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# Zero emission office building in Bergen: Experiences from first year of operation

Åse Lekang Sørensen[a]*, Mads Mysen[a], Inger Andresen[b], Bjarte Hårklau[c], Arild Lunde[d]

[a]*SINTEF Building and Infrastructure, P.O.Box 124 / Blindern, 0314 Oslo, Norway*
[b]*Norwegian University of Science and Technology (NTNU), Høgskoleringen 1, 7491 Trondheim, Norway*
[c]*Veidekke, Møllendalsbakken 9, 5009 Bergen, Norway*
[d]*The Norwegian Defence Estates Agency (Forsvarsbygg), Postboks 405 Sentrum 0103 OSLO, Norway*

**Abstract**

The Visund office building is a pilot project within the Research Centre on Zero Emission Buildings (ZEB) in Norway. The building has been in operation since January 2016. The design aimed at meeting the ZEB-criterion of net zero energy balance, excluding energy for appliances. The energy performance has been closely monitored and the energy measurements during the first year corresponds well with the predicted and required performance. A high focus on shared goals, contract based economic incentives, building design and technology choices, energy monitoring and follow-up measures have been key-factors to achieve the goals.


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*Keywords:* Zero emission building; Net zero energy; Office building; Energy monitoring; Norway

## 1. Introduction

The Visund office building is a pilot building project within the Research Centre on Zero Emission Buildings (ZEB). The building, which is owned by the Norwegian Defence Estates Agency (Forsvarsbygg), was constructed in 2015. It is located at Haakonsvern naval base, about 15 km from Bergen at the west of Norway (latitude 60°N).

* Corresponding author. Tel.: +47 45268682.
*E-mail address:* ase.sorensen@sintef.no.

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The building design aimed at meeting the ZEB-criterion of net zero energy and GHG emission balance for building operation during a year [1]. The energy for appliances (computers, printers, etc.) is not included in the balance. This paper presents the design of the building, the method for energy monitoring and results from the first year of operation.

### *1.1. Building design*

The Visund office building has three floors and a heated floor area of 2031m$^2$. A compact and simple building form was chosen in order to minimize heat losses, avoiding air leakages, and minimizing costs [2]. Good daylight conditions in the occupied spaces were obtained by placing offices and primary rooms along the facades, while secondary rooms where placed in the interior. Windows were designed to maximize daylight conditions.

Table 1. Building and climate data for the Visund office building in Bergen, Norway.

| | |
|---|---|
| Heated floor area | 2031m$^2$ |
| U-values: External walls/roof/floor on ground/windows and doors | 0.13 / 0.09 / 0.08 / 0.73 W/m²K |
| "Normalized" thermal bridge value (per m² heated floor area) | 0.03 W/m²K |
| Air tightness, air changes per hour (at 50 Pa), measured value | 0.11 |
| Yearly mean ambient temperature / winter design / summer design | 7.5°C / -11.7°C / 18.9°C |

### *1.2. Energy system design and energy budget*

A local seawater-based heat pump provides thermal energy to the building. It was predicted that the heat pump will deliver 90% of the heating and domestic hot water (DHW) need with a seasonal coefficient of performance (SCOP) of 3. The predicted efficiency of the 10% heating and DHW need delivered by electricity is 88%. All the cooling need will be covered by the seawater pump, with a predicted SCOP of 10. The thermal energy losses in the waterborne circuits are including in the estimated SCOP-values. The lighting system consists of T5 fluorescent tubes and LEDs, equipped with occupancy and daylight controls. The ventilation system encompass active terminal devices with built-in controls, which automatically measure and control the air volumes and temperatures at room level.

The predicted net energy need and delivered energy is shown in Table 2 [3], using terms from prEN 15603 [4] and NS3031 [5]. The total net energy need of the office building is 54.1 kWh/m$^2$ and the required delivered energy is 42.1 kWh/m$^2$ electricity. Excluding appliances of 15.7 kWh/m$^2$, a photovoltaic (PV) system has to generate minimum 26.4 kWh/m$^2$ solar electricity to satisfy the ZEB-criterion. This solar electricity is supplied by an 84.58 kW$_p$ PV-system installed on the roof, facing east/west. The predicted energy production is 55,320 kWh/year or 27.2 kWh/m$^2$ heated floor area, providing a margin of 0.8 kWh/m$^2$.

Table 2. Predicted annual net energy need and delivered energy for the Visund office building, per net heated floor area. Calculations are based on statistical weather data for Bergen and is according to NS 3031, using the simulation tool SIMIEN (www.programbyggerne.no).

| | Net energy need | Delivered energy |
|---|---|---|
| Space heating | 8.4 kWh/m² | 3.5 kWh/m² |
| Ventilation heating | 2.8 kWh/m² | 1.1 kWh/m² |
| Domestic hot water | 5.0 kWh/m² | 2.1 kWh/m² |
| Fans | 6.0 kWh/m² | 6.0 kWh/m² |
| Pumps | 1.0 kWh/m² | 1.0 kWh/m² |
| Lighting | 12.5 kWh/m² | 12.5 kWh/m² |
| Appliances | 15.7 kWh/m² | 15.7 kWh/m² |
| Space cooling | 2.8 kWh/m² | 0.3 kWh/m² |
| Total | 54.1 kWh/m² | 42.1 kWh/m² |

## 2. Methods

### *2.1. Predicted energy need and energy production*

Predicted energy need was calculated using the simulation tool SIMIEN (programbyggerne.no). The calculations were based on statistical weather data for Bergen, and according to the Norwegian standard 3031 [5]. Energy need for lighting was calculated using the standard NS-EN15193. Predicted energy production from the solar cells was calculated using the software PVsyst (pvsyst.com) and climate data from Meteonorm 7 [6].

### *2.2. Energy contract and follow-up*

During the two-year trial period, the contractor Veidekke needs to verify the energy goals. If the need for delivered energy is 20% higher than calculated or more, 4% of the building contract price is deducted, as a compensation for increased energy costs. The purpose is to give the contractor incentives to closely follow-up energy use from start of operation. The contractor should handle deviations, and close them quickly if expedient.

The building owner and the contractor had regular meetings during the first year of operation, discussing the performance of the building. The monitored energy performance was central in these meetings. If the building performance was not as expected, measures have been implemented.

### *2.3. Monitoring the energy performance*

The contractor collects the following data on a monthly basis, starting from January 2016:

- Temperatures and solar radiation: Outdoor temperature (average weekly and monthly) and indoor temperatures on each floor (average weekly) from temperature sensors. Global solar radiation is measured by a national weather station located on Flesland, about 4 km from Haakonsvern.
- Energy measurements according to the different energy uses, e.g. heating, DHW, fans, pumps, lighting, appliances and cooling, as well as energy delivered from the electricity grid and from the local seawater-based heat pump central. In total there are about 30 meters for electrical or thermal energy. The electricity meters (accuracy ±0.5 RDG) are mainly placed in the main distribution board in the building, while the meters for thermal energy (accuracy ~99-99.5%) are placed in the relevant waterborne circuits.
- Electricity generated by the PV-system. The measurements are based on an electricity meter, placed in the main distribution board in the building.

The energy measurements are rather complete, with few missing data. The collected data is added to an excel-based energy management system [7]. The energy measurements for the different energy uses are summarized to get the net energy need. The delivered energy is calculated based on the net energy need, using conversion values from the energy predictions for SCOP values, efficiencies and distribution between electricity and waterborne heating.

The heating need is temperature corrected monthly, by calculating a correcting factor described by [8], where the base temperature is set to 9°C. No other operational factors are currently corrected.

In the energy management system, the monthly net energy need, delivered energy and electricity generation are compared with predicted values. Further, the deviations are highlighted, divided on the different energy uses. Energy use/outdoor temperature (ET) charts are also created, based on weekly heating/cooling/electricity consumption and average outside temperatures.

### *2.4. Evaluating experiences from the building and monitoring process*

Experiences from the building project is described in a case study report [9]. The report is based on semi-structured interviews with eight informers. The interviews were done in April and May 2016, 4 to 5 months after the building was finished.

## 3. Results

### 3.1. Energy need and delivered energy to the building

The temperature corrected net energy need according to the different energy uses is shown in Figure 1. The total net energy need in 2016 was 57.4 kWh/m², 6% higher than the calculated value of 54.1 kWh/m².

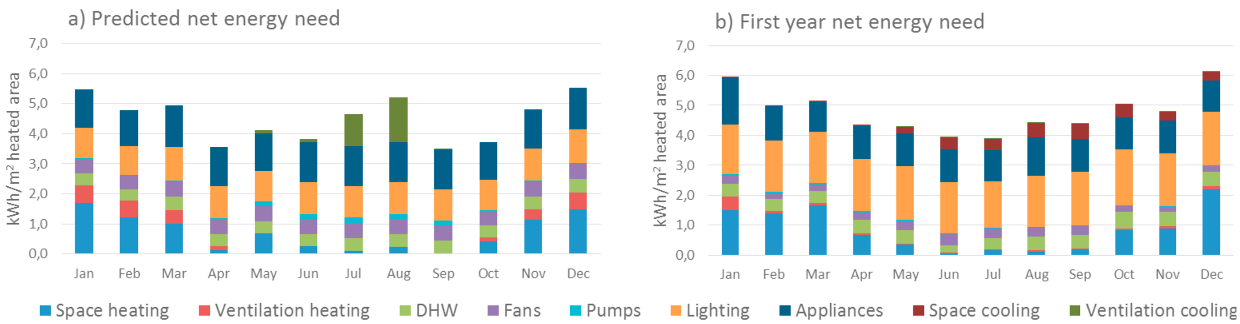


Figure 1. Net energy need based on a) predictions and b) first year measurements in the Visund office building, according to the different energy uses. The heating need is temperature corrected.

When looking at the space and ventilation heating added together, the 2016-measurements correspond to the predicted heating need. Compared to the predictions, space heating was higher and ventilation heating was lower than calculated. Also the need for domestic hot water corresponds to the predicted need.

Both the fans and pumps used only about half of the energy need predicted.

The energy need for lighting was 66% higher than predicted; 20.8 kWh/m² compared to calculated 12.5 kWh/m². Automatic control of lighting and sun shading screens has been a challenge during the first operational year. The project group has a focus on reducing this energy post. During the year, improvements have been done on the occupancy and daylight system.

Even though the energy need for appliances is not a part of the energy goal, also this energy post is monitored closely. In 2016, the energy need was 14% lower than predicted, or 13.5 kWh/m².

Energy for space and ventilation cooling was 3.2 kWh/m² in 2016, 15% higher than predicted.

In total, delivered electricity to cover the energy need of the building was 45.1 kWh/m² in 2016, 7% higher than the predicted value of 42.1 kWh/m². The delivered energy is calculated, using the conversion values from the energy predictions, as described in Chapter 2.3. If using an alternative method of summarizing the delivered electricity and thermal energy, and using the same SCOP for thermal energy, delivered electricity was 46.4 kWh/m² in 2016, 11% higher than the predicted value.

### 3.2. Energy production

The energy generation from the PV plant is shown in Figure 2, together with the solar radiation. The total electricity generation in 2016 was 55,770 kWh/year or 27.5 kWh/m², which corresponds well to the predicted energy generation.

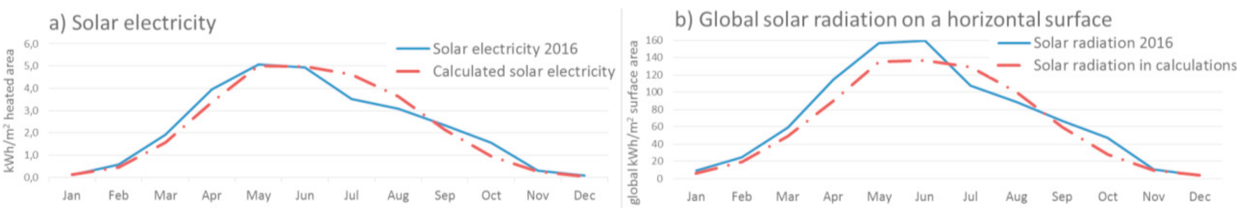


Figure 2. (a) Predicted and first year measurements of solar electricity; (b) Predicted and first year measurements of the solar radiation.

### 3.3. Evaluation of weekly energy consumption using ET charts

The relationships between temperatures and heating / cooling energy consumption in a building can be simplified using a linear model [10]. ET charts was used for the office building when evaluating the monitored data, showing weekly heating / cooling / electricity consumption and average outside temperatures. The ET curve for the weekly heating need in 2016 is shown in Figure 3. ET chart evaluation can detect exceptional situations or faults.

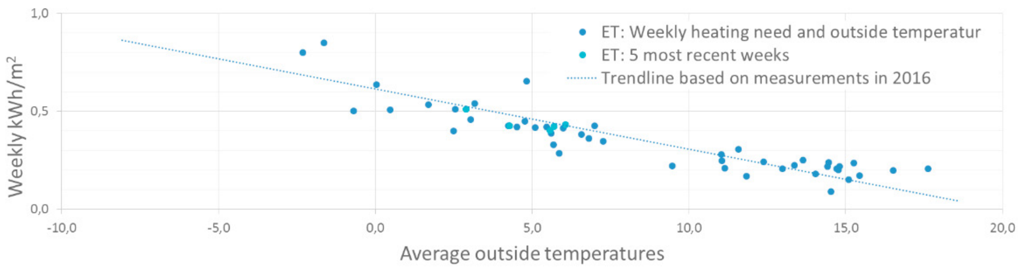


Figure 3. ET chart showing the relationship between weekly energy use for heating and average outside temperatures at Visund office building.

### 3.4. Net delivered energy after one year operation

To satisfy the ZEB-goal, the PV plant has to generate as much electricity as the energy delivered to the building, except the energy needed for appliances. In 2016, the energy need for appliances was 13.5 kWh/m². The delivered energy during the year was 45.1 kWh/m² and energy generation from the PV plant was 27.5 kWh/m², giving a net delivered energy of 17.6 kWh/m²; 4.1 kWh/m² more than the energy need for appliances. The ZEB-goal was therefore not completely achieved during the first year of operation. Figure 4 shows monthly net delivered energy.

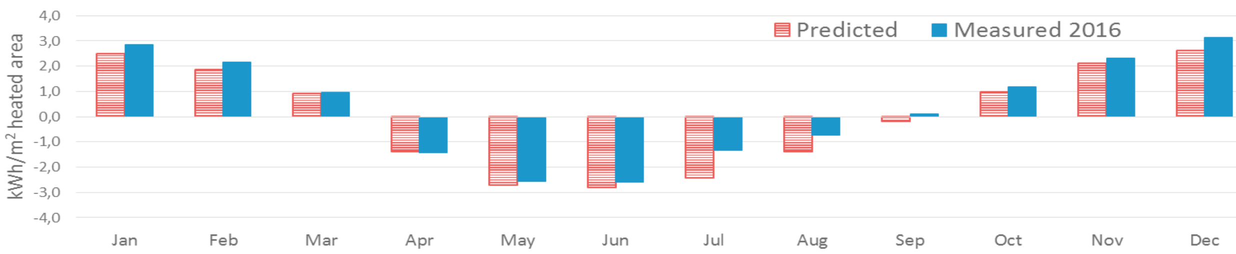


Figure 4. Net delivered energy at Visund office building during the first year of operation, not including energy for appliances.

## 4. Discussion

When analysing the energy performance according to the different energy uses, the net energy need during the first year of operation corresponds well with the predictions. Energy need for lighting is an exception, with 66% higher energy need than predicted. When appliances are excluded, energy for lighting represents a rather large share of the final energy use during the first year: 47% of the net energy need and 66% of the delivered energy.

Also the delivered energy to the building corresponds well with the calculations. This paper describes two different methods for summarizing the delivered energy during the first year of operation. The initial method, based on conversion values from the energy predictions, gives a delivered energy of 45.1 kWh/m². When using the alternative method of summarizing the delivered electricity and thermal energy, the delivered energy result for 2016 increases to 46.4 kWh/m². This alternative result is not temperature corrected, but the temperature correction changed the initial result with less than 0.5%. The reason for the difference between the two methods is that the real efficiencies and other conversion factors varies from the predictions.

In general, the predictions have provided a good basis for the energy monitoring; both the calculated energy need using SIMIEN and the calculated energy production using PVsyst. Except for the heat need, which is temperature corrected, no other measurements were modified. If correcting other operational parameters or weather parameters, the results would change. For example, the average indoor temperature was 22.9°C in 2016, while the predicted temperature was 21°C (19°C) within (and outside) operating hours. If recalculating the predicted heating need and delivered energy using the indoor temperatures of 22.5°C (20.5°C), the energy need would increase with 19% to 64.2 kWh/m² and the delivered energy would increase with 10% to 46.3 kWh/m². During the initial year 2016, both the energy need and the delivered energy were lower than these recalculated values.

The building owner and the contractor have had a high focus on energy monitoring and the subsequent need for improvements. During the two-year trial period, the contractor needs to verify the energy goals defined in the contract. If the need for delivered energy proves more than 20% higher than calculated, 4% of the building contract price is deducted. This gave the contractor incentives to closely follow-up energy use from the first day of operation. The follow-up required detailed monitoring with the purpose to reveal deviations caused by not optimal operation or energy related failures. The interaction between goals, contract and monitoring is rated as a success factor for achieving the project goals for energy [9]. The monitoring has provided a valuable generic knowledge on how the technology solutions actually work when the building is in use.

In 2016, delivered energy was 7% higher than the predicted value, achieving the contract requirement of maximum 20%. Given that this was the initial operational year, with a number of improvements, it seems possible to later achieve the ZEB-goal of net zero energy balance for building operation during a year, not including the energy for appliances. This can e.g. be achieved by reducing the energy use for lighting, or by reducing the indoor air temperature to a temperature closer to the design temperature. The energy post for lighting was 8.3 kWh/m² more than predicted in 2016, exceeding the needed reduction of 4.1 kWh/m² to achieve the ZEB goal this initial year.

After the first year of operation, the Visund office building appears like a success story. The case study report [9] describes a number of factors contributing to this result. Clear communication of the energy ambitions is one of these factors. The building contract and its economic consequences commits the contractor to follow up the energy performance for a 2-year period. Lastly, a positive project culture, good cooperation and personal commitment towards the environment and the energy targets are factors which have contributed to the project achievements [9].

## 5. Conclusion

The building project shows that it is possible to build a net zero energy office building in Bergen. The monitored energy need and production show a very good correspondence with the planned energy budget. A high focus on clear and shared goals, contract based economic incentives, building design and technology choices, energy monitoring and follow-up measures have been key-factors to achieve the ambitious energy goals.

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