapted to the terrain profile and the gallery roof. There is a hiking trail as well as a playground and ice-skating rink on the gallery roof. Directly next to the gallery, on the eastern side, is a residential area.

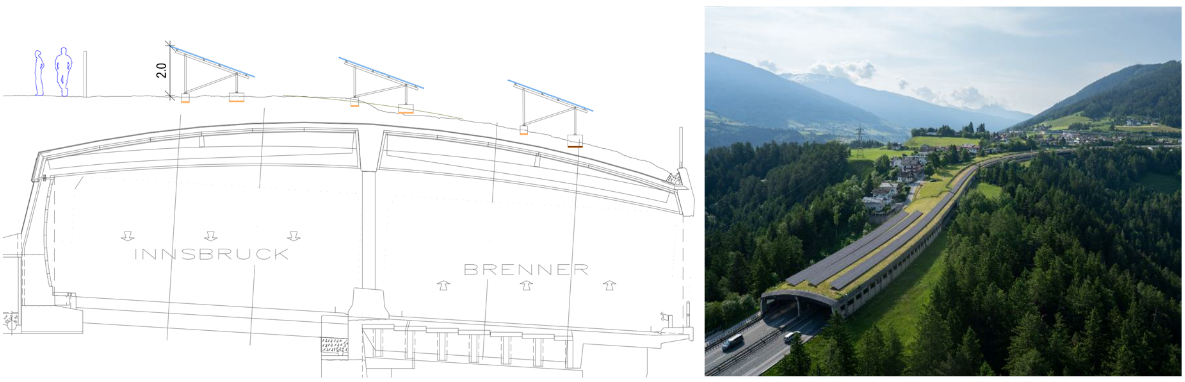


Figure 2: Example project

One of the project requirements is to protect residents from glare from the photovoltaic system. Taking into account the terrain profile of the gallery roof, it was decided that the PV modules will be installed parallel to the road, tilted and oriented between 230° and 310° West.

The PV system – a description of which is given in the table below – is to be installed on the unused parts of the gallery roof.

Table 4: main data example project

Capacity of the PV system	1,025 kWp
Orientation of the modules	230° South-West to 310° North-West
Module inclination	20°
Module area	4,700 m²
Global radiation	1,242 kWh/year
Specific annual yield	1,020 kWh/kWp
Total annual yield	1,040,000 kWh
Proportion of own consumption	320,000 kWh
Degree of self-sufficiency	63%
Grid feed-in	720,000 kWh

Despite the orientation of the modules deviating from the ideal orientation, it will be possible to achieve a high specific annual yield. The roof area is large enough to generate significantly more power than is needed at the site, despite the need to keep areas free for other uses. The surplus green electricity can be used to help meet climate targets.

Even without any storage facility, the photovoltaic system can already achieve a 63% degree of self-sufficiency.

3. COOLING ELECTRICAL ROOMS USING SUSTAINABLE SOURCES

Cooling of electrical rooms is crucial to maintain an optimal operating temperature for electronic equipment while simultaneously promoting energy efficiency. The Kramer tunnel close to Garmisch Partenkirchen in Germany has a North Operations Building, which houses the necessary technical equipment for the tunnel’s operation. The project explores the application of cooling methods in an Operations Building using two sustainable cooling sources: fire water and groundwater.

The use of fire water as a cooling source provides an innovative solution by utilising the existing infrastructure from fire protection systems. A resource-efficient and cost-effective alternative to conventional cooling systems is being investigated through the targeted diversion and use of fire water to cool electrical installations.

Concurrently, the use of groundwater as a cooling source is also being examined. This method is based on geothermal principles and utilizes the relatively constant temperature of groundwater to keep electrical rooms at an optimal temperature level. This approach minimizes energy consumption and contributes to the sustainability of the cooling process.

Comprehensive experimental testing and modelling is being used for these examinations, with the focus being on developing effective cooling systems that meet the specific requirements of electrical rooms. The aim is to optimize cooling performance while ensuring the reliability and safety of these innovative cooling approaches.

The results are not only intended to help improve energy efficiency in electrical rooms, but will also serve as a guide for the implementation of sustainable cooling technologies in other industries. Overall, this project will make a significant contribution to the development of environmentally friendly technologies for cooling electronic infrastructures.

3.1. Cooling Design of Electrical Rooms

A cooling load calculation according to VDI 2078 [1] has been carried out to determine the total cooling load of the North Operations Building. The calculation includes both the external and internal loads of the Operations Building. The room temperature setpoints listed in Table 3 were used to determine the cooling load.

Two cooling cases have been considered for cooling the electrical rooms in the North Operations Building. Groundwater cooling is used to cool the electrical rooms in the Operations Building. The fire water pipes in the tunnel are used for primary cooling. Secondary cooling (emergency cooling) is provided by groundwater, which is collected in a drainage pipe and discharged from the tunnel. Once its construction is complete, a water collection shaft next to the Operations Building will be used for emergency cooling. In emergency cooling mode, cooling water is extracted from this shaft, then pumped through the system separator (cold exchanger) by a centrifugal water pump and returned to the drainage pipe. During the cleaning process, the cooling system switches between spring water and fire-fighting water. This makes the complete system redundant.

For the primary circuit, the cooling water pipes are laid underground and connected to the fire water pipes. The connections are made in a shaft next to the plant building in which the fire water pipes run. Two connections are provided for the future installation of a water softening system to treat the groundwater. The necessary fittings, regulation, control and measuring equipment will be installed in the technical room in the Operations Building. A heat exchanger will also be installed to separate the cold and cooling water circuits. This heat exchanger has a redundant design so that the cooling system can be operated without interruption during maintenance work.

Depending on the cooling capacity, the indoor units must be installed either on the floor, wall or ceiling.

Table 5: Maximum cooling design parameters

Room	Cooling Design temp. [2]
Low Voltage Room	25 °C
UPS Room	25 °C
Battery Room	20 °C
Communication Room	25 °C
Control Room	25 °C

The calculation includes the external and internal loads for the Operations Building. The cooling load calculation results in a value of 18.3 kW.

An annual average of approximately 37 l/s of water currently flows out of the Main Dolomite section of the rescue tunnel which is built in parallel to the main tunnel. After construction of the main tunnel, a total water volume of approximately 45 l/s is projected to flow out of both tubes. Due to possible fluctuations in the discharge, the study is based on a total annual average (from both tubes) of 40 l/s.

According to water management evidence from September 2013 to February 2018, the following data apply to the groundwater:

Table 6: Groundwater Characteristics

	Average Value	Max. Value	Min. Value
Flow Volume [l/s]	37	57	24
Water Temperature [°C]	8.2	8.5	8.0
pH Value [-]	8.05	8.43	7.53

A water temperature, including losses of approximately 9 °C, was assumed for the calculation. The flow temperature is therefore 10 °C and the return temperature 15 °C. With a spread of 5 Kelvin, a water volume of 1 l/s is required to dissipate the waste heat generated.

3.2. Investment Costs for Cooling Systems

In general, the investment costs for groundwater cooling are higher than for the use of conventional split air conditioning units. However, this is offset by lower operating costs, as the compression process in split air conditioning systems requires more energy.

The estimated investment costs for these two different cooling systems are compared in the following table.

Table 7: Investment Costs for Cooling Systems

Cooling System	Price
Groundwater Cooling	€ 60,000
Split Air Conditioning Units	€ 45,000

The electrical power requirement for a split VRF air conditioning system of the size required in this project is approximately 8 kW. In comparison, the pumps for the groundwater cooling system require a connected electrical load of approximately 1 kW. Two different electricity prices have been used to calculate the energy consumption.

In the following table, the amortization times of the cooling systems are calculated with the assumed electricity prices.

Table 8: Amortization Times

	Electricity Price	
	0.4 €/kWh	0.6 €/kWh
Operating costs for groundwater cooling:	0.4 €/h	0.6 €/h
Operating costs for cooling Split-Air-Conditioning-Unit:	3.2 €/h	4.8 €/h
Difference in investment costs	€ 15,000	€ 15,000
Amortization times [in years]	10.5	7.0

At an electricity price of 0.40 €/kWh, groundwater cooling would be more favourable after 5,750 hours of operation, and at 0.60 €/kWh after 3,833 hours of operation (note: only the investment costs were compared with the operating costs; maintenance costs were not taken into account). The evaluation of the weather data (from WESTE – the Weather Data and Statistics Express of the German Weather Service) at the weather station closest to the project location revealed that the outdoor temperature was ≥ 21 °C for an average of 507 hours per year (for the years 2013 to 2017). The North operations building is cooled exclusively with fire water or, in an emergency, with groundwater. It is assumed that the electrical components are in operation all year round and generate waste heat. Using fire water or groundwater at an electricity price of 0.40 €/kWh, the cooling system would amortize after 10.5 years, and after 7 years with an electricity price of 0.60 €/kWh.

This does not take into account maintenance, inspection and cleaning costs, as well as interest and any necessary replacement purchases. Taking these aspects into account, the amortization period is further extended.

4. SUMMARY AND CONCLUSION

Photovoltaic Systems

Photovoltaic systems in the vicinity of tunnels are being planned and implemented with increasing frequency. Due to the recent sharp rise in electricity prices, increasing interest is also being shown in installing photovoltaic (PV) modules in other areas close to tunnel portals. In addition to selecting the right areas, planning and designing site-optimised installation and orientation of these PV modules is an essential part of the successful implementation of PV projects. There are a variety of options for installing PV modules. Project examples show that additional aspects, such as light and shadow effects or other constraints from nearby neighbourhoods, also need to be taken into account in order to find the optimized solution for PV module installation. Each of these approaches aims to optimise the energy yield and economic efficiency of the modules by utilising the available space.

Fire water and groundwater cooling

In principle, cooling with fire water and groundwater is possible. From a technical point of view, sufficient cold water is available to cover a tunnel's required cooling load. Even if there is no or insufficient groundwater available for cooling, any tunnel with fire water pipes in a loop design has an already built-in natural cooling source "free of charge", although the operational limitations in case of a leakage have to be carefully considered. The investment costs for groundwater cooling are generally higher than for conventional split air conditioning systems. However, the operating costs are lower as the compression process for split air conditioning systems requires more energy., The amortisation period of such a system is becoming shorter and shorter, especially due to global warming and increased energy prices.

5. REFERENCES

[1] VDI 2078:2015-06 Calculation of thermal loads and room temperatures (design cooling load and annual simulation)

[2] DIN EN 16798-1:2022-03 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6