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Roof-integrated PV in Nordic climate - Building physical challenges

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Abstract

Use of photovoltaics (PV) is key remedies in buildings where a large part of the energy supply should be based on renewable energy. PV in Nordic climate can be challenging because of
and temperatures below zero. The aim of this research work has been to provide a state-of-the art overview of recent experiences and challenges for building physical conditions related to the use of roof-integrated PV in Nordic climate. The study has identified practical guidelines for installation and ventilation of the roofing as challenges to be solved for extensive use of such systems in Nordic climate.

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Keywords:

1. Introduction

1.1. Building integrated photovoltaics (BIPVs)

Photovoltaic modules integrated into the building envelope, such as the roof or the façade, is commonly referred to as BIPV systems. Roof-integrated systems are preferred due to architectural design and an increasing focus on sustainability and embodied emissions[1]. The efficiency of devices is dependent on different factors; the building integrating technic/solution being one important factor.

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BIPVs have dual functionality; replacing the conventional elements of construction and generating energy[2]. This implies that roof integrated PVs replace the conventional roofing, such as tiles, slate and metal roofing, which is favorable because of material saving.

BIPV products that replace building components have to comply with the conventional building regulations and PV-standards. There is a missing link between PV, and the construction sector and lack of BIPV standards based on building product requirement as obstacles for large scale BIPV application[3].

1.2. Nordic climate

Characteristic for Norway is the extremely varied climate, the rugged topography being one of the main reasons for large local differences over short distances and extreme seasonal variations. The climate is putting great demand on our building envelopes. The building envelope and the roof in particular may be exposed to severe wind, snow load, precipitation, freeze thaw cycles and rather large temperature fluctuations. Concerning BIPVs the climate may be extra challenging due to the fact most of the systems are developed for other climate conditions than the Nordic.

2. Objectives and Scope

The aim of this work has been to provide a state-of-the art overview of recent experiences and building physical challenges related to the use of BIPV in Nordic climate. The paper is based on a literature review focusing mainly on challenges of cold, pitched roofs. Flat, compact roofs are not a part of the study.

3. The principal roof construction

The construction treated in this work is pitched roofs. The various design principles for wooden roofs are thoroughly discussed in[4-6]. The basic principle is that the roof construction must be vented in order to transport:

1. Moisture from the roof and thus prevent the growth of mold and other moisture damage
2. Heat and thus prevent unwanted melting snow and icing at the eaves and gutters

The roof ventilation may be built up in two different ways as shown in Fig. 1. Traditionally the roof construction separates the underlay roof and the wind barrier (Fig. 1A). This was the traditional construction system until the development of materials that combine the wind barrier function and the underlay roofing function. The roof is vented between the wind barrier and the underlayer roof and may dependent of the roofing also be aerated between the underlayer roof and the roofing. The underlayer roof consists usually of a vapour tight material. Because of the vapour tightness an extra material layer is added compared to the more modern roof build up given in Fig. 1B. The roof built up is thus more material consuming and requires more labor cost compared to the more modern roof construction. The more modern roof build up as given in Fig. 1B consist of a rain tight roofing, a ventilation gap and a vapour open and watertight wind barrier as underlayer roof. The thermal insulation can be placed directly under the underlayer roof because the underlayer roof is sufficiently vapour open and watertight wind barrier.

By introducing BIPV the construction sector seems to choose the "previous traditional" way of building up a roof construction, due to robustness reasons. From an environmental (less material) and a cost effective point of view it would be favorable if we could further develop systems and solutions which comply with the "modern more common" way of doing it.

Fig. 1. A: The "previous traditional" way of building up a roof construction by a separate wind barrier and an underlayer roof.
B: The "modern more common" way with a combined wind barrier and underlayer roof.

4. Roof integration experiences and challenges

4.1. Roofing performance

According to[2] almost 50 % of the BIPV market is roof installations. The primary function of the roof as a climate screen must still be fulfilled also with BIPV-systems. The water and air tightness of the roof has to be intact which imply that the joints between the BIPV-panels and roofing material have to be water tight. BIPV-systems can cover the whole roof or they can cover part of the roof. Systems covering part of the roof also demand rain tight fittings. A sufficient level of ventilation of air beneath the roofing is necessary in order to prevent the growth of mold and moisture damage[7,8]. In order to keep a high performing BIPV system it may be necessary to increase the ventilation in order to lower the temperature of the BIPV[9,10].

4.2. Degradation of BIPV

Generally commercial available modules are highly reliable[11]. The operating life is determined by the durability of the encapsulation of the solar module[12]. Moisture penetration is causing the majority of the long term failures[13]. Field measurements performed by[11,14] indicate energy performance losses in the range of 0,5-1% due to degradation per year. There is however little experience regarding degradation and service life of BIPV in Nordic climate.

4.3. Raintightness of BIPV systems

Wind-driven rain is one of the most important moisture sources affecting the hygrothermal performance and the durability of building façades and roofs[15,16]. In particular the western coast of Norway is exposed to challenging rain conditions[17]. It is thus pity that hardly any literature reveals experience with driving rain performance of BIPV-systems. Newertheless a promising method was proposed by[18]. They performed a large scale testing of water run off capabilities and wind driven rain resistance of a specific commercial system. The system was tested at two different inclinations (15° and 30°). In order to control strains on the underlayer roof, it is recommended to choose BIPV-system with well documented driving rain performance preferably performed by the method given by[18].

4.4. Snow and ice on PVs

Traditional roofs have been designed to keep snow on the roof. This is contradicting to what is preferred for BIPVs. In order to maximize the PV energy production PV panels should have no snow cover. PV panels covered by snow during long periods in the winter will suffer a decrease in both energy and cost effectiveness. The Nordic winter months are however characterized by low solar insolation and therefore low potential for solar harvesting[19].

The annual loss in power production due to snow on a roof mounted PV system in Munich was estimated to 0,3-2,7%[20]. Comparing the reported number of snow days in Munich with snow data from the high populated cities in Norway shows similar or lower number of snow days for the Norwegian cities Trondheim, Bergen, Stavanger, Oslo[21]. Losses due to snowfall is dependent on technology and angle of the PV system[22]. Over the two years studied the losses ranged from 1-3,5% in sites in south-east Ontario (45°N). Another study performed by [23] including PV modules mounted in three different tilt angles (0°, 24°, 39°) near Lake Tahoe (California USA), a high altitude site with an average of 5m of snow per year showed annual power production losses in the range of 12-18%. It is hard to generalize the results to other locations as the area studied represents extreme cold and snow conditions, but it shows the snow covering challenges concerning power production.

Snow and ice melting or sliding down the BIPV may cause hazards such as snow and ice falling down representing a risk for people passing beneath the roof. One way of stopping downfall of snow is by installation of snow stoppers beneath the BIPV. The snow stoppers can cause the snow to accumulate on the BIPV giving a decrease in energy effectiveness. Snow sliding of PV can freeze on the roofing below the modules and the build up of ice can damage the roofing and the gutters.

The challenge with snow downfall on BIPV-systems mounted on walls and roofs was investigated by[24,25] in order to maximize the solar energy efficiency, with a special emphasis given on possible research opportunities for the future. Several solutions to the ice and snow problem were suggested. A special emphasis was given on different material surfaces like e.g. self-cleaning surfaces with origin in photo-catalytic hydrophilic surfaces, super-hydrophobic or ultra-hydrophobic surfaces and coarse micro structured or nanostructured surfaces without giving any clear design recommendation for preventing the problem. Since the Nordic climate includes snowrich locations, standard solutions adapted to Nordic climate are necessary in order to solve the challenges associated with snow.

4.5. Condensation on the rear side of a PV

If the temperature of the rear side of the BIPV is lower than the dew point of the surrounding, air condensation will occur on the modules. The phenomenon typical occurs during nights with clear weather conditions. If the temperature is below zero the condensation water will freeze. When the temperature rises above zero the water will thaw and might drip on the underlayer roof[26]. Hence, the underlayer system must be water proof and drain the water, and sufficient ventilation of the air gap between the modules and the underlayer roof is necessary in order to dry out the water. The situation with condensation is of special interest in Nordic climate due to frequently cold radiation situations. The problem of condensation is mentioned by[27], but no further studies have been performed.

4.6. Venting below the BIPV

In order to maximize the energy yield, to lower the degradation processes, and to improve the building physical properties ventilation below the BIPV is necessary[28].

The temperature of the PV module is dependent on the heat gains from the sun and the heat losses to the surrounding air and the wind velocity. The efficiency of the PV-panels is strongly dependent on the temperature of the PV-panel[29]. A efficiency drop by as much as 0,5% per °K increase in module temp. is suggested by[10]. A power output decrease by 0,4-0,5%K^{-1} for crystalline silicon modules and 0,1%K^{-1} for amorphous silicon is suggested by[30]. Assuming still air and attached to a building with good rear ventilation[27] suggests a 30°C panel temperature increase relative to ambient temperature at 1kW/m^2 insolation. For crystalline silicon modules this will give an efficiency decrease of 15%[31].

In order to dry out build in moisture and avoid snow melt a recommendation of a minimum ventilation gap of 48mm for roof lengths up to 7m is suggested by[4] for well insulated roofs. No ventilation recommendation for BIPV systems are specified by[32].

Heat transfer and air flow pattern created between two vertical parallel walls heated from one side was studied by [33]. The setup of the experiment was a mock-up of a façade with integrated PV-panels. Temperature distribution and mean velocities as a function of heat input was recorded inside the air gap. The laboratory study resulted in velocity profiles of the vented air gap behind the PV and mean velocities as a function of heat input onto the PV. The laboratory study was performed on a façade and did not include roof measurements[33]. Similar studies for roof ventilation in Nordic climate were not found.

Simulations of the effect of mounting type and mounting geometry on the temperature of a PV panel were performed by[29]. Both roof angle and height of the air cavity below the PV-panel effected the temperature and hence the efficiency of the PV-panel. The results confirm that larger angles and small aspect ratios are associated with higher efficiencies because of lower PV temperature. The aspect ratio is given by the length of the air gap divided by the height of the air gap.

Air change rate, temperatures and velocities in a roof mock up was also studied by[34]. Only ventilation by natural convection was taken into account. The inclination (25°, 45°, 70°, 90°) and the air gap of the roof was varied (0.23m, 0.115m and 0.06m). It was found that increased air gap and roof inclination resulted in higher flow rates inside the air gap. However the study did not end up in recommendations regarding size of the air gap[34].

A numerical study (CFD calculations) was performed by[35] in order to find the best cooling strategy for BIPV panels. A comparison analysis of different heights of the air gap for cooling of the roof was conducted. The results showed that an air gap height of 50mm was not sufficient to provide cooling of a 70m long BIPV roof. The developed model was considered a good starting point for further investigations.

In addition to reduced efficiencies, increased temperatures will cause thermal expansion and increased stress to the interconnections between the cells possibly leading to delamination[13].

The knowledge base regarding temperature profiles and ventilation below BIPV modules was found to be insuffi. Measurements of temperature profiles for the air gap below BIPV roofs in Nordic climate are lacking. Practical guidelines are needed regarding ventilation of BIPVs depending on size and inclination of the roof.

4.7. Underlayer roof

OSB- and plywood boards are the most common robust alternatives used as underlayer roofs. Unfortunately the water vapor permeability of such boards may be unfavorable in order to ensure drying out of built in moisture in the roof construction. The risk of degradation and mold growth in the roof construction is therefore higher compared to more vapour permeable roof underlay materials. Recommended values from SINTEF states that the s_d-value of a wind barrier should be less than 0,5m[36].

An extensive measurement campaign of s_d-value of OSB/3-boards was performed by[37] on boards from four major producers in Europe. Results showed higher s_d-values than the tabulated values in[38] for both wet- and dry-cup conditions. None of the investigated OSB-boards complied with the recommendations from SINTEF.

An improved solution is to apply vapour open wind barrier sheets such as porous wood fibre boards with asphalt coating in combination with a wind barrier foil. This solution is both robust and satisfies the recommended s_d-value. It is important that the underlayer roof system is documented regarding driving rain performance[39].

Currently, the installation of BIPV-systems implies a longer building period compared to traditional roofing methods, since the experience with this kind of roofing is limited. Therefore the underlayer roof must withstand a longer period of direct climate stresses before the roofing is completed and traffic (due to labor) on the roof. This also stresses the importance to use robust underlayer roof systems which has documented driving rain performance.

4.8. Penetrations

BIPV-systems imply penetrations of cables through the roof construction. In some cases the penetrations have to be performed both through the roofing and through the underlayer roof. The penetrations must be water- and airtight in order to avoid moisture problems in the construction. This requires that the penetrations through the roofing must be adapted to the roofing material used, and the penetrations through the underlayer roof must be adapted to the material used as underlayer roof. Penetration details and products tested in the laboratory according to[39] or similar method should be used. The test method implies testing of underlayer roofs with penetration details.

5. Conclusions

Large scale BIPV application on cold pitched roofs may be favorable in many cases, even in Nordic countries. However, there is a need for linking the PV- and construction sectors and preparing BIPV-standards. The literature review has identified several building physical challenges that have to be solved for extensive use of roof-integrated PV in Nordic climate. Practical guidelines for installation and ventilation of the roof integrated PV are considered to be key challenges. The guidelines need to include ventilation strategies depending on the size and inclination of the roof. More research is necessary in order to develop new solutions to cope with challenges such as snow on BIPVs possibly causing hazards such as snow and ice falling down and to develop BIPV systems with sufficient rain tightness.

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