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Experimental testing under real conditions of different solar building skins when using multifunctional BIPV systems

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Abstract

When installing photovoltaic modules on buildings, the mounting system significantly affects both the heat-exchange between the module and the building envelope, and the operating temperatures of the PV modules, which in turn strongly influence the energy yield of the PV system. It is therefore important to be able to simulate and evaluate in advance the behaviour and the potential advantages of a certain type of installation. This paper presents the monitoring results of two examples of building integrated PV systems when installed as a façade cladding system or as roof tiles. The investigated parameter (i.e.: module temperature, electrical parameter, energy yield) can be used to predict the behaviour of such modules on real buildings.

Keywords: BIPV systems; Solar Building Skin; Multifunctional façades;

1. Introduction and general framework

Renewable energy systems, such as Photovoltaics (PV), play an important role in the scenario identified by the European Directive on Net Zero Energy Buildings (ED 2010/31/EU) [1], and are mandatory in order to reduce the energy performance of buildings and to engender the rational use of energy. There are currently a number of advanced, innovative building integration products that can be used in new or retrofitted installations, as either roof integrated or façade cladding systems.

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Nomenclature	
BiPV	Building integrated Photovoltaics
STC	Standard Test Condition
Tbom	Temperature on the back of the module [°C]
ins	Insulated
vent	Ventilated
G1, G2	BiPV modules insulated on the back and mounted as façade elements
H1, H3	BiPV modules naturally ventilated on the back and mounted as façade elements
A8, A9	BiPV modules insulated on the back and mounted as roof elements
A16	BiPV module, non-insulated and mounted on an open rack structure
PR	Performance Ratio

Roof-mounted PV systems, which are usually attached to the top of an existing roof, are rarely ventilated, whereas BIPV façade installations more frequently utilise ventilated mounted systems as curtain wall systems or as rear-ventilated cladding systems suitable for both new and existing buildings.

An increasing number of BIPV solutions and prototypes have been developed in order to improve the integration into the building envelope, and they fulfil a variety of functions, such as that of a building component that is not just aesthetically pleasing and representative. Some of these many solutions are illustrated in Fig. 1.

Fig. 1: Examples of BIPV systems integrated as building envelopes in new and existing buildings: (1) Kindergarten, Sant Celoni, Barcelona, Spain. Source: VidurSolar S.L.; (2) Residential building in Germany "Köln-Bocklemünd (II)" Source: ©Ecofys Germany GmbH; (3) Stuttgart University's Shimmering Solar Decathlon Home+, Technische Universität Darmstadt's surPLUShome, Solar Decathlon Competition; (4) Solar plant for Greenpeace, Bad Oeynhausen (Germany) - Source: Solar Fabrik AG; (5) Umwelt Arena – Source: Meyer Burger Technology AG; (6) Provincial Offices, Ex-Post building, Bolzano, Italy. Michael Tribus Architecture, Jan Steiger – Photo Source: Cristina Polo

In the case of BIPV systems, the mounting system of the photovoltaic installation significantly affects both the heat-exchange mechanisms with the indoor building areas, and the average and maximum operating temperatures of the PV modules, which in turn influence the energy yield of the whole PV system. Developers of new PV systems that employ different solar technologies (i.e.: cSi, aSi, etc..) are interested in discovering whether or not the electrical performances of these technologies are affected by the ventilation or insulation factors. Moreover, high average operating temperatures could probably contribute to an accelerated ageing of the materials constituting the module itself, therefore reducing the lifetime of the device.

Between 2012 and 2013, and with the contribution of two industry partners, the authors set up two test facilities in order to assess the behaviour of BiPV modules under real weather conditions in Southern Switzerland.

2. Description of the test facilities

The outdoor test facilities were constructed on the roof of one of the SUPSI buildings in Lugano (Switzerland). A real BIPV module integration system was reproduced in two outdoor experimental test facilities: the first replicating two vertical façades and the second a roof installation.

The two façades were installed at 90° (vertical position), and each consisted of four modules (see picture on left in Fig. 2). The left façade is naturally ventilated and the right has no ventilation: both are thermal insulated.

The roof was built with a wooden beam sub-structure and 3cm plywood in order to have a flat surface on which to position the nine BIPV modules (See picture on right in Fig. 2).

Two test reference modules were also installed behind the roof prototype, one at 6° and one at 45°. Both references modules were installed on an open rack system (fully ventilated).

All the 17 BiPV modules, and the two reference modules, are glass-glass modules with micromorph technology. The façade integrated modules are rated as 123 Watt, and the roof integrated modules are rated as 125 Wp.

2.1. Methodology and data acquisition system

In order to achieve the highest possible level of accuracy, the reference STC power for the kWh/Wp calculations was measured with a class A+A+A+ solar simulator and a spectrally matched reference cell. No spectral mismatch correction or spectral tuning of the simulator was applied. In order to detect any degradation, the modules were measured before and after outdoor exposure. For the purpose of bringing the modules into a comparable state, light soaking at temperatures between 40 and 50°C was performed before each performance measurement. The measurements were repeated at the end of the measurement campaign.

In addition to the STC measurements, the temperature coefficients and measurements at different irradiance levels were taken for each technology, in order to better characterize the modules and to obtain the parameters required to calculate the operating temperatures of the modules.

Four façade modules and five roof modules were equipped with Maximum Power Point Trackers (MPPT 3000) developed by SUPSI and adapted to their voltages and current ranges in order to optimize the measurement accuracy. As well as recording the voltage and current of the maximum power point, the full I-V curve was measured every five minutes.

Three pyranometers were installed on the stand to monitor the irradiance at 6°, 45° and 90°. Meteorological data such as global and diffuse horizontal irradiance, wind speed and ambient temperature, as well as the module performance data, were recorded simultaneously with a resolution of one minute. In order to achieve a high level of reliability in the inter-comparison, improved data quality control and an advanced data analysis procedure were used [2].

Fig. 2: Two vertical facades and a roof top BIPV installation are compared with reference free-standing modules.

All the BiPV modules were equipped with different PT100 temperature sensors in order to monitor the temperature behaviour on the different layers of the construction. The following surface temperatures were therefore monitored:

- Back of the modules temperature (Tbom)
- Insulation layer temperature (Tins)

Furthermore, a flux meter for evaluating the air speed velocity in the cavity of the façade was placed in the middle of the upper modules.

In order to understand also the temperature distribution of the non-ventilated modules, five PT100 sensors were placed on the back of the BIPV roof top module situated in the middle of the roof: one sensor in the centre of the module and four at the edges. Specific accelerated ageing tests were also performed in order to verify the durability of the materials used.

3. Results

3.1. Module temperature

The module temperature is influenced by the meteorological conditions, the orientation of the module and the type of integration.

Fig. 3 and Fig. 4 show the mean temperatures of the back of the module (Tbom) for the monitored period, for both the façade and the roof installations. It can be seen that, in both cases, the ventilation on the back of the module makes a strong impact on the module operating temperature. The impact is higher for the roof installation because the reference module (A16) was installed on an open rack. In the case of the façade, the air gap of about 10cm guarantees a small amount of natural ventilation (3m/s air speed) that can translate into a temperature reduction of approximately 4°C .

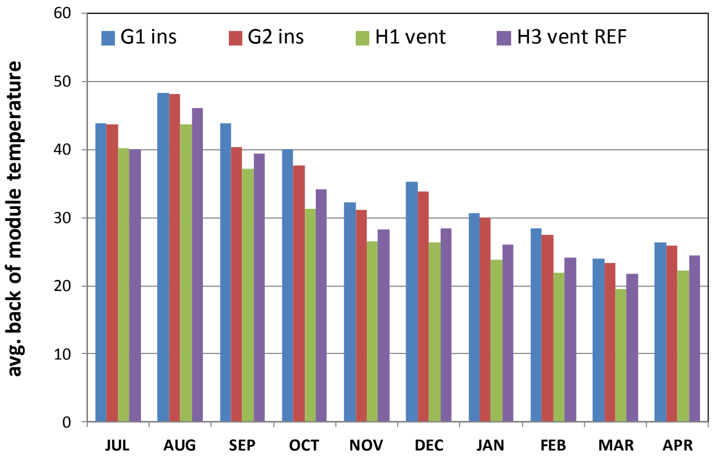

Fig. 3 Monthly average daylight (G > 0 W/m²) back of module temperature as measured for the four facade modules G1, G2, H1 and H3.

It is worth noting that, for the roof installation, the temperature reduction resulting from the free ventilation of the module is stronger in summer (about 5°C difference), but is negligible or opposite in winter (in December and January the mean temperature of the ventilated module is approximately 3° higher). This is mainly due to the thermal mass of the roof construction, which shifts the temperature rise in the morning and keeps the module cooler during the day. Fig. 5 shows the daily average mean different layer temperature of the prototype roof. The effect of the thermal insulation on temperature mitigation can be seen. The difference between the back of the module temperature (Tbom) and the back of the roof temperature (T1) in summer can be more than 20°. In winter the difference is smaller and remains in the range of 2°-3°C.

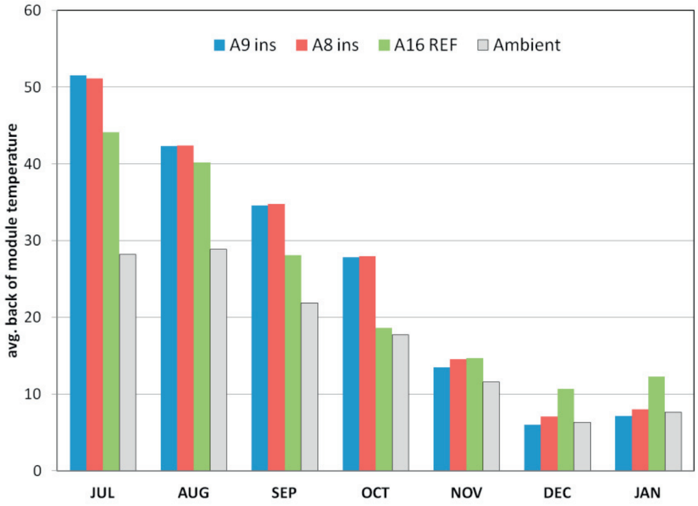

Fig. 4 Monthly average daylight (G > 0 W/m²) back of module temperature as measured for the three roof modules A8, A9 and the reference module ventilated on the back. The mean ambient temperature is also plotted.

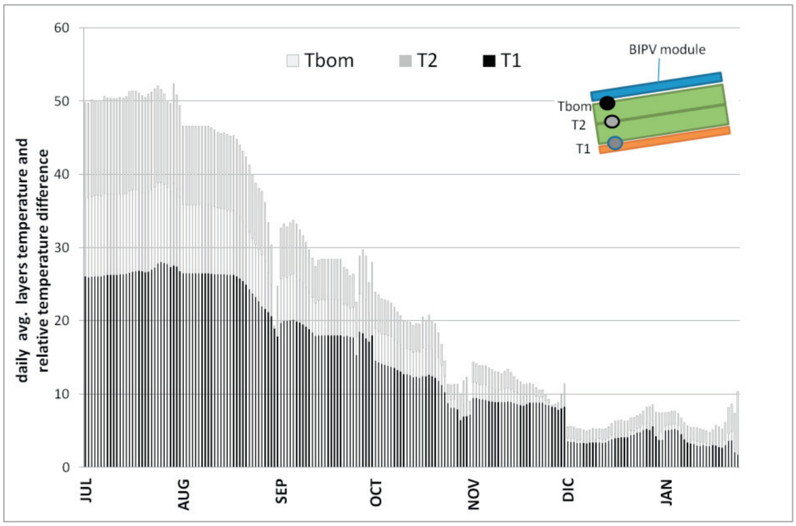

Fig. 5: The graph shows the different layer temperatures: The back of the module temperature (Tbom), the thermal insulation temperature (T2) and the back of the roof temperature (T1).

The temperature distribution of the modules was investigated through different PT100 systems placed on the back of the module, and by means of FLIR camera pictures taken during daytime.

Fig. 6 shows the behaviour of two different modules insulated on the back, and the temperature distribution of the open rack module on the right. In all cases it can be seen that the surface temperature is quite homogeneous, and that the roof integrated module records a small temperature reduction through the border.

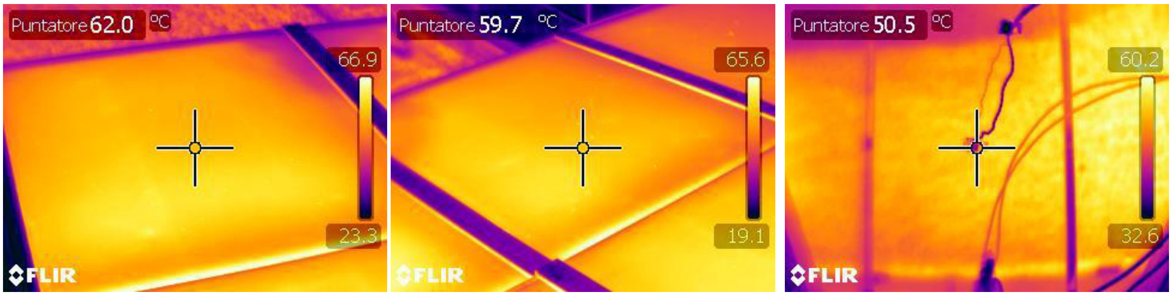

Fig. 6: the three pictures show the temperature distribution of the analyzed BiPV roof module. The picture on the right, which is cooler, is the back of the module temperature of the open rack module used as reference. Similar pictures were taken for the BiPV facade.

3.2. Performance analysis

The Performance ratio was calculated as follow:

$$PR = \frac{E \cdot 1000\ W/m^2}{H \cdot Pn} \quad (1)$$

The irradiance used for the calculation of the performance ratio was measured using a broadband pyranometer (Kipp & Zonen CMP11), and using the nominal STC power as reference.

The chart below gives the monthly and total performance ratio (PR) of the four modules calculated with the indoor measured STC power P1 (Fig. 7 for the façade modules and Fig. 8 for the roof modules).

The technological inter-comparison, with measured STC power (P1) as reference, shows that the ventilated and insulated micromorph modules recorded almost identical performances.
In particular, for the façade integrated micromorph modules the higher thermal losses due to back insulation, and a negative temperature coefficient, are fully compensated by thermal annealing.

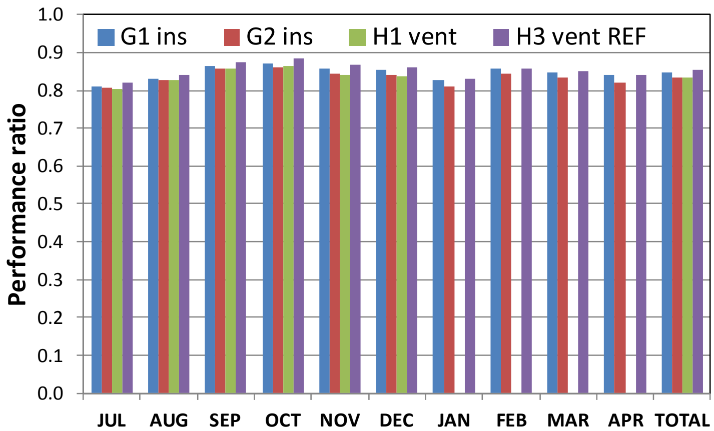

Fig. 7: PR trend calculated using the indoor measured STC power (P1) for the four facade modules.

For the roof integrated modules, the higher ventilation of the reference module (A16) makes a greater impact, and in summer leads to an almost similar PR.

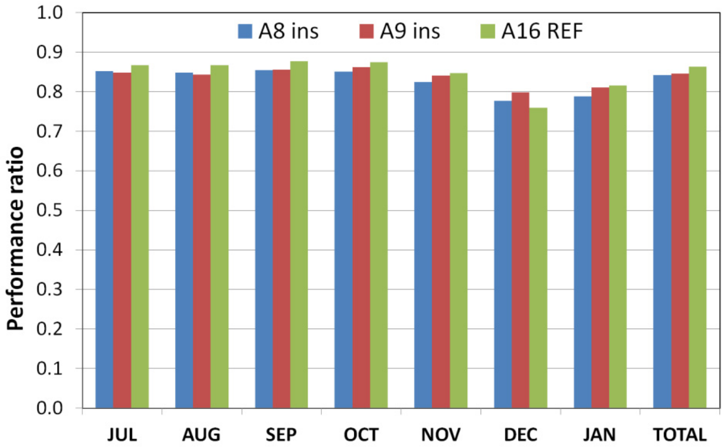

Fig. 8: PR calculated with the nominal power (Pn) for the two BIPV roof modules (A8 and A9) and the reference (A16) at 6°.

4. Conclusions

Outdoor energy yield measurements in combination with indoor performance measurements confirmed that façade or roof integrated micromorph modules perform similarly, irrespective of the level of integration (thermal back insulation or back ventilation). The thermal losses (due to the negative temperature coefficient) of the insulated façade modules are fully compensated by the annealing effects occurring at higher temperatures. The same case can be argued for the roof-top integrated modules.

As this research demonstrates, current BIPV technologies can be integrated as façade elements or roofs tiles, becoming part of the building envelope, and offering good performance in terms of electrical power (performance ratio) and thermal insulation, whether the type of installation is in direct contact with the building envelope or in a ventilated façade system. These photovoltaic systems could also be used as alternative BAPV elements, building added photovoltaic components or BIPV, building integrated photovoltaic modules for retrofit solutions, by combining high thermal insulation without significantly compromising the electrical performance or energy efficiency of the PV devices.

Another aspect to be considered is the technological integration of the BIPV module into the building system by means of an appropriate fastening system in order to secure the weather protection and guarantee the indoor comfort of the people. These crucial points were also investigated by the author but the results will form part of another publication.

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[2] Dittmann S. et al., Energy Yield Measurements at SUPSI – Importance of Data Quality Control and its Influence on kWh/Wp Inter-Comparison, 26th EUPVSEC, Hamburg, September 2011.