

Powerhouse Telemark: A plus energy building with a low exergy heating and cooling system.

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ABSTRACT

Powerhouse Telemark (PHT) is an eleven stories high office building in Telemark in Norway, built to plus energy standard. A plus energy building that is built according to the Powerhouse definition prior to 2019 must produce more renewable, locally produced energy during the lifetime of the building, and must produce enough renewable energy to cover the total embodied energy used for the production and transportation of the building materials used in the building. The local renewable energy production must also cover the yearly net energy needs for operations, renovations and demolition of the building. The local production of renewable energy on the building is not required to cover the energy needed for plug loads in the building.

The building will have a unique diamond shape, and the roof of the building is oriented towards the south, and slopes at an angle of 24 degrees from the horizontal. The building will be a net supplier of electricity when seen over a whole year.

In addition to other “normal” measures to achieve a plus energy building, like a high performance building envelope, and an extremely efficient ventilation system, energy efficient lighting and equipment and a solar PV system, a new low exergy heating and cooling system has been implemented in the building. This low exergy system (called Lowex) is based on low temperature heating and high temperature cooling, which together with an optimized energy well design will give extremely low demand for delivered energy (electricity). To design this Lowex system, a lot of different calculations and simulations had to be done, both with commercial software packages, but also with new develop dynamic simulation models. These design procedures and models are described in this paper. This paper also describes how these results will be used for the operation of the building.

The building is currently under construction and will be commissioned in late 2019/early 2020. The main experience from the design phase and early construction phase is that the Lowex system sets strict demands on both façade design and the interior design. Transparent vs. opaque area ratios, solar shading and glazing solutions set boundaries for the architectural concept, and must be taken into account early in the design process. Flooring materials, ratio of landscape vs. office cells, and thermal zoning of the building affects the interior design. The acoustic concept and the carbon footprint of the building as well as the design of the supplementary HVAC-system are also important factors that need to be taken into account at an early stage in the design phase. To solve these interdisciplinary problems it requires a design team that can work together closely. The architect, and the engineer that is responsible for the energy performance of the building, have a central role to play at the very beginning of the

design phase when the geometry and the general parameters of the building is still in flux.

INTRODUCTION

Powerhouse Telemark is a diamond shaped 11 story high office building situated close to the Skiens river. The building will have a total heated floor space of approximately 8000m² and will house mainly offices, but will also include a cantina, conference rooms and smaller meeting rooms. The roof of the building is inclined at a 24-degree angle facing south to maximise the incoming solar radiation to the photovoltaic (PV) modules mounted on the roof. The south facing façade is also completely covered with a building integrated PV-system.

The project has been given financial support by Enova, a government organisation owned by the Norwegian Ministry of Climate and Environment which has a goal of reducing CO₂ emissions in Norway.

Powerhouse Telemark is the first Powerhouse-concept office building in southern Norway (see www.powerhouse.no). A plus energy building that is built according to the Powerhouse definition prior to 2019 must produce more renewable, locally produced energy during the lifetime of the building, and must produce enough renewable energy to cover the total embodied energy used for the production and transportation of the building materials used in the building. The local renewable energy production must also cover the yearly net energy needs for operations, renovations and demolition of the building. The local production of renewable energy on the building is not required to cover the energy needed for plug loads in the building.

This report is divided into two parts. The first part discusses the energy used for the operations of the building. The second part discusses the embodied energy used in the building materials used in the building and during renovations.

KEYWORDS

Plus energy, Power House, Low exergy heating and cooling, Thermal indoor climate.

1 METHODOLOGY

The energy performance simulation program SIMIEN v 6.009 has been used to evaluate the energy concept for Powerhouse Telemark. An embodied energy calculation has been done to decide the total amount of solar energy production need to supply the building with enough energy to cover the embodied energy stored in the buildings materials.

The effect required for heating and cooling is calculated in Simien v 6.009 for different temperature zones and the results were imported into a calculation tool created by Skanska Norway AS and that is based on the ISO 11855-2. This tool is developed to calculate supply temperatures for heating and cooling as well as the control curves that regulate flow rates in the different zones.

2 ENERGY REQUIRED FOR BUILDING OPERATIONS

This chapter discusses the energy used for the everyday operations of the building.

2.1 Heat loss through climate envelope

To realise a plus energy building, the energy losses, through the buildings climate envelope and through the ventilation system, have to be minimised. This is done by increasing the thermal insulation and minimising thermal bridges where it has the most impact on the energy performance of the building.

The building is built air tight and the air exchange rate for infiltration across the climate envelope is set to 0,4 air exchanges per hour measured at a 50 Pascals pressure difference. This is a relatively conservative estimate of what is possible to achieve, but there has to be a focus on air tightness in the design phase as well as the production phase. The building will also be tested for air leakages before the thermal envelope is completed. This ensures that points of leakage are identified and sealed before the building is completed.

The windows in the building play an important role for the whole energy concept as they effect the energy performance of the building as well as parameters like thermal indoor climate, daylight, fire safety and acoustics. Even though the building will be cooled by the LowEx system during the summers, this cooling effect is not enough to support a comfortable indoor climate on its own. Windows facing south east will be equipped with external solar blinds that limit incoming solar radiation from the sun. The facades facing west and north east have integrated wooden solar shading in the façade and thus do not require other forms of solar shading to ensure a comfortable indoor climate. The windows, behind the integrated wooden façade shading, will only be equipped with internal manually controlled blinds that protect against glare. The large glass facades will have automated internal blinds that, in combination with the glazing layers in the glass, block the majority of the incoming solar radiation. The shape of the building also provides shading for the glass façade facing south west, see architectural renditions in the figure 1 below.

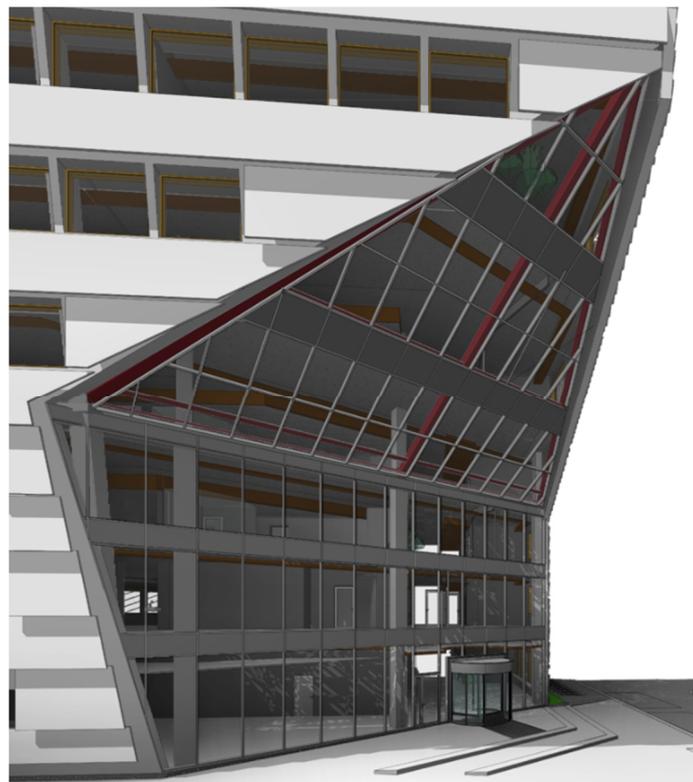


Figure 1. Overhang which shades the glass façade by the building entrance

The u-values of all the windows, including the frames, is set to 0,75 W/m²K and the glazing on the glass give a g-value of 37 % and a daylight transmission of 63 %. Even with these low U-values, 42 % of all the thermal energy is lost through the windows and glass facades in the building.

Table 1. U-values for climate envelope structural components

Climate envelope structural component	Average U-values (W/m ² K)
Insulated concrete slab on ground	0,11*
Wall type 1 (General wall type)	0,17
Wall type 2 (West facing façade)	0,15
Windows and doors and glass facades	0,75**
Roof	0,10

*Includes thermal resistance of the ground materials under the slab.

**Includes wooden window frames and aluminium profiles in glass facades.

2.2 Ventilation system

The ventilation system is a displacement ventilation system with ventilation ducts that are placed centrally in the buildings core and the main ducts branch out in the ceiling from the central core. The air is supplied to the occupancy zones and is distributed throughout the building through ventilation overflow units. The ventilation exhaust is extracted centrally in the bathrooms, closets and in the kitchen.

The variable air volume system (VAV) is controlled by CO₂ and temperature sensors. The air flow rate varies between approximately 4,5 m³/m²h in the winter and increases to approximately 6m³/m²h during the summer. The maximum capacity of the ventilation system in an extreme case is limited to around 10 m³/m²h.

This low pressure ventilation system is highly energy efficient and has a low specific fan power (SFP) value. The average SFP value during winter months is estimated to 0,6 and is 0,75 during the summer months. The supply air is preheated during the winter months with a rotary heat exchanger that has a heat recovery efficiency of approximately 87 %. The heat exchanger is supplied with heat from the energy wells in the ground beneath the building. The heating exchanger is used for cooling in the summer. This keeps the supply temperature at approximately 18 degrees during the summer period.

2.3 Tap water heating

The domestic hot water (DHW) demand is low in office buildings and thus the energy savings potential is limited. The initial energy performance concept included a CO₂ heat pump that would heat the DHW. The CO₂ heat pump was taken out of the energy concept and was replaced with electrical boilers on each storey. The reason for this switch is that the heat losses from circulating hot water is calculated to be relatively large in comparison to the total energy used for heating the DHW in the building. The energy savings potential is too low to motivate the extra cost inferred from a CO₂ heat pump specifically dedicated to the DHW system.

2.4 Lighting

Office buildings have traditionally had relatively high energy use for lighting. In Powerhouse Telemark the electrical use for lighting is minimised by tailoring the lighting design to the architects seating plan. This ensures sufficient light where it is necessary. The average energy use for the building during one year is calculated to be approximately 2,3 W/m² or 49591 kWh/year for the entire building. This is achieved by using daylight and motion activated sensors as well as using the most energy efficient commercially available LED lighting.

2.5 Thermal energy supply

The buildings thermal energy supply is a highly efficient heat pump connected to energy wells. The energy wells cover approximately 99 % of all heating energy needed for room and ventilation heating. The heat pump system will cover approximately 70-80 % of the peak heating load of the building. An electrical boiler covers the rest of energy needed during peak heating hours.

Heating and cooling is distributed through a system for low exergy heating and cooling which consists of pex pipes embedded into the concrete floors. The system will be referred to as the “LowEx” system in this report. This system has low supply temperatures for heating (between 23°C and 29°C) and relative high temperatures for cooling (19°C). This ensures good working conditions for the heat pump system, and a cooling system that can rely solely on free cooling from the geothermal wells in a normal year. The system is connected to 8 energy wells that are drilled approximately 300 m into the ground on the building site.

The Lowex system makes use of exposed thermal mass in the floors and the roof and the pex pipes are placed in a concrete strip in the slab that runs parallel with the façade and is approximately 4 m wide. The LowEx system will charge the wells with excess solar energy during the summer months and some of this stored heat energy will be extracted during the heating season. This results in a higher performance for the heat pump and the seasonal coefficient of power (SCOP) is improved by doing this. It is expected that it will be possible to achieve a SCOP of approximately 4,5 for heating.

In the summer season the lowex floor system is used as a self-regulating cooling system where all valves are 100 % open, and water with approximately 19 °C runs through the system. This acts as a stabilizing system which harvest surplus heat from zones with high loads (internal and/or solar) and in zones with small loads the cooling will be limited due to small or negligible temperature difference between the floor surface and the room temperature. The surplus heat from the building is heat exchanged with the brine in the geothermal wells, and will recharge the wells in the summer months, giving better working conditions for the heat pump in the winter months.

Low pressure design of the hydraulic system ensures low energy use for both brine pumps and circulation pumps. The lowex system described here has been tested in the plus energy project Lia Kindergarten (Dokka, 2019) with good results.

Due to the high thermal inertia of the lowex system, the temperature in the building is kept constant at approximately 21,5 °C even when the building is not in use (no night set back). This has a slightly negative outcome for the energy efficiency on the building, but the increase in energy use in the building is outweighed by the lower peaks for the electric power needed for heating.

2.6 Electric energy supply

The entire roof as well as the southeast facade are covered in high efficiency solar cells (22 % efficiency). The carport next to the building is also covered in solar cells. Together the system is designed to deliver a total of 243000 kWh per year of solar electric energy. During the summer months, when the production reaches its peak (210 kW), the excess energy that is produced will be exported to the electrical grid. When the solar cells do not produce enough energy to cover the operations of the building, electrical energy is purchased from the grid.

2.7 LowEx calculation model

The LowEx system is designed in Simien v 6.009. The results from the heat/cooling load simulations is then imported into the Skanska calculation tool mentioned previously.

The Lowex tool is used to calculate the necessary temperature in the floor slab that is needed to achieve optimal operative temperatures in the different rooms in the building. Due to the high thermal inertia of the system, the mass temperature in the slab is controlled using a weather forecasted weighted mean outdoor temperature for the next 48-hour period.

Figure 2 shows a typical control curve for the mass temperature as a function of the weighted mean outdoor temperature for a zone in the building. These curves will be implemented in the control system of the building. The central supply temperature (supplied by the heat pump system) will be calculated based on the zone with the highest demand for mass temperature (highest specific heat load), and the supply temperature will also be a similar control curve as a function of the weighted mean outdoor temperature. These control curves will then be tuned and calibrated to measurements that are done after the building is completed.

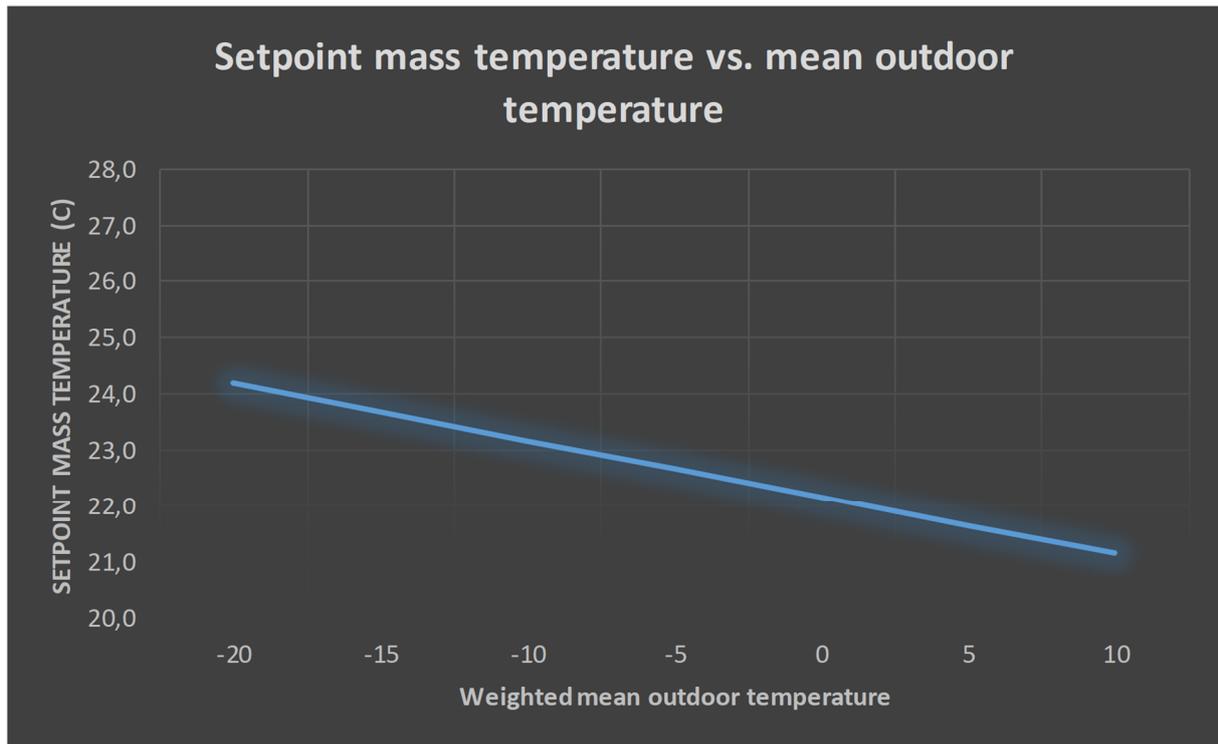


Figure 2. Control curve for the mass floor temperature for a zone in the building.

3 RESULTS AND DISCUSSION

3.1 Simulated energy use

The total net energy demand for the building and the demand for delivered energy is given in Table 2. According to the Powerhouse definition the plug load is not included in this result.

Table 2. Net energy need for Powerhouse Telemark.

	Net demand	SCOP	Delivered energy
Space and ventilation heating	14,5 kWh/m ² yr	4,50	3,2 kWh/m ² yr
DHW	1,9 kWh/m ² yr	0,85	2,2 kWh/m ² yr
Fans	3,3 kWh/m ² yr	1	3,3 kWh/m ² yr
Pumps	0,7 kWh/m ² yr	1	0,7 kWh/m ² yr
Lighting	6,3 kWh/m ² yr	1	6,3 kWh/m ² yr
Space and ventilation cooling	12,3 kWh/m ² yr	20	0,6 kWh/m ² yr
Total	39 kWh/m ² yr	-	16,4 kWh/m ² yr

3.2 Powerhouse balance calculations

The calculated embodied energy for all the building materials for including the PV-system, the energy use during construction and the embodied energy for retrofitting (after 30 years) and end of life treatment amounts to a total of 44,2 kWh/m²yr (calculated as primary energy). With a primary energy factor (PEF) of 2,5, the operational energy use is calculated to 41,5 kWh/m²yr. These two numbers have to be balanced with the local PV-system to achieve the Powerhouse definition. The designed PV-system has an annual production the first year of 243 000 kWh. Based on a technology scenario the PV-system is assumed replaced after 30 years by a system that is 50 % more efficient. Based on assumed primary energy factors during a 60 year time span, the specific PV-production calculated in primary energy amounts to 87,3 kWh/m²yr. This balances the operational energy use and embodied energy with a surplus of 1 kWh/m² yr, as illustrated in figure 3.

The assumed lifetime of the powerhouse balance calculation is 60 years.

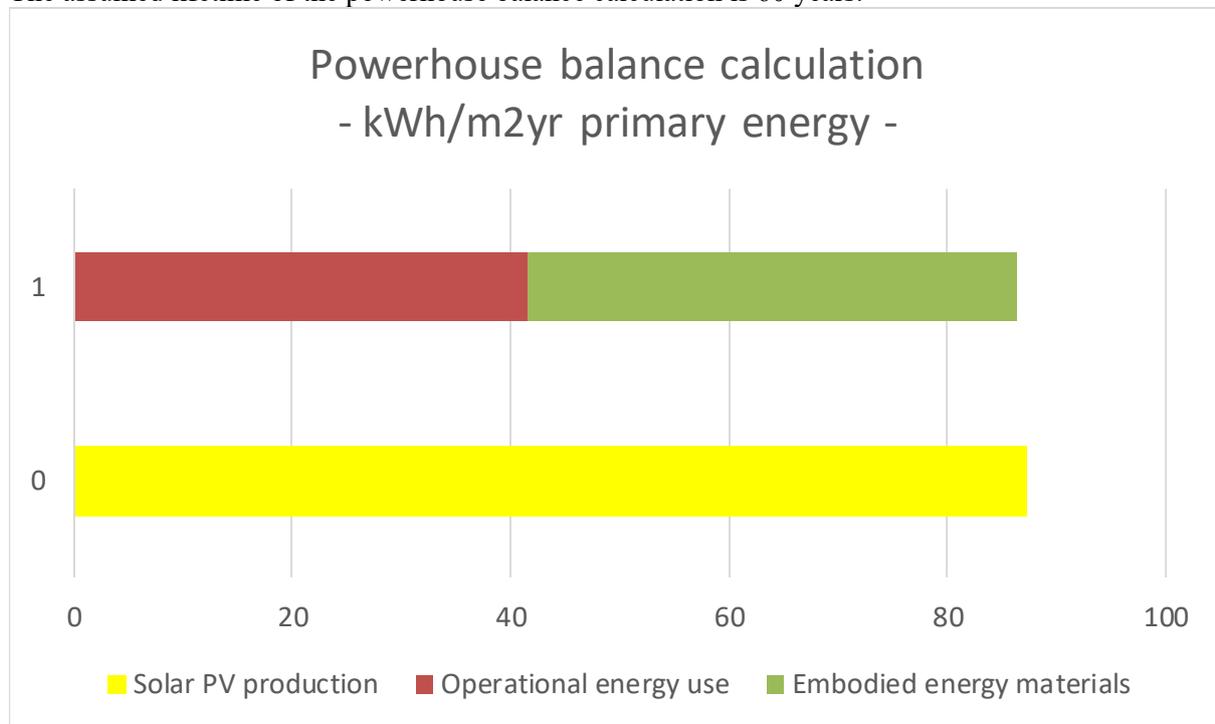


Figure 3. The powerhouse balance calculation of Powerhouse Telemark.

3.3 Challenges

The low temperature heating and high temperature cooling require large areas of exposed thermal mass in the building. This has proven difficult to achieve as this limits the area available for acoustic dampening. The Lowex system also applies restrictions for future renovations and changes in the floor plans.

Even though the building is very energy efficient, it still requires a large area for the solar PV-system. The shape of the building is designed so that the roof area is maximised for use of solar panels. Even though the roof is much larger than the base of the building the roof alone will not produce enough energy over one year to compensate for the energy used for the materials and the operation (excluding electrical energy used for plug loads) of the building as seen over the design lifespan of the building. It was thus necessary to find extra area for solar energy production. This was solved by integrating solar cells in the southeast facing façade and on the roof to the car port.

4 CONCLUSIONS

The different rooms in the building are relatively similar and can be grouped into a few different categories, for example office, landscape zones and meeting rooms. These rooms can share the same control curve, which is beneficial because it limits the amount of control curves that need to be operated. This makes the system simpler to run, and easier to tune once the building is completed.

The Lowex system supplies the room with comfort cooling but the cooling load is not sufficient to cover large thermal peak loads. It has therefore been necessary to manage the thermal peak loads for rooms with large windows. This is done by installing internal and external blinds, and by using glass with low g-values. Rooms with large internal loads also need to be complemented with ventilation cooling during the hottest summer days.

The domestic hot water (DHW) demand is very low in this building, and the heat losses from circulating hot water are relatively large. The savings made from installing a CO₂ heat pump do not motivate the extra investment costs.

REFERENCES

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