Powerhouse Kjørbo:
Taking a Life-Cycle Approach to Positive Energy Buildings

Powerhouse Kjørbo is a renovation project of two former office buildings that were originally constructed in 1979. It was the first time that buildings were renovated to a positive energy building standard.

In order to comply with Powerhouses' own definition of a positive energy building, the buildings should produce more energy over their lifetime than necessary for the production of construction materials, construction, operation and demolition. Plug loads are not taken into account.

An important first step towards reaching this target was to reuse and select environmental friendly construction materials. In addition, a ground-source heat pump system was installed in combination with an efficient ventilation system.

Special attention was paid to visual comfort by maximizing the use of natural daylight. The heavy concrete structure optimizes thermal comfort as the thermal mass tones down temperature fluctuations. Powerhouse Kjørbo received great national and international attention from authorities, politicians and professionals.

The project demonstrates that the positive energy building concept is feasible even in colder climates both in a commercial and environmental context.

Authors: VITO / Energyville
Background image on case study title page:

Table of Contents

EXCESS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

The Positive Energy Building in its Local Context

The Powerhouse Kjørbo project focused on the renovation of two office buildings that were originally constructed in 1979. The PEB is located in the municipality of Bærum in the east of Oslo, Norway. The project was initiated by the Powerhouse alliance in 2009 and was completed in 2014. The office buildings have a total floor area of 5180 m² with 3-4 floors each. Special attention was paid to the life cycle cost of the materials used during renovation and aesthetic appearance, e.g. by using high insulating wood façades in order to keep the original look of the structure. The Powerhouse Alliance defines a positive energy building as a building that produces more renewable energy than it consumes during its lifecycle. In order to achieve this, the following requirements were defined:

1) Setting a "zero energy" target for the operation of the building, based on a 60-year life-time perspective.

2) Developing a greenhouse gas emissions inventory that encompassed the transportation of materials, construction of the building, maintenance and possible renovation activity as well as building demolition.

Having calculated the emissions associated with the energy used in construction and operation (except energy use for equipment and appliances) as well as embodied emissions from materials, the Powerhouse alliance specified on-site renewable energy generation systems to compensate these.

Image 1

View of the exterior of the office buildings
[© Chris Aadland]

Image 2

The rooftop solar installation
[Source: Chris Aadland – photograph cropped]

The Building's Special Features

The buildings were designed with special attention to energy consumption and efficiency, which resulted in an air-tight and well-insulated building envelope. The heavy concrete structure supports a stable indoor climate as it gradually absorbs heat during warm summer days. A ground-source heat pump system is used to provide low temperature heat and to allow free cooling during summer. Solar shading is applied to further decrease the need for cooling. In addition, waste heat from the server room is also recuperated. The ventilation systems was designed as a part of the building structure as it uses the staircase to force warm air to rise towards the extraction vents in the ceiling. A high level of daylight transmission and distribution reduces the need for artificial lighting. The workstations are located along the building façade in order to improve visual comfort.

"…buildings were designed with special attention to energy consumption..."

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

A large photovoltaic installation on the roofs of the building provides enough energy to compensate for the buildings' internal energy consumption and for the embodied energy in terms of building materials and energy consumption during the construction process. An online energy dashboard was installed to monitor the buildings' energy consumption and renewable energy production.

The original building structure made out of reinforced steel was reused and environmental friendly construction materials were applied (e.g. the charred wooden façade). Glazed façade elements were reused as internal paneling and the aluminum window profiles were also earmarked for reuse. Materials from the demolition of the original building were divided into 12 different streams in order to avoid being landfilled.

The Powerhouse Kjørbo project was developed to achieve the classification "Outstanding" in the BREEAM-NOR environmental certification scheme (the Norwegian version of the international certification scheme). Indeed, the project was the first office building in Norway to achieve the highest rating in BREEAM-NOR (85.2%). The assessment covered energy & environmental performance, health conditions for tenants and economic sustainability. The building performed particularly well in categories such as energy (96%), use of area and ecology (90%), transportation (83%) and waste (83%).

Selected Performance Indicators

Energy Demand

Annual thermal energy demand (heating + cooling): 31.9 kWh/m²y

Annual electrical energy demand: 25.2 kWh/m²y

Breakdown of Energy Consumption

Heating: 23.1 kWh/m²y

Cooling: 8.8 kWh/m²y

Ventilation: 2.85 kWh/m²y

Lighting: 13.4 kWh/m²y

Renewable Energy Generation

Photovoltaic: 43.1 kWh/m²y

Building Envelope Performance:

Walls: 0.13 W/m²K
Low Floor: 0.12 W/m²K
Roof: 0.08 W/m²K
Joinery: 0.8 W/m²K
Air Tightness Value: 0.24 at 50 Pa

Greenhouse gas emissions for building:
6.58 kg CO_2 eq/m²y

To what Percentage* is the PEB Energy Positive? 113%

*according to the Powerhouse definition

Key Technologies Installed

- Standard brine-to-water heat pump/chiller: The supply water temperature in the heat distribution system is controlled according to an ambient temperature compensation curve (control curve). This means that the supply temperature from the heat pump is reduced when the ambient temperature (i.e. the space heating demand) increases and vice versa. This maximizes the heat pump's coefficient of performance (Stene and Alonso, 2016).

- R407C brine-to-water heat pump unit: The two storage tanks for domestic hot water (Oso Hotwater) are connected to the domestic hot water heat pumps (DHWHP) in series. Temperature sensors send signals to the central control system and the DHW-HP. One of the tanks has an electrical immersion heater for back-up (Nordang, 2014).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

- Standard brine-to-water heat pump/chiller unit: “Free cooling” is provided by circulating the brine from the boreholes through a heat exchanger in the ventilation system. The brine temperature is about 8-10 °C. During the first three summers, this was sufficient to cool the building, and there was no need to switch the heat pump on as a chiller (Rådstoga, 2017).

- Building Ventilation: Low emitting materials are used to reduce the ventilation demand. Furthermore, the system features demand control of ventilation supply, displacement ventilation, low pressure design to minimize fan energy, and heat recovery. The average ventilation air volume is about 3 $m^3/(m^2h)$ in wintertime with a maximum rate of about 6 $m^3/(m^2h)$ during warm days in the summer. The specific fan power varies between 0.5 and 0.8 $kW/m^3/s$ during operation hours (Rådstoga, 2017). A heat recovery wheel is used to recover the heat from ventilation. Each unit was expected to recover approximately 87% of the heat from the exhaust air during the heating season, however, the measured efficiency during operation turned out to be somewhat lower, at about 76% (Nordang, 2015). The main reason for this is believed to be a drop in heat recovery when the front air velocity is below 1 m/s through the rotating wheel. The heat recovery for Kjørbo is studied in more detail by Maria Justo-Alonso et al and by Peng et al. (published in 2017).

- Borehole thermal energy storage (BTES) for heating and cooling: The heat pump units are connected to a ground-source system comprising of 10 boreholes, each approx. 200 m deep. The borehole system was designed to cover the entire space and process cooling needs in the building (65 kW) by free cooling at 12/17 °C supply/return temperature in the distribution system.

- Photovoltaic modules (PV, solar cells) are placed on the roofs of the two office buildings as well as on part of the neighbouring garage. It consists of 954 modules with a total module area of 1556 m^2 and a total peak power of 312 kWp (Bernhard and Bugge, 2014). The PV modules are of the type Sunpower E20, which consists of high-performance monocrystalline cells. There are 16 multistring inverters with a total capacity of 244 kW, of the inverter type Synny Tripower 17000 TL from SMA Solar Technology. The vendor of the mounting system was Knubix GmbH.

Non-Exhaustive List of Involved Stakeholders

Investor
Entra
https://entra.no/

Project Developer
Skanska
https://www.skanska.com/

Architects
Snohetta
https://snohetta.com/

Consulting Company
Asplan viak
https://www.asplanviak.no/

Environmental Organization ZERO
https://zero.no/

Aluminium Profile Company
SAPA
www.sapabuildingsystems.com/

Aluminium Company
Hydro
http://hydro.com/

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author’s view and the Commission is not responsible for any use that may be made of the information it contains.

Catalysts, Challenges & Results

The basis for the project was the establishment of the Powerhouse alliance, a cooperation that was founded to pave the way for the realization of positive energy buildings. The main ambition and goal of the Powerhouse Alliance is to challenge and influence the existing planning processes, cooperation methods, technology, legislation, regulations, frameworks as well as relationships with vendors, contractors and consultants, to establish the best possible foundation for plus energy buildings. By cooperating in the Powerhouse alliance, the partners achieved better results than the sum of what the parties could have achieved individually (Jenssen et al., 2015). The Powerhouse alliance also forms the basis for new building projects, either within the Powerhouse alliance, or through other companies which have learned lessons from the Powerhouse alliance’s experiences and knowledge.

All stakeholders were involved in the early stages of the design process with a multidisciplinary team having been established to reduce the number of risks in the different stages of the project. This also increased the effectiveness of the overall project development. Stakeholders and the design teams were interacting on two levels, with discussion in a larger group (+/- 20 persons) being held in order to define functional needs and smaller subtask groups of 3 to 6 persons being organized to tackle more technical and detailed topics. These discussions were usually held as one day workshops.

Conflicts between environmental goals, technology and aesthetic objectives can create challenges in the design process, which will often result in compromise solutions. Powerhouse Kjørbo is the first renovated positive energy building in the world and therefore acts as an example and reference for future projects. The building received a lot of attention from authorities, politicians and professionals, guided tours are organized on a regular basis.

The project was developed by private investors and financed within commercial market conditions. A subsidy of approximately 2 M€ was granted. A general granting for fulfilling Norwegian passive house standard of 350 k€. In addition, a 1.5 M€ grant for new technology (PV) was secured.

One of the main beneficial outcomes of the project is the drastic reduction in energy costs in comparison with ‘standard’ buildings.

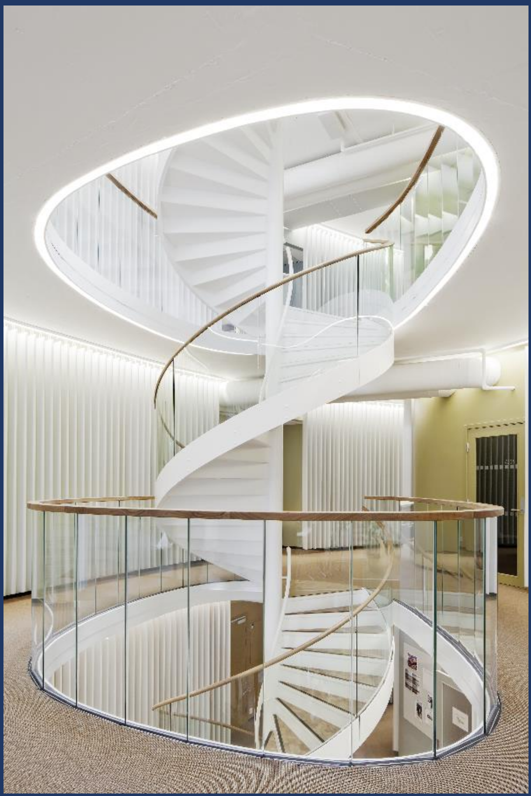


Image 3

Photo of an interior staircase that also functions as a ventilation shaft [Copyright holder: Snøhetta | Photographer: Ketil Jacobsen]

“…a multidisciplinary team was installed in order to reduce the number of risks in the different stages of the project…”

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author’s view and the Commission is not responsible for any use that may be made of the information it contains.

Both building owner and tenants profit from these savings. Also, the indoor climate is highly rated by the building occupants in terms of thermal comfort and indoor air quality, which improves productiveness and well-being. The building receives great international attention, therefore branding and image are an important beneficial outcome.

Naturally, the realization of such complex building project also brings challenges. For example, the energy consumption proved to be higher during the first years of operation in practice than anticipated. This was mainly caused by unfavorable settings in the technical installations and adjustments were made. In the design phase, the decision making process was sometimes accelerated by the project developer which resulted in certain sub optimal technical solutions. This can be prevented by reserving more time in the overall project planning and setting realistic milestones.

Replication Potential

The Powerhouse project demonstrates that it is feasible, both environmentally and financially, to retrofit buildings to a positive energy standard in a Nordic climate under the right conditions. The success of the concept can be attributed to various aspects:

- **Economical / financial:** Profit margins are important to attract investors. The building's operational costs are reduced drastically in comparison with other office buildings. Savings on energy consumption can create leverage for the rental price.
- **Environment:** Primary energy savings realized by the reduction of the energy consumption, the use of sustainable building materials and savings on water consumption inside the building. The proximity to major transport hubs and public transport is also an important factor.
- **Social / client:** Healthy indoor climates improve user satisfaction and well-being and makes the building more attractive. Positive Energy Buildings can also support the green image of the prospective tenant, making the building more desirable on the market.

When considering the design and construction process the following lessons were learned:

- All stakeholders have to be involved in an early stage of the design process and they should actively contribute.
- More time should be reserved in the early phases of the project in order to come up with an optimal integrated design.
- The quality of preliminary studies is crucial to support the decision making process.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

Norway is wholly dedicated to reducing CO_2 emissions across the country, with the ultimate goal of de-carbonizing transportation altogether. For these efforts, Oslo was elected the 2019 European Green Capital. Snøhetta architect Jette Hopp suggests this kind of environment-focused collectivism is partly informed by Norway's right to roam, a right codified by law that gives all Norwegians the freedom to pitch a tent almost anywhere they want (Source: https://www.citylab.com/environment/2018/12/norway-energy-positive-building-powerhouse-snohetta/577918/). This creates the right environment in Norway to push sustainable building design to the next level.

Conclusions & Lessons Learned

The overall approach to the design and construction process adopted in the context of the Powerhouse Kjørbo project proved to be very successful. The roles and interactions in the multidisciplinary design team proved to be crucial to successfully realise such a complex project, especially in the early design phase. More time should be reserved for bilateral meetings and communication in future projects and it is important to include all stakeholders. Therefore, when initiating a project to retrofit or construct a building to make it energy positive, a longer design phase should be anticipated and planned for.

The Powerhouse approach is being replicated by the alliance, with a third building block on the Kjørbo site renovated to the positive energy building standard in 2017. Entra, the investor within the Powerhouse alliance has commissioned a number of further PEB projects, including the Powerhouse Brattørkaia, the Powerhouse Telemark and the Powerhouse Drøbak Montessori school. An overview of realised and planned projects can be found on the Powerhouse website: www.powerhouse.no

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

Acknowledgements

The EXCESS project team would like to thank the following companies, institutions and individuals for their contributions to this case study:

- For all the involved companies for permitting the use of their logos.
- Snøhetta and Chris Aadland for their permission to use photos and other images of the building.

Selected References

- Stene, J. and Alonso, M. J. (2016) 'Field Measurements – Heat Pump Systems in NZEB', ZEB Project report 27 – 2016.
- Nordang, I. F. (2014) 'Analysis of the Thermal Energy Supply System at Powerhouse Kjørbo, Sandvika', Student project thesis, NTNU.
- Nordang, I. F. (2015) 'Analyse av varme- kjølesystemet ved Powerhouse Kjørbo', MSc-thesis NTNU.
- Bernhard, P. and Bugge, L. (2014) 'Powerhouse - Integrating solar in an energy plus refurbishment of office building', Conference Proceedings EuroSun 2014.
- Jenssen, B., Dæhli, F., Thyholt, M. and Fjeldheim, H. (2015) 'Enova Sluttrapport - Powerhouse Kjørbo'.
- Alonso, M. J., Nordang, I., Stene, J. and Jenssen, B. (2017) 'Analysis of Heat Pump System for Powerhouse Kjørbo - First Renovated Zero Energy Office Building'.
- Peng Liu, Hans Martin Mathisen, Maria Justo Alonso (2017) 'Theoretical Prediction of Longitudinal Heat Conduction Effects on the Efficiency of the Heat Wheel Used for Ventilation in Powerhouse Building "Kjørbo" in Norway'.ZEB Project report 35-2017, www.zeb.no
- Market Transformation Towards Nearly Zero Energy Buildings Through Widespread Use of Integrated Energy Design (MaTrID): IEE/11/989/SI2.615952
- https://klimaostfold.no/wp-content/uploads/2018/11/Liv-Eva-Wiedswang_%C3%98stfoldforskning-BK-climate-strategy-2030.pdf
- Skanska, Case Study 121, Powerhouse Kjørbo, Norway
- Indoor climate in a zero energy building, An analysis of the thermal environment and indoor air quality, Odin Budal, June 2015

Local Context Details

Address: Powerhouse Kjørbo, Kjørboveien 18-20, 1307 Sandvika, Norway

Geographic Coordinates [Google | EPSG:4326 – WGS 59°53'10.8"N 10°31'36.5"E

Local Government: Bærum

Population: 127700 [2020]   Total Area Administered: 192 km²

Total annual GHG emissions: 227962 tCO2e

Climate Commitments and Pacts Signed:

Municipality of Bærum has their own "Climate Strategy 2030" plan

Climatic Zone [Köppen]: [Dfb] Humid Continental Mild Summer | Wet All Year

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.

Further Images & Plans of the PEB

Image 4

View of one of the building's circulation spaces
[Copyright holder: Snøhetta | Photographer: Ketil Jacobsen]

Image 5

View of one of the building's office floors
[Copyright holder & Photographer: Leikny Havik Skjærseth]

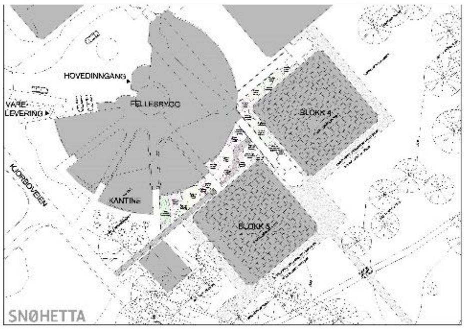
Image 6

View of the interior circulation spaces
[Copyright holder & Photographer: Leikny Havik Skjærseth]

Image 7

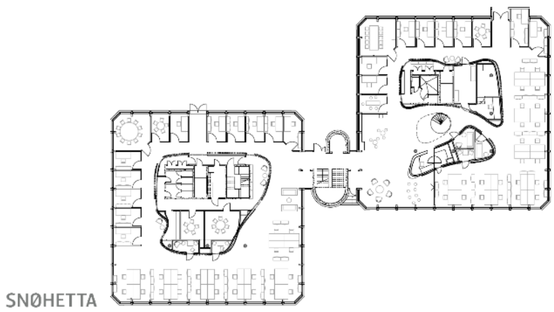
View of the interior circulation spaces
[Copyright holder: Snøhetta | Photographer: Ketil Jacobsen]

Image 8



Plan pf the Powehouse K
[Copyright holder: Snøhetta | Drawing: PScript5.dll Version 5.2.2]

Image 9



Cross-section of the Powerhouse Kjørbo
[Copyright holder: Snøhetta | Drawing: PScript5.dll Version 5.2.2]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 870157. This document reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains.