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# Energy measurements at Skarpnes zero energy homes in Southern Norway: Do the loads match up with the on-site energy production?

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**Abstract**

Five houses are designed as zero-energy homes in Skarpnes, Norway. The energy goal is to achieve net zero-energy balance on an annual basis. The houses have heat pumps and solar cells (PV). Energy use and delivered energy have been monitored from June 2015. Variations between calculations and measurements are explained by technical and non-technical reasons. For the first year, higher than expected energy loads result in a solar energy cover factor of 65–87% of delivered electricity. The PV generation performs satisfactorily, hence, it may be possible to achieve energy goals during later years provided technical adjustments or behavioral changes.


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*Keywords:* Zero energy homes; Zero Emission Buildings; Energy measurements; Photovoltaic system, Building energy simulations; Norway

## 1. Introduction

Smart Village Skarpnes is located close to the city of Arendal in southern Norway (58.43°N, 8.72°E). The village is near its completion and will consist of seventeen single-family houses and three apartment blocks when finished. Five detached houses are designed as zero energy homes. These were finalized in 2014/2015. The five houses are pilot building projects within the Research Centre on Zero Emission Buildings (ZEB). The buildings are designed according

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to the ZEB-O definition [1], where the carbon emissions due to operational energy use should be zero on an annual basis. All energy items, also plug loads, are taken into account.

As part of the research carried out in ZEB and the project EBLE "Evaluation of Buildings with Low Energy-consumption", the energy performance of the buildings is measured. In the project "Electricity Usage in Smart Village Skarpnes", the solar power production and the electrical consumption is analyzed. This paper presents the method for energy monitoring and one year of measurements from the five homes, from June 2015 onwards. In addition, the distribution of electricity production is compared with the energy consumption, on monthly and hourly basis, and the degree of matching is characterized in terms of load cover factors.

### 1.1. Building design

Each of the five zero energy homes has a heated floor area of 154 $m^2$, divided on two floors. There are four bedrooms in each home. The five buildings meet the requirements of the Norwegian passive house standard [2]. The form and architecture is rather conventional for new dwellings in Norway. However, the roof construction is asymmetric to enhance solar energy production from building integrated photovoltaic (BIPV) modules [3]. The solar modules are replacing exterior cladding of the sloped roof, as shown in **Feil! Fant ikke referansekilden.**. The slab on the ground is a concrete slab with EPS insulation and the cellar walls are made of core insulated lightweight aggregate blocks. The roof construction is made of prefabricated trusses, while the external wall has a wood-frame wall construction with additional insulation layers both on the inside and outside. The window sizes and distribution were designed to give adequate daylight conditions in different rooms. The windows facing east, south and west have external solar shading.

Table 1. Building and climate data for each of the five zero energy homes in Smart Village Skarpnes, Norway.

| | | |
|---|---|---|
| U-values: External walls/roof/floor on ground/windows and doors [3] | | 0.12 / 0.08 / 0.09 / 0.80 W/m²K |
| Normalized thermal bridge value | | 0.03 W/m²K |
| Air tightness, air changes per hour (at 50 Pa) | Design phase value [3]: 0.6 | As built-values: 0.4 - 0.51 |
| Yearly mean ambient temperature | | 8.0°C |

Figure 1. Zero energy homes.

### 1.2. Energy system design

The need for heating and domestic hot water (DHW) is covered by a ground source heat pump. Each dwelling has a 90 meter deep borehole. The houses have balanced ventilation systems with a rotary wheel heat recovery. In addition, the fresh air is preheated in the winter with the ground source brine loop, which also can be used to cool the air slightly in warm summer periods. The total efficiency of the rotary wheel and the preheating system is estimated to be 86%. The heat distribution system is a waterborne floor heating system. All houses have heating in the bathroom floors and some houses have floor heating also in other rooms. Additionally, there are one to two convectors installed in each house, also heated by the waterborne heat distribution system. DHW is primarily heated by the heat pump, with peak load covered by an electric element. Hot water is also provided to a hot-fill dishwasher and washing machine.

The BIPV system on each house consists of 32 mono-crystalline silicon PV modules [4]. The roof has a pitch angle of 32°, where the PV modules are placed on the southernmost facing roofs, ranging from +48° (South-West) to -51° (South-East) in azimuth angle. The total installed PV capacity per house is 7.36 $kW_P$, connected to a 7 kW three-phase inverter. The system is connected to the electrical grid using a standard 'Prosumer' agreement, where electricity is exported from the solar cells or imported from the grid, as needed.

## 2. Methods

### 2.1. Predicted energy need and delivered energy based on as-built input

The predictions for the energy need and delivered energy presented here is a combination of standardized and *as-built* input. The predictions therefore vary from the design phase [3], which were based on standardized values.

Predicted energy need is calculated using the simulation tool SIMIEN (programbyggerne.no), and according to the Norwegian standard NS3031 [5]. The calculations are based on statistical weather data for the area (Arendal), except for outdoor temperature, which is based on measured data. For each building, the predictions are based on measured indoor temperature and measured air tightness, which result in a variation of the prediction for each of the five homes. The seasonal coefficient of performance (SCOP) of the heat pumps, representing the annual average, is set to 2.2, based on measurements in two of the houses during the first year of operation.

During the early design phase, predicted energy production from the PV systems were calculated using the software PVsyst (pvsyst.com) and climate data from Meteonorm 7. The simulations were performed with slightly different system components and dimensions than the final installed system, which were later scaled to the actual installed system peak power. In the final design phase, the PV system supplier performed own simulations predicting an annual production of 6820 kWh for the South-East facing system.

### *2.2. Monitoring the energy performance*

The total energy purchase and sale is measured hourly using AMS-meters (Advanced Metering System) installed by the energy utility company. The AMS-values display net values, i.e. the total imported or exported energy within each time interval. The total electricity use in each building is calculated by adding the solar energy production to the AMS-measurements. The solar energy production is monitored by SMA-inverters with 15-minute resolution. In addition, the five zero energy houses are equipped with an Elspec G4400 power quality analyzer that measures net power and grid quality parameters, such as frequency, phase angle and voltage, at high temporal resolution (< 1 sec).

A number of sensors measure the specific energy needs and indoor and outdoor climate parameters with 1-minute resolution. ABB power meters are installed on various electrical circuits, such as the heat pump, ventilation, fan convector and circulation pump, to monitor load patterns. There are two Kamstrup flowmeters (Multical 402) measuring thermal energy delivered from the DHW-boilers and heat delivered to the waterborne floor heating system in each house. Indoor climate is monitored with wireless temperature, humidity, and $CO_2$-sensors.

The energy measurements presented span a period from July 2015 to June 2016. PV production data is only available from September 2015. Thus, PV production is predicted for July and August 2015, based on Global Horizontal Irradiance (GHI) measurements from the nearby location Kjøita, Kristiansand (58.15°N, 8.00°E). Furthermore, some of the measurements of the specific energy needs are missing during the measurement period due to instability in the data acquisition system. The total energy use for a period is usually available, hence the total is divided on the number of days equally, expect for the heat pump, where annual variations are taken into account.

Mismatch is investigated here in terms of hourly energy values, representing the typical data resolution available from electricity meters. For investigation of peak values and grid implications, higher resolution data is necessary.

## 3. Results

### *3.1. Predicted yearly net energy need and delivered energy*

The calculated yearly net energy need and delivered energy is shown in **Feil! Fant ikke referansekilden.** using terms from prEN 15603 [6] and NS3031 [5]. The total yearly net energy need for each building (H1-H5) is between 75.7 and 86.3 kWh/m$^2$, which can be covered by 55.2 to 60.6 kWh/m$^2$ delivered electricity. To satisfy the ZEB-criterion, this amount of electricity should be generated by the PV system. As the PV system was dimensioned according to a lower net energy need in the design phase, the ZEB-criterion is not achieved with the revised predictions using the real outdoor and indoor temperatures, measured SCOP- and air tightness values.

### *3.2. Yearly delivered energy to each of the five single-family houses*

Yearly calculated and measured delivered energy to each of the five single-family houses are shown in Figure 2. The measured delivered energy during the first year of operation is from 2% lower to 21% higher than predicted, when comparing measurements with the revised predictions. For the first year, the measured delivered energy, per net heated floor area, varies from 54.2 to 69.8 kWh/m$^2$ in the five houses, while energy production from solar cells is from 45.6 to 48.5 kWh/m$^2$. Solar energy production covers in total 65 to 87% of the delivered energy during the initial year.

Table 2. Predicted annual net energy need and delivered energy, per net heated floor area. Calculations are design phase values [3] and revised values based on *as-built* and standardized data. Calculations are according to NS3031 [5], using the simulation tool SIMIEN (programbyggerne).

| Five zero energy homes in Skarpnes | Design phase | Revised predictions | | | | |
|---|---|---|---|---|---|---|
| Net energy need (kWh/m²) | H1-H5 | H1 | H2 | H3 | H4 | H5 |
| Space heating and ventilation heating | 16 | 16.9 | 13.1 | 12.7 | 22.9 | 12.3 |
| Domestic hot water | 36 | 29.8 | | | | |
| Fans and pumps | 5 | 4.8 | 4.7 | 4.8 | 4.8 | 4.7 |
| Lighting / Appliances / Space cooling | 11 / 12 / 0 | 11.4 / 17.5 / 0.0 | | | | |
| Total net energy need (kWh/m²) | 80 | 80.4 | 76.5 | 76.2 | 86.3 | 75.7 |
| SCOP | 4 * | 2.2 | | | | |
| Delivered energy (kWh/m²) | 41 | 57.5 | 55.5 | 55.4 | 60.6 | 55.2 |
| Solar electricity (kWh/m²) | 44 | 44.3 | 44.3 | 44.3 | 44.3 | 44.3 |

* Design phase SCOP was based on another system solution, which incl. solar thermal collectors

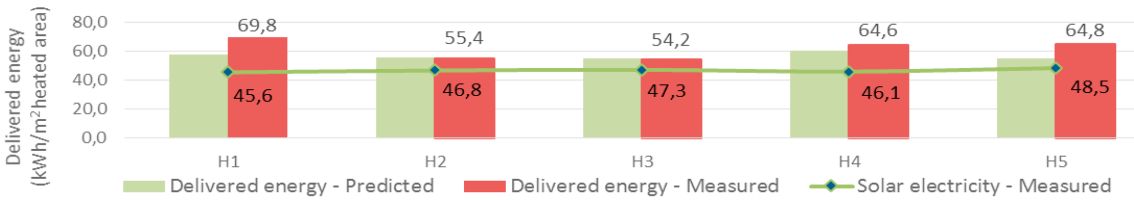


Figure 2. Measured delivered energy to each of the five single-family houses in Skarpnes after one year of measurements.

### 3.3. Specific net energy needs

First-year measurements of the specific net energy needs are available from four of the single-family houses, as shown in **Feil! Fant ikke referansekilden.**. The yearly net energy needs are divided on heating, DHW and other electricity. For heating and DHW, the SCOP value shows the relationship between the heating need and delivered energy for heating. In total, the specific net energy need varies between 87.7 and 111 kWh/m$^2$, which is about 16 to 36% higher than predicted.

The heating need is significantly higher than predicted for all the four houses. The use of DHW varies between the houses, but all houses have a lower energy need for DHW than predicted. The use of electricity includes energy for fans/ventilation, pumps, lighting and appliances, as well as a minor contribution to the DHW. This use of electricity is between 1 and 48% higher than predicted for the homes. Ventilation is for two of the houses measured to be 7.1 and 4.7 kWh/m$^2$, where the first of these houses used the ventilation system for cooling during the summer.

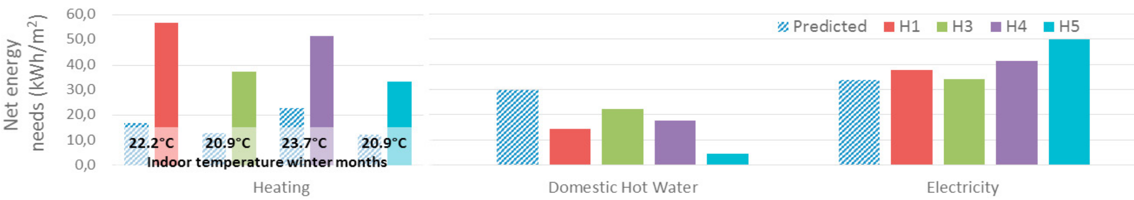


Figure 3. Specific net energy needs in four of the five single-family houses in Skarpnes after one year of measurements.

### *3.4. Matching of delivered energy and energy production*

Figure 4 shows the distribution of monthly electrical energy production and consumption for the five houses from June 2015 to September 2016. Individual variation in consumption is evident, whereas production is relatively similar and only slightly affected by the azimuthal difference in PV orientation. The average net energy (AVG NET) refers to the average difference between production and consumption for all five houses. Although aggregated data tend to smooth out individual fluctuations, this effect is small compared to the overall trend of simultaneous opposite production and consumption patterns seen as a function of season. Figure 5 shows two examples of the distribution of electrical energy production, consumption and net grid exchange for a day in January and June 2016, representing the two extreme situations of mismatch in winter and summer. Based on hourly data, the load cover factors are in the range 2-3% (demand) and 65-80% (supply) for the month of January, and in the range 47-52% (demand) and 20-36% (supply) for the month of June.

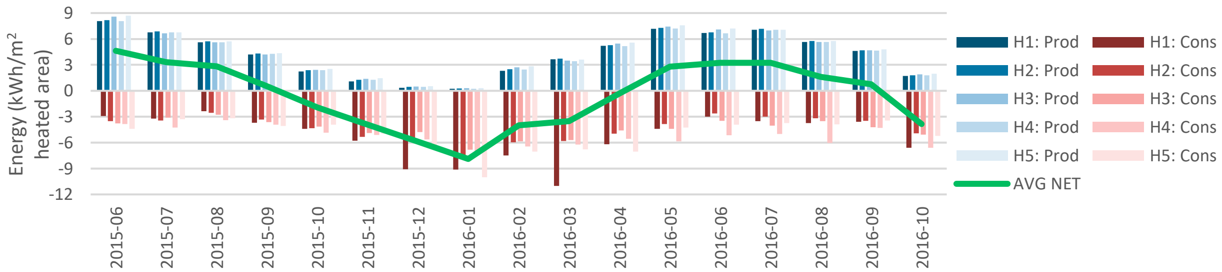


Figure 4. Distribution of monthly electrical energy production and consumption for the five households at Skarpnes, from June 15 to Oct. 16.

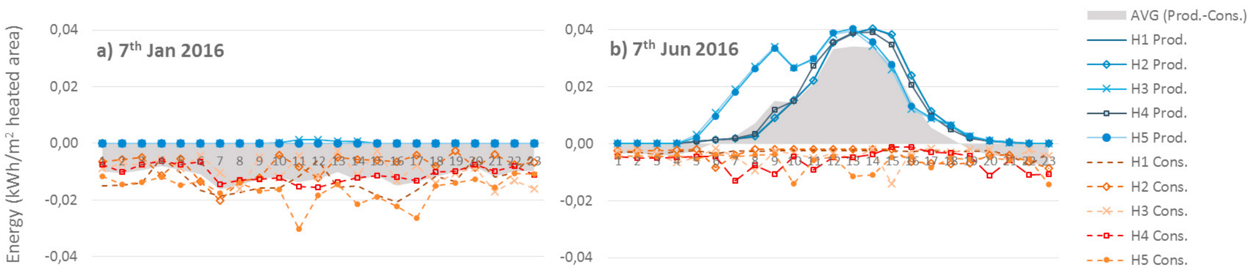


Figure 5. Daily distribution of hourly electricity production, consumption and net grid exchange for a day in a) January and b) June 2016.

## 4. Discussion

The results compare measurements with revised predicted values for delivered energy, net energy needs and energy production for the five homes. The revised predictions are calculated with *as-built* input, with the goal of getting calculations as close as possible to the real situation. Still, there are variations between the calculations and the measurements. The explanations for these variations can be divided into technical and non-technical reasons.

The technical explanations are especially relevant for the heating demand. A number of improvements were implemented during this initial operational year, and experiences from other projects show that the heating demand during the initial year may not be representative for the upcoming period [7]. For example, the regulation of the space heating systems needed tuning of set temperatures to reach the desired comfort levels in the houses. During the first winter, two of the houses experienced too cold indoor temperatures and installed electrical heaters to compensate, which increased the electricity consumption. With the systems now correctly tuned, the additional electrical heating should not be necessary. Also, two of the heat pumps were changed towards the end of the measurement period, since they were not operating as expected. Other technical explanations may be connected to the efficiencies in the energy systems. The SCOP of the heat pump is estimated to be 2.2 based on measurements in two buildings, but may vary in the remaining three buildings. In addition, the efficiency of the rotary wheel and the preheating system may be lower than the estimated 86%. Also, single measurements in the ventilation system show real airflows higher than estimated. Further analysis is needed to explain the exact difference between estimated and measured heating need.

The non-technical explanations are for instance connected to occupancy pattern and household size, which are important parameters to correctly predict the energy use of a household [8]. Interviews have been done with three of the five inhabitants as described in [9]. During the interviews, the inhabitants describe their habits related to energy use. For example, in houses H1 and H4 the inhabitants sleep with their windows open, also during the winter. This may contribute to the high heating need of these buildings [10, 11]. Also DHW need varies with the occupant's behavior. This has been confirmed in a Swedish study with about 1000 apartments, where the authors found a factor 14 in the variation between the 10 % apartments using most DHW and the 10% using the least DHW [12].

The PV production during the first year was slightly higher than predicted, and all systems perform satisfactorily. Even though the sum of energy consumption and production should be close to zero on an annual basis, the ZEB-O design involve no criteria for the degree of matching between energy import and export at other time scales. The highest loads usually occur in winter, which is opposite to the maximum PV production occurring during summer. On a daily basis, peak PV production during mid-day rarely coincides with peak consumption. Hence, on timescales less than a full year, the energy need and energy production in each home is generally characterized by mismatches. Hence, if the ZEB houses are to take full advantage of their PV systems for load shifting and higher self-consumption of solar power, smart control strategies, preferably combined with thermal or electrical storage options, will be necessary.

After the initial year, the energy production from the solar cells covers 65 to 87% of the delivered energy, on an annual basis. The energy goal of net zero delivered energy is therefore not achieved after the first year. There are several measures which can lower the need for delivered energy. One of these measures is to improve the heating system so the SCOP increases. The SCOP of 2.2 used in the predictions is lower than the initially predicted SCOP of 4. It may also be possible for the inhabitants to reduce their energy need by changing their occupancy patterns.

## 5. Conclusion

Although the building types are almost identical, there are significant variations in the energy use. During the initial operational year, the measured delivered energy varies from 54.2 to 69.8 kWh/m$^2$ in the five houses, while energy production from PV is from 45.6 to 48.5 kWh/m$^2$. The energy use during this first year may have been elevated due to initial challenges with tuning of indoor temperatures and performance of technical installations. In conclusion, the loads do not match up with the on-site production for the first year of operation, but it may be possible to achieve this ambitious goal in later years if technical adjustments or behavioral changes are followed up.

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