Conference Proceedings

EuroSun 2014

Aix-les-Bains (France), 16 - 19 September 2014

POWERHOUSE – INTEGRATING SOLAR IN AN ENERGY PLUS REFURBISHMENT OF OFFICE BUILDING

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Abstract

Powerhouse is a project in which actors in the Norwegian building sector collaborate to develop energy-positive buildings. A Powerhouse is defined as a building that during its lifecycle produces more renewable energy than it consumes for the production of building materials, construction, operation and demolition of the building. This paper describes how two office buildings outside Oslo, Norway, built in 1980, have been reconstructed to satisfy the powerhouse definition. The buildings have an area of 5.180 m^2 (internal area without outer walls). In addition to a very well insulated building envelope, the building will be equipped with heat pumps gaining heat from energy wells and a 310 kW PV system generating 230 MWh/year. These measures will reduce the annual energy consumption from 240 kWh/m^2 to approximately 50 kWh/m^2 (including internal loads). Since the requirements for a Powerhouse includes the energy use for the production of the materials, a detailed LCA has been carried out. In order to minimize embodied energy for the refurbished buildings, the Powerhouse rehabilitation also utilized recycled building materials such as used facade glass for doors and interior walls. The rehabilitated Powerhouse Kjørbo was completed in February 2014.

Introduction

The Powerhouse collaboration consists of major actors within the building and construction sector in Norway; a real estate owner / developer (Entra Eiendom AS), a construction company (Skanska Norway), an architect firm (Snøhetta Architechts AS), an environmental organization (Zero), and a Norwegian actor in the aluminum industry (Hydro) and as tenant, Asplan Viak AS, a leading Norwegian consulting firm also contributed in designing main elements i.e. the energy system in the building. The Norwegian Research Centre on zero emission buildings (ZEB) has also participated in the project. ZEB is hosted by The Norwegian University of Science and Technology (NTNU).

Energy-positive buildings have to solve two challenges within the same project: Firstly, energy demand has to be reduced as much as possible. Secondly, remaining energy demand has to be produced within defined boundaries. Buildings in Norway account for approximately 40 per cent of the country’s domestic energy consumption, of which half of this is used for heating. The Norwegian building sector possesses an important key in reducing the Norwegian greenhouse gas emissions.

The Powerhouse collaboration believes that energy-positive buildings are the buildings of the future. Buildings can be transformed from being part of the climate problem to becoming part of the solution.

POWERHOUSE DEFINITION

A Powerhouse is an energy-positive building which during its operational phase generates more energy than what was used for the production of building materials, its construction, operation and disposal.

This means that the produced renewable energy during the lifetime has to weight up for – the production and transport of all needed materials, the energy use during construction demolition, as well as the energy for the

doi:10.18086/eurosun.2014.20.01 Available at http://proceedings.ises.org

operation of the building.

Aside from the main energy related objective, Powerhouses also need to meet the following additional requirements:

- The energy production must be based on energy sources on site.
- Energy use for electrical equipment (i.e. computers, IT equipment) shall not be included in the energy balance account.
- BREEAM-NOR classification score: Outstanding
- The building shall be built within commercial marketable conditions.

Powerhouse Kjørbo – refurbishment of two office buildings

The Powerhouse collaboration's first refurbishment project is located at Kjørbo in Sandvika, 15 minutes west of the Norwegian capital Oslo. The refurbishment includes two buildings out of a total of 9 of the entire site, constructed in 1980. The refurbished buildings have an area of 5.180 m^2 internal area without outer walls. The two buildings included in the project are programmed for approximately 240 people, corresponding to an average area of 22 m^2 per person.

Figure 1: Office buildings before refurbishment

The main challenge was to find robust and affordable solutions to reduce the energy demand to an extend that energy production based on local resources could be obtained. Figure 2 shows schematic the main principle for balancing an energy positive building.

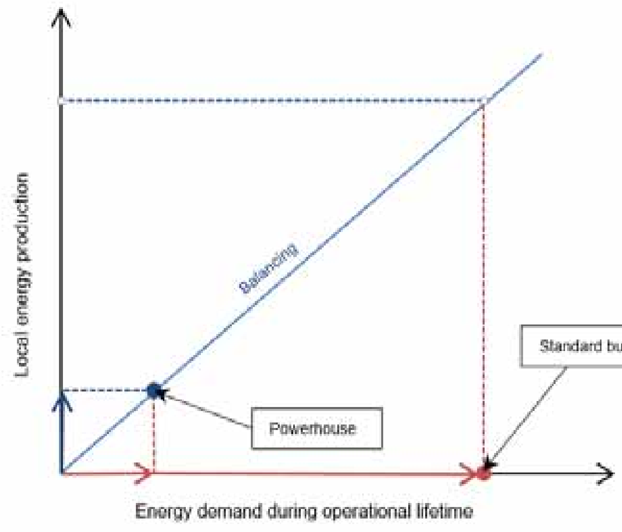

Figure 2: Principle for balancing an energy positive building

In order to obtain an energy positive building, local energy production, during the buildings operational lifetime, has to be equal or higher than accumulated energy demand. In most cases it is not possible to reach the "Balancing line" if the building is designed as a Standard building according to today's building code. Through consequent reduction of the energy demand, it is possible to produce the necessary energy to reach the balancing point.

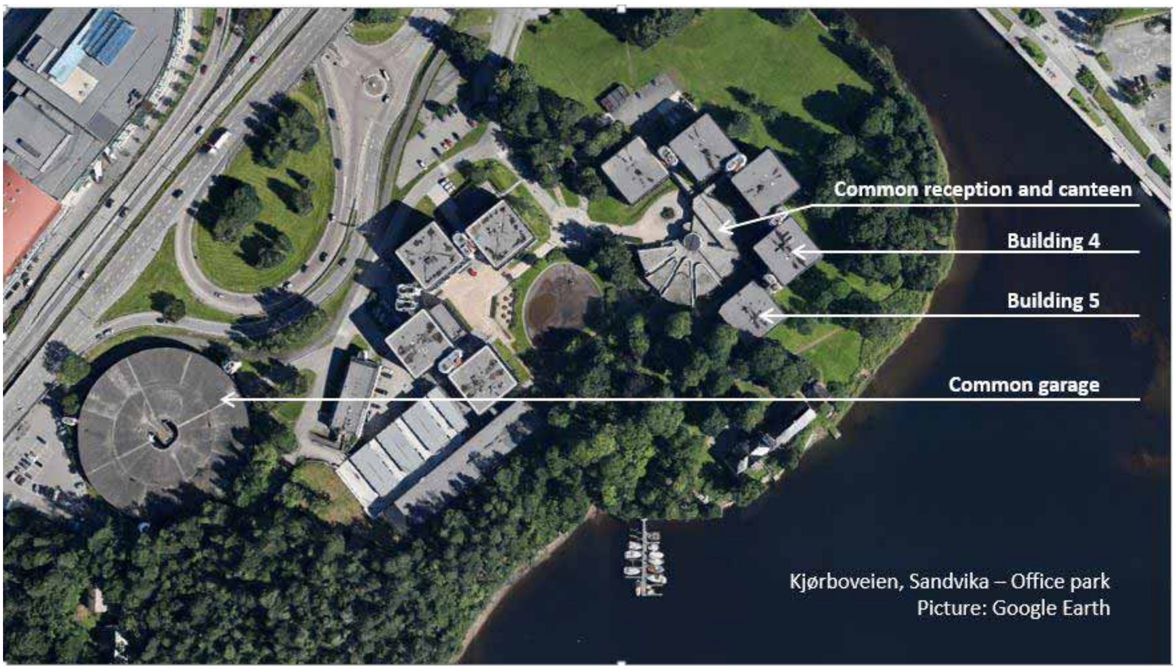

Figure 3: Satellite picture of the office park at Kjørbo, Sandvika

Figure 3 gives an overview over the localization of the Kjørbo office park with all nine buildings. Building 4 and building 5 have been refurbished to Powerhouse standard. PV-systems have been installed on the roof of building 4, building 5 and the two buildings relative share of the common garage. The energy wells have been installed between the Powerhouse buildings and the coastline of the Oslo fjord.

The main refurbishment topics are:

- High insulated facades:
- U-values: Roof: 0.08 W/m^{2}K, wall construction: 0.15 W/m^{2}K, windows 0.8 W/m^{2}K
- Airtightness: < 0,6 h^{-1} (measured during construction 0,3 h^{-1})
- High efficiency technical systems, ground coupled heat pump, COP = 15 for cooling, COP = 3.5 for heating, efficient ventilation system including heat recovery, and low SFP.
- PV-electricity production and utilization of produced electricity on site.

Building services system.

The overall design strategy is based on optimizing the building envelope and technical system, and in addition utilization of renewable energy.

LIGHTING SYSTEM:	New lighting system have planned LENI number ~ 9 kWh/m^2 year.
HEATING SYSTEM:	Before: Water based heating system. 40 radiators in each floor.
	After: Air heating delivered from ventilation system combined with 5 radiators in each floor, mounted on a wave shaped wall in the center of the building.
COOLING SYSTEM:	Before: Central cooling of inlet air for mechanical ventilation in combination with cooled beams.
	After: Central air cooling – mechanical and displacement ventilation
ENERGY SUPPLY:	Ground based heat pump (energy wells) and PV-system. District heating and grid electricity as peak- and back-up supply.

In order to reduce embodied energy, the new façades as shown in figure 4 are made of thermal treated wood. This is an old method originally from Japan.

Figure 4: Outside view of building 5

Energy concept

The annual energy consumption in the original building is reduced from 240 kWh/m^2 (Electricity: 125

kWh/m^2, District heating: 75 kWh/m^2, District cooling: 40 kWh/m^2) to approximately 50 kWh/m^2 per year (including internal loads). In order to achieve this goal, Powerhouse Kjørbo has combined a number of different solutions in its energy concept:

- Reduction in the energy need by employing energy efficient solutions and a well-insulated building structure.
- Efficient ventilation system
- Heating and cooling from vertical ground heat energy wells.
- Recycling of heat from computer servers.
- Two heat pumps running at different temperature levels; one intended for building heating and one for domestic hot water.
- Efficient external shading.
- Use of the thermal mass in the exposed concrete.
- Local production of PV-electricity from modules on available roof area.

Figure 5 shows schematic the energy concept consisting of 10 energy wells each 200 m deep. Heat pumps and the PV-systems.

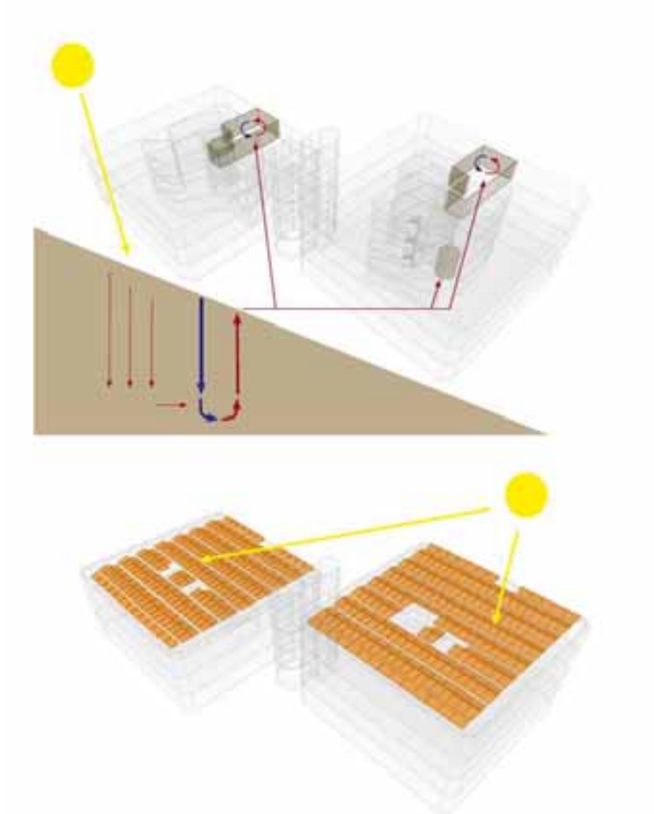

Figure 5: Schematic energy concept consisting of energy wells, heat pumps and PV-system

Embodied energy analysis

Being a refurbishment project, one must establish an appropriate method for the embodied energy calculations. Reuse of materials makes it easier to achieve the Powerhouse goals. Therefore, the possibilities for reusing materials from the older building were thoroughly assessed by the architects. In the “new” building, glass from the former façade is reused in the office front windows in inner walls. Several other possibilities for reusing materials were discussed, such as the reuse of spiro ducts, insulation, cable bridges and building boards etc.

More important was the conclusion made by the team working on embodied energy, stating that the service life time of the materials involved would decide the environmental burden of the materials in the retrofit building. Thus the environmental load of the concrete and steel in the “old” building structure could be subtracted from the embodied energy in the retrofitted building. The environmental load included is reduced, since the estimated lifetime of the concrete is prolonged from 60 to 90 years.

One can argue that in a refurbishment project that is older than 30 years, where the building has served more than 50 % of its estimated original lifetime, the environmental load from the concrete and steel should not be included. By retrofitting older buildings into buildings with high energy performance, the total environmental load from the building is reduced due to the reduced energy embedded in the materials. Alternatively, it is possible to argue that in a retrofit project there is no need to produce new steel and concrete. Thus the environmental benefits should be zero.

The results concerning energy are summed up in Table 1. The results are presented with annualized embodied energy – not the functional unit, but the functional unit divided by 60 years. This is done to simplify the combination of the embodied energy to the operational energy – which is always measured in the term kWh/m^2 annually.

Table 1 shows the annualized contribution for different building elements to the total embodied energy and greenhouse gas emissions. The calculated annualized embodied energy without reinforcing steel and concrete is approximately 22.1 kWh/m^2.

Table 1: Annualized contribution for different building elements to the total embodied energy.

Building element	Annualized embodied energy [kWh/m^2]	Annualized greenhouse gas emission [kg CO_2eq/m^2]
Superstructure	0.07	0.04
Outer walls	3.81	1.75
Inner walls	1.50	1.49
Structural deck	6.09	1.27
Outer roof	2.20	0.78
Stairs, balconies etc.	0.03	0.01
HVAC	1.99	0.30
Low voltage supply	0.23	0.11
Other electric power installations	9.57	1.78
Person and product transport	0.08	0.02
Other technical installations	0.33	0.07
Energy consumption in construction phase	1.23	0.06
Total with reinforcing steel and concrete	**27.2**	**5.7**
Total without reinforcing steel and concrete	**22.1**	**4.5**

Photovoltaic system

The PV-system is the key to balance the project so that the refurbished building over its lifetime generates more energy than it consumes. The annual electricity demand to operate the buildings (without user equipment) is calculated to approximately106 MWh. An additional 118 MWh/year have to be produced to compensate for the use of embodied energy (materials and production processes). The calculated annual electricity production of the installed PV-system is 230 MWh, somewhat larger than the demand.

One main challenge in designing the PV-system was the limited roof space available, and that the façade, do to shading was not suitable for BIPV. On this background, the criteria for selection modules were:

1. Highest possible system performance (expected annual production)
2. Embodied energy balance
3. Mounting solutions
4. Costs

Table 2: Overview PV-system

	Number PV-modules	PV-area [m^2]	Installed power [kWp]	Produced electricity [MWh/year]
Building 4	212	346	69	49
Building 5	182	297	60	43
Garage	560	913	183	138
SUM	**954**	**1556**	**312**	**230**

Table 2 summarizes the main specifications of the PV-system installed on the roof of building 4, building 5 and the roof of the common garage. Totally, the PV-system consists of 954 Sunpower E20 modules with an installed power of 312 kW_p. 16 SMA Tripower inverters have a total capacity of 244 kW. The vendor of the mounting system was Knubix GmbH. Figure 6 shows the installed PV-system on the roof of building 5.

Figure 6: PV-system consisting of Sunpower E20 modules and Knubix EW mounting System.

Energy Dash Board

By the end of September 2014 an Energy Dashboard allowing to monitor and display real time resource use, energy consumption and production, will be available on our websites. (www.asplanviak.no, www.powerhouse.com)

After four month of operation the first measurements indicate that the building performs as planned. Even during the extreme high mean temperatures in July, the cooling system based on the energy wells kept the building at comfortable indoor temperatures. So far, slightly higher electricity consumption for lightning has been monitored.