

# Operating Temperatures of Modules in Open-Rack and BIPV Configurations

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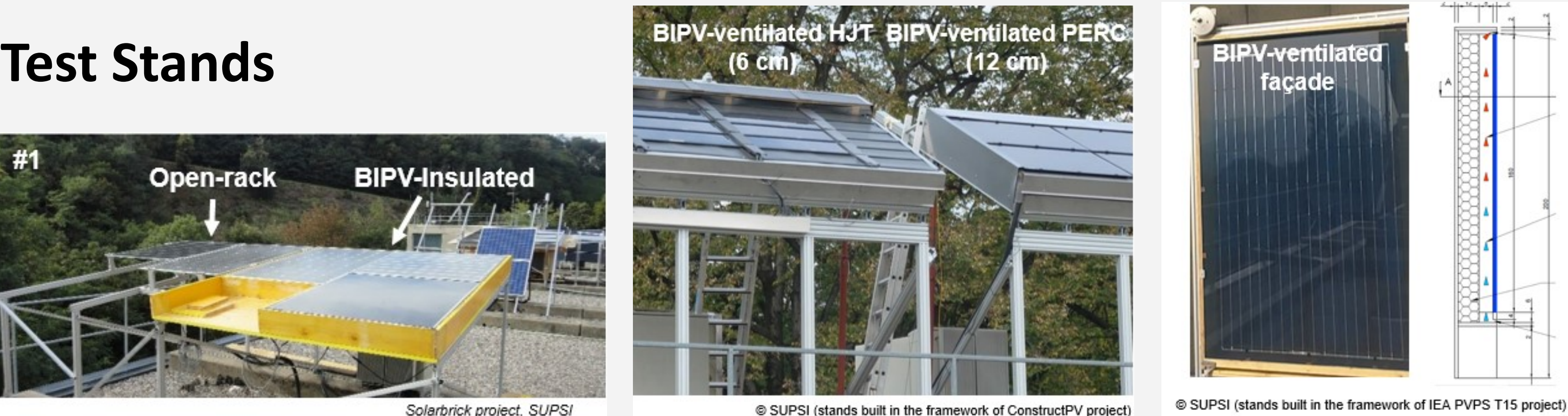
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## ABSTRACT

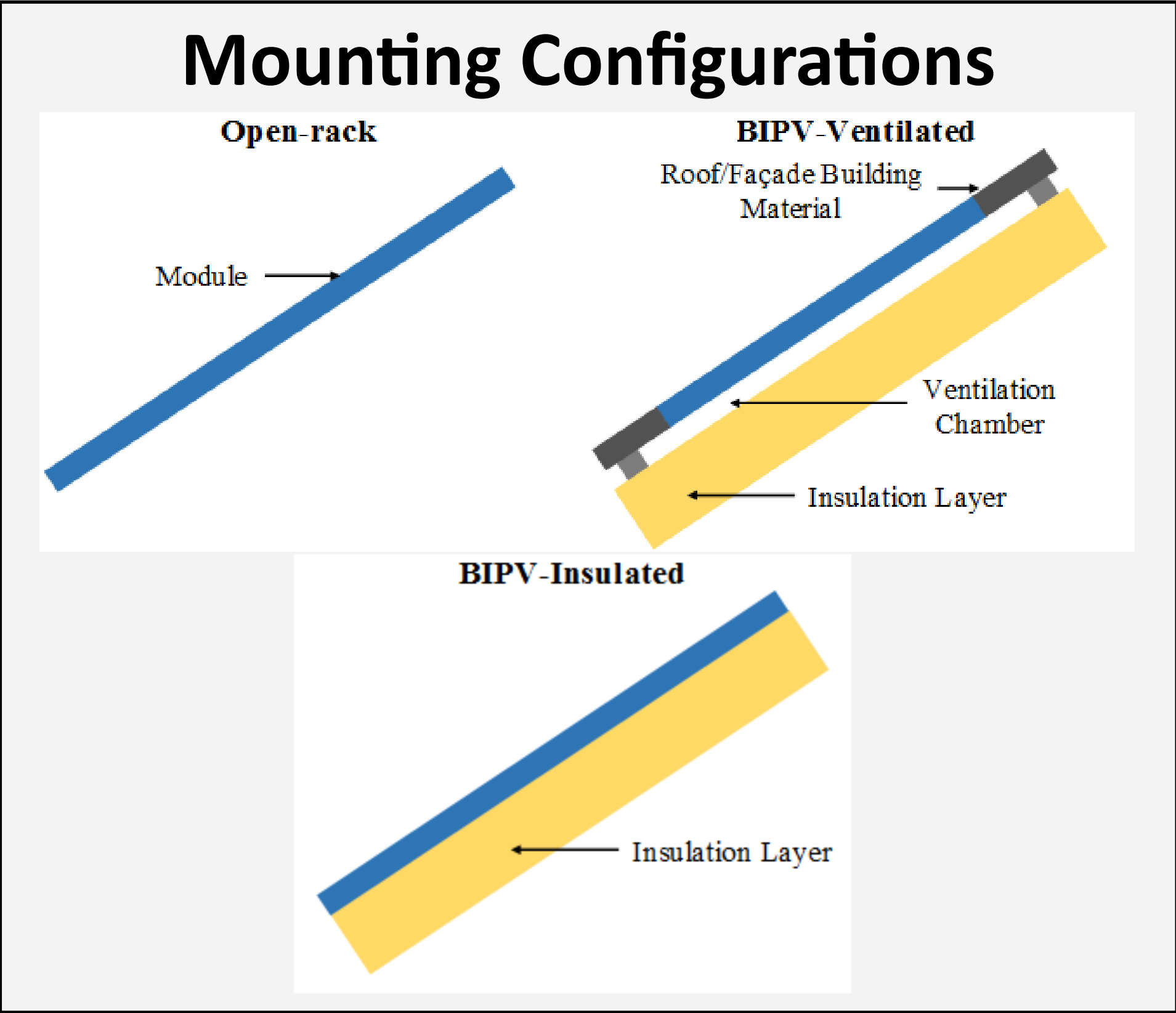
Elevated operating temperatures are expected in BIPV systems due to restricted or reduced rear-side ventilation, which impacts their performance and reliability. This work reports operating temperatures of the modules in open-rack and BIPV mounting configurations (BIPV-ventilated and BIPV-insulated) monitored over a period of 2-5 years in southern Switzerland. The modules in BIPV configurations operated at 20-30°C higher temperatures than the same modules in open-rack. The suitability of the indoor qualification and safety tests in IEC 61215 and IEC 61730 series were evaluated according to the 98th percentile real-life operating module temperature ( $T_{98}$ ) as defined in IEC TS 63126 guideline for qualifying PV modules operating at elevated temperatures. This work shows that according to IEC TS 63126, BIPV modules on a tilted surface in southern Switzerland may need to be tested at harsher conditions (e.g. higher temperatures) in a selection of indoor qualification and safety tests.

## Test Stands



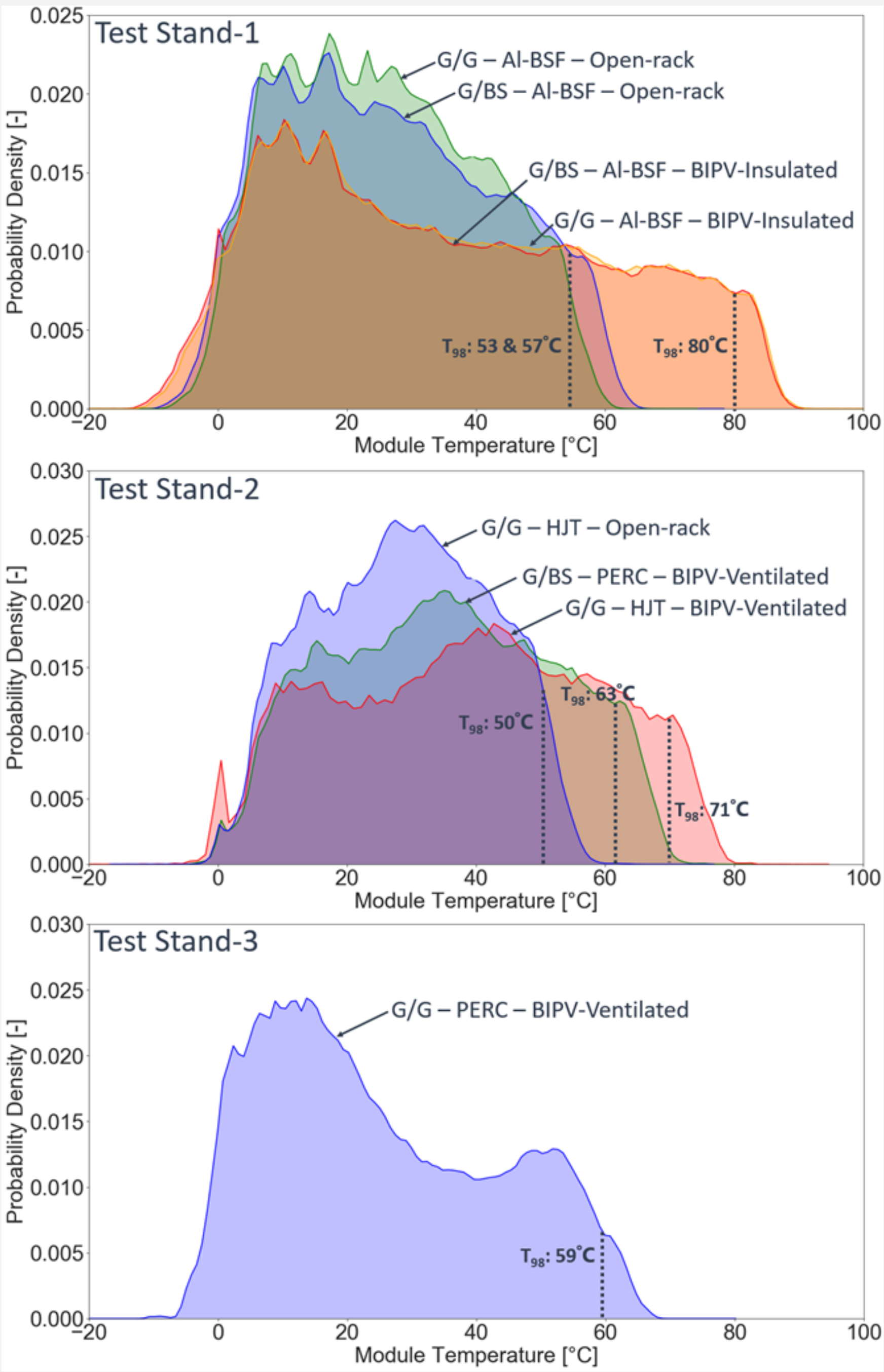
| Test Stand | Cell and Module Technologies        | Installation Configuration              | Azimuth (South = 0°) / Tilt Angles | Duration  | Monitored Parameters  |
|------------|-------------------------------------|---|------------------------------------|-----------|---|
| 1          | Al-BSF - G/EVA/BS Commercial module | • Open-rack<br>• BIPV-Insulated         | -4°/ 6° (Roof)                     | 51 Months | • G <sub>POA</sub> (every 1 minute)<br>• Module Temperature (Pt100 on rear-side of the modules) (every 1 minute)<br>• Electrical performance using MPP tracker (every 1 minute) |
|            | Al-BSF - G/PVB/G Commercial module  |   |                                    |           |   |
| 2          | HJT - G/G Prototype module          | • Open-rack<br>• BIPV-Ventilated (6 cm) | -4°/ 20° (Roof)                    | 53 Months |   |
|            | PERC - G/EVA/BS Commercial module   | • BIPV-Ventilated (12 cm)               |                                    |           |   |
| 3          | PERC - G/PVB/G Commercial module    | • BIPV-Ventilated (8 cm)                | -4°/ 90° (Façade)                  | 27 Months |   |

Al-BSF: Aluminum back surface field, HJT: Heterojunction Technology, PERC: Passivated Emitter and Rear Contact, G: Glass, BS: Backsheet, EVA: Ethylene-vinyl acetate, PVB: Polyvinyl-butyral, G<sub>POA</sub>: Plane of array irradiance and MPP: Maximum power point.



## Operating Temperature Distributions and $T_{98}$ (IEC TS 63126)

- The insulated modules in **Test Stand-1** operated at higher temperatures due to restricted rear-side ventilation. While the open-rack modules reached a maximum of 62°C and 66°C, respectively, the insulated modules exhibited a larger distribution, reaching temperatures slightly above 90°C in southern Switzerland.
- $T_{98}$  of the insulated modules in **Test Stand-1** are 80°C, while  $T_{98}$  of the open-rack G/BS and G/G modules are 57°C and 53°C, respectively .
- The insulated modules are exposed to lower temperatures (even below 0°C) with respect to modules in open-rack conditions due to the stronger radiative cooling at night.
- In **Test Stand-2**, the ventilated HJT module reached higher operating temperatures than the same module type in open-rack configuration due to limited rear-side ventilation.  $T_{98}$  of the open-rack and the ventilated HJT modules are 50°C and 71°C, respectively. The ventilated PERC module has a  $T_{98}$  of 63°C (maximum of 77°C).
- The ventilated G/G PERC BIPV module, installed as a façade module on **Test Stand-3**, operated at lower temperatures relative to the other modules in BIPV configurations. As expected, this is because there is usually a lower amount of irradiance on the vertical surface compared to the sloped surfaces, especially when solar altitude is high (e.g. in summer).
- $T_{98}$  of the **two insulated BIPV modules on Test Stand-1** and the **ventilated HJT module on Test Stand-2** are all higher than 70°C. According to the **IEC TS 63126**, these modules should be tested at **harsher testing conditions** (Level 1 Test Condition) in a selection of **indoor module qualification and safety tests defined in IEC 61215 and IEC 61730 series**.
- BIPV modules** installed in a mid-latitude country (Switzerland) with a reduced or restricted rear-side ventilation **operated at temperatures 20-30°C higher than the same modules installed in an open-rack** configuration. Exposure of the modules to **elevated operating temperatures (larger thermal stresses)** may lead to **higher degradation rates** (e.g. higher rate of encapsulant discoloration, damaged interconnections and solder joints, etc.) and a faster occurrence of **wear-out-failures** that shorten the lifetime of a PV module.



| Test Stand | Cell and Module Technologies | Tilt Angles | Open-Rack     |                | BIPV-Ventilated |                | BIPV-Insulated |                | Temperature Difference |                |
|------------|------------------------------|-------------|---------------|----------------|-----------------|----------------|----------------|----------------|------------------------|----------------|
|            |                              |             | $T_{98}$ [°C] | $T_{max}$ [°C] | $T_{98}$ [°C]   | $T_{max}$ [°C] | $T_{98}$ [°C]  | $T_{max}$ [°C] | $T_{98}$ [°C]          | $T_{max}$ [°C] |
| 1          | Al-BSF - G/EVA/BS            | 6°          | 57            | 66             | -               | -              | 80             | 92             | 23                     | 26             |
|            | Al-BSF - G/PVB/G             | 6°          | 53            | 62             | -               | -              | 80             | 91             | 27                     | 29             |
| 2          | HJT - G/G                    | 20°         | 50            | 64             | 71              | 83             | -              | -              | 21                     | 19             |
|            | PERC - G/EVA/BS              | 20°         | -             | -              | 63              | 77             | -              | -              | -                      | -              |
| 3          | PERC - G/PVB/G               | 90°         | -             | -              | 59              | 68             | -              | -              | -                      | -              |