



D6.9 Definition of monitoring plans for outdoor activities

T6.12 Outdoor Performance Testing Activities



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SEAMLESS-PV PROJECT

A novel manufacturing process for integrated photovoltaics

Integrated photovoltaics (IPVs) have demonstrated their success and impact as building-integrated photovoltaics. They are also considered promising in several other sectors. Their adaptation to other industries or devices could offer surprising benefits. Unfortunately, the very need for adaptable IPV solutions hinders their expansion as their current manufacturing processes cannot create IPV solutions customised to each sector. The EU-funded SEAMLESS-PV project aims to tackle this by developing revolutionary tools for photovoltaic manufacturing as well as new IPV products that offer improved efficiency, adaptability, and integrability while at the same time showcasing their cost-effectiveness in comparison to competitors.

The title of SEAMLESS-PV project is *“Development of advanced manufacturing equipment and processes aimed at the seamless integration of multifunctional PV solutions, enabling the deployment of IPV sectors”*. SEAMLESS-PV is a Horizon Europe Innovation Action started in January 2023 and will continue through December 2026.

More information can be found at:

<https://www.seamlesspv.eu/>

<https://cordis.europa.eu/project/id/101096126>

EXECUTIVE SUMMARY

The goal of Task 6.12 is to demonstrate the TRL6/7 (Technology Readiness Level) of the project's technologies, including integration methods, installation processes, and maintenance procedures. This is an intermediate step toward the full-scale demonstration activities planned in WP8, where the products will be installed at designated demonstration sites.

This deliverable (D6.9 – Definition of Outdoor Monitoring Plans) establishes the framework for defining and implementing monitoring plans for outdoor activities.

The scope of this document includes an examination of the outdoor testing structure for the products developed within the project. It provides a comprehensive overview of the test sites, addressing key factors such as geographical location, climate conditions, and structural characteristics. Additionally, the document delves into the design and assembly of the mock-ups, describing in detail the specific types of modules and sensors used, methods for collecting relevant data for each product type, and the methodologies employed for subsequent data analysis. This comprehensive approach ensures a clear understanding of the experimental setup and its significance to the project's overall objectives.

Future efforts will focus on defining a minimum monitoring period of six months, during which the anticipated performance of the technology in real-world environments will be evaluated. This period is crucial for identifying any critical operational issues, addressing challenges that may arise, and determining if further refinements to the BIPV technology are required before its installation at the demonstration buildings.

The target audience includes researchers, engineers, stakeholders involved in BIPV technology development, and project managers.

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1 INTRODUCTION

1.1 Description of the deliverable content and purpose

The objective of this deliverable is to define the monitoring plans for outdoor environments, providing the necessary information to understand which tests and data will be monitored for each small-scale prototypes (TRL6) before its installation at the demonstration sites (TRL7).

As part of the project activities, each technology manufacturer has been paired with a research institute, which has contributed to defining the assembly, verification, and monitoring plan to ensure relevant insights before deployment at the demonstration sites.

For some of the products developed within Task 6.12, this document outlines the objectives and provides a description of the site where the small-scale demonstrator will be installed. Each tested product will be detailed, including specifications related to its characteristics, installation, and potential maintenance. Additionally, information will be provided on the sensors used for monitoring and the data acquisition process.

The monitoring period will last a minimum of six months, during which the expected performance of the technology will be assessed in real-world conditions, in accordance with its technology readiness level (TRL 6/7), before full-scale deployment at the demonstration sites.

This public deliverable serves as a valuable reference for researchers, engineers, stakeholders involved in the development of various BIPV technologies, and project managers.

1.2 Reference material

Not applicable.

1.3 Relation with other activities in the project

This deliverable is part of the development activities of Work Package 6, specifically related to outdoor testing within Task 6.12, which focuses on the evaluation of products developed throughout the project.

All relevant Work Packages have been considered, as the tested products originate from the design and manufacturing approaches established within them, in particular:

- WP3 Highly flexible and automated IPV manufacturing
- WP4 Advanced manufacturing processes allowing the industrialisation of Solarface lightweight composite technology
- WP5 Development of prelaminates and compatible manufacturing processes aimed at facilitating the deployment of IPV sectors
- WP8 Pilot lines and IPV product demonstration activities

Table 1.1 Relation between current deliverable and other activities in the project

Project activity	Relation with current deliverable
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WP3	WP3 focuses on developing and validating advanced interconnection and prelamination equipment compatible with new c-Si cell formats and BIPV applications. It includes the design of innovative tabber-stringers, automated bussing systems, and ECA-based solutions enabling flexible, wire- and ribbon-based interconnections. The WP also integrates digital tools for process monitoring and optimization. The validated technologies provide the basis for pilot-line implementation and performance assessment under real conditions, closely linking WP3 outcomes with outdoor monitoring activities defined in D6.9.
WP4	WP4 focuses on developing advanced composite manufacturing processes for lightweight IPV modules, including C-RTM and hot-press prepreg lamination, to achieve scalability, improved quality, and significant cost reduction. The work also optimizes the Solarface composite bill of materials to balance cost, performance, and added functionalities across IPV sectors, while enhancing sustainability and recyclability. The materials and processes developed in WP4 are validated through outdoor testing activities defined in D6.9, ensuring performance assessment under real environmental conditions.
WP5	WP5 focuses on developing advanced prelamines and related manufacturing processes compatible with high-pressure injection, RIM, and standard lamination techniques. It also targets the creation of PV laminates (PVLs) that enable higher production volumes and cost reduction in line with VIPV market needs. The processes established and qualified in WP5 form the foundation for subsequent product development and pilot line demonstrations in WP6 and WP8, with performance validation through the outdoor testing activities defined in D6.9.
WP6	<i>D6.7 – Report on testing sequences and prototype manufacturing needs for each IPV product.</i> This Deliverable defines the testing sequences for product validation and identifies the key parameters to be analysed and provided information and data for the current document.
WP8	WP8 focuses on setting up and validating all SEAMLESS-PV pilot lines, assessing the new manufacturing capacities under real industrial conditions, and demonstrating scalability for European manufacturers. It aims to optimize costs and efficiency in BIPV production by improving workflows and reducing material losses. The pilot lines are used to manufacture and test new IPV solutions across sectors, verifying compliance with specifications and real-world performance. The outdoor monitoring activities defined in D6.9 provide essential data for evaluating these pilot demonstrations. <i>D8.5 – Monitoring guidelines and specific measurement & validation plan for each demo case.</i> Complementary to D6.9, it provides detailed measurement, and validation plans for the demo cases, serving as both a source and reference for outdoor testing data.
All	The current deliverable feeds from all project activities and the others work packages.

1.4 List of abbreviations

Table 1.2 List of abbreviations

Acronyms	Meaning
AgriPV	Agrivoltaic Photovoltaic
BIM	Building Information Modeling
BIPV	Building-Integrated Photovoltaics
Cfb	Temperate Oceanic Climate (Köppen-Geiger classification)
CSEM	Centre Suisse d'Électronique et de Microtechnique
DC	Direct Current
DHI	Diffuse Horizontal Irradiance
DLRI	Reflection Index
DLSI	Insulation Index
DNI	Direct Normal Irradiance
EPFL	École Polytechnique Fédérale de Lausanne
EVA	Ethylene Vinyl Acetate
FACT	FACade Tool facility
GDI	Global Diffuse Irradiance
GHI	Global Horizontal Irradiance
GTI	Global Tilted Irradiance
IEC	International Electrotechnical Commission
IEQ	Indoor Environmental Quality
ImpP	Maximum Power Point Current
IPV	Integrated Photovoltaics
IV	Current-Voltage
JB	Junction Box
KPI	Key Performance Indicator
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
O&M	Operation and Maintenance
OTF	Outdoor Solar Field Test

PERC	Passivated Emitter and Rear Cell
Pmpp	Maximum Power Point (Power at Maximum Power Point)
PR	Performance Ratio
PV	Photovoltaic
PVC	Polyvinyl Chloride
PVNB	Photovoltaic Noise Barriers
RH	Relative Humidity
STC	Standard Test Conditions
TRL	Technology Readiness Level
TVG	Heat-strengthened glass
Vmpp	Maximum Power Point Voltage
Wh/Wp/y	Watt-hour per Watt-peak per year
Wp	Watt-peak
WP	Work Package

2 SUPSI OUTDOOR TEST FACILITY

2.1 Aims of outdoor measurements at SUPSI

SUPSI's outdoor facility hosts the e-PIZ 54 mock-up, designed to validate the project technology at Technology Readiness Levels (TRL) 6. This validation includes not only the technology itself but also integration, installation methodologies, and maintenance procedures, serving as an intermediate step towards the full-scale demonstration activities planned in Work Package 8 (WP8) at TRL7 in the Morbegno demo site.

The e-PIZ 54 prototypes integrate an insulating layer and a glass-glass PV module. The primary research question investigates the impact of colour solutions on both the electrical and thermal performance, comparing them to a benchmark without colour. Additionally, the effect of incorporating an insulating layer on the electrical and thermal performance will be evaluated, with comparisons to a benchmark using an open-rack configuration.

2.2 General description of the test site

SUPSI's outdoor facility is located on the flat roof of the Department of Environment Constructions and Design of SUPSI in Mendrisio (45° 52.2' N, 8° 58.6' E, 354 m elevation), in the southern region of Switzerland, Ticino.

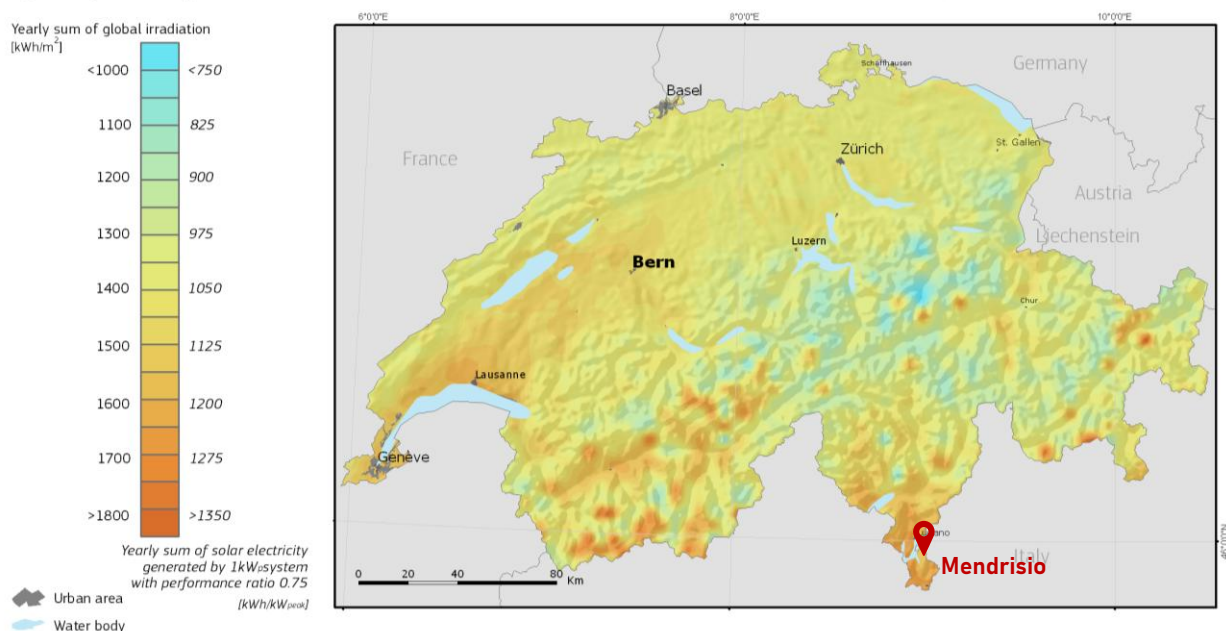


Figure 2-1: Geographical Position of Mendrisio and Global Irradiation in Switzerland. Source: PVGIS

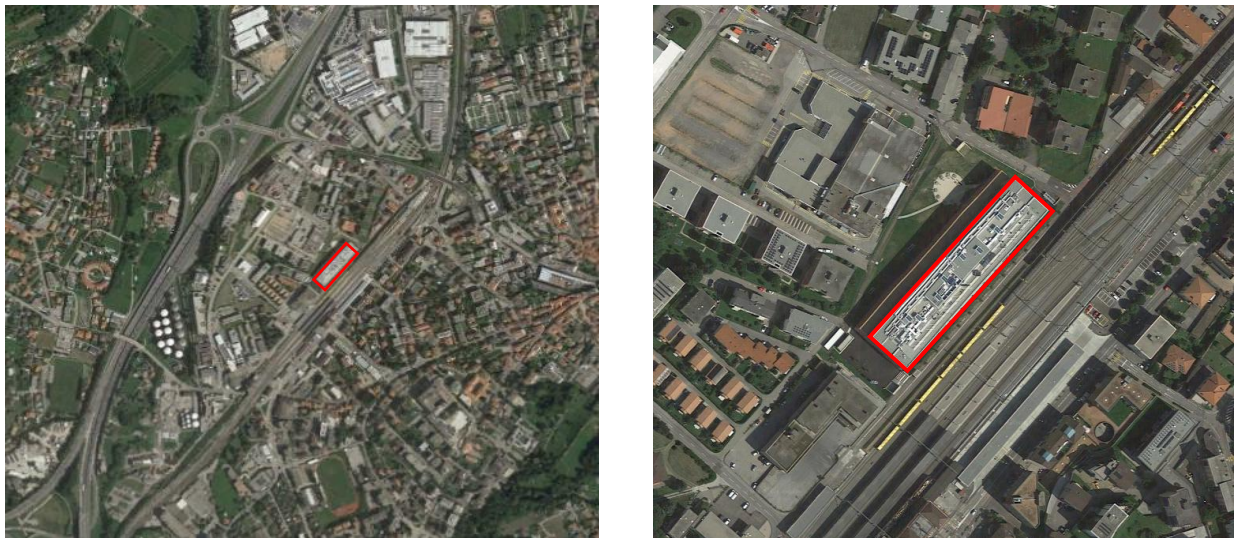


Figure 2-2: Satellite picture to identify the location of facilities where mock-ups will be installed.

The roof, which extends approximately 130 meters from northeast to southwest, is situated at a height greater than the surrounding buildings, minimizing the impact of shading except for the topographic profile of the horizon due to nearby mountains. This ensures optimal exposure for the project mock-up despite the building's cast mutual shading in the late afternoon. Given the roof's narrow and elongated shape, a solar horizon diagram, Figure 2-3, with the corresponding shading mask has been provided for the middle position of the Campus' roof.

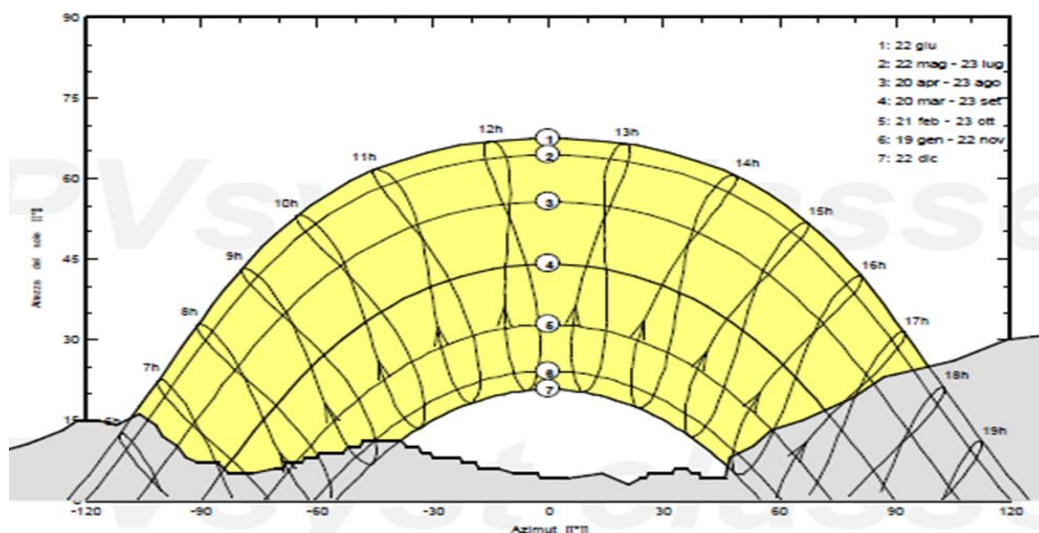


Figure 2-3: Horizon profile of the SUPSI building roof - Mendrisio, Switzerland

Regarding climatic conditions, Mendrisio experiences a warm and temperate climate with significant yearly rainfall. According to the Köppen-Geiger climate classification, this location falls under the Cfb category, indicating a temperate climate with a humid summer, an average temperature of the hottest month below 22°C, and at least four months with temperatures above 10°C.

2.3 Description of module prototypes

The e-PIZ 54 prototypes, illustrated in Figure 2-4 and Figure 2-5, represent an integration of the PIZ Rock Metabio H54 panel and the 3S glass-glass PV module.



Figure 2-4: PIZ Rock Metabio H54 panel

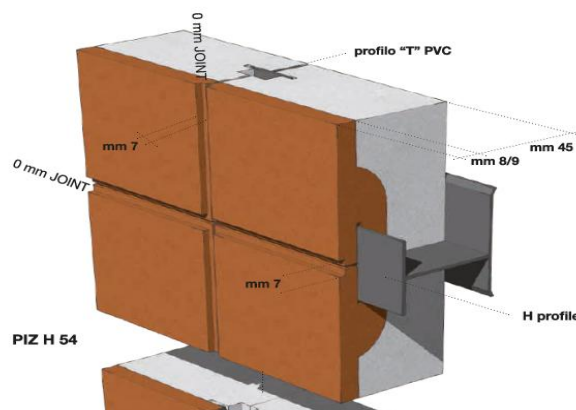


Figure 2-5: 3D detail of PIZ panel

The PIZ Rock Metabio H54 panel consists of a 45-mm-thick insulation layer with a 135 kg/m³ density coupled with an 8-mm-thick mortar layer. The latter is reinforced with alkaline-resistant fiberglass and includes modified cement mixed with metal oxide pigments, which offer resistance to atmospheric agents.

The 3S glass-glass PV module comprises two layers of glass: a 3 mm fully tempered (Thermally toughened glass) front layer, and a 2.1 mm semi-tempered (Heat strengthened glass) rear layer. These are integrated with silicon half-cut solar cells and a double EVA encapsulant sheet. A junction box (JB) containing all the essential electrical components is attached to the module's rear.



Figure 2-6: 3S PV module (front view)



Figure 2-7: 3S PV module (rear view)

Silicone adhesive is used to bond the mortar layer to the rear glass surface of the glass-glass PV module. The adhesive is applied exclusively behind the solar cells and along the edges of the module.

To enable seamless integration, the vertical edges of the insulation material (rock wool) are grooved to accommodate a Polyvinyl Chloride (PVC) "T" profile, ensuring a "0" mm gap joint. The top horizontal edge of the insulation is also grooved to create a dedicated passage for electrical wiring, enabling structured internal wiring within the module. Additionally, a hollow cavity with a 102 mm diameter is created inside the PIZ module to house the junction box. The horizontal edges of the mortar layer are thickened and grooved to allow for the insertion of an aluminium H-profile, providing structural support and facilitating easy installation.

2.3.1 Product specifications

The e-PIZ 54 modules, illustrated in Figure 2-8 and Figure 2-9, are developed as a multifunctional building-integrated photovoltaic façade cladding system. These modules produce energy while delivering high thermal and effective acoustic insulation. The system boasts a thermal resistance value of $1.18 \text{ m}^2\text{K/W}$ and a weighted sound reduction index of 13 dB.

The e-PIZ 54 modules are equipped with an integrated fixing and mounting system, and feature a pre-defined path for electrical wiring, simplifying installation and reducing the overall installation time. It also is underlined that the reduced weight of the product permits installers to move panels manually avoid using machinery for the installation and make it easier.

Each module measures 916 mm x 471 mm weighs 15 kg and has a nominal peak power output of 75 watts. The technology provides energy production of approximately $170\text{--}180 \text{ W/m}^2$, with a system weight of 35 kg/m^2 .

Customization options are available for the cladding system, focusing on two main aspects: panel dimensions and surface finish. The panel size can be adjusted to fit any rectangular shape, with a maximum dimension of 1200 x 600 mm. Finishing options include transparent glass, which reveals the solar cells and the distinctive PIZ pattern, or coloured glass that covers the entire surface.



Figure 2-8: e-PIZ 54 (front view)



Figure 2-9: e-PIZ 54 (side view)

2.3.2 Mounting/maintenance instructions

The e-PIZ 54 modules can be installed on walls using the same fastening and mounting system as traditional PIZ panels, which consist of horizontal aluminium H-profiles and vertical PVC T-profiles. The horizontal H-profiles are secured to the wall with metal expansion plugs spaced 45 cm apart.

For additional protection, aluminium safety clamps (Figure 2-10) can provide extra stability to the glass. Safety clamps are recommended due to the behaviour of polymeric materials, such as the EVA encapsulant and silicone used in these modules when exposed to high temperatures. In the

event of a fire, these polymeric materials could melt, potentially leading to glass detachment. The safety clamps ensure the glass remains securely attached, even under the worst conditions.

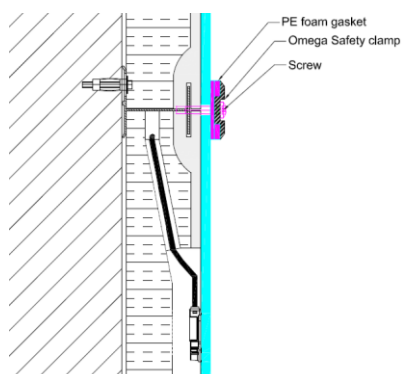


Figure 2-10: Aluminium safety clamp

2.4 Description of mock-up

The e-PIZ 54 mock-up, hosted at SUPSI's outdoor facility, simulates a multifunctional building-integrated photovoltaic façade. Figure 2-11 illustrates the mock-up's expected appearance, while Figure 2-12 showcases the mock-up's layout developed for the preceding European project, BIPVB00ST.



Figure 2-11: Rendering of the expected e-PIZ 54 mock-up in SUPSI



Figure 2-12: Old e-PIZ mock-up in SUPSI

In order to permit the comparison between the modules built in the previous project and the new ones now developed in the framework of the Seamless-PV project, four e-PIZ modules will be retained for ongoing monitoring.

The mock-up is oriented with an azimuth angle of 180 degrees (south) and a tilt angle of 90 degrees (vertical). Overall, it consists of fifteen modules, nine of which are arranged in a 3x3 grid. Within this grid, five modules are dummy units, while the remaining four incorporate photovoltaic cells, Figure 2-14.

The four older e-PIZ modules have been placed to the left of these modules, while two open racks of photovoltaic laminated glass are positioned on the adjacent right side. These additional components are intended to enable temperature and energy data comparisons. Furthermore, to minimize mutual shading, all the modules have been positioned so that their outermost surfaces are coplanar (Figure 2-13, left).

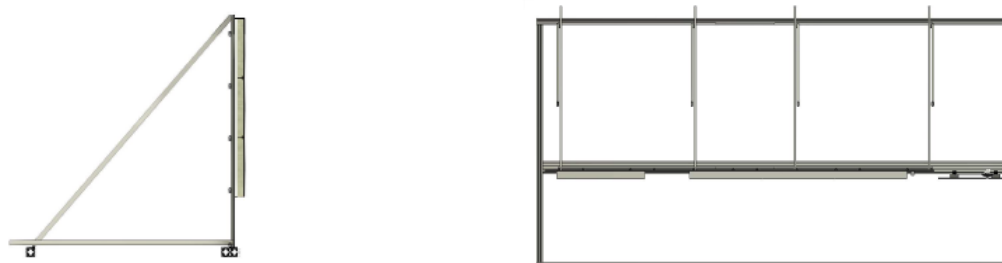


Figure 2-13: Left. Sectional representation of the e-PIZ 54 mock-up in SUPSI. Right. Plan representation of the e-PIZ mock-up in SUPSI.

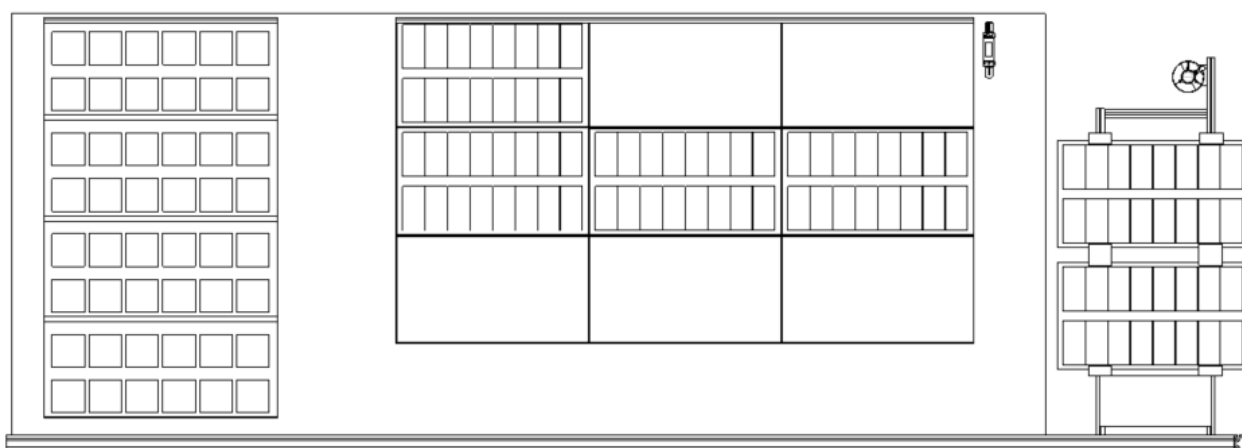


Figure 2-14: Front representation of the e-PIZ 54 mock-up in SUPSI.

2.4.1 Mock-up design

The e-PIZ mock-up retains the same design as the one developed under the BIPVBOOST European project, with slight modifications to the structure to accommodate the installation of two horizontally placed open-rack modules.

The load-bearing frame of the mock-up is constructed using aluminium B50 and steel box profiles with a rectangular cross-section, forming the primary support structure. To simulate a vertical wall, the Knauf AQUAPANEL® slab has been employed, onto which the profiles and, subsequently, the e-PIZ 54 modules will be mounted.



Figure 2-15: e-PIZ 54 mock-up support structure

The mounting system consists of horizontal aluminium H-profiles secured to the wall with specialized plugs and vertical PVC T-profiles. Additionally, aluminium safety clamps designed by PIZ could be integrated into the system to study mechanical retention. The mock-up also serves as a testing platform for these newly developed clamps.



Figure 2-16: Aluminium H-profile placed inside the upper horizontal grooves

2.5 Monitoring system and sensors

For monitoring the mock-up, SUPSI has opted for IV (current-voltage) scanners instead of an inverter connected to the grid. As a result, all mock-ups remain off-grid, with electrical characteristics being measured at the level of individual modules. This approach allows for a direct comparison of the energy output of individual modules rather than aggregating them into a single string or small plant.

The monitoring of the mock-up will employ Gantner's Outdoor Solar Field Test (OTF) system, PT100 temperature probes, and humidity sensors. The OTF system can conduct passive Maximum Power Point Tracking (MPPT), measuring the IV curve, and capturing key parameters like I_{sc} , R_{sc} , I_{mp} , V_{mp} , R_{oc} , and V_{oc} . To ensure accurate irradiation data, a pyranometer will be positioned co-planar to the modules on the left side of the main structure, complemented by an additional reference silicon cell. Table 2.1 collects all the variables, instruments, and working sensors used in the monitoring system.

Table 2.1: Parameters and instruments in the e-PIZ 54 mock-up monitoring system

Parameter	Unit	N°	Device	Technical Specifications
Glass/mortal interface temperature behind solar cells	°C	6	MINCO S17624PDXT120A 4 wire PT100 RTD sensor	- Temperature Range: -50°C to 200°C - High sensitivity - Fast response time
Junction box temperature	°C	5	MINCO S17624PDXT120A 4 wire PT100 RTD sensor	- Temperature Range: -50°C to 200°C - High sensitivity - Fast response time
Glass/mortal interface humidity	%RH	3	Honeywell HIH-5030/5031 Humidity Sensor	- Humidity Range: 0% to 100% - Accuracy: ±3% RH - Response Time: 5 s - Operating Temperature: -40°C to +85°C
Global Plane of Array Irradiance	W/m ²	1	Kipp & Zonen CMP11 Pyranometer	- Sensitivity: 7-14 $\mu\text{V}/\text{W}/\text{m}^2$ - Response Time: < 5s (95% response) - Spectral Range: 285-2800 nm - Temperature Dependence: <±1%
Global Plane of Array Irradiance	W/m ²	1	IMT Technology Si-mV-85-Pt100-4L Silicon Irradiance Sensor	- Output: approx. 85 mV at 1500 W/m² - Integrated Pt100 Temperature Sensor - Operating Temperature: -35°C to +80°C

Figure 2-17 provides an overview of the sensor layout. Of the fifteen installed modules, only eight are equipped with sensors. Additionally, one module has spare sensors installed and serves as a backup module.

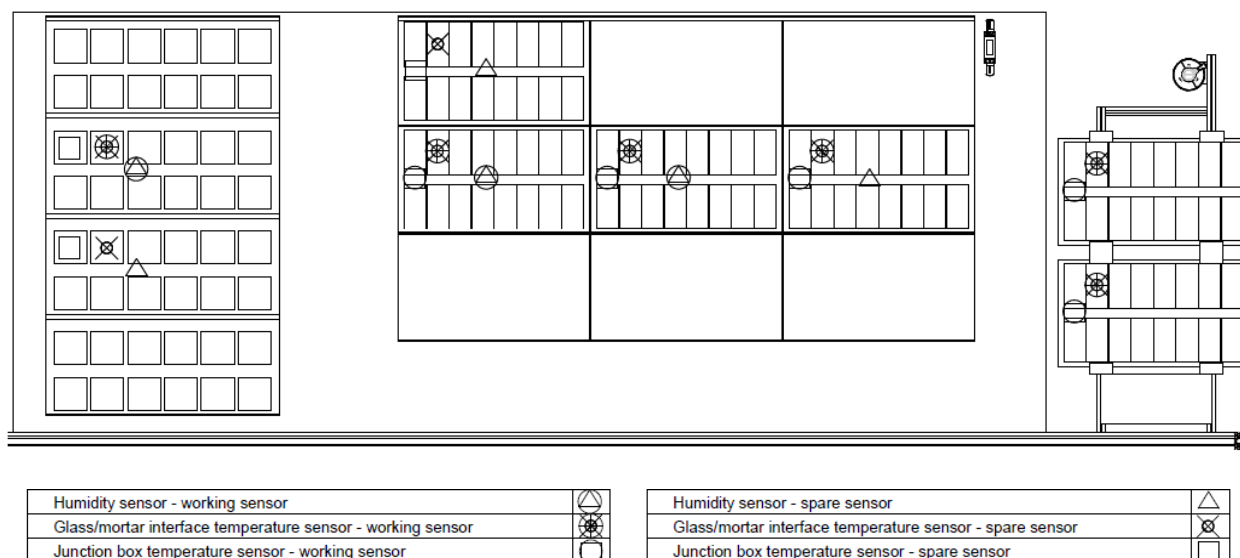


Figure 2-17: e-PIZ 54 mock-up sensors distribution

2.5.1 Data collection

The compliance with TRL 6 for the BIPV modules, coloured and non-coloured, will be verified by measuring and assessing the following aspects:

- **Electrical Performance Analysis:**
 - Energy Yield: Compare the energy yield of coloured and non-coloured modules to those of open-rack modules.
 - Performance Ratio (PR): Analyse PR time series at different resolutions, comparing coloured and non-coloured modules to open-rack modules.
- **Temperature Analysis:**
 - Temperature Distribution: Measure the operating temperatures at the back of the module, junction box (JB), and air gap. Compare these temperatures for coloured and non-coloured modules to those of open-rack modules.
 - 98th Percentile Temperature: Determine the 98th percentile operating module temperature according to IEC TS 63126.
- **Shading Analysis:**
 - Shading Effects: Verify the impact of shadows on operating conditions and temperature values, particularly in worst-case hotspot conditions.

3 CSEM OUTDOOR TEST FACILITY

3.1 Aims of Outdoor Measurements at CSEM

CSEM's outdoor facility will host the following prototypes:

- a) Two to four prototypes designed and manufactured by ONYX in order to validate the project technology in preparation for the installation of the final prototypes at the final demo site located in Florence (Italy). The main novelty of these BIPVs is the use of the new format's cells and the incorporation of a coloured intermediate layer inside the PV module.
- b) Two to four prototypes manufactured by 3S integrating colouring solutions. These prototypes will be used in the realization of Demo Number 2, located in northern Switzerland.

For both products, the energy yield of Seamless prototypes will be compared to that of a conventional product, which will serve as the benchmark (reference) technology. The main research question is to assess (for both prototypes) how the adoption of colouring solutions in BIPV modules impacts their energy yield (kWh/y or Wh/Wp/y), in comparison to a benchmark that excludes colour. While it is known that the introduction of colouring solutions may reduce the efficiency of the modules under Standard Test Conditions (STC), little is understood about their impact on long-term (annual) energy yield under typical operating conditions, which differ from STC. These conditions include variations in the angle of incidence, fluctuating irradiance levels, and higher operating temperatures, among others. However, given the limited temporal horizon, the long-term stability of the colouring solutions used will not be assessed.

3.2 General description of the test site

The outdoor testing site at CSEM, located on a flat roof adjacent to the CSEM building in Neuchâtel, Switzerland (46°59'N, 6°55'E, 444 meters above sea level), provides an ideal environment for evaluating the performance of innovative Building-Integrated Photovoltaic (BIPV) modules. The site benefits from optimal south-facing exposure, ensuring maximum sunlight exposure throughout the day. With a Cfb Köppen-Geiger climate classification (warm-temperate), the site experiences a relatively mild climate. While there is some potential for shading from nearby objects, steps will be taken to minimize the risk of shading effects during testing, ensuring the accuracy and reliability of the measurements.

The monitoring takes place at the module level (module-level monitoring, see Figure 3-1). More details about the monitoring system are given in Sec. 3.4.2.



Figure 3-1: Example of monitored solar PV modules at CSEM outdoor monitoring facilities. Default configuration: tilt=16°, azimuth = 175° (the tilt resembles more that of a C&I installation, rather than a utility-scale one)

3.3 Description of module prototypes

The BIPV prototypes manufactured by ONYX and 3S will be installed at the CSEM facilities, each featuring distinct design elements to assess the impact of colour on energy yield.

Prototype 1 - ONYX - The ONYX prototypes will consist of extra-clear front glass and black frit tempered rear glass, with M10 full-format crystalline silicon (c-Si) solar cells integrated between the two glass layers. An encapsulant and a dark grey interlayer developed by CSEM will also be incorporated, enabling the uniform application of colour and transforming the visual appearance of the module. For the outdoor testing, two to four prototypes will be produced. One or two of these modules will feature the coloured interlayer, while one conventional module will be manufactured without the coloured interlayer to serve as a reference benchmark for comparison.

Prototype 2 - 3S - The BIPV prototypes from 3S will be glass-glass façade modules featuring both colour and anti-glare technologies. The colour is achieved through a thin-film coating applied to the inner side of the front glass, which produces colour through selective interference between incoming and reflected light. The anti-glare effect is obtained by etching the outer surface of the front glass. For the outdoor tests, three prototypes will be manufactured: one with an orange colour, one with a blue colour, and one conventional module without colour or anti-glare features to act as a reference for performance comparison.

3.3.1 Product specifications

Prototype 1 - ONYX – Each PV module for the final demo will have a regular size and dimensions, with a measure of 1000 mm x 1000 mm, and a weight of about 30 kg. However, the dimensions for these prototypes are pending to be defined. To withstand the design loads and consider the final fixing solution, both the front and rear glass panels have a thickness of 6 mm. With a total glass thickness of 12 mm, together with the encapsulant, this combination achieves a total thickness of about 14 mm. For this reason, the module dimensions have been limited to facilitate easier handling. The front glass will be extra-clear, while the rear glass will be black frit. The crystalline silicon solar cells used in these prototypes will be M10 mono facial solar cells, with strings manufactured using the developed tabber by MASS.

Prototype 3S – For the outdoor testing, 3S will use the largest standard module size available in their portfolio, which is expected to be the most commonly used size for Demonstrator 2. The dimensions of this module are 1300 mm x 935 mm x 9 mm, with a weight of 26.7 kg. The final module sizes for the demonstration will be a mix of 3S standard module sizes and custom sizes. The exact dimensions for the demo site are still to be determined. 3S typically uses G12 half-cut PERC cells for these modules. The glass used in both the front and rear of the façade modules is 4 mm thick.



Figure 3-2: Standard dimensions of 3S modules

3.3.2 Mounting/maintenance instructions

Prototype 1 - ONYX – For the preventive maintenance and cleaning of ONYX BIPV modules, it is recommended that maintenance be performed at least twice a year. During these checks, special attention should be given to key components such as the wires and junction box, ensuring that no damage is present. Regarding the cleaning of the PV glazing, rainwater generally eliminates the need for cleaning, as it naturally washes away dust and debris. However, if cleaning is necessary, a solution of neutral detergent mixed with water is recommended. Specifically, a mixture containing 3% ammonia and a surfactant is ideal. It is advisable to use a rubber brush or other typical glass cleaning tools to avoid scratching the surface while cleaning the PV module.

Prototype 2 - 3S - A 3S solar façade is normally cleaned of dust and dirt by rain. In cases where the façade becomes excessively dirty, it can be cleaned with plenty of water and a gentle cleaning tool, such as a sponge. 3S recommends continuous function monitoring of the 3S solar façade with a data logger or similar. Additionally, an annual inspection should be conducted by a trained specialist. The inspection should include the following tasks:

- **Visual inspection** for:
 - Damaged or loose solar modules
 - Bent hooks
 - Blocked water drainage channels
 - Cables (if accessible)
 - Connectors (if accessible)
 - Earthing cable (if accessible)
- **System performance checks:**
 - Measure system voltage and current
 - Check the functionality of fuse elements
 - Measure inverter temperature
 - Use thermography to identify hotspots or inactive cells/modules

3.4 Description of mock-ups

For both 3S and ONYX products the monitoring will take place at the module level for multiple reasons:

- a. **CSEM Outdoor Monitoring Setup:** CSEM's outdoor monitoring system is designed to support module-level monitoring, ensuring accurate data collection for each module.
- b. **Use of Proven Components:** Both 3S and ONYX will utilize conventional and proven components, such as mounting structures, fixation systems, cables, and connectors for the realization of the demos.
- c. **Main Research Focus:** The main research question is to assess (for both prototypes) how the adoption of colouring solutions in BIPV modules impact the energy yield (kWh/y or Wh/Wp/y) of the BIPV modules, compared to a benchmark that does not include colour. While it is known that the inclusion of colouring solutions may reduce the efficiency of the modules under Standard Test Conditions (STC), little is understood about their impact on long-term, annual energy yield under typical operating conditions, which differ from STC. These conditions include variations in the angle of incidence, fluctuating irradiance levels, and higher operating temperatures, among others. Due to the limited duration of the testing, the temporal stability of the colouring solutions will not be assessed.

3.4.1 Mock-up design

This section is not relevant, as module-level monitoring will be implemented instead. Refer to Figure 3-1 for further details.

3.4.2 Monitoring system and sensors

Each module will be connected to a functional unit that can scan IV curves, record the relevant electrical quantities, and scan IV curves with a 1-minute resolution. During measurement, the devices are kept at MPP conditions. The monitoring station is also equipped with a meteorological station that allows the recording of conventional data used in solar PV modules/system monitoring. This will include:

1. Radiometric sensors (measuring GHI, GTI, GDI, etc.)
2. Rain, wind, and humidity gauges
3. Ambient temperature and back-of-module temperature sensors



Figure 3-3: (Top row and bottom left) Examples of the radiometric sensors and wind gauge available on the CSEM monitoring platform, and (bottom right) a detailed view of the monitoring/MPPT unit.

3.4.3 Data collection

The electrical parameters (Power, I_{mpp} , and V_{mpp}) of the BIPV prototypes will be recorded with a 1-min resolution, as well as all meteorological parameters. The prototypes will be characterized in the laboratory (IV curve and EL measurements) before and after the installation of the modules. The monitoring will extend for a minimum of 6 months. Colour changes of the colouring solutions during the exposure period will be assessed too.

4 BECSA OUTDOOR TEST FACILITY

4.1 Aims of Outdoor Measurements at BECSA

BECSA's outdoor facilities will host the prototypes for the final demonstration on the road along the AP8 "Variante Sur Metropolitana" highway, placed in area named the "Supersur". This validation process will include the methodology to be followed to create an explanatory document with the procedure for installing the fastening systems and maintenance procedures, which will be essential prior to the final demo installation. The measurements in this Mediterranean climate will enable the evaluation of the proposed solutions in terms of thermal and acoustic insulation for the building, as well as their impact on energy performance. To this end, the installation of Photovoltaic Noise Barriers (PVNB) has been considered. It is expected to obtain from these measurements a significant improvement in terms of acoustic insulation, thus offering a more comfortable infrastructure.

4.2 General description of test site

The place for this demonstration is located in Catellón/España (Ctra. Nacional 340-A, Km 62.5, 12550) in the warehouses-workshop of BECSA. The test site is exposed to traffic along the National Highway, Amazonas Avenue, and on the other side of the train passage. This industrial building has a rectangular floor plan, consisting of four façades, and serves a dual purpose: as a hub for industrial activities and as office spaces for BECSA.

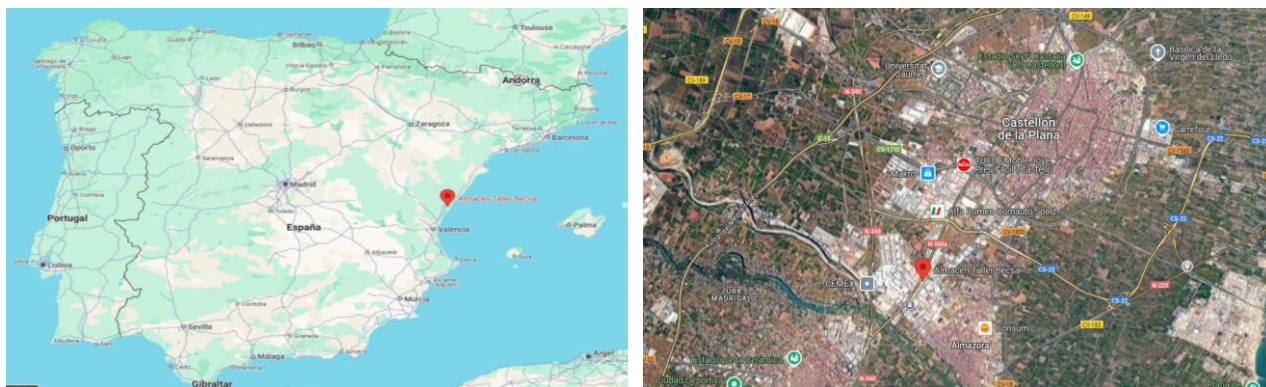


Figure 4-1: Satellite view of the BECSA warehouses and workshop



Figure 4-2: BECSA warehouses and workshop

To assess the impact of shadow caused by nearby objects, particularly from the sun, BECSA conducted a study on the monitoring and behaviour of light and shadow. This study, carried out using specialized software over several days, aimed to understand the variability and effects of shadow on the site, ensuring that the final demonstration installation would be appropriately positioned to minimize any potential negative impacts.

4.3 Description of module prototypes

With the prototypes of modules developed, flexibility, automation, lightness, transparency, and the coupling of the acoustic solution with the photovoltaic solution are sought. The maximum screen dimensions have been defined, taking into account the modularity of the panels provided by ONYX, which allows for significant variation in panel size. The choice of dimensions was based on the standard sizes of acoustic road panels, enabling the system to replace existing structures seamlessly. The design of the panels focuses on optimizing the balance between acoustic performance, mechanical strength, and energy generation. In this process, the glass and encapsulant thicknesses are carefully analysed. Variations such as 6mm/10mm or 4mm/12mm for the glass and between 1.8mm and 2.7mm for the encapsulant were considered. After evaluating the technical specifications, the configuration that meets sound insulation standards is 8mm glass and 6mm glass with a 2.3mm thickness encapsulant. Additionally, an asymmetrical glass configuration has been implemented to further enhance acoustic reduction.

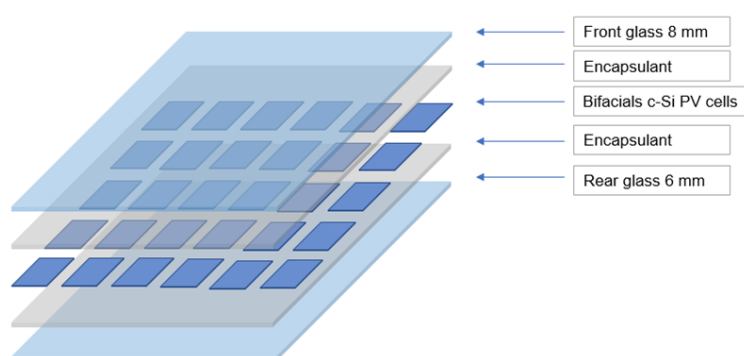


Figure 4-3: Configuration of the panels that meets sound insulation standards, featuring an 8mm/6mm glass arrangement with a 2.3mm thick encapsulant.

The support structure, including the frame and joints, is designed with careful consideration of the materials to be used, such as aluminium, for each component. The proposed frame features a U-shaped profile, which will be sized according to external forces such as wind and snow. Additionally, the structure will incorporate a camera to pass the wiring and house the junction boxes. Interior machining will be performed on the necessary profiles to accommodate and conceal the junction boxes. This preliminary design will be bolted to the pillar laterally by the shape of the profile.

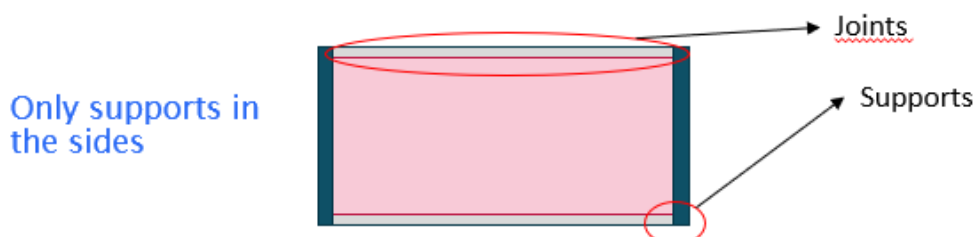


Figure 4-4: Noise barrier lateral support schema

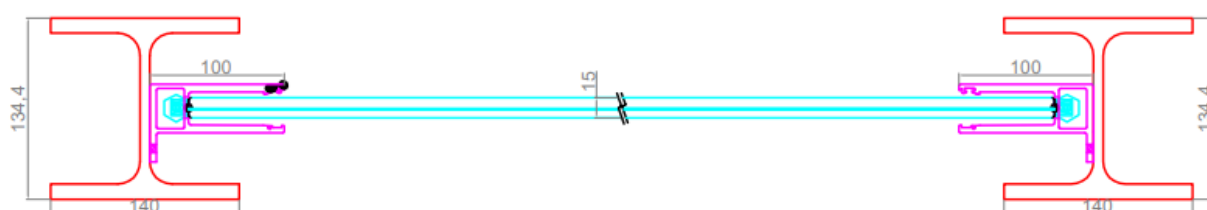


Figure 4-5: Noise barrier support structure. Glasses support

4.3.1 Product specifications

The developed IPV system consists of Photovoltaic Noise Barriers (PVNBs) to be installed along the AP8 "Variante Sur Metropolitana" highway, specifically between km 113+120 and km 113+640 in northern Spain, at a location known as "Supersur." These barriers will serve to protect nearby users from noise pollution. The PVNBs are divided into two main components: the photovoltaic module at the top and the acoustic material at the bottom, working together with a double function: generating energy and reducing noise.

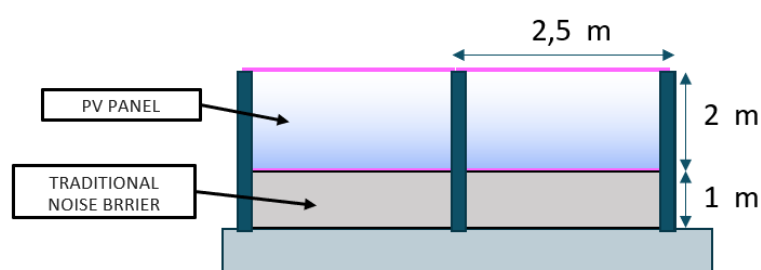


Figure 4-6: Representation of a photovoltaic noise barrier

The structural base consists of a continuous reinforced foundation, incorporating steel reinforcement to satisfy the design load requirements. Steel anchor plates, recessed into the foundation, are employed to ensure a reliable connection between the upper metal columns and the reinforced base.

The supporting profiles for the photovoltaic (PV) component will be fabricated from galvanized steel, selected for its corrosion resistance, structural durability, design flexibility, and ease of installation.

The PV noise-reducing section comprises laminated glass panels embedded with photovoltaic cells. These semi-transparent active elements generate electricity from solar radiation while contributing to acoustic attenuation. The PV glass consists of two asymmetrical glass sheets of differing thicknesses, measuring 1480 mm × 1230 mm with a total thickness of 15.8 mm (8 mm for the front glass and 6 mm for the rear). This asymmetrical configuration and mass have been selected to optimize sound insulation performance.

Due to the glass dimensions and thickness, each panel weighs approximately 175 kg, necessitating a robust and purpose-designed mounting structure. To avoid joints that could compromise acoustic insulation, the PV module acting as an acoustic barrier will have an effective large-format size of 2500 mm × 2000 mm.

The active PV layer will consist of bifacial monocrystalline silicon (c-Si) M10 cells, balancing semi-transparency and power output. To enhance mechanical resistance and durability, the cell architecture adopts a four-layer configuration. Each laminated glass PV module includes 56 solar cells arranged in eight strings of seven cells each, using a five-busbar interconnection. The encapsulant is ethylene-vinyl acetate (EVA), and the junction box is TALENT-TN-BOX-DB (SIDE)*4. Electrical connections between modules will be made using 900 mm cables and 4 × 0.3 mm busbars.

To ensure resilience under adverse weather conditions, the PV modules are required to pass the IEC 61215 Damp Heat Test, conducted under extreme environmental conditions of 85 °C and 85% relative humidity for 1000 hours. The maximum allowable power degradation after testing is limited to 5%.

4.3.2 Mounting/maintenance instructions

For the assembly of the profiles, certain specifications must be met, including:

- **Self-Supporting Design:** The photovoltaic panel must not bear any additional load beyond its weight.
- **Panel Dimensions:** Each panel should measure 2.5 m x 2 m.
- **Maximum Deadlift:** The panels are designed to withstand a maximum deadlift of 225 kg.
- **Profile Design:** U-shaped profiles will be used for the frame structure.
- **Cable Management:** All cables should be discreetly routed along the sides of the frame to maintain a clean and organized appearance.
- **Material Specifications:** The profiles will be constructed from galvanized steel or aluminium, with aluminium frames, pressors, and plackets to ensure durability.

Some of the more unfavourable configurations include:

- Two Vertical Panels
- Three Horizontal Panels

The electrical installations between the modules will be made vertically through the frames. The screens will be stacked in a traditional manner, with each screen placed on top of the previous one until the required height is reached, ensuring the system's stability and ease of maintenance. A small gap, potentially a few millimetres, may exist between the frames. This space will be covered with a proper lid.

Maintenance of the PVNB is designed to be similar to that of traditional acoustic barriers. No specialized procedures are required. In the event of panel damage, replacement will be carried out using standard methods. The damaged panel will be removed by lifting it upwards through the top of the main pillars, following the established approach used in modular screen systems.

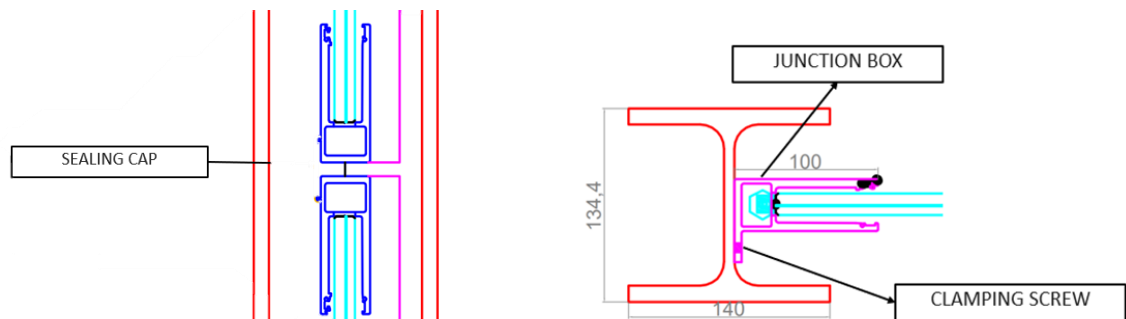


Figure 4-7: Constructive detail. SX) PV panel and mounting system. DX) Junction box and mounting system

4.4 Description of mock-up

The main objective of the mock-up is to validate the fixing system of the acoustic-photovoltaic modules that will be used in the final demonstration. For this purpose, a full-scale unit has been built, replicating the final module dimensions, which combine a concrete acoustic barrier with a glass-glass photovoltaic panel.

In addition, the mock-up will be used to test the acoustic performance of the screen, aiming to identify any potential issues related to sound insulation. This intermediate step will allow to detect and address deficiencies in the acoustic behaviour of the system before the final installation, ensuring the effectiveness of the barrier in real conditions.

4.4.1 Mock-up design

The mock-up has total dimensions of 3,5 meters in height (including an estimated 0,5-meter foundation) and 5,0 meters in width, divided into two sections of 2,5 meters each. Vertically, the lower part consists of a traditional acoustic barrier of 1,0 meter in height, while the upper part integrates the 2,5x2m bi-facial glass-glass photovoltaic panel. This configuration allows for realistic testing of both structural and functional aspects, simulating the full-scale conditions that will be encountered in the final demonstration.

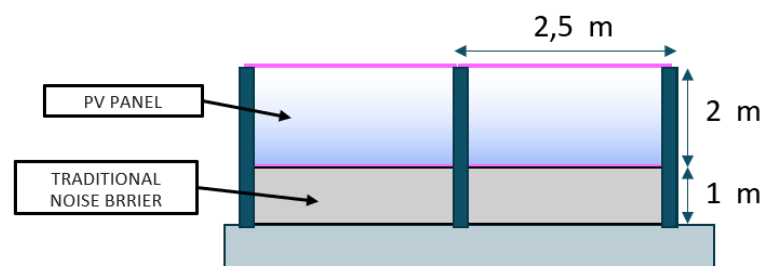


Figure 4-8: PVNB mock-up design

4.4.2 Monitoring system and sensors

Tests will be carried out to verify the effectiveness of the joints and closures of the panel and profile system, ensuring that the insulation performance meets the design requirements. Additionally, the sound absorption properties of the entire product, including the absorbent panels and the overall system shape, will be evaluated.

The measurement system will follow the guidelines defined by standards ISO 1793-5 and ISO 1793-6, which will be used to determine the DLRI (Directivity-Weighted Reflection Index) and the DLSI (Directivity-Weighted Sound Insulation) of the system, ensuring the insulation level exceeds $DLSI > 25$ dB.

To carry out the noise monitoring, the following equipment, provided by Tecnia, will be used:

- Array of 9 Microphones for environmental noise, Type 1
- Sound Calibrator, Class 1
- BK Connect - Modular Analysis Software
- Modular Data Acquisition System and Analyzer Platform LAN-XI, designed to provide a dynamic input range for capturing sound and vibration data
- DIRAC Software
- ZIRCON Sound Source

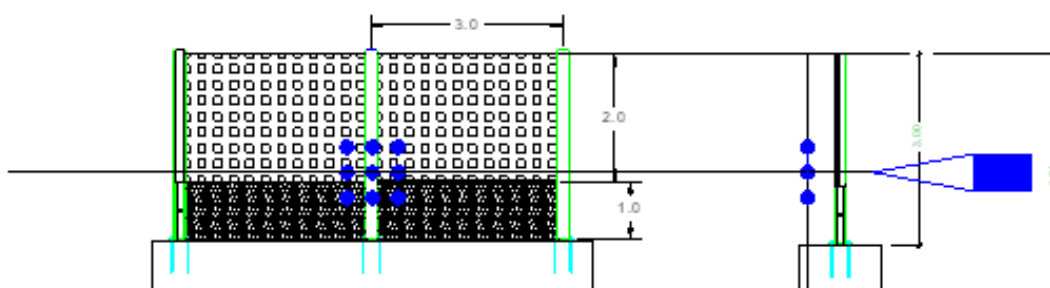


Figure 4-9: Schematic representation of the experimental setup for noise reduction performance assessment.

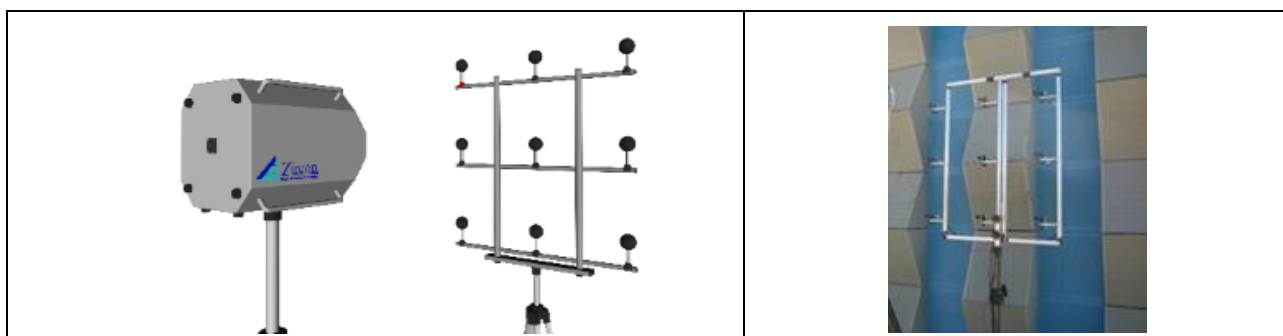


Figure 4-10: Schematic representation of the 9-microphone ambient noise array and the adopted measurement methodology for acoustic data acquisition.

4.4.3 Data collection

The primary objective of the mock-up is to develop a comprehensive assembly guide that compiles all the necessary technical specifications and installation steps for the new screen model. Unlike traditional screens, this version includes integrated photovoltaic components and structural differences that require clear and precise instructions. The goal is to ensure that any technician or operator can assemble the unit safely and efficiently, following standardized procedures validated through this prototype.

Acoustic Properties Verification

The photovoltaic acoustic barrier system will be verified to achieve the desired insulation (DLSI > 25 dB). This will guarantee that, when installed on a traffic lane, the noise passing through the barrier will be at least 10 dB lower than what would otherwise reach the barrier due to top and side diffraction. Additionally, the system's acoustic absorption properties will be assessed to ensure it minimizes noise reflection on the barrier as much as possible.

The following aspects will be tested:

- Insulation index at different positions of the system at noise global level and noise spectrum and noise isolation losses by zones, DLSI.
- Reflection Index at different positions of the system at noise global level and noise spectrum and noise isolation losses by zones, DLRI

The properties of the PVNB system, including the mechanical response of the assembly, its safety, and environmental aspects (as defined by EN 1793-4), will be analysed at Tecnia to ensure that all performance and safety standards are met before final implementation.

5 TECNALIA OUTDOOR TEST FACILITY

5.1 Aims of outdoor measurements at TECNALIA

TECNALIA's outdoor facility will host three mock-ups: 1) the lightweight composite roofing shingle mock-up; 2) the lightweight AgriPV module mock-up; and 3) Cargo Box (VIPV-truck) mock-up. The primary objective of these tests is to validate both the project technology itself, and the integration and installation systems intended for the full-scale demonstration planned in WP 8.

For both products, the PV production will be continuously monitored throughout the entire outdoor testing period. The mock-ups will replicate the full-scale demonstration to proactively identify potential issues that may arise during installation or operation, either from a mechanical point of view (fixing method) or from a product point of view (degradation or damage of the modules).

This outdoor validation phase is critical for detecting and mitigating risks before the final demonstration. The roofing shingle system will be installed at the Mons demo site, while the AgriPV modules will be deployed at NEIKER'S facilities. By addressing challenges early, the project will ensure a more efficient and reliable implementation of the full-scale systems.

5.2 General description of test site

The outdoor facilities for PV testing of Tecnalia are located in the north of Spain, near Bilbao (43°17'46"N 2°52'14"W). They are close to one of TECNALIA'S main buildings, in an area where the module can face South with very limited impact of shadows (Figure 5-1, Figure 5-2).

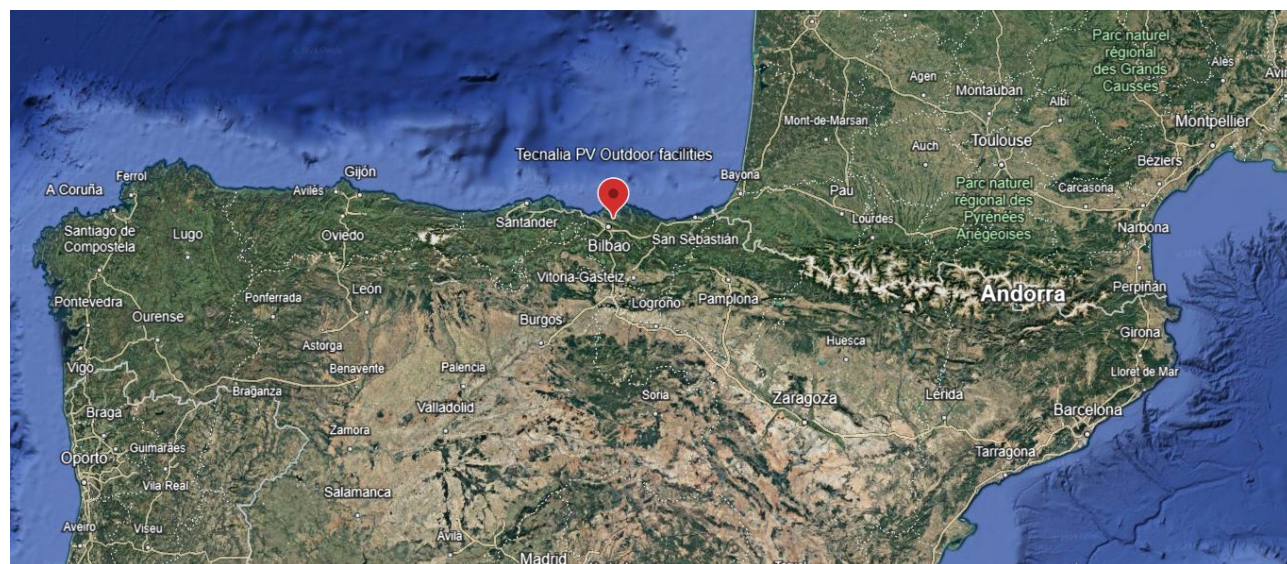


Figure 5-1: Location of Tecnalia's outdoor facilities for PV testing

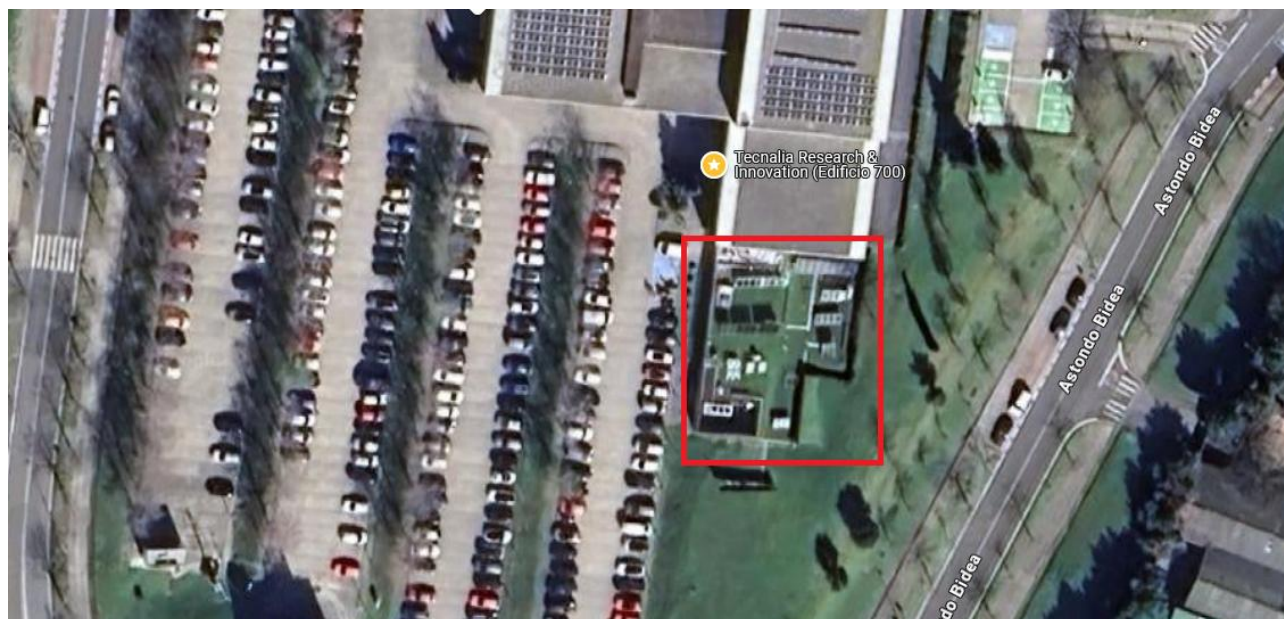


Figure 5-2: Detail of location of Tecnalia's outdoor facilities for PV testing

Table 5.1 shows the usual climatic conditions of the testing site, including temperature, precipitation, humidity, and irradiance data, both for winter and summer.

Table 5.1. TECNALIA testing site's climatic conditions

Weather Condition	Winter	Summer
Average Temperature	8.3°C	19.5°C
Maximum Temperature	12°C	24°C
Minimum Temperature	6°C	16°C
Average Precipitation	119 mm	62 mm
Average Humidity	78%	79%
Average Irradiance	2.5 kWh/m ² /day	5.5 kWh/m ² /day

The facility is equipped with a comprehensive set of sensors for meteorological characterization, including:

- Irradiance: DNI, DHI, GHI, albedo Kipp Zonnen RAZON+ for DNI and DHI, HukseFlux SR 30 M 2 D 1 Eko MS 80 s (class A pyranometers).
- Global tilted Irradiance HukseFlux SR 30 MS 80 s (class A pyranometers), Atersa MET calibrated cell.
- Wind Speed, Relative humidity, Air Temperature, Rain.

Additionally, the facility is equipped with specialized instrumentation for PV performance characterization, including voltage/current sensors, automatic IV tracers, daylight electroluminescence, data loggers, etc.



Figure 5-3: Meteorological sensors at TecNALIA outdoor facilities

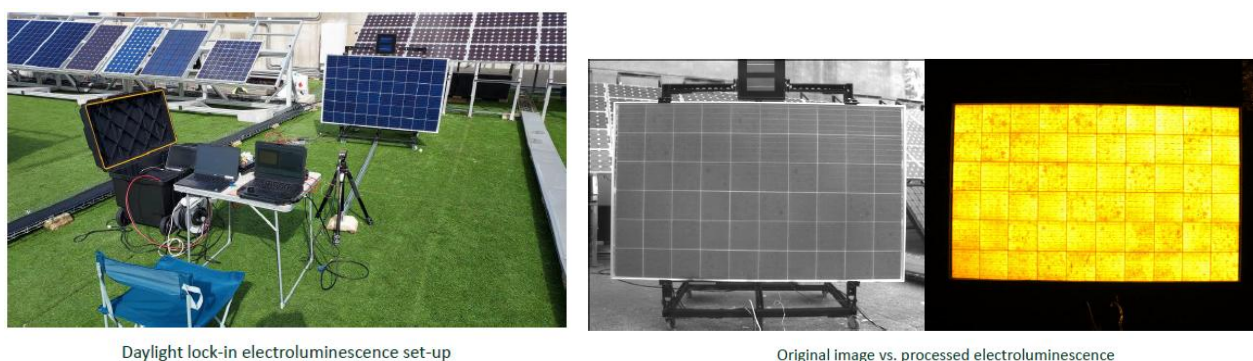


Figure 5-4: Example of daylight electroluminescence characterization

5.3 Description of module prototypes

TECNALIA's outdoor facilities will host three distinct photovoltaic prototypes.

Roofing Shingle Prototype

The first prototype is the roofing shingle, a lightweight composite photovoltaic (PV) tile designed to replace conventional ceramic tiles by being installed directly on top of the roof battens. The design (Figure 5-5) consists of a flat part containing the solar cells, with two vertical parts on the sides that fit into a gutter in order to collect the water that slips from the tiles. The trapezoidal shape of both the flat part containing the solar cells and the vertical parts that fit into the gutter enables the tiles to fit with each other, similar to traditional tile systems.

To achieve seamless integration, the prototype will be painted black. This black colouring, in combination with the back-contact solar cells, will create a full black aesthetic (Figure 5-6).

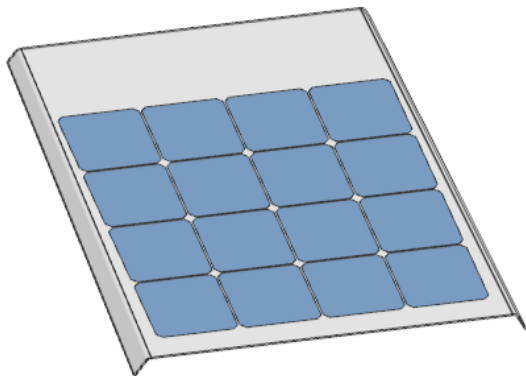


Figure 5-5: Roofing shingle prototype

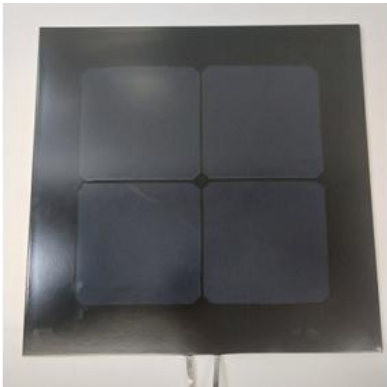


Figure 5-6: Full black sample using back-contact Moxeon3 solar cells

AgriPV Module Prototype

The second prototype is the AgriPV module, which features a stripe-like design, approximately 1 meter long and 400 mm wide. This module consists of two strings of bifacial half-cut M10 cells, as shown in Figure 5-7. The primary objective behind creating thin modules is to place them on top of the greenhouse envelope, leaving a certain distance between them, in order to guarantee that enough light reaches the plants inside while maintaining a homogeneous light distribution.

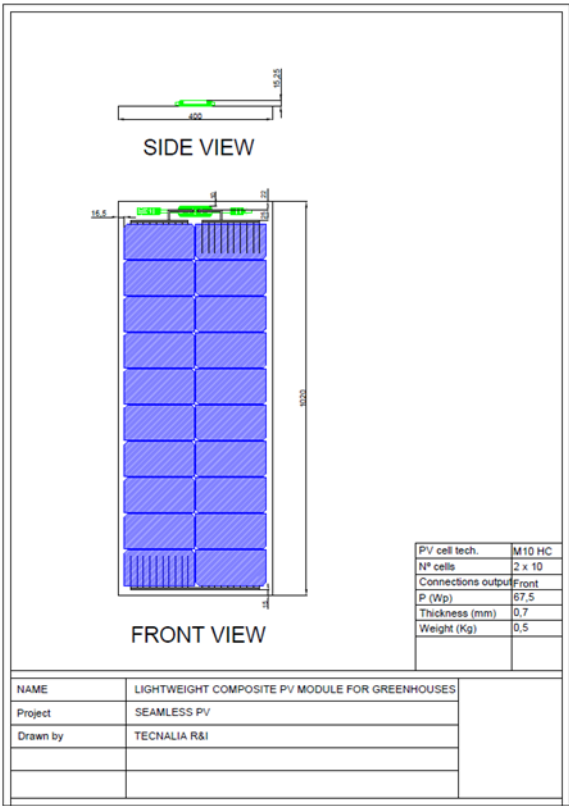


Figure 5-7: AgriPV module design

Cargo Box Mock-up Prototype (BRANKA)

The third prototype is a set of two **cargo box mock-ups**, designed to replicate the structural and thermal behaviour of real small truck cargo boxes. Each mock-up consists of a rectangular box of 2.0 m length × 1.2 m width × 1.0 m height, including an access door. The boxes are manufactured with the same composite sandwich panels used in full-scale cargo box production, thus ensuring representativeness of the final VIPV application.

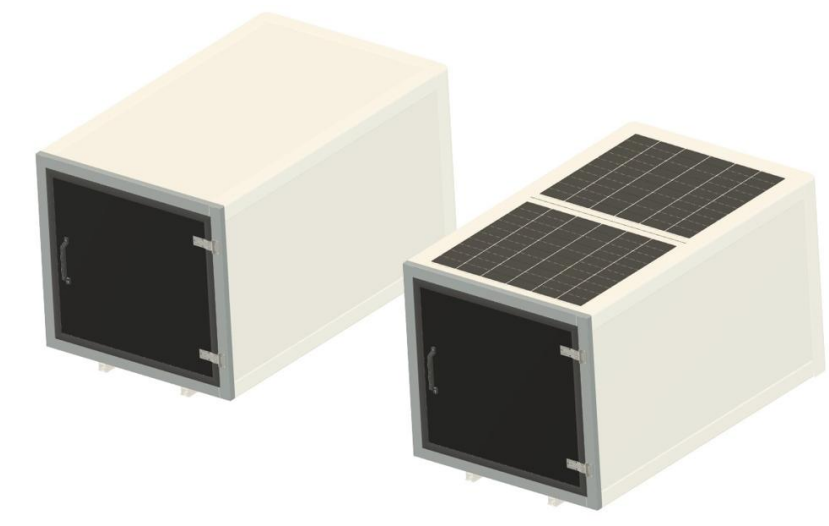


Figure 5-8: A box with FV solar panels in the top and the other box without solar panels

5.3.1 Product specifications

Table 5.2 shows the product specifications for the lightweight roofing shingle, the AgriPV modules and cargo Box Mock-up

Table 5.2. Product specifications

	Lightweight roofing shingle	AgriPV module	Cargo Box Mock-up
Cells	4 strings of 4 Maxeon3 cells	2 strings of 10 M10HC cells,	2 modules of 6 strings of 10 Zebra HC cells
Nominal peak power (Wp)	52	67.5	175
Dimensions (mm)	620 x 710	1020 x 400	1200 x1000
Thickness (mm)	2	0.5	0.5
Weight (kg)	2.5	0.5	<3

As additional information, the vertical side sections of the roofing shingle measure 32 mm at their highest point, facilitating proper interlocking. The upper portion of the flat section remains free of solar cells to allow for overlapping installation without shading active areas.

Regarding the AgriPV and VIPV modules, the module technology is thin, flexible and light, which makes it suitable for greenhouses with polymeric envelopes that cannot withstand high loads, and for EVs.

5.3.2 Mounting/maintenance instructions

Roofing Shingle Prototype

The tiles are installed over wooden battens, and then, fixing hooks are nailed into them to hold the tiles in place. The hooks support the bottom part of the shingle while pressing down the top of the next shingle. To guarantee the watertightness of the roof, a rubber is needed on the overlap between shingles (Figure 5-9).

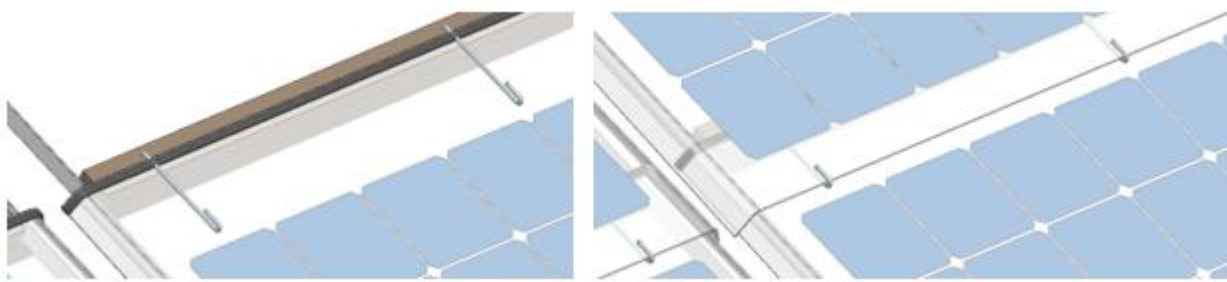


Figure 5-9: Fixing hook and rubber joint system

The vertical edges of the tiles fit into a gutter positioned on top of the battens, which functions as a water drainage system, preventing leaks and ensuring proper runoff (Figure 5-10).

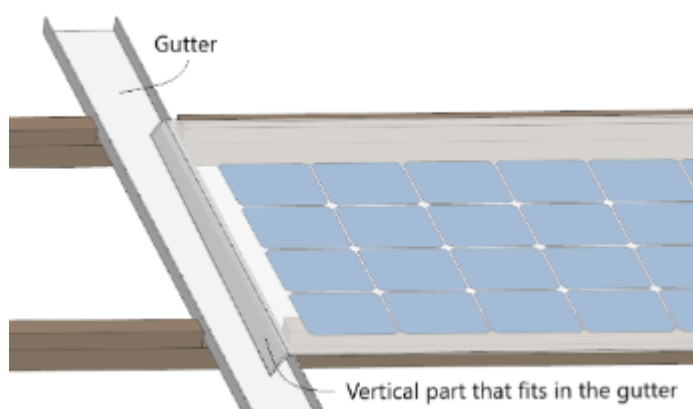


Figure 5-10: Gutter system

During the outdoor testing period, the maintenance of the roofing shingle mock-up will involve:

- No-cleaning. The prototype will not be cleaned, deliberately, in order to observe its possible behaviour in operation when dirty.
- Structure check-ups. Since one of the goals of the mock-up is to verify the fixing system, all structural components—including gutters, battens, hooks, and rubber joints—will be inspected periodically. In case any of the components get damaged, or if it is not holding the tiles in place as it should, it will have to be replaced.

AgriPV Module Prototype

The AgriPV modules are designed in order to be fixed to the greenhouse envelope using the existing fixing points. The fixing system has been designed so that a thin metal sheet will be attached to the top and bottom of the module, which will be approximately 100 mm wider than the module itself. This metal sheet will be attached in situ using a double-sided type, for ease of installation, and the operator will ensure that the metal sheet falls on top of the metallic profiles of the greenhouse structure, where the fixations for the envelope are placed. The metal sheet must be wide enough so that it can reach two of the fixing points of the structure.

Once positioned, the metal sheet will be drilled at the points corresponding to the existing fixing locations of the structure. Finally, the module will be secured to the structure using appropriate screws and fixing elements.



Figure 5-11: Fixing method of the AgriPV module

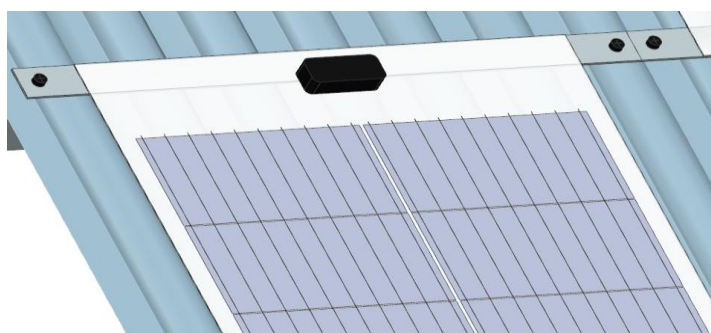


Figure 5-12: Detailed view. Fixing method of the AgriPV module.

The final specifications of the fixing method are still under development to determine the most suitable screws, nuts, washers, and other essential components for optimal installation.

The maintenance requirements for the AgriPV modules are similar to those of the roofing shingles and include:

- No-cleaning. The prototype will not be cleaned, deliberately, in order to observe its possible behaviour in operation when dirty.
- Structure check-ups. Since one of the goals of the mock-up is to verify the fixing system, the metallic plates, paired with their screws, washers, and nuts have to be checked periodically. In case any of the components get damaged, or if it is not holding the modules in place as it should, it will have to be replaced.

Cargo Box Mockup Prototype

Two cargo box mock-ups will be deployed in a dedicated outdoor test area at TECNALIA's facilities in Derio. Both prototypes will be mounted on a metallic support frame designed to ensure structural stability and provide sufficient ground clearance to enable natural air circulation and prevent moisture ingress.

The Solarface VIPV box integrates two photovoltaic modules directly into the top surface of the sandwich panels during fabrication, replicating the industrial manufacturing process of real cargo boxes. The reference box will be built using the same composite panels, but without PV integration, serving as a control unit for comparative analysis.

The two units will be positioned side by side, oriented southwards, to guarantee equal exposure to solar radiation and ambient climatic conditions. Each box includes an access door enabling the installation of temperature and humidity sensors inside the cavity. Since the PV modules in the Solarface prototype are pre-laminated within the composite structure, no additional mounting hardware or sealing operations are required during installation.

Throughout the testing campaign, periodic visual inspections will be carried out to ensure the airtightness and watertightness of the sealing joints and to verify the integrity of the embedded electrical connections accessible via the junction box. The PV surface will not be cleaned to observe its possible behaviour in operation when dirty.

Both boxes will be continuously monitored to compare internal temperature distributions and overall thermal behaviour under identical operating conditions. This experimental setup provides a realistic representation of cargo box operation, minimizing the need for maintenance interventions while focusing on the long-term assessment of thermal and photovoltaic performance.

This experimental setup provides a realistic simulation of cargo box operation, minimizing maintenance requirements while enabling the long-term assessment of thermal and photovoltaic performance.

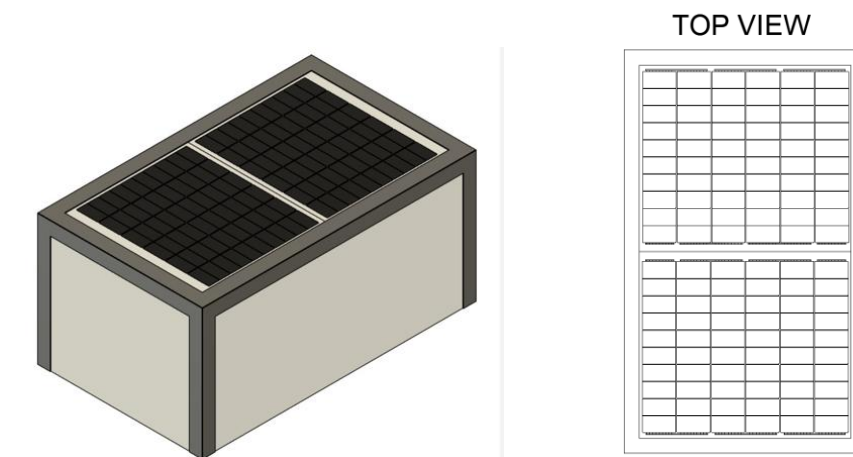


Figure 5-13: One of the mock-up's cargo box simulations and the 2 FV Solarface Zebra panels in the top.

5.4 Description of mock-ups

5.4.1 Mock-up design

Roofing Shingle Mock-up

The roofing shingle mock-up (Figure 5-14) will consist of four shingles installed in a manner that replicates the roof system of the demo site. The supporting metallic structure (dimensions: 1925 mm × 3000 mm × 2000 mm) will be positioned at a 30° angle to accurately simulate the slope of the demo roof. Finally, wooden battens and gutters will be installed on the metallic frame to ensure a realistic setup before securing the shingles using the appropriate fixing hooks and rubber joints.

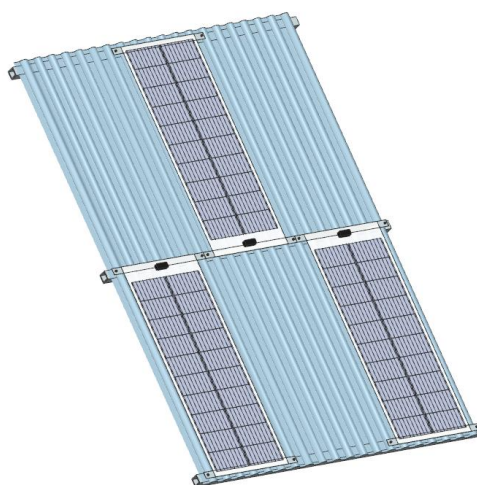


Figure 5-14: AgriPV module mock-up 3D design

AgriPV Mock-up

For the AgriPV modules, a polycarbonate sheet will be placed on top of the metallic structure, aiming to replicate the usual curvature of a greenhouse cover. The greenhouse where the demo will be installed has been used as a reference measurement, which can be seen in Figure 5-15.

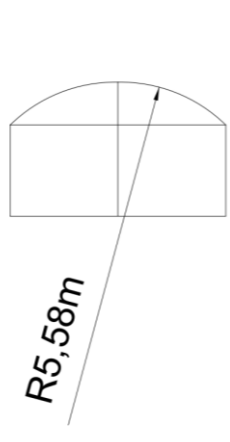


Figure 5-15: Sketch of the radius of a greenhouse to be considered in the outdoor test

To replicate the greenhouse curvature within the given structural dimensions, the polycarbonate sheet will be raised by 30 mm at its centre, as detailed in Figure 5-16.

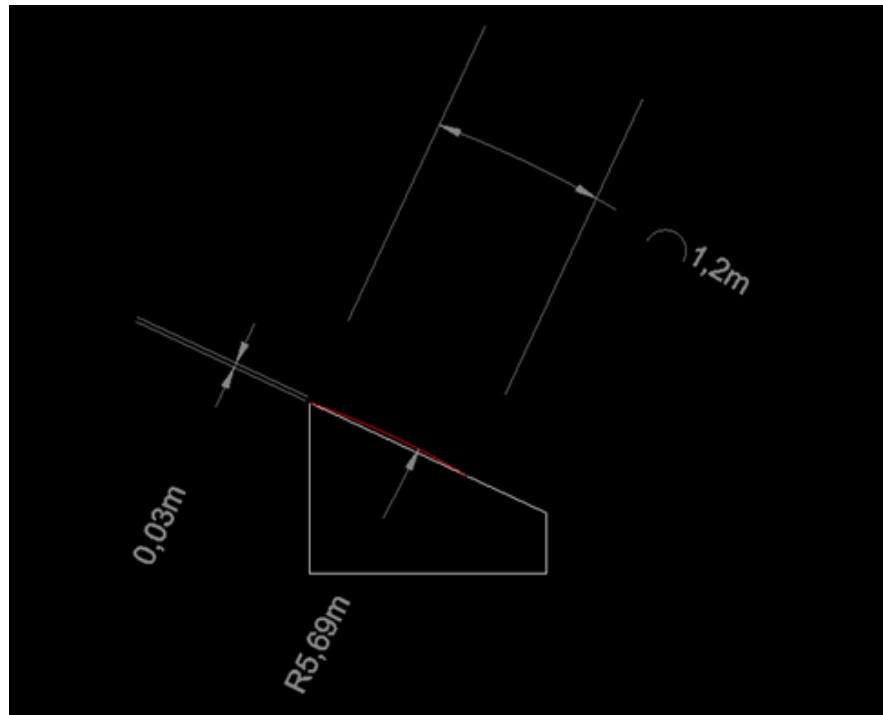


Figure 5-16: Schematic drawing of the curvature of the polycarbonate for the AgriPV modules

Figure 5-17 shows the metallic structure with the polycarbonate sheet attached to it, and a detailed view of the plastic part that has been used to raise the centre 30mm.



Figure 5-17: Metallic structure with polycarbonate sheet (left) and detail of the curvature (right)

It is important to highlight that the total dimensions of the metallic support structure have been designed to accommodate both mock-ups within a single frame. Figure 5-18 presents a 3D model of the structure illustrating the positioning of the two units. For clarity, some auxiliary components such as battens, gutters, and curved profiles are not shown in the figure.

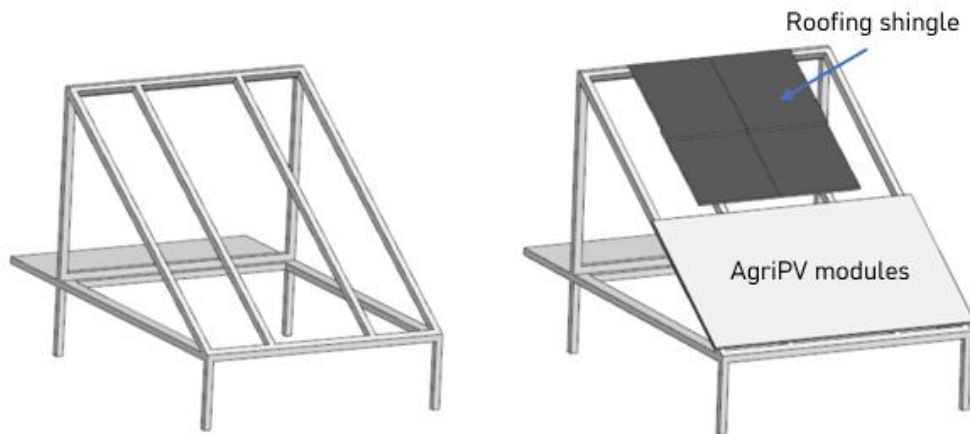


Figure 5-18: 3D drawing of the metallic structure (left) and the placement of the mock-ups (right)

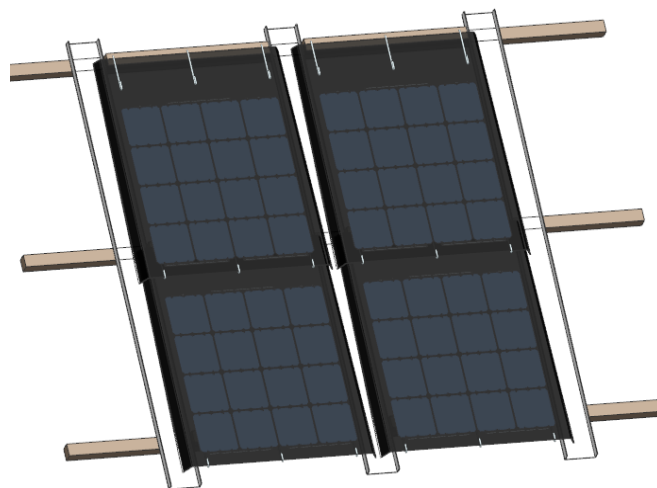


Figure 5-19: Roofing shingle mock-up 3D design

A potential electrical integration strategy is presented in Figure 5-20, which outlines a grid connection approach for both mock-ups.

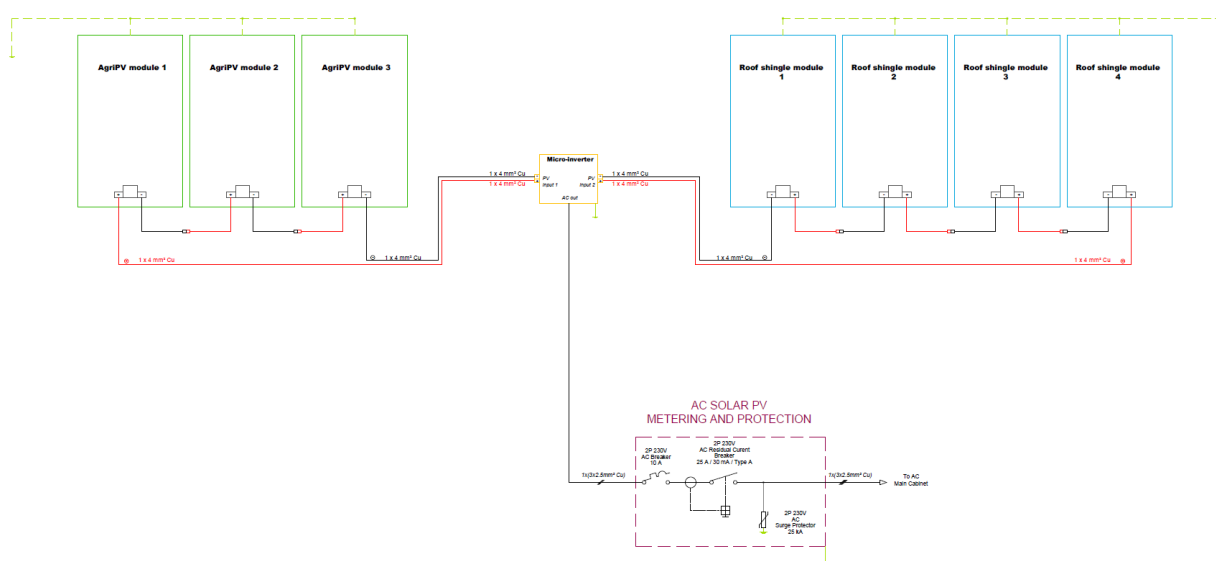


Figure 5-20: Diagram for grid connection.

The proposed solution suggests using a small inverter or micro inverter with two independent DC inputs, one for the serial grouping of the AgriPV modules and the other input for the serial grouping of the Roof shingle modules. Both inputs would have independent maximum power point tracking and their own DC energy measurement.

As the micro-inverter will be located near both installations, dedicated DC protection elements will not be necessary. On the AC side of the micro-inverter, the corresponding protections will be installed before connecting to the general electrical grid.

Cargo box Mock-up

The prototype consists of two insulated cargo box mock-ups (2.0 m × 1.2 m × 1.0 m each), replicating the design and materials used in Liderkit's full-scale truck boxes. Both mock-ups include an access door to enable instrumentation and measurements inside the boxes.

- Reference box: manufactured with composite sandwich panels without PV integration.
- Solarface VIPV box: equipped with two Solarface photovoltaic panels, based on ZEBRA back-contact cells, seamlessly integrated on the top surface.

This twin-box configuration allows a direct comparative analysis of thermal insulation and internal temperature stability, assessing whether the PV integration affects the insulation properties of the cargo box. The Solarface box additionally enables monitoring of PV energy production and verification of seamless lightweight VIPV integration under outdoor conditions.

5.4.2 Monitoring system and sensors

The micro-inverter will serve as the primary data source for electrical parameters, monitoring both input (DC side) and output (AC side); additionally, dedicated sensors will be installed to measure temperatures and irradiance. These sensors will be directly connected to a data acquisition system or datalogger, which supports both analog input connections and communication via the Modbus protocol, enabling real-time data collection and analysis. The

micro-inverter, along with the cabinet where the protections and acquisition system will be accommodated, will be installed near the two PV groupings, sharing the main structure.

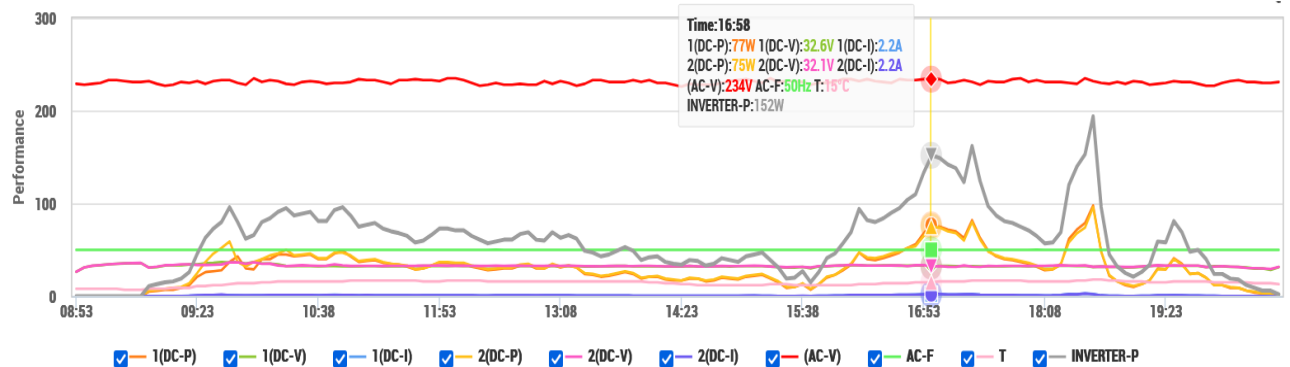


Figure 5-21: Data provided by APSystems micro-inverter (Two DC inputs / One AC output).

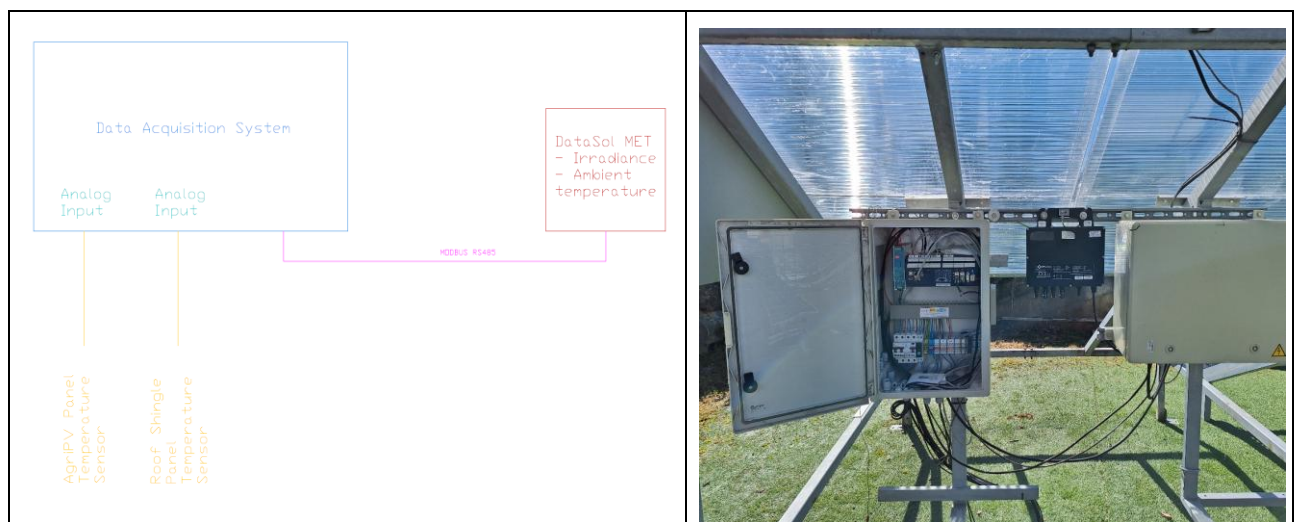


Figure 5-22: On the left Metering diagram, on the right image of the PV Cabinet and Micro-inverter

The module temperature measurement will be conducted on a centrally positioned module, with the sensor securely attached to its backside to capture accurate thermal data. Meanwhile, some of the irradiance sensors will be installed on the same plane as the PV array, ensuring no permanent shading affects the readings.

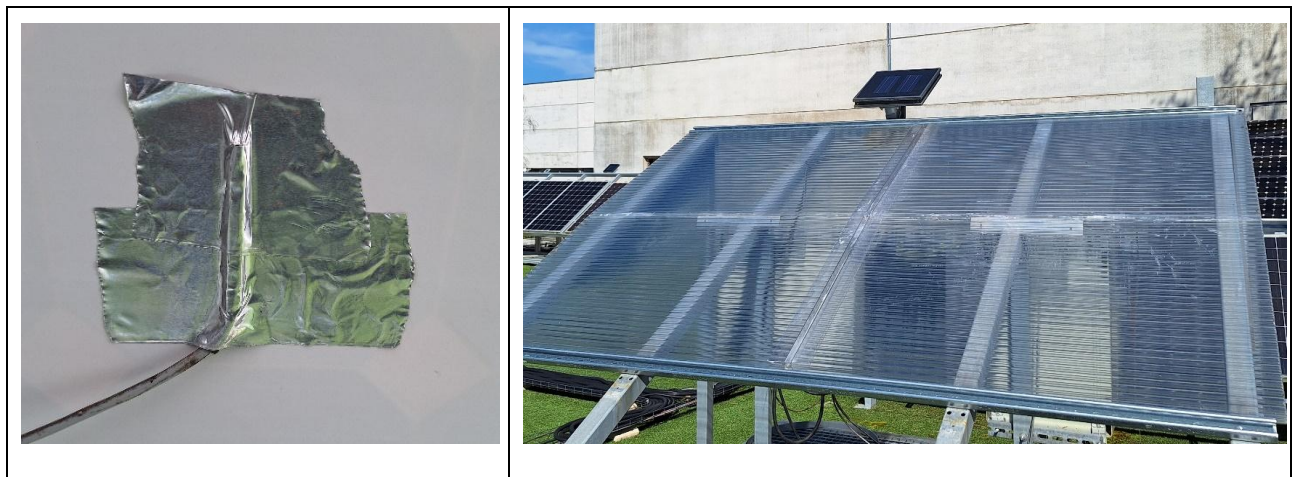


Figure 5-23: On the left temperature sensor attached on the rear part of the module, on the right image of the Irradiance sensor.

Additionally, ambient temperature will be measured using the integrated probe of the irradiance sensor. The manufacturer's placement guidelines will be adhered to, ensuring the probe is shielded from direct sunlight and positioned in an area free from heat sources such as air outlets or other potential influences.

Table 5.3 summarizes the equipment along with the main variables that will be recorded.

Table 5.3: List of sensors installed for Roofing Shingle and AgriPV demos

Parameter	Unit	N°	Device	Technical Specifications
Module temperature	°C	2	TC DIRECT PT100	- Temperature Range: -50°C to 150°C - Accuracy: Class B according to IEC 60751
Ambient temperature	°C	1	ATERSA DataSol MET	- Sensor: PT100 - Tolerance: ± 0.8
Irradiance calibrated cell	W/m ²	1	ATERSA DataSol MET	- Irradiation range: 0 to 1400 W/m ² - Measurement precision: $\pm 2\%$
DC meter	V, A, W	2	APSYSTEMS MICROINVERTER	Data registered by the microinverter itself.
AC meter	kW, V, Hz	1	APSYSTEMS MICROINVERTER	Data registered by the microinverter itself.

In the case of Cargo Box mock-up prototypes both mock-ups will be instrumented with an equivalent set of sensors to ensure reliable comparison:

- Electrical monitoring (Solarface box only): DC voltage, current, and power output of the integrated PV panels.
- Thermal monitoring (both boxes): temperature probes inside the boxes, thermocouples on the internal surfaces, and external ambient sensors.
- Humidity monitoring (both boxes): relative humidity sensors inside the boxes to evaluate insulation and air tightness performance.

- Environmental monitoring: irradiance, ambient temperature, wind speed and direction, and relative humidity measured at TECNALIA's test facility.

This monitoring system enables a full thermal-energy characterization of both units, focusing on differences induced by PV integration.

Table 5.4: List of sensors installed for Cargo Box demo

Parameter	Unit	N°	Device	Technical Specifications
Module temperature	°C	2	TC DIRECT PT100	- Temperature Range: -50°C to 150°C - Accuracy: Class B according to IEC 60751
Thermal and humidity monitoring (internal boxes)	°C, RH(%)	2	RS485 Temperature Humidity Sensor Probe	- Temperature Measuring Range: -30~80°C - Humidity Measuring Range: 0~100%RH
Ambient temperature	°C	1	ATERSA DataSol MET	- Sensor: PT100 - Tolerance: ± 0.8
Irradiance calibrated cell	W/m ²	1	ATERSA DataSol MET	- Irradiation range: 0 to 1400 W/m ² - Measurement precision: $\pm 2\%$
DC meter	V, A, W	2	APSYSTEMS MICROINVERTER	Data registered by the microinverter itself.
AC meter	kW, V, Hz	1	APSYSTEMS MICROINVERTER	Data registered by the microinverter itself.

5.4.3 Data collection

The test area, including the setups for the AgriPV and Roof Shingle prototypes, is designed to store a comprehensive range of electrical and environmental variables. This data collection will facilitate the calculation of several performance indicators to evaluate the installation's optimal performance, including:

- Reference Yield (Y_r): energy obtainable under standard conditions, with no losses, over a certain period.
- PV system final energy yield (Y_f): the measure of the total energy generated per kWp installed over a certain time.
- Performance Ratio (PR): the ratio between the final energy Yield and the theoretically possible Reference Yield.
- Temperature-corrected Performance Ratio PR.

These Key Performance Indicators (KPIs) directly reflect the performance of the PV power plant. Additionally, the monitoring system of the photovoltaic inverters allows for the recording of alarms due to grid anomalies or internal issues within the equipment itself, stopping the inverter if the limit values are exceeded (In Spain: Royal Decree 1699/2011, which regulates the grid connection of small power generation installations). Some examples are:

- The internal temperature of the inverter.
- Over and under voltage alarm.

- Over and under frequency alarm.
- Anti-islanding protection.

Event Id	Event	Inverter ID	Date
1	Channel B: DC Voltage Too Low	705000000047	2025-03-04 19:15:00
2	Channel B: DC Voltage Too Low	705000000068	2025-03-04 19:15:00
3	Channel B: DC Voltage Too Low	705000000047	2025-03-04 19:10:00
4	Channel B: DC Voltage Too Low	705000000220	2025-03-04 19:10:00
5	Channel B: DC Voltage Too Low	705000000068	2025-03-04 19:10:00
6	Channel B: DC Voltage Too Low	705000000047	2025-03-04 19:05:00
7	Channel B: DC Voltage Too Low	705000000220	2025-03-04 19:05:00
8	Channel B: DC Voltage Too Low	705000000047	2025-03-04 19:00:00
9	BUS Voltage Too Low	705000000068	2025-03-04 08:40:00
10	BUS Voltage Too Low	705000000220	2025-03-04 08:35:00
11	BUS Voltage Too Low	705000000068	2025-03-04 08:35:00

Figure 5-24: Event recording for APSYSTEMS micro-inverter

An example of the available measurements is as follows:

- DC output current for AgriPV array (A)
- DC output current for Roof Shingle array (A)
- DC output voltage for AgriPV array (V)
- DC output voltage for Roof Shingle array (V)
- Active power output for AgriPV array (W)
- Active power output for Roof Shingle array (W)
- Active energy output AgriPV array (Wh)
- Active energy output Roof Shingle array (Wh)
- AgriPV array panel temperature (°C)
- Roof Shingle array panel temperature (°C)
- Ambient temperature (°C)
- Solar irradiance (W/m²)
- Other meteorological data: wind speed and direction

In summary, TECNALIA's test bench offers outstanding features due to:

- High capacity for handling numerous recorded variables.
- Short intervals between recordings (1 minute).
- Scalability to integrate new sensors if the number of variables to be recorded needs to be increased.
- Capacity to feed benchmark tools with the collected data.

In the case of Cargo Box mock-up prototypes data will be continuously collected over a monitoring period of some months, with a defined logging interval, in line with the general monitoring strategy of WP6.

The collected dataset will include:

- Electrical performance indicators of the Solarface box (energy yield, voltage/current profiles, performance ratio).
- Thermal indicators for both boxes: average internal temperature, maximum/minimum temperature, daily thermal swings, and insulation effectiveness.
- Comparative analysis of thermal performance between the Solarface and the reference box, with special attention to potential temperature drifts or loss of insulation efficiency.
- Synergies between PV generation and auxiliary applications (e.g., refrigeration systems).

This experimental setup will provide critical insights into the feasibility of lightweight VIPV integration for cargo boxes, ensuring that PV integration does not compromise insulation properties while enabling additional energy generation capacity.

6 CEA OUTDOOR TEST FACILITY

6.1 Aims of outdoor measurements at CEA

At the CEA INES site, full black BIPV modules manufactured at CEA and PV modules from the 3S company will be integrated into a south-oriented ventilated curtain wall facade configuration, aiming for full wall coverage. For this, different sizes of PV modules will be considered to include all the facade outlines (walls and columns, among others).

A suitable instrumentation, including sensors to measure thermal, electrical, aerodynamic, and weather data, will be installed to evaluate the thermal behaviour and electrical production of the PV modules during a six-month test campaign. The electrical connection will be designed with inverters aiming for uniform temperature distribution along the facade. In this section, the main technical specifications for the installation of the experimental setup are presented.

6.2 General description of test site

The demonstration will be performed on the southern facade of the FACT experimental building (or FACade Tool facility) located at the CEA INES site at Le Bourget du Lac in France (45°38'44" N, 5°51'33" E) (see Figure 6-1 sx and dx).

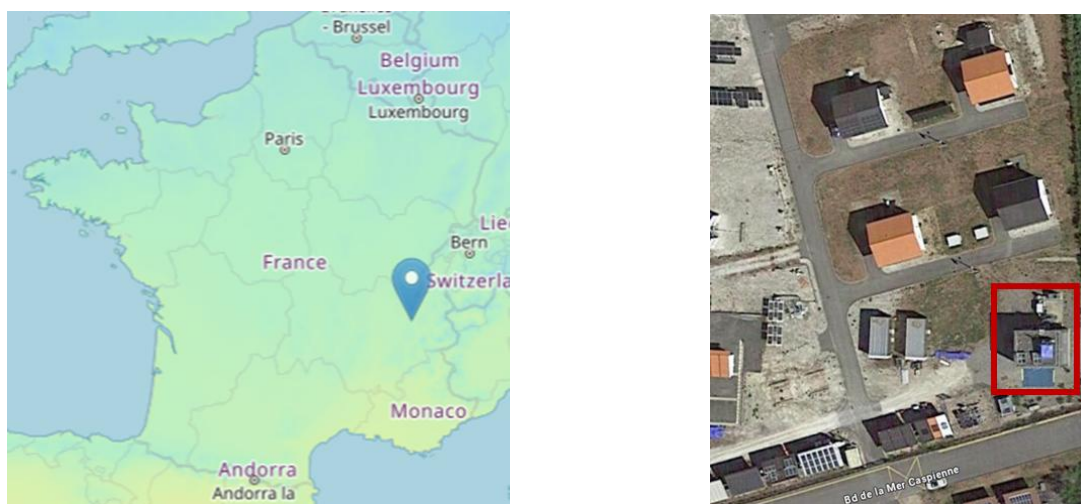


Figure 6-1: Sx) Geographical Position of Le Bourget du Lac (Source : PVGIS). Dx) Satellite picture to identify the location of the FACT tool where the BIPV facade will be installed

The site is surrounded by mountains to the east and west, which could result in distant shading effects, particularly early in the morning and late in the afternoon, especially during the colder months when the sun is at a lower angle. The climate at the installation site features warm, dry summers and mild winters. The mean monthly ambient temperatures range from 1.6°C in January to 20.4°C in July. Figure 6-2 presents the outline of the horizon of the south-oriented BIPV façade on the FACT tool at the CEA site.

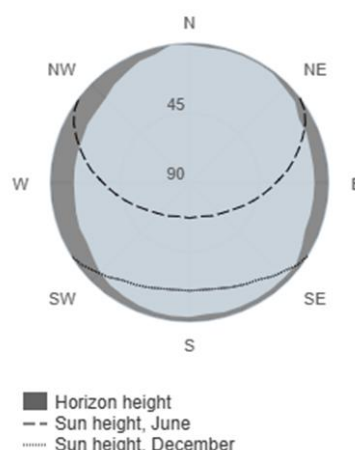


Figure 6-2: Outline of horizon of the south-oriented BIPV façade on the FACT tool – Le Bourget du lac, France

6.3 Description of module prototypes

6.3.1 Product specifications

PV modules from CEA will be fully black with black interconnection. Four different sizes will be used, ranging from 750 x 390 mm² to 1110 x 590 mm².

Additionally, the MEGASLATE PV modules, already available on the market from 3S, will be integrated into the facade (see Figure 6-3). Each PV module is composed of two 4 mm heat-strengthened (TVG) solar glasses and 156.75 mm * 156.75 mm PERC monocrystalline silicon PV cells.

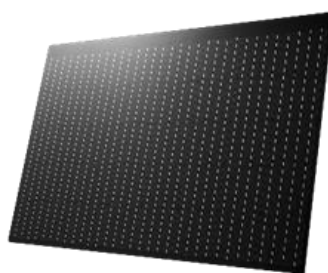


Figure 6-3: Example of PV module from 3S to be installed on the FACT tool

6.3.2 Mounting/maintenance instructions

The FACT facility is a two-floor building with a total height of 8.34 m and an external gross dimension of 7.8 m x 9.8 m. It is composed of 2 fixed technique rooms and 10 test cells. Each test cell presents two facades of test with an area of nearly 7.70 m² (2.33 m width x 3.30 m height) except for two cells presenting only one facade of test that is south exposed (see Figure 6-4a).

Thus, the BIPV modules will be installed on the south oriented facades of six test cells (three per floor: test cells 3 to 5 and 8 to 10). This provides a total available facade area of 6.90 meters (height: 3.30 meters * 2) by 6.66 meters (width: 2.33 meters * 3) (see Figure 6-4b).

The design of the facility focused also on the possibility to do the measurement of the energy performance and the impact on Indoor Environmental Quality (IEQ) of the building envelope on the indoor environment.

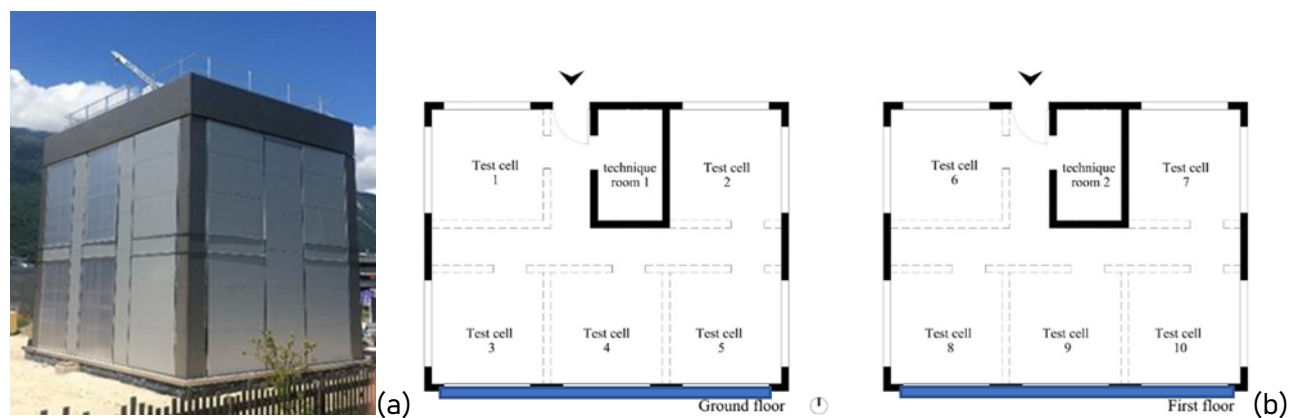


Figure 6-4: FACT tool: photograph and plan of ground and first floors (PV system in blue)

All concrete facades of the six test cells considered will have external insulation. PV modules will be integrated into a curtain wall ventilated façade configuration with at least 10 to 20 cm air gap thickness to limit thermal exchanges with the test cells' indoor air temperature. Thus, the PV installation could be considered as a mock-up.

A metal structure laid on the ground, parallel to the facade and attached to its metal frame, will be designed. It will allow the mounting of the different PV modules according to a suitable layout (see Figure 6-5) aiming for full coverage of the initial facade. The spacing between PV modules will be 8mm.

The PV modules will be connected in various strings to inverters, in accordance with the specifications provided by the manufacturers.

6.4 Description of mock-up

6.4.1 Mock-up design

Table 6.1 provides the dimensions of the PV modules proposed for installation on the FACT tool, utilizing the custom-designed metal structure, while Figure 6-5 illustrates the layout for the BIPV façade, ensuring full coverage of the wall's surface area.

Table 6.1: Sizes of CEA and 3S PV modules considered, and example of layout for the BIPV facade

PV module type	Number of PV modules	Length (mm)	Height (mm)	Area (m ²)
3S-2	9	1300	720	0.9
3S-4	9	985	720	0.7
CEA6	18	720	510	0.4
CEA8	36	890	720	0.6
CEA9	9	1440	1050	1.5
CEA10	18	1440	720	1.5

FACT tool is an experimental building so, all prototypes' installations are mock-ups. The PV modules will be mounted on a metal frame that will be ground-mounted and fixed on the facade.

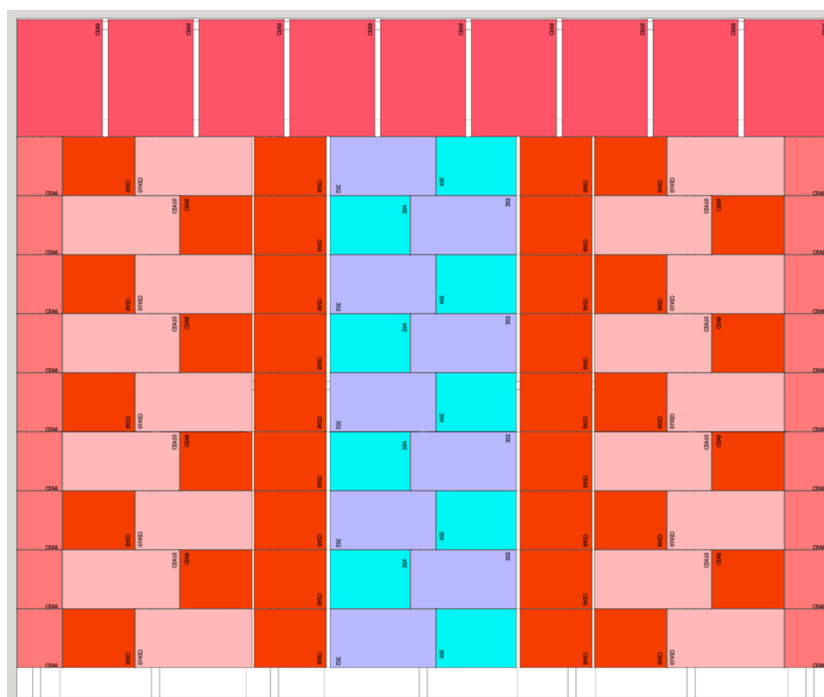


Figure 6-5: Example of layout of the south-oriented BIPV facade on the FACT tool

6.4.2 Monitoring system and sensors

The measurement of thermal data along the BIPV façade, of electrical data, and of weather data (solar radiations in the vertical plane, outdoor ambient air temperature, wind velocity and wind direction) will be realized. (See Table 6.2 and Figure 6-6)

Table 6.2: Sensors to be installed on the Demo at CEA INES site.

Device	Parameter	N°	Manufacturer/ provider	Model/ reference	Technical Specifications
Pyranometer	Total solar radiation in the PV modules plane (90°)	1	KIPP & ZONEN	CMP21	± 2% (Sensitivity: 9.9 10 ⁻⁶ V/W/m²)
Anemometer (PT100 sensor)	Ambient temperature	1	CAMPBELL	CS215	±0.3°C at 25°C; ±0.4°C (between +5° and +40°C); ±0.9°C (between -40° and +70°C)
Firstrate Sensor CO_FST200-2022311	Wind direction	1	Firstrate Sensor	N°FX1604097	±3 °
Firstrate Sensor CO_FST200-2012311	Wind velocity	1	Firstrate Sensor	N°FS1604095	±0.5m/s (<5m/s) ±3%FS (≥5m/s)

Thermocouple	Temperatures in the air gap (behind each PV module, optionally, in the air gap and on the wall)	6 (behind PV modules) 6 in the air gap 6 on the wall	TC Direct	Type T	+/-2%
Omnidirectional hot wire anemometers (optional)	Air velocity in the air gap (top and bottom)	2	TSI	8465 (of 15 cm length)	+/- 2% of reading in temperature range [18 -28°C] +/- 0.5% of the selected full scale (10 m/s)
Inverters	Electrical measurements in DC: Power (Pmpp), voltage (Vmpp), current (Impp) (continuous measurement)	2	-	-	-

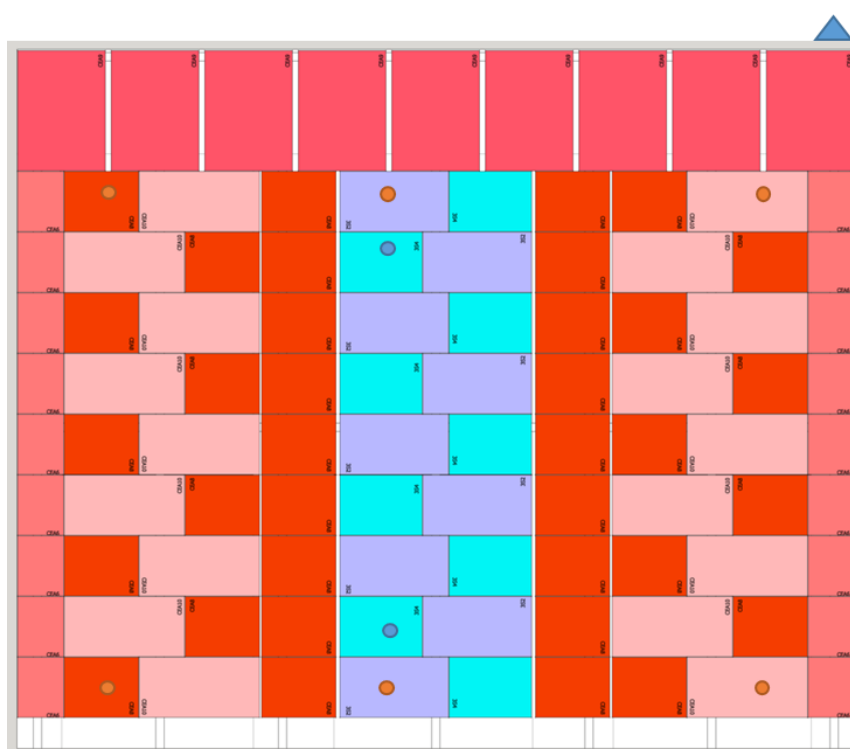


Figure 6-6: Locations of thermocouples (orange dots) behind the PV modules, in the air gap and on the wall, of omnidirectional anemometers in the air gap (blue dots), and of the weather station (blue triangle) on the BIPV facade on the FACT tool.

6.4.3 Data collection

All sensors will be connected to an Agilent data logger located within the test cells, with daily data files being stored on the CEA's common database for further analysis. The monitoring will permit the assessment of the temperature distribution along the BIPV façade, of the air velocity magnitude in the facade air gap, and of the electrical production of each PV field monthly and considering sunny and cloudy periods.

7 CONCLUSIONS

This deliverable presents the assembly and real-environment monitoring activities conducted on small-scale mock-ups for the various product technologies developed within Work Package 6. For each product type, the rationale behind the mock-up design is described, highlighting the most critical aspects to be assessed in order to identify potential issues prior to installation on demonstration sites. Specific monitoring activities have been outlined for each product to evaluate their reliability under outdoor conditions and identify any challenges requiring mitigation. Detailed information on the sensor types and data acquisition methodologies has been provided, supporting the definition of the monitoring strategy over a minimum period of six months. This deliverable serves as a preparatory step for the further deliverable, which will present the results obtained from these field evaluations.



Seamless-PV



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