Powerhouse Kjørbo: a plus-energy renovation office building project in Norway

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Summary

The main definition of a Powerhouse is a building that shall produce at least the same amount of energy from on-site renewables as the energy used during construction, manufacturering of materials, renovation, demolition and operation exclusive energy used during manufacturering of equipment such as PCs, coffee machines etc. In addition the exported energy shall in average not have less quality than the imported energy. This implies that produced and exported electricity can offset corresponding amount of imported energy for both electricity and thermal purposes, while produced and exported thermal energy cannot offset imported electricity. The building shall also as a minimum fulfil all the requirements of the Passive House standard according to NS 3701 [1].

The first Powerhouse renovation building will be built at the Kjørbo site in Bærum, and start of construction was in March (2013). For the Powerhouse Kjørbo project, PV panels will balance the energy needed during it's lifetime. The two buildings will thus export more electricity than it will use for operation. A geothermal heat pump, in addition to waste heat from the data/server room, will cover the heating and cooling demand. There will be no export of thermal energy. In a broader environmental perspective, an aim of this project is also to achieve the classification "Outstanding" in the BREEAM-NOR environmental certification scheme [2].

The heated useful floor area of the two office buildings at Kjørbo, which will be renovated to plus-energy standard, is about 5.180 m2, distributed on 3 or 4 floors. Energy efficiency measures and materials with low embodied energy have been crucial for obtaining the energy goal. A very efficient ventilation concept has been developed.

Powerhouse Kjørbo is a ZEB pilot building, i.e. a pilot within the Research Centre on Zero Emission Buildings (www.zeb.no). Therefore an aim is also very low greenhouse gas emissions during the building's lifetime.

Calculations indicate that the energy balance during the building's lifetime, and within the defined definition, fulfils the goal of plus-energy.

Keywords

Powerhouse, plus-energy commercial building, renovation, zero-emission building, ZEB

Introduction

“Powerhouse” is a collaborative project that will demonstrate that it is possible to build plus-energy buildings in cold climates (www.powerhouse.no). Powerhouse Kjørbo in Bærum is a refurbishment project of two office building, and will be renovated to modern and very energy efficient buildings, aiming at achieving plus-energy standard according to the definition of a Powerhouse building. The project will be completed in February 2014.

Bærum is located at approximately **60 degrees north** latitude, and with an annual mean outdoor temperature of about 5,9°C and an annual mean horizontal irradiation of about 110 W/m² (955 kWh/m²a).

The office buildings were built in 1980. Each of the buildings have heated useful floor area of about 2500 m2, divided on three or four floors. The energy consumption of the buildings today is about 250 kWh /m2 heated area and year. When the refurbishment is completed, the need of energy will be covered with energy production from the building’s own solar panels, geological thermal heating and surplus heat from the data (server) room. The solar panels of about 1390 m^2 or 278 kWp installed power will yearly produce more than 200 000 kWh, or about 41 kWh per square meter heated area. This electricity will be supplied to the buildings at the Kjørbo site, or to the grid in periods with surplus production.

In addition to the plus-energy goal, Powerhouse Kjørbo aims for the classification “Outstanding” in BREEAM-NOR. BREEAM is the world's leading design and assessment method for sustainable buildings. BREEAM- NOR is suited for Norwegian standards and criteria. There are five assessment levels in BREEAM- NOR, and “Outstanding” have the hardest environmental requirements and is thus the hardest level to achieve.

Definition of Powerhouse and plus-energy

The main definition of a Powerhouse is a building that shall produce at least the same amount of energy from on-site renewables as the energy used for construction, manufacturering of materials, maintenance, demolition and operation exclusive equipment (such as PCs, coffee machines etc.). For renovation projects, only the materials added during renovation (but including maintenance and replacement during the building’s lifetime), are included.

In addition, the exported energy shall in average not have less quality than the imported energy. This implies that produced and exported electricity can offset corresponding amount of imported energy for both electricity and thermal purposes, while produced and exported thermal energy cannot offset imported electricity. The building shall also as a minimum fulfil all the requirements of the Passive House standard. For the first Powerhouse projects, a realistic aim is achieving an energy balance including the energy use related to operation, materials (including maintenance) and the construction phase. For later projects, the aim is that the energy use related to the demolition also shall be included in the balance account.

Concepts and solutions

The plus-energy goal has been the definitive most important factor from the early start of the design of Powerhouse Kjørbo. This multidisciplinary design has been crucial for achieving the energy goal, and other qualities such as the building's adaptation to the site and surroundings, its functionality, esthetical qualities and indoor environment in general.

As the most costly measure to reach the Powerhouse goal is the on-site electricity production (photovoltaic panels - PV), great efforts have been concentrated on reducing the need for energy during the operation stage and for producing materials for both the building and all technical installations. Limited available and efficient area for the electricity production (PV) enhances the need for substantial measures for energy efficiency, including minimizing the embodied energy for materials.

Due to the fact that the energy need for ventilation normally comprises a large share of the energy budget in office buildings, there has particularly been a high focus on reducing the energy need for ventilation for Powerhouse Kjørbo. This includes both using low emitting materials to reduce the ventilation demand, demand control, displacement ventilation, low pressure design to minimize fan energy, and highly efficient heat recovery. During normal operation, the average ventilation air volume will be about 3 m3/m2h wintertime, and about 6 m3/m2h summertime (on warm days).

For the Powerhouse energy account, the embodied energy related to the production of all new materials constitute near the same quantity as the energy needed for the operation of the building. Hence, this subject has also been central in the efforts of minimizing the energy demand. Energy related to the construction phase is also included, based on results from another green project. The demolition stage has not yet been considered.

Architecture

The Kjørbo office site consists of a total of nine almost similar black, cubical blocks, surrounded by a beautiful park. There have been strong directions from the municipality keeping the exterior expression as similar to the original as possible. This implies no change of shape, and the color should still be black. The facades of the Kjørbo office blocks, which before the renovation were covered with black façade glass, were in high need of renovation. In order to achieve a new and more environmentally friendly façade of the two renovated blocks – and still keep the black/dark color - the existing glass panels will be replaced by a charred wood cladding.

Picture 1: The Kjørbo site. Photo: Entra Eiendom

Picture 2 shows the two renovated blocks before the renovation.

Picture 2:Block 4 (to the left, three floors) and block 5 (four floors). Photo: Skanska

After the renovation, the blocks will still have the same shape and dark expression, se the illustration below. The windows have the same design. However, the size is a bit increased in order to improve view and daylight conditions. The thermal insulation and air tightness standard of the renovated facades will be highly improved, and will have a slightly better performance than of a passive house façade – see table 1.

Illustration 1: The Kjørbo blocks after refurbishment. Illustration: MIR/Snøhetta

The building envelope

The building envelope will be very god insulated, and the air tightness will also be very god. The U-values and the level of air tightness are shown in table 1 below.

Table 1: Thermal properties of the building envelope, before and after renovation.

Properties	Before renovation (expected values)	After renovation
U-value external walls	0.30 W/m²K	0.13 W/m²K
U-value roof	0.22 W/m²K	0.08 W/m²K
U-value floor on ground	0.15 W/m²K	0.14 W/m²K
U-value windows and doors	2.5 W/m²	0.80 W/m²
"Normalized" thermal bridge value, (per m² heated floor area)	0.15 W/m²K	0.02 W/m²K
Air tightness, air changes per hour (at 50 Pa)	3.5	0.50

Ventilation

The ventilation concept is based on a system with extremely low pressure drop over the components and in the ventilation ducts. Components with high pressure drop, such as the heat recovery unit, are bypassed when not in use. The system utilizes displacement ventilation, which is a more efficient way to ventilate spaces than the more traditional mixing ventilation method.

The air handling unit is placed between the north-west façade and a central (existing) shaft on the upper floors. In order to reduce the velocity and pressure drop as much as possible, the existing shaft in each of the blocks will be converted to pure supply air shafts.

From the shafts, the supply air will be distributed to the different zones via spacious designed ventilation ducts. The concept is further based on overflow from cell offices to landscape, and further to secondary functions before the air is extracted out via the stairwell in block 5, and an central atrium in block 4.

A spacious designed mixing battery will be utilized for free cooling of the ventilation air during the summer, and for preheating during the winter.

In addition, the users will always have the possibility to open windows in the office areas. The airing via the windows will be a supplement to the mechanical ventilation system.

The heating system

Due to the very good insulated and air tight building envelope, the heating demand is very low. Simulations have shown that the requirements to thermal comfort in the cell offices will be satisfied without local heat sources. However, during the coldest days and when the cell offices are not used, the heating strategy is based on leaving the doors open towards the office landscape. The radiator plant will be limited to central placed and larger heating units in the office landscapes. The result is reduced heat loss, reduced energy for pumps, fever components, less embodied energy and reduced costs.

Lighting

Electric lighting comprises a large share of the energy demand in new office buildings. An energy efficient lighting concept is therefore of high importance for Powerhouse Kjørbo. Keywords are daylight utilization, a lighting and control system fitting the different user needs, and energy efficiency. The lighting system will be locally controlled; in the landscapes a typical lighting zone will cover four work stations (about 15 m2). There will be full illumination only in the work areas. Lighting fixtures with low energy demand will be installed.

Efficient daylight utilization contributes to good indoor environment and minimal use of artificial lighting. The windows are designed for high level of daylight transmission and distribution in to the rooms. All work places are located in areas along the facades.

The energy supply system

For all thermal purposes, the building will benefit from 10 and 200 meter deep energy wells, in which liquid is circulated in a closed circuit. The tempered liquid will be directly utilized for free cooling during the summer, and for production of high-tempered heat during winter. Two heat pumps are planned, designed to cover the total heat demand, including tap water.

For the two office buildings, a server-room with 15 kW cooling capacity is planned. Expected peak at normal use is 10 kW. The installation is designed for utilization of free-cooling via the energy wells in the summer season. In addition, the heat from the server-room will be utilized for heating of tap water and space heating when needed.

An installation of about 1400 m2 PV panels, placed on the roof of the two office blocks and a common garage, is expected to produce between 210.000 and 230.000 kWh electricity annually. Due to the requirements from the municipality of keeping the shape of the buildings unchanged, the PV installation has to be kept more or less invisible from the ground. The tilt of the installation is therefore limited to 10 degrees towards south, and with a certain mutual distance to avoid shading. The electricity will annually constitute about 41 kWh per m2 heated floor area.

Using thermal solar energy was assessed, but was not considered to be suitable due to the lack of match between heat demand and the production of solar heat.

Materials and embodied energy

Embodied energy is traditionally not taken into consideration in traditional building projects. For Powerhouse Kjørbo, a study of the embodied energy has shown that embodied energy, regarded for a lifetime of 60 years, constitutes almost the same amount of energy (primary energy) as the energy used for operation of the buildings. For Powerhouse Kjørbo, the embodied energy is included in the energy balance account, and shall be balanced by energy production. Hence, a considerable effort has been taken to reduce the embodied energy in the building.

All existing reinforcing steel and concrete constructions will remain. In addition, the existing glass facade panels will be reused as interior panels in the refurbished buildings. The old facades will be replaces by new and far more energy efficient walls and windows. The new façade cladding will be made of charred wood, with long lifetime and marginal need for maintains.

The embodied energy calculations are mainly based on information from energy product declarations (EPD), but also the database EcoInvent and several professional reports and scientific articles. Due to lack of transparency and consistence in much of the documentation, there are large uncertainties associated with the calculated figure of embodied energy.

The total embodied energy is distributed on the different building elements as seen in table 2 below.

Table 2: Primary energy related to different building elements

Building table element	**kWh/m^{2}·år**
22 Superstructure	0.07
23 Outer walls	3.81
24 Inner walls	1.50
25 Structural deck	6.09
26 Outer roof	2.20
28 Stairs, balconies etc.	0.03
36 HVAC system	1.99
43 Low voltage supply	0.23
49 Other electric power installations	9.57
62 Person and product transport	0.08
69 Other technical installations	0.33
Energy _consumption in construction phase	1.21
Total with reinforcing steel and concrete	**27.2**
Total without reinforcing steel and concrete	**22.1**

The energy balance

Based on a high degree of energy efficiency measures, and a presumption of an optimal operation of the technical installations, the calculated demand for energy (net energy, delivered energy) is shown in table 3 below. The simulations are carried out with the dynamic energy simulation tool SIMIEN [3], and are in accordance with the Norwegian Standard NS 3031 [4]. However, energy use for lighting and equipment is in accordance with expected real use, but for a normalized operation period. For the further design, another and a more advanced simulation tool will be used.

Table 3: The “best case” net energy demand, and demand for delivered energy for Powerhouse Kjørbo. Embodied energy and electricity production is not included.

	Net specific demand kWh/m^2/y	Spesific demand for delivered energy kWh/m^2/y
Space heating	15.5	4.9
Ventilation heating	3.1	1.0
Tap water heating	4.3	1,4
Fans	2.3	2.3
Pumps	0.8	0.8
Lighting	7.7	7.7
Equipment	12.0	12.0
Equipment (data/server-room)	16.9	16.9
Space cooling	0.0	0.0
Cooling server-room	16.9	1.1
Ventilation cooling	3.4	0.2
Total	82.9	48.1
Total excluding data/server.room	66.0	31.2
Total excluding server-room and equipment	54.0	19.3

The embodied energy account for the materials is given in primary energy. These figures have shown to be hard to convert to delivered energy, which is the measuring point of the operation energy demand. In order to be able to calculate the total energy demand, and also to explore the need for electricity production to balance the energy need, both operation energy and energy production is converted to primary energy. The primary energy factors have been developed by the research center ZEB, based on the same principles as for the CO2-factors for electricity [5]. The primary energy factor, which is constantly being reduced towards the end of the lifetime of the buildings (due to expected increased share of renewables in the European electricity production), is shown inTable 4.

Table 4: Primary energy factors

	Primary energy factor
PEF 2010	2.50
PEF 2050	1.11
PEF 2070	0.41
PEF 2010-2040 (average 30 years lifetime)	1.98
PEF 2040-2070 (average 30 years lifetime)	0.93
PEF 2010-2070 (average 60 years lifetime)	1.46

The PV installation is assumed to be replaced after 30 years, and then with 50 % higher efficiency. At the same time, increased efficiency is weighted by a lower mean primary energy factor for the last 30 years, resulting in a lower primary energy contribution than for the first period. In Table 5, the total primary energy account for the Powerhouse Kjørbo is shown.

Table 5: Primary energy account for Powerhouse Kjørbo (Operational energy use excluding equipment)

Energy demand/production	Delivered/ produced energy (kWh/m^{2}year)	Primary energy factor	Primary energy (kWh/m^{2}year)
PV-production, first 30 years	40,5	1,98	80,2
PV-production, last 30 years	60,8	0,93	56,5
PV-production, average 60 years			**68,3**
Operational energy use	-19,0	1,46	**-27,9**
Embodied energy			**-22,1**
SUM			**+18,4**

The result shows that the project, during its lifetime, will produce more renewable energy than it will consume. The construction phase is included. When it comes to the demolition phase, there has so far been no time in the projects studying the amount of this contribution to the balance account. However, the surplus in the account is expected to cover the demolition phase with a high margin.

Conclusion

At this stage of the design phase of the refurbishment project Powerhouse Kjørbo, the analyses show that a plus-energy level, including the construction phase and embodied energy for materials, is achievable for the two office blocks in Norway.

Necessary strategies for obtaining this extremely high-ambition level, is a significant level of energy efficiency (passive house standard, innovative ventilation strategies/solutions etc.), high focus on materials used, and combined with an optimized energy supply system for production of thermal energy and electricity on-site.

The project is expected to be an important demonstration project for plus-energy buildings, both in Norway and world-wide.

Acknowledgement

The Powerhouse alliance was established by Entra Eiendom, Skanska, Snøhetta, the environmental organisation ZERO and the aluminium company Hydro in 2011.

Entra Eiendom is the owner of the two Powerhouse Kjørbo office buildings. Skanska is the contractor, and in addition the company's energy experts also lead the energy concept development. The architect is Snøhetta. The engineering company Asplan Viak, which will be the renter of the renovated buildings, is also joining the design team. The energy concept, and in particular the work with estimating project specific values of the embodied energy of the materials as correct as possible, has been carried out in close cooperation with the research center ZEB.

References

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