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D5.5 Definition of monitoring plans for Kubik building and outdoor mock-ups and test benches

T5.4 Outdoor performance validation testing activities to support market strategy and development.

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"Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs implementation"

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Summary

In the frame of Task 5.4 (Outdoor performance validation testing activities to support market strategy and development), D5.5 focuses on definition of monitoring plans for Kubik building and outdoor mock-ups and test benches. These elements are included in this report for a better overview even though they do not constitute the chore of this deliverable.

This report falls within the context of deliverable D5.6 (Report on outdoor testing activities), conducted as a preliminary work of the T 5.4. While experimental building are providing privileged experimental platform to demonstrate a TRL6 for the project technologies as well as integration, installation methodologies and maintenance procedures, the experimental building (TECNALIA) and the outdoor monitoring activities (CSTB, SUPSI, EURAC), will focus on energy performance and definition or testing procedure allowing to measure and to assess relevant performance indicators. Given the fact that every partner is using internal monitoring systems, an in-depth identification and analysis of current used systems is conducted. Then identification of "Primary level data" according to requirement of standard IEC 61724 (Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis) is carried on harmonizing data collection, post treatment analysis and determination of energy performance. In parallel harvesting of "secondary level date", dependent or specific to each experimental building is also carried on, in order to duplicate dependent sensors on mock-ups and facilities.

The experimental building (TECNALIA) and the outdoor monitoring activities (CSTB, SUPSI, EURAC), together with the products to be tested at each site, have been described in Sections 2-3-4 and 5. The activity will be coordinated by CSTB. The product prototypes, mounting instructions, etc. will be provided by ONYX, TULIPPS, FLISOM, PIZ and SCHWEIZER (WP3,4).

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1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

This document contains all details concerning monitoring solutions implemented by the four partners involved in WP5, Task 5.4 activity related to outdoor testing activities aimed to assess performance of the BIPV solutions developed in the project.

All information details are provided by partners, EURAC, SUPSI, TECNALIA and CSTB. All of them have specific mock-ups which are compliant with national regulatory requirements. Based on this recognition some specificities test conditions, with specific measurement and data acquisition systems could be presented.

In the first part of the report, a full description of facilities from each partner test site, including BIPV layout, construction solutions and equipment are provided. In addition, a full description of monitoring system implemented is presented, including weather, energy and thermal data, with a complete description of used sensors.

In the second part, as annex, requirements of EN-61853 standard are reported as reference for further investigations and next research steps.

The full list of setups is filled in the following table with the description of all PV technologies applied including the integration solution.

Table 1: Identification of BIPV solutions and testing location

Partner Facility	Manufacturer(s)	BIPV Solution
CSTB	ONYX	Canopy
	FLISOM, PIZ	ePIZ - CIGS version
	FLISOM, SCHWEIZER	CIGS + Solrif
	ONYX, PIZ	ePIZ -c-Si version (rain test)
EURAC	ONYX, TULIPPS	a-Si patterned + lock-&-go
	ONYX, TULIPPS	Opaque c-Si + lock-&-go
SUPSI	ONYX	Bifacial balustrade
	ONYX, PIZ	ePIZ - c-Si version
	FLISOM, SCHWEIZER	CIGS + Solrif
TECNALIA	ONYX	Curtain wall - Back-contact

Each facility is located in a different geographical location with different weather conditions allowing to assess all the BIPV solution in different weather surroundings. A complete description of every experimental site is provided in the following chapters including climate description, monitoring solution and mock-ups definition.

1.2 Relation with other activities in the project

Table 2 depicts the main links of this deliverable to other activities (work packages, tasks, deliverables, etc.) within BIPVBOOST project. The table should be considered along with the current document for further understanding of the deliverable contents and purpose.

Table 2 : Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
WP3, Task 3.5	Manufacturing of glass-glass modules for indoor and outdoor testing
WP4, Task 4.6	Prototypes manufacturing for indoor and outdoor testing (WP4)

1.3 Reference material

D3.2: Low cost a-Si patterned glass-glass BIPV modules samples. Cost parity with digitally printed glass.
D3.3: Low cost bifacial cell modules for integration in balustrades. Overcost limited to 100 €/m2 regarding non-PV equivalent products.
D3.4: Low cost back-contact cell modules for walkable floors and curtain wall integration at 275 €/m2 as target
D3.5: Glass-glass modules samples for indoor and outdoor testing activities.
D4.1: Functional samples of multifunctional BIPV façade cladding system with integrated insulation complying with specifications
D4.2: Functional samples of cost-effective roof systems complying with specifications
D4.3: Functional samples of cost-effective façade systems complying with specifications
D4.6: Façade and roof prototypes for indoor and outdoor testing

1.4 Abbreviation list

APP – Agence pour la Protection des Programmes (Programme Protection Agency (France))
AR – Augmented Reality
a-Si – amorphous Silicon
BB - Busbar
b-c – back-contact cell
BIM – Building Information Modelling
BIPV – Building Integrated Photovoltaic
CIGS – Cadmium Indium Gallium Selenide
CII – Computer Implemented Invention
CMS – Content Management System
c-Si – crystalline Silicon
EPC – European Patent Convention
EPO – European Patent Office
ER – Exploitation Result
ESCOs – Energy Service Companies
EU – European Union

EUIPO – European Union Intellectual Property Office

FTO – Freedom to Operate

GDPR – General Data Protection Regulation

IEA PVPS – International Energy Agency – Photovoltaic Power Systems

IEC – International Electrotechnical Commission

IP – Intellectual Property

IPR – Intellectual Property Rights

ISO – International Organisation for Standardisation

ITC – International Trading Centre

KPI – Key Performance Indicator

KTI – Knowledge Transfer Ireland

nZEB – nearly Zero Energy Building

PESTEL – Political Economic Sociological Technological Environmental and Legal

PLC – Programmable Logic Controller

PV - Photovoltaic

R&D – Research and Development

SaaS – Software as a Service

SWOT – Strength Weakness Opportunity Threat

TRL – Technology Readiness Level

UCD – Unregistered Community Design

USA – United States of America

WP – Work Package

ZEB – Zero Energy Building

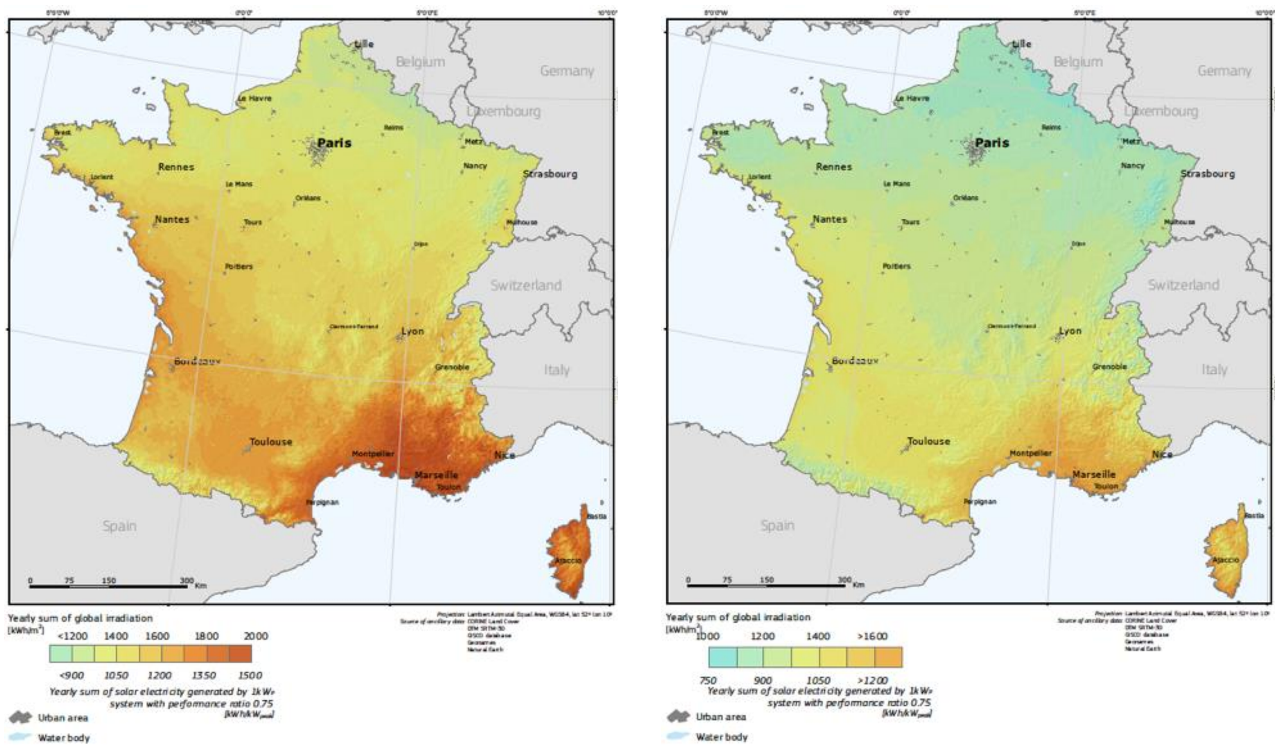
2 CSTB

CSTB facilities host 4 different innovative BIPV solutions from 4 manufactures (ONYX, FLISOM, PIZ and SCHWEIZER), with a dedicated mock-up per BIPV solution. That means that each mock-up is independent in terms or energy generation with dedicated conversion system, in terms of monitoring system with a dedicated data acquisition system and dedicated sensors. Last point concerning meteorological measurement, a weather station is implemented for each mock-up to provide the most relevant information as possible without any modelling calculation. The last configuration (ONYX-PIZ) is an additional experimentation from their previous experimental plan looking for impact of rain rate on moisture generation or soiling and validation of pasting solution of a glass-glass PV module one PIZ mortar.

2.1 General information of facilities

The CSTB Facilities are located in South-East of France, CSTB experimental platform called "INTI" is able to host 6 different roof mock-ups from 9 to 35 m^2 with an adjustable tilt from 0° to 50° but without azimuth adjustments. Only a south orientation is available right now. Two additional mock-ups are available for façade BIPV solutions, the first is dedicated for cladding solution on insulated or ventilated façade, the second for glazing solution. Both can host samples or systems up to 12 m^2 with a south orientation and a till of 90° (±7°). A third platform, dedicated for long terms experimentation and aging assessment, is also available for large power generators (up to 15 kWc). Currently 4 mock-ups of 5 KWc each are currently working. Elevation and azimuth are tunable and configured for the test durations.

The geographical location is L: 43,61° and l:7,05° with an elevation above the sea level of 162 m. Köppen climate classification of this location is a subtype of Mediterranean climate, namely classified as "Csa" subtype corresponding to a Hot-summer Mediterranean climate, is the most common form of the Mediterranean climate, therefore it is also known as a "typical Mediterranean climate

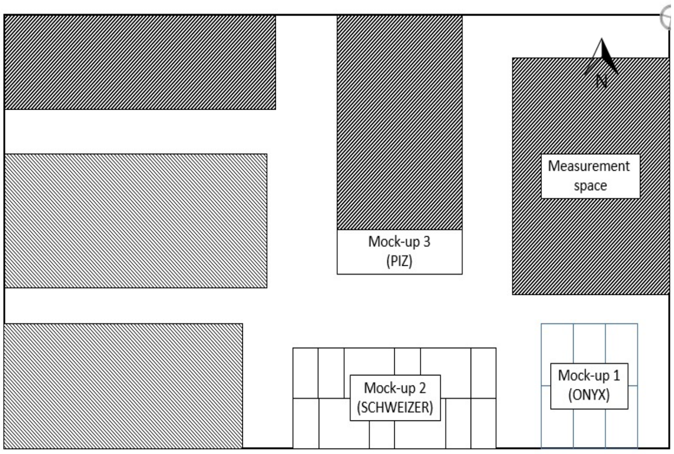


Optimally-inclined photovoltaic modules, Source: PVGIS   Horizontally mounted photovoltaic modules, Source: PVGIS

Figure 1: Potential irradiation for optimized and horizontal elements - France

Figure 2: Satellite view to identify location of facilities and where BIPVBOOST mock-ups are installed

Site horizon description for far shadow effects and shading horizon according to real location of experimentation. This work will allow to select only representative data allowing to calculate performance according to the power matrix from EN 61853-1 standard.



Manufacturer(s)	BIPV Solution	Mock-up N°
ONYX	Canopy	1
FLISOM, PIZ	ePIZ - CIGS version	3
FLISOM, SCHWEIZER	CIGS + Solrif	2
ONYX, PIZ	ePIZ -c-Si version (rain test)	-

Figure 3: Position of each mock-up on the "INTI" experimental platform

The mock-up number 4 (- in red mark) dedicated to rain test on ONYX-PIZ elements are located to another platform located at CSTB facility and is not in the present picture. This last mock-up is still under construction. For each mock-up a full solar diagram is realized to express shadowing effect and select only representative data from monitoring solution with a clear view.

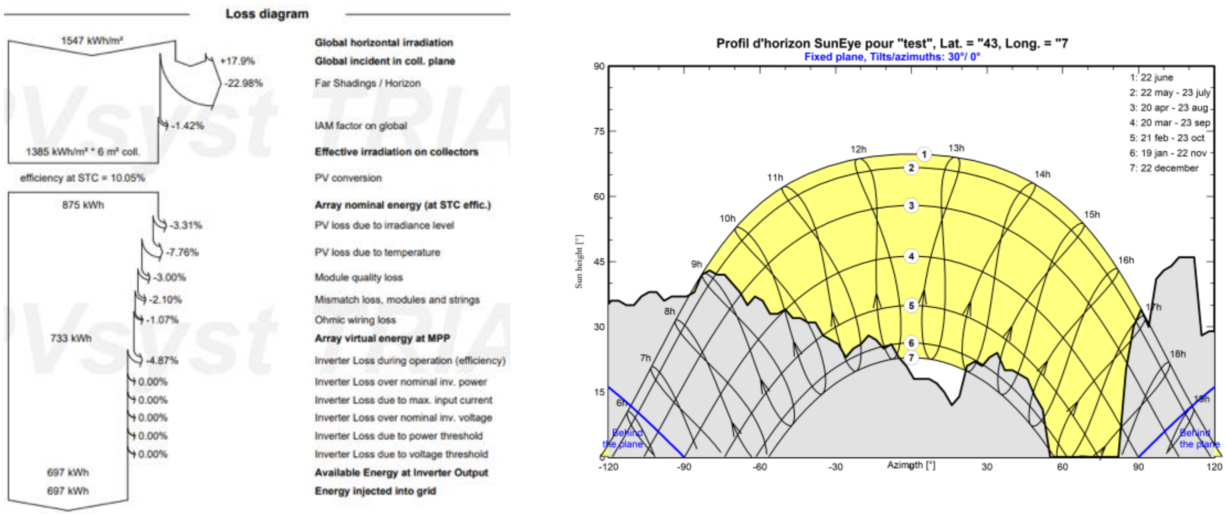


Figure 4: Sankey diagram and horizon profile from INTI experimental platform for mock-up 1 – ONYX

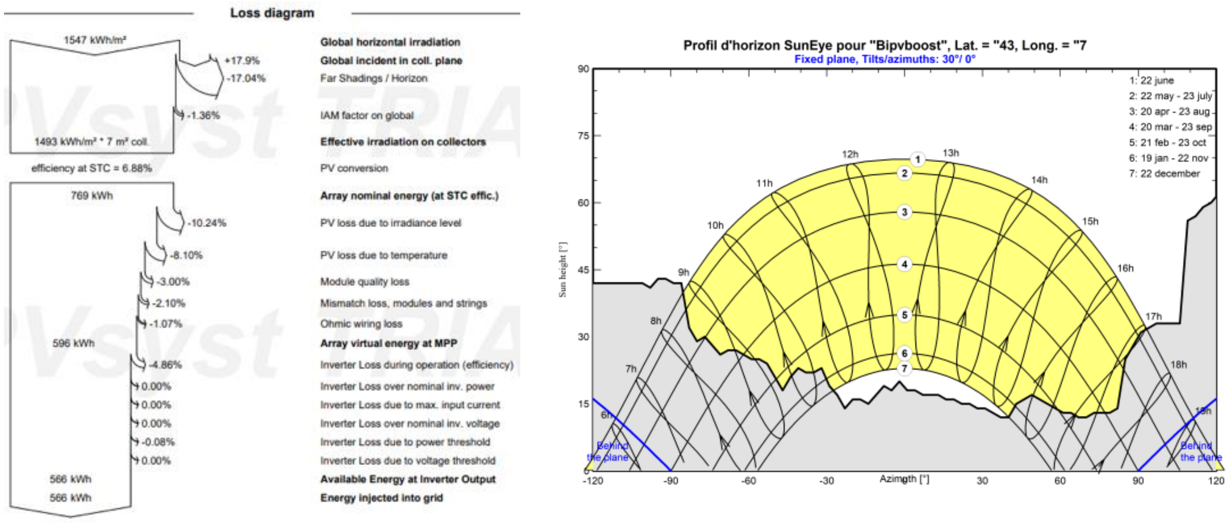


Figure 5: Sankey diagram and horizon profile from INTI experimental platform for mock-up 2 - FLISOM-SCHWEIZER

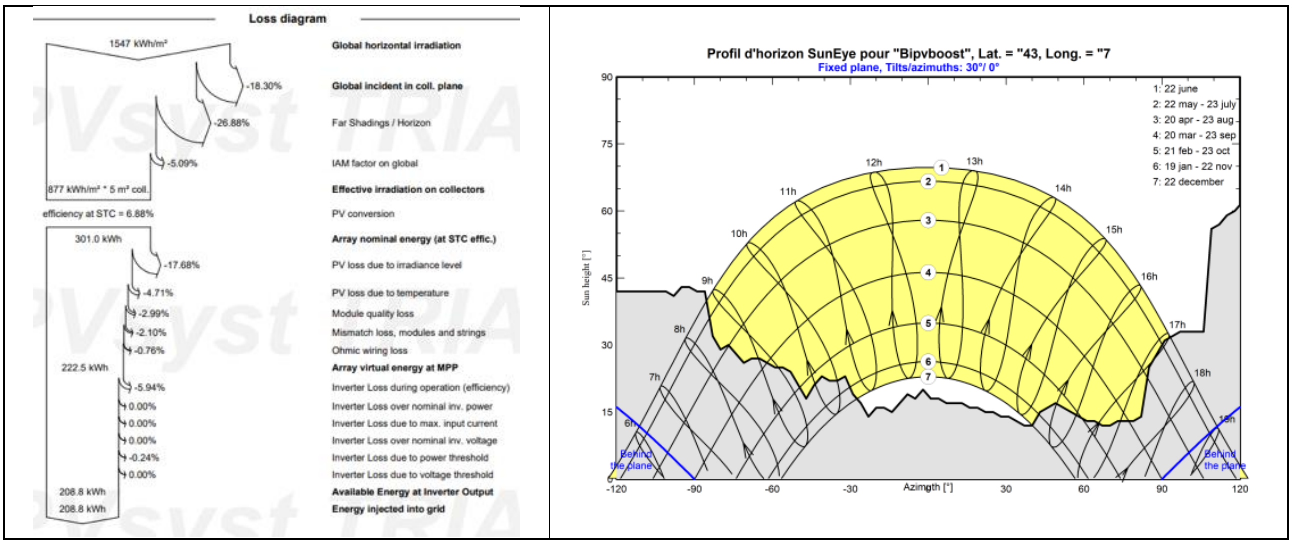


Figure 6: Sankey diagram and horizon profile from INTI experimental platform for mock-up 2 - FLISOM-PIZ

2.2 ONYX Canopy

2.2.1 ONYX Canopy – Mock-up and layout description

Onyx provides us glass/glass bifacial modules to make a canopy installation. According to French canopy definition, does not lead to the watertightness of the structure and could be also applied as a car park solution. The commonly represented structure is a light mounting structure with fastening solution with a 20° tilt angle.

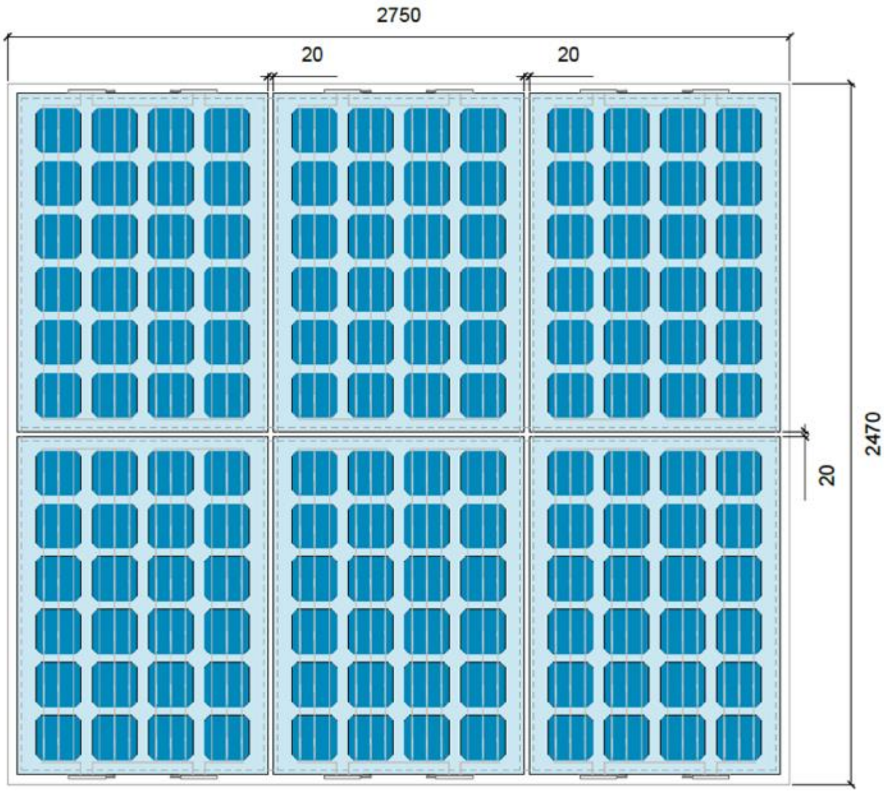


Figure 7 : Layout from manufacturer ONYX

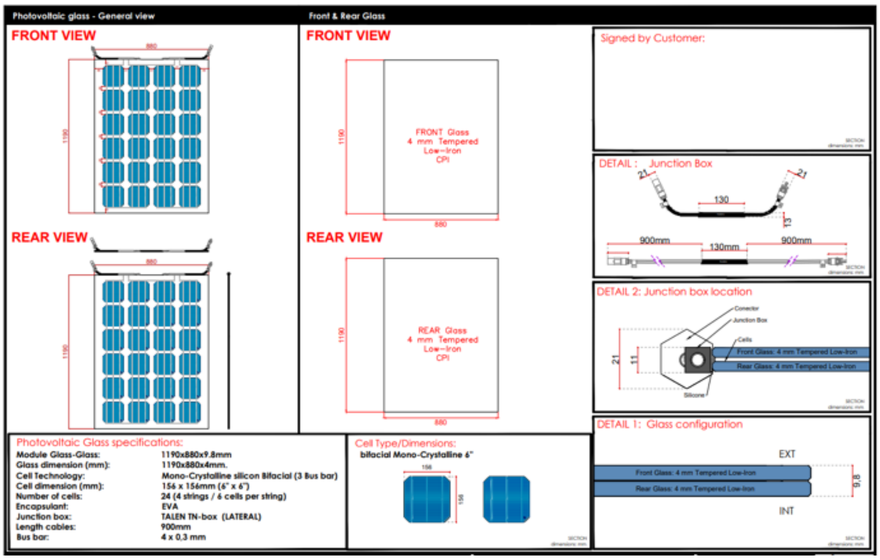


Figure 8 : Module details about ONYX glass/glass bifacial solution

PHOTOVOLTAIC GLASS	1.190 x	880
	6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	102	P_{mpp} (Wp)
Open-circuit voltage	15	V_{oc} (V)
Short-circuit current	8,67	I_{sc} (A)
Voltage at nominal power	13	V_{mpp} (V)
Current at nominal power	8,08	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	1190	mm
Width	880	mm
Thickness	9,8	mm
Surface area	1,05	sqm
Weight	21	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	47%
Front Glass	4 mm	Tempered Glass Low-Iron
Rear Glass	4 mm	Tempered Glass Low-Iron
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or	4,0 mm²
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

** NOMINAL REAR POWER OUTPUT AT 50%

Figure 9 : Data sheet from ONYX PV Modules

Figure 10: First to fourth step of the installation of Canopy - CSTB

As it can be seen on the different steps of the mock-up installation, the structure supporting the modules is composed of three rods which can be adjusted to fix the modules and another four rods which are supporting the three previous ones but unlike them cannot be adjusted. The modules working on both sides, the four fixed rods may prevent the modules' back cells from well working by shadowing them. The following figure represents the position of each rod under the modules to show which cells are the most subject to produce less energy. The two rods from the left side seem to have less effects than those on the right side.

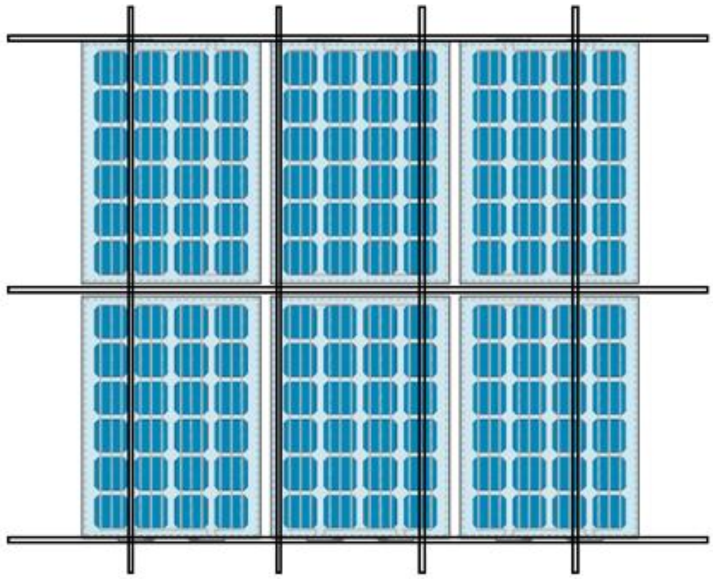


Figure 11: Position of the structure supporting the mock-up - CSTB

2.2.2 ONYX Canopy – Measurements and monitoring descriptions

In respect of IEC 61853, 4 thermal sensors are placed at the back of the modules to estimate an average temperature of the whole mock-up. Two more sensors are placed at the front of the mock-up to see if there is a great difference of temperature between the front and the back, these two sensors are not used to determinate the module's temperature. Half of the sensors are placed on a PV cell and the other half on the glass to have a more average temperature in case the difference of temperature between the two kind of place is significant. In case there is no real differences, the ideal position of the sensors in on the glass part to limit the disturbance of the measurement on the cell's production.

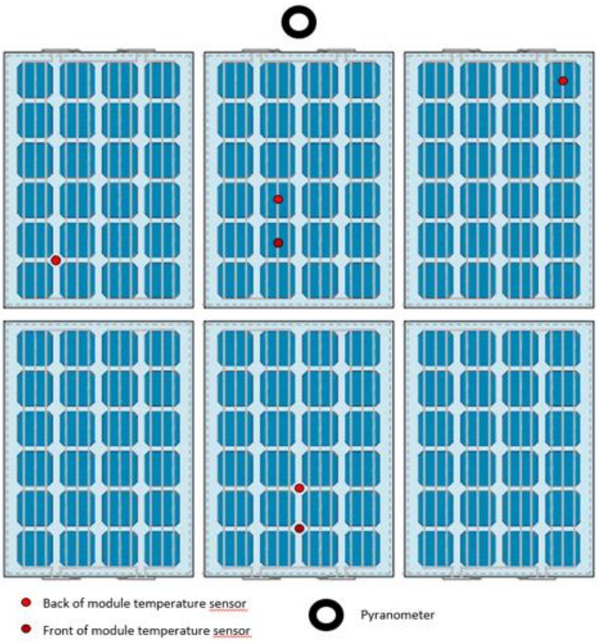


Figure 12: Sensors position on Canopy - CSTB

The mock-up uses 3 micro-inverters with 2 modules in series per micro-inverter to respect the utilisation conditions of the micro-inverters. With an installation in series, each micro-inverter receives a Short Circuit Current of 8,67 A, an Open Circuit Voltage of 30 V and a nominal peak power of 204 W which are under the maximum level authorized for Isc and Voc and in the interval of recommended power for Pmax for the nominal power. For each micro-inverter is installed 2 transducers, one for DC measurement and one for AC measurement.

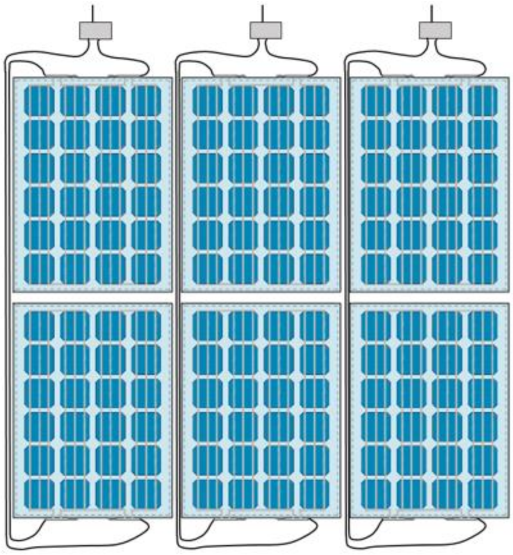


Figure 13: Installation of the different micro-inverters on Canopy – CSTB

2.2.3 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of south oriented dual modules sub-systems, bifacial gains. Yield benchmarking value is considered a Yearly PV energy production of 1280 kWh/kWp (south oriented pane, 20° tilt)
- Contribution of albedo on above performance
- Temperature analysis: determination of 98th percentile operating module temperature according to IEC TS 63126
- Visual/optical verification of aesthetical characteristics (opacification, yellowing...), dirtying and self-cleaning aspect.

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

2.3 FLISOM-SCHWEIZER Roof

2.3.1 FLISOM-SCHWEIZER Roof – Mock-up and layout descriptions

The second mock-up tested in CSTB is the SCHWEIZER-FLISOM mock-up. It is a mock-up which is composed of 12 modules using the CIGS technology (8 are 1x1V modules and 4 are 2x1V modules) which are used on tiled roof. It is oriented to the South (azimuth of 180°) and an angle between the ground/platform and the mock-up of approximately 25°.

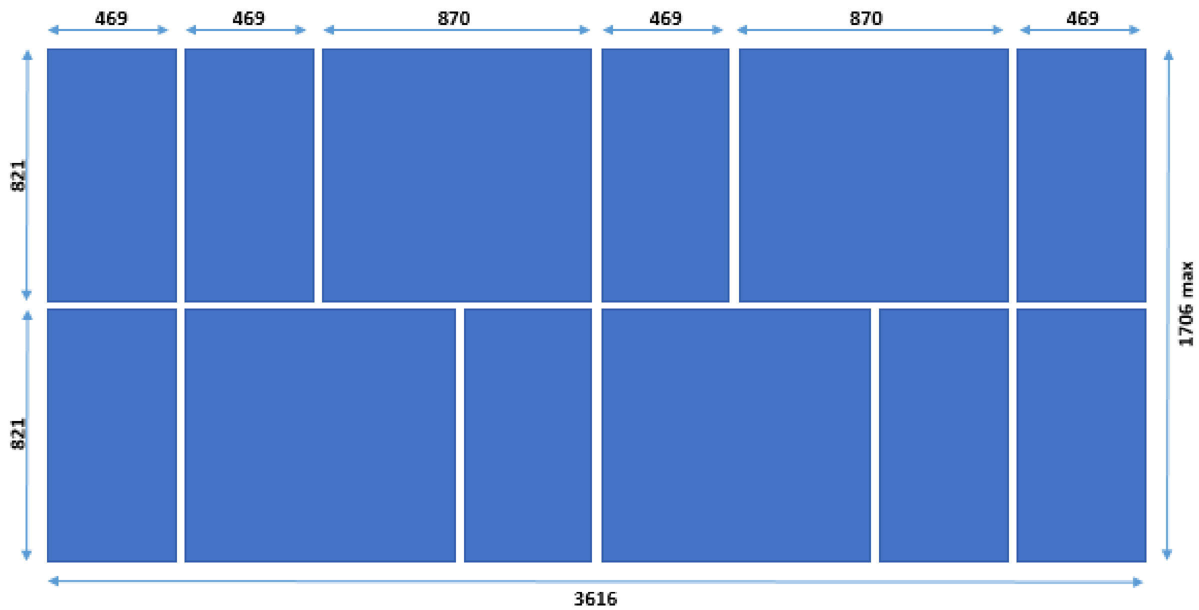


Figure 14: Layout from manufacturer SCHWEIZER - CSTB

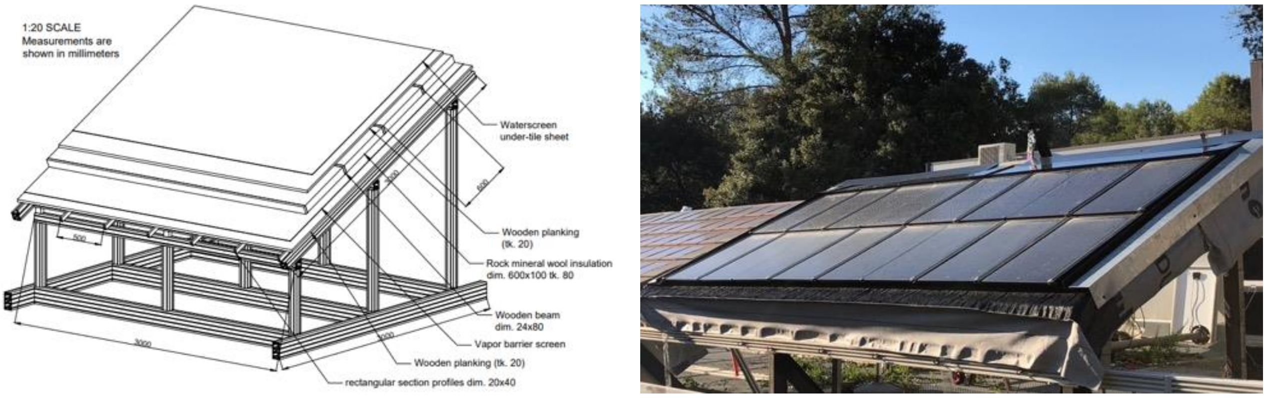


Figure 15: Layers description for SCHWEIZER's mock-up (Sketch from SUPSI)

PV-Module [Roof_1]

Manufacturer:	**Ernst Schweizer AG**
Name	**CIGS_BIPV_1x1V**
Width [mm]:	**853**
Height [mm]:	**487**
Thickness [mm]:	**17**
Weight (kg)	**4**
Nominal Power [Watt]:	**30**
Module Type:	**CIGS**
Temperature coefficient [%/°C]:	**-0.35**
Efficiency STC:	**0.087**
Output current MPP - STC [A]:	**0.84**
Output voltage MPP - STC [V]:	**34**
Short circuit current [A]:	**0.97**
Open circuit voltage [V]:	**46**
Temperature coefficient Current [%/K]:	**0.01**
Temperature coefficient Voltage [%/K]:	**-0.3**
Max. System voltage EU:	**1000**
Max module backcurrent [A]	**10**
Galvanic seperation required:	**No**
Manufacturer:	**Ernst Schweizer AG**
Name	**CIGS_BIPV_2x1V**
Width [mm]:	**853**
Height [mm]:	**888**
Thickness [mm]:	**17**
Weight (kg)	**3**
Nominal Power [Watt]:	**60**
Module Type:	**CIGS**
Temperature coefficient [%/°C]:	**-0.35**
Efficiency STC:	**0.081**
Output current MPP - STC [A]:	**0.88**
Output voltage MPP - STC [V]:	**34**
Short circuit current [A]:	**1.94**
Open circuit voltage [V]:	**46**
Temperature coefficient Current [%/K]:	**0.01**
Temperature coefficient Voltage [%/K]:	**-0.3**
Max. System voltage EU:	**1000**
Max module backcurrent [A]	**10**
Galvanic seperation required:	**No**

Figure 16: Data sheet from SCHWEIZER

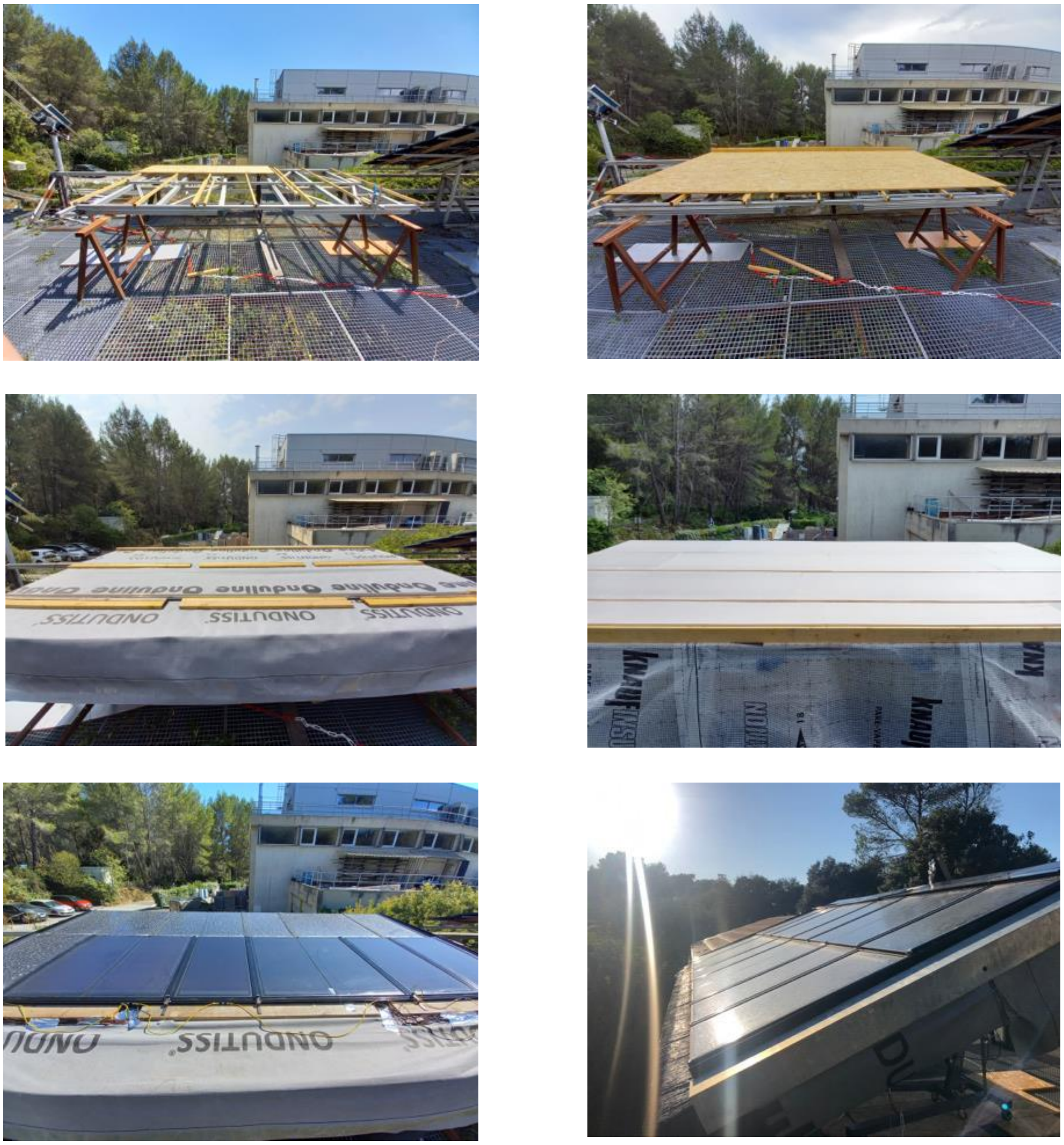


Figure 17: Stages of the FLISOM-SCHWEIZER mock-up installation

2.3.2 SCHWEIZER Roof – Measurements and monitoring descriptions

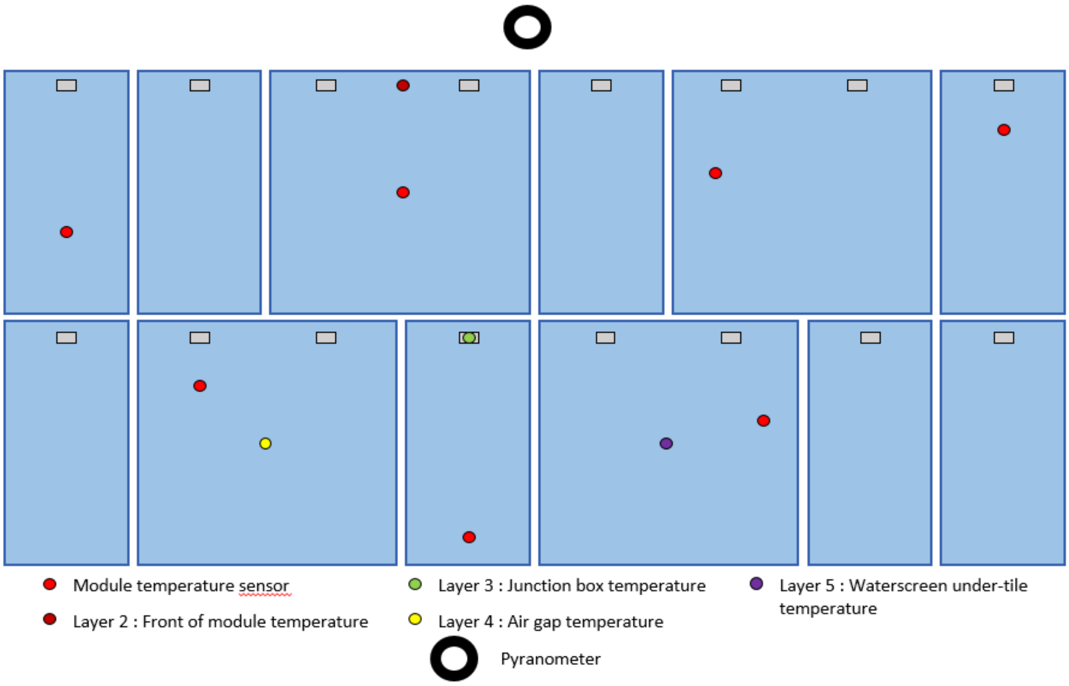


Figure 18: Sensors position on SCHWEIRZER's mock-up - CSTB

In respect of IEC 61853, 7 thermal sensors are used to evaluate an average temperature of every modules composing the mock-up. The sensors are placed behind the PV-modules. There are 4 additional sensors used for different purposes. One is to know the temperature in the front part of a module, one for the temperature of a junction box, one is for the temperature of the air gap between a module and the supporting structure and the last one is the temperature of the supporting structure.

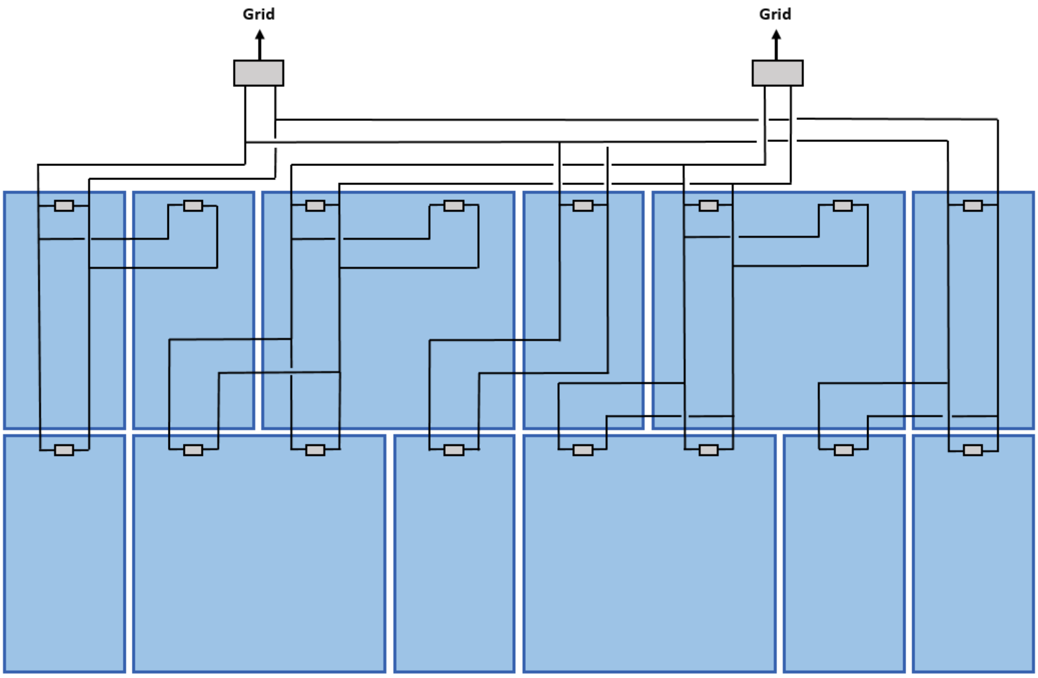


Figure 19: Installation of the different micro-inverters for SCHWEIZER/FLISOM solution - CSTB

The mock-up uses 2 micro-inverters with the 8 modules 1x1V in parallel for the first one and the 4 modules 2x1V in parallel for the second one to respect the utilisation conditions of the micro-inverters described by manufacturer. For each micro-inverter the Short Circuit Current is approximately 8 A, the Open Circuit Voltage is 46 V and the nominal peak power is 240 W. For each micro-inverter is installed 2 transducers, one for DC measurement and one for AC measurement.

2.3.3 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of different sub-strings/modules (X2), stability over time. Yield benchmarking value is considered a Yearly PV energy production of 1'080 kWh/kWp
- Temperature analysis: back-of module operating temperature distributions and dependencies of ventilated modules, non-uniformities within the roof, JB and layer temperatures, determination of 98th percentile operating module temperature according to IEC TS 63126
- Air temperature levels in the roof layers during the operation
- Visual inspection of all modules to analyze dust and pollen retention

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

2.4 PIZ-FLISOM Facade

2.4.1 PIZ-FLISOM façade Mock-ups and layout descriptions – CSTB

The third mock-up tested in CSTB is the PIZ-FLISOM mock-up. It is a mock-up which is composed of 16 modules using the CIGS technology which are uses as BIPV façade cladding systems with integrated insulation. It is oriented to the South (azimuth of 180°) and the mock-up is vertical (angle of 90°).

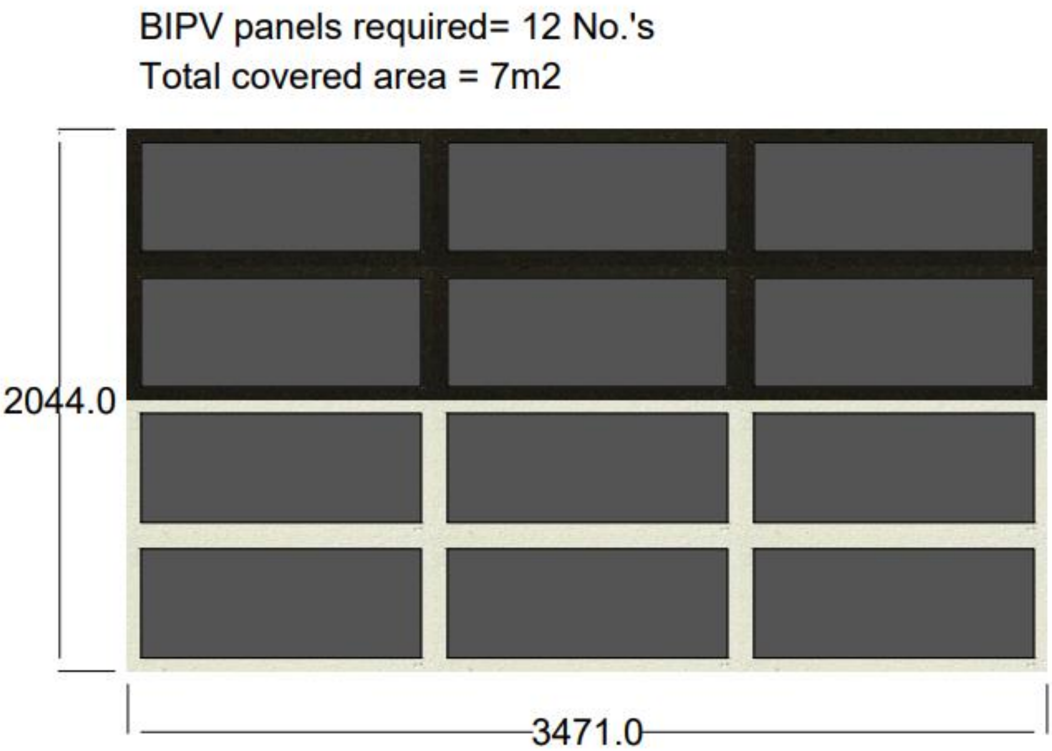


Figure 20: Mock-up for PIZ - CSTB

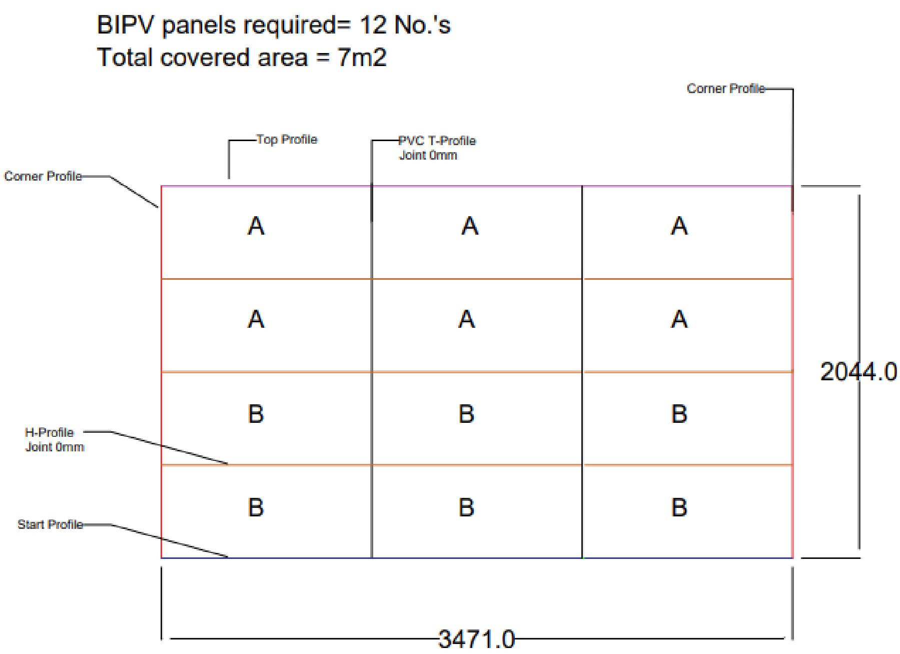


Figure 21: Layout from manufacturer PIZ - CSTB

Figure 22: PIZ Mock-up installed- CSTB

Figure 23: Additional information on PIZ/FLISOM solution - CSTB

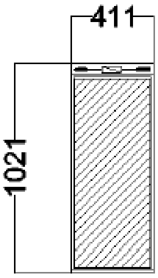
eFlex- Flexible CIGS Solar PV modules

Flisom
Flexible Solar Modules

Dimensions			
Length		[mm]	1021 ±2
Width		[mm]	411 ±1
Thickness of module			
without backside adhesive		[mm]	1.5 ± 0.2
with backside adhesive			2.2 ± 0.2
Thickness at J-Box		[mm]	20 ± 1
Weight			
without backside adhesive		[Kg]	0.8
with backside adhesive			1.2

Electrical characteristics at STC[1]			35W
Model number			
Nominal power	Pmpp	[W]	35
Tolerance*		[%]	-10/ +10
Voltage at nom. power	Vmpp	[V]	34.4
Current at nom. power	Impp	[A]	1.02
Open circuit voltage	Voc	[V]	48.0
Short circuit current	Isc	[A]	1.28
Max. system voltage	IEC	[V]	1000
Max. serial fuse rating	I	[A]	10

*Average power over all modules shipped to any customer shall be 35W or above. Modules will be sorted into boxes of 5W/10W increments depending on the project size.



Thermal Characteristics			
Temperature coefficient	Voc	[%/°C]	-0.30
Temperature coefficient	Isc	[%/°C]	0.01
Temperature coefficient	Pmpp	[%/°C]	-0.35

Operating Conditions		
Temperature range	[°C]	-40 to +85
Max. mechanical load [2]		2400 Pa, 245 kg/m2

Additional Information	
Cell type	Flexible CIGS on Polyimide
Junction box	Front side including bypass diode, IP68 for box, MC4 type connectors, 400mm long stranded wire 2.5 mm²
Encapsulation	Fluoropolymer front sheet / plastic back sheet
Customization	Possible on request
Packaging	Shipped rolled on Euro pallets in boxes of 16 pcs without backside adhesive or 14 pcs with backside adhesive – max. 192/ 168 per pallet

Warranty & Certification	
Performance guarantee	10 years on 90% of Pmpp under STC[1] & 20 year on 80% of Pmpp under STC[1]
Warranty	5 years' workmanship after delivery date
Certification	IEC 61215:2016 testing underway; IEC 61730:2016 testing underway
Safety class	II

Notes

[1] STC: 1000 W/m2, AM1.5G, 25°C, stabilized module state. We continuously develop our products. Electrical and physical properties are subject to change without prior notice.

[2] Higher load ratings can be met with additional support, subject to testing.

Figure 24: Data sheet from PIZ

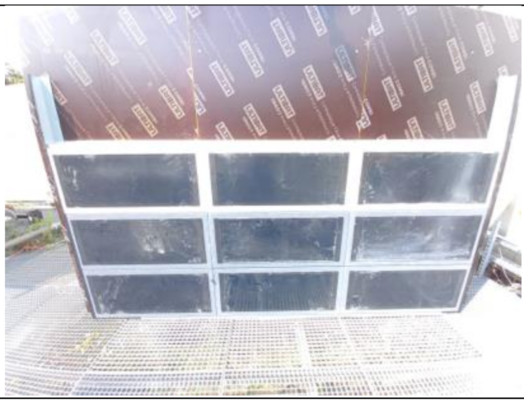


Figure 25: Mock-up building stages on CSTB site

2.4.2 PIZ-FLISOM façade Measurements and monitoring descriptions

Are described below main sensors used according to standards but also possibility to instal sensors behind the PV module in the adhesive layer to measure the module temperature and compare results with numerical models. Due to the difficulty to access to this layer, we paste the thermal sensors directly on the front surface, close to the PV module to collect the most accurate data as possible without damage the module.

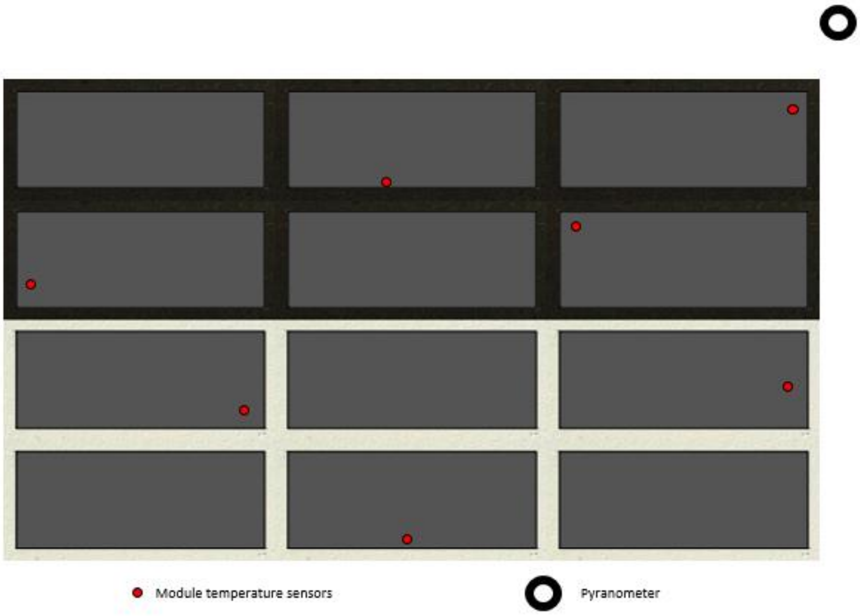


Figure 26: Thermal sensors position on PIZ's mock-up - CSTB

In respect of IEC 61853, 8 thermal sensors are used to evaluate an average temperature of every module composing the mock-up.

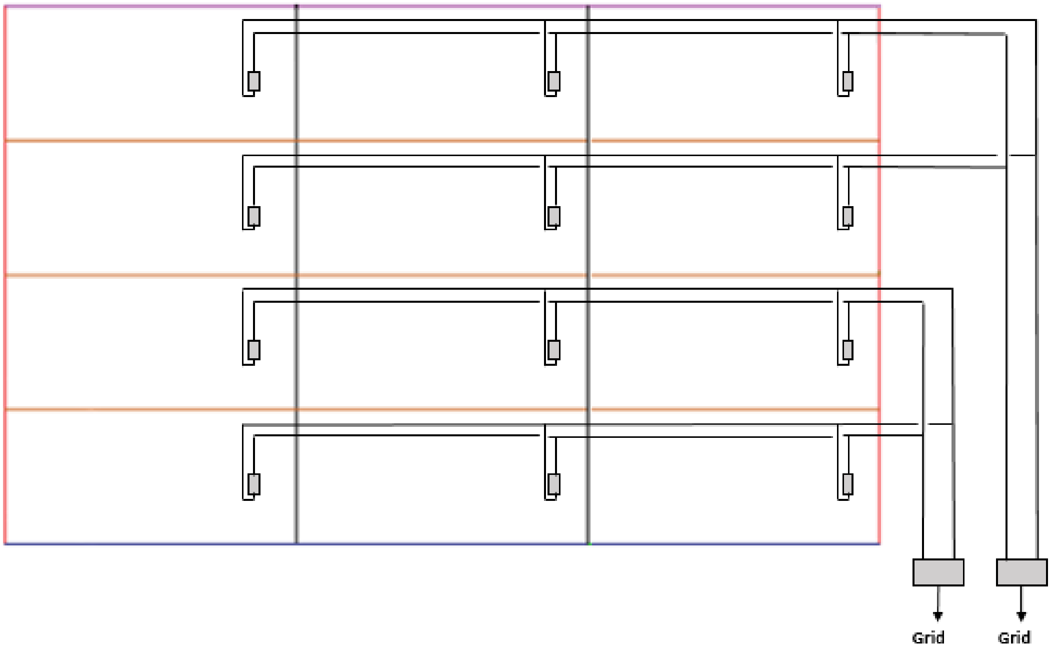


Figure 27: Installation of the different micro-inverters for PIZ/FLISOM solution - CSTB

The mock-up uses 2 micro-inverters with the 8 modules in parallel for each to respect the range conditions of the micro-inverters described by manufacturer. For each micro-inverter the Short Circuit Current is approximately 6 A, the Open Circuit Voltage is 48 V and the nominal peak power is 210 W. For each micro-inverter are installed 2 transducers, one for DC measurement and one for AC measurement.

2.4.3 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of different sub-strings/modules, stability over time. Yield benchmarking value is considered a Yearly PV energy production of 800 kWh/kWp
- Temperature analysis: back-of module operating temperature distributions and dependencies of integrated and open-rack mounted modules, non-uniformities within the facade, JB and layer temperatures, determination of 98th percentile operating module temperature according to IEC TS 63126
- Humidity penetration trends mortar/glass during operation (humidity sensors)
- Hygrothermal behavior in string S5: humidity penetration for different sealing approaches (visual/optical comparison)
- Visual inspection of single modules

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

2.5 Measurements and monitoring descriptions

A complete description of all sensors or measurement elements are showed below to give an overview of measurement installation applied to each mock-up

- **Main sensors description:**

Temperatures: The temperatures are measured by several Thermocouples Type T (copper/constantan). The sensors are fixed to the mock-up with thermal paste and aluminium tape which prevent the apparition of hot spots and reduce the potential measure errors associated. (Repeatability of ± 0.1 °C from - 200 °C to 200 °C, relative error of ± 0.5 °C).

Figure 28: Thermocouple Type T

Connection: 2 wires (tests with DS18B20 are not conclusive due to contact resistance)
Thermocouples 2 wires

Electrical: The different electrical measurements are made using two kinds of Solea's multi-parameters transducers which convert an electrical signal into a digital signal. The first kind is a DC transducer with a relative error of 1 %, and the second one is an AC transducer with an error of 0.5 %.

Table 3: Characteristics of the electrical transducers - CSTB

Device	Characteristics	Measured values
Multi-parameters transducer DC SOLEA AD12B	0 to 10 A 0 to 200/300/400/500 V 24 VDC power supply Digital output RS485	U, I, P, W
Multi-parameters transducer AC SOLEA AJ12B	0 to 2 A 0 to 230 V 24 VDC power supply Digital output RS485	U, I, P, W, Q, P, cos(ϕ),f

Table 4: Transducers used for each mock-up

Manufacturer	Used transducers	
ONYX	1 x AD12B 200V 10A 1 x AD12B 300V 10A 1 x AD12B 400V 10A	3 x AJ12B 230V 2A
SCHWEIZER / FLISOM	1 x AD12B 400V 10A	2 x AJ12B 230V 2A
PIZ / FLISOM	2 x AD12B 500V 10A	2 x AJ12B 230V 2A

Figure 29: Transducer AC

Figure 30: Transducer DC

Solar measurement: The solar measurements are made thanks to the CMP11 and CMP 21 secondary standard pyranometer from Kipp & Zonen, used here for the Global Horizontal Irradiance (GHI). The instrument uses the Peltier Effect to power itself and does not require any other supply.
Its 95th percentile of the response time is less than 5 seconds and it can measure the irradiance up to 4,000 W/m² with a daily error of 2 %.

Figure 31: Pyranometer CMP11 and CMP 21

Ambient temperature: The sensor currently used for the ambient temperature is a PT100-class A, 4 wires and protected with a radiative shield. The relative error of this sensor is ± 0.1 °C.

Figure 32 :Temperature sensor PT100

Figure 33 : Radiative shield for Tamb

Wind: The Gill WindSonic (an ultrasonic wind sensor) is used for both speed and direction measurements. The instrument requires a power supply of 24 VDC. Its output signal starts at 0 V and is up to 5 V depending on the wind velocity and 4 to 20 mA with the direction (see Appendix 2).

It can measure any wind speed under 60 m/s with a relative error of 2 % for a speed of 12 m/s. It is able to measure a wind's speed coming from any direction (360°) with a precision of 1°. And its response time is 0.25 s.

Figure 34: Anemometer WindSonic®

- **Monitoring system:**

A data logging system (AGILENT) is used for the analogical sensors described above, all measures are scanned by 1 second interval. The whole system is controlled by the software TRNSYS which is able to read data from both analogical sensors through the AGILENT system and digital sensors. All the data are stored in internal memory with a copy on HDD computer and FTP website.

Energy conversion system employed + IV curve system used

- **MPP-tracking method:**

MPP-tracking is performed via an ENPHASE M250 micro-inverter. Their outputs are connected to the grid according to VDE-126-1 requirement. Additional monitoring sensors are installed to record DC and AC Voltage and Current every minute on the purpose of this activity (Umpp and Impp)

- **IV curve method measurement:**

IV Curves are performed manually every week with PVE PVPM 1000C curve tracer or with a MPPT3000 curve tracer from SUPSI lab.

This curve tracer is able to perform curves every minute (or lower) on undefined time laps (usually 20 curves are traced) Uoc, Isc, Umpp and Impp are collected and calculated and corrected according to STC conditions.

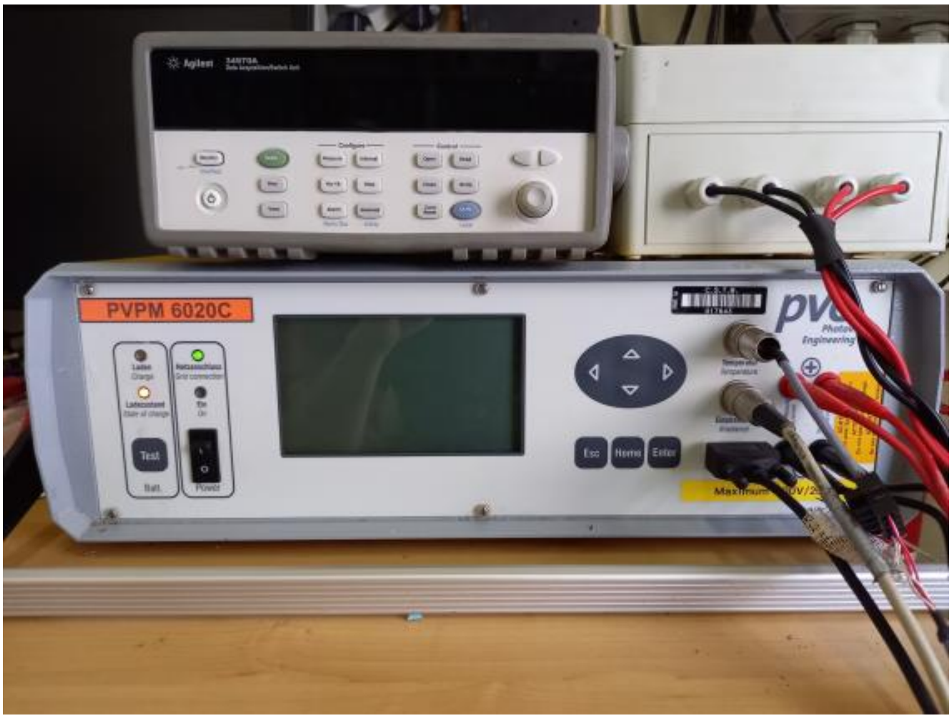


Figure 35: Monitoring and IV curves devices.

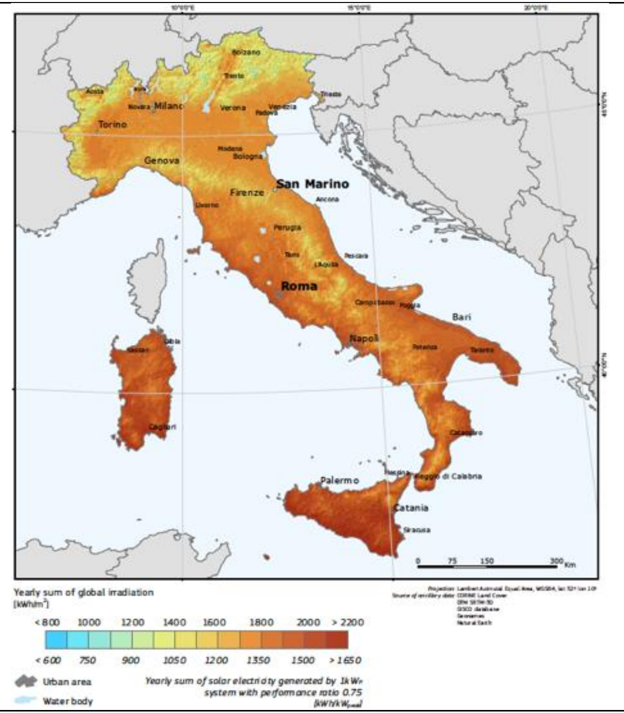
3 EURAC

3.1 General information of facilities – EURAC

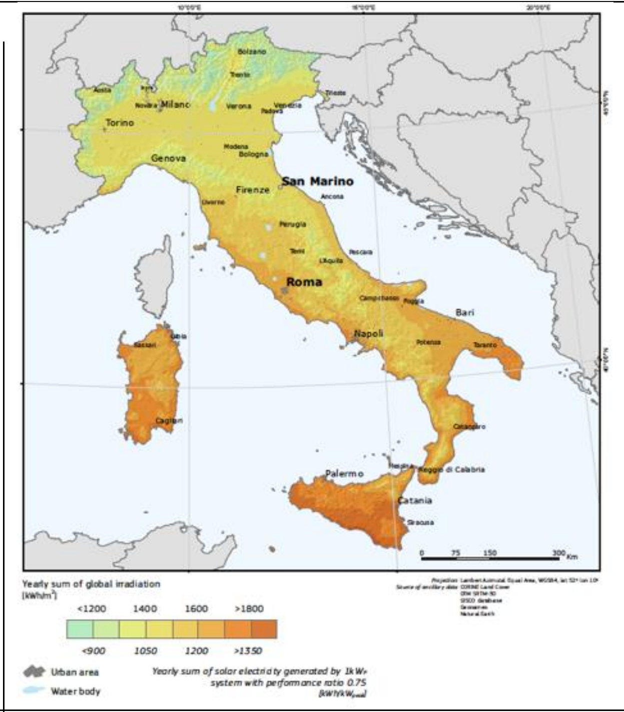
EURAC facilities host 2 different innovative BIPV solutions from 2 manufactures (ONYX and TULIPPS) with a dedicated mock-up per BIPV solution. First solution is a vertical installation of patterned amorphous silicon technology manufactured by Onyx together with a fixing system developed by Tulipps. The second solution is a vertical installation of coloured crystalline silicon photovoltaic modules using as well the fixing system by Tulipps.

Each mock-up is independent in terms of energy generation with dedicated conversion system, in terms of monitoring system with a dedicated data acquisition system and dedicated sensors. Additionally, a meteo station installed in the facilities can provide valuable information to the test.

Eurac outdoor facilities, named PV Integration Lab, are located in the north of Italy. The geographical location is longitude: 46.4755 N and latitude: 11.3306 E with an elevation above the sea level of 262 m. Köppen climate classification of this location is ”Dfb” corresponding to a warm summer continental climate.



Optimally-inclined photovoltaic modules, Source: PVGIS



Horizontally mounted photovoltaic modules, Source: PVGIS

Figure 36: Potential irradiation for optimized and horizontal elements - Italy

Figure 37: Satellite picture of facilities where mock-ups will be installed - Eurac

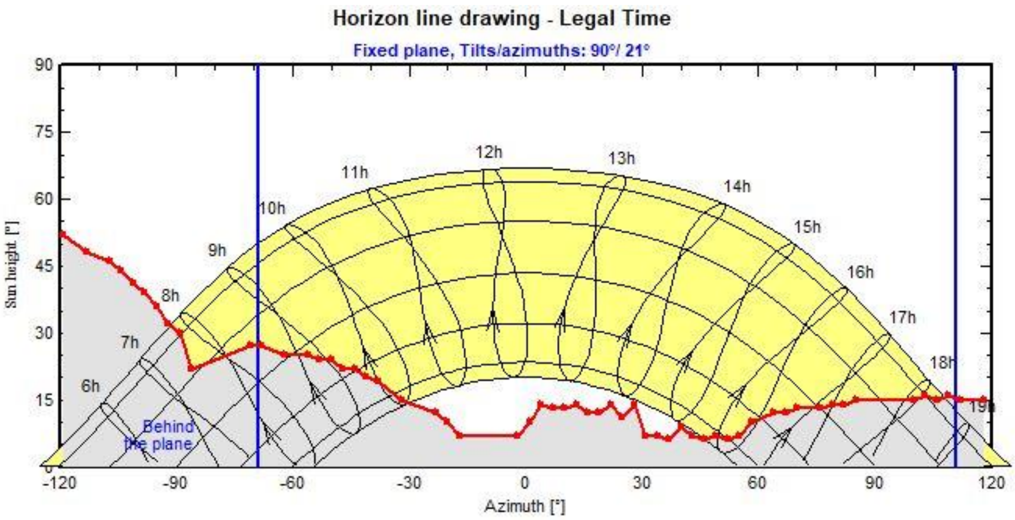


Figure 38: Horizon profile for a-Si mockup

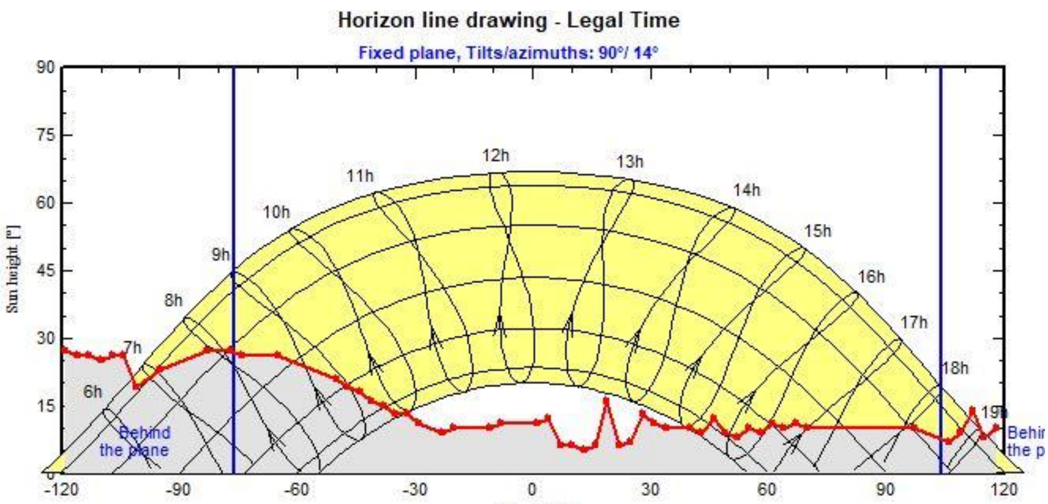


Figure 39: Horizon profile for c-Si mockup

3.2 Mock-ups and layout descriptions – EURAC

3.2.1 Patterned a-Si Mock-up

The first product to be installed in the PV Integration lab is the patterned a-Si technology manufactured by Onyx with anchorage system developed by Tulipps. The number of modules to be installed are 10 in landscape position in the vertical structure shown in Figure 42**¡Error! No se encuentra el origen de la referencia.**.

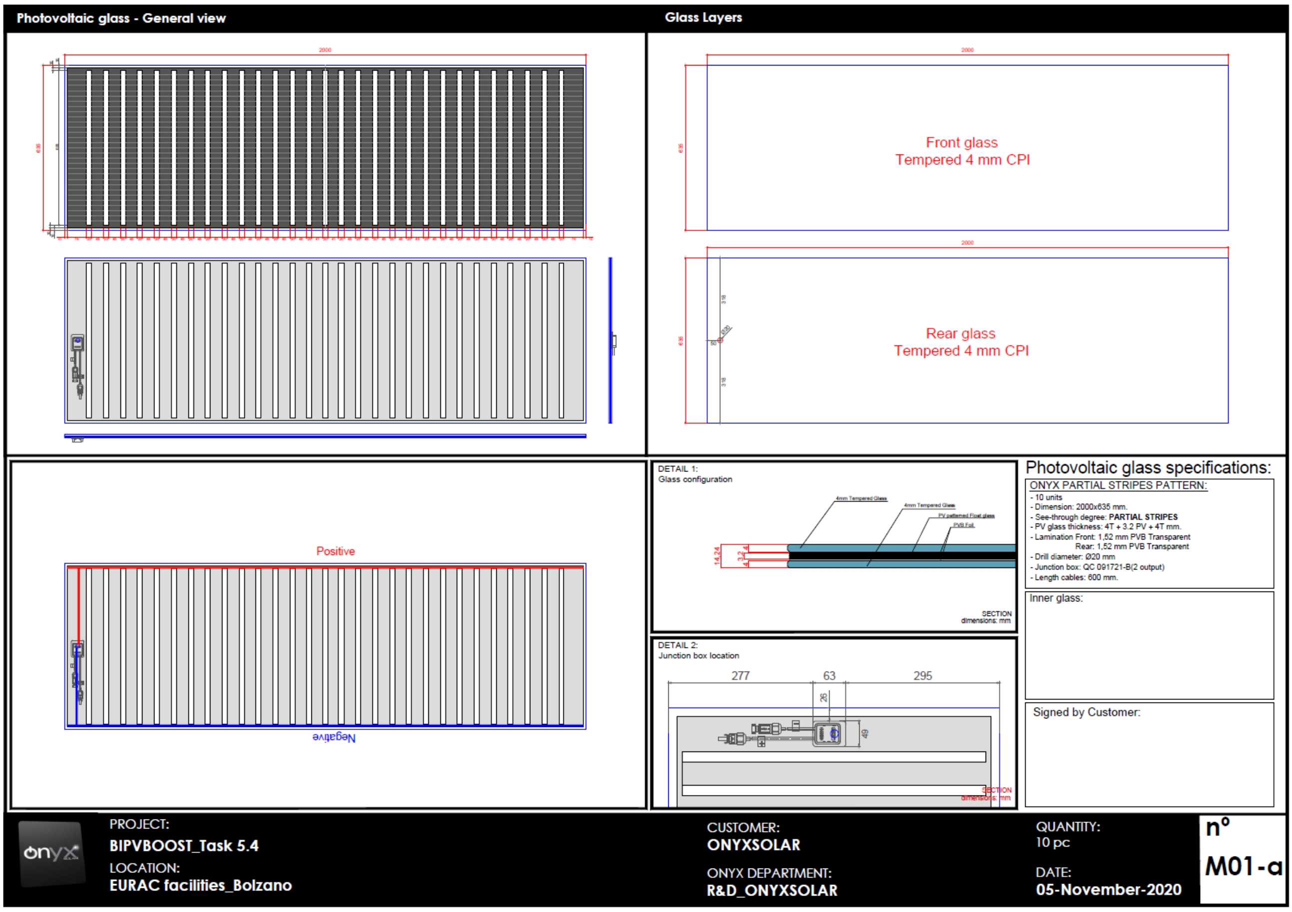


Figure 40: ONYX patterned a-Si module design

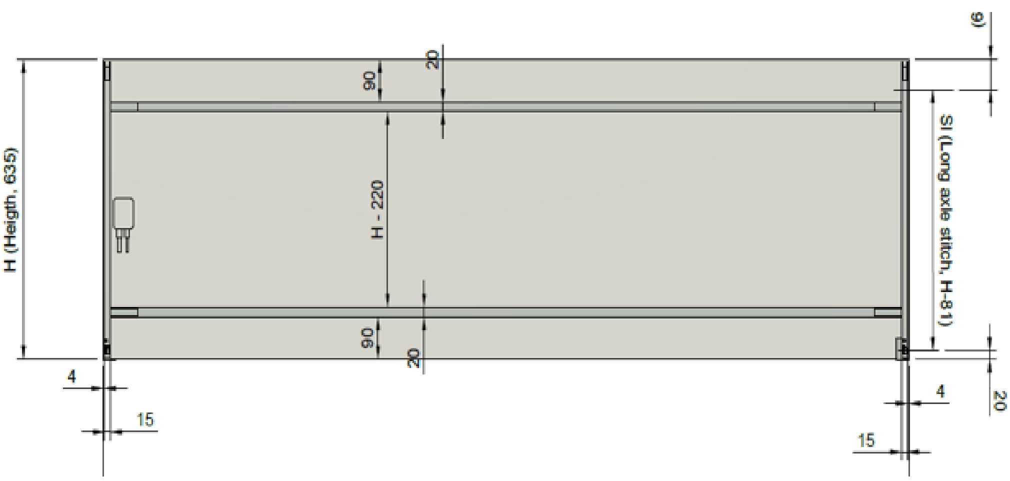


Figure 41: Tulipps rear frame design for patterned a-Si module

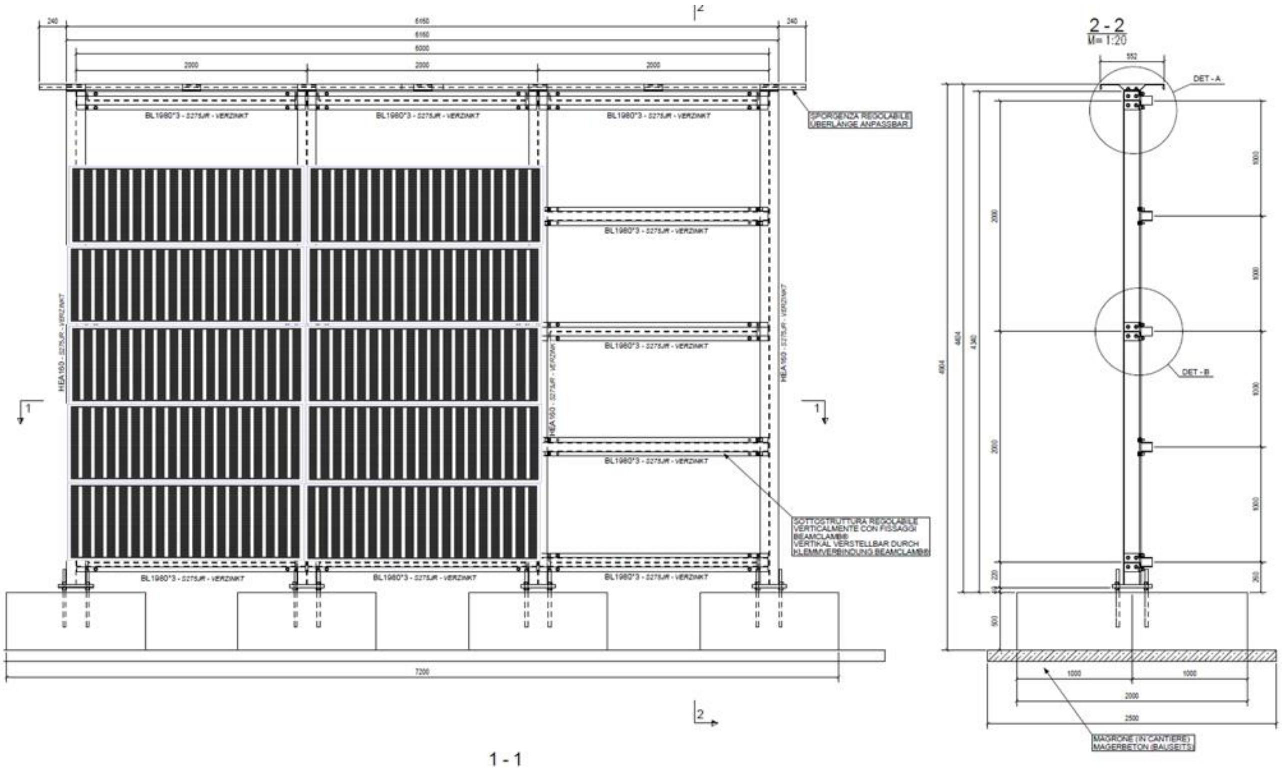


Figure 42: Vertical structure drawing where a-Si mock-up will be installed.

Isc	1.427 A
Imp	1.207 A
Voc	56.06 V
Vmp	39.36 V
Pmp	47.5 W

Figure 43: Electrical parameters of patterned a-Si modules

3.2.2 Coloured c-Si Mock-up

The second product to be tested is the coloured glass-glass c-Si solution by Onyx together with Tulipps fixing system. The number of modules to be installed are 5 in vertical position (in the container façade shown in Figure 47).

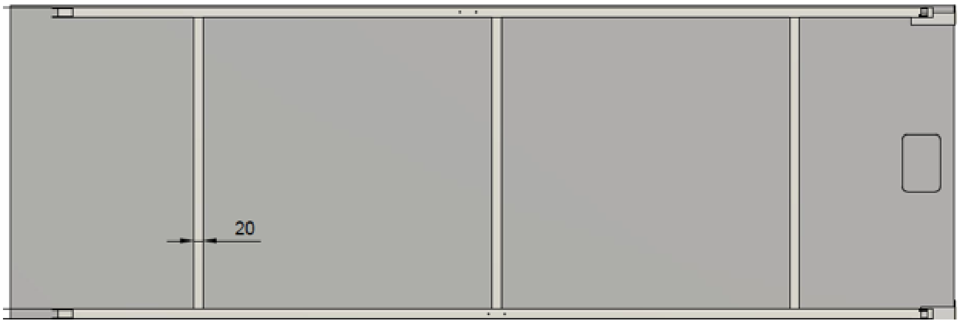


Figure 44: Tulipps rear frame design for coloured c-Si module

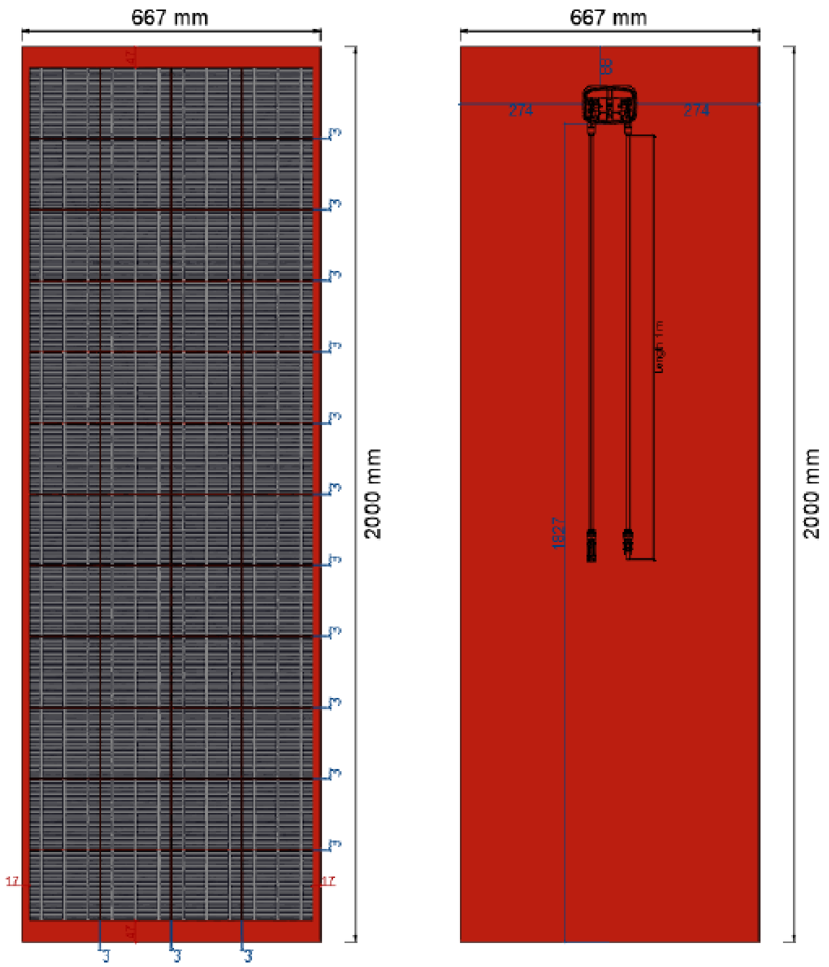


Figure 1.2 Façade glass-glass with 48 poly-crystalline cells, and tempered Glass RAL 3020

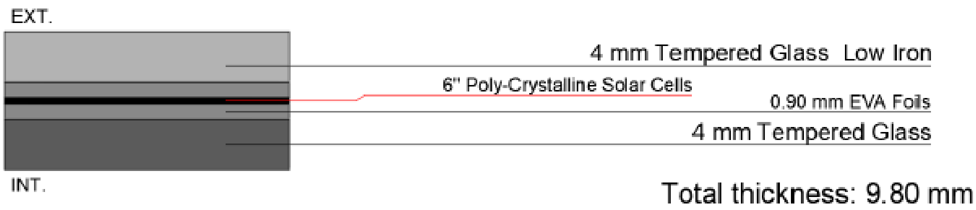


Figure 45: Coloured glass-glass module composition.

PHOTOVOLTAIC GLASS 48 cells	2.000 x 667 6" Poly	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	202	P_{mpp} (Wp)
Open-circuit voltage	31	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	26	V_{mpp} (V)
Current at nominal power	7,81	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	2000	mm
Width	667	mm
Thickness	9,8	mm
Surface area	1,33	sqm
Weight	27	Kgs
Cell type	6" Poly	Crystalline
No PV cells / Transparency degree	48	12%
Front Glass	4 mm	Tempered Glass Low-Iron
Rear Glass	4 mm	Tempered Glass RAL 3020
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

GLASS PROPERTIES	Onyx Equivalent Glass
Light Transmission	12%
U-value [W/sqm.K]	5,4
Peak Power [Wp/sqm]	151,2

Figure 46: Data sheet glass-glass with 48 poly-crystalline cells, and tempered Glass with RAL 3020

Figure 47: Coloured c-Si modules and click-&-go mounting system installed at EURAC.

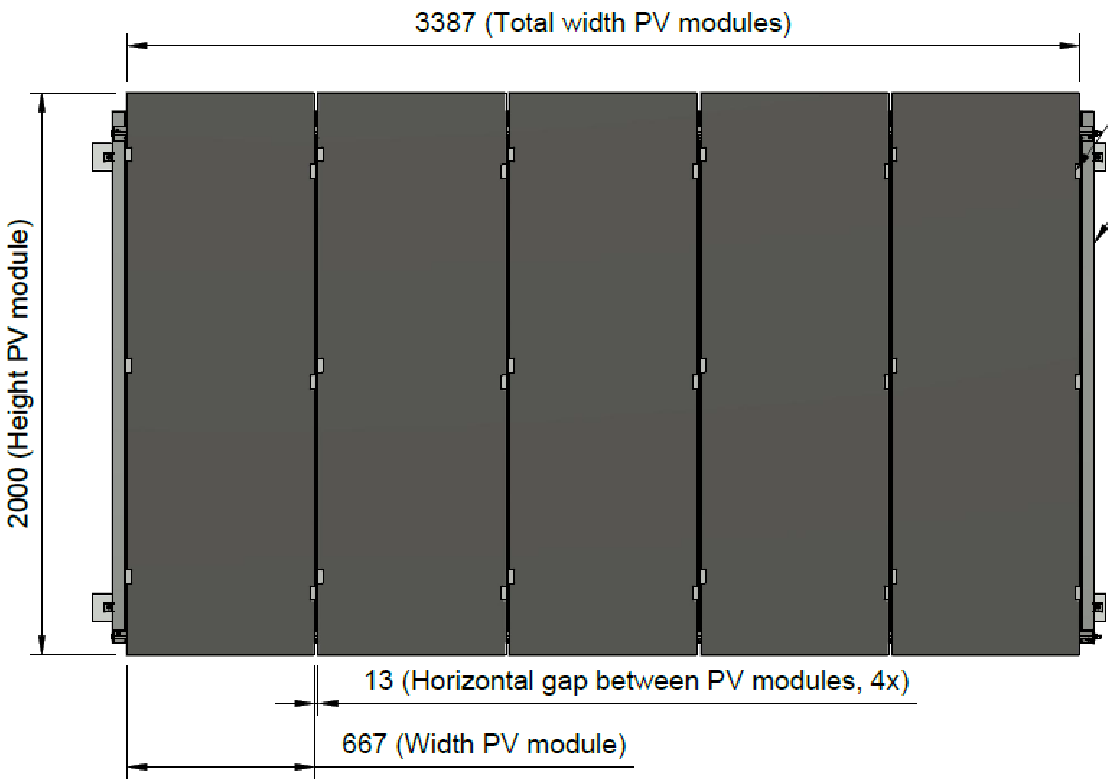


Figure 48: Drawing of 5 vertical modules installed on Tulipps structure.

3.3 Measurements and monitoring descriptions - EURAC

3.3.1 Patterned a-Si Mock-up

The monitoring system consists of two MPPT 3000 devices, Agilent 39480 measure unit, Panel industrial PC and sensors.

The MPPT3000 is a multifunctional measuring device for testing photovoltaic modules that, when connected to the individual modules, can identify their maximum power points. MPPT3000 can also be used to calculate the I-V curves. The Agilent 39480 is a multichannel measure unit with high accuracy and scanning rate. Finally, the Panel Industrial PC makes possible the data storage and remote connection with the two MPPT3000 and Agilent 39480.

Next table collects all the variables instruments and sensors used in the monitoring system for the patterned a-Si Mock-up.

Table 5: Parameters and instruments in the a-Si mock-up monitoring system

PARAMETER	UNIT	Number	DEVICE	SENSOR	MEASUREMENT ACCURACY
PV module surface temperatures	°C	4	MPPT 3000	3 wire - class A - PT100 Surface sensor	0.2%
String Voltage (V)	V	2	MPPT 3000	Built-in voltage sensor	0.5 %
String Current (A)	A	2	MPPT 3000	Built-In current sensor	0.5 %
Plane of Array Irradiance	W/m2	1	MPPT 3000	Kipp & Zonen CMP11 pyranometer	0.1%
PV module and fixing system surface temperatures	°C	8	Agilent 34980A	3 wire - class A - PT100 Surface sensor	0.1%

Figure 49. Position of temperature sensors on the façade.

3.3.2 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series in different resolutions. Yield benchmarking value is considered a Yearly PV energy production of ~880 kWh/kWp, based on a preliminary energy production simulation.
- Temperature analysis at different points on the rear surface of the modules including the frame attached to the module.
- Visual inspection of the modules to identify and locate visual defects that could affect the performance and aesthetics of the PV module.
- Inspection of mechanical stability of the framing attached to the modules and the anchoring system.

3.3.3 Coloured c-Si Mock-up

The monitoring system consists of a Seneca acquisition system, Raspberry pi 3b+ minicomputer and sensors.

The Seneca acquisition system will transform the analogue signals from the sensors in digital data that will be collected by the Raspberry pi 3b+ minicomputer. The Raspberry pi 3b+ offers a low cost and reliable solution for communication with the hardware and data collection and storage in cloud-based databases. Python is the programming language needed to achieve this purpose.

Next table collects all the variables instruments and sensors used in the monitoring system for the coloured c-Si Mock-up.

Table 6: Parameters and instruments in the coloured c-Si mock-up monitoring system.

PARAMETER	UNIT	Number	DEVICE	SENSOR	MEASUREMENT ACCURACY
String Voltage (V)	V	1	SENECA acquisition system	Seneca 202-LP	0.35%
String Current (A)	A	1	SENECA acquisition system	Seneca T201DC	0.6%
Plane of Array Irradiance	W/m2	1	SENECA acquisition system	Kipp & Zonen CMP11 pyranometer	0.1%
PV module and fixing system surface temperatures	°C	10	SENECA acquisition system	Seneca Z-4RTD2	0.1%

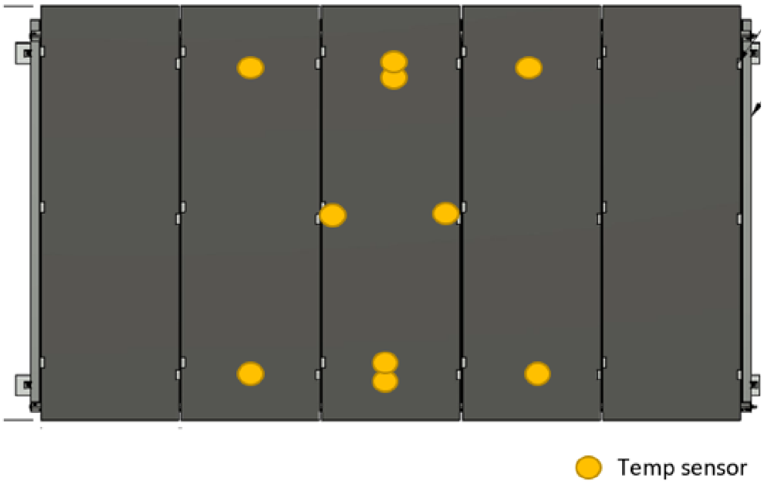


Figure 50. Position of temperature sensors on coloured c-si façade

Regarding data acquisition and recording, following the IEC 61724-1:2021, both systems (patterned a-Si and coloured c-Si) will comply the Class B medium accuracy monitoring. The recorded parameter values for each record will be the average of the samples acquired during the recording interval of 15min.

Table 7.: Sampling and recording interval requirements proposed by IEC 61724-1:2021.

	Class A High accuracy	Class B Medium accuracy
Maximum sampling interval For irradiance, temperature, wind and electrical output	5 s	1 min
Maximum recording interval	5 min (1 min – recommended)	15 min

3.3.4 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series in different resolutions. Yield benchmarking value is considered a Yearly PV energy production of ~890 kWh/kWp, based on a preliminary energy production simulation.
- Temperature analysis at different points on the rear surface of the modules including the frame attached to the module.
- Visual inspection of the modules to identify and locate visual defects that could affect the performance and aesthetics of the PV module.
- Inspection of mechanical stability of the framing attached to the modules and the anchoring system.

4 SUPSI

4.1 General information of facilities – SUPSI

The structures for the project mock-ups were built on the flat roof of the "New SUPSI's University Campus" in the city of Mendrisio, which can be found with the following geographical coordinates:

Latitude (λ): 45° 52,2’ N

Longitude (ϕ): 008° 58,6’ E

The flat roof of the building that houses the structures extends for a length of about 130m from the North East to the South-West and all the mock-ups are oriented towards the South (about 45 degrees with respect to the longitudinal line). The SUPSI structures host 3 different innovative BIPV solutions involving 4 manufacturers (ONYX, PIZ, FLISOM, and SCHWEIZER).

Each BIPV product will have its own dedicated mockup independent of the others in terms of energy generation with its own sensors for the acquisition data. Each mock-up has been built according to the intended use of the technology to be tested.

SUPSI's choice for mock-up monitoring is to use IV tracking tools and not an inverter connected to the grid. Therefore, all mock-ups are not connected to the network and the electrical characteristics are detected by a single module or at most by two / three modules in series. In this way, it is possible to compare the energy of different modules and not have all the modules connected in series to form a single string or a small plant.

The Onyx BIPV modules (made of glass-glass with bifacial crystalline cells) will be mounted to form a balustrade, the photovoltaic roof tiles produced by Flisom-Schweizer will be mounted on mock-ups that reconstruct a portion of an inclined roof, and finally the modules e-PIZ by PIZ - ONYX manufacturers will be mounted on mock-ups that reproduce a portion of the building's facade.

Compared to the climatic conditions, in Mendrisio, there is a warm and temperate climate with significant rainfall throughout the year.

According to the Köppen and Geiger classification, the climate has been classified as Cfb (Cf: temperate climates with humid summer - b: average temperature of the hottest month below 22 ° C; at least 4 months above 10 ° C.

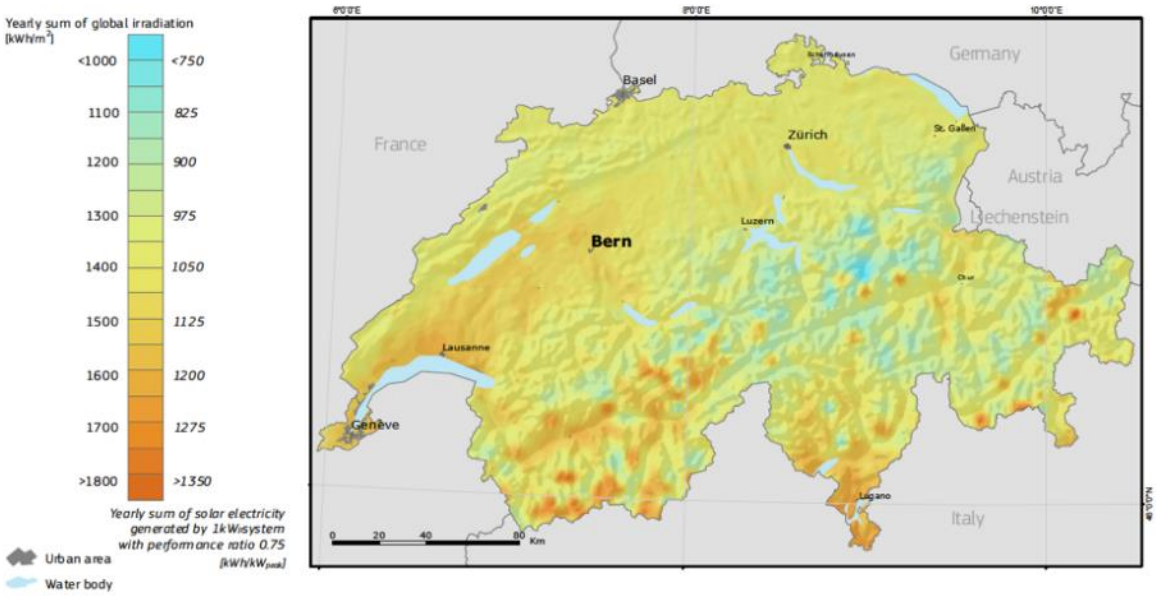


Figure 51: Optimally-inclined photovoltaic modules in Switzerland, Source: PVGIS

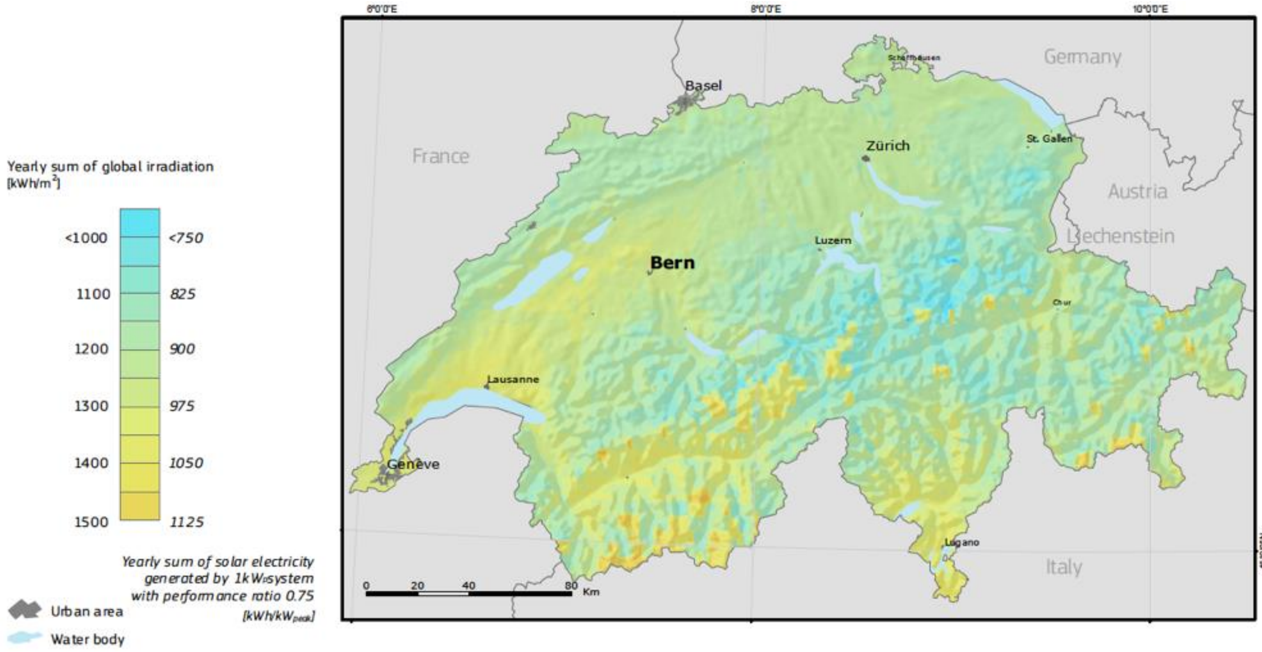


Figure 52: Horizontally mounted photovoltaic modules in Switzerland, Source: PVGIS

Figure 53: Satellite picture to identify location of SUPSI's building

The building of the New SUPSI Campus is located in the urban context of Mendrisio's city next to the railway line; rectangular in shape, it develops parallel to it. All the facilities necessary for the evaluation of the BIPV modules have been placed on the roof.

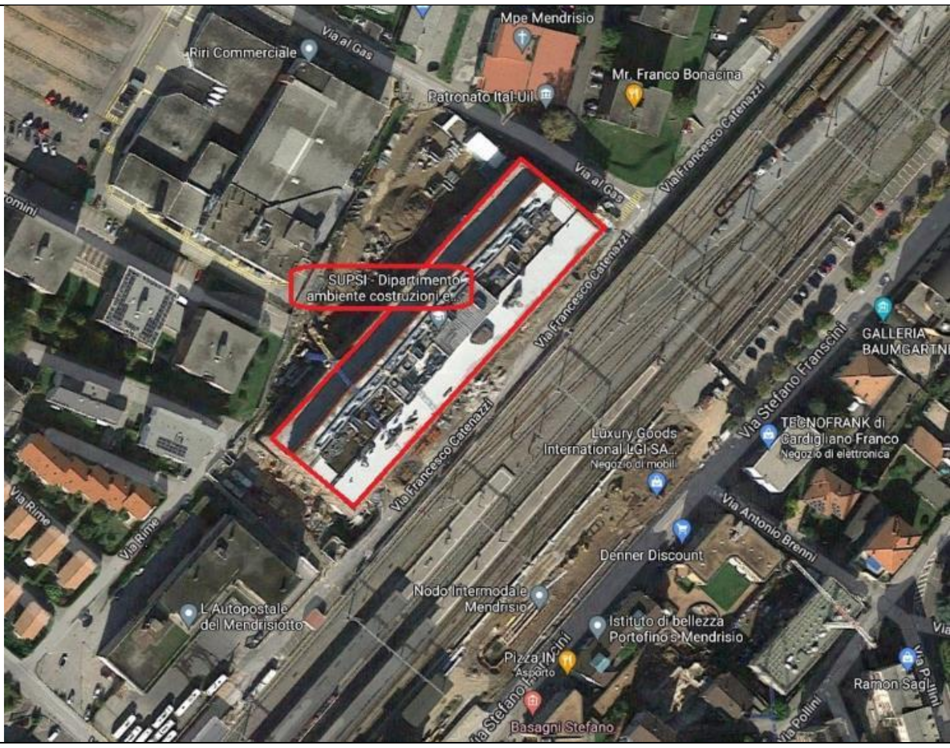


Figure 54: Satellite picture to identify location of facilities where mock-ups will be installed - Switzerland

With a height greater than surrounding buildings, the roof area occupied for test stands building is not subject to shading apart from topographic profile of the horizon due to the mountains. However, the positioning of the project mock-ups can be considered as well exposed.

Considering the shape of the roof, narrow and long, the diagram of the solar horizon with the shading mask is shown below for the middle position. Each mockup is built to accommodate a different BIPV product typology and with a different angle of tilt of the active surface with respect to the horizontal plane and, in some cases with a different azimuth angle. The three different mock-ups are described below.

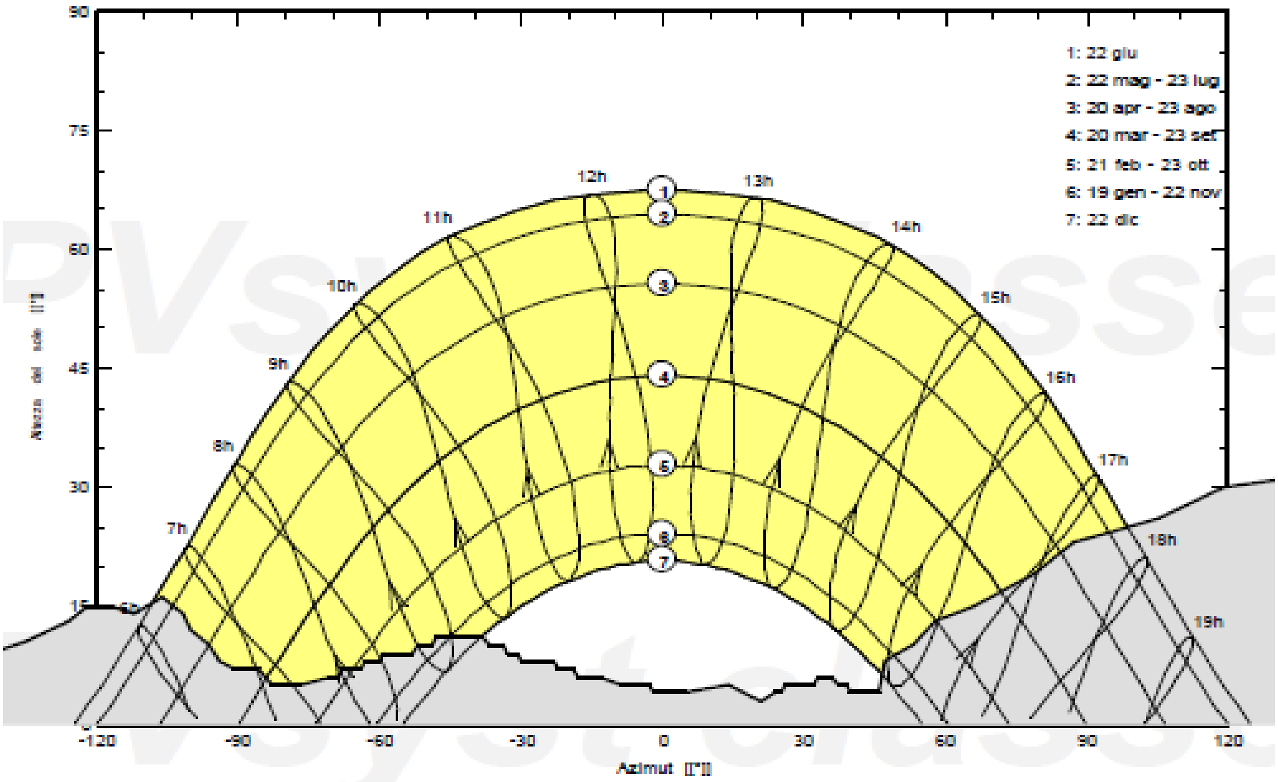


Figure 55: Horizon profile of the SUPSI building roof - Mendrisio, Switzerland

4.2 Mock-ups and layout descriptions – SUPSI

4.2.1 e-PIZ Mock-up and layout descriptions – SUPSI

This BIPV product is based on a facade cladding system, namely a Veture kit – Prefabricated units for external wall insulation and their fixing devices.

The BIPVBOOST product ePIZ, object of monitoring, is a composite element consisting of an 80 mm thick layer of rockwool insulation coupled with a 9 mm thick layer of mortar, as external cladding support, to which a photovoltaic laminated glass produced by Onyx is added by adhesion.

The laminated glass' design is reported in the following image.

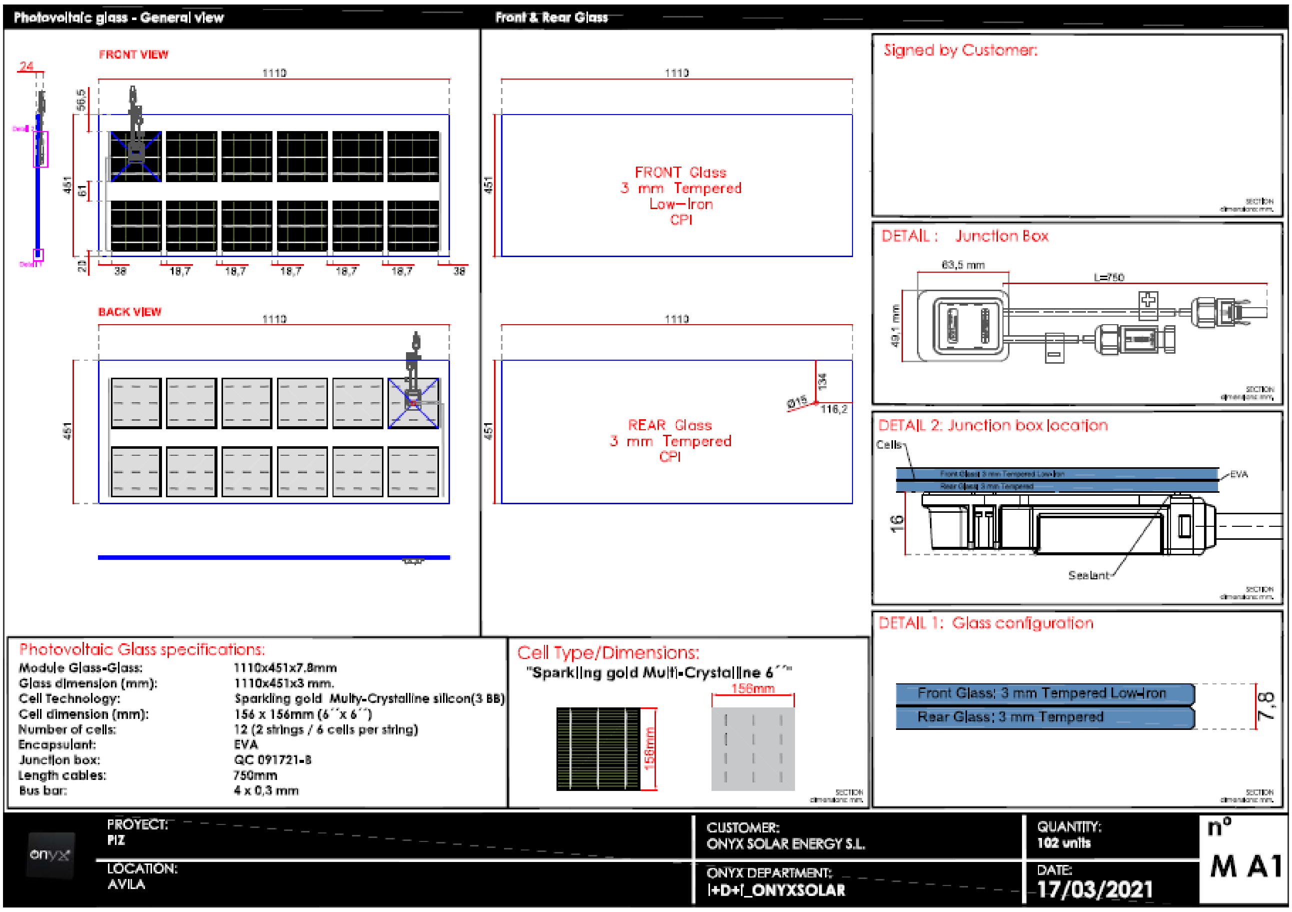


Figure 56: Onyx laminated glass design for e-PIZ

The mockup made at SUPSI for the e-PIZ product simulates a vertical wall to which the composite BIPV cladding will be fixed.

In the following image wall-mounted e-PIZ prototypes.

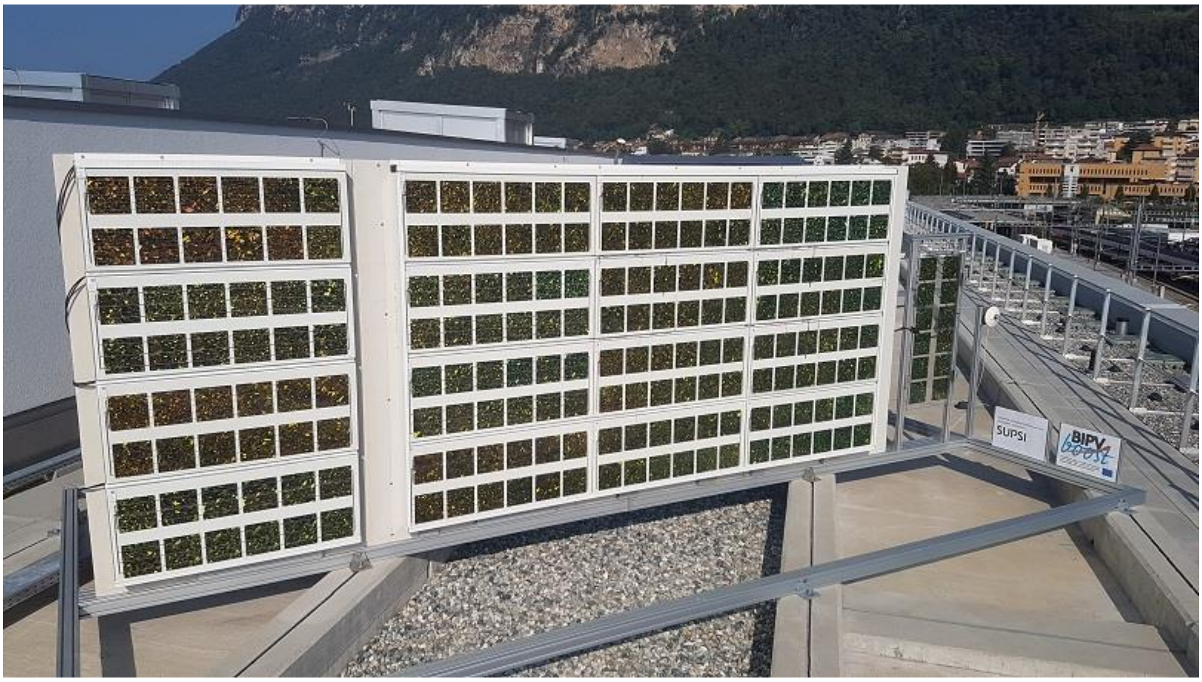


Figure 57: e-PIZ mockup in SUPSI

The mounting system is made up of horizontal aluminum H profiles, fixed to the wall by means of special plugs, and vertical PVC T profiles. Additional aluminum safety clamps are used to provide additional safety mechanical retention to the system.

Figure 58: Aluminium H-profile placed inside the upper horizontal grooves

Figure 59: Middle safety clamp between two PV modules.

The load-bearing frame of the mock-up is made with aluminum BSO and steel box profiles with a rectangular section that creates the support structure.

Figure 60: e-PIZ mockup support structure

In order to simulate the vertical wall support, the Knauf AQUAPANEL® slab was used to which the profiles and then the e-PIZ modules will be mounted.

The electrical characteristics of the modules are shown below.

PHOTOVOLTAIC GLASS	1.110 x 451	
Sparkling gold 16.3-16.1%	6" Poly Color	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	47	P_{mpp} (Wp)
Open-circuit voltage	7	V_{oc} (V)
Short-circuit current	8,22	I_{sc} (A)
Voltage at nominal power	6	V_{mpp} (V)
Current at nominal power	7,68	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	1110	mm
Width	451	mm
Thickness	7,8	mm
Surface area	0,50	sqm
Weight	7,5	Kgs
Cell type	6" Poly Color	Crystalline sparkling gold
No PV cells / Transparency degree	12	42%
Front Glass	3 mm	Tempered Glass Low-Iron
Rear Glass	3 mm	Tempered Glass
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

GLASS PROPERTIES	Onyx Equivalent Glass
Light Transmission	42%
U-value [W/sqm.K]	-
Peak Power [Wp/sqm]	93,7

Figure 61: Electrical data of the e-PIZ modules

With an azimuth angle of 180 degrees (SOUTH) and tilt angle of 90 degrees (vertical wall), it is made up of 16 modules arranged in 4 rows by 4 columns. Adjacent to the mock-up an identical photovoltaic laminated glass was positioned in order to compare the temperature and energy data.

The first column made by 4 e-PIZ modules will be separately investigated and dedicated to an aesthetic evaluation in outdoor conditions in the relation with the behavior of hygroscopic materials. In this part, the sealing profile is not mounted continuously but in pieces to allow water penetration without flashings. The modules are constructed as follows:

- M1 silicone on the entire edge;
- M5 silicone on the edge with two holes at the bottom;
- M9 without perimeter sealing;
- M13 silicone only on the four edges.

The other modules are analyzed in small strings up to three modules or individually according to the scheme shown in the following image. All the modules are not grid-connected but connected to IV tracking tools.

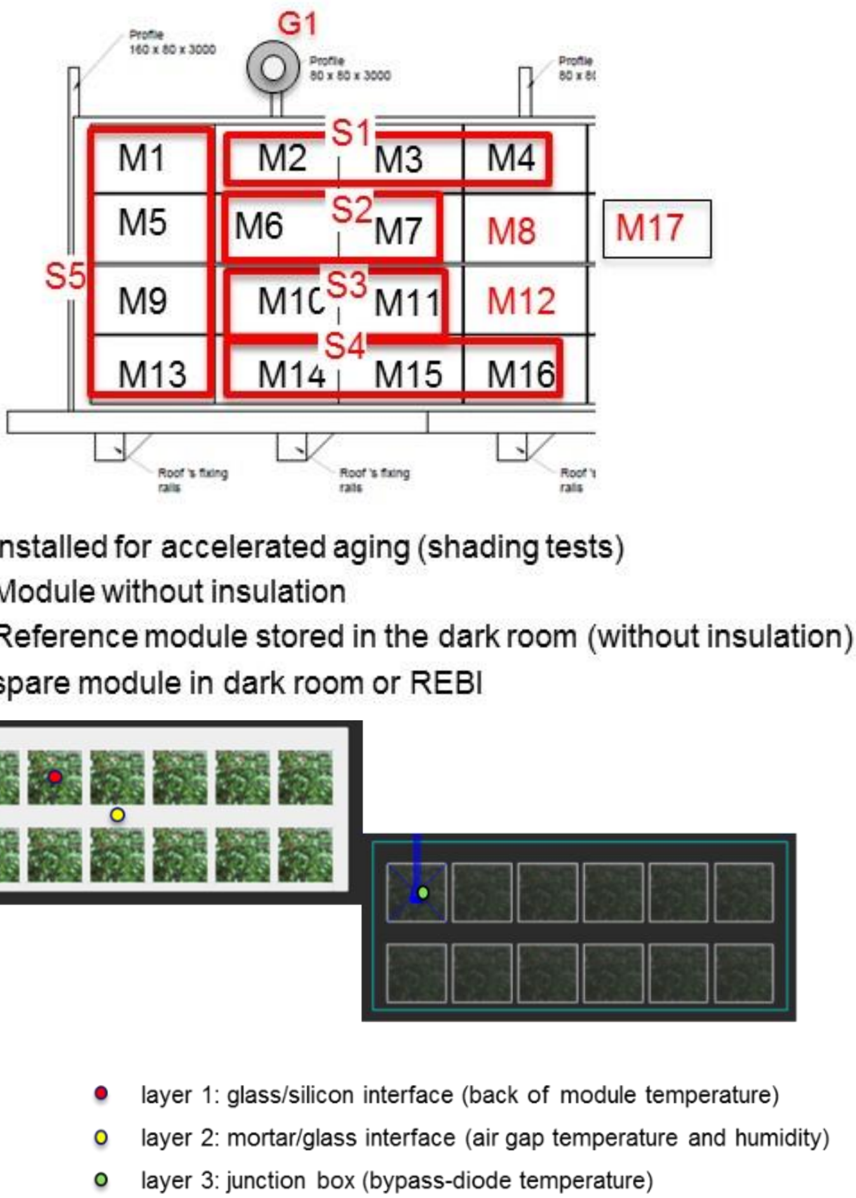


Figure 62: PIZ modules distribution

Parameter	Hardware	Output data	channels
Module/string performance	Gantner OTF (MPP tracking + IV)	IV-curve (1min) → I_m, V_m, P_m, I_{sc}, V_{oc}, R_s, R_{sh}	S1, S2, S3, S4, S5, M8, M12, M17
Layer temperatures	PT100	$T_{module,layer}$ (1min)	($T_{3.1}$), $T_{7.1}$, $T_{11.1}$, ($T_{15.1}$), $T_{8.1}$, $T_{12.1}$, $T_{17.1}$ ($T_{7.2}$), $T_{8.2}$, $T_{12.2}$ ($T_{7.3}$), $T_{8.3}$, $T_{12.3}$, $T_{17.3}$
Irradiance	Kipp & Zonen pyranometer	G_i (1min)	G1
Rel. humidity	tbd	$RH_{module,layer}$ (1min)	$RH_{7.2}$, ($RH_{8.2}$), ($RH_{12.2}$)

Figure 63 e-PIZ modules position and monitoring scheme

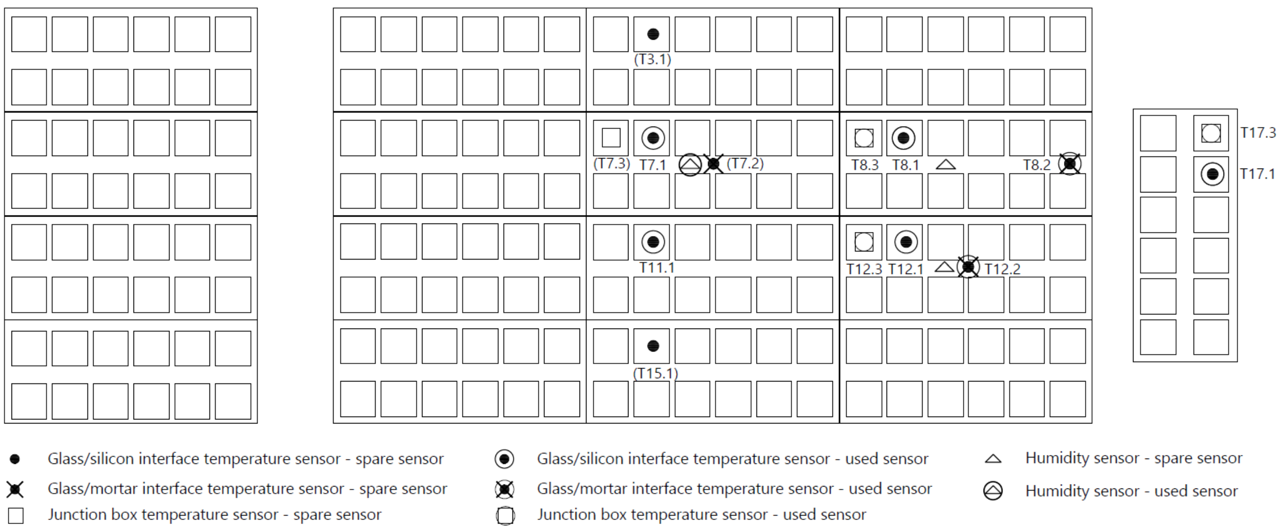


Figure 64: Sensors positioning

To monitor the mockup, the use of Gantner's OTF data acquisition system, PT100 temperature probes, and humidity sensors is envisaged. The OTF system is able to perform an MPPT tracing, to detect the IV curve and the main voltage and current parameters over the shunt and parallel resistances. A pyranometer positioned vertically and centrally to the part provides the irradiation data of the mockup.

Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of different sub-strings/modules, stability over time. Yield benchmarking value is considered a Yearly PV energy production of 800kWh/kWp
- Temperature analysis: back-of module operating temperature distributions and dependencies of integrated and open-rack mounted modules, non-uniformities within the facade, JB and layer temperatures, determination of 98th percentile operating module temperature according to IEC TS 63126
- Humidity penetration trends mortar/glass during operation (humidity sensors)

- Hygrothermal behavior in string S5: humidity penetration for different sealing approaches (visual/optical comparison)
- Visual inspection of single modules

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

4.2.2 Flisom/Schweizer Mock-up and layout descriptions – SUPSI

The second mock-up at SUPSI was built to test Schweizer-Flisom's shingle for discontinuous roof tiling in pitched roof. The photovoltaic shingle is made of CIGS active layer deposited on metal sheet with a special completion frame to complete the solar roof tiles. With a special fixing system, shingles are placed on the pitches of the roofs as a roof tiling system able to replace the conventional roofing materials. The mock-up simulates a portion of an opaque inclined roof pitch with a discontinuous tiling.

Figure 65: Flisom Schweizer mockup built in SUPSI- frontal image

Figure 66: Flisom Schweizer mockup built in SUPSI – lateral image

With an azimuth angle of 180 degrees (SOUTH) and a tilt angle of approximately 25 degrees (sloping roof), it consists of 15 modules arranged in 3 rows by 5 columns. The modules used are of different sizes in order to evaluate the behaviour of both types used. The product data-sheet is reported below.

Manufacturer:	Ernst Schweizer AG
Name	CIGS_BIPV_1x1V
Width [mm]:	853
Height [mm]:	487
Thickness [mm]:	17
Weight (kg)	4
Nominal Power [Watt]:	30
Module Type:	CIGS
Temperature coefficient [%/°C]:	-0.35
Efficiency STC:	0.087
Output current MPP - STC [A]:	0.84
Output voltage MPP - STC [V]:	34
Short circuit current [A]:	0.97
Open circuit voltage [V]:	46
Temperature coefficient Current [%/K]:	0.01
Temperature coefficient Voltage [%/K]:	-0.3
Max. System voltage EU:	1000
Max module backcurrent [A]	10
Galvanic seperation required:	No

Manufacturer:	Ernst Schweizer AG
Name	CIGS_BIPV_2x1V
Width [mm]:	853
Height [mm]:	888
Thickness [mm]:	17
Weight (kg)	3
Nominal Power [Watt]:	60
Module Type:	CIGS
Temperature coefficient [%/°C]:	-0.35
Efficiency STC:	0.081
Output current MPP - STC [A]:	0.88
Output voltage MPP - STC [V]:	34
Short circuit current [A]:	1.94
Open circuit voltage [V]:	46
Temperature coefficient Current [%/K]:	0.01
Temperature coefficient Voltage [%/K]:	-0.3
Max. System voltage EU:	1000
Max module backcurrent [A]	10
Galvanic seperation required:	No

Figure 67: Schweizer tiles data sheet

The roof structure is built on a load bearing metal frame, on which a rigid structural layer made by an OSB/3 board is fixed. An external insulation of 160 mm is made with XPS, and a moisture control sheet ensure an adequate transpirability and additional watertightness to the roof. The roof tiling is ventilated thanks to a double order of wooden roof battens (40+40mm) allowing thermal chimney effect in order to reproduce the real construction and hygrothermal conditions of a roof.

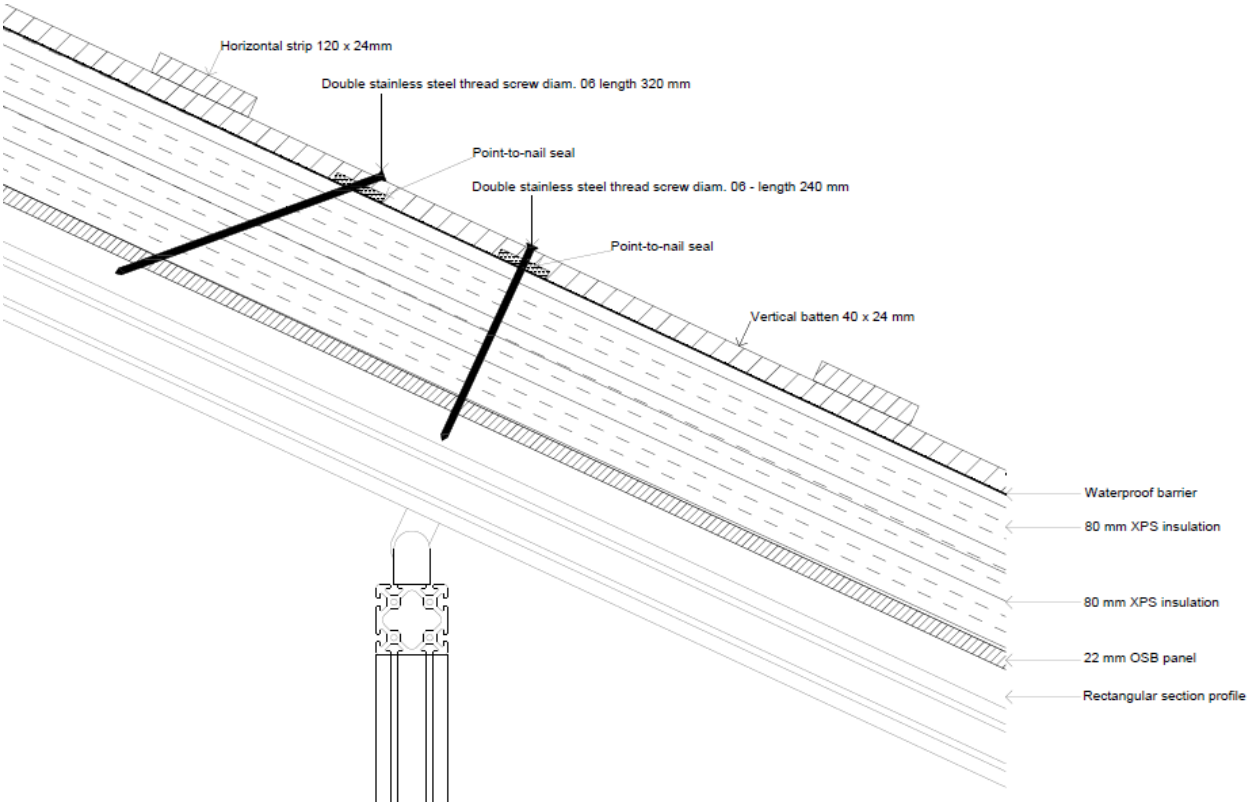


Figure 68: SUPSI mockup roof layers

As with the PIZ mockup, the Gantner OTF data acquisition system, with PT100 temperature probes and humidity sensors, will be used to monitor the mock-up. In addition to measuring the module temperature, the air temperature between modules and the foil temperature will be detected.

The entire roof was electrically divided into small strings and individual modules as reported in the following image by using an OTF system to detect the MPPT, the IV curve, and the main voltage and current parameters over the shunt and parallel resistances. A pyranometer is positioned at the top in a central position with the same inclination of the roof pitch to acquire the irradiation data.

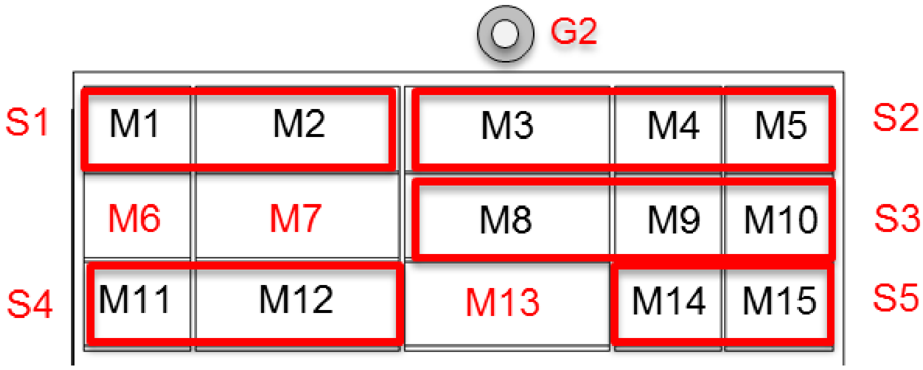
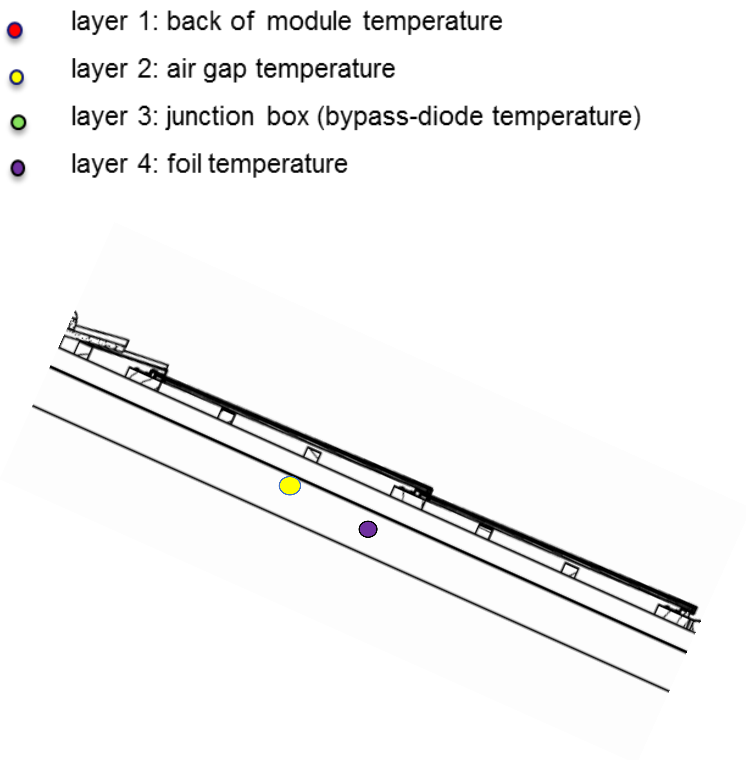


Figure 69: Flisom modules position and subdivision in strings or single modules



Parameter	Hardware	Output data	channels
Module/string performance	Gantner OTF (MPP tracking + IV)	IV-curve (1min) → I_m, V_m, P_m, I_{sc}, V_{oc}, R_s, R_{sh}	S1, S2, M6, M7, S3, S4, M13, S5
Layer temperatures	PT100	$T_{module,layer}$ (1min)	$T_{2.1}$, $T_{4.1}$, $T_{6.1}$, $T_{7.1}$, $T_{9.1}$, $T_{12.1}$, ($T_{14.1}$) $T_{8.2}$, ($T_{7.2}$) $T_{3.3}$, ($T_{6.3}$), ($T_{2.3}$), $T_{8.3}$, ($Troof_{7.4}$), $Troof_{8.4}$
Irradiance	Kipp & Zonen pyranometer	G_i (1min)	G2
Rel. humidity	Honeywell HIH-4010	RH_{air} (1min)	$RH_{8.2}$, ($RH_{9.2}$)

Figure 70: Flisom-Schweizer tiles monitoring scheme

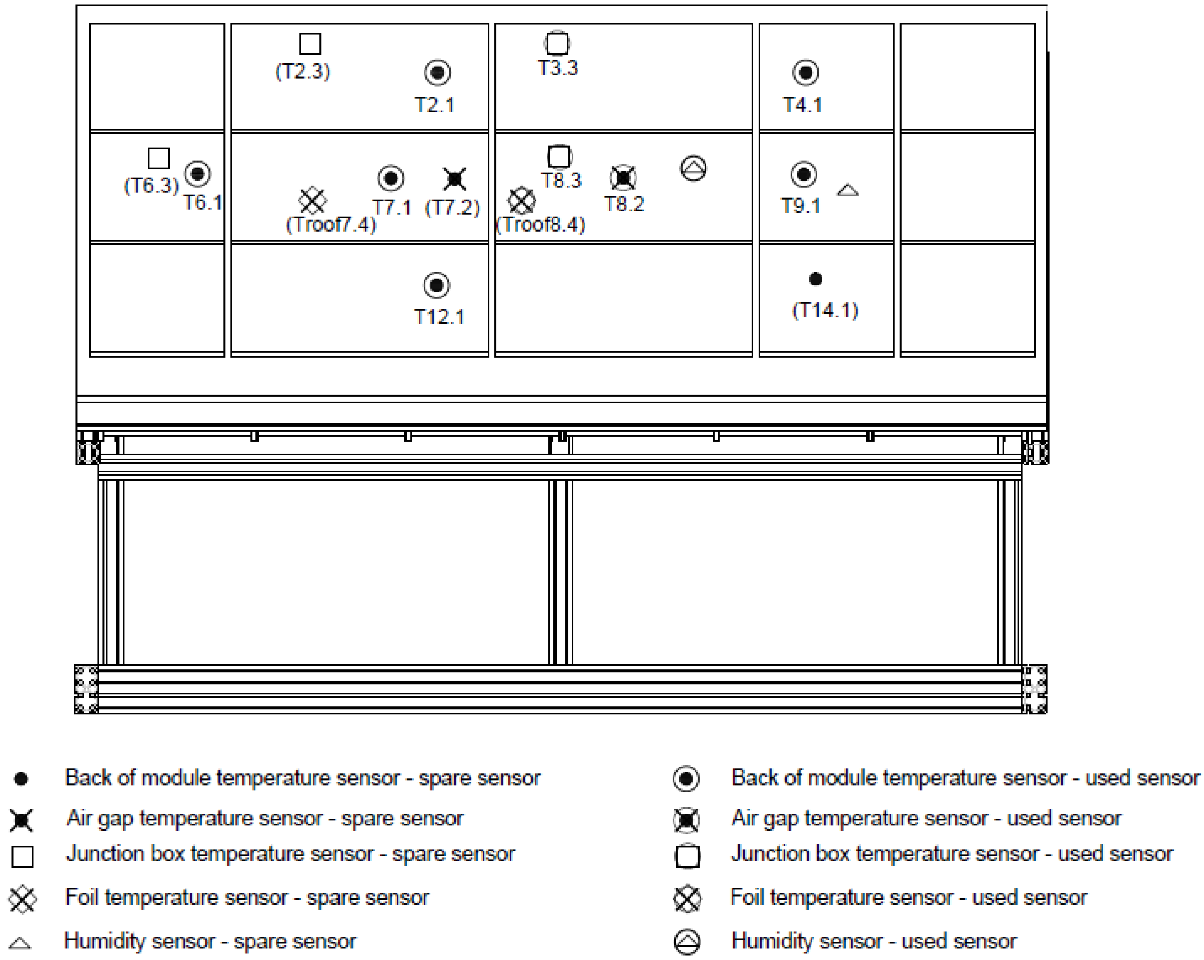


Figure 71: Sensors positioning

Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of different sub-strings/modules, stability over time. Yield benchmarking value is considered a Yearly PV energy production of 1'120 kWh/kWp
- Temperature analysis: back-of module operating temperature distributions and dependencies of ventilated modules, non-uniformities within the roof, JB and layer temperatures, determination of 98th percentile operating module temperature according to IEC TS 63126
- Air temperature and humidity levels in the ventilated roof during the roof operation
- Visual inspection of all modules

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

4.2.3 ISFOC balustrade Mock-up and layout descriptions – SUPSI

This mock-up consists of a semi-transparent PV laminated glass produced by ONYX for the ISFOC demo balustrades.

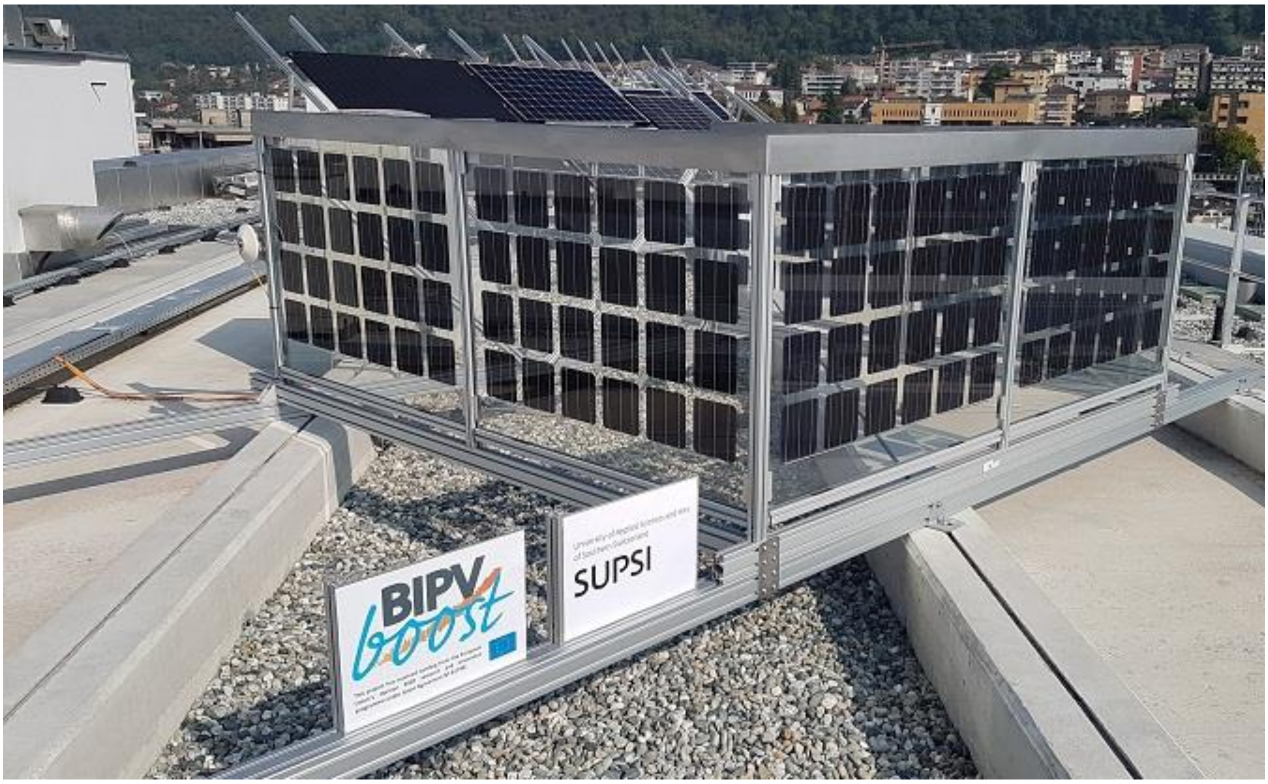


Figure 72: ISFOC balustrades mock-up built in SUPSI

Figure 73: ISFOC balustrades mock-up built in SUPSI

The mock-up was built with a shape able to reproduce normal installation scenarios and the interference that the glasses of the balustrade creates between them in terms of self-shadows and reflections effects.

The mock-up consisting of 6 glasses is designed to have three different exposures with 2 glasses on each side. Each PV glass is independent of others and is monitored individually, even in this case, there is no inverter and the modules are not grid-connected.
These glass-glass BIPV modules are made up of two glasses of 10mm each and bifacial crystalline silicon cells, below the data sheet.

PHOTOVOLTAIC GLASS	1.190 x 880 6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	102	P_{mpp} (Wp)
Open-circuit voltage	15	V_{oc} (V)
Short-circuit current	8,67	I_{sc} (A)
Voltage at nominal power	13	V_{mpp} (V)
Current at nominal power	8,08	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	1190	mm
Width	880	mm
Thickness	21,8	mm
Surface area	1,05	sqm
Weight	52	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	47%
Front Glass	10 mm	Tempered Glass Low-Iron
Rear Glass	10 mm	Tempered Glass Low-Iron
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

** NOMINAL REAR POWER OUTPUT AT 50%

Figure 74: Balustrade's electrical data sheet

Details and glasses' dimensions are reported below.

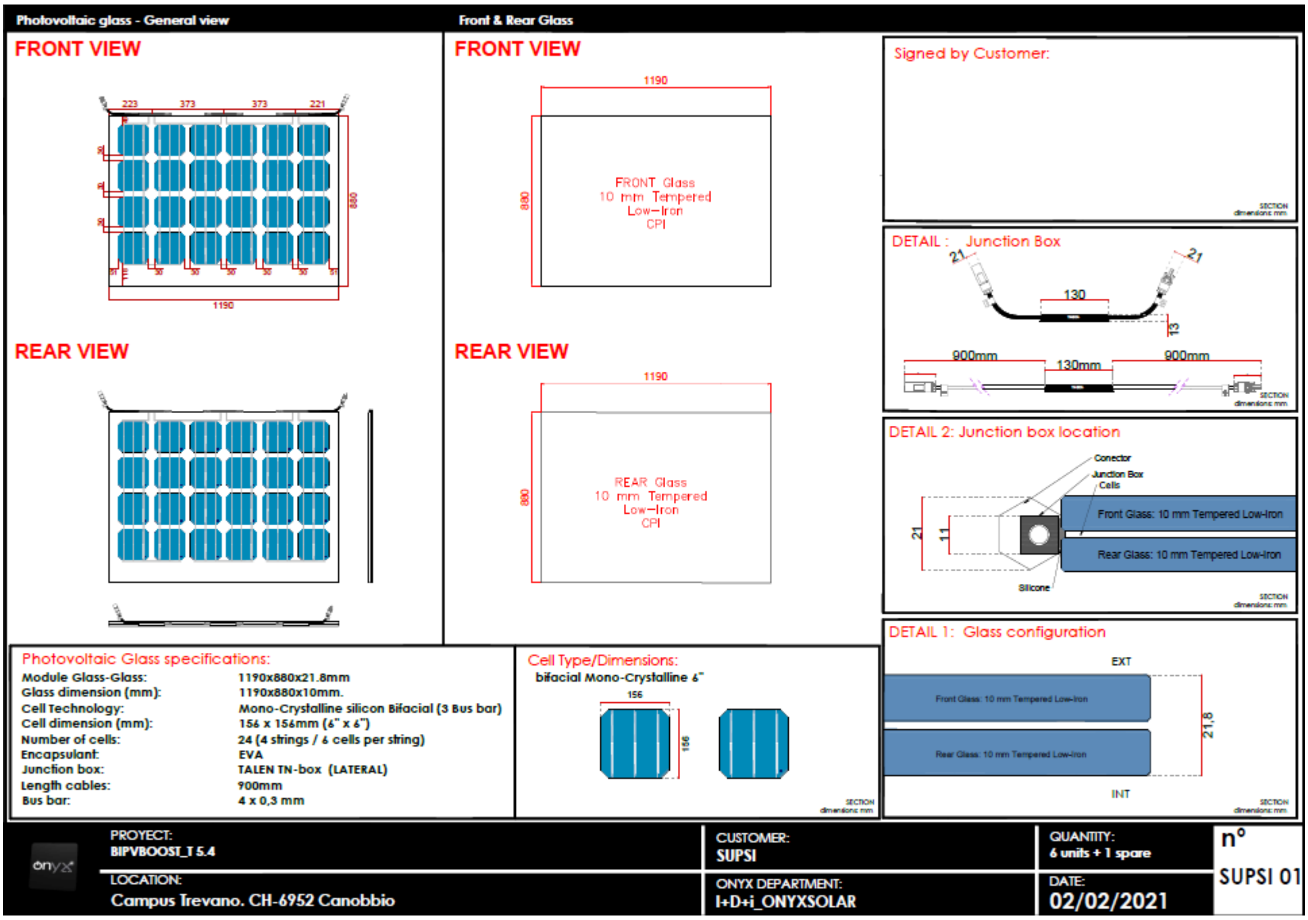


Figure 75: Details and dimension of balustrades

The IV curve is detected by an MPPT tracking and PT100 temperature probes have been used for the analysis of the glass temperatures. Compared to the other mock-ups for monitoring, the MPPT3000 system will be used also for data acquisition.

Since the mock-up consists of double-sided cells, pyranometers are provided to detect the irradiation on the 3 exposures by analysing the front and back. The following image shows the monitoring scheme.

Parameter	Hardware	Output data	channels
Module performance	MPPT3000	IV-curve (5min) → I_m, V_m, P_m, I_{sc}, V_{oc}, R_s, R_{sh}	M1, M2, M3, M4, M5, M6
Module temperature	PT100 (small/transparent glue)	$T_{module,position}$ (1min)	$T_{1,1}$, $T_{2,1}$, $T_{3,1}$, $T_{4,1}$, $T_{5,1}$, $T_{6,1}$ $T_{2,2}$, $T_{3,2}$, $T_{5,2}$ $T_{2,3}$, $T_{3,3}$, $T_{5,3}$
Irradiance front	Kipp & Zonen pyranometer	$G_{module\ plane,front}$ (1min)	G_3, $G_{1,front\ (G1e\text{-}PIZ)}$, G_5
Irradiance back	Kipp & Zonen pyranometer	$G_{module\ plane,back}$ (1min)	G_5, G_4, G_3

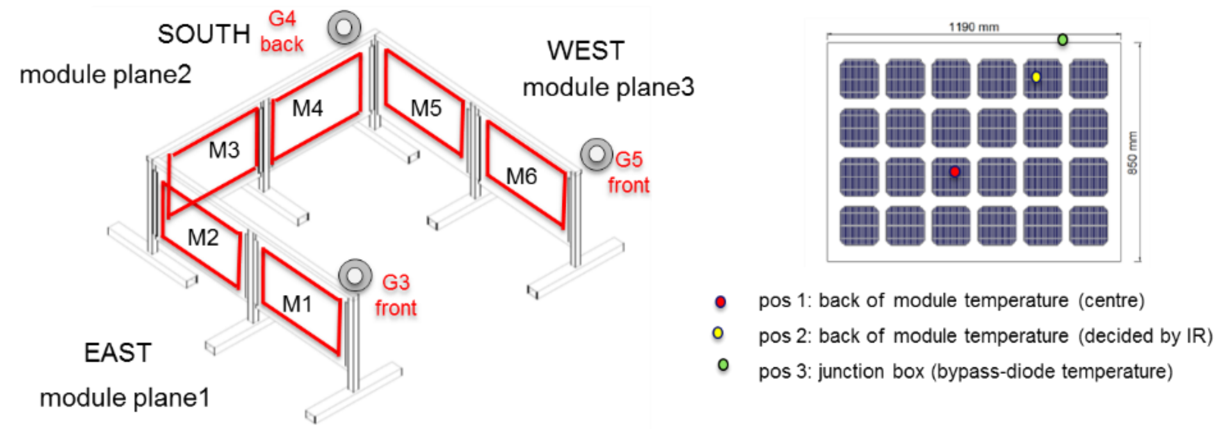


Figure 76: ISFOC balustrades monitoring scheme

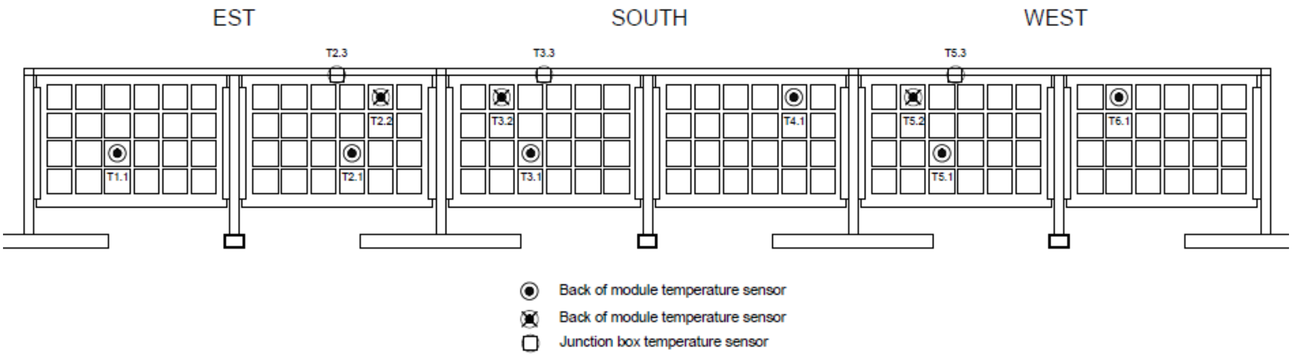


Figure 77: Sensors positioning

Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV system:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of differently oriented modules, bifacial gains. Yield benchmarking value is considered a Yearly PV energy production of 810 kWh/kWp (south oriented pane, front side), 290 kWh/kWp (west) and 360 kWh/kWp (east)[1].

- Identification of effects of self-shadings on above performance
- Temperature analysis: back-of module operating temperature distributions and dependencies, non-uniformities within the balustrade, JB and layer temperatures, determination of 98th percentile operating module temperature according to IEC TS 63126
- Visual/optical verification of aesthetical characteristics (opacification, yellowing...)

As result of the analysis, reference performance for the product operation will be established with the relative KPIs.

4.3 Measurements and monitoring descriptions – SUPSI

For monitoring the performance of the modules SUPSI uses two different hardware solutions. The first is the OTF Gantner system, a commercial system, while the second is the MPPT3000, entirely developed and produced by SUPSI. All the equipment is calibrated before its installation.

For the mock-up of the facade modules (cladding system) of PIZ, the use of the Gantner system was chosen as well as for the Schweizer-Flisom solar roof tiles. For the mock-up with the ISOFOC laminated photovoltaic glass balustrades, the MPPT3000 system was chosen.

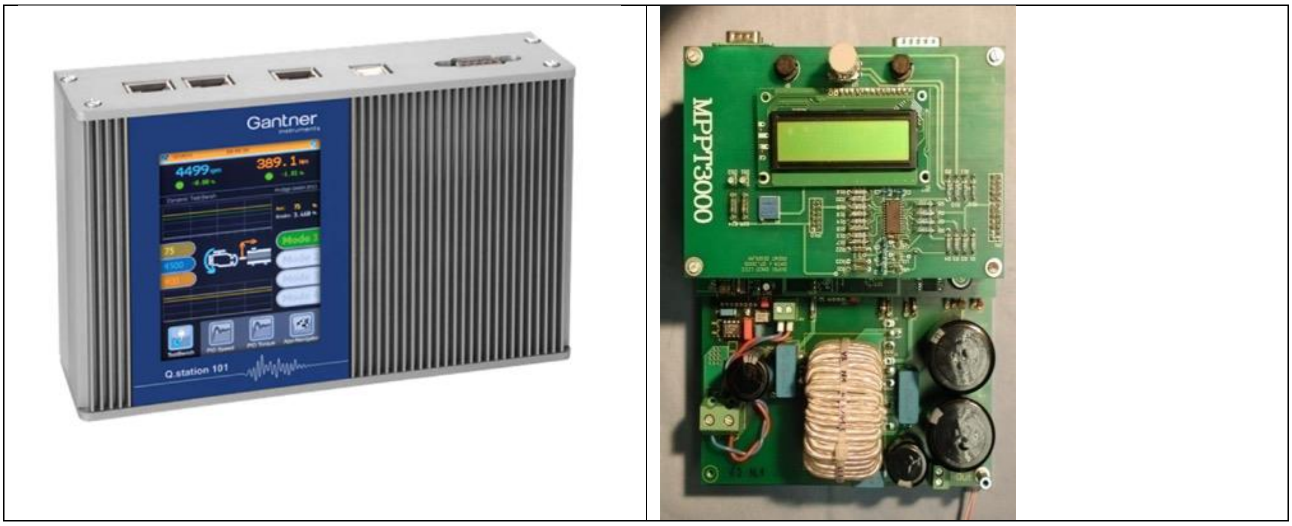


Figure 78: Image of the two different monitoring systems

The characteristics and differences between the two systems used are shown in the following table.

Table 4.1: Characteristics and differences among two monitoring systems

Features	OTF	MPPT3000

[1] values determined through a preliminary simulation. A more detailed assessment of local and self-shading effects, will be done during the data analysis

IV curve	1 quadrant, 4 wire meas. max 200V, 20A, 500W; 800W short time 24bit, 100kHz max IV sweep time: 1 sec IV interval: 1 min	1 quadrant, 4 wire meas. max. 150V, 20A, 250W; 600W short time 14bit, 35Hz IV sweep time: 1 sec IV interval: 5 min
MPP tracking	Passive tracking adjusted after each IV measurement	Active tracking Im, Vm data storage every 1 minute
Aux input (RTD, Gi, ecc.)	Extendable channels; 24 bit, 10kHz max	3 channels/unit; 24bit, same interval as MPP

For the acquisition of all environmental data, a weather station is installed that detects the main environmental parameters such as ambient temperature, wind speed and rainfall, and so on.

Table 4.2: Metereological parameters description

Parameter	Abbr.	Hardware description
METEOROLOGICAL PARAMETERS		
Global plane of array irradiance	Gpoa	Secondary standard pyranometer (Kipp & Zonen)
Global horizontal irradiance	Gh	Secondary standard pyranometer (Kipp & Zonen)
Diffuse horizontal irradiance	Dh	Secondary standard pyranometer (Kipp & Zonen)
Wind speed and direction	WS, WD	Vaisalla WXT536
Relative air humidity	RH	
Precipitation	pr	
Ambient temperature	Tamb	

Compact temperature probes (PT100 model) are used to acquire temperature data on modules installed in mock-ups for precise point detection and rapid response.

Honeywell's HIH-4010/4020/4021 series sensors are used for moisture detection, offering excellent resistance to most application hazards such as wetting, dust, dirt, oils, and common environmental chemicals.

The following table summarizes the parameters, the abbreviation used and the description of the hardware used.

Table 4.3: Sensors description

PV MODULE/STRING PARAMETERS		
Module/layer temperatures	Tx	PT100 - Thermal Tab^{TM} Sensors
Layer humidity	RH_l	Honeywell HI-4010/4020/4021 Series – Humidity Sensors
Maximum power	Pm	Gantner (OTF system) or SUPSI (MPPT3000)
Short circuit current	Isc	
Maximium power current	Im	
Open circuit voltage	Voc	
Maximum power voltage	Vm	

5 TECNALIA

5.1 General information of facilities – TECNALIA

KUBIK by TECNALIA is a full-scale R&D test facility for the development of new concepts, products and services in order to improve energy efficiency in buildings. KUBIK building is located next to TECNALIA's facilities in Derio, close to the northern coastline of Spain (43°17'N 2°52'W).

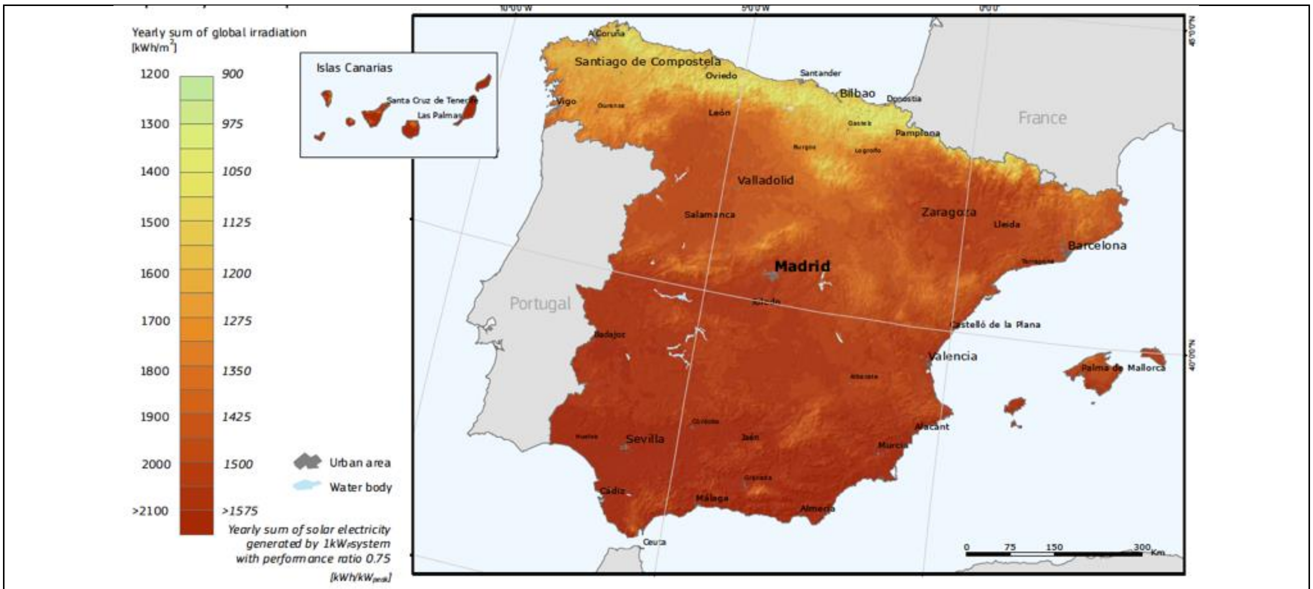
KUBIK offers a flexible infrastructure for the testing and validation of realistic scenarios with different building components and systems; their assembly and disassembly is a critical aspect supported by KUBIK, permitting not only service performance assessment but also aiding the development and evaluation of assembly and erection procedures. KUBIK allows the validation of products or systems in conditions close to those of service. This testing process speeds up the product development and reduces the risk of malfunction of highly innovative products or products without previous experiences on the marketplace. The experimentally obtained results enable diagnoses and proposals for potential product improvements to be made.

TECNALIA has transferred the concept of the Digital Twin to KUBIK building. The digital twin offers the operator a synchronisation between the physical and virtual world of the building in real time. This platform exploits the static and dynamic information extracted automatically from advanced BIM models, through powerful technologies such as Machine-Learning, the Internet of Things and Big Data.

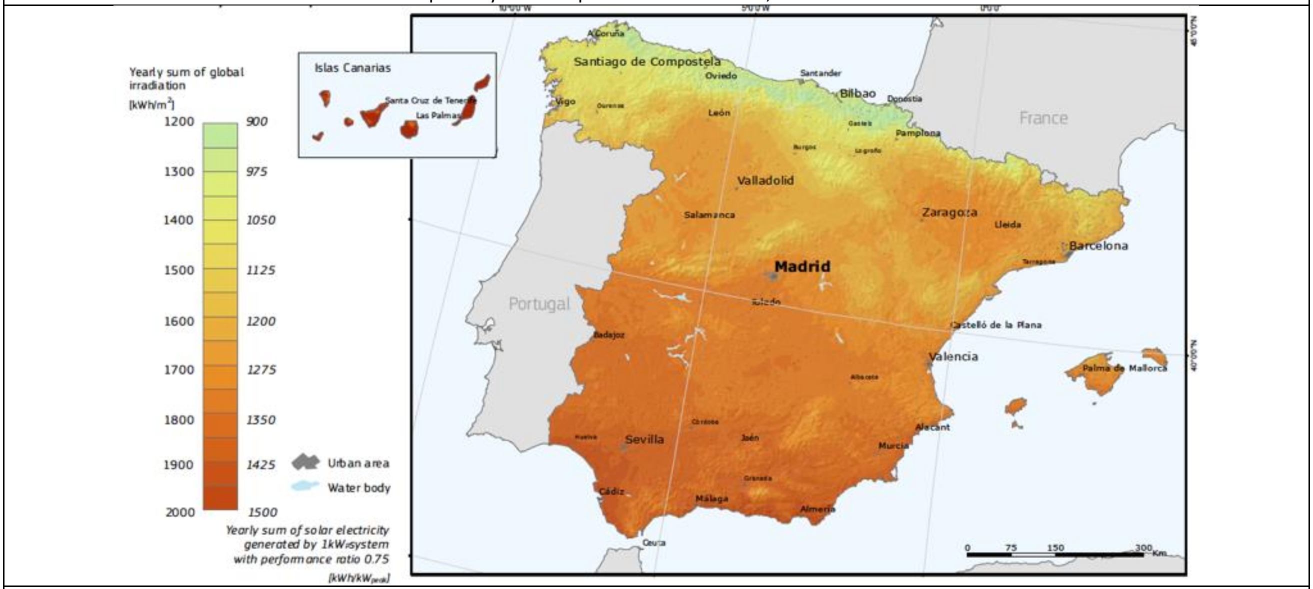
KUBIK Digital Twin has the following infrastructure:

- 3,500 sensors and actuators; that allow a total control of each one of the elements of the installation.
- Singular and experimental thermal systems:
  - Heat Pump coupled to PCM thermal storage battery.
  - Solar thermal installation and absorption heat pump
  - Cogeneration system and availability of PV and wind through electrical connection with a micro-grid.
- IoT node for data interconnection, where different market technologies coexist for the monitoring and control of facilities. (Modbus, Backnet, KNX, Dali, Z-wave, EnOcean, LORA,...)
- It has a complete system of monitoring and control that allows to carry in parallel up to 10 digital experiments of the building.
- Virtualization Environment. BIM-MEP model of the building connected in real time with the building's infrastructure. Allowing a complete monitoring of the installation.
- Hadoop and Spark environment for Big Data based simulation and data serialization of installation behaviour

According to the Köppen-Geiger classification, the climate zone is Cfb: "warm temperate" (C), "fully humid" (f) and with "warm summer" (b). This climate zone covers most of Central and Western Europe, including the British Irelands.



Optimally-inclined photovoltaic modules, Source: PVGIS



Horizontally mounted photovoltaic modules, Source: PVGIS

Figure 79: Potential irradiation for optimized and horizontal elements - Spain

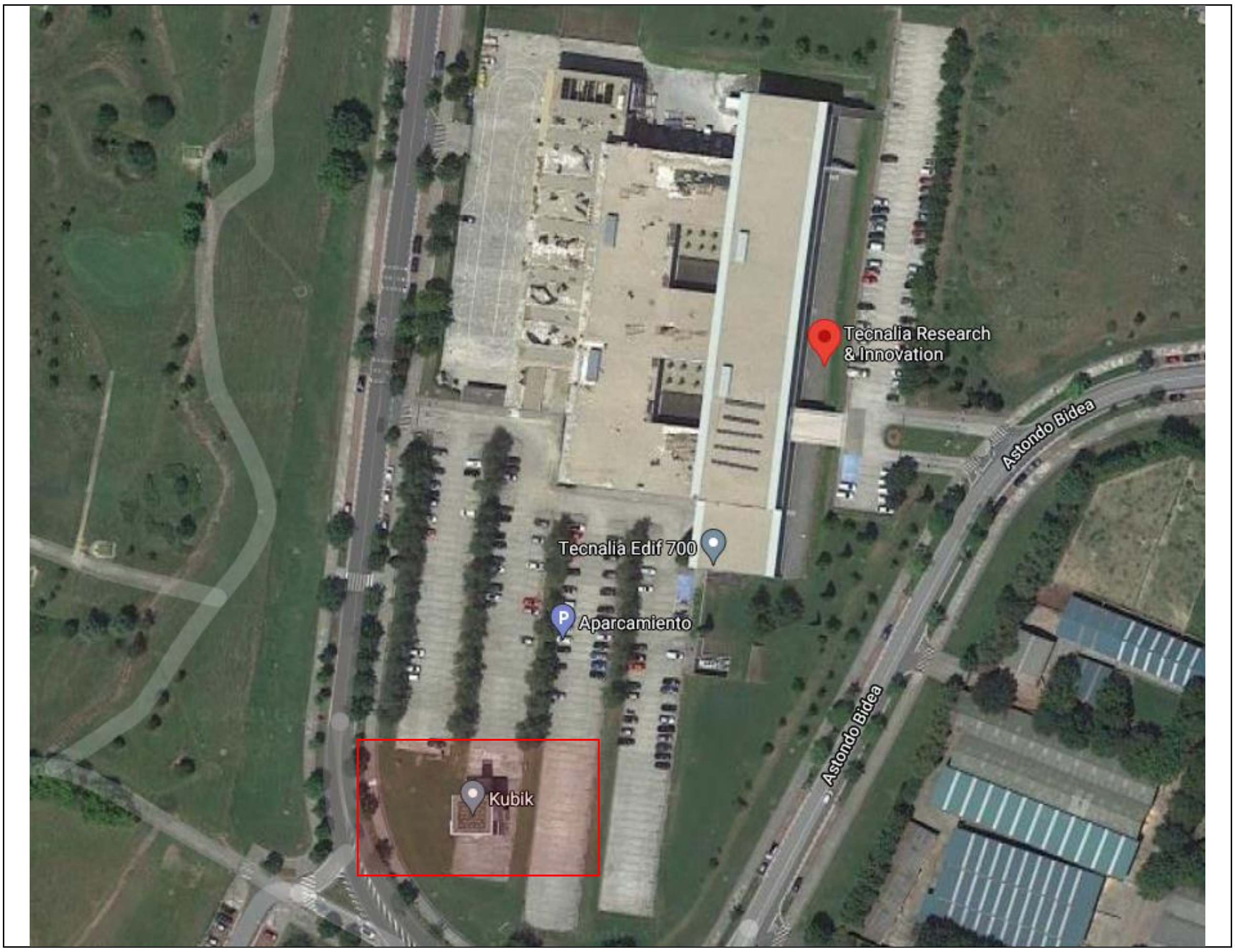


Figure 80: Satellite picture to identify location of facilities where mock-ups will be installed - Spain

	
EAST	**WEST**
	
NORTH	**SOUTH**

Figure 81: Overview of KUBIK experimental building facades

5.2 Mock-ups and layout descriptions – TECNALIA

The BIPV system to be demonstrated in KUBIK is a curtain wall using back-contact solar cells. East and South facades from KUBIK will host the new BIPV curtain wall. The design is composed by four different double glazing, with references V1-V6-V8-V10 as shown in Figure 83**.** Back-contact solar cells are located on the top and bottom parts of each laminate, leaving an area free of cells in between that allows the vision from the inside.

Figure 82: Areas of intervention in KUBIK, South (left) and East (right) façades

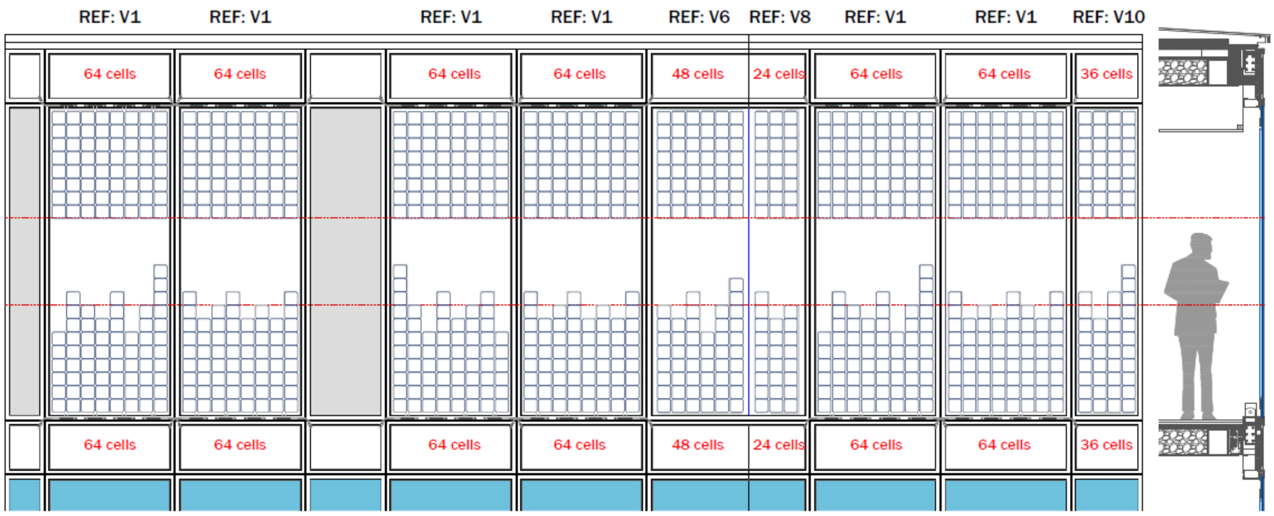


Figure 83: Representation of the PV layout in KUBIK

Although the original concept considered the use of edge junction boxes on the top and bottom sides of the module, in practice this was only feasible for the top part. The current curtain wall design was not conceived taking this situation into consideration and, therefore, using a traditional junction box will be finally needed for the bottom part of each module.

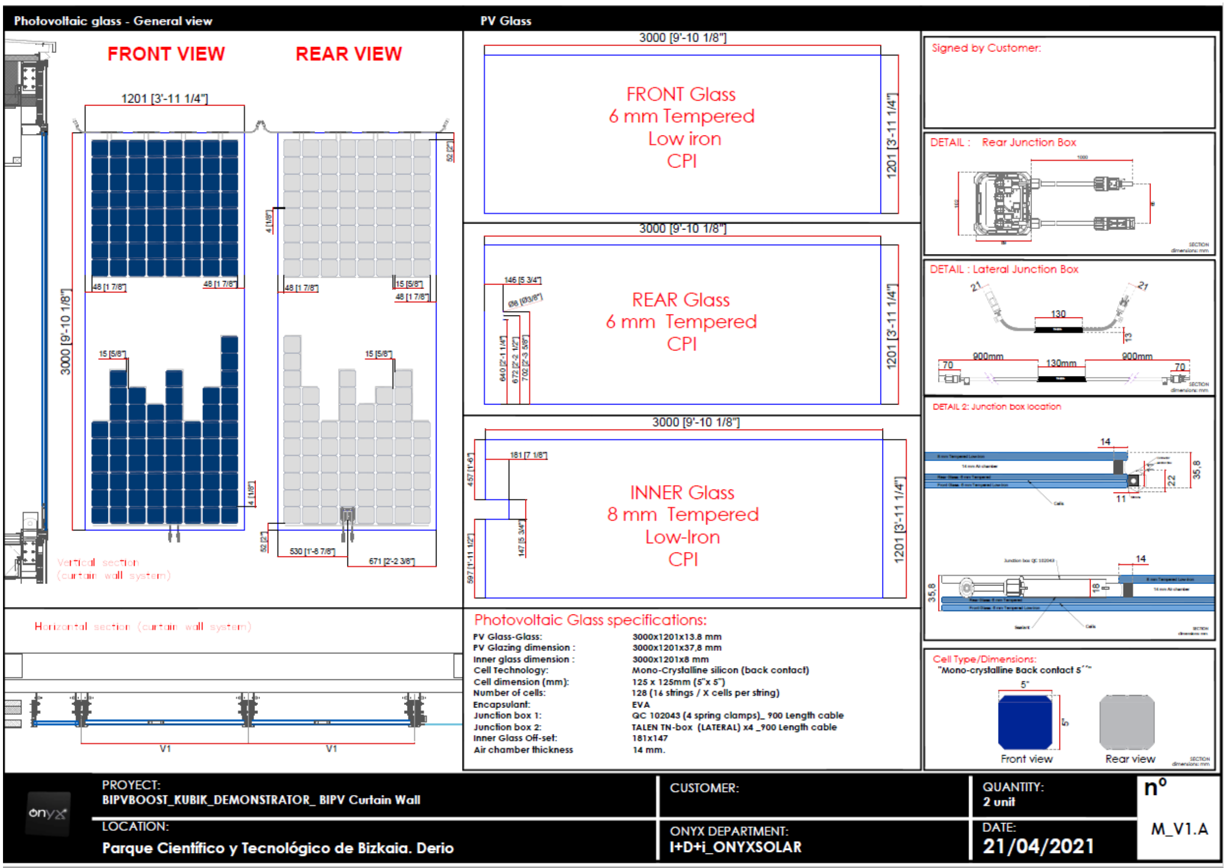


Figure 84 : Drawing of the V1 module reference

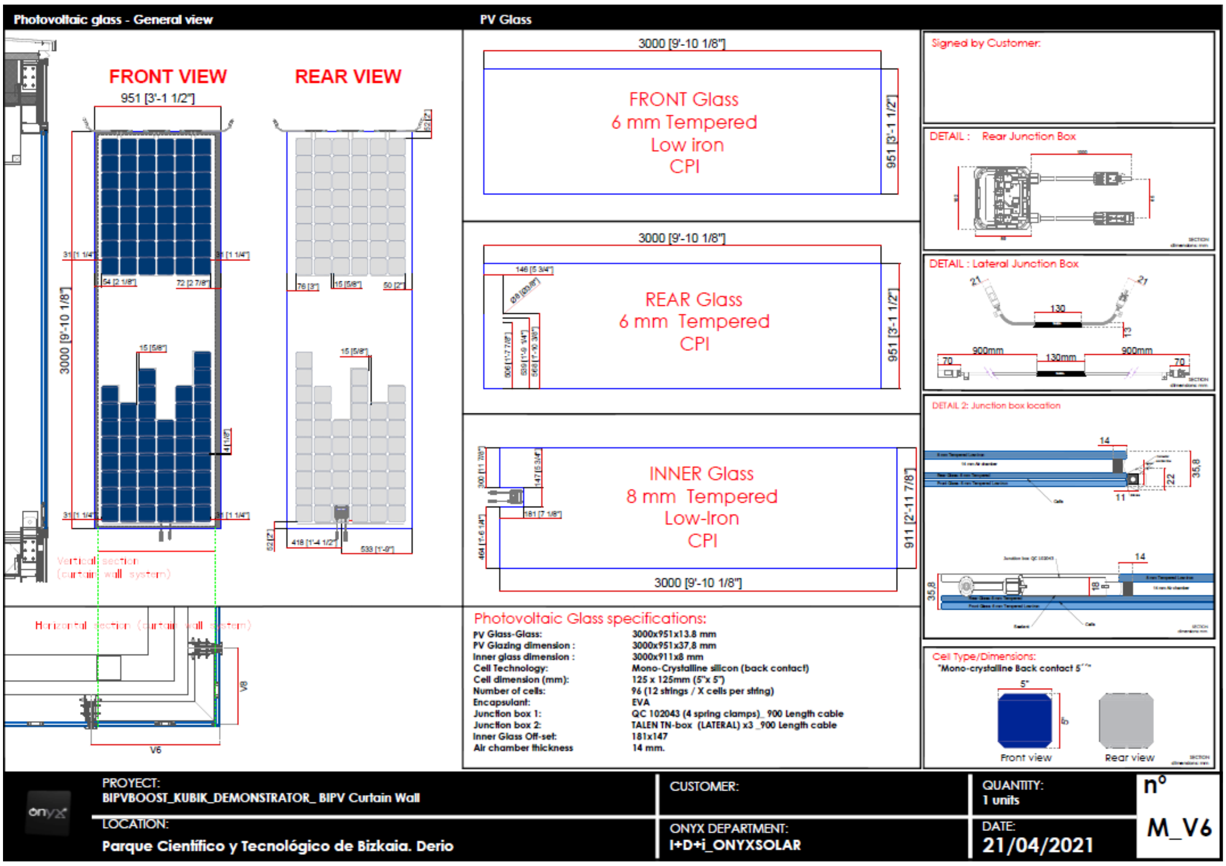


Figure 85: Drawing of the V6 module reference

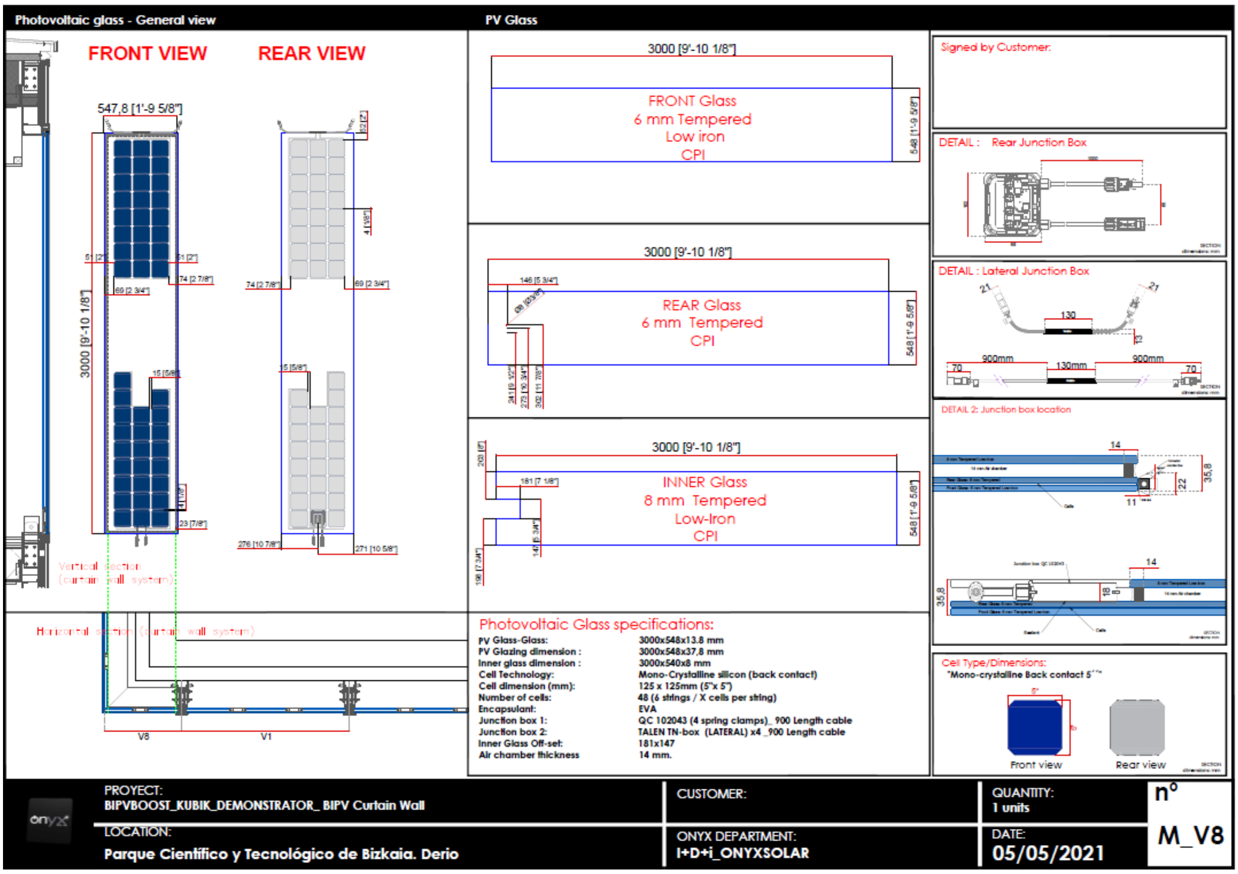


Figure 86: Drawing of the V8 module reference

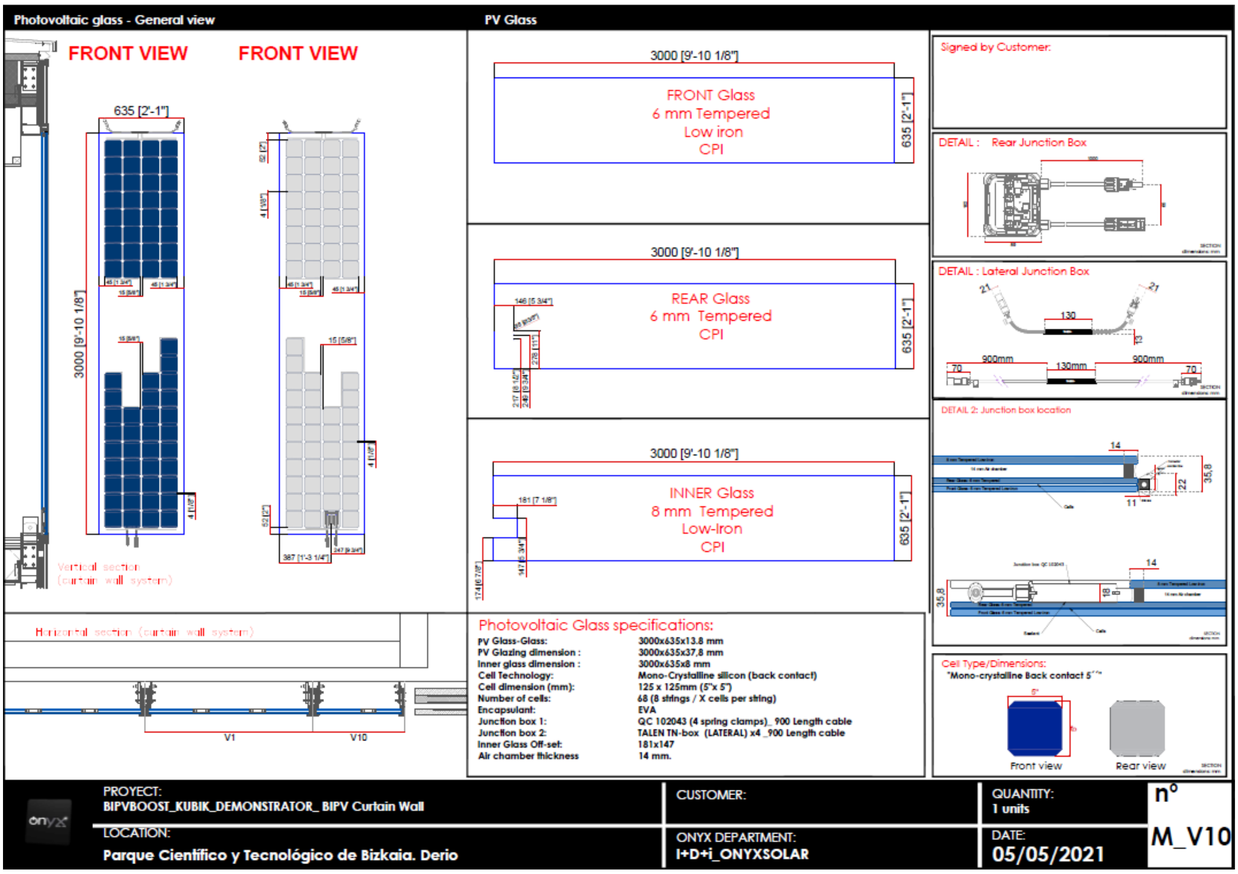


Figure 87: Drawing of the V10 module reference

M_V1 (variants A, B, C & D)_PV module 3000x1201 mm_128 cells.

PHOTOVOLTAIC GLASS 128 cells	3000 x 1201 5" Mono	Back Contact Cells
Electrical data test conditions (STC)		
Nominal peak power	406	P_{mpp} (Wp)
Open-circuit voltage	86,53	V_{oc} (V)
Short-circuit current	6,01	I_{sc} (A)
Voltage at nominal power	72,96	V_{mpp} (V)
Current at nominal power	5,56	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25ºC, stabilized module state.		
Mechanical description		
Length	3000	mm
Width	1201	mm
Thickness	35,8	mm
Surface area	3,60	sqm
Weight	182,31	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	128	43%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Gas Spacer	14 mm	Air Chamber
Inner Glass	8 mm	Tempered Glass
Inner Glass	0	0
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	ºC
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/ºC
Temperature Coefficient of Voc	-0,361	%/ºC
Temperature Coefficient of Isc	+0,08	%/ºC

* All technical specifications are subject to change without notice by Onyx Solar

M_V6 _PV module 3000x951 mm_96 cells

PHOTOVOLTAIC GLASS 96 cells	3000 x 951 5" Mono	Back Contact Cells
Electrical data test conditions (STC)		
Nominal peak power	304	P_{mpp} (Wp)
Open-circuit voltage	64,90	V_{oc} (V)
Short-circuit current	6,01	I_{sc} (A)
Voltage at nominal power	54,72	V_{mpp} (V)
Current at nominal power	5,56	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25ºC, stabilized module state.		
Mechanical description		
Length	3000	mm
Width	951	mm
Thickness	35,8	mm
Surface area	2,85	sqm
Weight	144,36	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	96	46%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Gas Spacer	14 mm	Air Chamber
Inner Glass	8 mm	Tempered Glass
Inner Glass	0	0
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	ºC
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/ºC
Temperature Coefficient of Voc	-0,361	%/ºC
Temperature Coefficient of Isc	+0,08	%/ºC

* All technical specifications are subject to change without notice by Onyx Solar

M_V8 _PV module 3000x548 mm_48 cells

PHOTOVOLTAIC GLASS	3000 x 553	
48 cells	5" Mono	Back Contact Cells
Electrical data test conditions (STC)		
Nominal peak power	152	P_{mpp} (Wp)
Open-circuit voltage	32,45	V_{oc} (V)
Short-circuit current	6,01	I_{sc} (A)
Voltage at nominal power	27,36	V_{mpp} (V)
Current at nominal power	5,56	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	3000	mm
Width	553	mm
Thickness	35,8	mm
Surface area	1,66	sqm
Weight	83,95	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	48	55%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Gas Spacer	14 mm	Air Chamber
Inner Glass	8 mm	Tempered Glass
Inner Glass	0	0
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

M_V10 _PV module 3000x635 mm_68 cells

PHOTOVOLTAIC GLASS	3000 x 635	
68 cells	5" Mono	Back Contact Cells
Electrical data test conditions (STC)		
Nominal peak power	216	P_{mpp} (Wp)
Open-circuit voltage	45,97	V_{oc} (V)
Short-circuit current	6,01	I_{sc} (A)
Voltage at nominal power	38,76	V_{mpp} (V)
Current at nominal power	5,56	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 1.5 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	3000	mm
Width	635	mm
Thickness	36,7	mm
Surface area	1,91	sqm
Weight	96,39	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	68	44%
Front Glass	6 mm	Tempered Glass Low-Iron
Rear Glass	6 mm	Tempered Glass
Gas Spacer	14 mm	Air Chamber
Inner Glass	8 mm	Tempered Glass
Inner Glass	0	0
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm² or 4,0 mm²	
Limits		
Maximum system voltage	1000	Vsys (V)
Operating module temperature	-40...+85	°C
Temperature Coefficients		
Temperature Coefficient of Pmpp	-0,451	%/°C
Temperature Coefficient of Voc	-0,361	%/°C
Temperature Coefficient of Isc	+0,08	%/°C

* All technical specifications are subject to change without notice by Onyx Solar

Figure 88: BIPV module datasheets

5.3 Measurements and monitoring descriptions – TECNALIA

KUBIK has an advanced monitoring system, equipped with over 800 sensors that records conditions inside and outside the experimental facility, including climatic conditions. Researchers and customers have access via the Internet to measurements being taken. The KUBIK digital twin offers the researcher a synchronisation between the physical and virtual world of the building in real time.

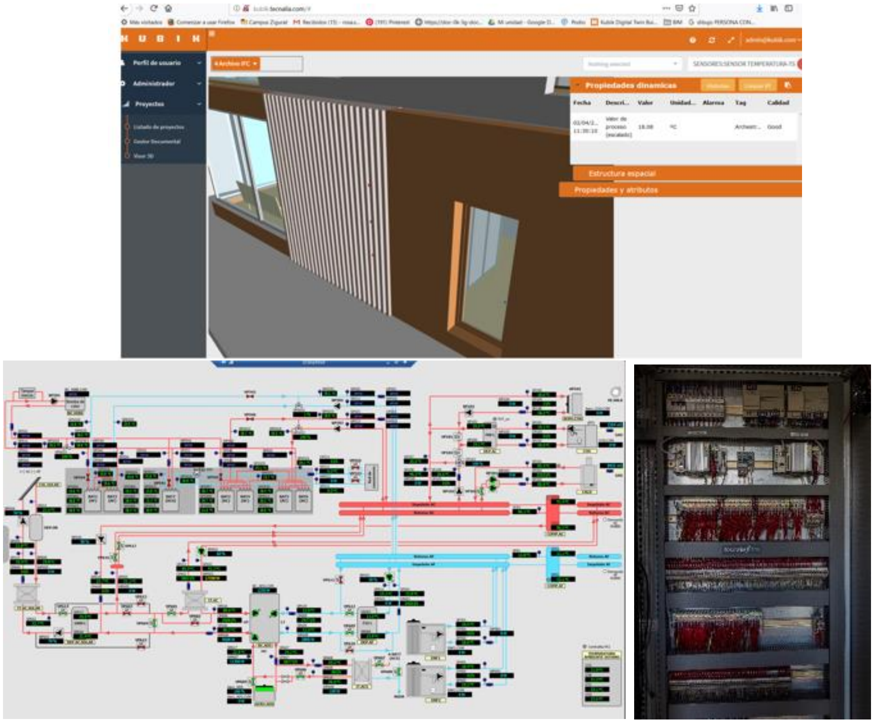


Figure 89: Configurable equipment control

This Digital Twin is connected to the control SCADA that orchestrates all systems such as test monitoring and climate information systems. Researchers and clients have access through a web, to the Digital Twin platform, which allows them to check in real time, through a virtual element that reflects reality, the parameters that are controlled in the experiment.

This new version of KUBIK, allows to continue with the functions for which it was designed, but also provides a testing ground where one can apply techniques framed within the INDUSTRY 4.0 current, such as cybersecurity, blockchain, IoT (internet of things), AI (Artificial Intelligence) and Big Data.

In the case of BIPVBOOST, the indoor control will not be part of the experiment. The monitoring plan has been conceived to monitor the PV performance and to evaluate the thermal working conditions of a BIPV curtain wall, and its consequences in the U and g-value of such systems.

Table 2.9 shows all the variables to be monitored and the instruments. The variables have been divided in 3 main groups:

1) the variables needed for BIPV energy performance evaluation
2) thermal performance (U and g value data) evaluation
3) the meteorological data (used for energy and thermal performance evaluations

On one hand, the PV energy performance will be evaluated by means of DC energy production and Meteorological data (Plane-Of-Array irradiance, Ambient temperature, module temperature).

During the evaluation tests, the energy production will be controlled by Fronius (Primo 3.0-1) inverter with two MPPT, one for south façade modules and the other for east façade modules. Figure 94 shows the interconnection scheme between South and East facade modules, the DC energy meter, and the inverter. The energy production will be measured with two DC energy meters.

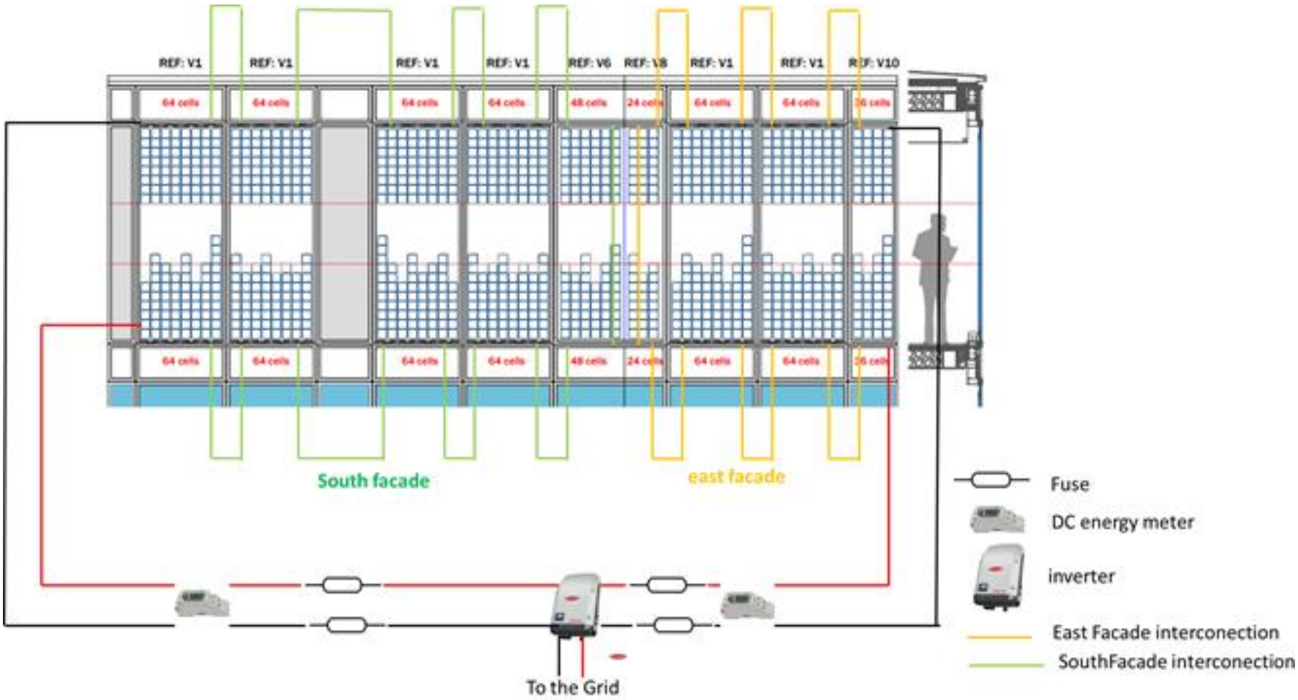


Figure 90: Kubik Mock-up lay out and electrical scheme.

On the other hand, the thermal performance characterization of the modules requires the instrumentalization of one of these modules. The instrumentalization will be carried out in the module located on the left corner of South façade (see Figure 96). The collected data will be used to validate the thermal model for BIPV modules developed in Task 5.2. The locations of sensors have been selected to feed and validate the mentioned model.

Figure 91: Localization of instrumented PV module

The thermal working condition of BIPV modules will be evaluated by means of temperature distribution and heat fluxes across the different layers of the windows. The BIPV curtain wall section is composed by the following 5 layers, from the external layer to internal layer; 1) the front glass,2) PV cells, 3) rear glass, 4) air chamber and 5) the inner glass. This configuration is translated in 6 surfaces that have been identify from 1 to 6 as shown in Figure 97 (Left).

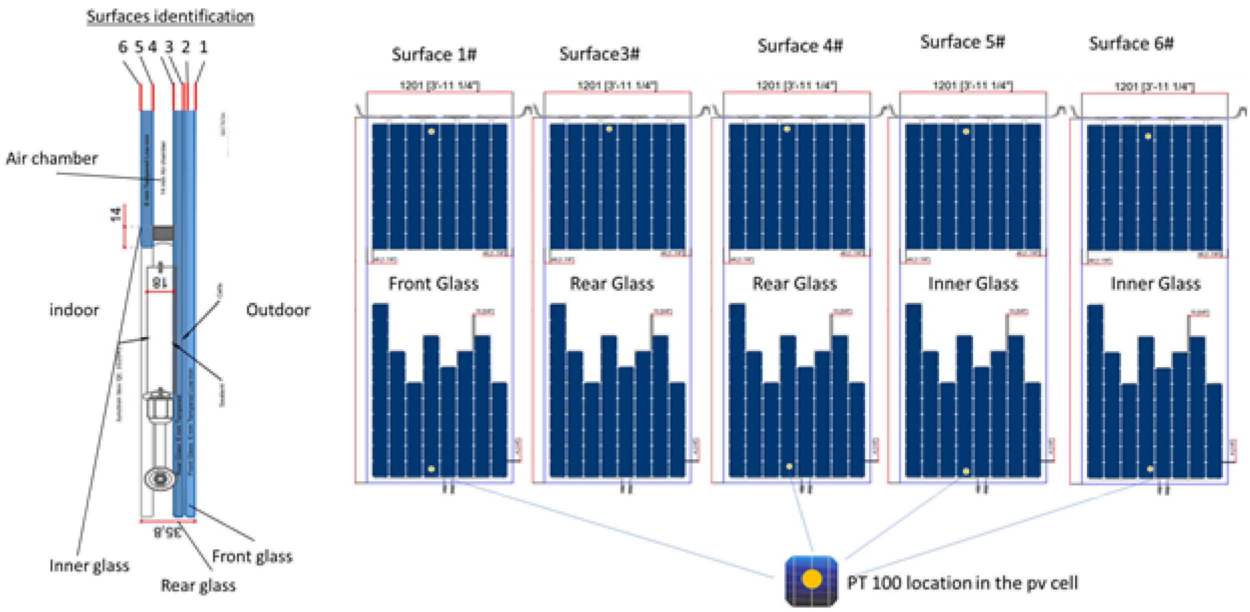


Figure 92: layer distribution and surface identification in the tested modules (left) and temperature sensor location in the different surfaces (right)

The following temperatures will be monitored: the front glass (surface 1#), PV cell back side (surface 3#), air chamber (surface 4# and 5#), and the inner glass (surface 6#). See Figure 92 to identification of surfaces. In order to minimize the effect of irradiance in the temperature sensors, the PT-100 located in the front glass (surface 1#) will be protected with aluminium tape and the rest of PT-100s will be located backward of the cell (in surfaces 3#,4#,5#,6#). Figure 92 (right) shows the location of the PT 100 in the module plane where all the PT 100s are aligned with the centre of a given PV cell.

The temperature sensors of surfaces 3#,4# and 5# are not accessible and will be placed during the fabrication of the modules by Onyx and the rest of sensors will be located on site by TECNALIA.

The heat flux will be measured with heat flux meters sensors in the inner and front glass (Surfaces 1# and 6#). Moreover, the energy balance will be completed with the measurement of the wind speed and direction in the PV plane, the ambient temperature, and the radiant temperature.

5.3.1 Monitored performance for technology demonstration in a relevant environment (TRL6)

The compliance with a technology readiness level TRL6 will be verified by measuring and checking the following aspects of the BIPV curtain wall:

- Electrical performance analysis: Yield and PR time series (different resolutions) and matrices of differently oriented modules. Yield benchmarking value is considered a Yearly PV energy production of ~700 kWh/kWp and ~500 kWh/kWp for South and East orientations, based on a preliminary energy production simulation.
- Temperature analysis at different surfaces of the curtain wall, determination of 98th percentile operating module temperature according to IEC TS 63126
- Visual inspection of aesthetical characteristics (opacification, yellowing...)
- Mechanical stability of the framing and chamber due to higher operating temperatures than a standard glass-based curtain wall.

In the following table the monitored performance variables are reported.

Table 4: Variables and instrumentations details.

Variable	Symbol	Units	Required accuracy	Sensor	Model
Electrical characterization					
PV array voltage (South Facade)	V_{as}	V	Uncertainty ± 2%	Energy meter	TBD
PV array current (South Facade)	I_{as}	A	Uncertainty ± 2%		
PV array power (South Facade)	P_{as}	kW	Uncertainty ± 2%		
Output energy (South Facade)	E_{as}	kWh	Uncertainty ± 2%		
PV array voltage (East Facade)	V_{ae}	V	Uncertainty ± 2%	Energy meter	TBD
PV array current (East Facade)	I_{ae}	A	Uncertainty ± 2%		
PV array power (East Facade)	P_{ae}	kW	Uncertainty ± 2%		
Output energy (East Facade)	E_{ae}	kWh	Uncertainty ± 2%		
Thermal characterizitation (U and g-value)					
Radiative temperature in external wall	T_{1R}	ºC	--	Pirgiometer	TBD
Surface 1# temperature	T_1	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2700
Surface 3# temperature	T_3	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2701
Surface 4# temperature	T_4	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2702

Surface 5# temperature	T_5	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2703
Surface 6# temperature	T_6	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2704
Room temperature	T_{room}	ºC	Uncertainty ≤2°C	PT100	DS2047X2F1M Ref : FP2705
Heat flux in the inner Surface 6#	Q_6	W/m^2	Uncertainty ± 5%	Heat flux meter	FHF04 Hukseflux
Heat flux in the outer Surface 6#	Q_1	W/m^2	Uncertainty ± 5%	Heat flux meter	FHF04 Hukseflux
Meteorological Variables					
Global Horizontal Irradiance	GHI	W/m^2	Uncertainty ≤3%	Piranometer	CMP-6 KIPP ZONEN
Diffuse irradiance	G_{DIFF}	W/m2	Uncertainty below ≤3%	Piranometer with shadow ring	CMP-6 KIPP ZONEN
Plane-Of-Array irradiance (South Facade)	G_{POA}	W/m^2	Uncertainty ≤2%	Piranometer	CMP-6 KIPP ZONEN
Plane-Of-Array irradiance (East Facade)	G_{POA}	W/m^2	Uncertainty ≤2%	Piranometer	CMP-6 KIPP ZONEN
Ambient air temperature	Tamb	°C	Uncertainty ± 0.1%	PT100	VAISALA WEATHER TRANSMITTER WXT520
Wind speed (on site)	Ws	m/s	Uncertainty ≤ 0,5 m/s (for Ws ≤ 5 m/s)	Anemometer	VAISALA WEATHER TRANSMITTER WXT520
Wind direction (on site)	Wθ	degrees	Accuracy of 5°		
Wind speed on the BIPV modules plane (South facade)	Ws	m/s	Uncertainty ≤ 0,5 m/s (for Ws ≤ 5 m/s)	Ultrasonic Anemometer	VAISALA WINDCAP ULTRASONIC WIND SENSOR WMT52
Wind direction on the BIPV modules plane (South facade)	Wθ	degrees	Accuracy of 5°		

6 ANNEX: further indications for performance measurements and energy rating

In the previous chapters monitoring layouts, goals and systems for each test site are described along with the main performance parameters to focus on in order to demonstrate the product TRL6.

As possible guideline for further and future investigations regarding performance measurement, power and energy rating, in this chapter is also reported a summary of the work performed under the IEA Task 15 framework, part of PVPS program where a specific subtask was dedicated to the development of a specific measurement methodology allowing to compare performances of an identical BIPV element in different climatic environments[2].

This methodology allows to directly compare the performance and energy yield of identical BIPV elements installed and monitored under well-defined conditions in different environments. As expressed, a direct influence of the environmental and climatic conditions on the performance data and yearly yield of the BIPV elements can be concluded.

This methodology implies knowing beforehand a set of date mainly provided by standards requirements, with the measurement results under STC conditions, preferably, in a reference lab for a pre-characterization, and the irradiance and temperature matrix of the Energy Rating Standard[3] and the module's spectral response[4]. The requirements of IEC 61215-1:2021 must be fulfilled at least internally as a first step.

The object of this part of IEC 61853 is to define a testing and rating system, which provides the PV module power (watts) at maximum power operation point for a set of defined conditions. A second purpose is to provide a full set of characterization parameters for the module under various values of irradiance and temperature. We remind that this set of measurements is required to perform the module energy rating described in IEC 61853-3. This part of IEC 61853 describes requirements for evaluating PV module performance in terms of rating (PR) over a range of irradiances and temperatures.

Monthly reports in pre-established data formats[5,6] of the monitoring data (weather and operational data) needs to be collected for comparative data treatment. The BIPV modules used, the reference building as well as constructive requirements and monitoring methodology are described in the following sections.

6.1 Main monitoring method

In addition to the definition of constructive requirements of the BIPV mock-ups, the monitoring method was also designed by all participants and have to respect as close as possible the following descriptions to improve the quality of final results comparison. The minimum requirement of data recording is depending on shadowing condition of each mockup to define morning and evening time. According to the IEA PVPS task 15 (T15) round robin test experience, requirement was fixed to be daily morning to evening data when the (in-plane) irradiance is above or equal to 20W/m². Any missing data must be reported. Furthermore, it is strongly recommended to notice and report the date and time of the last cleaning operation of sensors and BIPV Mock-ups. In a general way, a cleaning operation every two weeks is preferred and have to be applied during the monitoring period. If a different cleaning frequency is operated, it must be noticed and reported.

[2] Peter Illich & Al., Comparative performance measurements of identical BIPV-elements in different climatic environments - a round robin action within the iea pvps task 15 collaboration, 35th EUPVSEC, 6BV.1.32.

[3] IEC 61853-1 ED1 (2011): Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating.

[4] IEC 61853-2 ED1 (2016): Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements

[5] IEC 61724-1:2017 Photovoltaic system performance - Part 1: Monitoring

[6] ISO 8601:2004 Data elements and interchange formats

The monitoring raw data files for climatic and BIPV operational data are provided as a csv-files with lists separated by semicolon and time stamps, file headers as well as file naming following a pre-defined format for all participants. The minimum following data must be monitored:

- I_{mp} (A),
- V_{mp} (V),
- T_{mod} (°C),
- G_i (W/m²),
- T_{amb} (°C),
- $W_{indspeed}$ (m/s).

The above list data must be recorded and showed as presented in the Figure 93. The time stamps in the first column ([YYYY][MM][DD]T[hh][mm]Z, e.g. 20210101T10:00Z, see below. Note that the Z mark indicate the UTC time stamp). According to the localisation of partner facility, the time deviation must be indicated according to the UTC reference

UTCdev	+1					
Time	Imp	Vmp	Tmod	Gi	Tamb	Windspeed
20210101T10:00Z	7.821	28.312	25.254	990.254	20.585	0.823
20210101T10:01Z	7.881	28.214	26.0214	996.323	20.786	0.801

Figure 93: Exemple of file header for BIPV operational and climatic data.

Note that some electrical installations have to manage serial or parallel connections to fit with inverter input range (if grid connection is operating). For those configurations it is relevant to indicate the electrical scheme and the multiplication factor on current (in case of parallel connection) and voltage (in case of serial connection) to identify the number of modules involved in the mockup.

Some additional data such as information about shading condition, wind direction, relative humidity, or direct normal irradiance (DNI), diffuse horizontal irradiance (DHI) and global horizontal irradiance (GHI) can also be collected. To facilitate the handling of data, the used time stamp format should match the standard ISO 8601 according to the recommendation of the IEC 61724 monitoring standard. Time stamps are at the end of each minute of 1-minute aggregated, arithmetical averages of instantaneous data points.
A sampling interval of 5 seconds (or below) is chosen to be sufficient for the purposes of this activity – as for e.g. for class A equipment, a sampling interval of max. 3 seconds is recommended, according to the monitoring standard. The instantaneous measurements, taken every 5 seconds, are then aggregated to 1 minute arithmetically averaged values, and saved in the corresponding column of the csv-file – according to the pre-defined format. Only a one-minute data value is to provide to each time step, if additional values are stored, they could be used for further exploitations.

6.2 File name for operational BIPV data and climatic data

The raw data files shall be provided naming the .csv-files according to the following naming convention: “File_ID-YYYMMDD.csv”, where File_ID reference is indicated in the
Table 5.

Table 5: File ID and File naming convention

Partner Facility	File_ID	Manufacturer(s)	BIPV Solution
CSTB	CSTB_1	ONYX	Canopy

	CSTB_2	FLISOM, PIZ	ePIZ - CIGS version
	CSTB_3	FLISOM, SCHWEIZER	CIGS + Solrif
	#	ONYX, PIZ	ePIZ -c-Si version (rain test)
EURAC	EURAC_1	ONYX, TULIPPS	a-Si patterned + lock-&-go
	EURAC_2	ONYX, TULIPPS	Opaque c-Si + lock-&-go
SUPSI	SUPSI_1	ONYX	Bifacial balustrade
	SUPSI_2	ONYX, PIZ	ePIZ - c-Si version
	SUPSI_3	FLISOM, SCHWEIZER	CIGS + Solrif
TECNALIA	TECNALIA_1	ONYX	Curtain wall - Back-contact

For the ONYX canopy mockup located at CSTB facility, file naming will be, "CSTB_1-20210101.csv" for a recording that started on January 1, 2021.

6.3 Data acquisition and IV curves' descriptions

In addition of continuous measurements concerning photovoltaic energy generation and climatic surrounding conditions IV curves can be measured to define the field factor (FF) of each BIPV system, considering integration mode and deviation due to geometrical configuration (vertical installation) and thermal confinement (insulation layer). The IV curve generation over the time could also reveal the aging effect on power generation.

Note that a separate csv-files are used for the IV curve measurements to insure an efficient data post-treatment. Files also include the module temperature at the start time of the IV curve measurement in the header. File headers as well as file naming follow a pre-defined format. The minimum frequency measure is one time per week. If a more frequently measurement is possible, we recommend providing IV curves on an hourly basis. The IV curves contain 128 triples of data points as minimum requirement of the following data:

- V (V),
- I (A),
- G_i (W/m²)

If only I-V pairs are recorded, the header includes the maximum and minimum value of G_i during the IV measurement interval to assure that the irradiance has not changed significantly during the measurement. However, if I-V pairs are recorded together with G_i, the irradiance change during the IV curve sweep should be within a threshold of ±2%. The IV characteristics measurement standard, IEC 60904-1, requires ±0.2% of I_{sc} and V_{oc} at STC.

UTCdev	+1	
Tmod	28.235	
Time	20210101T10:00Z	
Gi	I	V
995.256	8.120	-0.5
993.200	8.101	0.0

Figure 94: Exemple of file header for IV curves measurments per module.

According to the raw data files given, the recording of IV curves shall be provided naming the .csv-files according to the following naming convention: "File_ID-YYYMMDD-IV.csv", where File_ID reference remains the same. For partners equipped of IV curves generators, two files will be to provide every month.

6.4 Measurement ranges

As partners have different modules different BIPV system configurations and cell classification or technologies (ONYX – Si, CIGS and FLISOM - CIGS) it would be strongly recommended to adapt the V_{oc} and I_{sc} range according to the maximum voltage value and maximum correct value of the manufacturer line-up. You can have below a line-up example of glass-glass CIGS module available in the BIPVBOOST project.

BIPV MODULES

GLASS SPECIFICATION: 1245x0635 mm			
Reference	Glass Thickness	Transparency	Junction Box
434-BN-12450635-XX-1	4mm	0% - 10% - 20% - 30%	QC091721-B - 2 Output
535-BN-12450635-XX-1	5mm	0% - 10% - 20% - 30%	QC091721-B - 2 Output
636-BN-12450635-XX-1	6mm	0% - 10% - 20% - 30%	QC091721-B - 2 Output

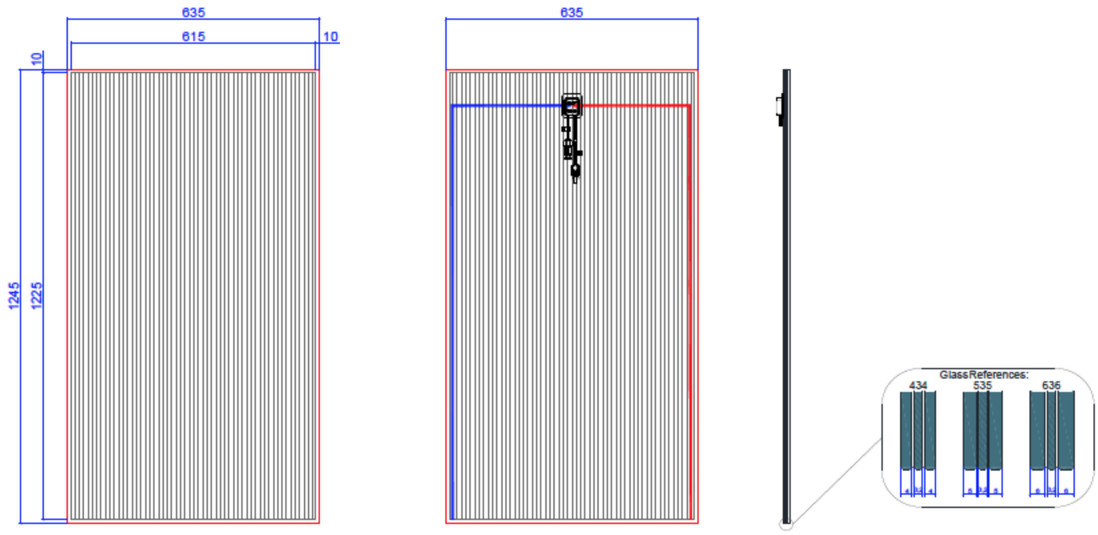


Figure 95: Exemple of module provided by ONYX for BIPVBOOST mock-ups.

Rated electrical characteristics at STC before stabilization

Module Model*	REF: 12450635				REF: 12451242				REF: 124501849				REF: 12452456			
	DARK	10%	20%	30%	DARK	10%	20%	30%	DARK	10%	20%	30%	DARK	10%	20%	30%
Rated power (Wp)	49	34	28	23	99	68	57	46	150	104	88	70	197	135	114	91
Open-circuit voltage (V)	49	49	49	49	95	95	95	95	140	140	140	140	182	182	182	182
Short-circuit current (A)	1,6	1,3	1,1	0,81	1,6	1,3	1,1	0,81	1,6	1,3	1,1	0,81	1,6	1,3	1,1	0,81
Rated Voltage (V)	36	36	36	36	72	72	72	72	110	110	110	110	143	143	143	143
Rated Current (A)	1,38	0,95	0,8	0,64	1,38	0,95	0,8	0,64	1,38	0,95	0,8	0,64	1,38	0,95	0,8	0,64

**See reference list valid for these information on page 2.*

Figure 96: Electrical characteristic table used for definition of range measurement.

All measurements have to follow the minimum and maximum V_{oc} ranging from -0.5 to rounded up to the nearest ten voltage V value according to the module specification or system configuration accordingly the final setup. As showed on Figure 96, for the first module reference (REF 12451242 – 20% transparency) the upper limit of V_{oc} is 100 V. For the short circuit current the range comes from -0.5 to rounded up to the nearest digit current I value. Following the same example as previously showed, the I_{sc} upper limit is 2 A. Please note that measurement range has to be adapted according to the serial/parallel couplings specific to each mockup.

6.5 General measurements recommendations

For the present experiment, we suggest providing a maximum uncertainty of ±2% at 200W/m², i.e. ±0.4% at STC. IV curve measurements are done at stable weather conditions, while taking care that the modules are not (partly) shaded before and during measurement and that the MPP-tracking is interrupted only for a very short time (less than 1 minute), to avoid mismatch between the average cell temperature and the sensors for the module temperature. For measurements performed manually a mean value on three measures in a row must be provided to avoid measurement mistakes or bias.

As mainstream, a class A sensor equipment is preferably used, as it allows most of the typical applications according to the monitoring system classification of IEC 61724-1. Sensor calibration reports (of irradiance sensors) must be checked to avoid any deviation during the project measurement period. In case of any issues on a sensor calibration, the corresponding dataset could be excluded of post-treatment.

Thermopile pyranometers are chosen to be best suited for the global horizontal irradiance (GHI) measurements, while matched PV reference devices are best for in-plane (POA) measurement. If pyranometers are used for POA measurement, the correction procedures for the 90° tilt angle must be double checked. For all measurement setup additional temperature correction is applied if required, following the procedures for irradiance and temperature corrections, according to the IEC 60904-1:2006[7].

6.6 Data classification

To define power rating conditions, reference conditions are necessary and the table hereafter. The first three reference power conditions are defined in IEC 61215-1:2021 and will be provided by manufacturers. The modules shall be tested, and the maximum power determined for the following rating conditions. For each rating condition the Air Mass 1.5 spectral irradiance distribution as given in IEC 60904-3 shall be used as well as normal incidence irradiance.

Table 6 : IEC 61215/61646 reference conditions table for power rating

Condition	Irradiance $W \cdot m^{-2}$	Temperature °C
STC Standard Test Conditions	1 000	25 of cell
NOCT Nominal Operating Cell Temperature (Determined according to IEC 61215 or IEC 61646)	800	20 of ambient
LIC Low Irradiance Condition	200	25 of cell
HTC High Temperature Condition	1000	75 of cell
LTC Low Temperature Condition	500	15 of cell
NOTE The conditions provided in this table may be measured directly as part of the performance matrix defined in Clause 8.		

7 IEC 60904-1:2006 Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics

6.7 Procedure for outdoor measurements without tracking systems

In BIPVBOOST project, no installations BIPV are using a tracking system on outdoor devices, the procedure allows the acquisition of data for a long time period. Only a few requirements must then be respected:

- The wind speed has to be less than 2 m/s;
- The short term irradiance variations (clouds, smoke or haze) shall be less than +/- 1 % of the total irradiance measured by the reference device;
- The data have to be collected until standard deviation for all Voc, Isc and Pmpp are less than 5%;
- The angular response must be corrected by using a tracker;
- The spectral response also must be corrected by relying on specially matched reference cells or on a spectroradiometer and carrying out a spectral mismatch calculation.

With the exception of the last two criteria (angular and spectral responses), all the data that does not meet the requirements of the standards will not be included in the calculation process.

6.8 Rating of power

As described in paragraph 9 of IEC 61853-1[8], it is possible to determine Isc, Voc, Vmax and Pmax at intermediate values of irradiance and temperature other than those directly measured, by using interpolations.

- **Isc, Voc, Vmax and Pmax with respect to temperature**
  To determine all four parameters at intermediate values, it is possible to use a linear interpolation method while carrying about the temperature dependence.
- **Isc with respect to irradiance**
  For Isc determination, it is also possible to use a linear interpolation while respecting the irradiance.
- **Voc and Vmax with respect to irradiance**
  To determine both Voc and Vmax, a linear interpolation is not possible, but the following equation can be used if data can help to find v1 and v2 which are not the same for the two parameters.

$$V(G) = v_1 \times \ln(G) + v_2$$

- **Pmax with respect of irradiance**

To determine the parameter at intermediate values of irradiance, a polynomial equation should fit for data from a region near the irradiance of interest within a limit of 30 %. If the device is linear and the difference between irradiances does not exceed 30 %, using a linear interpolation is possible.

Thanks to the valuable support of manufacturers involved in the project, all electrical parameters of every module are available and allow to fix starting data for calculation. With the support of IV curves tracers or generators, maximum values could also be determined.

All the monitoring description and measurement used by every partner for mock-ups can generate data measurements allowing a full representation of efficiency of each BIPV system, according to weather and building surrounding.

[8] IEC 61853-1:2011 Photovoltaic (PV) module performance testing and energy rating —Part 1: Irradiance and temperature performance measurements and power rating

7 ANNEX: further indications for data processing for PR results and Energy Ratings

All data collected should follow the same format suggested by the standard used by the IEA PVPS Task 15 program round robin test[9] in order to each partner to provide results in the same format with the same calculation process, and thus make the results inter-comparable with comprehensive results of the electrical and corresponding meteorological monitoring data.

7.1 Monitoring and measurements

The monitoring data should be uploaded on a dedicated shared folder by every involved partner in, with the appropriate format. In addition of the raw files it is requested to any partner to process and filter data for easy data handling or for further analysis.

According to the same protocol of T15 round robin tests, the available measurements will be presented as a different interesting figure that reveal the thermal and electrical performance of BIPV components developed and tested on facilities:

(1) Distribution (frequency) of the module temperatures (T_{module}) and the in-plane irradiation at the outdoor test locations (see Figure 97) which is the result of the thermal balance of the component including the climatic and the integration conditions. Note that irradiation lower than 200W/m^2 all the data will be deleted from final files.

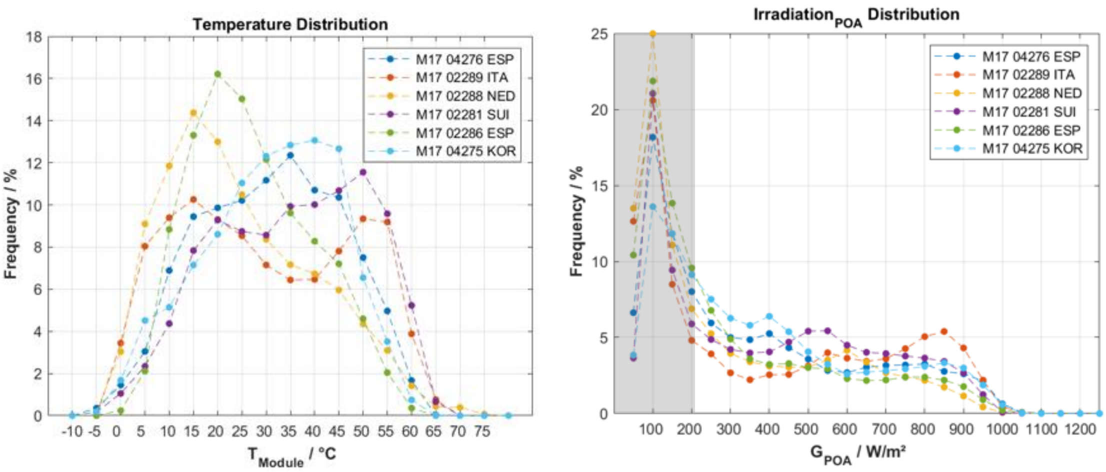


Figure 97: Distribution of the module temperature and in-plane irradiation.

(2) Time series of mean daily performance ratio coefficients (PR) of all monitored days is also a requested representation of performance being of BIPV installations (see Figure 98). The mean daily PR ratio as well as the PR mean value on the monitoring considering period will be the expression of the conversion potential of the energy received on the BIPV mockups.

[9] L. Gaisberger and Al. BIPV round robin action of IEA PVPS task 15, 6 BV4.7, 36th EUPVSEC

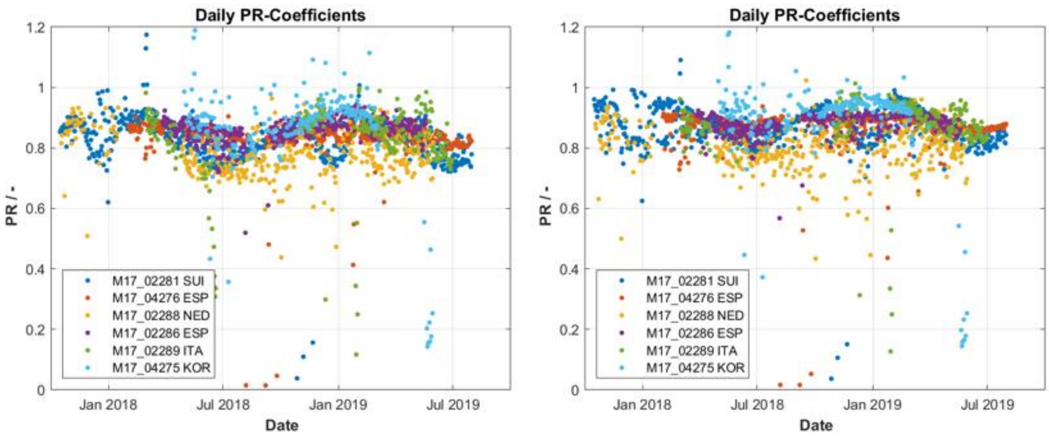


Figure 98: Mean daily PR (right including T_{module} correction)

(3) A statistical approach could also be used to display the data distribution with the median value and the standard deviation for every mockup during the considering period with the PR values (**Figure 99**). This one is optional because it will include the differences in precision measurements and accuracy but also all the temporal data specific to the site due to different shadowing effect, the contribution of albedo factor and so on. Each partner is free to handle this representation.

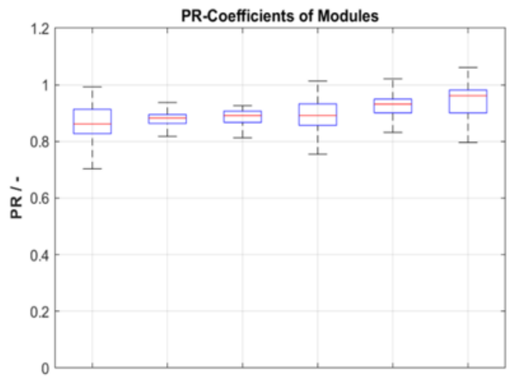


Figure 99: Median and standard deviation plot of PR per module/mockup

(4) Comparison of ambient and module temperatures is a reflect of the thermal stress that the BIPV modules can undergo due to the lack of free cooling ventilation on the back side of modules for some BIPV configuration. PIZ solution (façade) and SCHWEIZER (roof) configurations will be particularly observed due to the vicinity with insulation elements, or the mounting structure used (Figure 100). This representation is not mandatory either, as the PR deviation seen previously, but provide relevant information on the thermal sensitivity that affect the efficiency of the photovoltaic conversion.

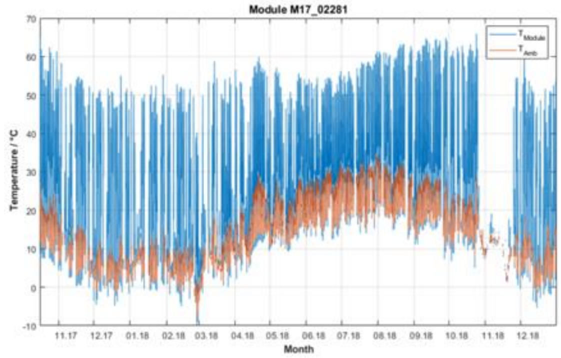


Figure 100: Comparison of T_{module} (blue) ant $T_{ambiant}$ (red)

(5) Yield matrix plots is the most relevant aggregation previously figures showing the relative yield over module temperature and irradiance (**Figure 101**). This figure makes it possible to present the most interesting production condition according to the climatic and architectural combinations

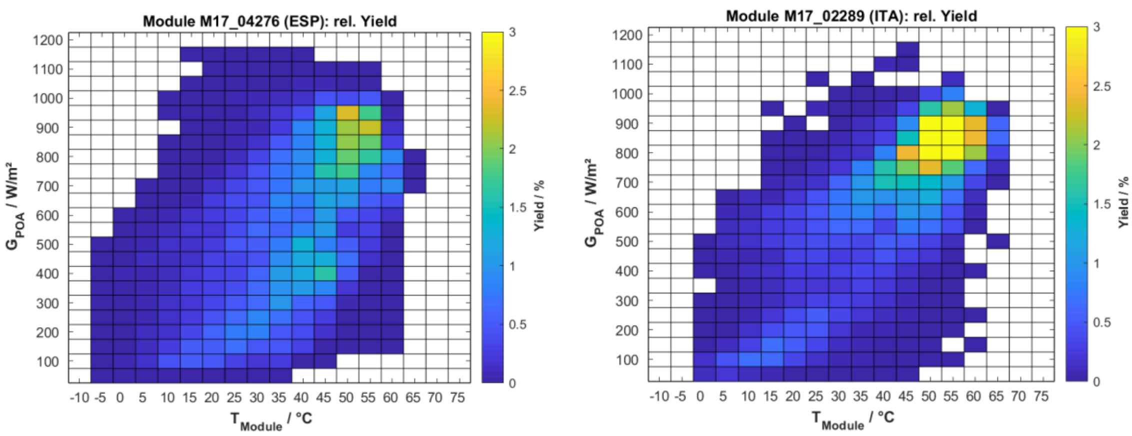


Figure 101: Relative yield of identical BIPV configuration in two different geographical places (Spain and Italy), plotted over the module temperature and the irradiance in 5°C / 50 W/m² per div.

The massive work provided within the Task 15 action demonstrates a way to represent the module performance including the climatic environments and the building integration mode. The color of every box represents the relative yield, calculated as yield within one bin divided by the total yield. The sum of all boxes represents 100 % of the total yield over a considered period (let's start with 1 month as an initial considered period for a final annual display). From these matrix-plots information about the climate as well as the operating conditions of the module can be derived.

With the availability of all data series provided by all partners, Time series plotting by a monthly step could be used to present the yield at every test site and every BIPV solution to compare the conversion ability of every system assessed. In the two lasts articles published within the framework of the IEA PVPS task 15[10,11], the results are obtained using the calculation methods detailed in the standard IEC 61853 part 1 – Part 4:

[10] R. Valckenborg and Al. : IEC61853-Matrix Analysis of PVPS Task 15 BIPV Round-Robin for more than one year at seven test sites over the world, 6 DO12.1, 37th EUPVSEC

[11] R. Valckenborg and Al. : Comparison of IEC 61853-1 matrix evaluations based on indoor and outdoor measurement data from PVPS Task 15 BIPV Round-Robin, 6 DO6.4, 38th EUPVSEC

2018[12]. These publications of the work carried out in T15 suggest different filtering solution and plotting option to clarify the results by displaying the number of datapoints in addition of the color bar scale.

7.2 PR representation and Yield representation

The daily PR coefficients were calculated as the ratio of the specific yield in kWh/kWp (with the rated power in kW at STC) in relation to the specific insolation reference yield in kWh/m²/1kW/m² (using the STC irradiance of 1kW/m² as the reference). It's a relevant representation of PV performance during an operation period. The representation with T_{module} and G_{POA} is reflecting all surrounding phenomena that affect the electric and thermal balance of the BIPV solution tested under the BIPVBOOST project as the different localization with different climatic condition with, moreover, building integration solution.

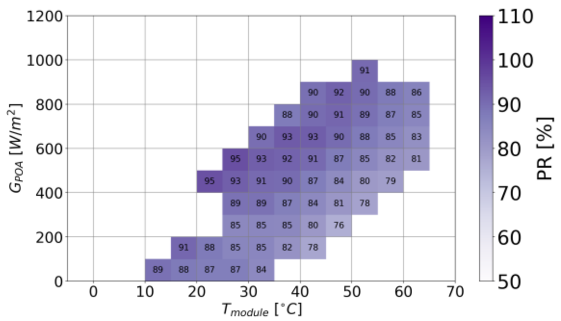


Figure 102: PR representation (%).

We remind that if a temperature correction is applied on the daily PR values, the specific yield values were corrected by means of module temperature values, using the relative module's power temperature coefficient of -0.37 %/°C. For CIGS modules, the corrective temperature coefficient will be changed according to the Flisom datasheets.

As a second representation, the specific yield values can be plotted to identify the area of the most frequent distribution of production as a combination of T_{mod} and G_{POA} during the monitoring period.

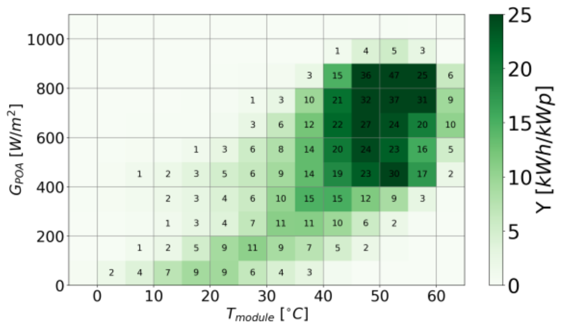


Figure 103: Specific yield representation Y(kWh/kWc).

The PR and Y representations are using the same datapoints with the yield value divided by the sum or irradtion on the considering period.

[12] IEC 61853-3 : Photovoltaic (PV) module performance testing and energy rating – Part 3: Energy rating of PV modules

7.3 Energy rating

If the PR value or Y value are interesting comparison parameters, the Energy Rating calculation process according to the IEC 61853-3:2018 standard allows a full inter-comparison scheme by using IEC 61853-4:2018[13] reference climatic values.

The purpose of this document is to define a methodology to determine the PV module energy output (watt-hours), and the climatic specific energy rating (dimensionless) for a complete year at maximum power operation for the reference climatic profile(s) given. It is applied to determine a specific module output in a standard reference climatic profile for the purposes of comparison of rated modules.

7.4 Data Handling procedure

The calculation procedure is described in the IEC 61853-3:2018 standard and expressed as a flowchart calculation process as showed in Figure 104. Even if many calculations correction must be taken for indoor measurements, the outdoor measurement protocol can admit some simplifying assumption, such as spectral corrections. We could expect that the PR representation is a significant part of energy rating procedure.

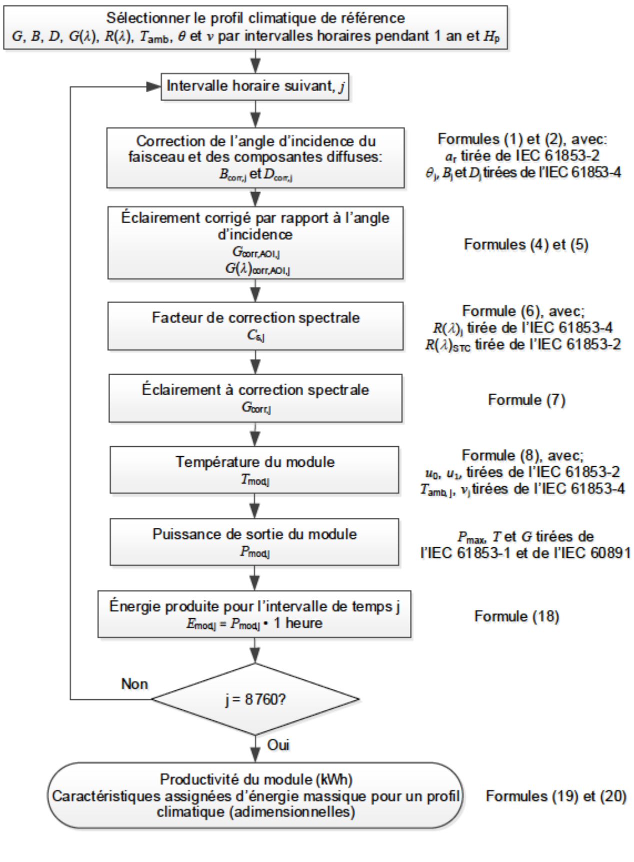


Figure 104: Flowchart of the calculation procedure (to be updated with the EN version).

A full description of data handling is perfectly described in the article of R. Valkenborg[14] as previously noticed for the PR representation with a lot of warnings or recommendations on the data handling to emphasize only the most relevant values with different plotting investigations.

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13 IEC 61853-3 : Photovoltaic (PV) module performance testing and energy rating – Part 4: Standard reference climatic profiles

14 R. Valckenborg and Al. : Comparison of IEC 61853-1 matrix evaluations based on indoor and outdoor measurement data from PVPS Task 15 BIPV Round-Robin, 6 DO6.4, 38th EUPVSEC

7.5 Results presentation

Even if Energy rating is considered as a standard reference, the PR value could also be used and many different plotting solutions could be investigated to rank the best BIPV solution according to the weather conditions and module efficiency. Figure 105 shows the average PR values for an identical BIPV solution (left) and de relative deviation of one identified site of test (right) to underline positive or negative contribution of every site on the average trend.

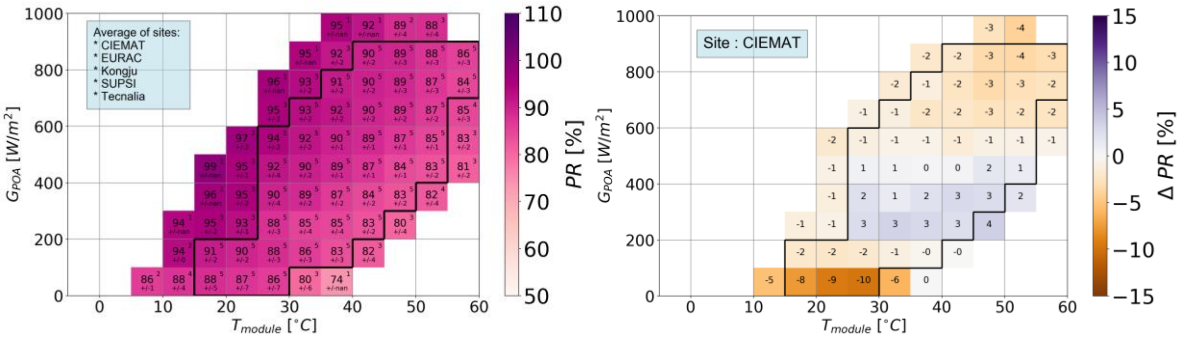

Figure 105: Average PR values of all sites and specific deviation from on site

On the previous example, for this case study and those experimental conditions the site contribution could be assessed as mostly negative dues to deviations values lower than the average. As a possible conclusion is the non-optimal configuration or an incompatible configuration according to the needs or the potential of other technical solutions.

Every partner will have to provide raw data, and pre-configured datasets/datapoints to allow a handling procedure friendly and to give an easy access of results comparisons.

7.6 Limitations

The spectral effect can play a significant role on PR evaluation and won't be used in the PR calculation process due to a lack of equipment and necessity to have continuous measurements. Angle of incidence (AOI) is also prominent and will have a significant effect in front of several experimental configurations assessed in BIPVBOOST project.

8 SUMMARY

All the partners involved as demonstration and assessment site have a well described monitoring and measurement systems allowing to harvest many relevant information on quality and efficiency of energy conversion of different BIPV systems in different site locations.
The definition of monitored performance for each product technology will support the demonstration of TRL6 level and the definition of reference KPIs for each BIPV system as result of the monitoring (performance, installation, maintenance, etc), to be used as product performance thresholds.

9 CONCLUSIONS AND NEXT STEPS

This report defines the details of the test sites and the details of each monitored system for the definition of TRL6 level for each product technology through outdoor testing. In order to correctly assess each BIPV system by considering the threshold levels established with manufacturers a the calculation procedure to assess the contribution of energy production according to the geographical conditions and construction requirements /integration mode of the BIPV systems, as described in the chapters above, will be investigated in each test site of the BIPVBOOST project. As next step of further investigation on power and energy rating, the reference to the work carried out within the IEA PVPS Task 15 framework was also reported.