Scuola universitaria professionale della Svizzera italiana
Dipartimento ambiente costruzioni e design
Istituto sostenibilità applicata all'ambiente costruito
Laboratorio SUPSI PVLab

SUPSI

The Effect of Partial Shading on the Reliability of BC Modules

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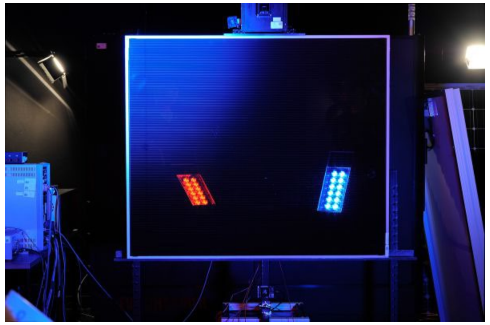
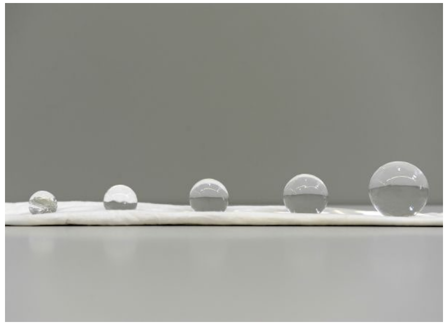
12th BC Workshop, 4-5 December 2024
Delft, the Netherlands

SUPSI PVLab – Indoor

- N.2 **Pasan Flasher**, class AAA, for the electrical characterisation with best uncertainty of **+/-1.1%** (spectral response measurement at module level, spectrum fine tuning with LEDs)
- N.3 **continuos light simulators, with visible light (2) and UV light (1),** for characterisation, stabilisation and accelerated degradation of materials
- N.2 **climate chambers**, 3 m^3 volume, for environmental testing with humidity and thermal cycling.
- PID testing
- N.1 **mechanical load test setup** up to **18.000 Pa** in pressure, with optional inclination up to 30°
- N.1 **hail test setup**, with max diameter of hailstone of **90 mm (accredited)**
- N.1 **mechanical test machine** for shear, pull test, 4 point bending test on materials and components (JB, connectors, laminates)
- N.1 megaohmeter for dry and wet insulation test
- Bypass diode thermal and reverse breakdown testing.
- N.2 IR camera systems for electroluminescence and thermal mapping

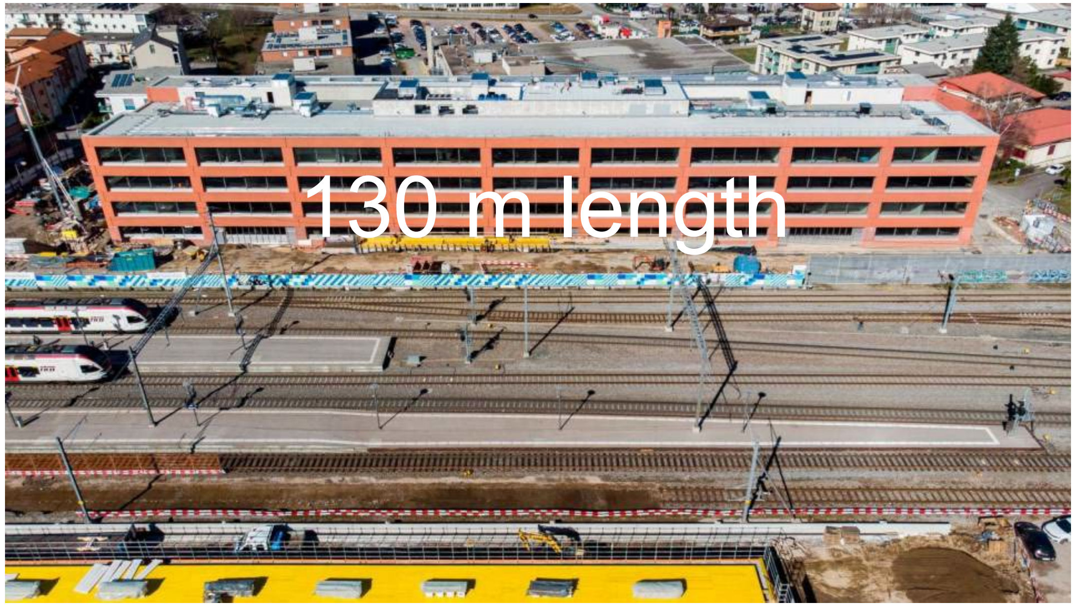





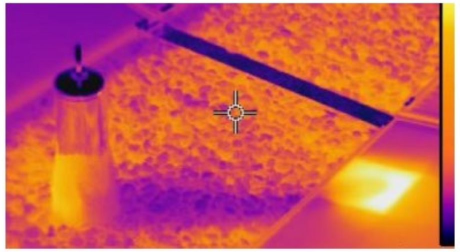

SUPSI PVLab – Outdoor

- **Outdoor monitoring area** for the energy yield evaluation and comparison to other reference technologies
- **Meteo station**, with calibrated spectroradiometers, pyranometers and reference cells for a precise monitoring of composition and quantity of light, further to environmental parameters
- N.2 IV curve tracers for string performance measurements on the field (calibration with reference modules for uncertainty reduction)
- N.1 PV system performance checker
- N.1 Insulation, short circuit current and open circuit voltage tester for PV system analysis



Introduction

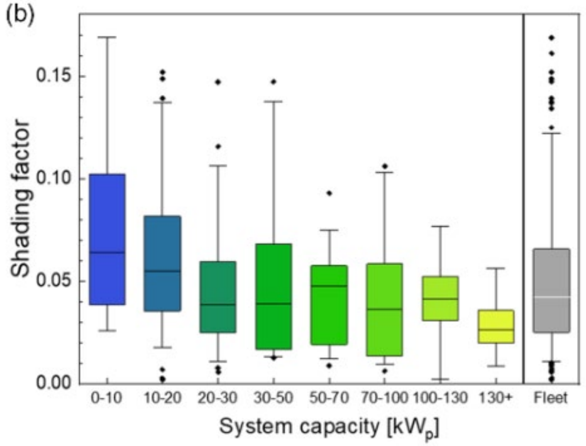
D. Chianese et al., EUPVSEC (2020)



$$\text{Shading factor} = \frac{\text{Time in shading fault}}{\text{Time in operation}}$$

A. Fairbrother et al.
Solar RRL (2021)

55 BIPV-roof systems in Switzerland



Hot spot endurance test (IEC 61215-2:2021)

- To assess module's ability to resist local-point/cell heating under partial shading
- **IEC TS 63126:2020** Guidelines for qualifying PV modules, components and materials for operation at high temperatures → **T_{98} (175.2hour/year)**

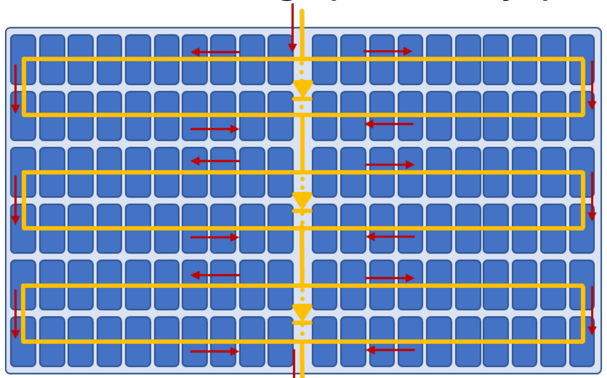
Module Temperature	IEC 61215:2021 (T_{98} ≤ 70°C)	Level 1 (70°C < T_{98} ≤ 80°C)	Level 2 (80°C < T_{98} ≤ 90°C)
IEC TS 63126:2020	55±15°C (*50±10°C**)	60±10°C	70±10°C

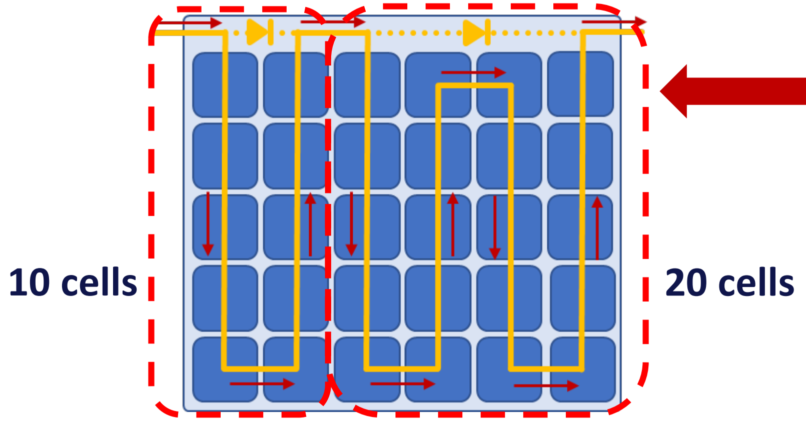
*IEC 61215:2016

Objectives

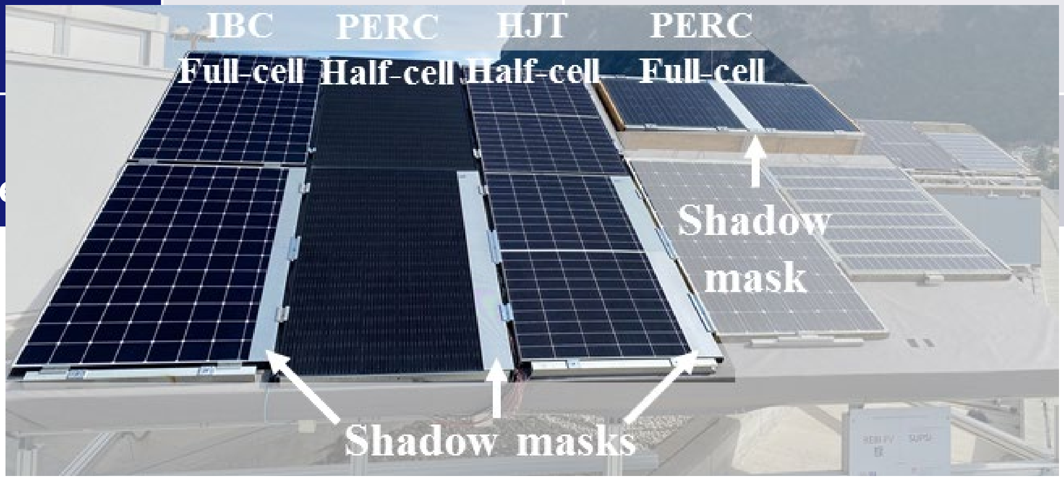
- Effect of **cell technology** and **string length** on hot-spot temperature
- **Sufficiency of Hot-spot Endurance (HS) test for BIPV** in terms of **testing temperature**

Parallel strings («Butterfly»)

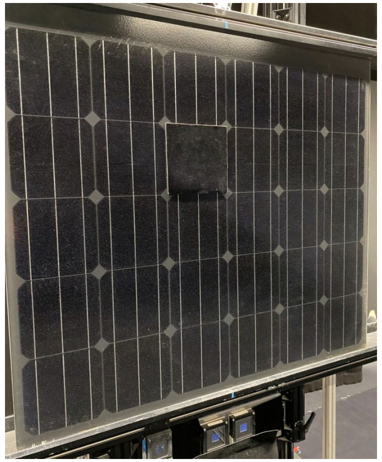


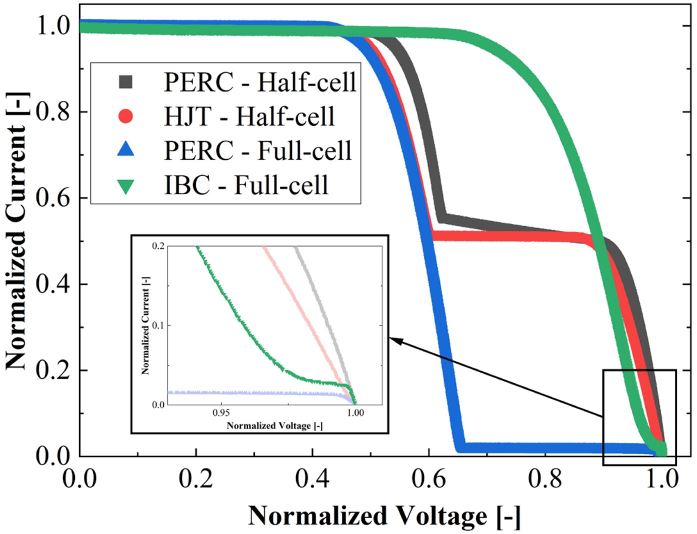


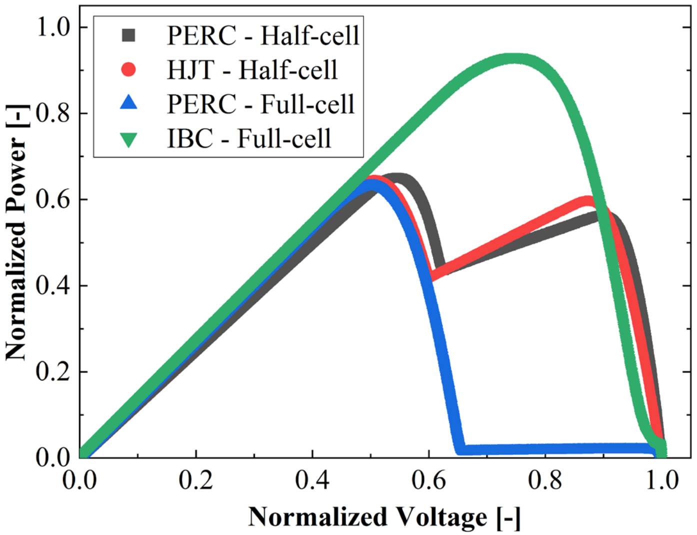
Module Technology	Indoor Hot-spot Endurance Tests	
	IEC 61215-2:2021 (55°C, 5 hours)	IEC TS 63126:2020 Level-2 (75°C, 5 hours)
1 - PERC Half-Cell (20 cells/diode)	1	1
2 - HJT Half-Cell (20 cells/diode)	1	1
3 - IBC Full-Cell (104 cells, 3 diodes)		
4 - PERC Full-cell (Short + Long (10 cells/diode + 20 cells/diode		



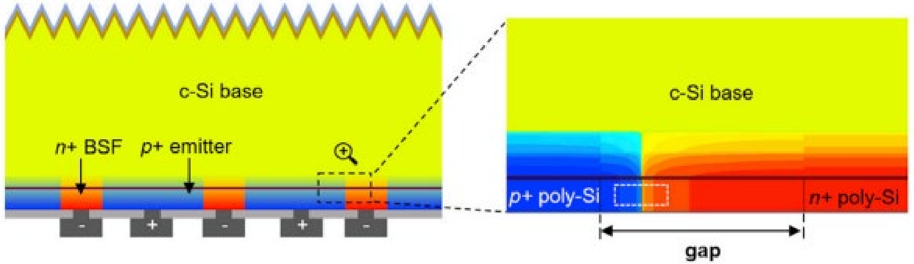
Normalized IV & PV Curves – One Cell Shaded (100%)

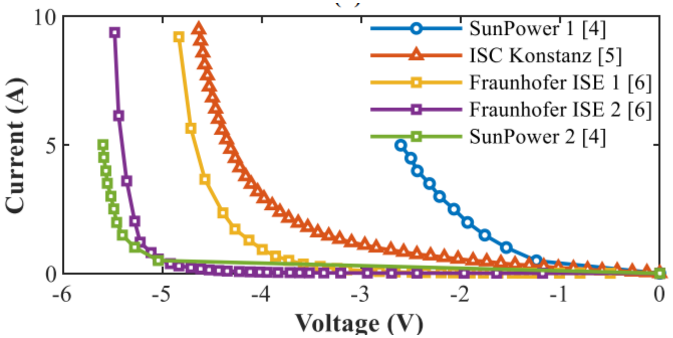




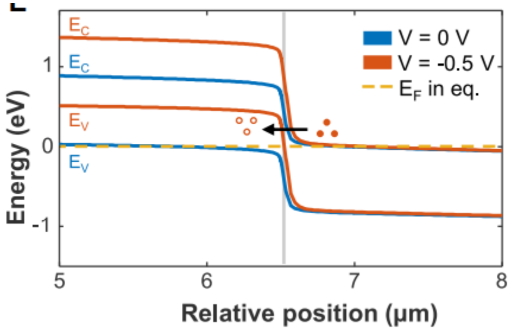


- Half-cell modules → two parallel strings connected in parallel to a diode
- IBC cell → p+ and n+ junction → forms a Zener diode
  - Functions as a built-in bypass diode (tunneling)
  - Less negative breakdown voltage ($V_{br} > -6$ V)
- Breakdown voltage of PERC at around -20 V





A. Calcabrini et al.
IEEE PVSC (2021)

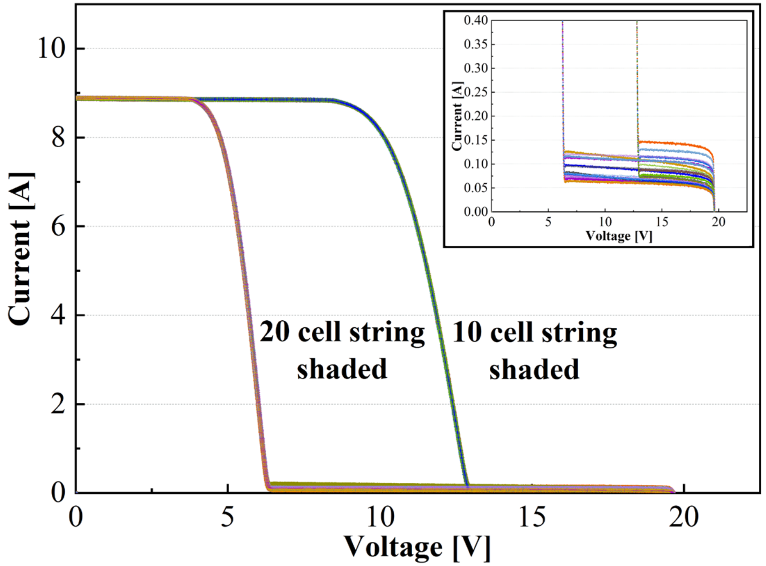


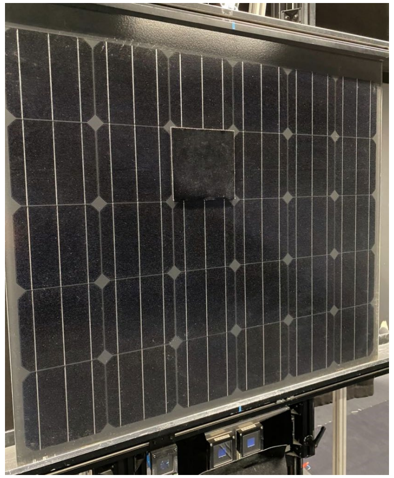
A. Calcabrini et al.
CellPress (2022)

Indoor Hot-Spot Endurance Tests

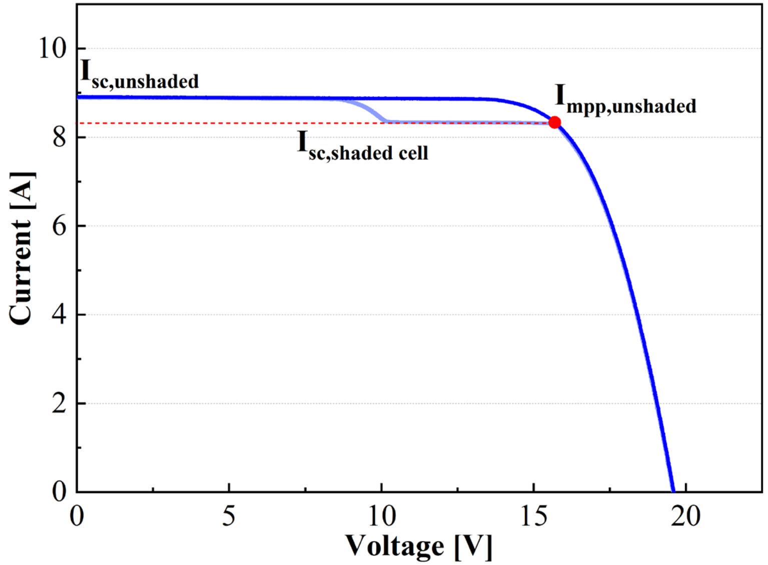
Hot-spot Endurance test (IEC 61215-2:2021)

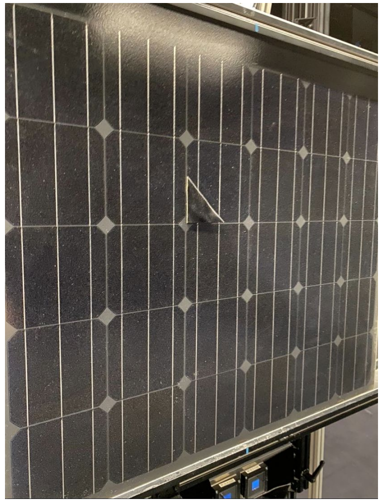
Step 1: Cell Selection (4 cells) (Low and High Shunt Resistance)



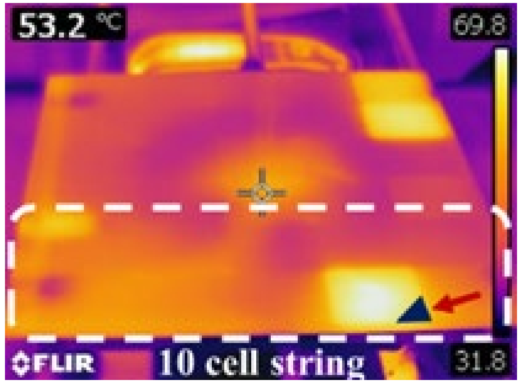


Step 2: Worst-case shadow (Max Heat Dissipation)





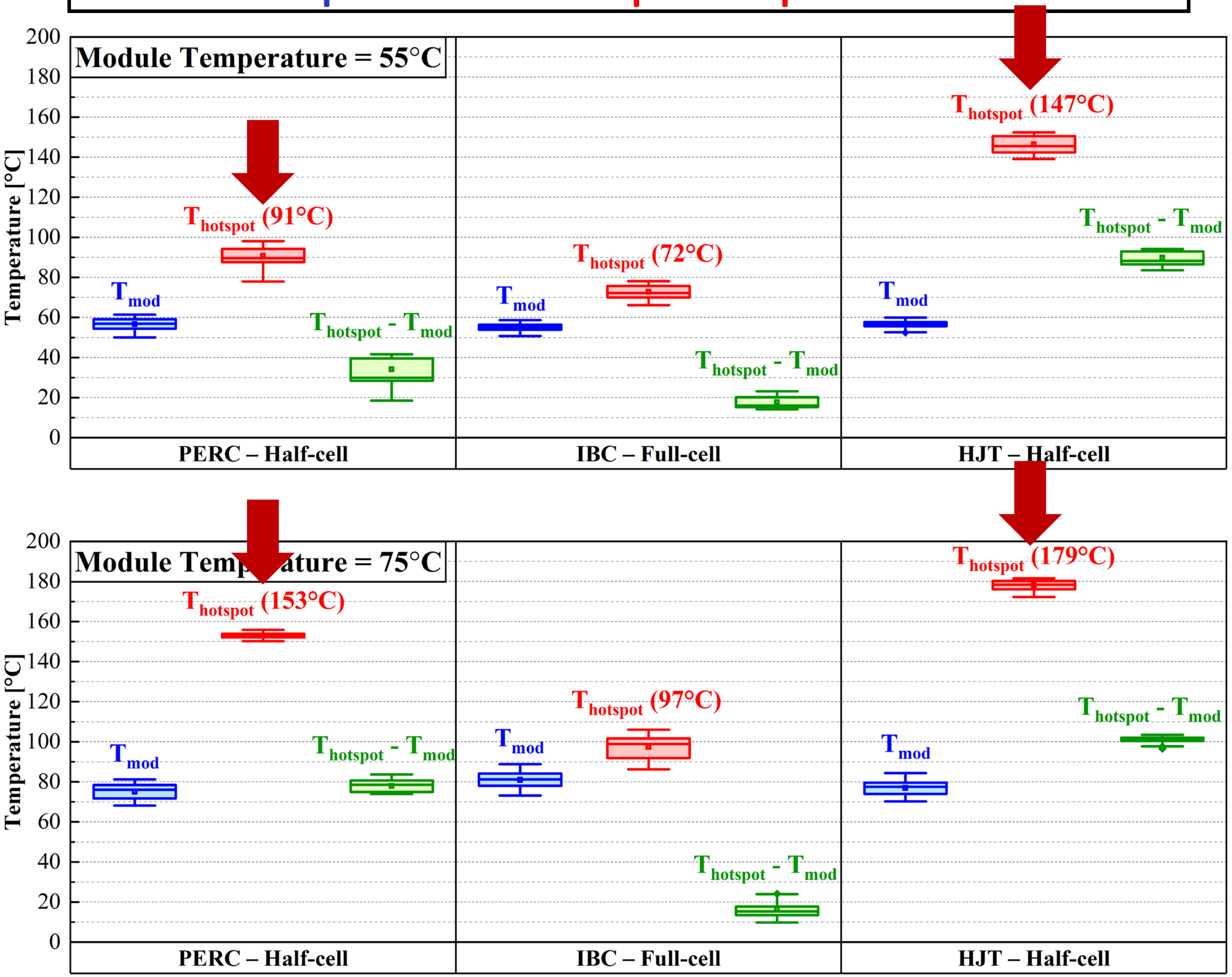
Step 3: Light soaking

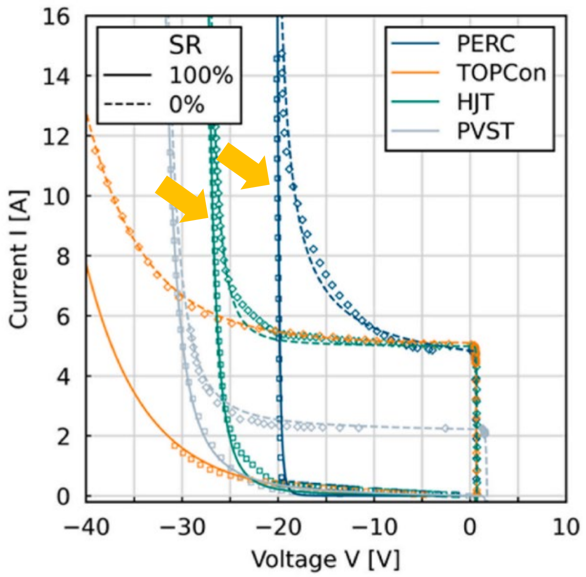


- Short-circuit condition
- 1000±100 W/m²
- 55±15˚C module temp.
- 1 hour + 4 hours

Module and Hot-Spot Temperatures during HS Tests

Module Temperature Hot-spot Temperature Difference

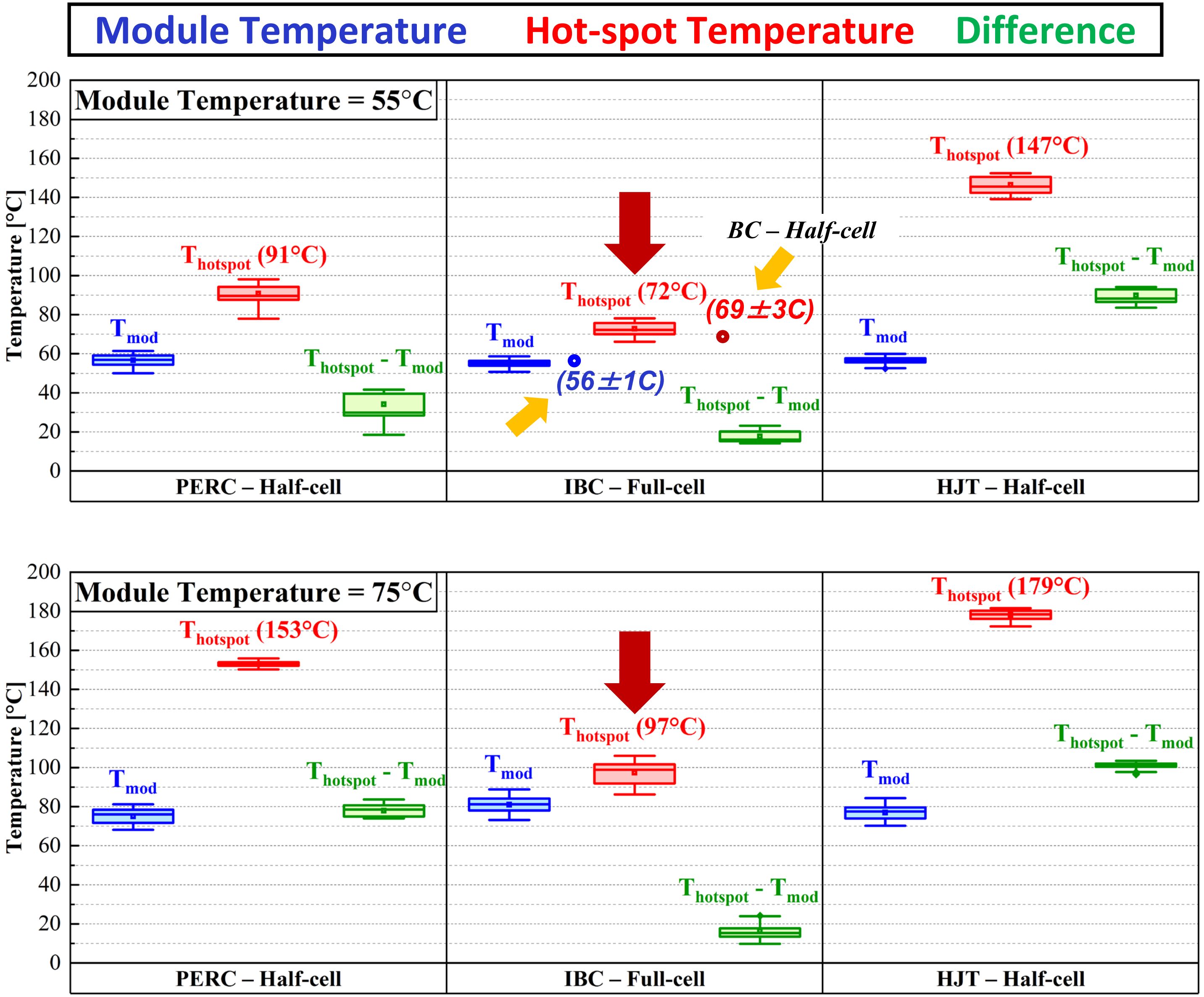




C. Reichel et al., Sol. En. Mat. (2022)

- **HJT and PERC – Half-cell modules** have the **highest hot-spot temperature**
- **IBC** module has the **lowest hot-spot temperature**
- **Shorter string, lower hot-spot temperature** (less negative reverse voltage) – **PERC**

Module and Hot-Spot Temperatures during HS Tests



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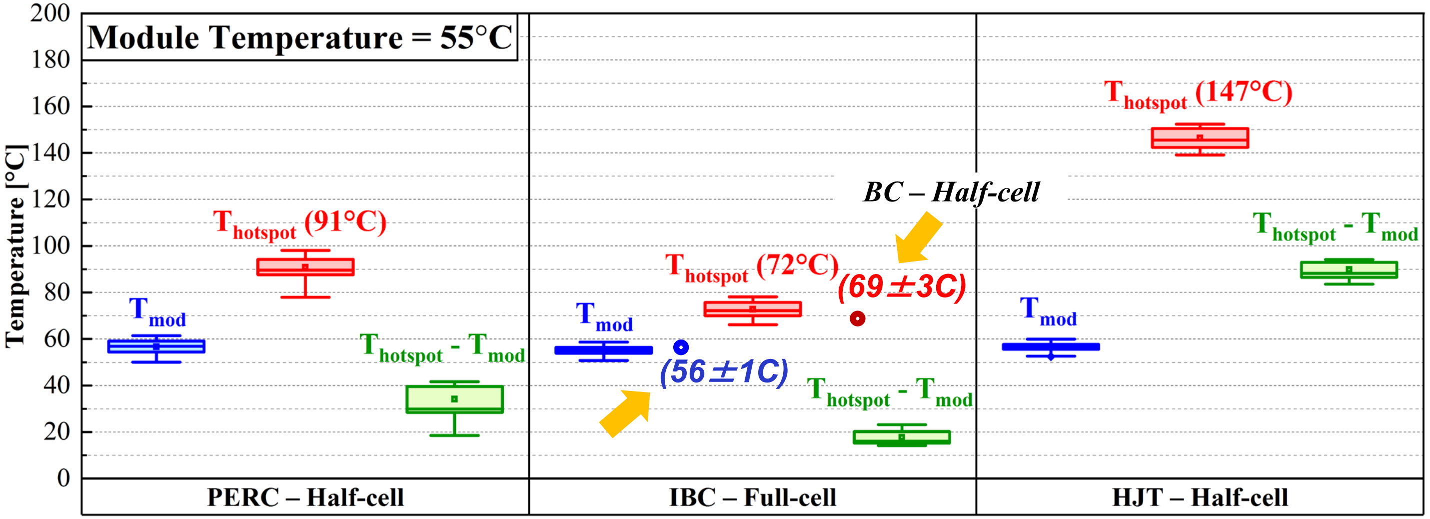
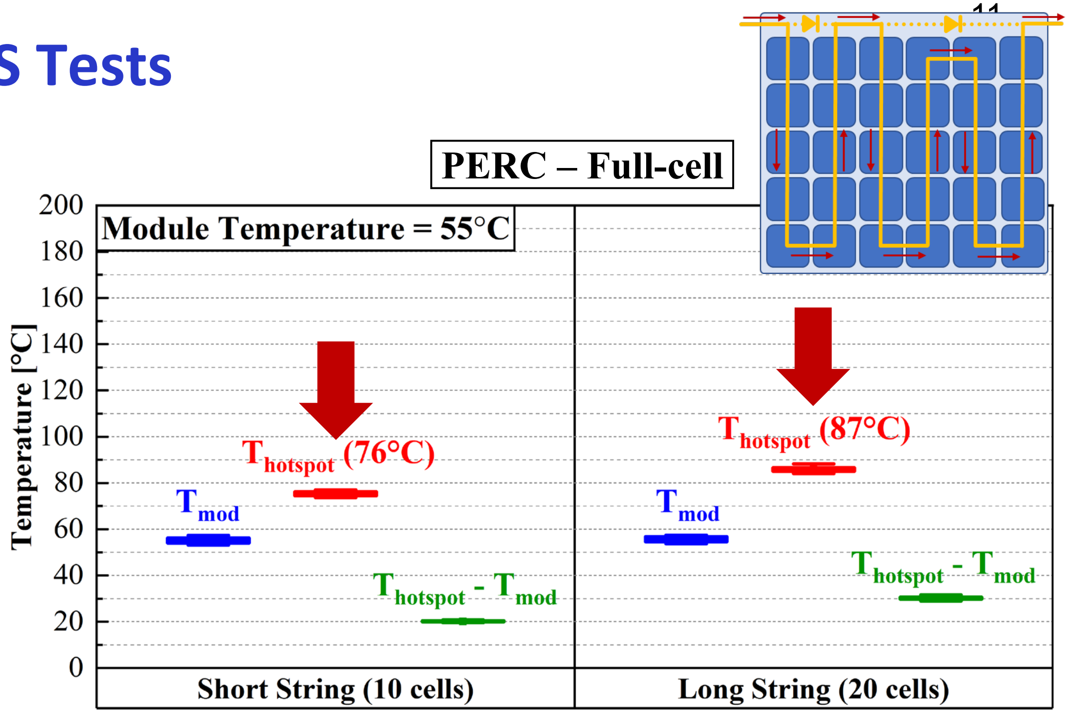
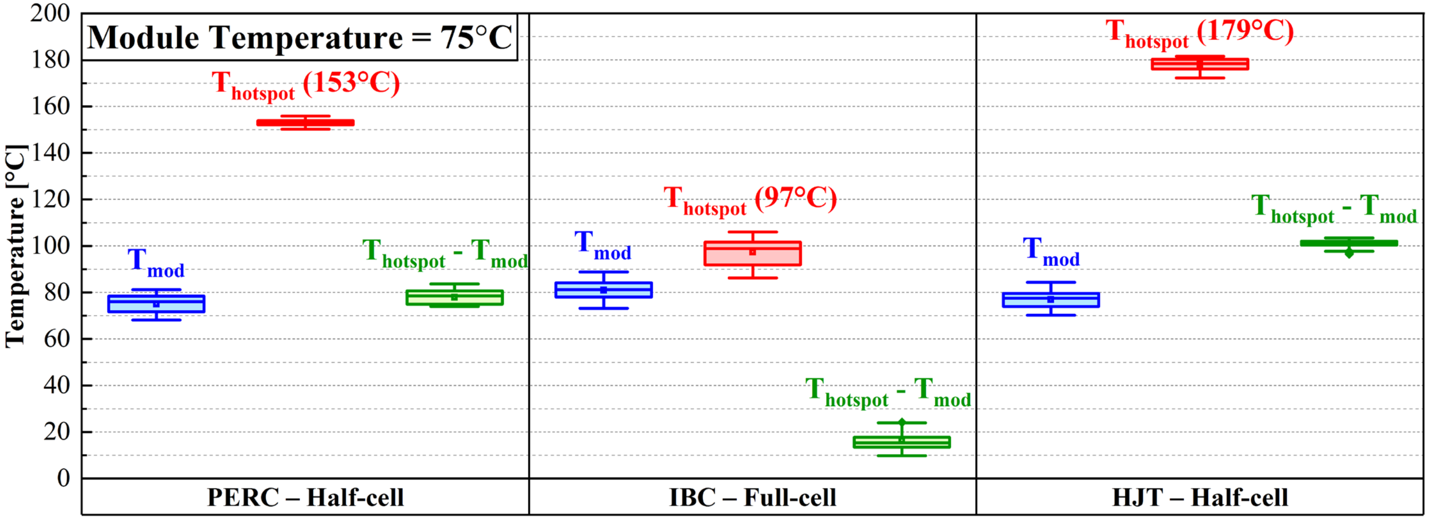
Module and Hot-Spot Temperatures during HS Tests

Module Temperature **Hot-spot Temperature** **Difference**







- **HJT and PERC – Half-cell modules** have the **highest hot-spot temperature**
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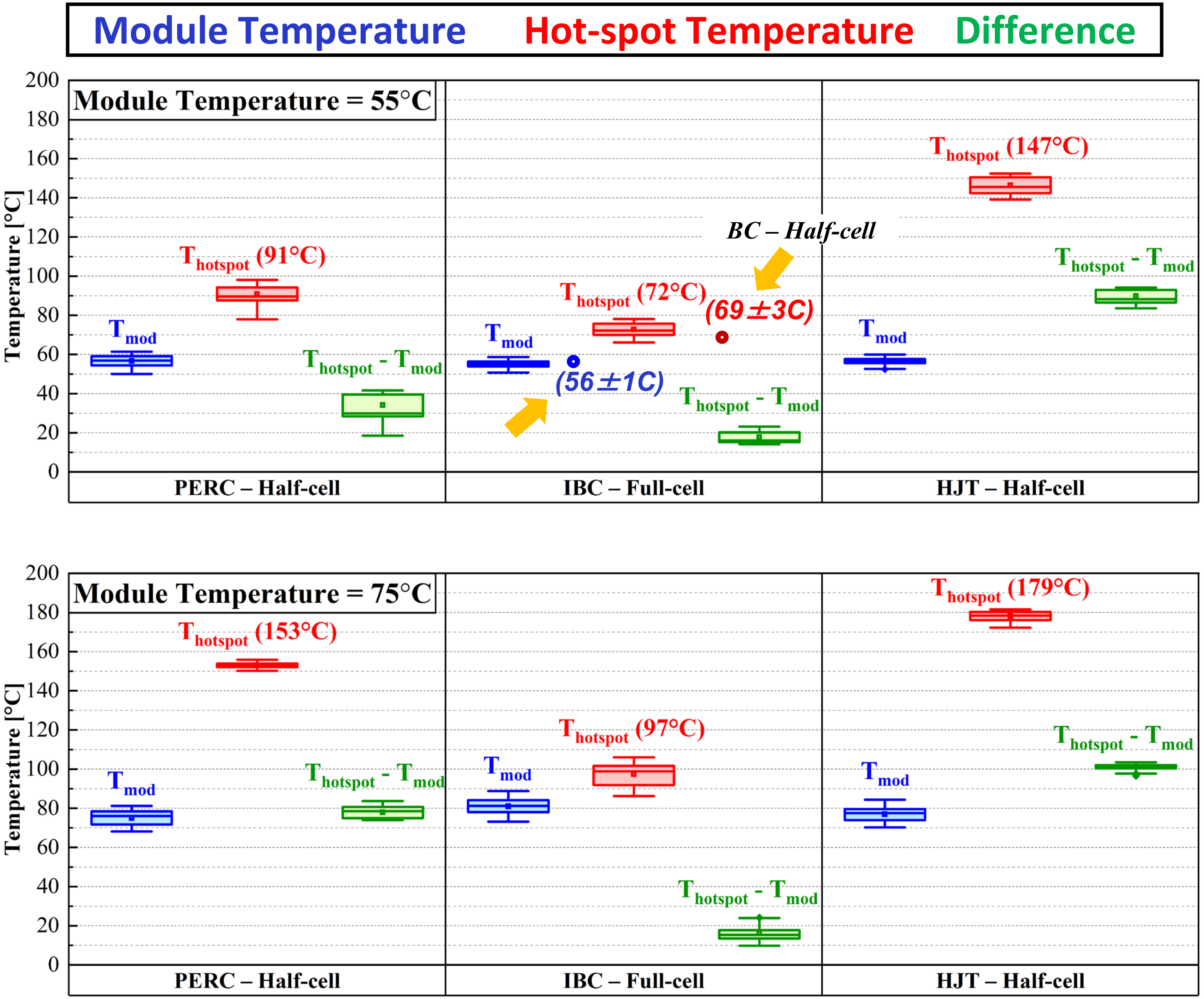
Module and Hot-Spot Temperatures during HS Tests



What temperatures are dangerous?

- **IEC 61730-2 MST 21 Temperature Test** exposes the module to 1000 W/m^2 sunlight until the temperature stabilized, and the pass criteria is that **no measured temperature exceed the limits of the surface materials (e.g. TI/RTE/RTI)**, as TI/RTE/RTI is the maximum service temperature at which the critical properties of a material will remain within acceptable limits over a long period of time.

10.15.4 Pass criteria

The pass criteria are as follows:

a) No measured temperatures exceed any of the applicable temperature limits (e.g. TI/RTE/RTI) of surfaces, materials, or components. Thermal material requirements are given in 5.5 of IEC 61730-1:2016.

b) No visual defects as defined in MST 01.

c) MST 16, MST 17 shall meet the same requirements as for the initial measurements.

IEC 61730-1 requires reporting of the maximum measured operating temperature as determined by this test method.

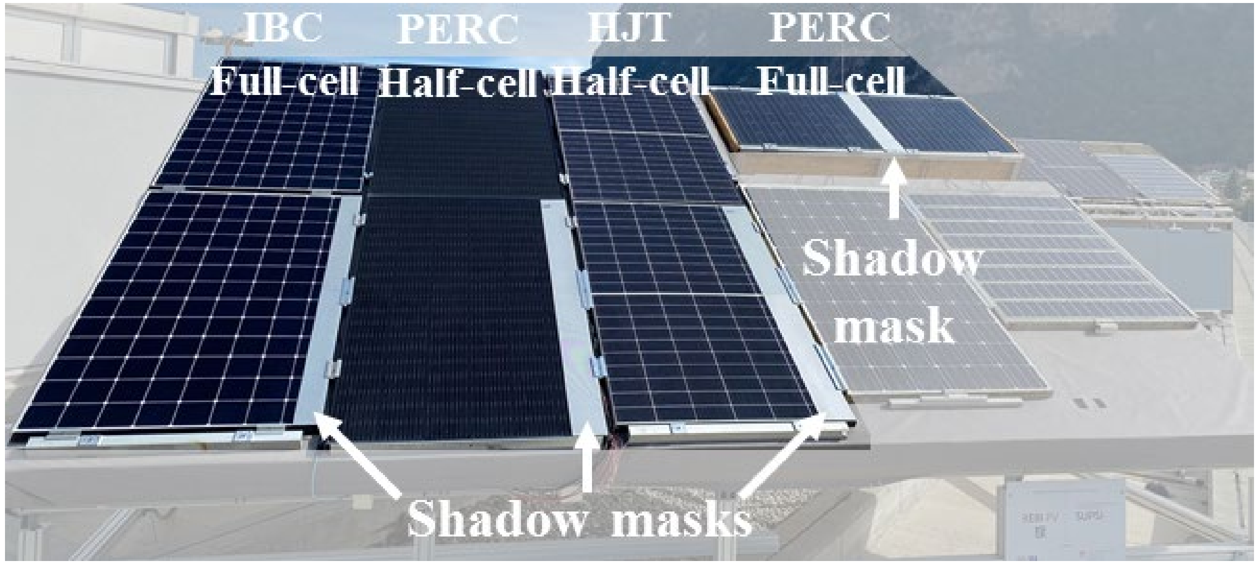
- **RTI (relative temperature index):** characteristic parameter related to the ability of plastic materials to resist thermal degradation.
- **RTE:** Relative Thermal Endurance
- **TI:** Thermal Index

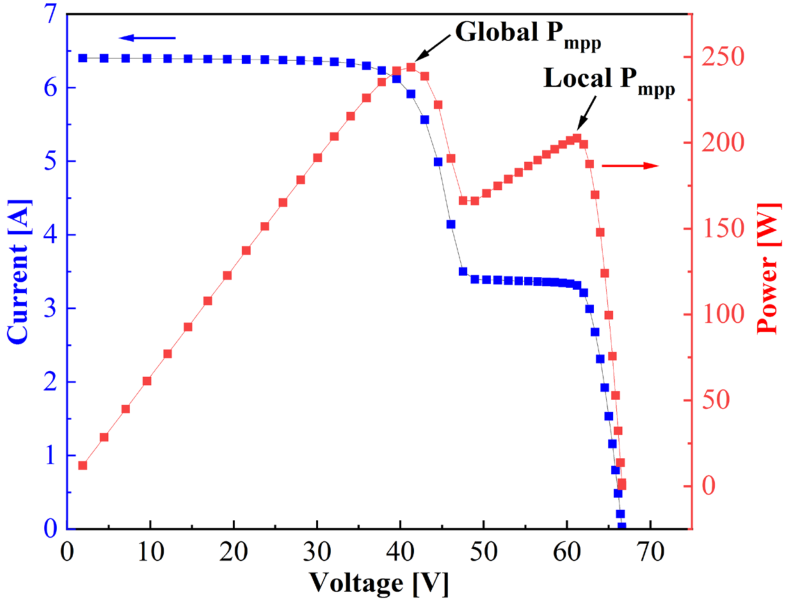
3.5.5.3
relative temperature index
RTI
temperature index of an insulating material or system obtained from the time which corresponds to the known temperature index of a reference material or system when both are subjected to the same ageing and diagnostic procedures in a comparative test

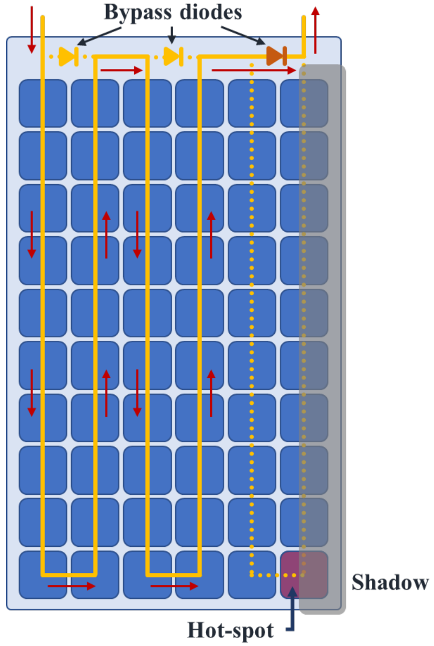
[SOURCE: IEC 60050-212:2010, 212-12-12]

Outdoor Accelerated Ageing Test using Shadow Masks

Outdoor Accelerated Ageing using Shadow Masks

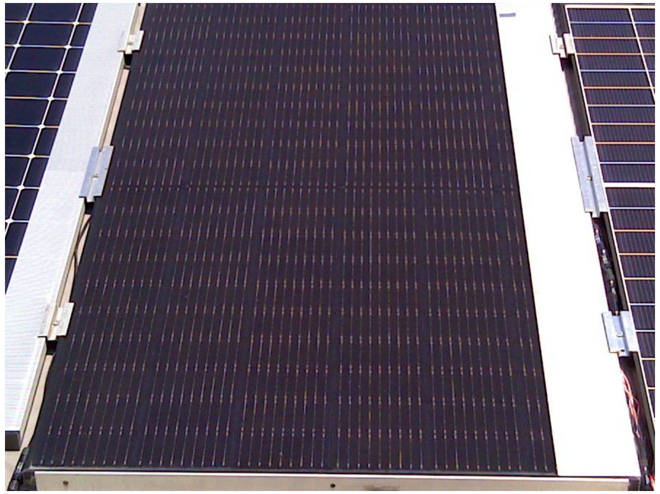


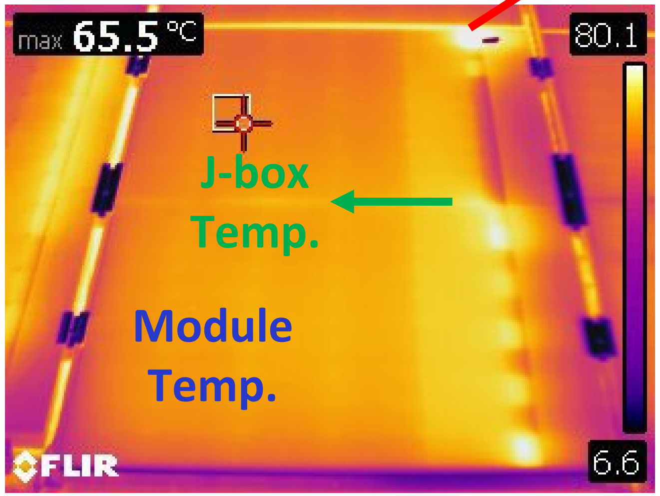


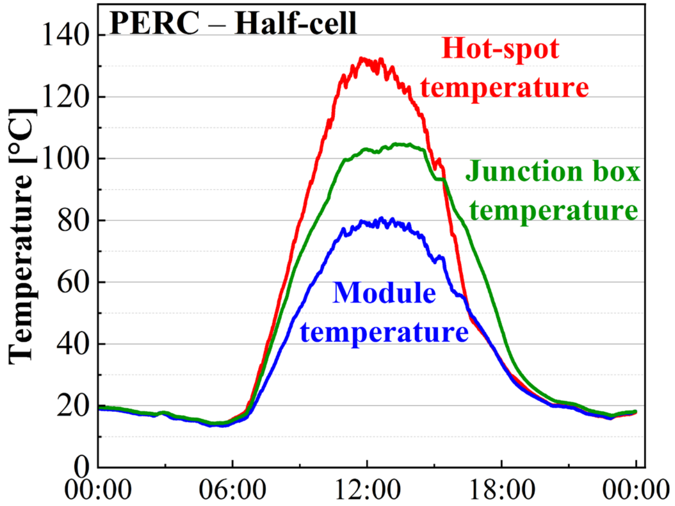


- Stress on **bypass diode** and **module materials**
- Difference between **Global P_{mpp} and Local P_{mpp} is 10±5%**
- Shadow mask **36% transmittance**
- 13 months of monitoring
- **Module**, **hot-spot** and **junction box temperatures** every minute
- IV curves every minute

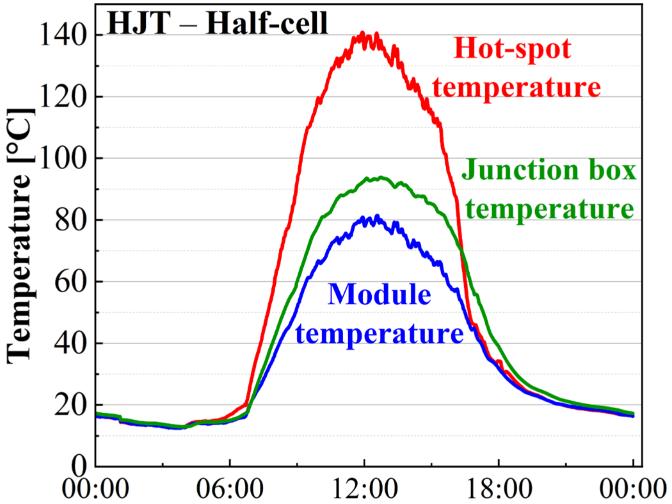
Daily Temperature Profiles (August – Clear Sky Day)







BIPV-Insulated (no ventilation)



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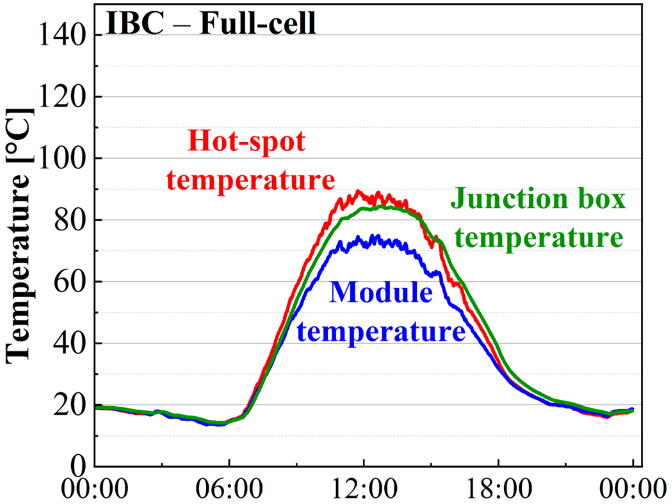
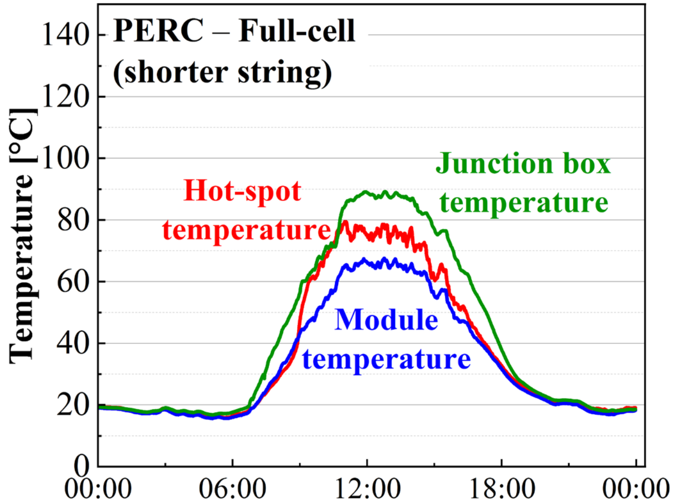


BIPV-Insulated (no ventilation)

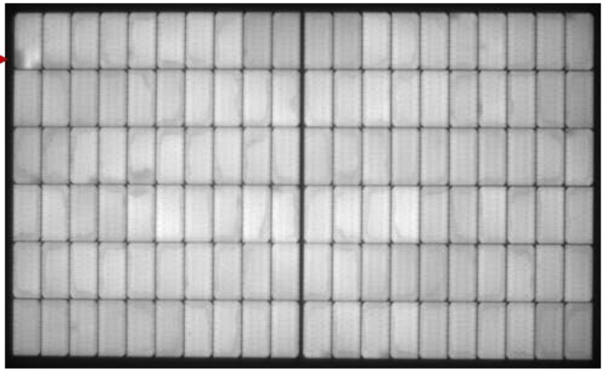


BIPV-Partially Ventilated

Performance Change After 13 Months

PERC – Half-cell

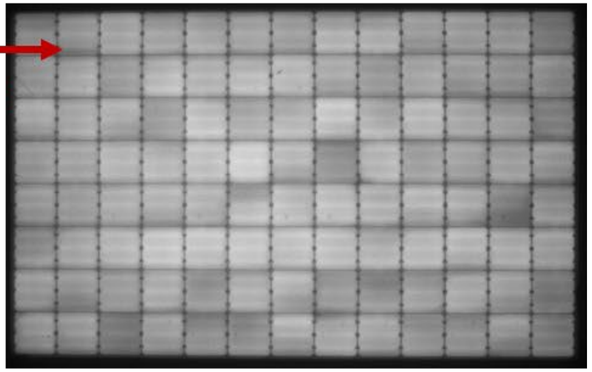
Hot-spot
$T_{max} = 143.4°C$
$T_{98} = 125.5°C$



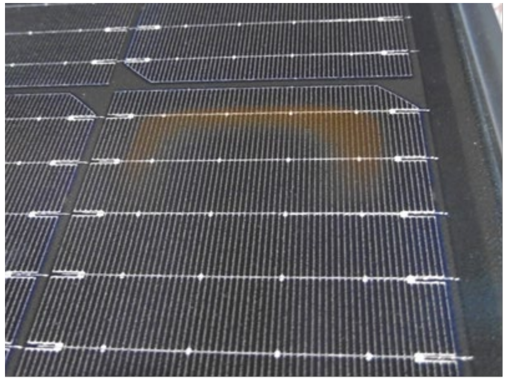
Module
$T_{max} = 89.8°C$
$T_{98} = 78.4°C$

IBC – Full-cell

Hot-spot
$T_{max} = 97.6°C$
$T_{98} = 86.2°C$

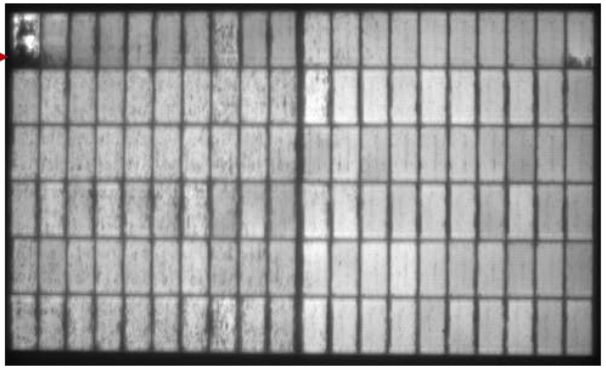


Module
$T_{max} = 84.4°C$
$T_{98} = 73°C$



HJT – Half-cell

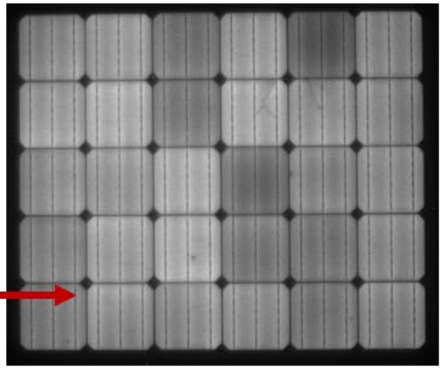
Hot-spot
$T_{max} = 156.5°C$
$T_{98} = 130°C$



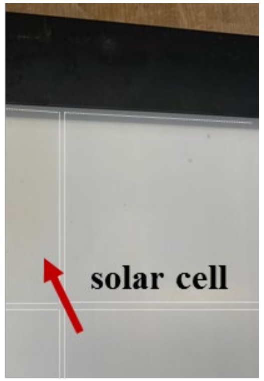
Module
$T_{max} = 88°C$
$T_{98} = 76.6°C$

PERC – Full-cell

Module
$T_{max} = 76.5°C$
$T_{98} = 66.2°C$



Hot-spot
$T_{max} = 88.4°C$
$T_{98} = 77.2°C$



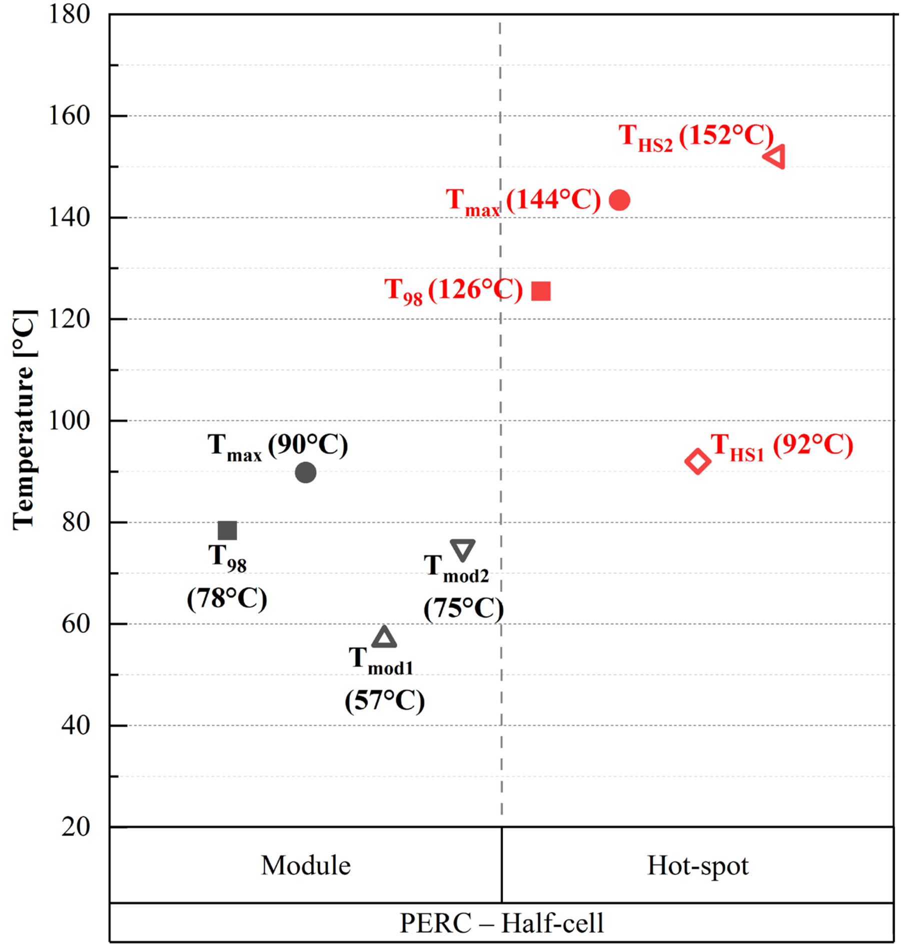
- There are changes in the performance of unshaded and shaded modules, but there is **no performance change attributable to the shadow mask.** ***(update: after 2 years, shaded HJT degraded more than unshaded HJT)***[1]
- **No diode failure** after slightly more than 2 years of monitoring
- **PERC – Half-cell** and **HJT – Half-cell** modules → Darker areas - Shunt faults?
- **PERC – Half-cell** → **Discoloration of encapsulant** and **backsheet**

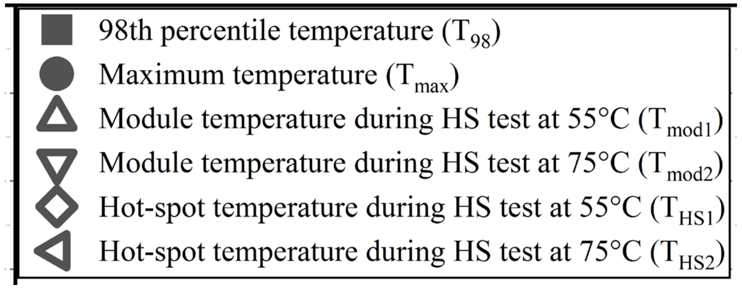
[1] G. Friesen, et al. EUPVSEC (2024)

Sufficieny of Hot-Spot Test for BIPV Testing

Filled: Outdoor Tests

Unfilled: Indoor Hot-spot Tests



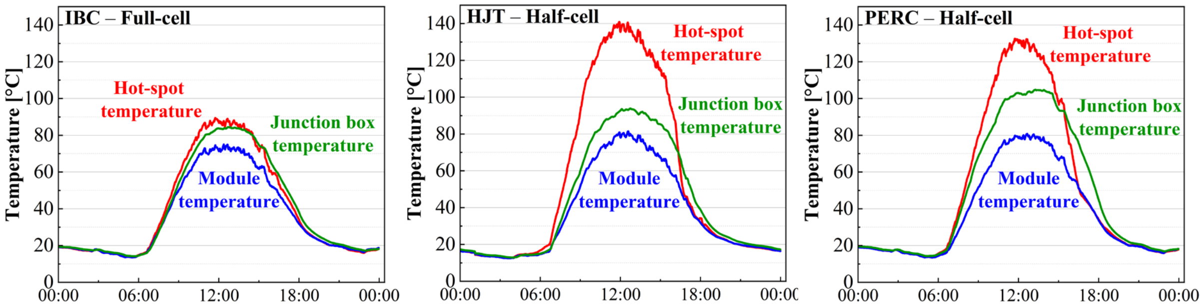


Hot-spot Endurance Test	IEC 61215-2:2021 (2016)	Level 1 ($70^\circ C < T_{98} \le 80^\circ C$)	Level 2 ($80^\circ C < T_{98} \le 90^\circ C$)
IEC TS 63126:2020	55±15°C (50±10°C)	60±10°C	70±10°C
Proposal of this study	55±15°C	*75±15°C*	*85±15°C*

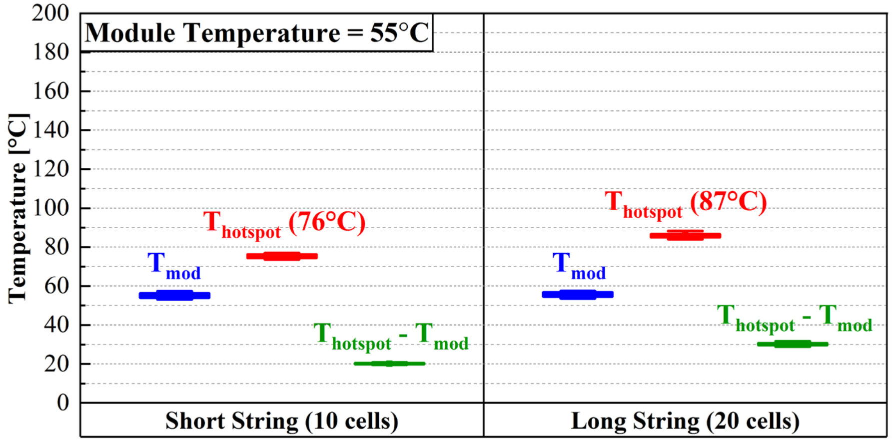
HS test should be performed at higher module temperatures for BIPV testing!

Summary and Conclusions

- Effect of **cell technology** on hot-spot temperature
  - Reverse characteristics (V_{br}, bypass diode function)
  - **BC-Full-cell** and **BC-Half-cell modules** have similar hot spot temperatures



- Effect of **string length** on hot-spot temperature
  - Shorter string → less negative reverse voltage, less heating for PERC
  - **BC modules?**



- **Sufficiency of HS test for BIPV** in terms of testing temperature
  - 15° C higher module temperature for Level 1 & 2 in IEC TS 63126:2020

Hot-spot Endurance Test	IEC 61215-2:2021 (2016)	Level 1 (70°C < T_{98} ≤ 80°C)	Level 2 (80°C < T_{98} ≤ 90°C)
IEC TS 63126:2020	55±15°C (50±10°C)	60±10°C	70±10°C
Proposal of this study	55±15°C	*75±15°C*	*85±15°C*

SUPSI

Thank you for your attention!

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SUPSI PVLab and **SUPSI ISAAC Engineering team** researchers and personnel

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

Schweizerischer Nationalfonds
Fonds national suisse
Fondo nazionale svizzero
Swiss National Science Foundation

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E. Özkalay et al., The effect of partial shading on the reliability of photovoltaic modules in the built-environment, EPJ Photovoltaics 15, 7 (2024)