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TEMPERATURE COEFFICIENTS OF N-TYPE BIFACIAL SILICON PV MODULES UNDER NATURAL AND SIMULATED SUNLIGHT

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ESTI European Solar Test Installation

European Commission

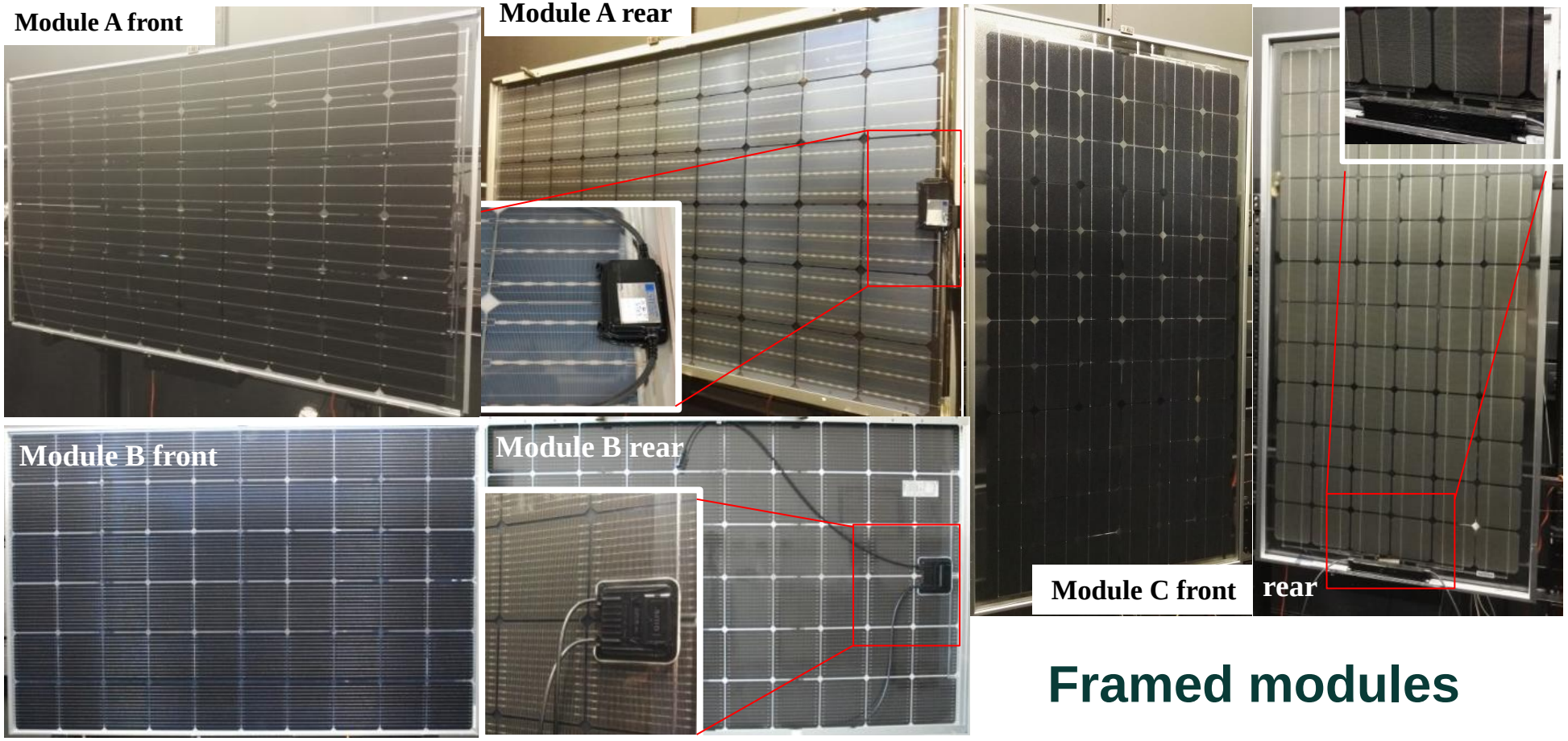
Outline

- ESTI
- Introduction
- Experimental details
- Results and discussion
  - Temperature distribution
  - Temperature coefficients: Front and rear / indoor and outdoor measurements
  - Comparison with datasheet
  - Effects of opaque or reflective rear cover
- Conclusions

Introduction

- **Bifacial modules**: both sides of the cell/module absorb solar radiation, using scattered light from ground and surroundings.
- Indoor measurements under standard test conditions (STC) to assess their performance and quality
- No standards for bifacial modules (draft IEC 60904-1-2): difficult direct comparison between bifacial manufacturers.
- Dependency of the performance of photovoltaic modules on temperature: **temperature coefficients (TC)** ⇒ required for accurate yield estimations and modules energy rating.
- Manufacturer datasheet only declare the TC for the front side.
  - Check influence of measurement or module conditions and characteristics on TC ⇒ Indoor and outdoor determination of front and rear TC of c-Si bifacial PV modules: 5 different manufacturers.

Experimental details: module characteristics

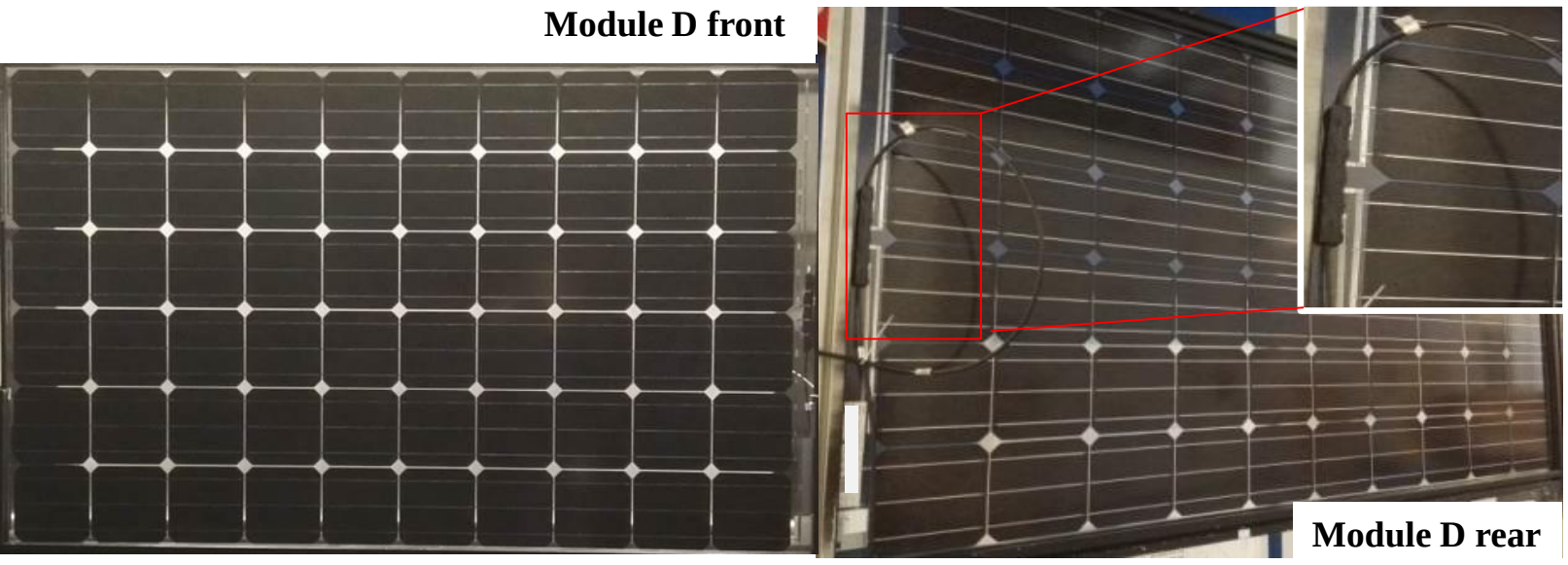


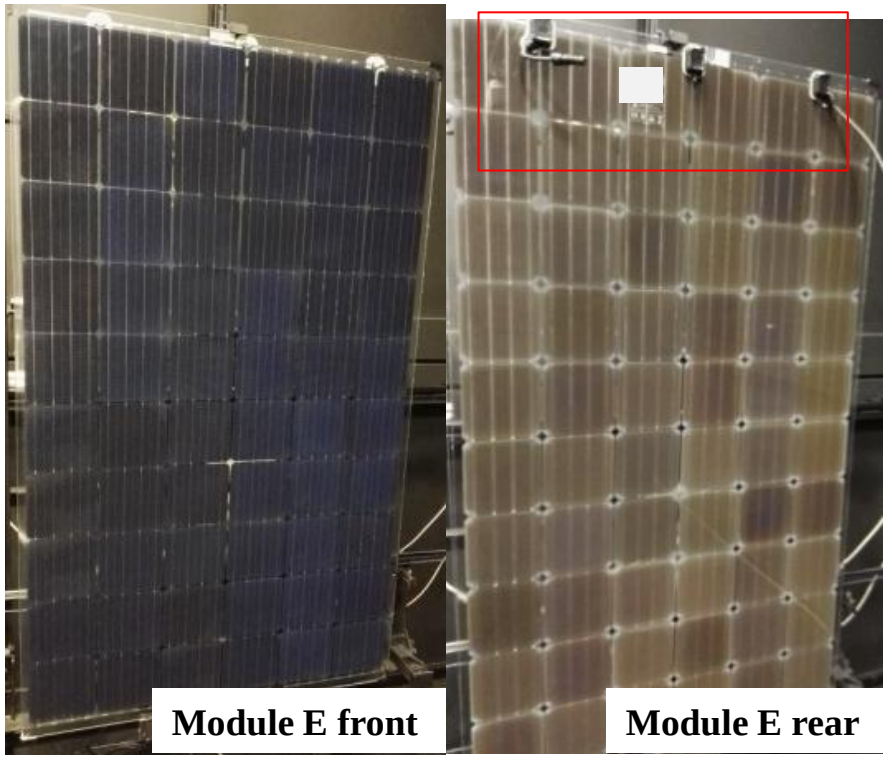
Framed modules

- Module **C**: wider edge spacing → rear cells **not shaded** by the frame or the junction box.

- Module **A** and **B**, **cells** partially **covered** by a lip of the frame and junction boxes.
- PERC/n-PERT and HIT technologies

Experimental details: module characteristics



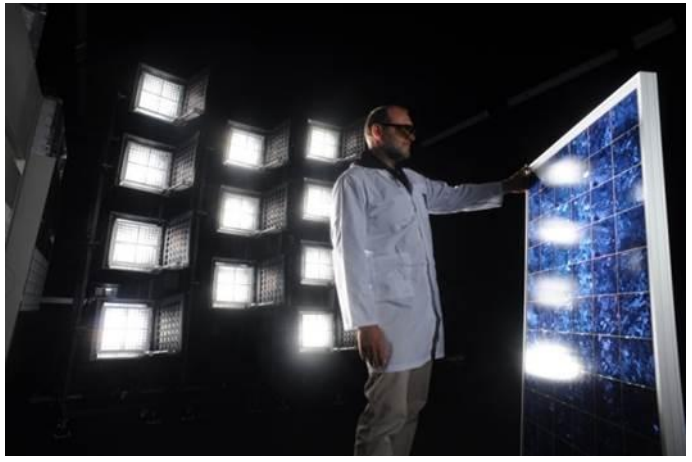


Frameless modules

- Module D: narrow junction box not covering the rear side of the cells.
- Module **E**: 3 junction boxes and label **covering partially cells** in the 3 strings.
- PERC and n-PERT technologies

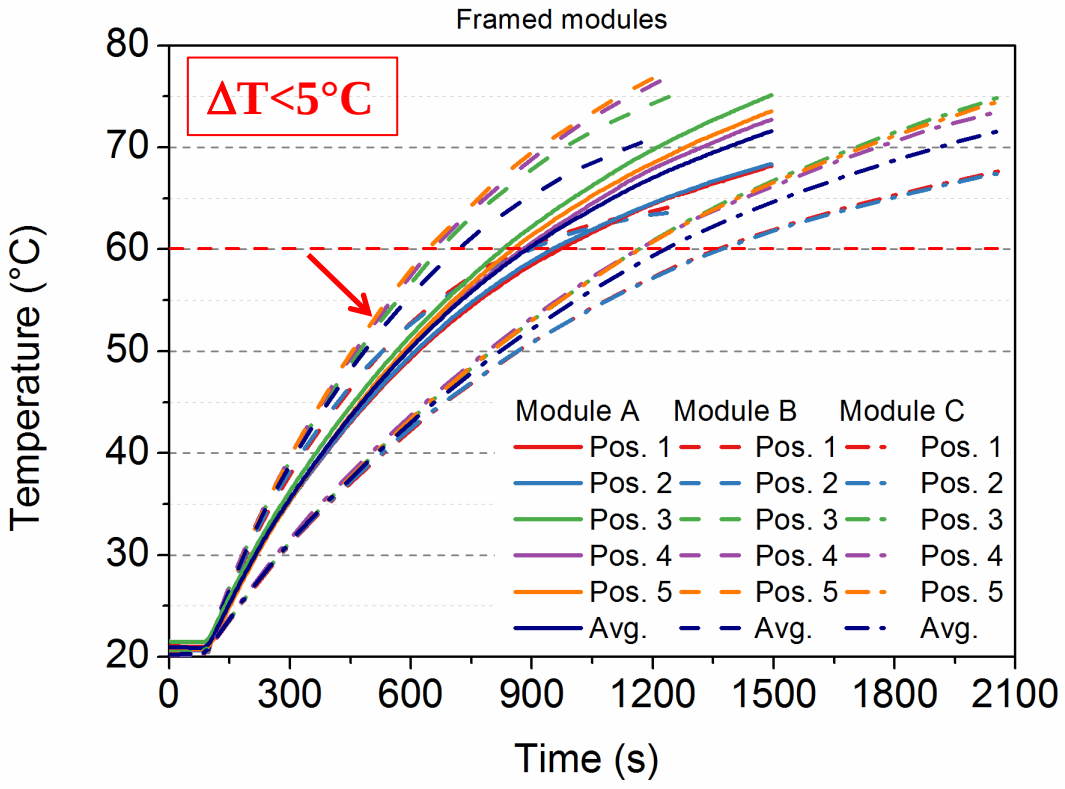
Experimental details: I-V measurement setup.

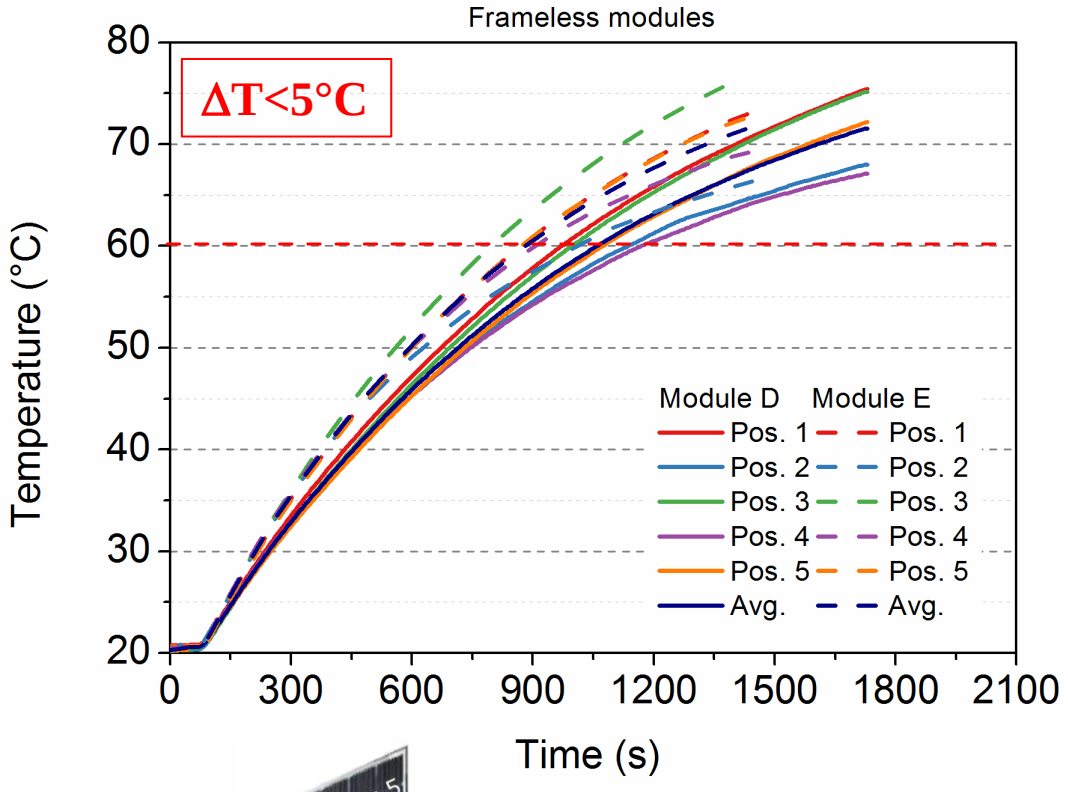
- Large-area (2x2 m^2) continuous or **Steady state** solar **simulator** (sweep times ~1 sec class AAA)
- **Natural sunlight** in **outdoor** conditions
- Module **heated due to the radiation**: T° range of at least 30°C according to IEC 60891.
- **Rear cover** same dimensions as module
- Placed in direct contact to non-illuminated surface
  - **Black** (non-reflective) painted panel (R<4.5%)
  - Gloss **white** reflective panel (R>93%)



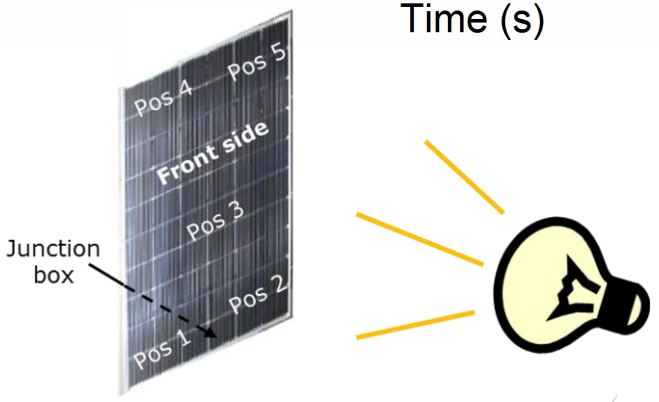
ESTI P_{max} uncertainties for steady state and outdoor system: 1.7%

Results and discussion: temperature distribution

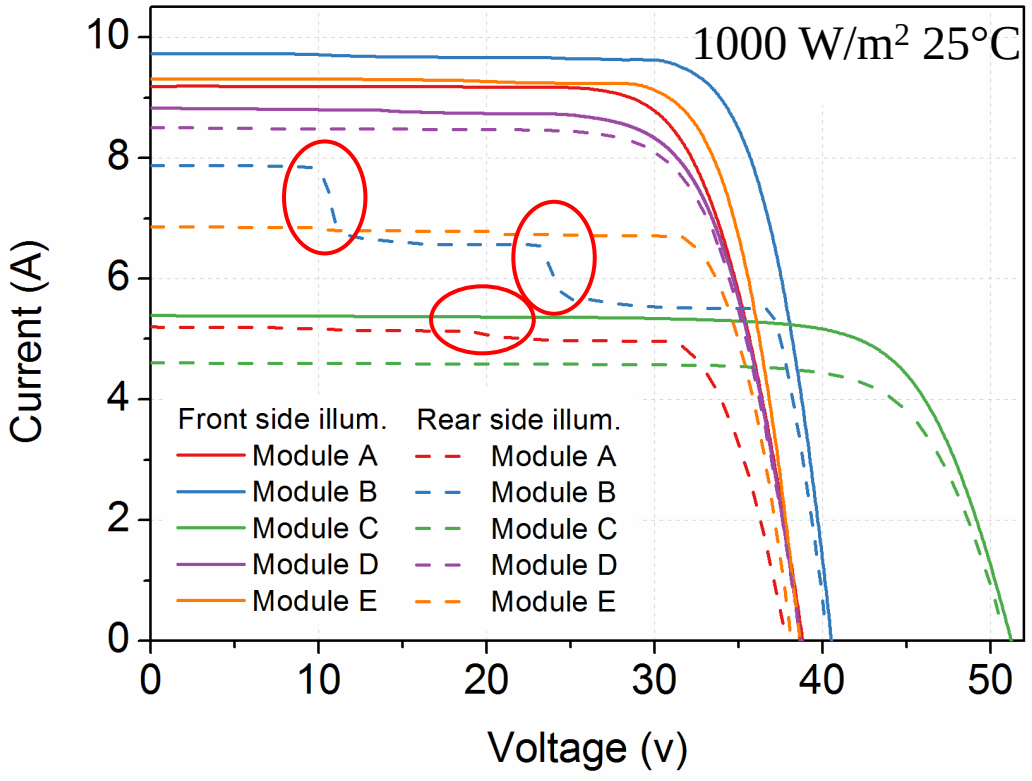




- glass/foil, required less time to increase the T° than the more massive glass/glass modules
- **ΔT<5°C** for temperature coefficient measurements range



Results and discussion: I-V measurements STC



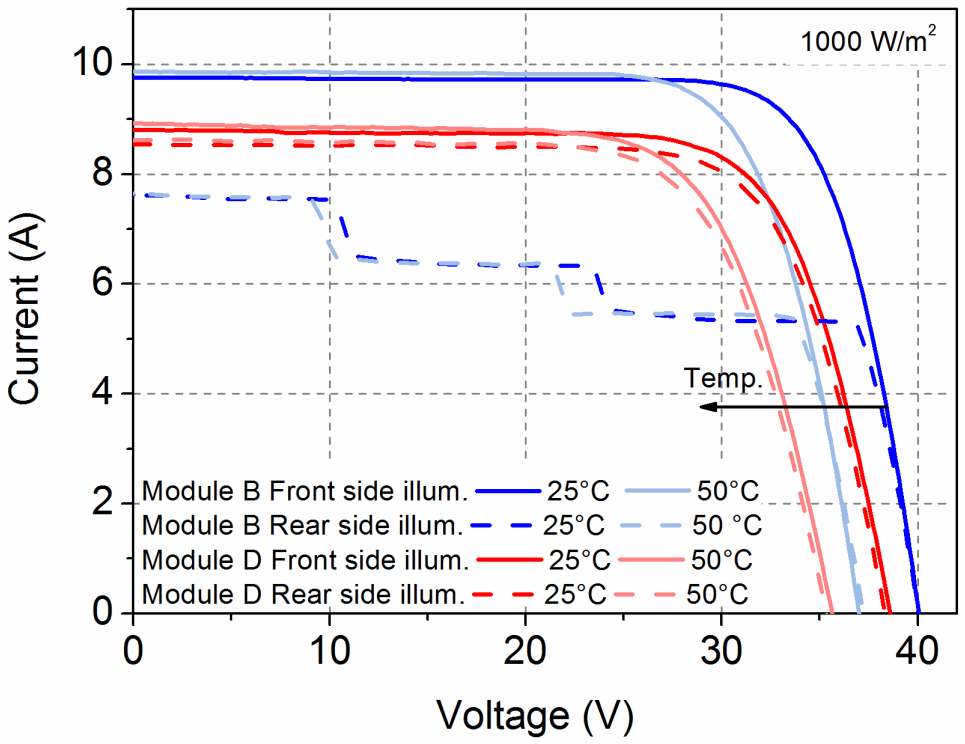
- Modules **A, B and E** show up to three **kinks** in the **rear** I-V curves due to partial shading by frames and junction box
- decrease rear I_{mpp} and P_{max}.

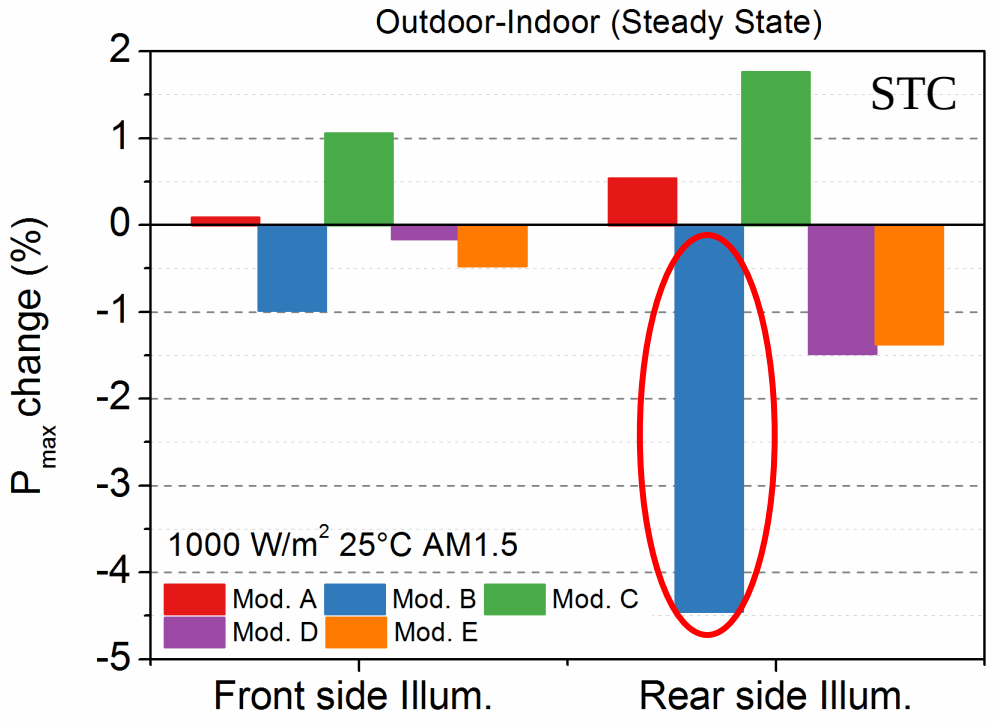
Module	Frame	φ_{Pmax} (%)	N° Cells
Module A	Yes	58	60
Module B	Yes	66	60
Module C	Yes	86	72
Module D	No	97	60
Module E	No	76	60

$$\text{Maximun power Bifaciality } \varphi_{Pmax}\ (\%) = \frac{P_{\text{max REAR}}}{P_{\text{max FRONT}}} \times 100$$

$$\text{Short circuit current Bifaciality } \varphi_{Isc}\ (\%) = \frac{I_{sc\ \text{REAR}}}{I_{sc\ FRONT}} \times 100$$

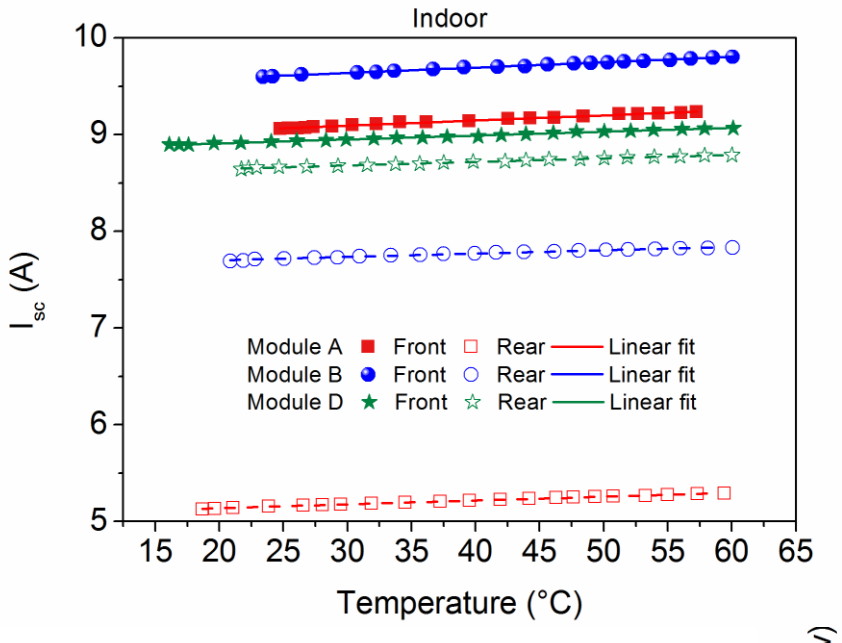
Results and discussion: I-V measurements STC



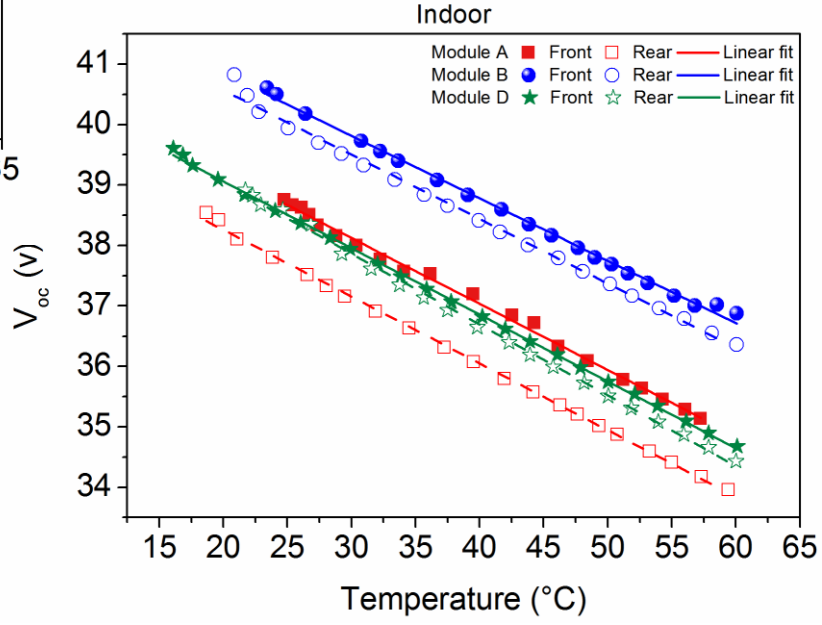


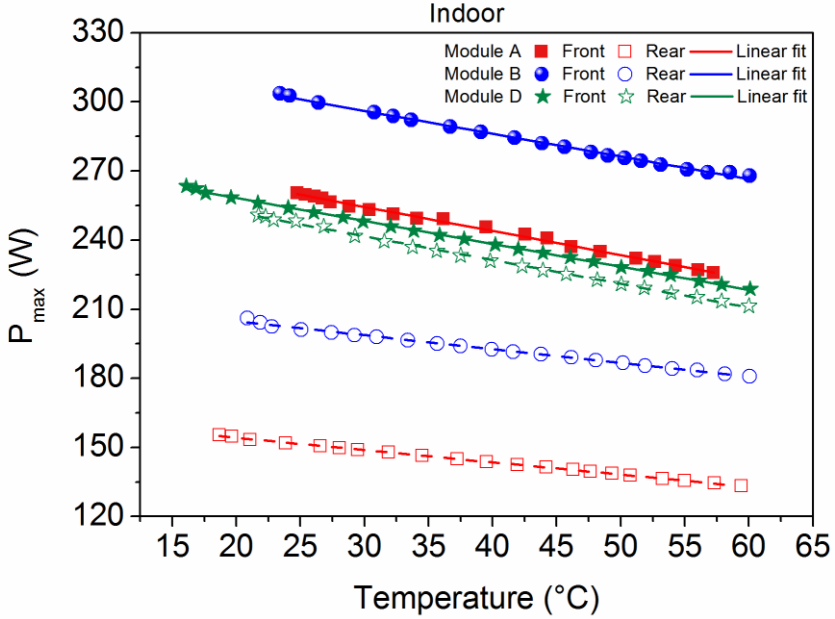
- Under STC conditions, differences below ±1% between the P_{max} measured indoor and under natural sunlight (front side illuminated).
- Slightly higher differences for module B for rear side (effect of the module design)

Results and discussion: Temperature dependency electrical parameters



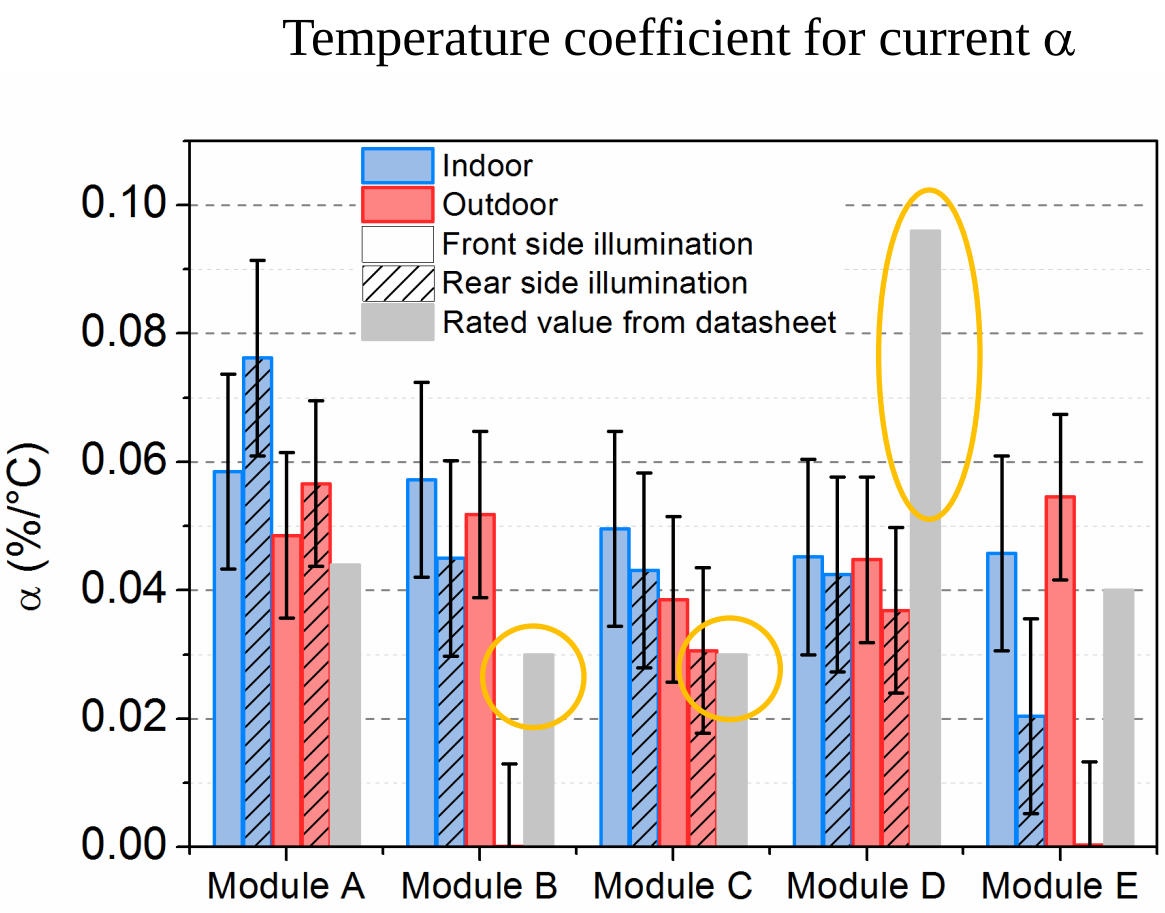
- Slightly linear increase in I_{sc} with temperature for both side of the module.
- V_{oc} and P_{max} shows a linear decrease with temperature.





- TC for current, voltage and power calculated form the slope of the curves.

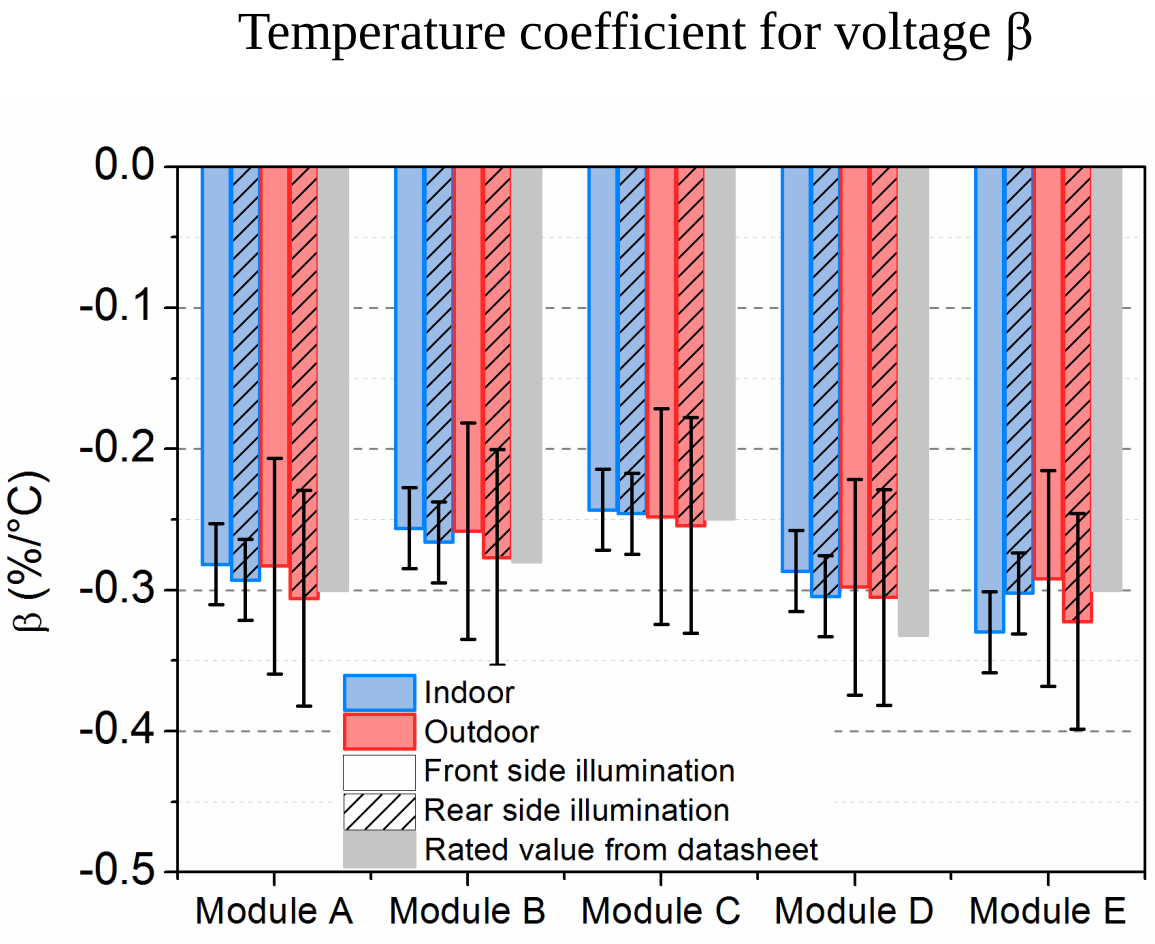
Results and discussion: temperature coefficient for current α



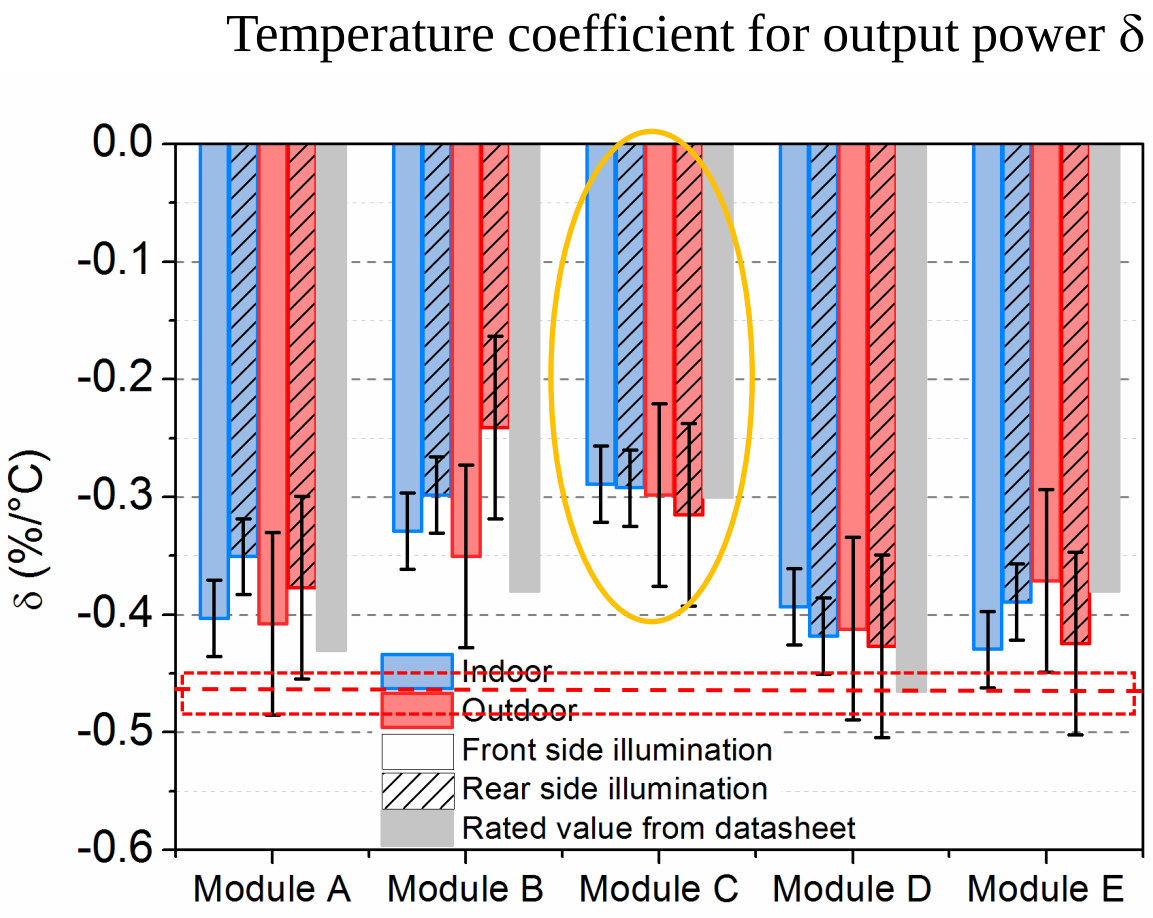
- In general, variation for front and rear both indoor and outdoor measurements within the uncertainty.
- Near zero TC for rear side in outdoor condition for mod. B and E
- Disagreement between datasheet and front side indoor and outdoor measured values:
  - However, manufacturers do not declare the uncertainties in TC → difficult comparison

Results and discussion: temperature coefficient for current β

- Similar β coefficients for front and rear side of the modules.
- No significant differences between indoor and outdoor measurements.
- β in good agreement with the datasheet values given by the manufacturers.

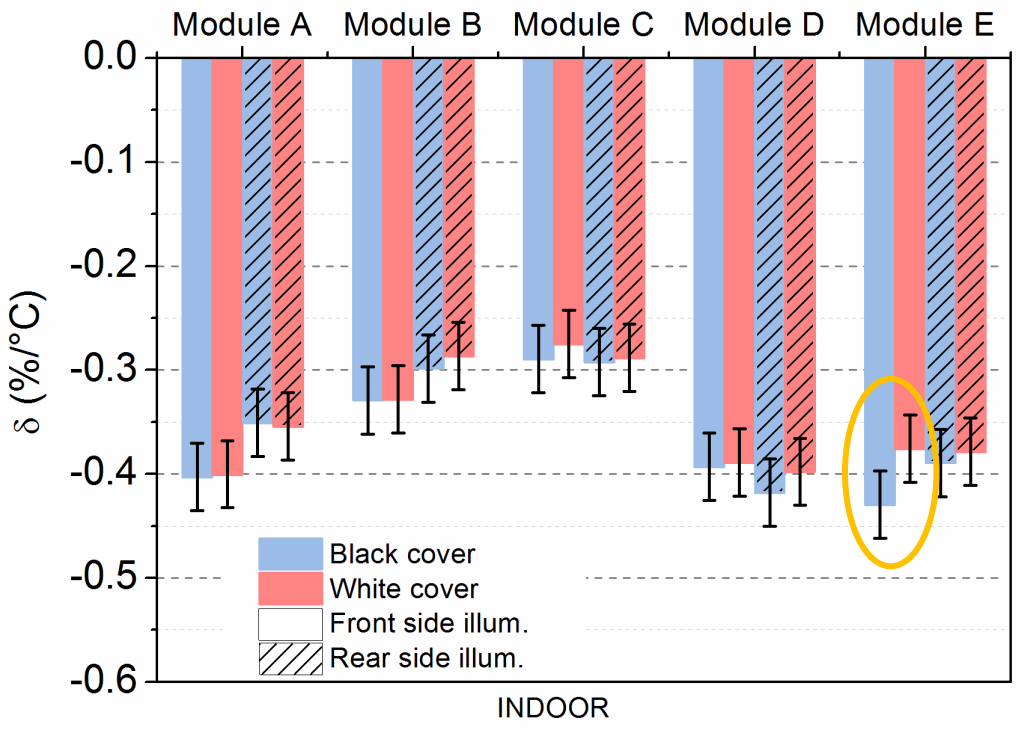


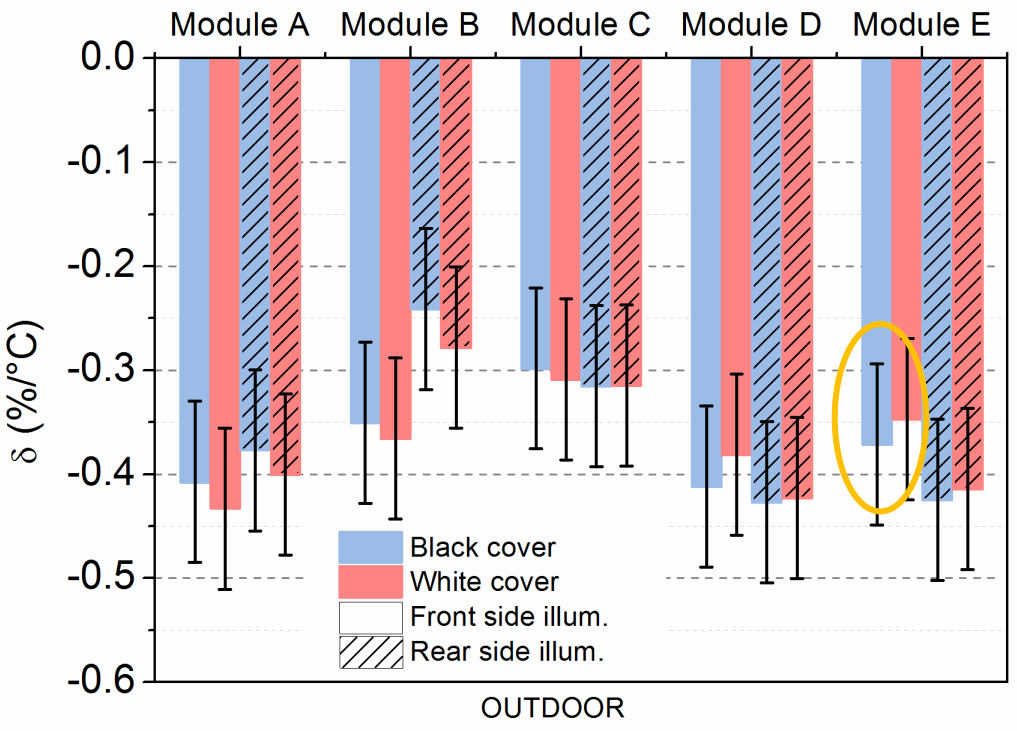
Results and discussion: temperature coefficient for current δ



- Similar TC δ for front and rear side.
- Similar indoor and outdoor measurements values.
- Slight divergence between ESTI measured front TC δ and manufacturer datasheet value
  - TC uncertainties not declared by manufacturers: difficult comparison with the measured values and energy forecast.
- Monofacial c-Si cells:
  - Avg. TC δ -0.463±0.016 %/°C for 33 poly and mono c-Si modules tested at ESTI
- TC δ technology dependent (HIT lowest)

Results and discussion





- Differences in TC δ <-5% for indoor and ±7% outdoor (higher P_{max} for reflective cover) between the black and white covers.
- No significant differences between black and with cover

Conclusions

For I-V measurements:

- Influence of junction box, nameplate and frame location on I-V curves of the rear side: partial "self-shading" leading to kinks in the I-V curves reducing rear I_{mpp} and P_{max}
- In agreement with IEC 60904-1-2, parasitic reflections from the rear side of the PV module increase P_{max} and then the uncertainty in measurements.
  - use of non-reflective rear material is recommended to obtain reproducible and reliable results.

For Temperature coefficients:

- **No** significant **differences** between **front and rear TC** for a particular technology or design.
- Both **indoor and outdoor** methods yield approximately **equal TC**: the difference is the uncertainty associated.
- **ESTI and manufacturer** datasheet TC **similar** β and δ values:
  - However, manufacturers should **declare** the **TC uncertainties**
- Even if indicated in IEC 60904-1-2 for I-V measurements, Opaque cover not so relevant for TC
- TC δ more **dependent on technology** than on measurement conditions

Thank you

Any questions?

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Next meeting: 27th PVSEC at Otsu, **Japan** 12-17th Nov 2017 "Electrical performance of bifacial PV Si modules under different indoor settings affecting the rear reflected irradiance" **7MoO.6.5**

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