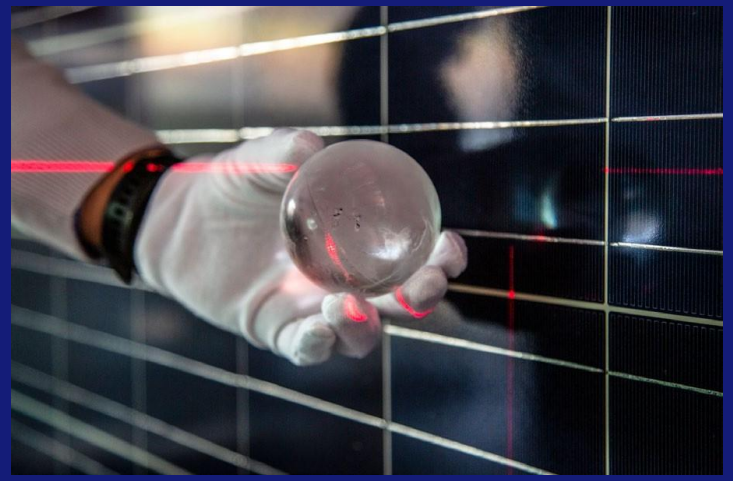
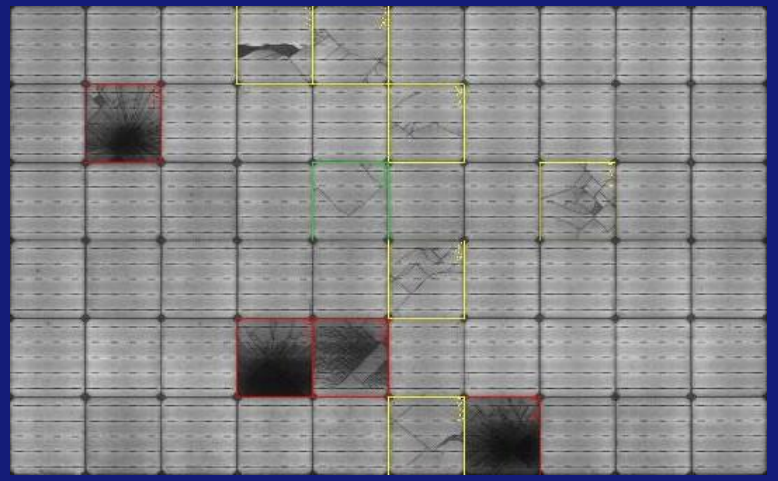
SUPSI PVLab

ACHILLES

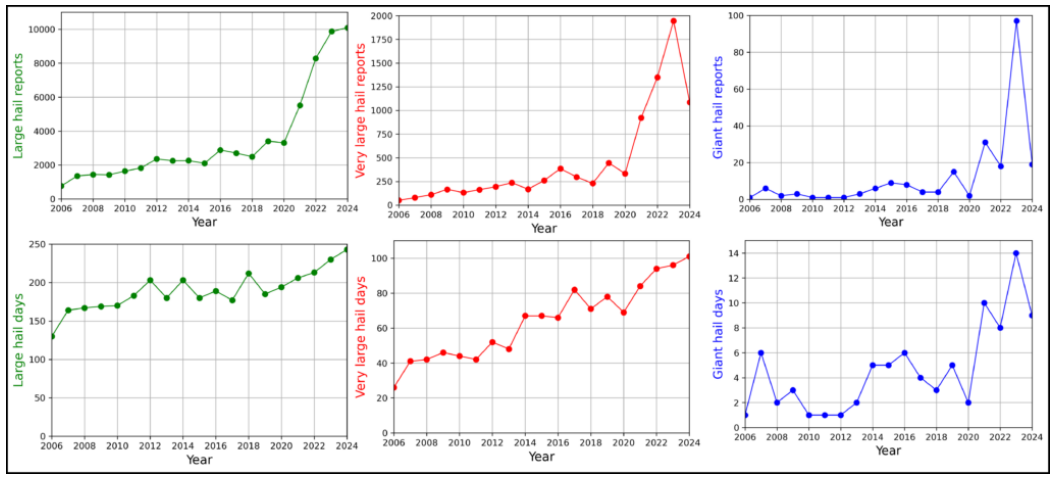
Advanced Characterisation of Photovoltaics for Hail Resistance



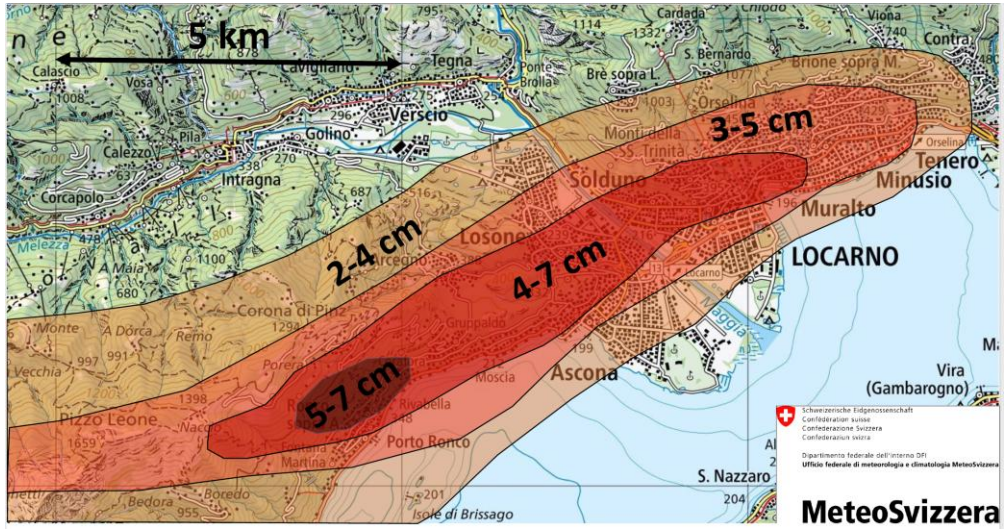


Industry Day 2026
Mauro Caccivio, Dominika Chudy,
21.05.2026, Mendrisio

Hailstorm occurrence



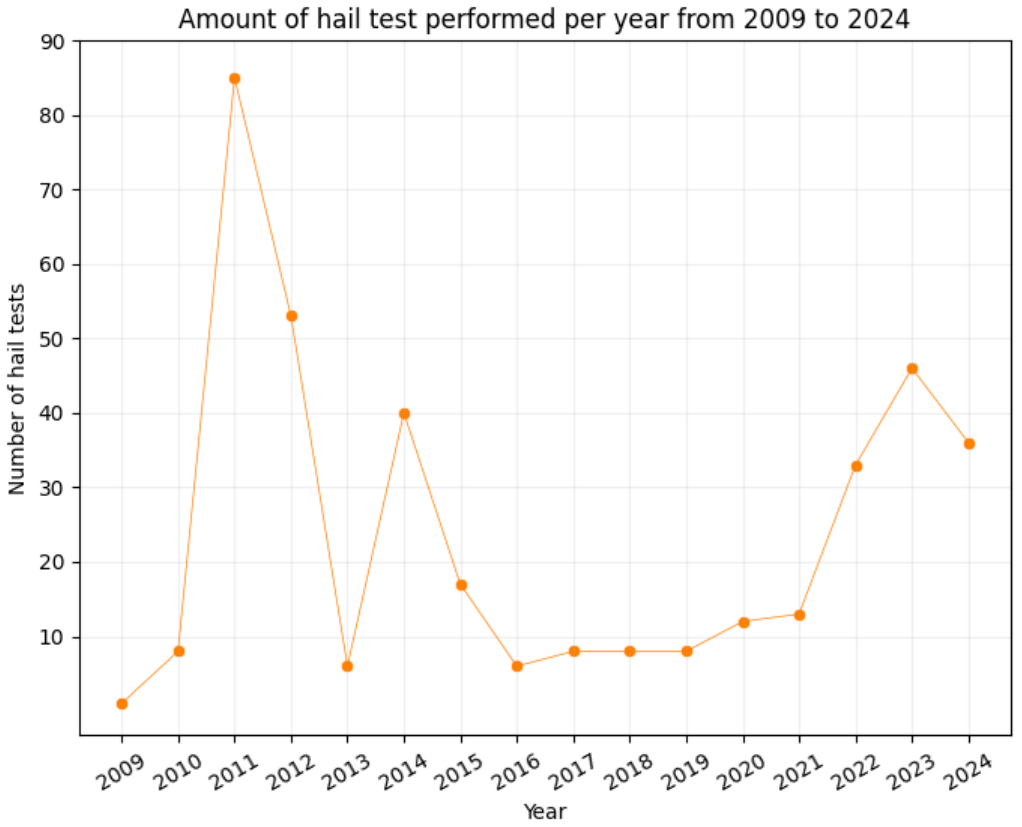
European Severe Storm Laboratory (ESSL) data on large, very large, and giant hail in Europe (2006–2024)



Hailstorm event: Locarno area, August 25, 2023

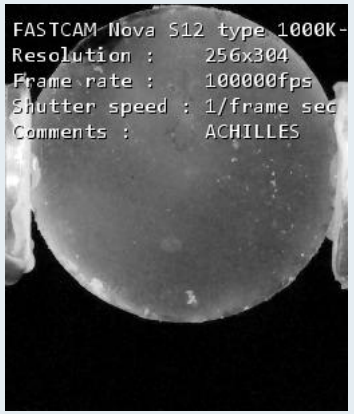
Hail Resistance Test - Historical laboratory data

Standard	IEC 61215 (International)	VKF Hail Test Standard (Switzerland)
Hailstone size	25 mm	30 mm (HW3) 40 mm (HW4, recommended in hail prone areas)
Impact velocity	23 m/s	~21 m/s (HW3, 30 mm) ~27 m/s (HW4, 40 mm)
Ice ball temperature	– 4 ± 2 °C	– 20 ± 3 °C
Test points	11 predefined points	11 IEC points + critical points
Pass criteria	No visible damage, No significant power loss	No visible damage that reduces performance

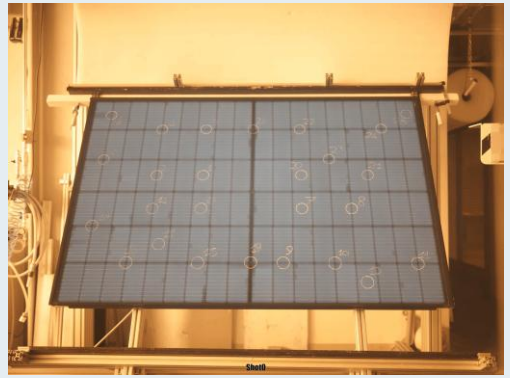


Project collaboration

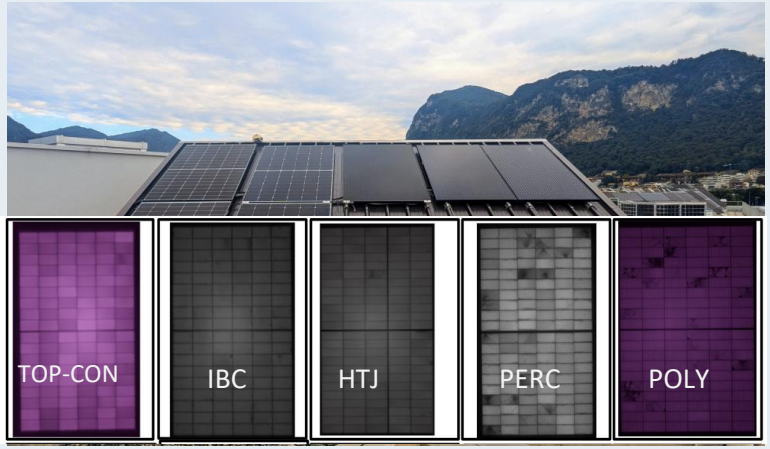
1 Static and dynamic characterisation of ice properties



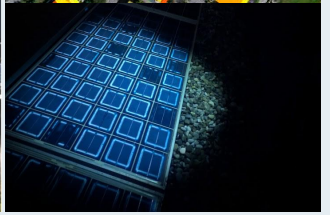
2 Ice impact on rigid target and PV module



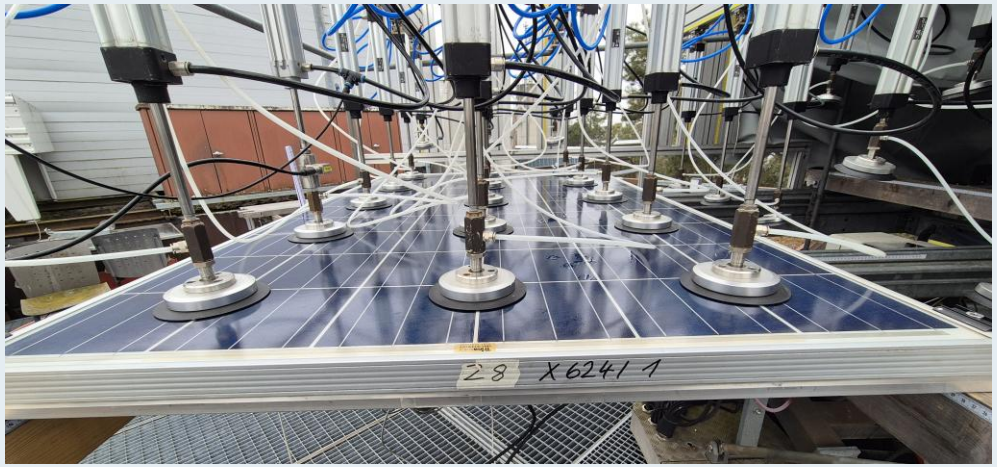
3 Indoor accelerated aging and outdoor monitoring

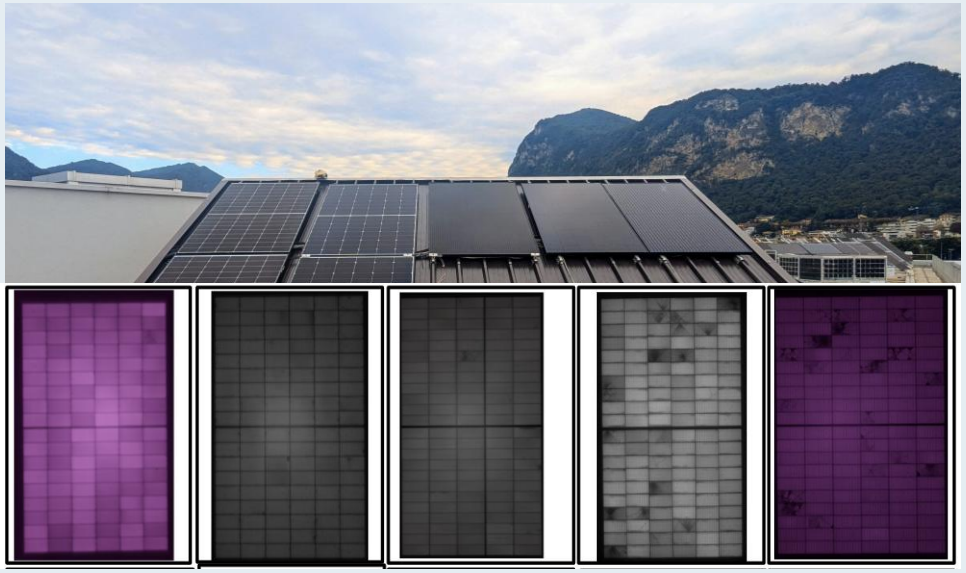


4 Evaluation of PV system performance data



Indoor Accelerated Aging and Outdoor Monitoring





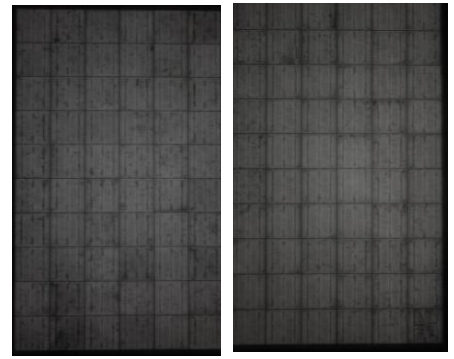
Investigating the propagation and long-term evolution of hail impact-induced defects

Indoor Accelerated Aging - Samples

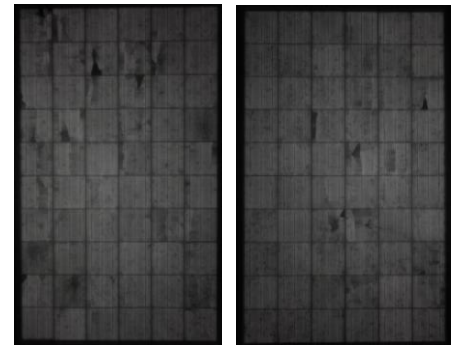
- 7 modules selected
- Module production year: 2013-2015
- PV system installation: 2014 – 2024

	Front glass	Back	s glass [mm]	Pm [W]	Vmp p [V]	Impp [A]	Voc [V]	Isc [A]	Eff [%]
Module nameplate parameters	Tempered	Tedlar	3.2	260	30.6	8.50	38.2	9.00	15.9

- Modules with minor initial cracks



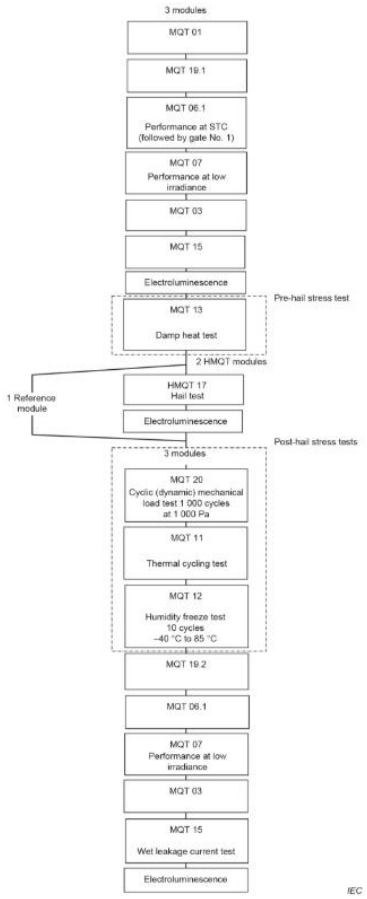
- Modules with major initial cracks



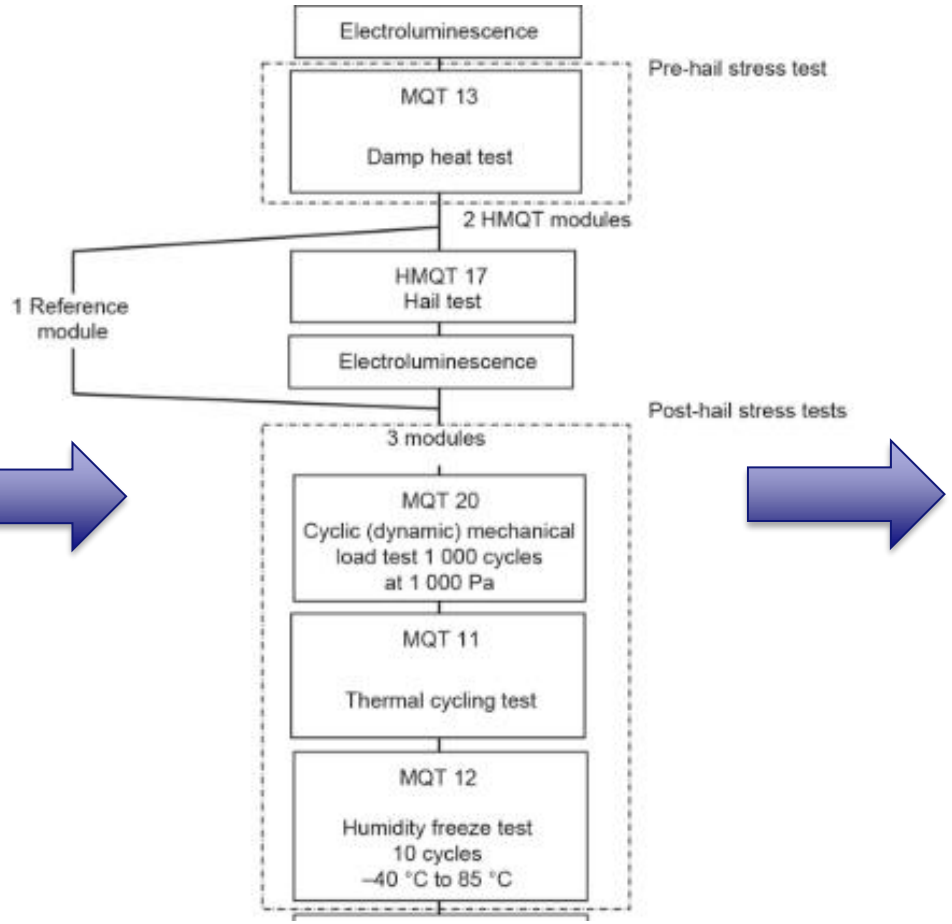
- Modules with significant dark cell areas

- Module with concentrated HAIL impact

Indoor Accelerated Aging



IEC TS 63397:2022
Test flow



IEC TS 63397:2022
Selected part of the test flow

Adapted Protocol
HAILSTORM-DAMAGED MODULES

Initial characterization
Visual, IV (Pmax at STC and Low) ,EL
+ Wet leakage current test

Cyclic (dynamic) mechanical load test (1000 cycles at 1000Pa)
Characterization: Visual, IV, EL

Thermal cycling test (50 cycles)
Characterization: Visual, IV, EL

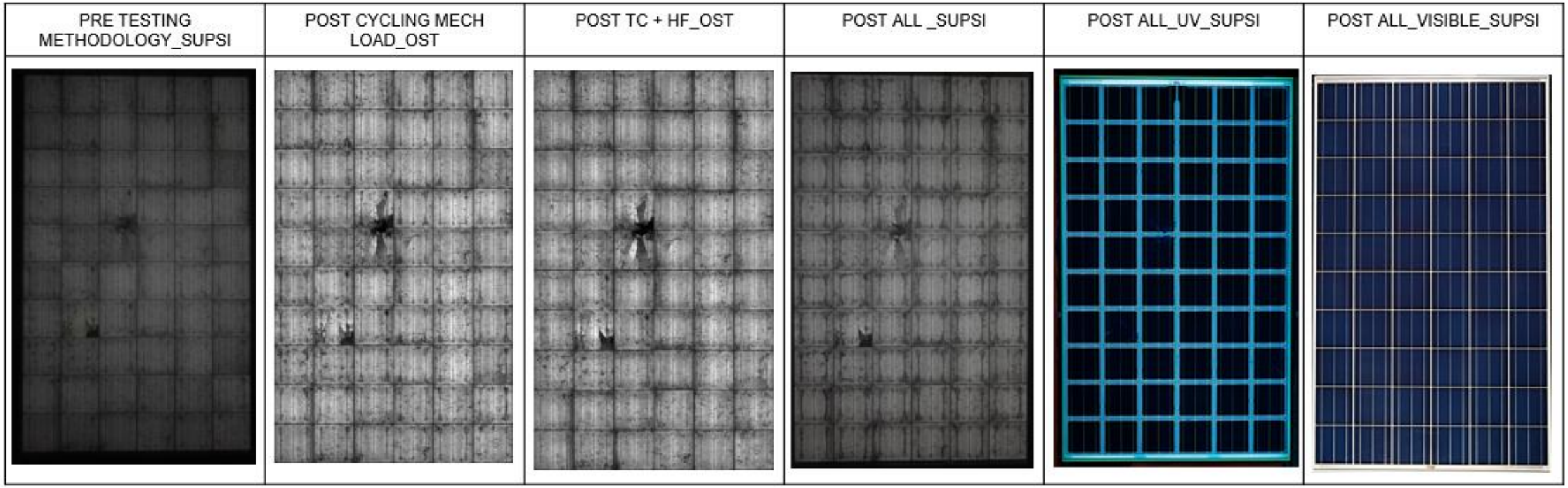
Humidity Freeze (10 cycles)
Characterization: Visual, IV, EL

Final characterization
Visual, IV (Pmax at STC and Low) ,EL, wet leakage current + UV fluorescence imaging (UVF)

IEC TS 63397:2022 – Modification made for the study

Indoor Accelerated Aging

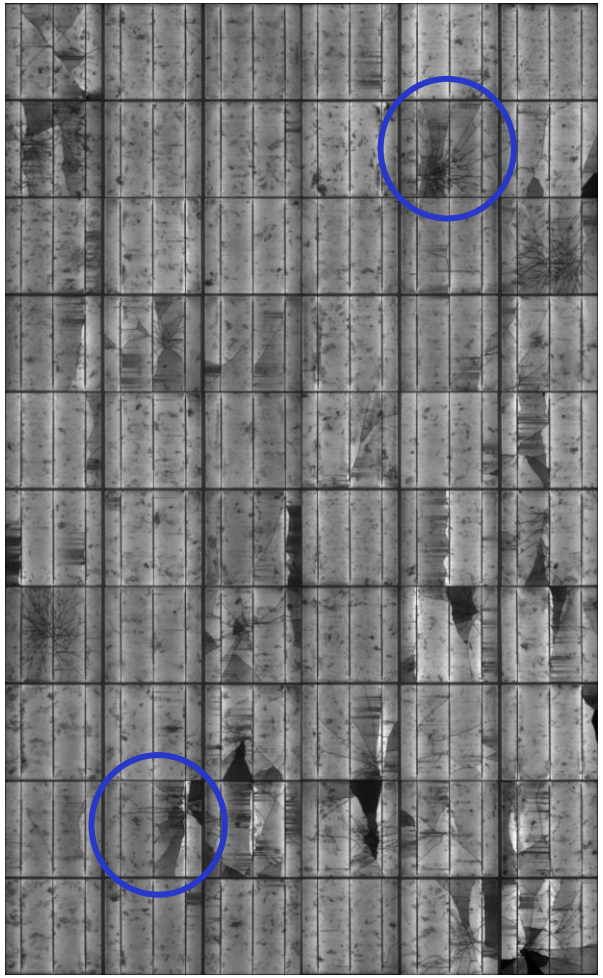
Module with concentrated impact

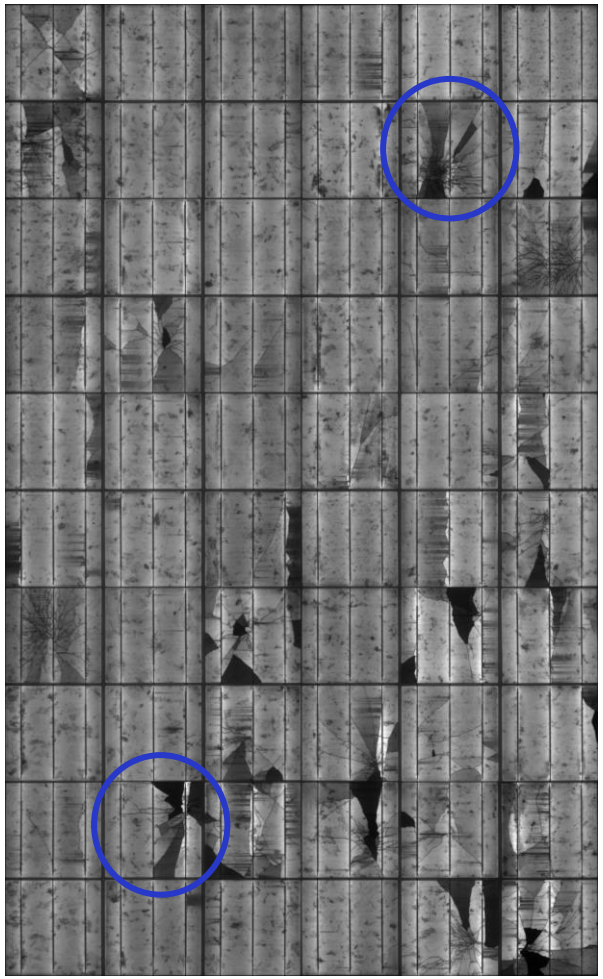


Characterisation: EL, IV, UVF, Visual inspection

Indoor Accelerated Aging

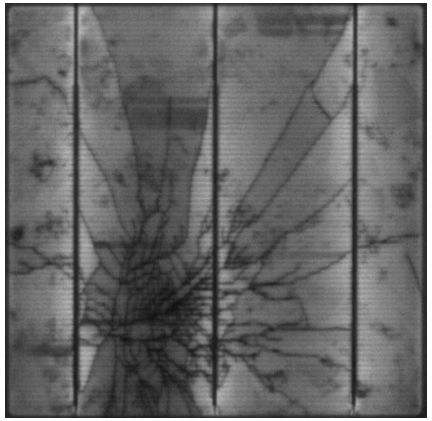
Cycling dynamic mechanical load test (1000 cycles at 1000 Pa)

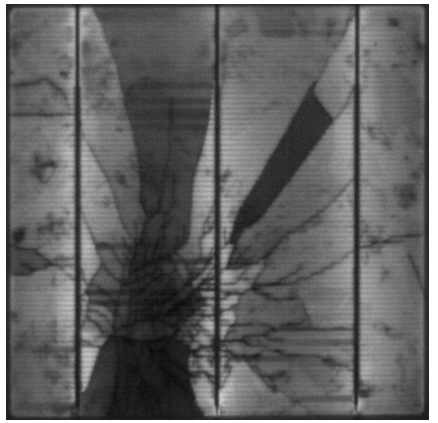


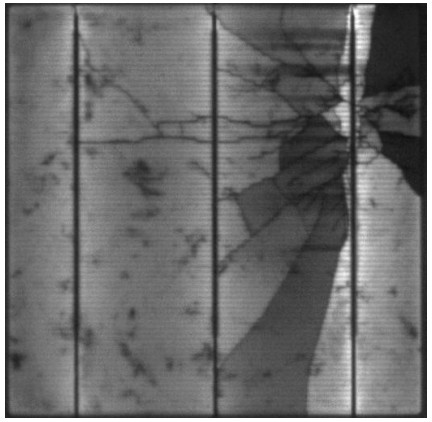


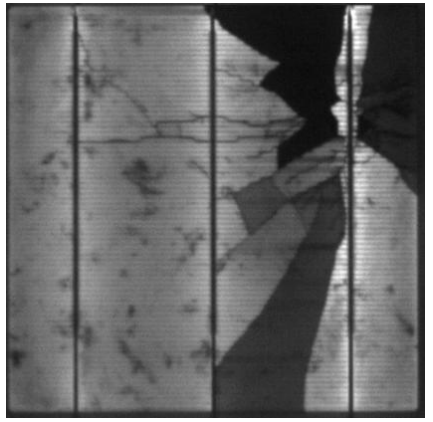
INITIAL

AFTER CDML



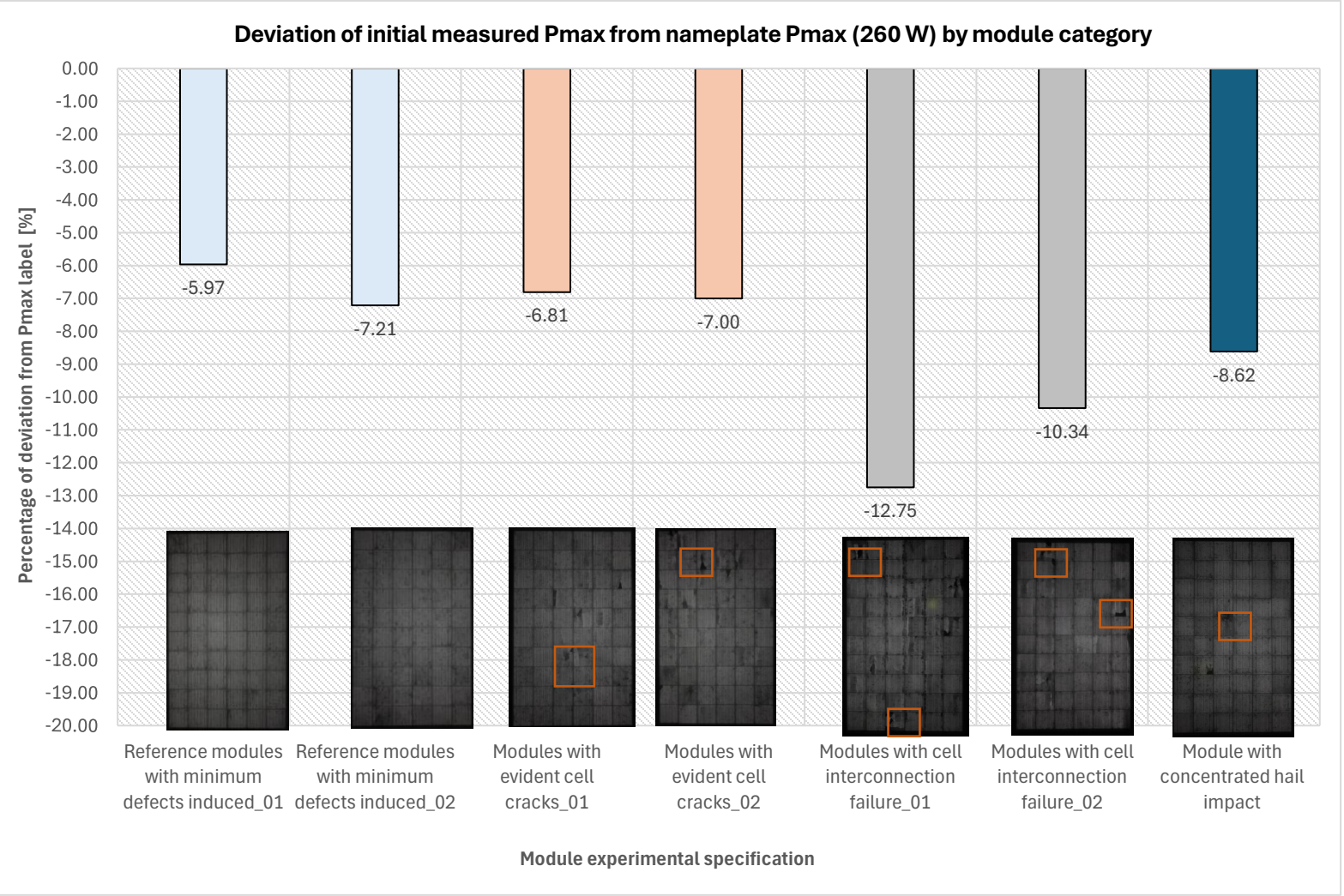






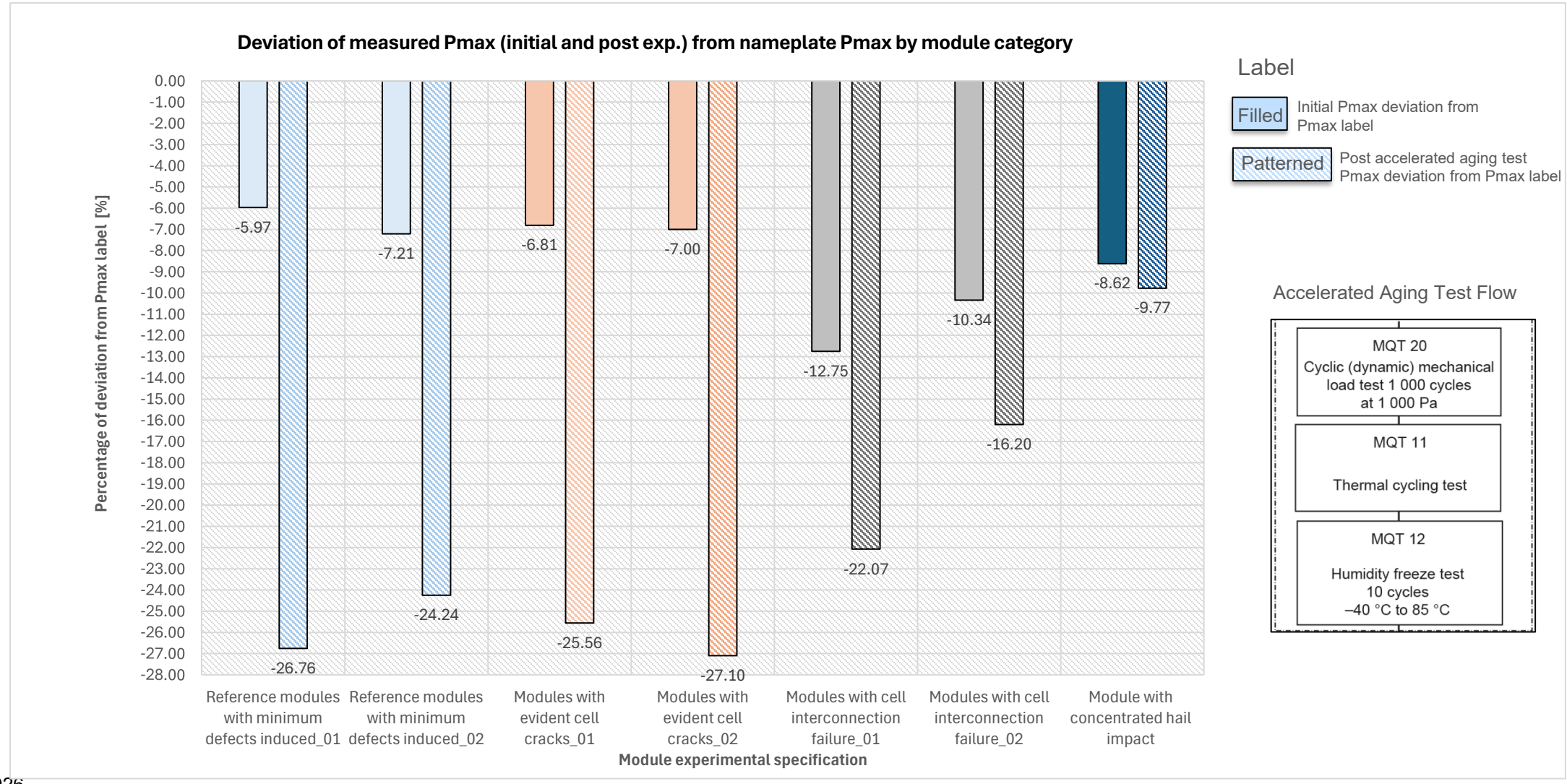
Indoor Accelerated Aging

Initial module deviation from Pmax nameplate



Indoor Accelerated Aging

Module deviation after accelerating aging test sequence



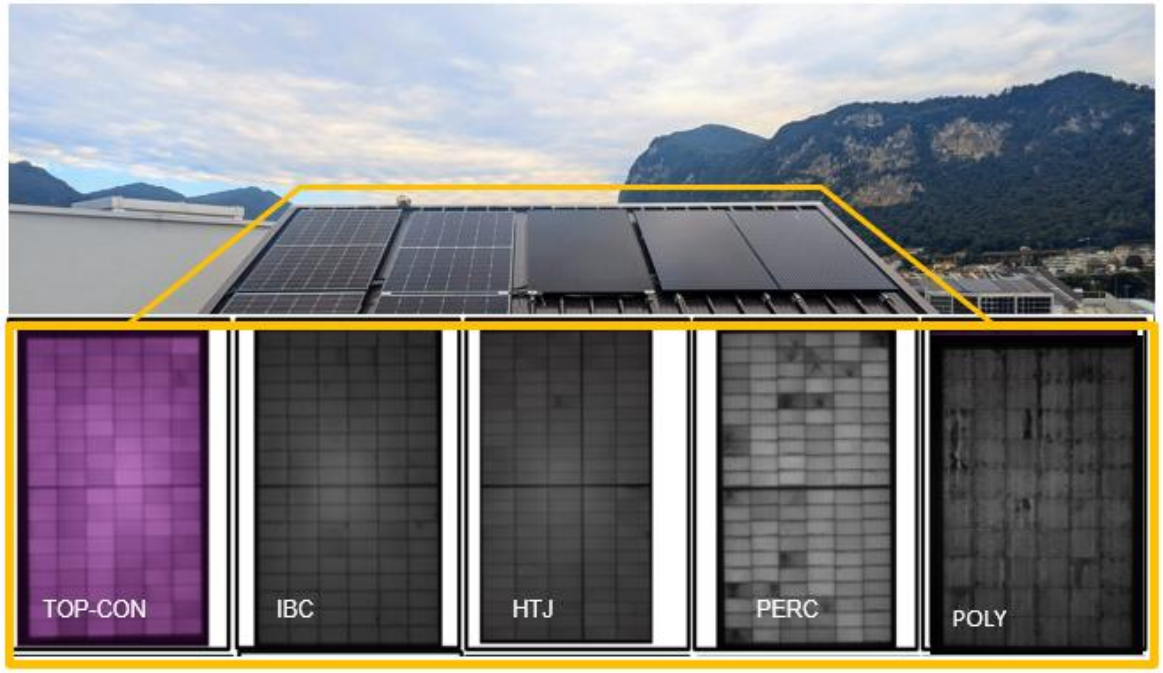
Conclusions

- Hail-induced microcracks are not only an immediate mechanical defect, but a long-term reliability risk for PV modules.
- Accelerated aging tests showed that environmental stressors amplify degradation after hail impact.
- Microcracks remained physically stable, but acted as capillary pathways for moisture penetration.
- Moisture ingress combined with thermal and mechanical stresses caused severe power degradation.
- 6 of 7 tested modules exceeded IEC acceptable power-loss limits (>17% power loss).
- The key finding: the major threat in hail-damaged PV modules is not the initial impact itself, but the accelerated secondary degradation driven by environmental aging.

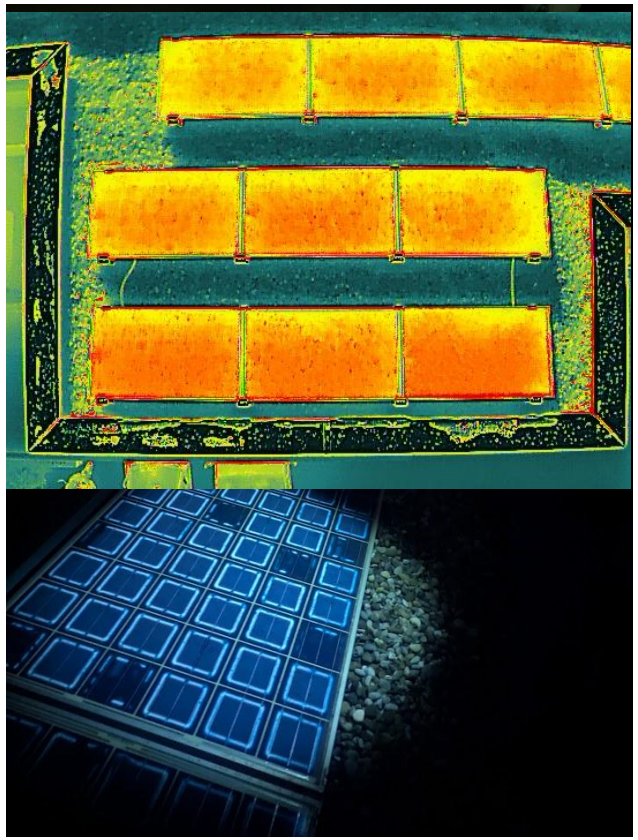
Outdoor Monitoring

- Long-term monitoring of performance and degradation of PV modules collected after hail events, representing five different module technologies, under outdoor conditions at two test sites (Mendrisio and Rapperswil).

- Investigation of 15 PV systems affected by an extreme hail event in collaboration with the CASSANDRA project.



Monitoring parameters
Modules were collected after severe hailstorm in the Locarno area.
Top row shows hail-damaged PV modules, while the bottom row presents corresponding new reference modules of the same technology.
Installed on a corrugated roofing system solution.



- After one year of monitoring, laboratory power measurements indicate less than 5% Pmax degradation in hail-damaged modules.
- The monitoring campaign is ongoing

ACHILLES Project Outcomes

- **Guidelines for Stakeholders**: Create a decision guideline for inspectors, insurers, and installers.
- **Hail Damage Assessment**: Detect and classify defects caused by hail damage.
- **Accelerated Aging Simulation**: Predict long-term effects of hail damage under real-world conditions.
- **Annual Technology Updates**: Yearly technology updates to ensure that assessment criteria remains relevant with the latest PV technologies.

Thank you for your attention!

Acknowledgement:

Special acknowledgment goes to the Swiss Prevention Foundation (VKF – Vereinigung Kantonaler Feuerversicherungen) for the financial support of the ACHILLES project.