MONITORING THE OUTDOOR OPERATING TEMPERATURE OF GLASS-FREE LIGHTWEIGHT SOLAR MODULES FOR BUILDING-INTEGRATED PHOTOVOLTAICS

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ABSTRACT: In the case of older buildings undergoing renovation, excessive loads are often not well tolerated by roofs or other building structures (e.g. facades) [1, 2], which limits the adoption of PV in these contexts. The idea of lightweight modules is very attractive especially for the building-integration of photovoltaics (BIPV) thanks to their reduced weight and strong improvements in durability [3–5]. On the other hand, the thick alternative light backsheet structure of such modules may be seen as a disadvantage, because it may induce higher module operating temperatures (OT). This work demonstrates that lightweight (≈ 6 kg/m^2) photovoltaic module based on a composite sandwich backsheet and a polymeric frontsheet can reach equivalent (or lower) operating temperatures of standard glass-glass modules thanks to a careful material selection.

Keywords: BIPV, lightweight, composite sandwich structures, qualification testing, module operating temperature

1 INTRODUCTION

In densely populated countries, little free land is available for the deployment of photovoltaics (PV) in field installations. In addition, 40% of the world's demand for electricity is related to buildings. These facts provide a strong argument for the accelerated development of building-integrated PV (BIPV), as it enables electricity production with a minimal impact on free land. However, BIPV elements currently on the market show some limitations, which includes their relatively high prices, as most products are custom-made and produced in small volumes. Moreover, the relatively high weight (≈ 15-20 kg/m^2) of these products may preclude their use in the potentially promising market of renovations of older buildings, for which excessive load could be a serious constraint.

With the aim of limiting the module weight while preserving excellent mechanical stability and durability, we previously demonstrate that, with a careful material selection and a proper adaptation of the manufacturing processes, we are able to manufacture lightweight modules with a weight of ≈ 6 kg/m^2 [6]. The weight reduction is achieved by replacing the backsheet, conventionally glass or a polymer foil, with a rigid and thick composite sandwich structure and by replacing the front cover glass with a thin polymer foil. However, one can expect higher cell operating temperatures when using thick composite backsheet structures. For the full integration of modules, several authors have analyzed the rise of module temperatures (T_{module} - $T_{ambient}$) as a function of irradiation for different systems. These works show that the peak operating temperature can typically be 15 to 35°C higher for BIPV modules compared to, respectively, partly-ventilated or fully ventilated modules [8].

The present work shows that lightweight PV modules can provide acceptable module operating temperatures.

2 STRUCTURE OF THE LIGHWEIGHT SOLAR MODULES

The lightweight solar module is achieved by replacing the standard glass frontsheet by a thin transparent polymeric layer and by engineering the backsheet to replace the standard thin polymeric co-laminated PV backsheet by a composite sandwich structure. The presented lightweight module has a final weight of 6 kg/m^2. Figure 1 shows the different layers of the lightweight module. The lightweight module is composed of a composite sandwich structure, solar cells embedded in a polymer layer (EVA) and protected by a thin frontsheet (ETFE). The backsheet structure is made by two glass-fiber skins and a honeycomb core (aluminum or aramid) bounded with an adhesive. With this material selection, we reduce the module weight down to 70%.

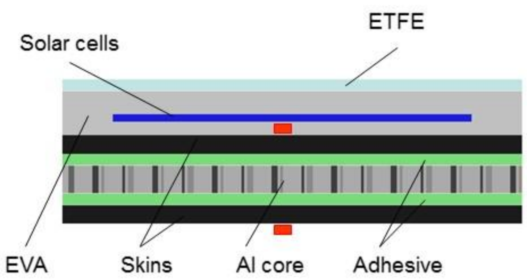

Figure 1: Schematic of a lightweight PV module structure. Each module is laminated with two thermocouples: one in direct contact to the solar cell and another placed at the back of the backsheet.

3 EXPERIMENTAL WORK

3.1 Mini-modules production

One-cell (156 x 156 mm^2 PERC c-Si solar cells with five busbars) mini-modules are produced according to **Error! Reference source not found.**. Six modules with the following design configurations are manufactured:
(i) glass (3.2 mm) / EVA / glass (3.2 mm) configuration (reference sample); (ii) lightweight module composed of

an aluminum-based honeycomb core (7-mm-thick backsheet) and (iii) lightweight module composed of an aramid-based honeycomb core (7-mm-thick backsheet).

All lightweight modules are manufactured in a single lamination process, which we use to manufacture the composite backsheet and the full module stack in a single run. All modules were manufactured with 2thermocouples (type K) located on the back of the cell (to monitor the cell operating temperature, T_{cell}) and another at the back of the module, to monitor the module operating temperature on the rear side of the module (T_{module}), as shown in Figure 1.

3.2 Monitoring of the outdoor operating temperature (OT)

Figure 2 shows the mock-structure built to evaluate the impact on the operating temperature for the different samples as a function of tilt angle and ventilation.

(a)

(b)

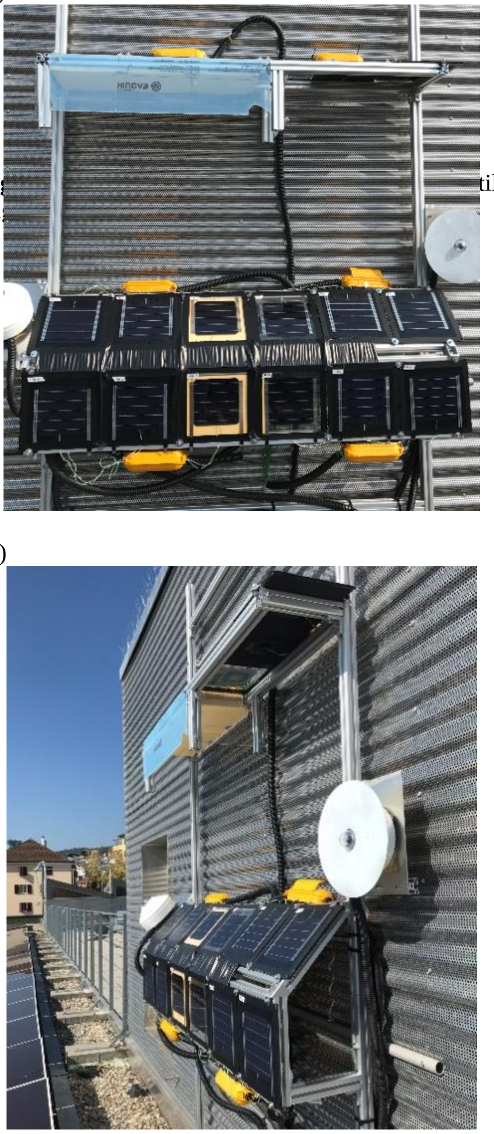

Figure 2: (a) Front and **(b)** side view of the mock-up structure used to monitor the temperature of the different samples. The mini-modules are facing south and are installed at three different tilts: 0°, 45°, and 90°. Two types of mounting configurations are used: full-insulation, and open-rack mount.

The T_{cell} and the T_{module} are monitored of the mini-modules are measured in open-circuit (OC) conditions. The modules are installed south facing at three different tilts (0°, 45°, and 90°). Two types of mounting configurations are used: full-insulation, and open-rack mount.
A rigid 6-cm-thick insulation panel in polystyrene foam is used to fully insulate the rear-side of the PV modules, to simulate BIPV integration. The irradiance at the different tilts is measured using complanar pyranometers (see Fig. 2).

3.3 Innovative mounting system – Velcro

In order to simplify the installation process of our BIPV modules, we also investigate the use of *Velcro* as a bounding material that can be used to fix a cladding element to a wall surface. The use of Velcro in the built environment as already been documented [7]. This system may provide considerable advantages: it will reduce the labor and installation time, it is a simple and clean mounting system, it is easy to remove (in case of needed PV maintenance), and it can resist high loads (average tensile disengagement of 207 KPa).

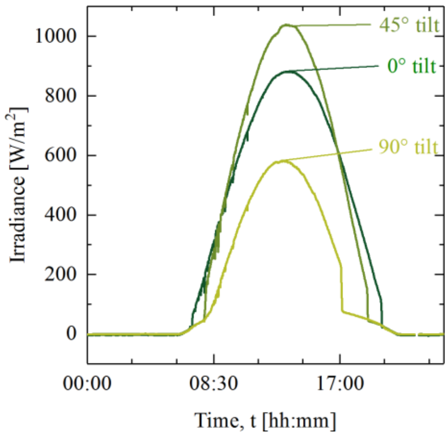

Figure 4: Irradiance measured for the different tilt angles at the end of summer (2018).

4 RESULTS

4.1 Monitoring of outdoor operating temperature (OT)

Figures 4 and 5 show, respectively, the irradiance at different tilts and the operating temperature of the samples installed on the outdoor monitoring station (on the roof). From these results, we conclude that for all module designs, the module temperatures (T_{module}) obtained at 0° and 45° are similar. However, a significant decrease in temperature is observed at 90°. This decrease is due mainly to the decrease in the irradiance at this angle (a maximum of 522 W/m² which corresponds to only 52% of the irradiance on modules installed at the optimum tilt). This is especially noticeable because the measurements is performed during summertime. We also notice that the operating temperatures of the module are higher when they are insulated on the back side. A maximum ΔT of 13°C is observed between the insulated and non-insulated modules.

Regarding the module designs, the maximum T_{module} of the aluminum-based lightweight module is similar to the maximum T_{module} reached by the glass-glass configuration. Moreover, a very small difference between T_{cell} and T_{module} is measured (a maximum ΔT of 3°C). The aluminum-based lightweight module shows good heat dissipation from the cell towards the module outside. The T_{module} of the aramid-based lightweight module is similar to the T_{module} of the other two configurations (only 1°C higher). However, due to poor heat transfer in the backsheet the T_{cell} is higher than for the previous cases (≈ 5 – 7°C). The temperature difference between T_{cell} and T_{module} of the aramid-based module is also much higher: in some cases (optimum tilt) a ΔT of 14°C is observed. Due to the low thermal conductivity of the aramid core, the heat is not dissipated through the backsheet causing a higher T_{cell}.

These results show the importance of the correct module design to optimize the energy production of the BIPV module. The use of an aluminum core is an advantage not only for processing and cost [3, 4], but also
because it lowers the operating temperature of the cells, which will otherwise be penalized in terms of performance by the use of a thick backsheet structure, as in the case of the sample using a Nomex honeycomb.

CONCLUSIONS

We show the potential to use glass-free lightweight PV modules with a weight of 6 kg/m² as building component. The temperature monitoring under real operating conditions shows that in a ventilated mounting configuration, an aluminium core is preferred to an aramid core, and can lead to a lower cell operating temperature than a glass-glass configuration. Temperature monitoring also showed that, in an insulating mounting configuration, there is no difference between the two tested cores. However, the aluminum core is still preferred over aramid thanks to the shorter manufacturing process, higher shear stiffness and lower price. In conclusion, this work shows that thanks to the innovative design proposed and careful selection of the materials the operating temperature of our lightweight solar modules is equivalent to that of conventional glass-glass modules.

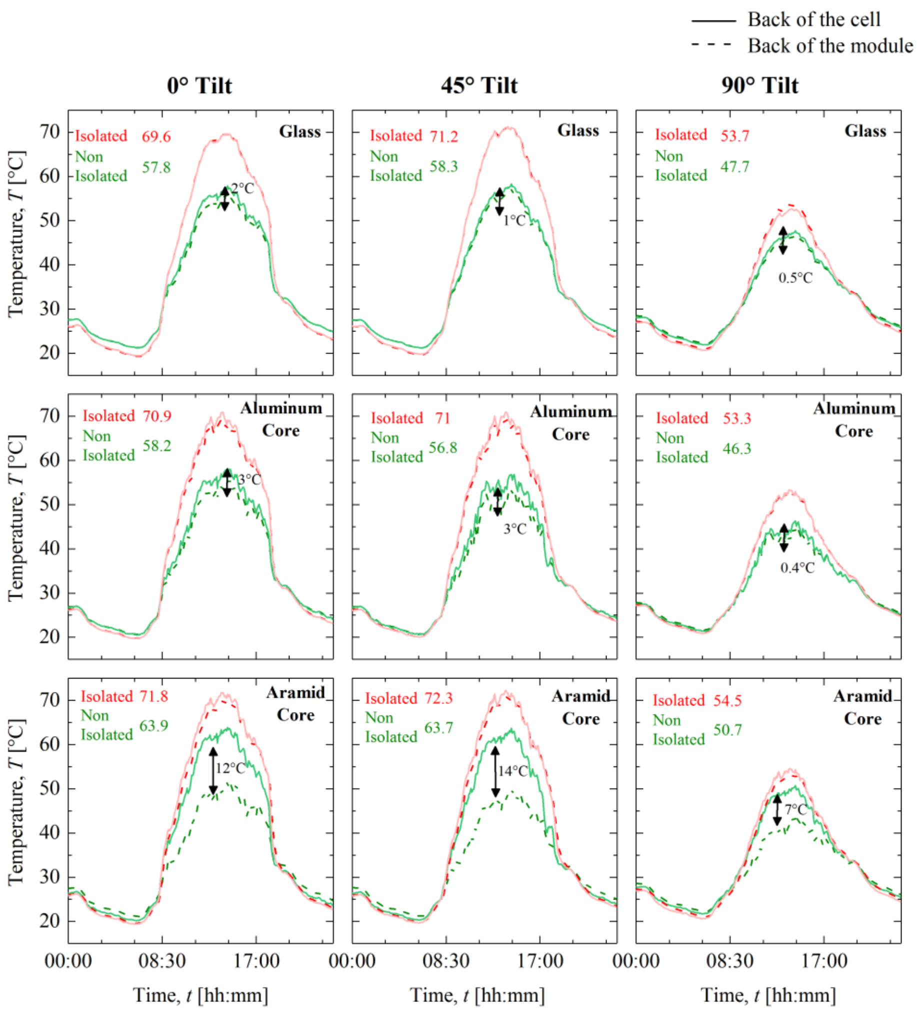

Figure 5: Temperature monitoring of the different installations (0°/45°/90°) for a typical end-of-summer cloudless day. The cell temperature is represented in red and the back-of-module temperature in green. ΔT represents the difference in the cell temperature between modules with full insulation (mimicking BIPV) and those with a well-ventilated rear side.

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REFERENCES

1. Kajisa T, Miyauchi H, Mizuhara K, et al (2014) Novel lighter weight crystalline silicon photovoltaic module using acrylic-film as a cover sheet. Japanese Journal of Applied Physics 53:092302. http://dx.doi.org/ 10.7567/JJAP.53.092302

2. Zhang F, Deng H, Margolis R, Su J (2015) Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China. Energy Policy 81:43–55. https://doi.org/10.1016/j.enpol.2015.02.010

3. Martins AC, Chapuis V, Sculati-Meillaud F, et al (2018) Light and durable: Composite structures for building-integrated photovoltaic modules. Progress in Photovoltaics: Research and Applications 12. https://doi.org/10.1002/pip.3009

4. Martins AC, Chapuis V, Virtuani A, et al (2018) Thermo-mechanical stability of lightweight glass-free photovoltaic modules based on a composite substrate. Solar Energy Materials and Solar Cells 187:82–90

5. Martins AC, Chapuis V, Virtuani A, Ballif C (2017) Ultra-Lightweight PV module design for Building Integrated Photovoltaics. proc. of the of 44th IEEE Photovoltaic Solar Energy Conference, Washington D.C., United States

6. Martins AC, Chapuis V, Sculati-Meillaud F, et al (2018) Light and reliable: composite structures for building integrated photovoltaic (BIPV) modules. Progress in Photovoltaics: Research and applications. https://doi.org/10.1002/pip.300

8. Sample T, Virtuani A (2009) Modification to the standard reference environment (SER) for nominal operating cell temperature (NOCT) to account for building integration. proc. of the 24th European Photovoltaic Solar Energy Conference, Hamburg, Germany, pp 3332–3337

9. Martins AC (2019) Glass-free lightweight PV building elements: solutions to minimize weight and maximize durability. PhD thesis n° 9149, École polytechnique fédérale de Lausanne (EPFL)