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Efficiency of BIPV system – Field study in Norwegian climate

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Lars Gullbrekken[a], Nora Schjøth Bunkholt[b], Steinar Grynning[a] , Martin Bellman[c] and Tore Kvande[b]

a SINTEF Building and Infrastructure, Department of Architecture, Building materials and Construction, Høgskoleringen 7b, 7491 Trondheim, Norway

b Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim

c SINTEF Industry, Department of Sustainable Energy Technology, Trondheim

* corresponding author: email: lars.gullbrekken@sintef.no.

Abstract. Use of solar cells (PV) and solar collectors are key remedies in buildings where a large part of the energy supply should be based on renewable energy. The aim of this work has been to evaluate calculated and measured solar production of two identical BIPV roofs located at the ZEB Living Laboratory situated at NTNU-campus in Trondheim. Temperature, irradiance and wind speed and direction at the rooftop of the building have been monitored since the construction of the house. There was found a large difference in energy production of the northern roof section and the southern. One possible explanation is shading of the northern roof because of low solar azimuth during the measuring period. In order to avoid such disadvantages, design of the PV-roofs should be considered early in the design phase of the building project. A small difference was found between the hourly measured and the calculated values of the PV performance based on the monitored local climate data. Use of generic climate data expect to cause a larger difference between measured and simulated energy performance due to lack of consideration to local conditions.

1. Introduction

Use of solar cells (PV) and solar collectors are key remedies in buildings where a large part of the energy supply should be based on renewable energy. PVs are for example used in the pilot buildings of the ZEB-research project [1]. However, in Nordic climate, the use of solar collectors and PV can be challenging due to snow, wind and temperatures below zero. Characteristics for Norway are the varied climate and the rugged topography with corresponding large local differences over short distances and extreme seasonal variations. The climate is putting a great strain on the building envelopes of our buildings. The building envelope and the roof in particular may be exposed to severe wind, snow loads, precipitation, freeze thaw cycles and large temperature fluctuations.

Interest in building integration of photovoltaics and solar collectors, which means that PVs and solar collectors become an integral part of the building, is growing worldwide. Photovoltaics integrated in the building envelope, such as the roof or the façade, is referred to as Building Integrated Photovoltaics (BIPV). According to Ceron [2] almost 50 % of the BIPV market is roof applications. The primary function of the roof as a climate screen must still be fulfilled with BIPV-systems.

To maximize energy yield, to lower degradation processes, and from a building physical point of view, ventilation below BIPV is necessary. Ventilation may reduce the temperature of the solar cells, which is dependent on the heat gains from the sun and the heat losses to the surroundings. The efficiency of the PV-panels is strongly dependent on the temperature of the PV-panel [3,4,5]. Assuming still air and PV attached to a building with good rear ventilation Häberlin [6] suggests a 30°C temperature increase relative to ambient temperature at 1 kW/m² insolation. For crystalline silicon modules this will give an efficiency decrease of 15 % [7].

The performance of three different commercially available PV modules in outdoor conditions in Southern Norway was compared by Midtgard et al. [8]. As expected, it was found that the amorphous module had the lowest overall efficiency and the monocrystalline the highest, also when considering gross efficiency at all irradiances over a complete year. A good correspondence between the measurements and the calculations of the energy yield was found. The calculations were performed with the software PV Potential Estimation Utility. Another study by Imenes [9] showed a relatively large difference in the energy yield of 13 BIPV systems situated at different locations in Norway. This was among others due to shading challenges and non-optimal site conditions. The importance of including knowledge about the PV planning into the early stages of a building project was pointed out as a central measure in order to avoid shading problems and unforeseen added costs during the installation phase.

In order find the best cooling strategy for BIPV panels Misiopecki et.al [10] performed a numerical study (CFD calculations). A comparative analysis of different air gap widths for cooling of the roof was conducted. The results showed that an air gap height of 50 mm was not sufficient to provide cooling of a 70 m long BIPV roof. The developed model was considered a good starting point for further investigations. However, to the authors knowledge such investigations in Nordic climate has not been performed.

The aim of this work has been to evaluate calculated and measured solar production of two BIPV roofs with identical PV installations. The roofs are located at the ZEB Living Laboratory situated at the NTNU-campus in Trondheim. This has been done through an extensive measurements campaign where analysis of solar production, weather conditions and temperature on PV modules and in the air cavity beneath the modules has been carried out.

2. Method

2.1. Test site

The ZEB Living Laboratory is a demonstration building that is representative, as a typology, of the most common Norwegian dwelling – the single-family house – to show that CO_2-neutral constructions (ZEB-OM ambition level) can be realized in the Norwegian climate with todays' technologies.

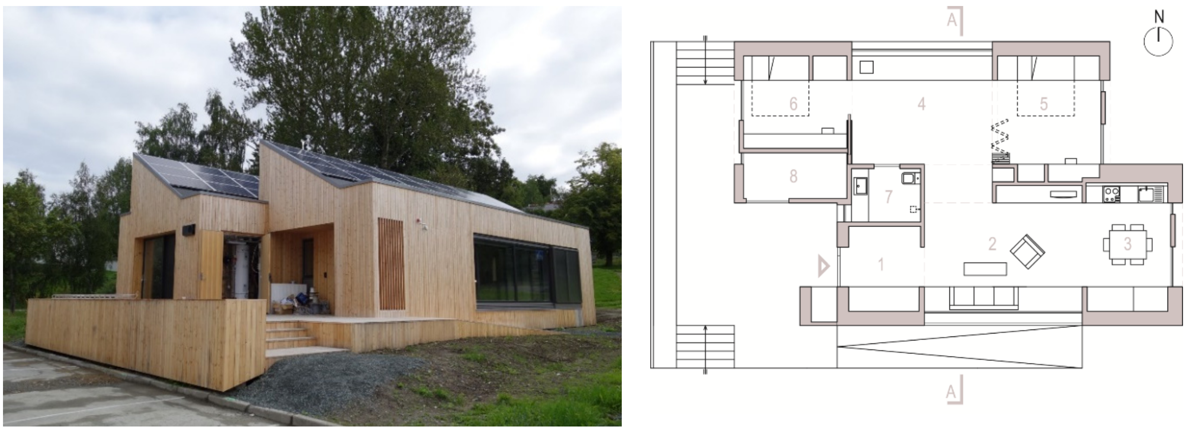

Figure 1. Left: Zeb Living Laboratory with two parallel PV-roofs. Right: The floor plan of the house consists of combined living room and kitchen and two bedrooms. Illustration: Gabrielle Lobacarro

2.2. PV Roof

The modules on each roof is arranged in one upper and one lower string of 12 modules (the middle row of modules is split between the upper and the lower string), resulting in a total of 39.6 m^2 PV on each roof. The mounting system is InterSole from Renusol (Figure 2). The PV modules are mounted on aluminium profiles, which are fastened on top of a HDPE membrane. The air gap beneath the PV modules is 49 mm. The lower part of both roofs is covered by asphalt roofing. Since the PV system does not replace any other part of the building envelope (the roof would have been weather-proof without it) the system can only be referred to as semi-integrated. The PV system replaces other roofing materials, but it is the membrane and not the PV modules that act as the climate shield. The specification of the roofs is given in Table 1. Data is collected using the Labview system.

Temperatures are measured on the rear face of the PV-panel and on the lower face of the air cavity by thermocouples of type T.

Figure 2. Closer view of the two parallel PV-roofs. Photo: Clara Good

Table 1. Specification of the PV roofs

Roof tilt	30°
PV	poly-Si REC 260PE
Efficiency	15.8 %
Area (gross modules/total)	1.65/79.2 m²
Total installed power	12.48 kWp
Inverter power per roof	5.25 kW
Weight	10.9 kg/m²

2.3. Calculations

In order to calculate the energy production, the dynamic simulation program PVSol with 3D visualization and detailed shading analysis of photovoltaic systems was used. The simulations included the set up at the ZEB Livinglab and were performed using measured climate data on an hourly basis in the proximity of the Livinglab, including irradiance onto horizontal plane, outside temperature, humidity and wind speed.

3. Results

3.1. Energy production, solar radiation and PV temperature

Measured energy production and solar radiation as a function of time in October 2018 is given in Figure 3. Figure 4 shows energy production as a function of solar radiation for the two PV roofs. The relation between energy production and temperature on the rear surface of the PV panels at variable solar radiation is presented in Figure 5.

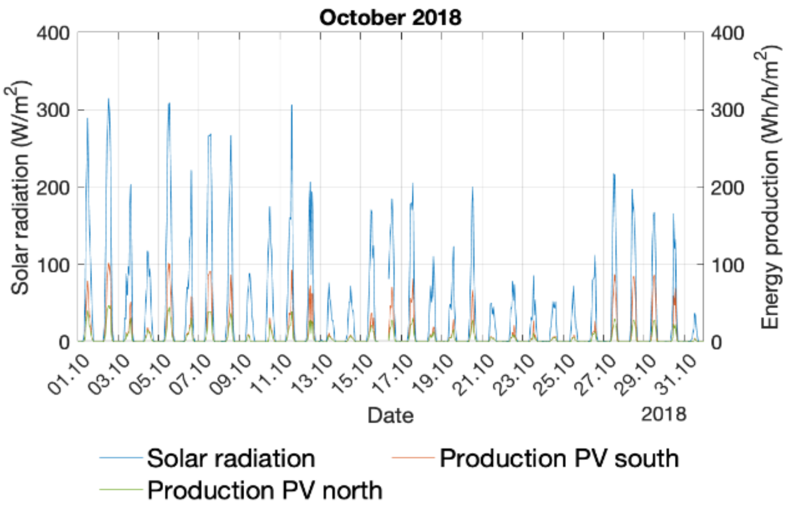

Figure 3. Energy production and solar radiation as a function of time in October 2018.

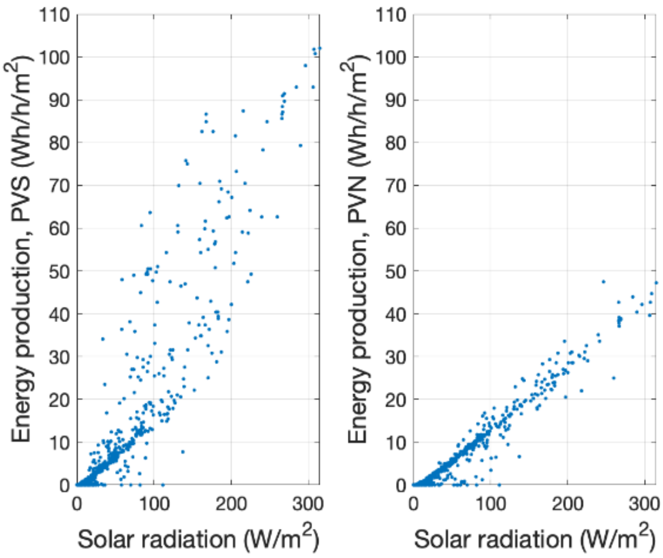

Figure 4. Energy production as a function of solar radiation in the horizontal plane. The southernmost PV-roof is given in the left diagram. The northernmost PV-roof is given in the right diagram.

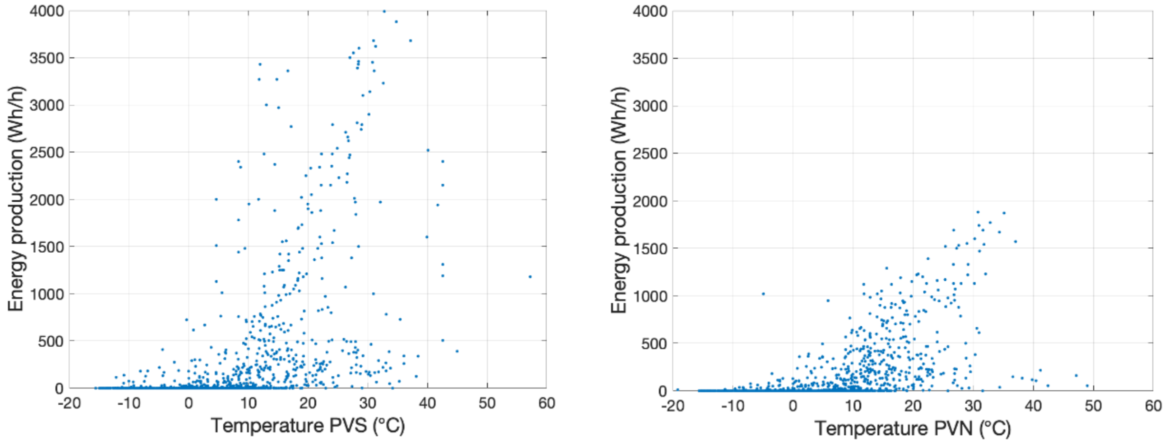

Figure 5. Relation between temperature on the rear surface of the PV-panels and energy production. The southernmost PV-roof is given in the left diagram. The northernmost PV-roof is given in the right diagram.

3.2. Calculations and measurements

Measured and calculated energy production of the two roofs are given in Figure 6-9.

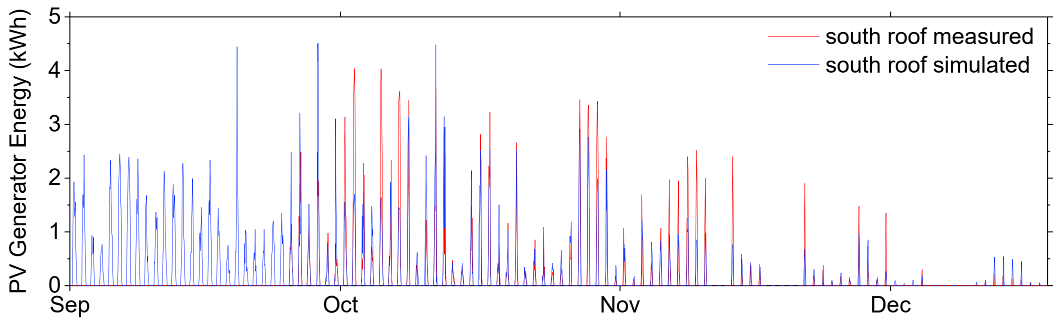

Figure 6. Calculations and measurement of the energy production for the south roof.

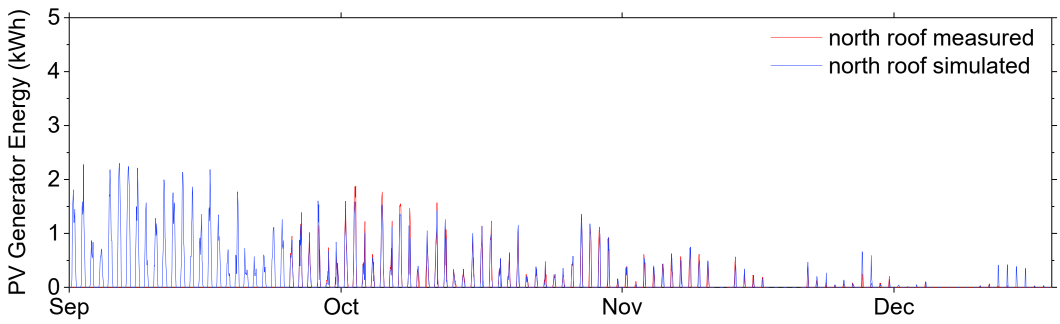

Figure 7. Calculations and measurement of the energy production for the north roof.

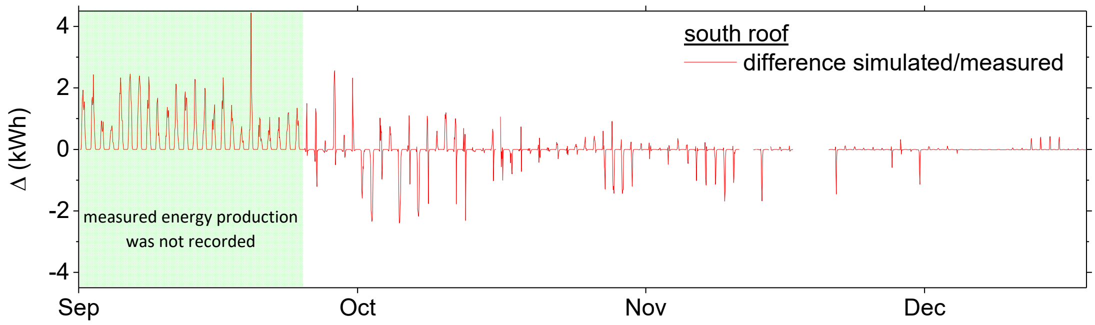

Figure 8. Difference between the simulated and measured energy production

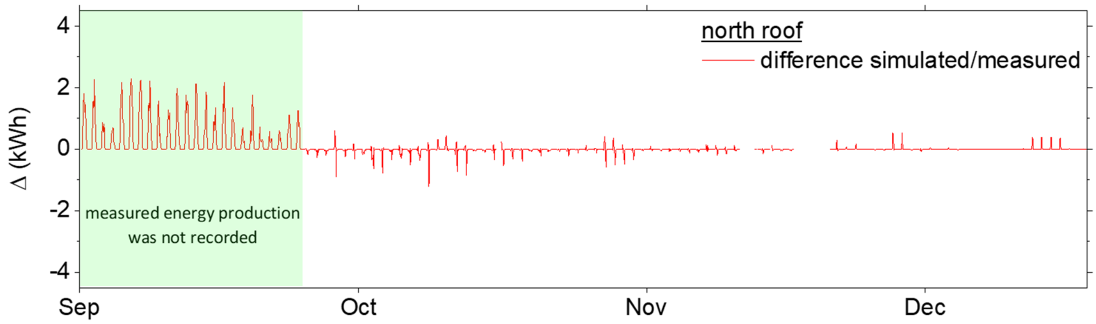

Figure 9. Difference between the simulated and measured energy production.

Figure 10. ZEB Living Laboratory during December 2018 with snow on the PV roofs.

4. Discussion

4.1. Energy production and PV temperature

As presented in Figure 5, the temperature conditions on the two roofs were approximately equal. The results show that increased energy production was associated with increased temperature on the PV panels. This is due to the fact that both energy production and temperature on the PV-panels increase with increased solar radiation.

According to the specification of the PV modules the efficiency is given as 15.8%. This value corresponds to the measured results in Figure 4 which gives the energy production as a function of solar radiation in the horizontal plane.

4.2. Calculations and measurements

A large difference in energy production between the north roof and the south roof was found, as presented in Figure 6 and 7. One possible explanation is shading of the north roof because of low solar azimuth during the measuring period. In order to avoid such problems, design of the PV-roofs should be considered early in the design phase of the building project. This has also been pointed out by [9]. Shading should be avoided in order to ensure a high performance of the PV-systems.

Figure 8 and 9 shows that for most cases the energy production is underestimated in calculations. The north roof shows a small difference between measurements and calculations. The difference is larger for the south roof. This could be due to shading effects from nearby buildings and trees not taken into account in the simulation program. However, the results imply that the simulation program can calculate the effect of the shading of the north section by the south roof in a good way. A high correspondence between measurements and calculations requires correct input data. In this case the input data were measured temperatures, irradiance as well as wind speed and direction at the rooftop of the building. As can be expected, use of generic climate data will cause a larger difference between measured and simulated energy performance.

In the period from 5th-20th of December the PV roof was covered by snow, see Figure 10. As Figure 8 shows there were some periods with sun during this period. This causes the calculated energy production to be overestimated during this period. However, the solar radiation is low in winter and hence it is a very limited amount of energy production that is lost due to the fact that the PV-panels were covered by snow. The situation in November and December can be compared to January and February conditions concerning solar radiation and snow cover. However, during March and April the solar irradiance will increase. The loss in production due to snow cover can be assumed to be larger in these periods.

5. Conclusion

The temperature conditions on the north and south roof were measured to be approximately equal. Still, a large difference in energy production between the two roof sections was found. A possible explanation is shading of the north section by the south roof because of low solar azimuth during the measuring period. In order to avoid such problems, design of PV roofs should be considered early in the design phase of the building project. Shading should be avoided in order to ensure a high performance of PV-systems.

The results show that the difference between the hourly measured and calculated values of energy production of the PV-roofs is small. In this case the input data for the energy production calculation were measured temperatures, irradiance and wind speed and direction at the rooftop of the building. Use of generic climate data will most likely cause a larger difference between measured and simulated energy performance.

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