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Review

The challenge of removing snow downfall on photovoltaic solar cell roofs in order to maximize solar energy efficiency—Research opportunities for the future

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ABSTRACT

The challenge of removing snow downfall on photovoltaic solar cell roofs, also including solar thermal panels and walls, in order to maximize the solar energy efficiency, is investigated. A special emphasis is given on possible research opportunities for the future. As the application of building integrated photovoltaic (BIPV) products is increasing, it is becoming more important to solve this challenge in order to maximize the solar energy harvesting from buildings, e.g. when attempting to reach the goals of zero energy and zero emission buildings. In addition, a solution within this field, may also be utilized in other areas, e.g. for window roofs and traffic signs which are often concealed by snow and ice. Various ideas and possible steps toward a solution of the challenge are discussed, which may then in turn set in motion creative thinking and problem solving paths with new follow-up investigations. Several aspects with snow covering solar panels are treated and discussed, including possible paths toward a working solution, where different material surface solutions like e.g. self-cleaning surfaces with origin in photocatalytic hydrophilic surfaces, superhydrophobic or ultrahydrophobic surfaces and coarse microstructured or nanostructured surfaces are reviewed and treated in particular. Furthermore, this work presents the compilation and discussion of an experimental method for measuring friction between snow/ice and various building roof surfaces. Some results from these experimental investigations are discussed, including a slip angle and a friction coefficient classification system for roofing types and material surfaces with respect to snow and ice.

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1. Introduction and background

1.1. Origin of work

The origin of this work was through the collective research project "*European Performance Requirements and Guidance for Active Roofers*" (*Eur-Active Roofer* for short) during 2005–2008, where the challenge to be addressed arised from work within work package E (WP E) – Snow and Ice Load. The Eur-Active Roofer project has its origin in the increasing variety in new products such as photovoltaic (PV) systems, solar collectors, roof lights, ventilation devices, insulation and safety devices which are being introduced in roofing. The roof changes into an *active roof* where it supplies electricity and hot water while providing daylight and ventilation. Active roofs may contribute significantly to the quality of the living space under the roof.

The definition active roofs cover all roofs which are active in one way or another beyond the traditional task of protecting the inside of the building from the various climate exposure factors. Several typical active roof installations for both flat and pitched roofs are depicted in Fig. 1. There is an increased attention to active roofs due to the following:

- New installation types
- Increased use of installations
- Change in climate and climate loads
- Increased focus on moisture problems and indoor environment

1.2. Background snow and ice on roofs

Traditionally, roofs have been designed to keep the snow in its place on top of the roofs. However, solar cell roofs should ideally have no snow covering the cells, in order to maximize the solar cell energy production. Other active roofs, such as roof windows, may also require as little snow as possible on top of them.

Solar cell roofs covered by snow during long periods in the winter, will suffer from a substantial decrease of both energy and cost effectiveness, at the time of the year when the energy is most needed. Devoting parts of the roof for snow accumulation will, in addition to decreased energy generation due to less solar cell area, lead to new strains on these parts of the roof, both with respect to building physics problems like moisture, freezing, thawing, etc., and with respect to structural building and roof properties. Some typical roof problems, caused by snow and ice, which may affect active roof installations, are shown in Figs. 2–6. Modifications of the roof surfaces may easily alter the snow friction as depicted in Figs. 5 and 6, e.g. resulting in unexpected snow avalanches from the roof. Ross and Usher [1,2] and Ross [3] address some of the issues related to snow accumulation and icing on photovoltaic panels.

Both new material surface technologies and new architectural roof designs may play important roles in the task of avoiding snow from staying on the active roof installations. This task will also become more important with increased use of building integrated photovoltaic (BIPV) systems, see e.g. the experimental investigations by Breivik et al. [87] and the state-of-the-art reviews and future research possibilites on BIPVs by Jelle et al. [4] and Jelle and Breivik [5,6].

Naturally, the discussions within this article may also be valid for other systems than photovoltaic solar cell roofs. Solar thermal panels, window roofs and various information signs (e.g. traffic road signs) are some examples. In additon to pitched roofs, the discussions may then also be applicable to walls and vertical solutions. Note in this respect the various application and technology areas for fenestration of today and tomorrow (Jelle et al. [7]), including windows being able to control the solar radiation transmission throughput, i.e. smart windows (Baetens et al. [8], Granqvist [9,10], Granqvist et al. [11], Jelle and Hagen [12,13], Jelle et al. [14], Lampert [15–17]), which may readily be characterized by solar radiation glazing factors as described by Jelle [93]. Potential new hazards, such as downfall of snow and ice, representing a risk for people passing beneath the roof, and undesirable snow accumulation or snowdrift, e.g. in front of building entrances and pathways, have to be evaluated.

1.3. Objective of work

Hence, with background in the above, our main objective in this work is to address and investigate the challenge with snow downfall on photovoltaic solar cell roofs, also including solar thermal panels and walls, in order to maximize the solar energy efficiency, with a special emphasis given on possible research opportunities for the future. A solution within this field, i.e. snow and ice sticking to solar cell panels, may also be utilized in both similar and totally different fields, e.g. from window roofs to traffic signs which are often concealed by snow and ice, and furthermore to the serious threat of ice build-up on electrical power transmission lines. In addition, this work also presents the compilation and discussion of an experimental method for measuring friction between snow/ice and various roofing surfaces, where some results from these experimental investigations are discussed, including a slip angle and a friction coefficient classification system for roofing types and material surfaces with respect to snow and ice.

As will be discussed later, this work aims at removing the snow and ice, or rather inhibiting the snow and ice from forming at all, at e.g. the solar panel (solar cell and solar thermal collector) surfaces. Therefore, as there should be no snow and ice at the solar panel surfaces, there should ideally neither be any solar efficiency influences in this respect to be calculated. Hence, it is outside the