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D8.2 Report on the design and simulation of PV and energy performance of each demonstration installation

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BIPVBOOST

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

Start date: October 2018. Duration: 4 Years

Coordinator: TECNALIA   Grant Agreement No: 817991   www.bipvboost.eu

Summary

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1 EXECUTIVE SUMMARY

1.1 DESCRIPTION OF THE DELIVERABLE CONTENT AND PURPOSE

This deliverable is the result of 30 months of work dedicated to the design and simulation of BIPVBOOST solutions to be implemented in four demo-sites in Spain, Belgium and Italy. In October 2019, it was submitted a preliminary version of this deliverable including the Pre-design of all the demo-sites, as a mean of verification of Milestone 1 (MS1) *Predesign of all demo-sites completed*.

The design of the demo-sites has evolved according to the work performed in the project (development of BIPVBOOST technologies and demo-sites characteristics) to a state of maturity. The design detailed in this deliverable is the executive design for each BIPVBOOST demo-site.

This deliverable highlights the main information for the complete design and implementation of the work to be performed at the demo-sites, with the aim of achieving the optimal conditions for demonstration of viability, performance, reliability and cost-effectiveness of project results.

The current status of demo-site implementations, the different scenarios considered, and the relevant partners that will supply the product, can be found in the following table. Each demo-site currently considers at least two scenarios, one of which has been selected based on the preliminary assessment of the projected impact on the KPIs of the project.

	Demo 1		Demo 2		Demo 3					Demo 4			
Demo manager	ISFOC		MASS		OPTIMAL					PIZ			
Scenario	**PRODUCT 1**	**PRODUCT 2**	**SCEN. 1** 2m panels (var. 38)	**SCEN. 2** 1m panels	**SCEN. 1.1** 2 sizes	**SCEN. 1.11** 2 sizes	**SCEN. 1.12** 2 sizes	**SCEN . 1.2** 3 sizes	**SCEN. 2** 1 size	**SCEN. A1** 3-phase inverters	**SCEN. A2** 1-phase inverters	**SCEN. B** 3 façades	**SCEN. E** 4 façades, 1-phase inverters
Product	Glass-glass bifacial modules (ONYX)	Glass-glass back contact modules from automated tabber (ONYX)	Glass-glass c-Si modules with different configurations (ONYX). Façade structure (TULIPPS)		CIGS modules (FLISOM). Roof structure (SCHWEIZER)					Multifunctional BIPV element with integrated insulation (ONYX+PIZ)			
Implementation	Balustrades	Walkable floor	Ventilade façade		Roof retrofitting					Opaque cladding			
Orientation	S + E + W	S	SE		E + W					SW+ SE + NW + NE		SW + SE + NW	SW + SE + NW + NE
Surface	126 m^2	69m^2	152 m^2	155 m^2	150 m^2					120 m^2		131 m^2	110 m^2
Power	12,8 kWp	9,22 kWp	21,6 kWp	22,2 kWp	10,2 kWp	9,99 kWp (10,38 kWp)	10,26 kWp	9,81 kWp	9,42 kWp	10,2 kWp		10,9 kWp	9,83 kWp
O&M	FDD tool and BEMS for BIPV, HVAC and storage									FDD and BEMS for BIPV and potential flexible demand			

Figure 1.1 Demo-Site design Scenario Chart

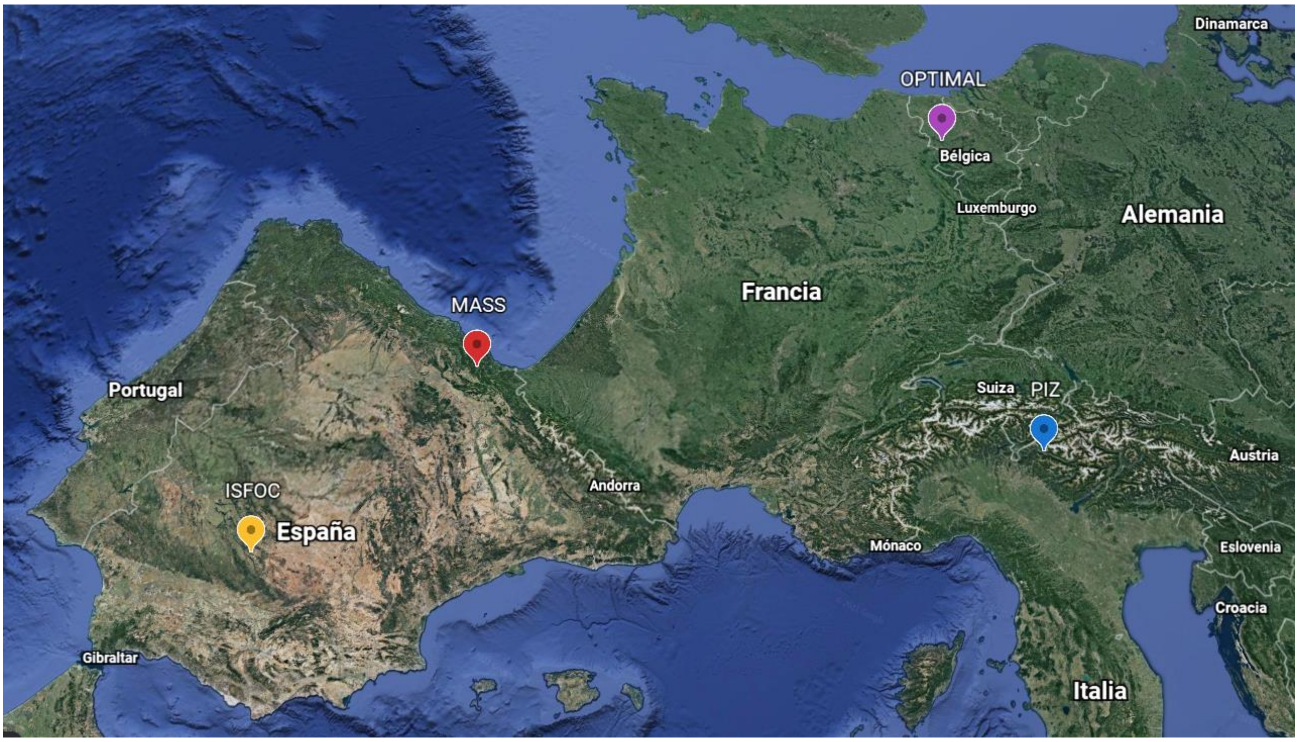


Figure 1.2: Location of the four demo-sites: ISFOC, MASS, OPTIMAL and PIZ.

1.2 RELATION WITH OTHER ACTIVITIES IN THE PROJECT

This task focuses on the implementation and testing of the KPIs identified within the project within WP 1 and Deliverables D1.1 and D1.2, as well as the monitoring objectives identified within task T8.3. The design of the demo sites is performed on the basis of the pre-audit of the demo-site in T8.1, the BIPV technologies developed in WPs 2 – 4 and using the digital tools developed in WPs 6 and 7. This deliverable will serve as a plan for the implementation phases in Tasks 8.4, 8.5 and 8.6.

2 DEMO SITE 1: ISFOC

2.1 DEMO-SITE BUILDING DESCRIPTION

This demo-site building corresponds to ISFOC's Headquarter building. ISFOC's Headquarter is located in Puertollano (Ciudad Real) at the centre-south area of Spain.

Location details:

- Address: C/ Francia 7. Polígono Industrial La Nava III. 13500 Puertollano.
- Industrial Area, 5km away from Puertollano city.
- Geographic coordinates (Latitude, Longitude): 38.67, -4.156.

Figure 2.1: ISFOC Headquarter satellite view (Google maps)

ISFOC operates a Concentration Photovoltaic power plant of 800 kW that it is installed at the facilities.

Figure 2.2: ISFOC 800kW CPV power plant

The only energy supply of the building is electrical, reason why ISFOC is interested in PV self-consumption systems.

The building hosts an area of offices and a warehouse including laboratories and mechanical and electrical areas with different purposes. The overall area of the building is of 135m x 14.5m, being the long dimension practically oriented to the south.

Figure 2.3: Drawing of ISFOC building

2.2 ARCHITECTURAL BIPV DESIGN

From an architectural point of view and looking for the integration of BIPV solutions, it is important to remark a couple of issues of ISFOC building:

- It has a long façade (135m) oriented to the south with large windows in the office area. But the building includes shadowing eaves for the first and the second floors that allows the entrance of the sunlight through the windows during the winter period to permit the illumination and heating of the interior areas and avoids the entrance during the summer period to prevent the warming and to reduce the air conditioning necessities.
- The rooftop floor is a walkable floor, normally circulated by people, whether employees or visitors.

Taking into account these considerations, it results that the south façade (the windows area) is not appropriate to make a BIPV installation since the area is shaded every day during the central hours and even more during the summer months. But the rooftop seems to be ideal to test **PV balustrades** and **PV walkable floor** in real people circulation conditions.

Figure 2.4: ISFOC building – South façade

2.2.1 Existing demo-site building

Currently, the rooftop includes a metal balustrade and a walkable floor based on removable tiles. The approach at this demo site is to replace part of the balustrade and part of the walkable floor with the BIPVBOOST solutions.

- **Balustrades.** The rooftop has a perimeter balustrade for the complete building (floor section: 135m x 14.5m). The current balustrade is only composed of a metallic frame, without glass or similar closure.
- **Walkable floor.** The floor of the rooftop is of removable tiles. The current tiles are of concrete, of 60cm x 40cm.

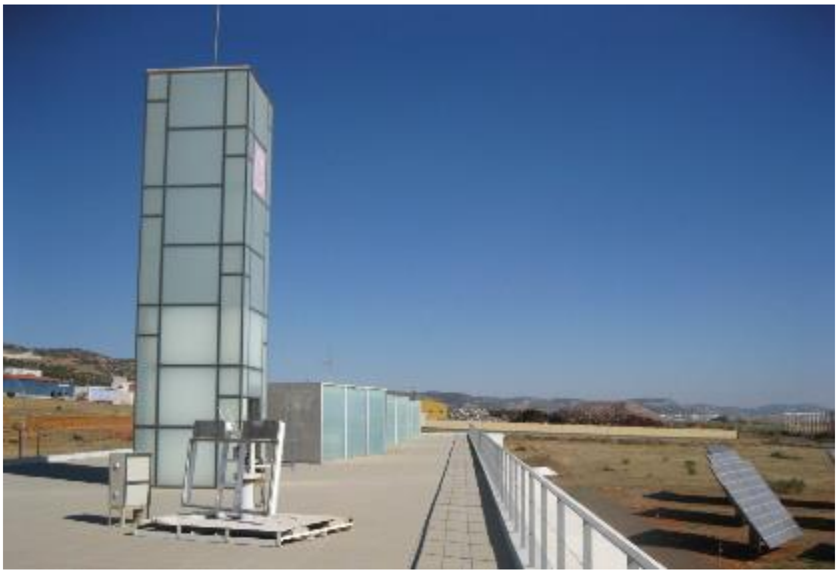


Figure 2.5: ISFOC building – Rooftop floor

2.2.2 Architectural BIPVBOOST design

Initially, in the proposal of the project, the installation of the BIPV solutions at ISFOC building demo site was as follows:

- **Product 1: Glass-glass bifacial modules**.
  - Implementation: Balustrades.
  - Orientation: East, West, South.
  - Surface: 13.5 + 13.5 + 73 = 100m^2.
  - Installed power: ≈ 8.7kW.
- **Product 2: Glass-glass back contact modules from automated tabber.**
  - Implementation: Walkable floors.
  - Orientation: South.
  - Surface: 100m^2.
  - Installed power: ≈ 14kW.

Once the partners of the project, Viriden, Onyx and Tecnalia, visited the demo site, it was decided, in accordance with all the partners involved that the complete area of the balustrade should be covered by the BIPVBOOST solution, in order to favour the aesthetic of the building and fully integrate the system. Next, the reasoning offered by Viriden is presented.

The Design of the building and the integration of the BIPV installations has to be handled as a whole. The existing building has a very clear concept and from the point of view of the architects (Viriden) we should *work towards that concept by integrating BIPV and not just randomly place it somewhere just to achieve the amount of 100m^2. Due to the presented dimension of the two areas (floor and balustrade) we would recommend focusing on the East, West and South facade to place balustrades. Therefore, we would need to add some of the 100m^2 walkable floor area to the area of the balustrade. To fully add to the architectural quality of the existing building we would highly recommend adding a PV balustrade on all facades. The Demo site installations should present the work and the results of the BIPVBOOST project. It should be seen and it should be obvious. If we just add small parts of PV elements it will not appear as a Demo site for the results of the whole project but rather as a presentation of samples of the producers.*

Therefore, the area to be covered by BIPV balustrades (identified in blue in the following picture) is going to be increased and the area of walkable floor (in green) is going to be reduced. The idea is to maintain, as much as possible, the total area and/or power of both BIPVBOOST solutions as a whole in accordance with the original proposal. The following image of Figure 2.6 shows the first proposal of areas to be covered by the solutions.

Figure 2.6: ISFOC building, areas to cover with the BIPVBOOST solutions

The first approach is to make the walkable floor based on back-contact solar cells at the center of the rooftop, around the exit to the rooftop from the elevator in order to increase the visibility of the demo installation.

The final design of the BIPVBOOST installation is as follows:

- **Product 1: Glass-glass bifacial modules**.
  - Implementation: Balustrades.
  - Orientation: East, West, South.
  - Surface: 124.58 m^2.
  - Installed power: ≈ 12.80 kW.
- **Product 2: Glass-glass back contact modules from automated tabber.**
  - Implementation: Walkable floor.
  - Orientation: South.
  - Surface: 69.12 m^2.
  - Installed power: ≈ 9.22 kW.

A first approximation of the estimated costs of implementation of these solutions is detailed below.

Table 2.1: South balustrade - PV glass module data-sheet

		Glass-glass bifacial	Glass-glass back cont
1. Materials		**Price [€]**	**Price [€]**
1.1	Fastening and mounting system	4 092.00 €	275.40 €
1.2	BIPV modules	62 269.68 €	48 867.84 €
1.3	Cabling	included in 1.6	
1.4	Inverters	2 708.00 €	2 009.00 €
1.5	Monitoring system	391.33 €	195.67 €
1.6	Electrical installation materials	3 532.67 €	1 766.33 €
1.7	Battery System	to be defined in WP7	
	MATERIALS SUBTOTAL	**72 993.68 €**	**53 114.24 €**
2. Labor		**Price [€]**	**Price [€]**
2.1	Permit obtaining	650.00 €	
2.2	Detailed Executive Project	1 280.00 €	
2.3	Structural and mechanical installation	1 580.00 €	
2.4	Electrical installation	3 816.00 €	
2.5	Certification of the installation	250.00 €	
2.6	Operation and Maintenance (optional)		
	LABOR SUBTOTAL	**7 576.00 €**	**0.00 €**
TOTAL TURN-KEY INSTALLATION:		**80 569.68 €**	**53 114.24 €**

This cost estimation does not include neither the reinforcement of the balustrade nor the manufacture of the custom-made parts for fastening the PV modules since these are specific costs of our installation and are not directly attributable to the integration of PV in buildings. An approximated cost of this actuation could be around 40 000.00€.

2.3 BIPV STRUCTURE DESIGN

In this demo site, the existing structure of the building to be analysed for the proper implementation of the BIPVBOOST solutions are the elements of the existing balustrade and its supporting structure and supporting elements of the walkable floor.

2.3.1 Existing building structure

The existing elements of the balustrade and the walkable floor have been analysed to define the modifications required in order to make the replacement of the existing elements with the BIPVBOOST solutions.

After the visit of Onyx, ISFOC has contracted a technical consultancy and engineering to analyse the existing elements and their attachment to the structure of the building to ensure a safe and reliable assembly of the BIPVBOOST solutions in the building.

2.3.1.1 ISFOC rooftop balustrades

The existing balustrade of the building, which is surrounding the whole rooftop floor, is shown in Figure 2-7. As it can be observed, the balustrade is built with consecutive elements, being each element an open metallic frame, and the elements are grouped in groups of 6. The total number of elements and their dimensions are different in the south and the west/east balustrades.

- South balustrade.

    - 108 elements
    - Dimensions: 1230mm x 910mm
- East/West balustrade.
    - 12+12 elements
    - Dimensions: 1200mm x 880mm

Figure 2.7: ISFOC rooftop balustrade

The following drawing is a scheme of the measurements of the elements of the balustrade.

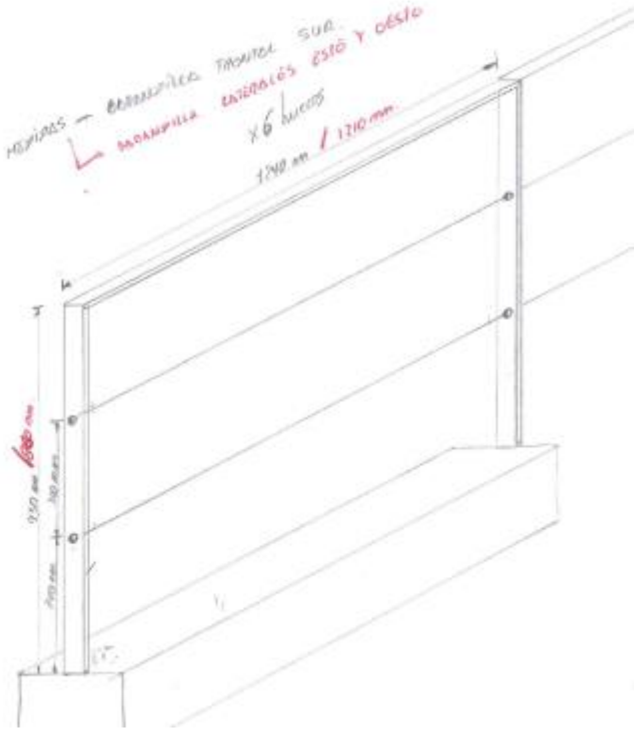


Figure 2.8: Balustrade element

The frame is made of 50mm wide and 10mm thick metal plate. The frames are crossed by two tensioner threads, as shown in Figure 2.8. The holes (10mm diameter) in the plate for the tensioner threads can be used to mount the modules in the balustrade structure.

The fixing of the balustrade to the building is done through metal plates as shown in Figure 2.9. This mechanical connection has to be analyzed to ensure the safety of the balustrade itself and for the people.

Figure 2.9: Attachment of the balustrade to ISFOC building

2.3.1.2 ISFOC walkable floor

The floor of the rooftop is a walkable floor of removable concrete tiles Figure 2.10. Each tile is of 600mm x 400mm, of 50mm thickness and weighs around 24kg. The tiles are placed on a system of adjustable plastic plots. Water tightness is guaranteed by the membrane underneath.

Figure 2.10: ISFOC walkable floor, concrete tiles

After the visit of the technicians of Onyx it seems that the same support elements used with the current tiles (see the detail in Figure 2.11) can be used to assembly the BIPVBOOST tiles based on back-contact solar cells.

Figure 2.11: Detail of the supporting elements (plots)

2.3.2 BIPVBOOST structure

ISFOC has subcontracted a third party, a technical consultancy and engineering specialized in building facades, to analyse the integration of the BIPVBOOST solutions in ISFOC building. The analysis is based on the main requirements defined by the Spanish Building regulations (CTE[1]) that should be fulfilled by the BIPVBOOST solutions to be installed, for instance to withstand wind load, to have a proper impact classification, guarantee the fire resistance, service overload…

2.3.2.1 ISFOC rooftop balustrades

In the case of the rooftop balustrade, there are two main issues to analyse:

- On the one hand, the effect and forces generated over the balustrade frame and its fixation to the building because of the introduction of the PV modules. The current balustrade is only a metallic frame that does not offer any resistance to the wind, but once the modules are installed, the effect of the wind load over the balustrade itself and its fixation to the building (see Figure 2.9) can be critical. Therefore, it is mandatory to calculate the forces that must be supported by the balustrade because of the wind mainly and also by the type of use according to the CTE.
- On the other hand, the fixing of the PV glass-glass bifacial modules to the frames of the balustrade must be designed according to the CTE requirements also. The holes in the metal plate for the tensioner threads of the balustrade can be used to support the modules.

The conclusion obtained is that the current balustrade and its fixation will not be able to withstand the wind and thrust loads, so it must be reinforced. The reinforcement solution proposed for the South and East/West balustrade is different.

The reinforcement proposed for the South façade is a structure of galvanised steel plate that will be soldered to the existing frame of the balustrade and fixed to the shadowing eaves, as shown in Figure 2.12. This design has been proposed to avoid, as much as possible, intervening in any element of the building that could put at risk the watertightness of the roof, and to avoid problems of dampness in the future.

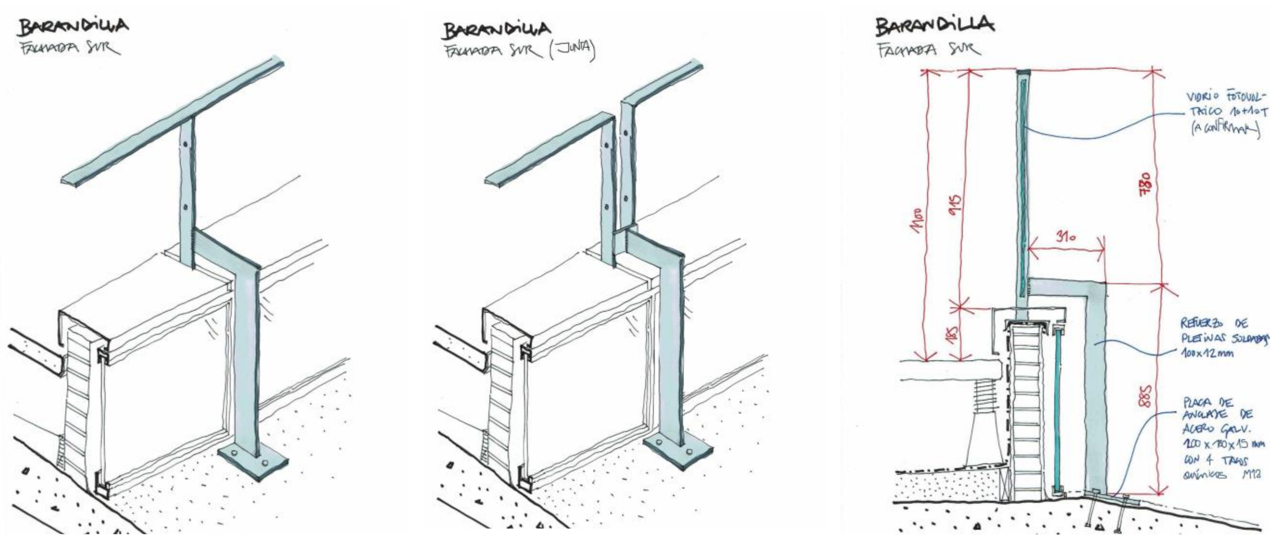


Figure 2.12: Reinforcement of the south balustrade

[1] CTE – Código técnico de la Edificación (Building technical code)

For the East/West façade, at the end it has been impossible to find a suitable option for the attachment of the reinforcement to the building, so it is going to be anchored to the roof slab of the building, modifying the waterproofing layer of the rooftop inevitably. Currently, the balustrade is fixed with some metal sheets to a brick wall that it is built on top of the roof slab with apparently no mechanical junction between them. The solution proposed is to build some anchoring metallic pieces that will be soldered to some of the balustrade pillars, which will permit the attachment directly to the roof slab, removing an area of brick wall to make this fixation. Then the wall surrounding the new fixations will be rebuilt and the watertightness layer should be laid again. A first drawing of this solution is shown in Figure 2.13.

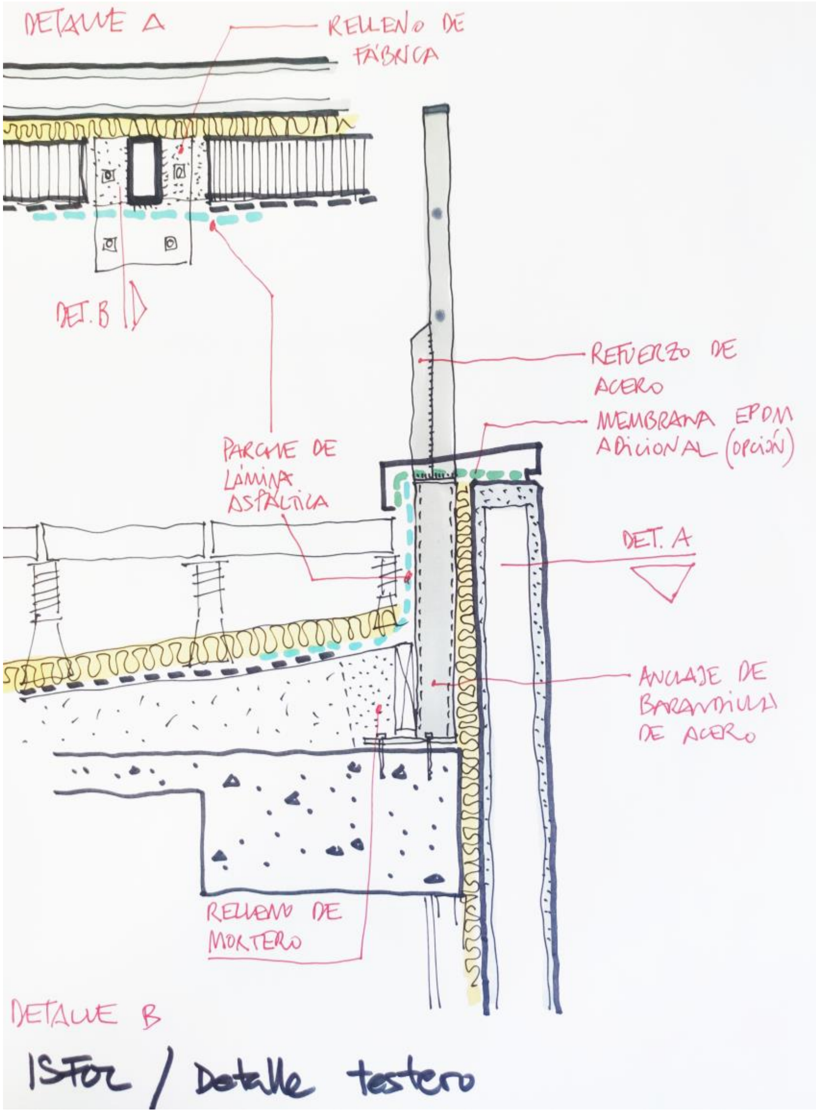


Figure 2.13: Reinforcement of the east/west balustrade

The installation of the PV modules in the balustrade frame will be done following the scheme of Figure 2.14. They will be installed using 2 longitudinal steel angle profiles that will be attached to the sides of the PV modules and an horizontal plate will be soldered to the larger angle at the lower part to support the weight of the module. To avoid direct contact of metal and glass, all the parts where a contact between the glass of the modules and the steel is foreseen will be protected using plastic spacers or silicone. Then, these steel profiles will be fixed to the frame of the balustrade using the existing holes of the tensioner threads of the current balustrade.

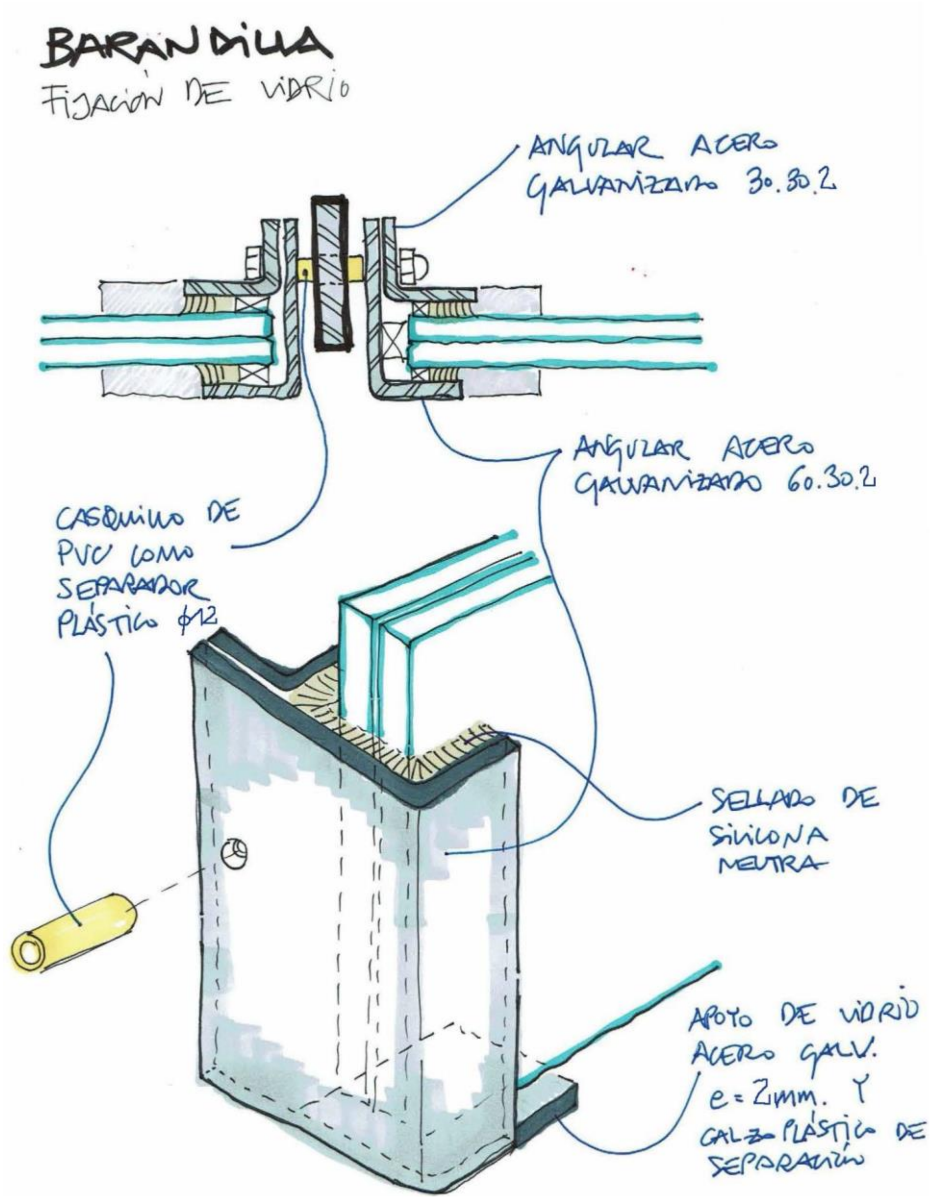


Figure 2.14: Detail of the assembly elements to use for the installation of the PV modules in the balustrade

2.3.2.2 ISFOC walkable floor

The walkable floor will be installed using the same support elements that are currently used to support the concrete tiles. Two options have been considered at pre-design stage: the first one considered the use of a metallic sub-frame over the plots where the PV tiles could be attached, as shown in Figure 2.15, in this way the tiles are not supported only in the 4 corners and the forces are distributed. A second option is to install directly the PV tiles on the support elements (plots). by gluing the BIPV modules to the support elements to ensure that the suction of the wind will not be able raise them and generate a contact with another tile, which could lead to the breakage of the modules.

As observed in Figure 2.16, the result of the calculations concludes that the tiles of the walkable floor can withstand the forces generated when they are installed using only the support elements on the 4 corners.

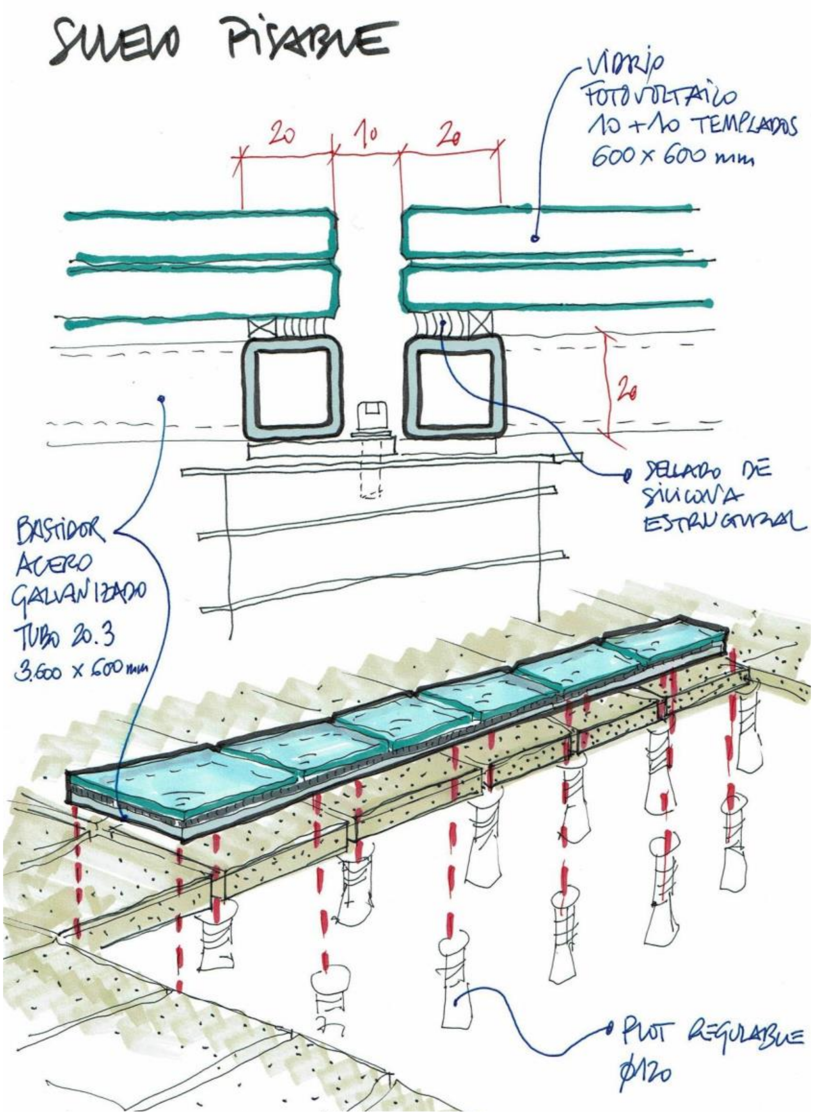


Figure 2.15: Walkable floor. Metallic frame over the plots to mount the PV tiles

The FEM simulation of the walkable floor demonstrates that both stress and deformation levels are within the admissible range when applying a concentrated load of 4 kN. As a consequence, the installation of the BIPV modules will be performed directly over the existing plots. The solution will be in any case validated as per EN 12825, using a 5kN uniform load and 4kN concentrated load over real prototypes.

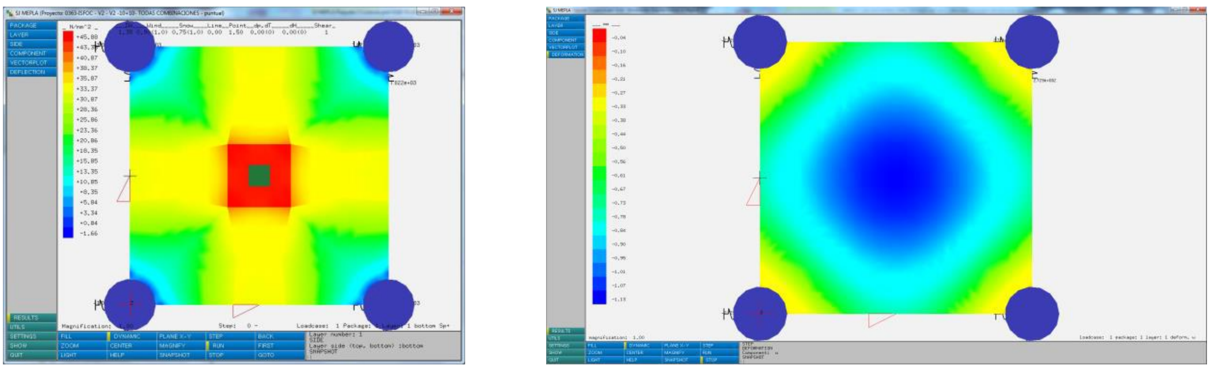


Figure 2.16: Walkable floor. Forces calculation

Figure 2.16 shows the results of the FEM calculations carried out to the 10T.10T.1, 600mm side, BIPV tiles of the walkable floor when they are supported only on the four corners and applying a concentrated load of 4kN and a uniform load of 5kN/m2. The picture of the left shows the result of the stress verification, the stress obtained from the simulation is within the admissible limits of the material, tempered glass. And the picture from the right shows the result of the deformation simulation, where the deformation obtained it is also below the admissible limit of the tempered glass.

2.4 BIPV MODULE DESIGN

Two different products of ONYX Solar are going to be tested at ISFOC demo site: a balustrade based on glass-glass bifacial modules and a walkable floor based on back-contact solar cells.

Next, the characteristics of the modules to be installed are described.

2.4.1 Balustrades based on glass-glass bifacial modules

As explained in previous sections, the glass-glass bifacial modules will be installed in the balustrades (South, East and West). The modules are going to be assembled into the existing balustrades. It has been also mentioned before that the dimensions of the elements of the balustrade are not the same for the elements of the South and the elements of the East/West.

As a consequence, Onyx Solar has designed two different options taking into account the difference in the dimensions between the elements and the implementation of the PV modules in the inner area of the existing balustrade.

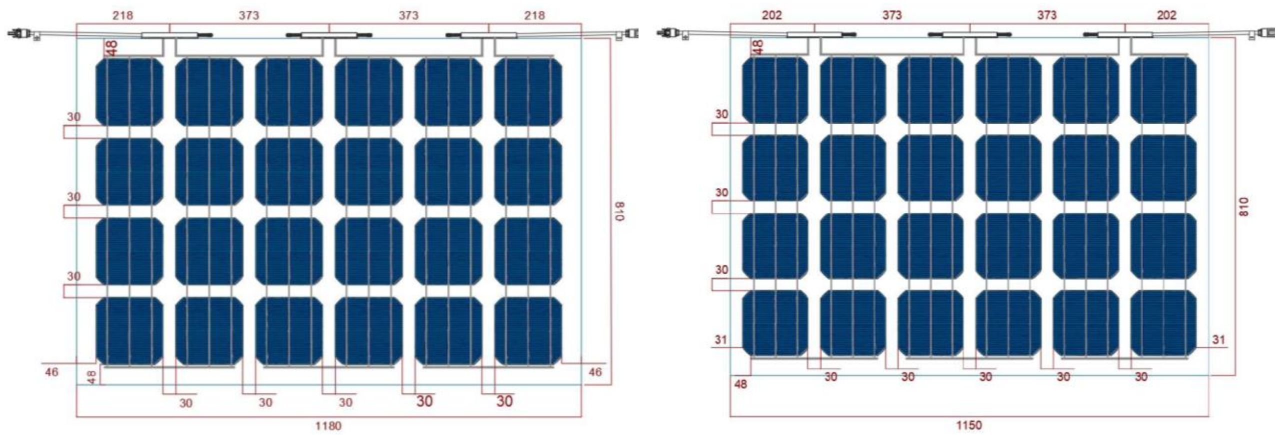


Figure 2.17: PV glass module design for South (left) and West/East (right) balustrades respectively

The design of the PV glass module for the South balustrade is shown in the photo of the left of Figure 2.17 and its characteristics are collected in its data-sheet shown in Table 2.2.

The design of the PV glass module for the East and West balustrades is shown in the photo of the right of Figure 2.17 and its characteristics are collected in its data-sheet shown in Table 2.3.

Table 2.2: South balustrade - PV glass module data-sheet

PHOTOVOLTAIC GLASS FRONT SIDE	1.180 x 810 6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	97,2	P_{mpp} (Wp)
Open-circuit voltage	15,94	V_{oc} (V)
Short-circuit current	8,07	I_{sc} (A)
Voltage at nominal power	12,59	V_{mpp} (V)
Current at nominal power	7,72	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	1180	mm
Width	810	mm
Thickness	21,8	mm
Surface area	0,96	sqm
Weight	48	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	42%
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	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

GLASS PROPERTIES	Onyx Equivalent Glass
Light Transmission	**47%**
U-value [W/sqm.K]	**5,2**
Peak Power [Wp/sqm]	**97,8**

Table 2.3: East and West balustrades - PV glass module data-sheet

PHOTOVOLTAIC GLASS FRONT SIDE	1.150 x 810 6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	95,90	P_{mpp} (Wp)
Open-circuit voltage	15,93	V_{oc} (V)
Short-circuit current	7,88	I_{sc} (A)
Voltage at nominal power	12,47	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	1150	mm
Width	810	mm
Thickness	21,8	mm
Surface area	0,93	sqm
Weight	47	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	41%
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	$2{,}5\ mm^2$ or $4{,}0\ mm^2$	
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]	**5,2**
Peak Power [Wp/sqm]	**107,7**

The aim of Onyx with this design is to maintain the same aesthetics, as much as possible, in all the orientations by using the same number of cells and the same disposition of these cells in the glass respect to its centre.

For the two types of PV modules for the balustrades the glass configuration is as shown in Figure 2.18.

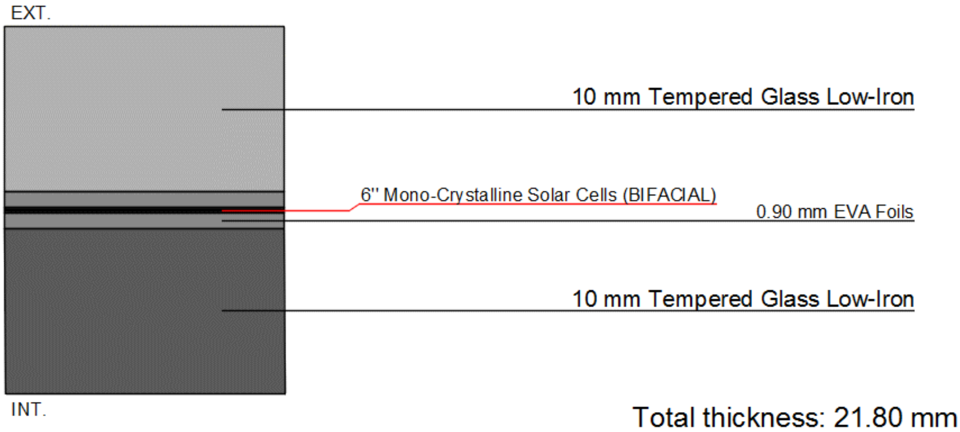


Figure 2.18: Glass configuration of the PV glass module design for the balustrades

All this work has been developed following the previous steps linked to WP3 (Task 3.3: Low cost, large thickness glass-glass bifacial cell modules for integration in balustrades), with the design and manufacturing of the small modules.

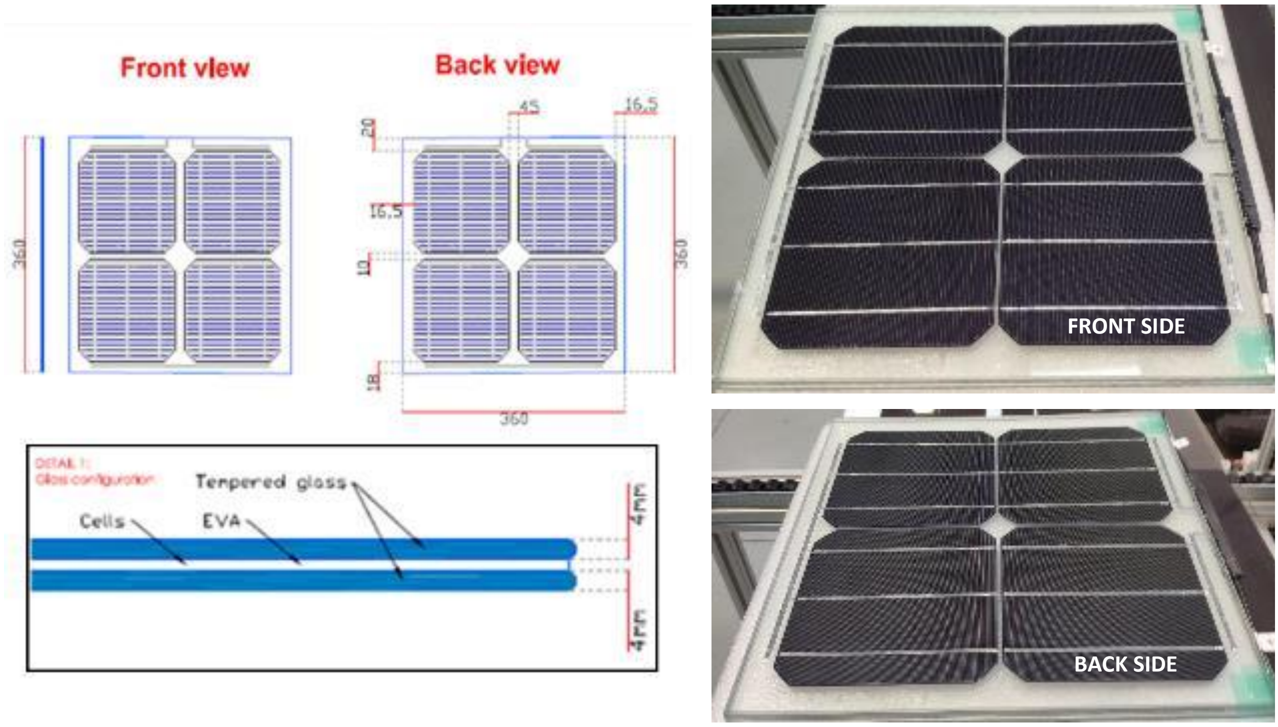


Figure 2.19: Small module design. Front and back side of the manufactured bifacial module

2.4.2 Walkable floor based on back-contact solar cells

As explained in previous sections, the back-contact solar cells modules are going to be installed as a walkable floor in the rooftop of the building by the replacement of some of the tiles of the floor.

Onyx has designed the PV tiles based on the work developed in WP3, Task 3.4: Back-contact cells modules for walkable floors and curtain walls, as it is shown in Figure 2.20.

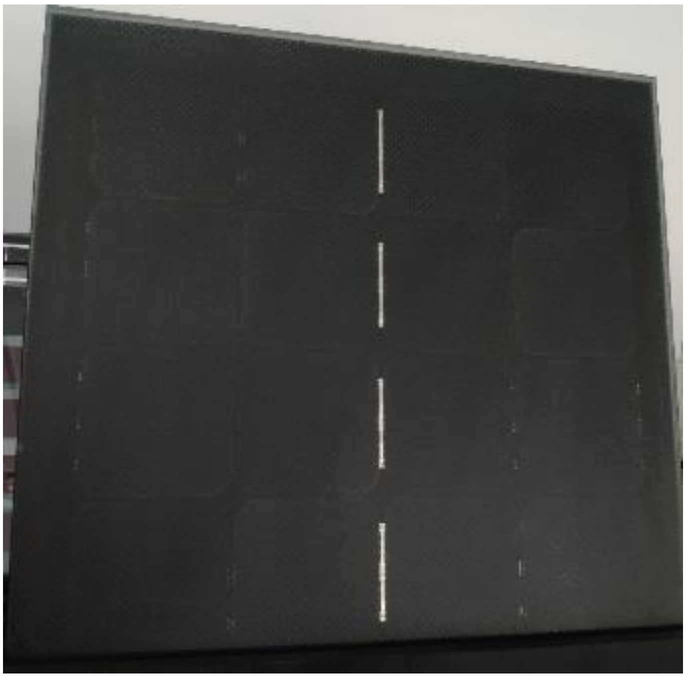


Figure 2.20: Front side of the PV tile manufactured: 8mm anti-slip / back-contact / 8mm glass

In this case, Onyx Solar has designed different solutions based on the glass size, number of cells and distribution of the cells. The three options proposed are shown in Figure 2.21 and the characteristic parameters of each of them are collected in their data-sheets from Table 2.4 to Table 2.6

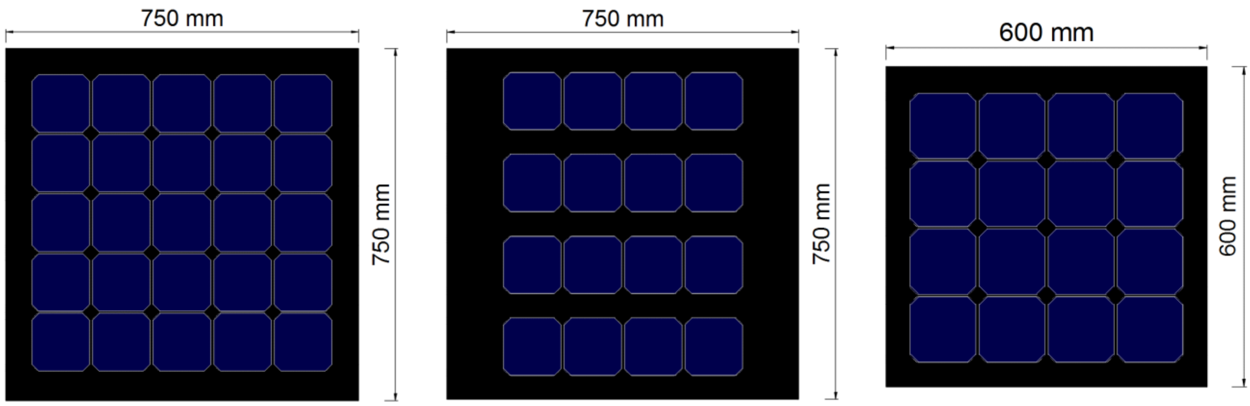


Figure 2.21: PV designs for the walkable floor

Table 2.4: 750 x 750 (25 cells) walkable floor tile data-sheet

PHOTOVOLTAIC GLASS	**750 x**	**750**
	5" Mono	**Crystalline**
Electrical data test conditions (STC)		
Nominal peak power	75	P_{mpp} (Wp)
Open-circuit voltage	17	V_{oc} (V)
Short-circuit current	5,71	I_{sc} (A)
Voltage at nominal power	14	V_{mpp} (V)
Current at nominal power	5,28	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	750	mm
Width	750	mm
Thickness	17,8	mm
Surface area	0,56	sqm
Weight	23	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	25	0%
Front Glass	8 mm	Tempered Glass Anti-slip
Rear Glass	8 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
NOTE: Anti-slipery glass induce a 5% of power loss. It has been considered in this data sheet.

GLASS PROPERTIES	**Onyx Equivalent Glass**
Light Transmission	**0%**
U-value [W/sqm.K]	**5,3**
Peak Power [Wp/sqm]	**133,8**

Table 2.5: 750 x 750 (16 cells) walkable floor tile data-sheet

PHOTOVOLTAIC GLASS	750 x 750 5" Mono	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	48	P_{mpp} (Wp)
Open-circuit voltage	11	V_{oc} (V)
Short-circuit current	5,71	I_{sc} (A)
Voltage at nominal power	9	V_{mpp} (V)
Current at nominal power	5,28	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	750	mm
Width	750	mm
Thickness	17,8	mm
Surface area	0,56	sqm
Weight	23	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	16	0%
Front Glass	8 mm	Tempered Glass Anti-slip
Rear Glass	8 mm	Tempered Glass
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm^2 or	4,0 mm^2
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
NOTE: Anti-slipery glass induce a 5% of power loss. It has been considered in this data sheet.

GLASS PROPERTIES	Onyx Equivalent Glass
Light Transmission	**0%**
U-value [W/sqm.K]	**5,3**
Peak Power [Wp/sqm]	**85,7**

Table 2.6: 600 x 600 (16 cells) walkable floor tile data-sheet

PHOTOVOLTAIC GLASS	600 x 5" Mono	600 Crystalline
Electrical data test conditions (STC)		
Nominal peak power	48	P_{mpp} (Wp)
Open-circuit voltage	11	V_{oc} (V)
Short-circuit current	5,71	I_{sc} (A)
Voltage at nominal power	9	V_{mpp} (V)
Current at nominal power	5,28	I_{mpp} (A)
Power tolerance not to exceed	±10	%
STC: 1000 w/m², AM 15 and a cell temperature of 25°C, stabilized module state.		
Mechanical description		
Length	600	mm
Width	600	mm
Thickness	17,8	mm
Surface area	0,36	sqm
Weight	14	Kgs
Cell type	5" Mono	Back Contact Cells
No PV cells / Transparency degree	16	0%
Front Glass	8 mm	Tempered Glass Anti-slip
Rear Glass	8 mm	Tempered Glass
Thickness encapsulation	1,80 mm	EVA Foils
Category / Color code		
Junction Box		
Protection	IP65	
Wiring Section	2,5 mm^2 or	4,0 mm^2
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
NOTE: Anti-slipery glass induce a 5% of power loss. It has been considered in this data sheet.

GLASS PROPERTIES	Onyx Equivalent Glass
Light Transmission	0%
U-value [W/sqm.K]	5,3
Peak Power [Wp/sqm]	133,8

For the three types of PV glass tiles of the walkable floor the glass configuration will be as shown in Figure 2.22.

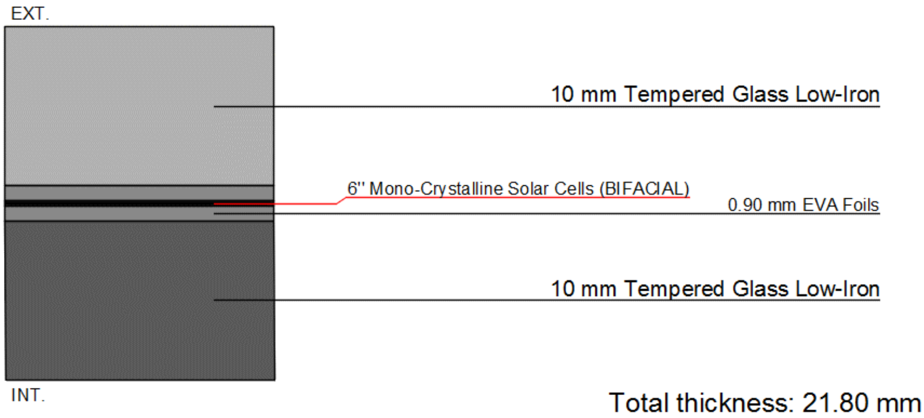


Figure 2.22: Glass configuration of the PV glass tile design for the walkable floor

2.4.3 BIPVBOOST modules electrical design

As it has been indicated in Section 2.2.2, the total area to demonstrate the BIPVBOOST balustrades is going to be increased, so that the entire balustrades of the East, South and West façades are replaced by the glass-glass bifacial module balustrades. With the modules presented by Onyx in Section 2.4.1 and 2.4.2, the premises of maintaining a total power (22.7kW) or a total area (200m^2) like in the original proposal and taking into account all the technical (electrical) and aesthetical characteristics of the building, the definitive distribution of power between the balustrades and the floor can be calculated as well as the number of modules to install. ISFOC has selected the 600x600mm tiles, as shown in Table 2.7, where the main characteristics of the installation are summarized:

Table 2.7: ISFOC demo installation characteristics

BIPVBOOST INSTALLATION AT ISFOC			
BALUSTRADE			
Power	12.80 kWp		
Area	125.58 m^2		
Balustrade	**South**	**East**	**West**
Modules Nº	108	12	12
Total	132		
Area	103.23 m^2	11.18 m^2	11.18 m^2
	125.58 m^2		
Power	10.50 kWp	1.15 kWp	1.15 kWp
	12.80 kWp		
WALKABLE FLOOR			
	Option 3		
Dimensions	600x600mm^2		
Tiles Nº	192		
Power	**9.22 kWp**		
Area	**69.12 m^2**		
TOTAL			
Total Power	**22.02 kWp**		
Total Area	**194.70 m^2**		

The total numbers of the installation are very similar to the initial ones included in the proposal, 22kWp in 195m^2.

- The power of the balustrades based on glass-glass bifacial modules to install at ISFOC is increased to 12.80kWp in 126m^2 instead of 8.7kWp in 100m^2.
- The power of the walkable floor based on back-contact solar cells to install at ISFOC is reduced to 9.22kWp in 69m^2 instead of 14kWp in 100m^2.

In this way the entire East, West and South facades will be converted into PV balustrades.

The first approach for the installation of the PV floor is as shown in Figure 2.23, a rectangular area, in the South section of the floor, at the exit of the elevator.

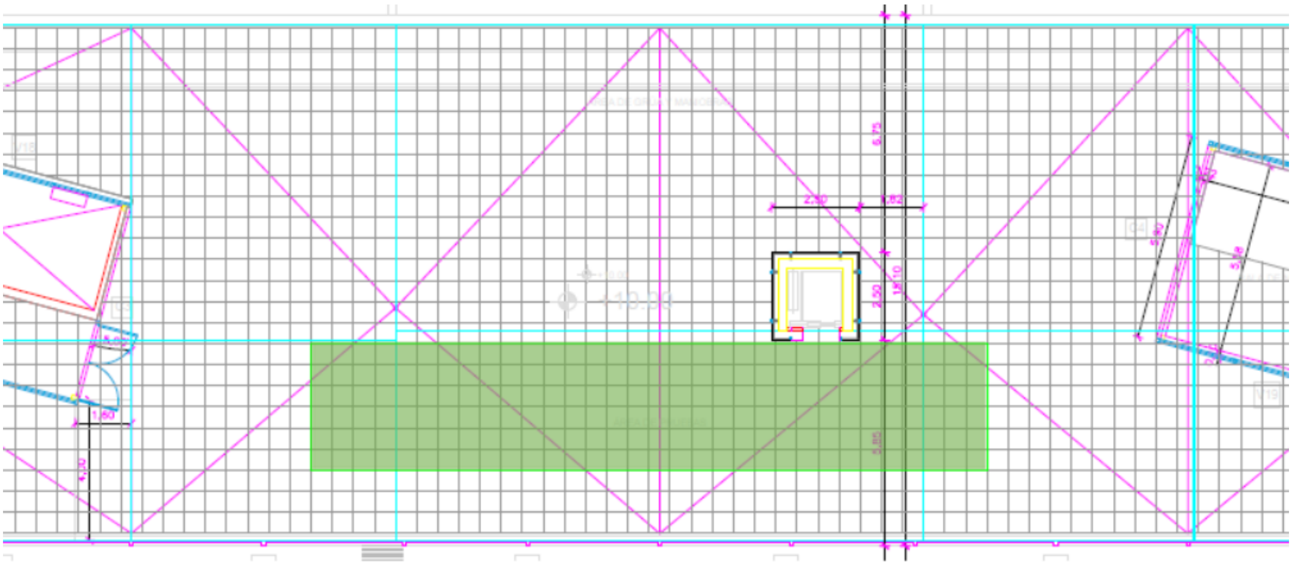


Figure 2.23: Walkable floor based on back-contact solar cells. ISFOC rooftop design

2.5 BIPV ELECTRICAL SYSTEM DESIGN

Next, the design of the electrical installation of the BIPV installation is presented.

In a first approach, the installation at ISFOC demo site is going to include a battery component in order to manage the energy generation and the building demand, (analysed in WP7). It is going to be an installation without excess energy, which means that it will not inject electricity to the distribution grid.

The PV installation is composed by the different modules provided by ONYX SOLAR divided in three PV generators:

- **PV GENERATOR 1: East and west balustrades**. These two strings of 12 modules will be connected to one PV inverter. Each string will be connected to one MPPT of the HUAWEI SUN2000L-2KTL inverter, it is a one-phase inverter. The modules of each string will be connected all in series.
- **PV GENERATOR 2: South balustrade**. These are all the modules installed in the south façade. They will be connected in two serial strings of 96 modules, each one connected to one MPPT of the HUAWEI SUN2000-10KTL-M1 inverter, it is a three-phases inverter. Additionally, the Li-on battery pack will be connected to this inverter.
- **PV GENERATOR 3 Walkable Floor**. These modules will be connected in four serial strings of 48 modules. This generator will use a HUAWEI SUN2000L-8KTL-M1 inverter with two MPPT, connecting two strings in parallel to each MPPT. It is also a three-phase inverter.

All the components of the electrical installation are shown in Figure 2.24.

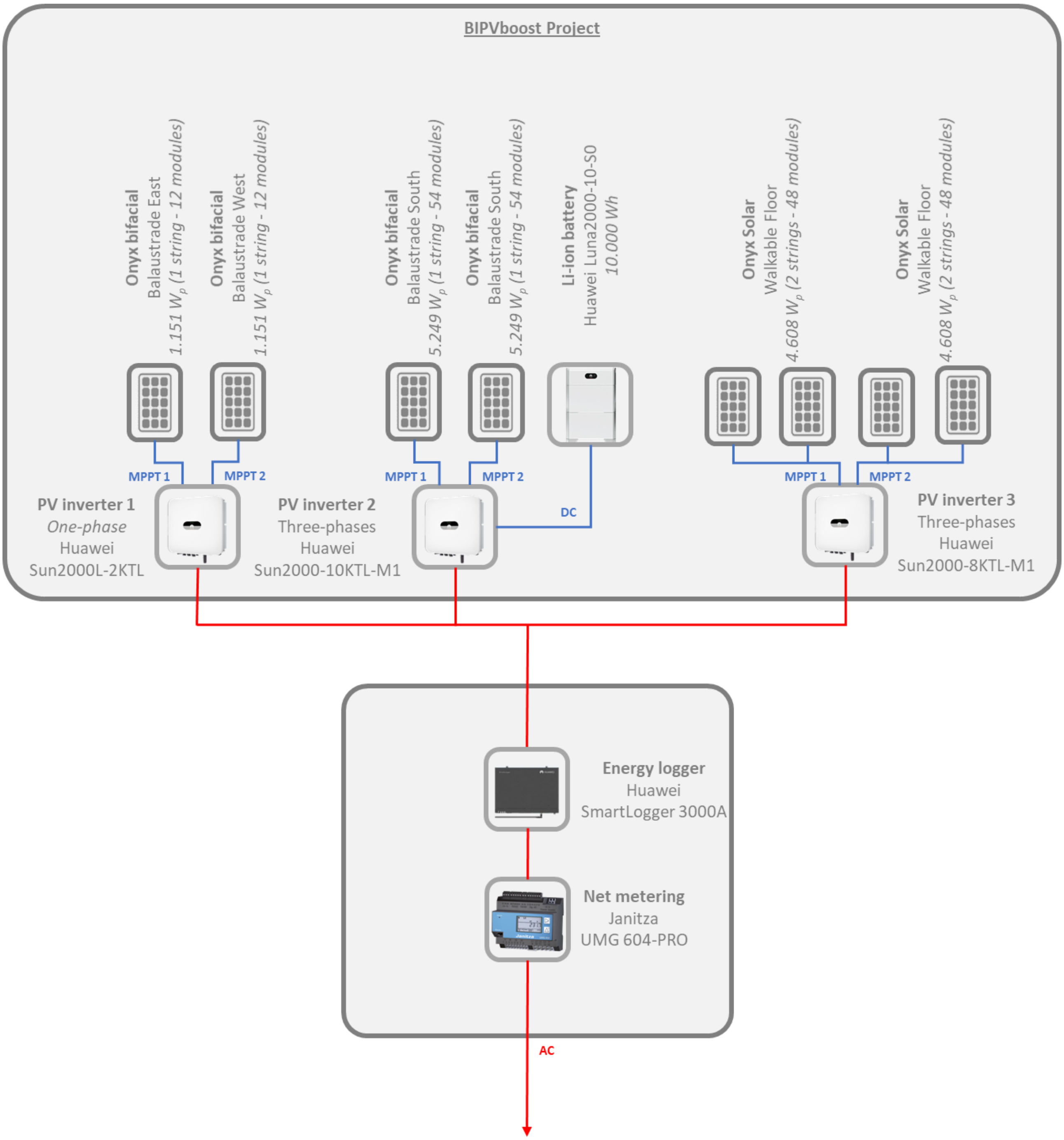


Figure 2.24: BIPVBOOST ISFOC demonstration – Electrical installation

The installation includes a net metering, Janitza UMG 604-PRO, to measure the total power consumption of the building and an energy logger, HUAWEI SmartLogger 3000A, to make the smart zero export control to avoid the electricity injection to the grid.

2.5.1 BIPVBOOST system components

Next, a brief description of the different components of the installation is presented. Different energy meters will be installed where needed to make the detailed monitoring of the installation (as presented in section 2.6).

2.5.1.1 Photovoltaic inverters

Following, the inverters to use in the different PV generators are presented:

- **PV GENERATOR 1.** The east and west balustrades will be connected to the inverter **HUAWEI SUN2000-2KTL**. The inverter is shown in Figure 2.25 and its efficiency curve and circuit diagram are shown in Figure 2.26.

Figure 2.25: Photovoltaic inverter HUAWEI SUN2000-2KTL-L1

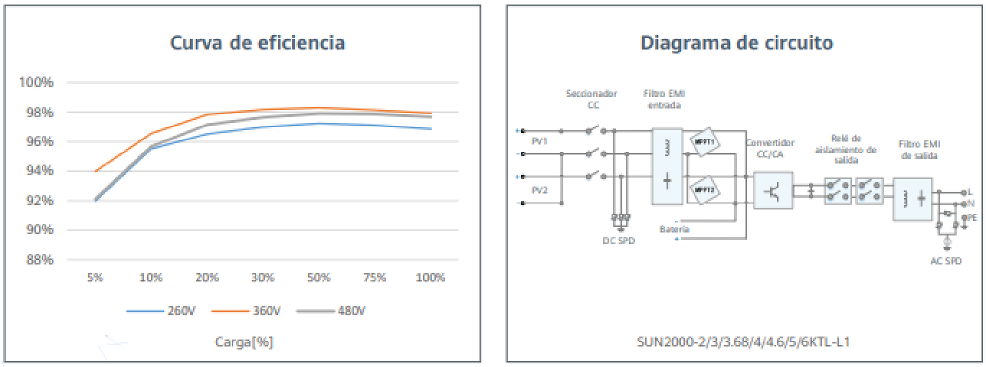


Figure 2.26: Efficiency curve and circuit diagram - HUAWEI SUN2000-2KTL inverter

- **PV GENERATOR 2.** The south balustrade South will be connected to the inverter **HUAWEI SUN2000-10KTL-M1.** The inverter is shown in Figure 2.27 and its efficiency curve and circuit diagram are shown in Figure 2.28.

Figure 2.27: Photovoltaic inverter HUAWEI SUN2000-10KTL-M1

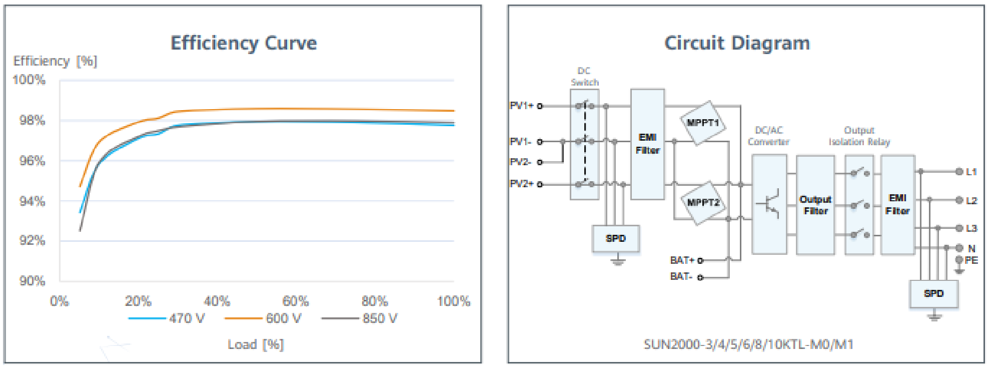


Figure 2.28: Efficiency curve and circuit diagram - HUAWEI SUN2000-10KTL-M0 inverter

- **PV GENERATOR 3.** The walkable floor is composed of 192 modules. In this case, the modules will be grouped in four strings of 48 modules connected in series and the strings will be connected in parallel two by two. The two resulting strings will be connected then to each MPPT of the **HUAWEI SUN2000L-8KTL-M1**. The inverter is shown in Figure 2.27 and its efficiency curve and circuit diagram are shown in Figure 2.28.

2.5.1.2 Li-ion batteries.

For the storage of the generator there are two possibilities, there are two different Li-ion batteries compatible with the HUAWEI inverters; LG CHEM and HUAWEI. But, trying to avoid any issues related with the compatibility of the components, the batteries to be installed will be **HUAWEI LUNA2000-10-S0** of 10kWh. The battery pack will be managed by the inverter of the PV GENERATOR 2. The battery pack is shown in Figure 2.29 and its main characteristics are collected in Table 2.8.

Figure 2.29: Li-ion batteries pack HUAWEI Luna 2000-10-S0

Table 2.8: Main characteristics - HUAWEI Luna 2000-10-S0 storage

		Performance	
Power module		LUNA2000-5KW-C0	
Number of power modules		1	
Battery module		LUNA2000-5-E0	
Battery module energy		5 kWh	
Number of battery Modules	1	2	3
Battery usable energy [1]	5 kWh	10 kWh	15 kWh
Max. output power	2.5 kW	5 kW	5 kW
Peak output power	3.5 kW, 10 s	7 kW, 10 s	7 kW, 10 s
Nominal voltage (single phase system)		450 V	
Operating voltage range (single phase system)		350 – 560 V	
Nominal voltage (three phase system)		600 V	
Operating voltage range (three phase system)		600 – 980 V	

2.5.1.3 Smart zero export control unit.

As it has been said before, the demonstrator at ISFOC is going to be a PV generation installation without surplus, which means that it will not inject electricity to the distribution grid. The smart zero export control is carried out by the **HUAWEI SmartLogger 3000A**, equipment that must be verified by the distribution company. The total power consumption of the building is measured by a **Janitza UMG 604-PRO** (see section 2.6) equipment, which sends data to the SmartLogger. The SmartLogger unit is shown in Figure 2.30 and its main characteristics are collected in Figure 2.28

Figure 2.30: Smart zero export control - HUAWEI SmartLogger 3000A

Table 2.9: Main characteristics - HUAWEI SmartLogger 3000A

Technical Specification	SmartLogger3000A03EU	SmartLogger3000A01EU
	Device Management	
Max. Number of Connected Devices	80	
	Communication Interface	
WAN	WAN x 1, 10 / 100 / 1000 Mbps	
LAN	LAN x 1, 10 / 100 / 1000 Mbps	
RS485	COM x 3, 1200 / 2400 / 4800 / 9600 / 19200 / 115200 bps, 1000 m	
MBUS	MBUS x 1, 115.2 kbps, Compatible with PLC	No MBUS Communication Interface
2G / 3G / 4G [1]	LTE(FDD) : B1,B2,B3,B4,B5,B7,B8,B20 DC-HSPA+/HSPA+/HSPA/UMTS : 850/900/1900/2100 MHz GSM/GPRS/EDGE: 850/900/1800/1900 MHz [2]	
Digital / Analog Input / Output	DI x 4, DO x 2, AI x 4	
Active DO	12V, 100mA (connection with relay, sensor)	
	Communication Protocol	
Ethernet	Modbus-TCP, IEC 60870-5-104	
RS485	Modbus-RTU, IEC 60870-5-103 (standard), DL / T645	

2.5.2 BIPVBOOST electrical diagram

The basic electrical diagram of the installation is shown in Figure 2.24. The PV installation is organized in smaller PV generators, so that each different orientation is connected independently to one MPPT.

- One inverter HUAWEI SUN2000-2KTL for West and East balustrade:
  - 1 MPPT for East Balustrade.
  - 1 MPPT for West Balustrade.
- One inverter HUAWEI SUN2000-10KTL-M1 for South Balustrade
  - 1 MPPT for a half of the south balustrade
  - 1 MPPT for a half of the south balustrade
- One inverter HUAWEI SUN2000-8KTL-M1 for Walkable Floor
  - 1 MPPT for a parallel association of 2 strings of PV tiles connected in series. Half of the walkable floor.

- 1 MPPT for a parallel association of 2 strings of PV tiles connected in series. Half of the walkable floor.

The installation will be connected to the grid but without surpluses and up to now it is going to include some batteries for storage purposes. The first approach is to have a storage capacity of 10kWh using the Li-ion HUAWEI LUNA2000-10-S0 connected to the SUN2000-10KTL inverter of the south balustrade.

The controllable loads at ISFOC, which are also included in the BIPVBOOST project, are the air conditioning system and the lightning.

Next, the wiring of the electrical installation is presented. Figure 2.31 shows the single-line diagram of the installation, where the type, length and sections of the cables can be observed. All the calculations are presented in Table 2.10.

- The DC wires will have a section of 25mm^2 for the west string of generator 1 and of 10mm^2 for the east string of generator 1, for the rest of generators it will be of 4mm^2.
- The AC wires from the inverters to the interconnection point will have a section of 4mm^2 and of 70mm^2 from the interconnection point to the connection to the grid point.
  The length of each cable is indicated in the diagram, being the longest for the east/west balustrade since the inverters will be located in one of the rooftop cabinets of the centre.

Table 2.10: BIPVBOOST – ISFOC installation. Wiring calculations

Cálculo Cableados CC										
Dimensionamiento por caída de tensión										
		Longitud [m]	Potencia [W]	Intensidad Isc [A]	Tensión [V]	Caída tensión [V] 1%	Coeficiente [Cu]	Sección [mm²]	Sección mínima [mm²]	**Sección [mm²]**
Rama 1	Serie 1 - Oeste	129	1.224	8,67	180	1,80	56	22,19	25	**25**
Rama 2	Serie 2 - Este	53	1.224	8,67	180	1,80	56	9,03	10	**10**
Rama 3	Serie 3 - Sur 1	86	5.832	8,67	810	8,10	56	3,27	1,5	**4**
Rama 4	Serie 4 - Sur 2	49	5.832	8,67	810	8,10	56	1,87	2,5	**4**
Rama 5	Serie 5 - Suelo 1	45	2.304	8,67	720	7,20	56	1,94	2,5	**4**
Rama 6	Serie 6 - Suelo 2	57	2.304	8,67	720	7,20	56	2,46	2,5	**4**
Rama 7	Serie 7 - Suelo 3	48	2.304	8,67	720	7,20	56	2,04	2,5	**4**
Rama 8	Serie 8 - Suelo 4	60	2.304	8,67	720	7,20	56	2,56	4	**4**
Dimensionamiento por intensidad máxima admisible										
		Tipo instalación	Potencia [W]	Intensidad Isc [A]	Tensión [V]	Tipo conductores	Factor reducción	Sección [mm²]	Imáx sección [A]	**Sección [mm²]**
Rama 1	Serie 1 - Oeste	B2	1.224	8,67	180	2PVC -Cu	1	25	84	**25**
Rama 2	Serie 2 - Este	B2	1.224	8,67	180	2PVC -Cu	1	10	50	**10**
Rama 3	Serie 3 - Sur 1	B2	5.832	8,67	810	2PVC -Cu	1	4	27	**4**
Rama 4	Serie 4 - Sur 2	B2	5.832	8,67	810	2PVC -Cu	1	4	27	**4**
Rama 5	Serie 5 - Suelo 1	B2	2.304	8,67	720	2PVC -Cu	1	4	27	**4**
Rama 6	Serie 6 - Suelo 2	B2	2.304	8,67	720	2PVC -Cu	1	4	27	**4**
Rama 7	Serie 7 - Suelo 3	B2	2.304	8,67	720	2PVC -Cu	1	4	27	**4**
Rama 8	Serie 8 - Suelo 4	B2	2.304	8,67	720	2PVC -Cu	1	4	27	**4**

Cálculo Cableados CA										
Dimensionamiento por caída de tensión										
		Longitud [m]	Potencia [W]	Intensidad Isc [A]	Tensión [V]	Caída tensión [V] 0,5%	Coeficiente [Cu]	Sección [mm²]	Sección mínima [mm²]	**Sección [mm²]**
Inv1	Inv1-CAG	5	2.000	8,70	230,00	1,15	56	1,35	1,5	**4**
Inv2	Inv2-CAG	5	10.000	14,43	400,00	2,00	56	1,12	1,5	**4**
Inv3	Inv3-CAG	5	8.000	11,55	400,00	2,00	56	0,89	1,5	**4**
CAG	CAG-PCC	130	20.000	28,87	400,00	2,00	56	58,04	70	**70**
Dimensionamiento por intensidad máxima admisible										
		Tipo instalación	Potencia [W]	Tensión [V]	Intensidad [A]	Tipo conductores	Factor reducción	Sección [mm²]	Imáx sección [A]	**Sección [mm²]**
Inv1	Inv1-CAG	B2	2.000	230	8,70	2XLPE - Cu	1	4	27	**4**
Inv2	Inv2-CAG	B2	10.000	400	14,43	3XLPE - Cu	1	4	27	**4**
Inv3	Inv3-CAG	B2	8.000	400	11,55	3XLPE - Cu	1	4	27	**4**
CAG	CAG-PCC	A2	20.000	400	28,87	3XLPE - Cu	1	70	149	**70**

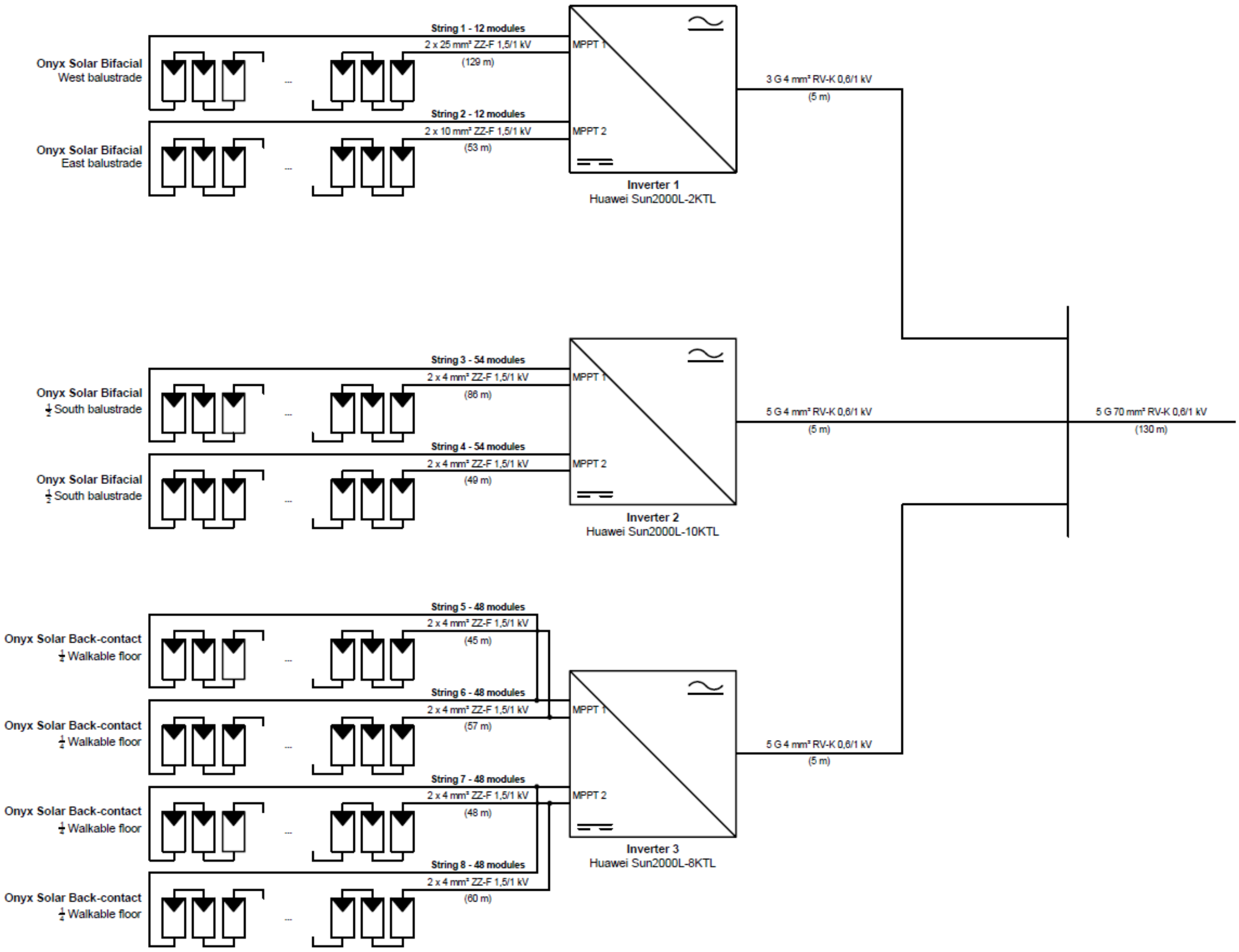


Figure 2.31: BIPVBOOST – ISFOC installation single-line diagram

2.6 BIPV MONITORING DESIGN

2.6.1 Definition of monitoring objectives: BIPV performance validation, economic viability and progress towards NZEB requirements

The main objective of the monitoring system is to verify and validate the Energy performance of the BIPVBOOST project developments implementations through the measurement of key variables. The measurement methodology and key variables to be measured were defined in deliverable 8.3. The monitoring methodology described in deliverable 8.3 is base in the inter-comparison of two monitoring periods, defined as the pre-intervention period (base line) and the post intervention period.

The implementation of pre-intervention period monitoring system has been finished in June 2020 and measurements are being gathered since august 2020.The post-intervention monitoring system will be implemented after the intervention described in this document in September 2021.

Next the pre-intervention period monitoring system is presented and later this document will be updated which the implementation of e post-intervention monitoring system.

2.6.2 Definition of variables to be monitored

The monitoring objectives will be reached through the measurement of the energy variables shown in Figure 2.32. Table 2.11 shows a short definition of the variables shown in Figure 2.32 and additional information about instruments used for the measurements. The variables monitored during pre-intervention period are written in blue and, during the post-intervention period, variables written in red will be also measured.

As it can be seen, during the pre-intervention period, the monitored variables are related with meteorology and building consumption and during the post intervention period the energy production of BIPV modules will be also measured.

Demo 1-ISFOC

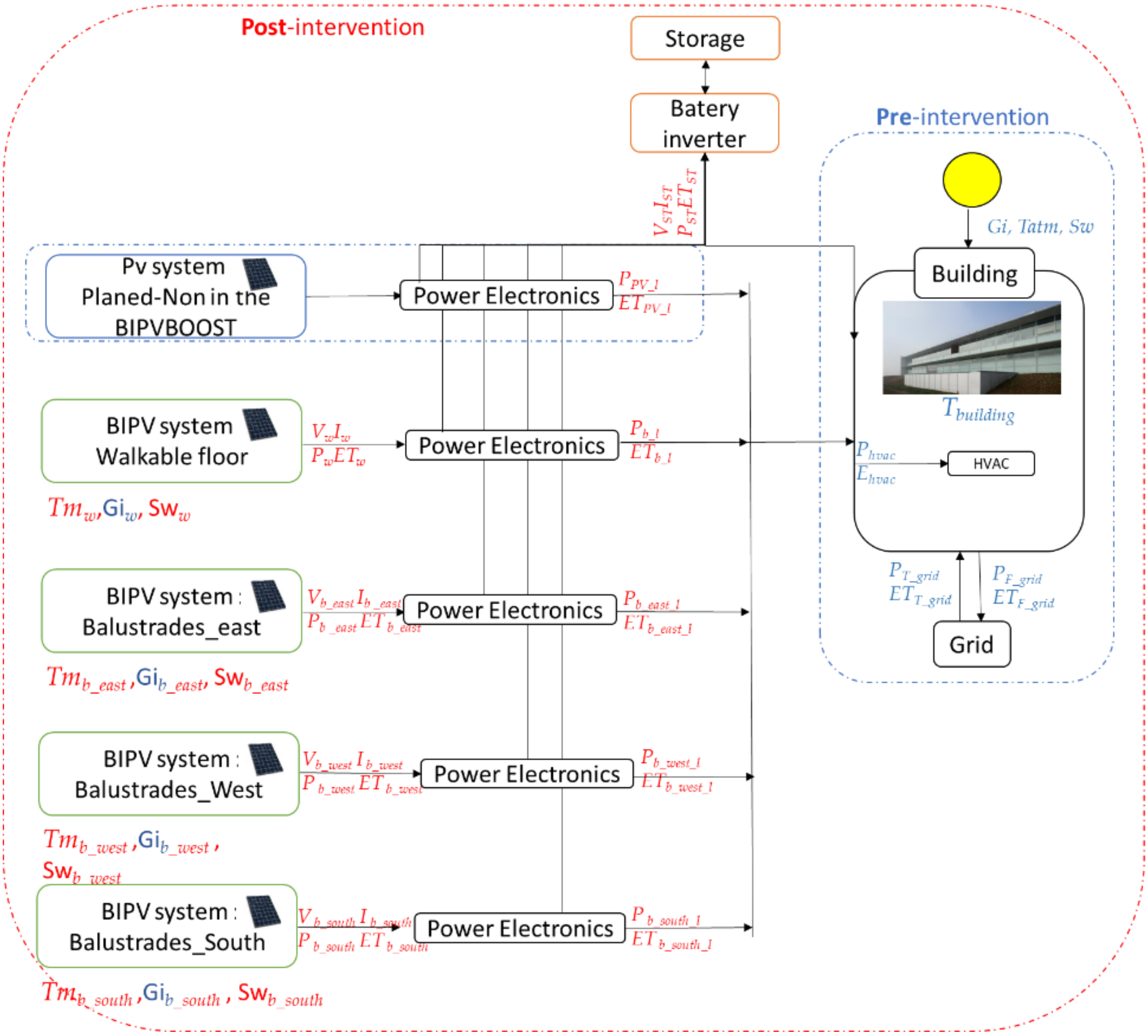


Figure 2.32: Main measuring variables of Puertollano demo site. Blue variables will be monitored since the pre-intervention year and the red variables will be monitored from the postintervention onwards

Table 2.11: Description of the variables shown in Figure 2.32 and the intruments used to for the measurements

Variable	**Description**	**instrument**	**Range**	**Units**	**Time Resolution**	**Accuracy**
BIPV components						
Balustrades east						
Meteo	-					
Gi_{east_1}	*Irradiance East plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Gi_{west_1}	*Irradiance West plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{b_east}	*Module temperature*	Thermocouple type T	0-100	ºC	<1min	1K
DC	-					
I_{b_east}	DC Intensity	Amperimeter		A	<1min	1% of the reading
V_{b_east}	DC Voltage	Voltimeter		V	<1min	1% of the reading
P_{b_east}	DC Power	Power meter	1,2	Kw	<1min	2% of the reading
ET_{b_east}	DC Energy	Energy meter		Kw/h	<1min	
AC	-					
$P_{b\_east\_I}$	AC Power	Power meter	1,2	Kw	<1min	2% of the reading
$ET_{b\_east\_I}$	AC Energy	Energy meter		Kw/h	<1min	
Balustrades West						
Meteo	-					
Gi_{east_2}	*Irradiance East plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Gi_{west_2}	*Irradiance West plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{b_west}	*Module temperature*	Thermocouple type T		ºC	<1min	1K
DC	-					
I_{b_west}	DC Intensity	Amperimeter		A	<1min	1% of the reading
V_{b_west}	DC Voltage	Voltimeter		V	<1min	1% of the reading
P_{b_west}	DC Power	Power meter	1,2	Kw	<1min	2% of the reading
ET_{b_west}	DC Energy	Energy meter		Kw/h	<1min	
AC	-					
$P_{b\_west\_I}$	AC Power	Power meter	1,2	Kw	<1min	2% of the reading
$ET_{b\_west\_I}$	AC Energy	Energy meter		Kw/h	<1min	
Balustrades South						
Meteo	-					
$Gi_{\_south}$	*Irradiance south plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
$Gi_{\_north}$	*Irradiance North plane*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{b_south}	*Module temperature*	Thermocouple type T		ºC	<1min	1K
DC	-					
I_{b_south}	DC Intensity	Amperimeter		A	<1min	1% of the reading
V_{b_south}	DC Voltage	Voltimeter		V	<1min	1% of the reading
P_{b_south}	DC Power	Power meter	6,4	Kw	<1min	2% of the reading
ET_{b_south}	DC Energy	Energy meter		Kw/h	<1min	
AC	-					
$P_{b\_south\_I}$	AC Power	Power meter	6,4	Kw	<1min	2% of the reading
$ET_{b\_south\_I}$	AC Energy	Energy meter		Kw/h	<1min	
Walkable Flor						
Meteo	-					

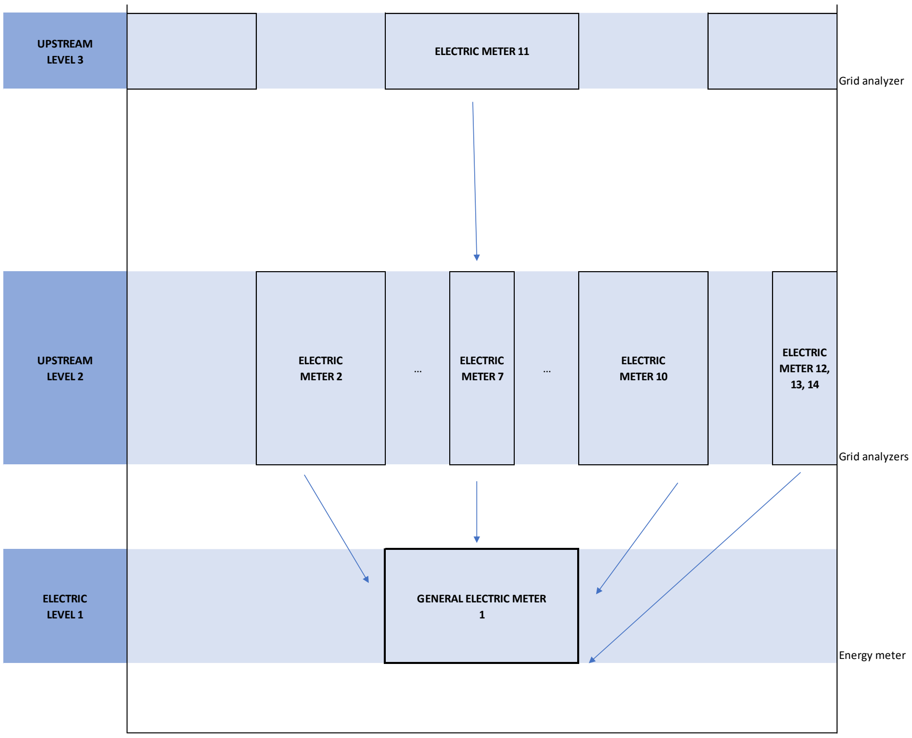
Variable	Description	instrument	Range	Units	Time Resolution	Accuracy
Gi_w	*Irradiance azimut*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_w	*Module temperature*	Thermocouple type T	0-100	ºC	<1min	1K
DC						
I_w	DC Intensity	Amperimeter		A	<1min	1% of the reading
V_w	DC Voltage	Voltimeter		V	<1min	1% of the reading
P_w	DC Power	Power meter	14	Kw	<1min	2% of the reading
ET_w	DC Energy	Energy meter		Kw/h	<1min	
AC						
P_{w_I}	AC Power	Power meter	14	Kw	<1min	2% of the reading
ET_{w_I}	AC Energy	Energy meter		Kw/h	<1min	
Storage						
Imput						
I_{st_in}	Intensity	Amperimeter		A	<1min	
V_{st_in}	Voltage	Voltimeter		V	<1min	1% of the reading
P_{st_in}	Power	Power meter	89	Kw	<1min	2% of the reading
ET_{st_In}	Energy	Energy meter		Kw/h	<1min	
Output						
I_{st_out}	Intensity	Amperimeter		A	<1min	1% of the reading
V_{st_out}	Voltage	Voltimeter		V	<1min	1% of the reading
P_{st_out}	Power	Power meter		Kw	<1min	2% of the reading
ET_{st_out}	Energy	Energy meter		Kw/h	<1min	
Building						
HVAC						
I_{hvac}	Intensity	Amperimeter		A	<1min	1% of the reading
V_{hvac}	Voltage	Voltimeter		V	<1min	1% of the reading
P_{hvac}	Power	Power meter		Kw	<1min	2% of the reading
Existing PV field						
DC						
I_{pv}	DC Intensity	Amperimeter		A	<1min	1% of the reading
V_{pv}	DC Voltage	Voltimeter		V	<1min	1% of the reading
P_{pv}	DC Power	Power meter	89	Kw	<1min	2% of the reading
ET_{pv}	DC Energy	Energy meter		kW/h	<1min	
AC						
P_{pv_I}	AC Power	Power meter	89	kW	<1min	
Et_{pv_I}	AC Energy	Energy meter		kW/h	<1min	
Grid						
P_{gr}	Power	Power meter		kW	<1min	
ET_{pv_I}	Energy	Energy meter		kW/h	<1min	

2.6.3 Existing monitoring system

ISFOC has already a monitoring system in its building in charge of measuring the energy consumption of the building, complete, and also some circuits independently. The purpose of this monitoring was different so only some of the measurements will be taken into account and it will be completed with additional components.

The different energy circuits monitored are shown in Table 2.12.

Table 2.12: List of the pre-existing monitoring equipment at ISFOC



ELECTRIC METER	Short explanation about the loads being measured by the spepecified electric meter or similar device	ACCES TO THIS DATA? Y/N
1	Total energy consumption of ISFOC headquarter	YES
2	"Red IRIS" server and ISFOC servers consumprion.	YES
3	Urbanization (exterior lights, irrigation, door…)	YES
4	Climatic chambers laboratory consumption	YES
5	Power consumprions to be protected by a UPS (not installed) for workers computers	YES
6	Office lights	YES
7	General Power consumptions	YES
8	HVAC system unit 2	YES
9	Kitchen	YES
10	HVAC system unit 1	YES
11	Solar Simulator laboratory	YES
12	Third company (offices and workshops) consumption. Offices	YES
13	Third company (offices and workshops) consumption. Workshps power	YES
14	Third company (offices and workshops) consumption. Workshops lights	YES
OBSERVATIONS		
The numbers of the meters are also marked as comments in the document "*Esquema_Unifilar_ISFOC_Num.pdf*"		
the electric meter 1 is the utility gri energy meter. We access to the data and we store it. You can have acces to this data stored but not to the instantaneous value		
the electric meters from 2 to 14 are grid analyzers. The data of all of them are stored in a DB where you can acces or we can generate the file you need. I think it is not possible to have acces to instantaneous value neither.		

Figure 2.33: Pre-existing monitoring equipment at ISFOC

2.6.4 BIPVBOOST monitoring system

As mentioned, the installation of the pre-intervention monitoring system was finished in June (2020) and data are being gathered since august (2020). This monitoring system will be updated after the BIPVBOOST intervention in the demo site and the results will be reported later.

Pre-intervention monitoring system.

In order to measure all the key variables, it have been used the already installed instruments of the ISFOC pre-existing monitoring system and additional variables have been measured with a complementary monitoring system installed within the frame of BIPVBOOST project.

Figure 2.34 shows the variables measured by the pre-existing monitoring system (Highlighted in yellow) and the variable measured with the monitoring system installed during the BIPVBOOST project framework (Highlighted in GREEN).

As it can be seen, the BIPVBOOST monitoring system is measuring the meteorological (irradiance in the module plane, Ambient temperature and wind direction) data and the pre-existing monitoring system in ISFOC is measuring the energy consumption of the building and its temperature.

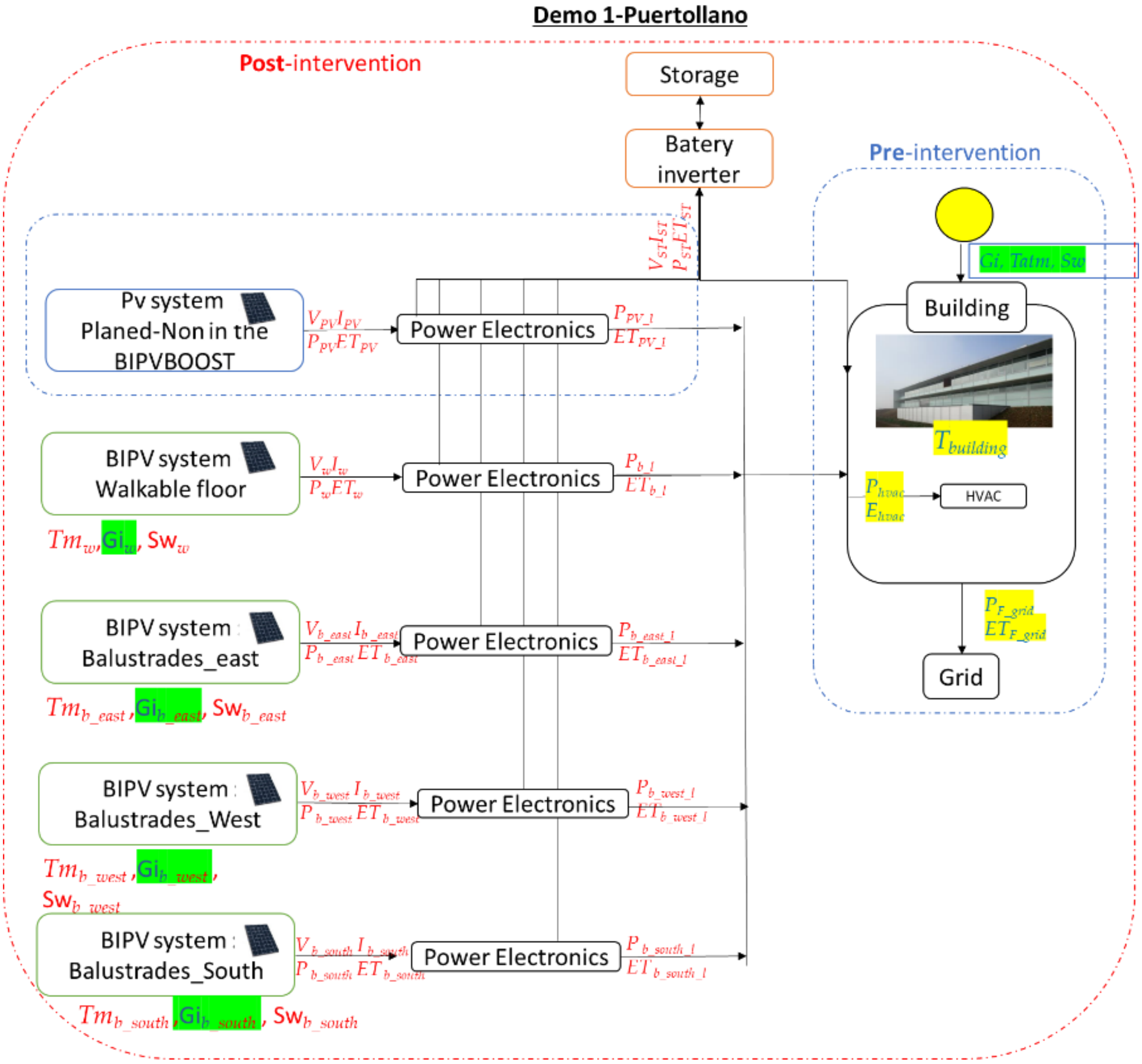


Figure 2.34: Main measuring variables of Puertollano demo site.

Blue variables will be monitored since the pre intervention year and the red variables will be monitored from the post intervention onwards. Green variables are already being monitored

The meteorological instruments have been installed on the roof. The Figure 2.35: shows the layout and some detailed photo of the finished installation. The ambient temperature (T_{atm}) is being measured by the PT100; the East (Gi_{b_east}), West (Gi_{b_West}), North (Gi_{b_south}), South(Gi_{b_south}) and azimuthal plane(Gi_w) Irradiance is being measured at certain height to avoid the albedo effect and additionally at low height (near the ground) to evaluate the albedo effect with a cube formed by reference cells; Gi with a pyranometer and wind direction with a anemometer.

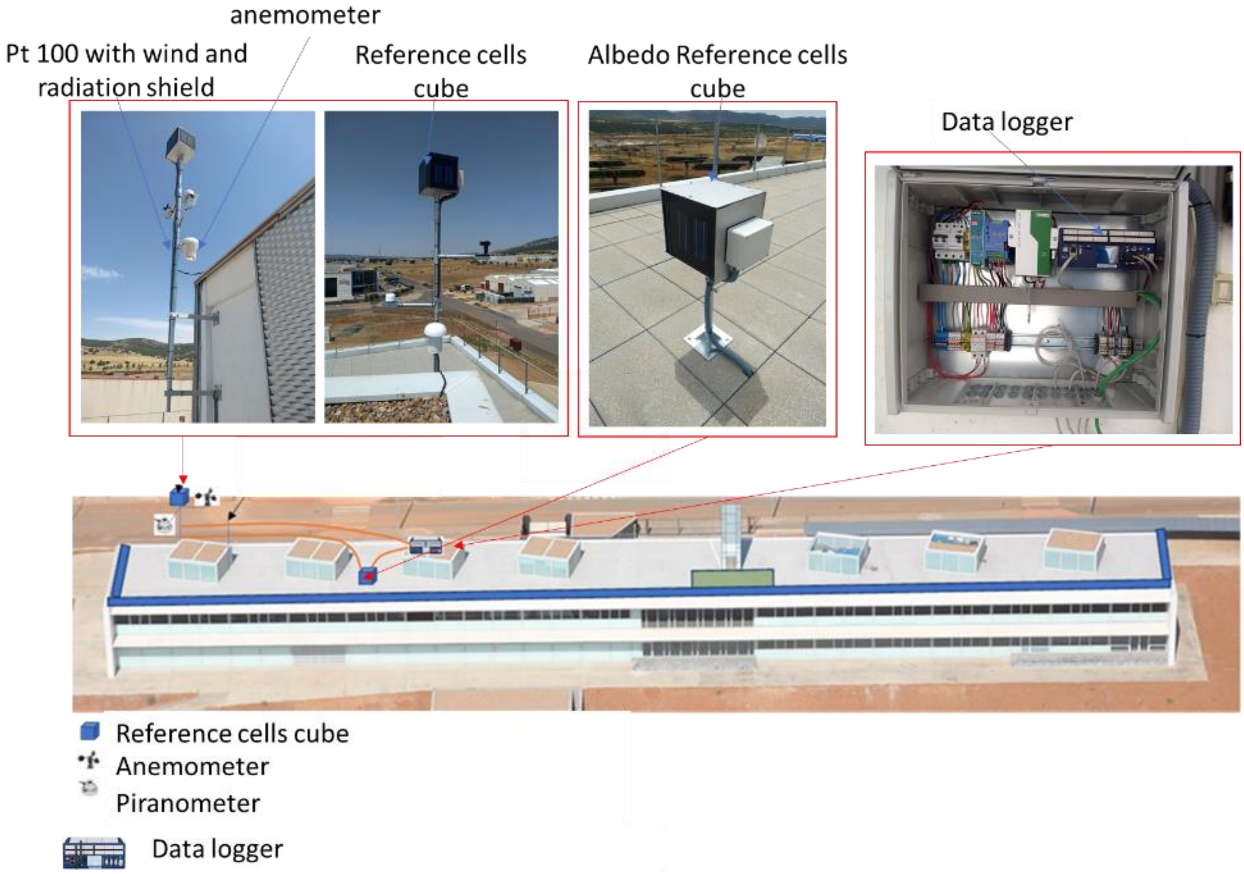


Figure 2.36: Layout of pre intervention monitoring system at Puertollano demo site

The data measured by the instruments are sent to the data logger via Modbus communication. Figure 2.37 shows all the connections between the instruments and the datalogger.

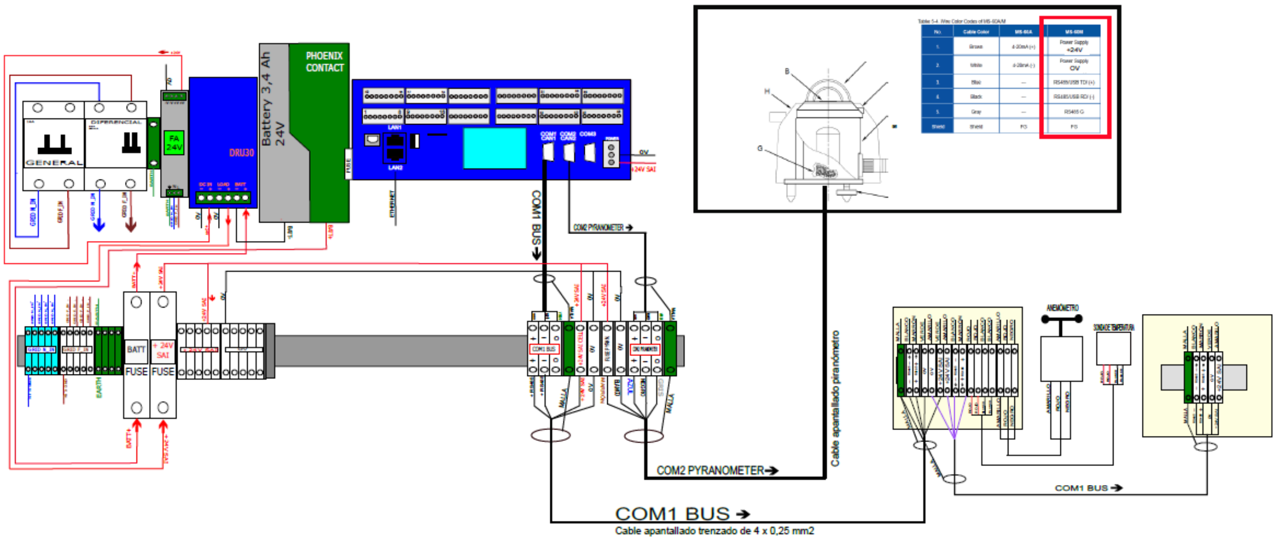


Figure 2.37: Detailed schema of the installed monitoring system connections

Data collection

On the one hand the gathered data are send to TECNALIA via internet by a modem integrated in the monitoring system. On the other hand, the data gathered by the pre-existing monitoring system in ISFOC are sent to TECNALIA through FTC. The data can be check online in the website prepared for this purpose (see Figure 2.38).

Figure 2.38: Screenshot of the web-datalogger

2.7 BIPV MODELLING AND PERFORMANCE SIMULATION

EnerBIM, as WP6 leader and BIMsolar tool developer, has completed BIPV systems digital modelling and simulation works as a pre-study.

2.7.1 Element level to building level methodology using 3D modelling and simulation tools

2.7.1.1 Overall methodology

a. EnerBIM develops BIMsolar as a BIPV dedicated software, first for integrated simulation performance at building level with BIPV and BAPV systems, second for BIPVBOOST products virtualization with significant level of information.

b. **Inputs**
BIMsolar software (version BIPVBOOST) is designed to import 3D geometry through various formats:

- Trimble SketchUp native (.SKP)
- AutoDesk REVIT native (projects and families) through dedicated plugins
- Generic ISO/open BIM (.IFC)
- Green Building open format (gbXML)
- EnergyPlus open format (.IDF)

Weather data come from various reliable sources such as METEONORM®, PVGIS®.
Each BIPVBOOST demo site is geo-localized with the highest level of accuracy (WGS84 coordinates) to generate the most reliable TMY as an epw file from PVGIS®.

c. **BIPV Modelling-Simulation**
BIMsolar software runs contextual simulation in real time to bridge the gap between 3D modelling and performance calculation:

- Primary modelling comes from an architectural design (architect, designer): 3D CAD 3D file; SKP preferred as BIM is not necessary for preliminary studies,
- **Step#1 –** Environment: 3D model generation, weather data, albedo selection, sun course, shadowing, sun exposure,
- **Step#2 –** Irradiation: global yearly to hourly direct and diffuse irradiation simulation (kWh/m2) using our own raytracing technologies. Shading effects on energy ratio are highlighted in 3D,
- **Step#3 –** BIPV layouts: configuration of pre-series of BIPVBOOST products (cell editor to glazing editor) using SCHWEIZER and ONYX Solar datasheets. Virtual objects handling from user (mouse+click) enables integration of modules, tiles, on selected surfaces; global performance is computed and displayed: installed power (kWp), modules area (m2), array yield (kWh/kWp), module yield, yearly PV generation (kWh), shading losses, heat losses. The software enables KPIs calculation at element level (module),
- **Step#4 –** Inverter selection and wiring: the user can set-up any inverter or select inverter(s) from the PHOTON database or project database. Sizing of the inverter and strings strategies are performed with a dedicated algorithm (design support); cable / wiring specifications enable users to interact with the balance of system. Mismatching of modules and ohmic losses in strings are computed and displayed.
- **Step#5 –** Results: array production is displayed at PV layout level at various time steps (yearly to hourly). Several outcomes are computed and displayed in a contextual mode: shading losses, heat losses, ohmic losses, leading to DC & AC production and final yield. Sets of data can be extracted as outputs (production, hourly figures) through CSV files at any moment, to feed the downstream processing (Energy Management, specific studies with external tools).

Locations and configurations of the BIPV systems are considered as inputs for EnerBIM 3D modelling; they are detailed upstream in this report.

2.7.2 Modelling strategy retained for transparent and opaque BIPV

The software is being developed to fit with ONYX Solar strategies regarding glazing systems and transparent BIPV products. The BIPV module configurator is based on 4 editors:

- Cell editor
- Pattern editor
- Transparent Glass editor
- Glazing editor

To design a transparent BIPV system, we have fixed the following steps:

<u>BIPV Layout</u>

Balance of System (downstream studies)

2.7.3 DEMO#1 – ISFOC building, 3D design from 2D plans, simulation with BIMsolar

2.7.3.1 Hypothesis

BIPV modules have been set up from ONYX Solar datasets (up to date version).

BIFACIAL technologies: the full development of these specific innovations for BIPV is not completed for BIMsolar software at this stage (WP6 T6.3 – M48).

On the other hand, the bifacial modules have not been tested in laboratory to set-up their bifaciality. In this sense, the simulation of bifacial features is not possible yet.

To perform design simulations, we have selected mono crystalline cells and glass modules from ONYX datasheets (modules front side as specified). We have created "digital twin modules" to capture front side irradiation (mainly direct + diffuse irradiance). This is a first approach before going into deeper investigations.

2.7.3.2 Walkable floor modules

Specifications from ONYX Solar:

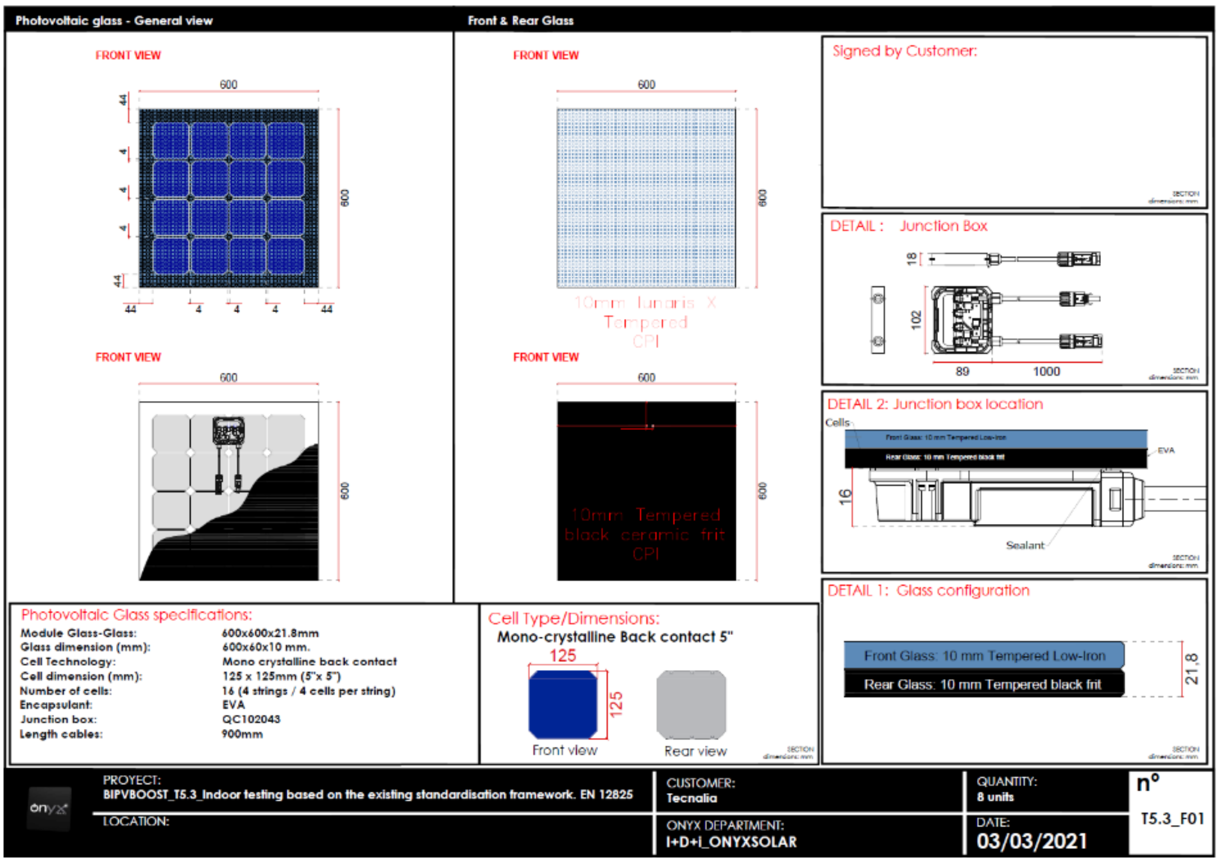


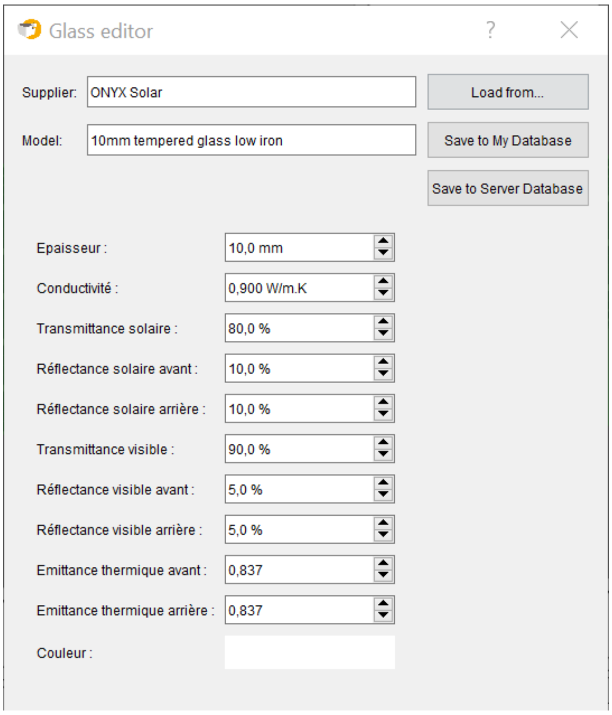
Figure 2.39 Walkable floor – ONYX Solar

Table 2.13 Configuration of ONYX Solar Walkable floor modules

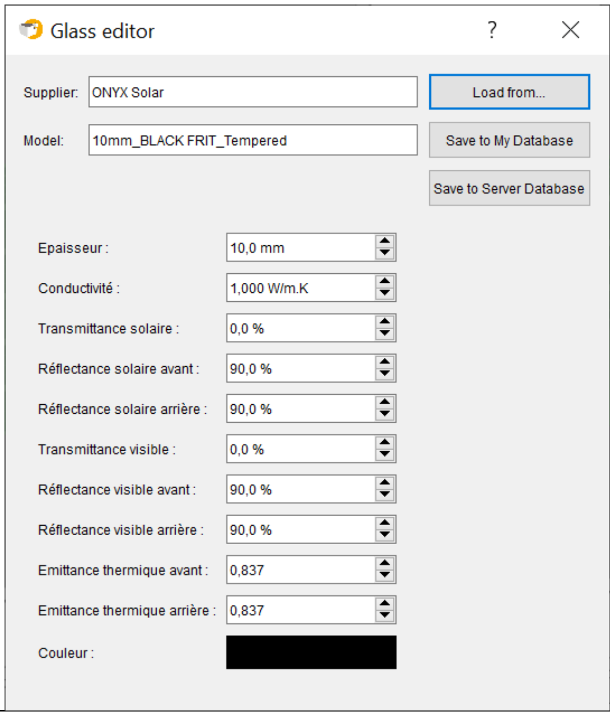
<table>
<tr>
<td>GLASS

Front: 10mm tempered Low-Iron

Back: 10mm tempered Black Frit</td>
<td>
Front



Back



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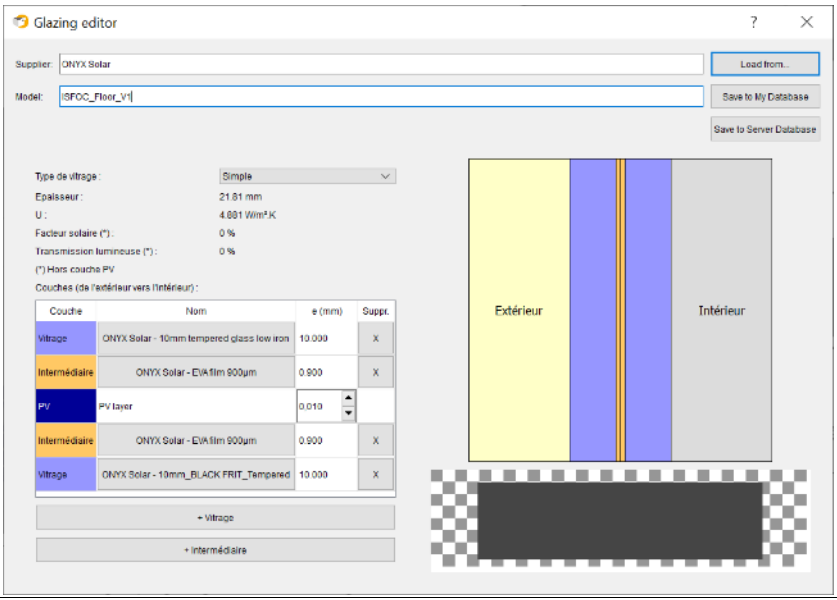
<tr>
<td>GLAZING system</td>
<td>
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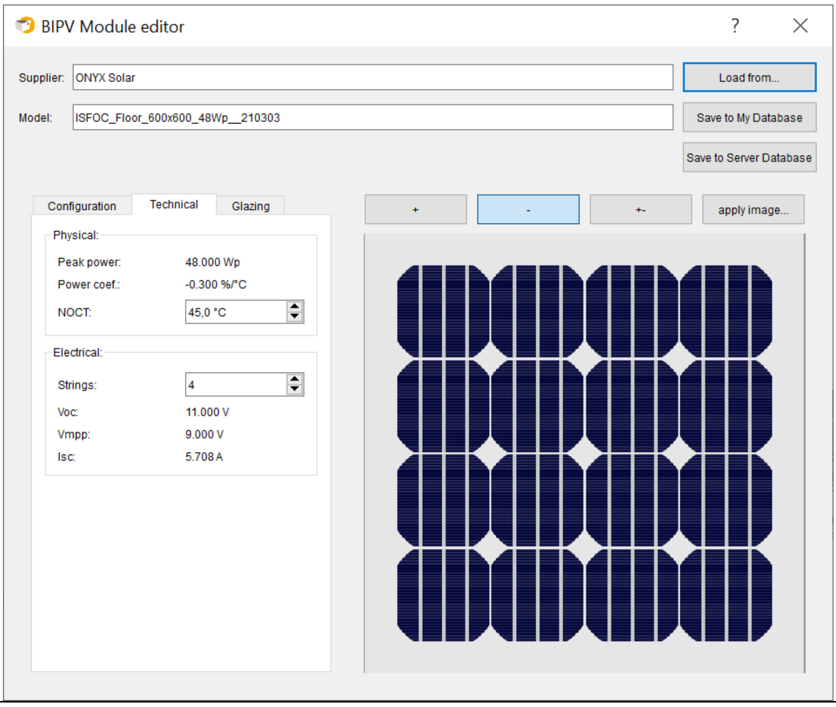
</tr>
<tr>
<td>FLOOR MODULES – 600x600mm

48Wp</td>
<td>
</td>
</tr>
</table>

2.7.3.3 Balustrade modules

Specifications from ONYX Solar:

PHOTOVOLTAIC GLASS FRONT SIDE	1.180 x 810 6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	97,2	P_{mpp} (Wp)
Open-circuit voltage	15,94	V_{oc} (V)
Short-circuit current	8,07	I_{sc} (A)
Voltage at nominal power	12,59	V_{mpp} (V)
Current at nominal power	7,72	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	1180	mm
Width	810	mm
Thickness	21,8	mm
Surface area	0,96	sqm
Weight	48	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	42%
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	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

Figure 2.40 Data sheets of the front face of the prototype of 1180 mm x 810 mm

PHOTOVOLTAIC GLASS FRONT SIDE	1.150 x 810 6" Mono	Crystalline Bifacial
Electrical data test conditions (STC)		
Nominal peak power	95,90	P_{mpp} (Wp)
Open-circuit voltage	15,93	V_{oc} (V)
Short-circuit current	7,88	I_{sc} (A)
Voltage at nominal power	12,47	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	1150	mm
Width	810	mm
Thickness	21,8	mm
Surface area	0,93	sqm
Weight	47	Kgs
Cell type	6" Mono	Crystalline bifacial
No PV cells / Transparency degree	24	41%
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	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

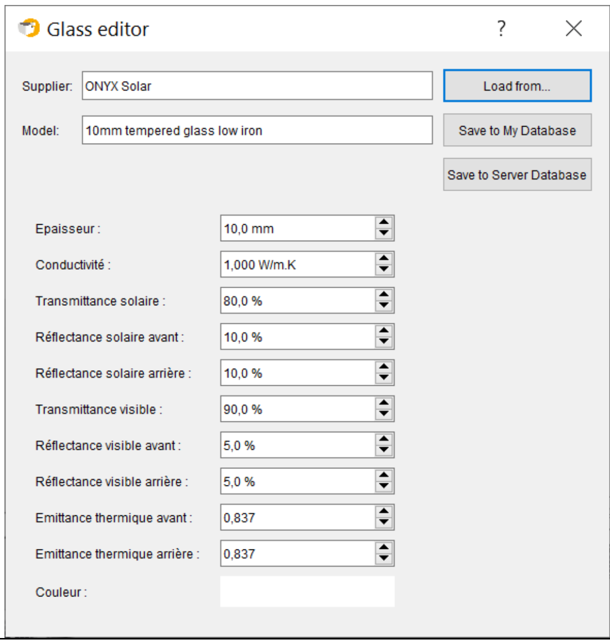
Figure 2.41 Data sheets of the front face of the prototype of 11580 mm x 810 mm

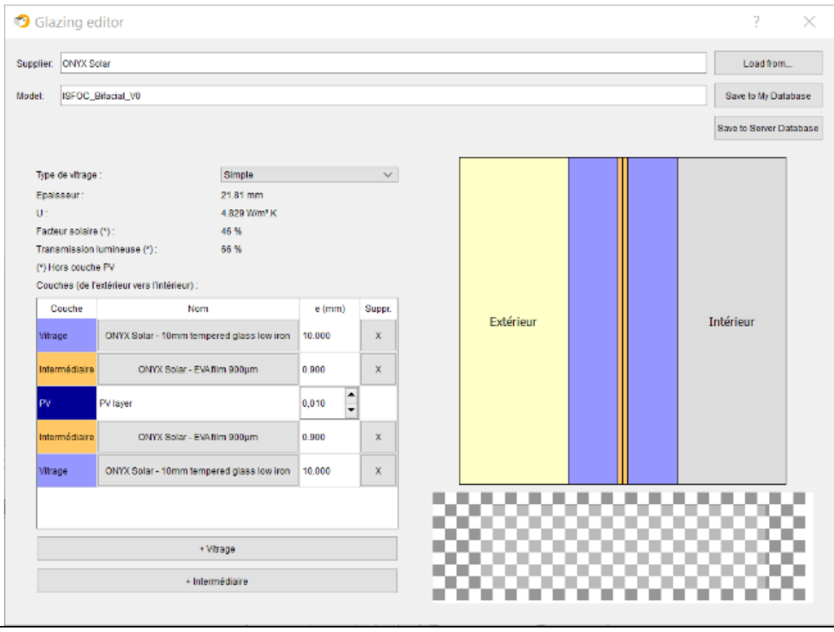
Table 2.14 Configuration of ONYX Solar Balustrade modules

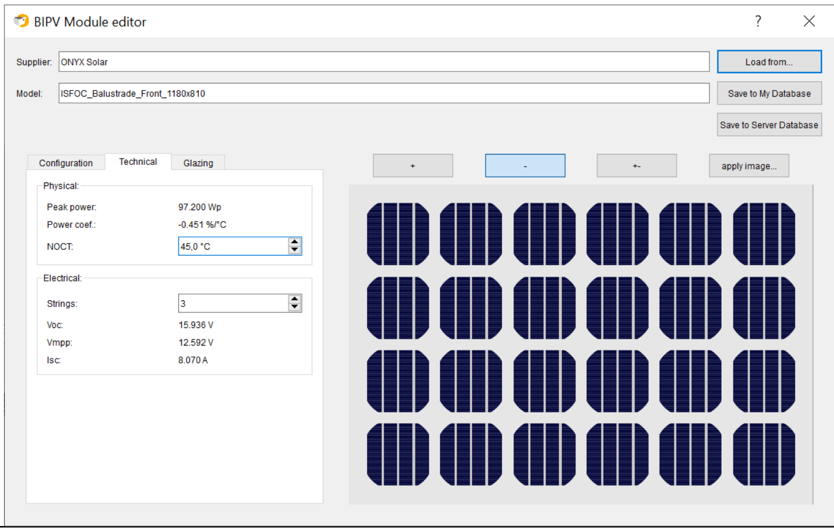
GLASS

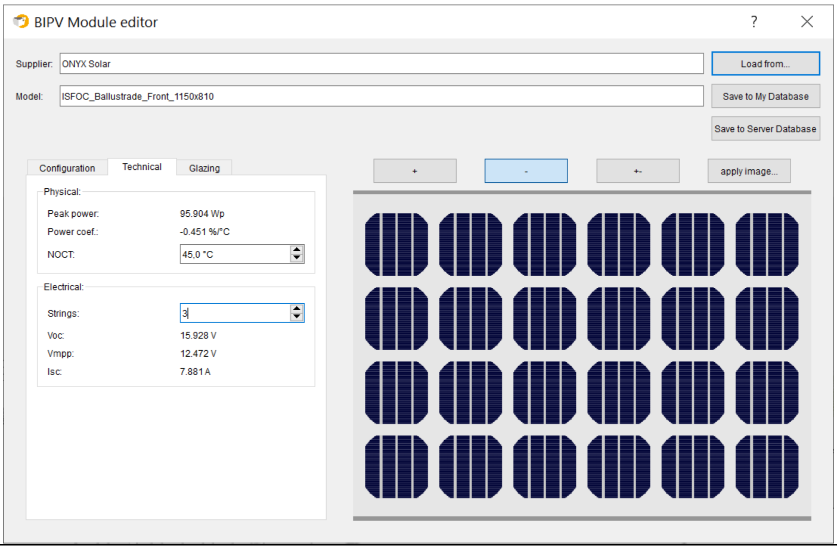
Front: 10mm tempered Low-Iron

Back: 10mm tempered Low-Iron



<table>
<tr>
<td>GLAZING system</td>
<td>
</td>
</tr>
<tr>
<td>SOUTH BALLUSTRADE MODULES

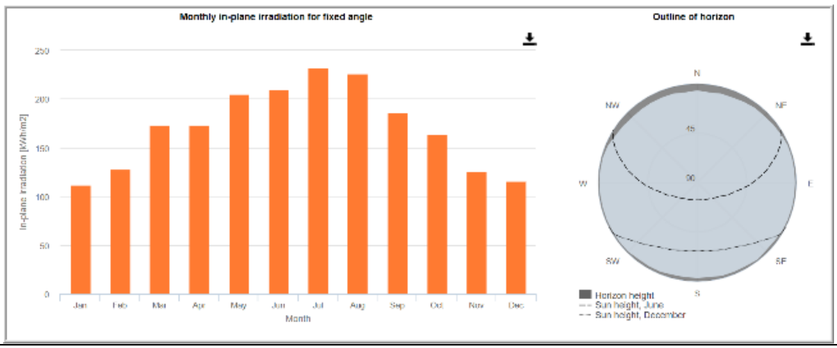
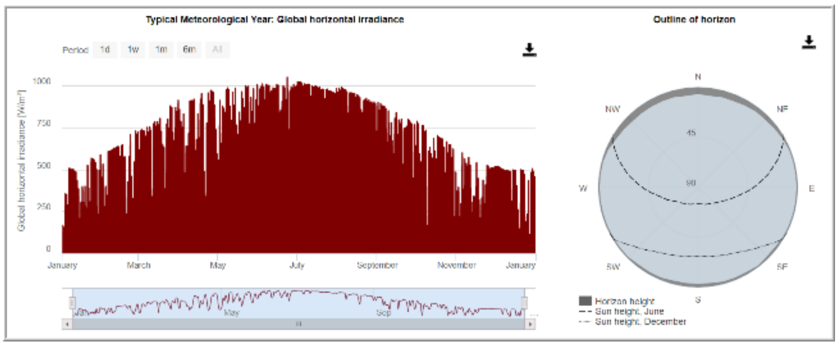
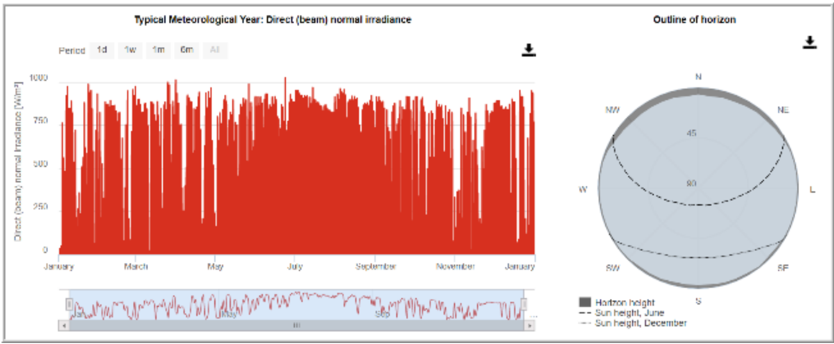
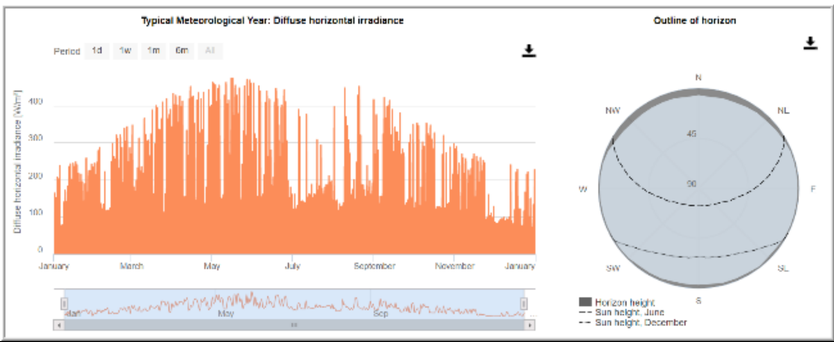
FRONT side</td>
<td>
</td>
</tr>
<tr>
<td>EAST/WEST BALLUSTRADES MODULES

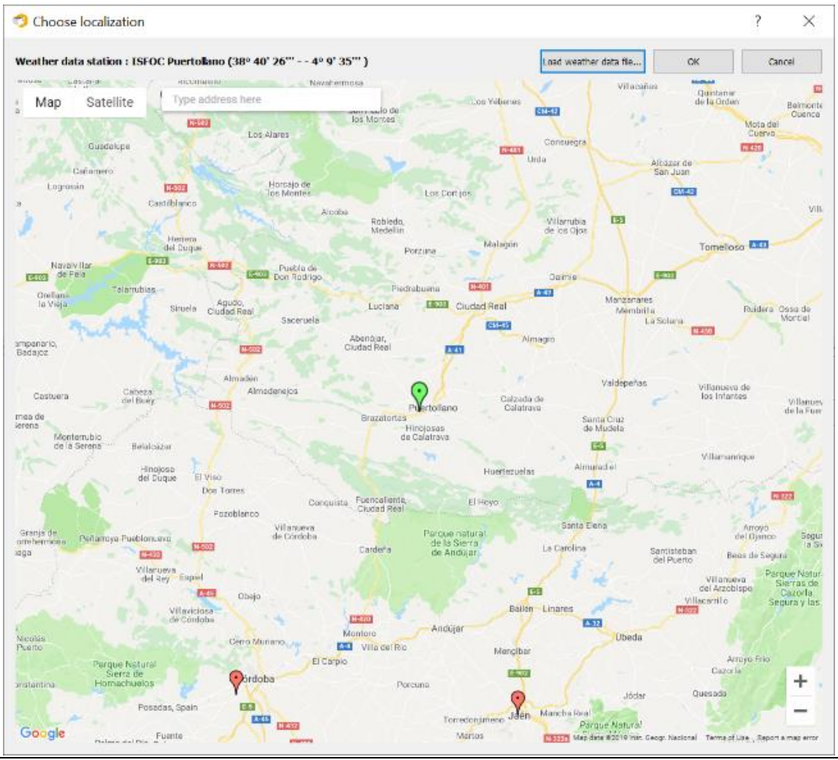
FRONT side</td>
<td>
</td>
</tr>
</table>

2.7.3.4 Weather data and Irradiation modelling

We chose to use the European open access reference tool PVGIS to generate meteorological and site data at the exact location of the demo site. Visualization from satellite enable considering terrain modelling, albedo evaluation and masking effects.

GEO LOCATION → Google Maps → PVGIS	
ALBEDO → 50% for surroundings	 
ORIENTATION → -15° (EAST)	

HORIZON IN PLANE IRRADIATION for typical 35° PV angle ➔ No masking for PV production	
IRRADIANCE TMY data from PVGIS© to generate weather file as input for BIMsolar (epw import format) TMY Period: 2007-2016 Time step: hourly	  

BIMsolar epw importation	

2.7.3.5 3D modelling – setup – existing building

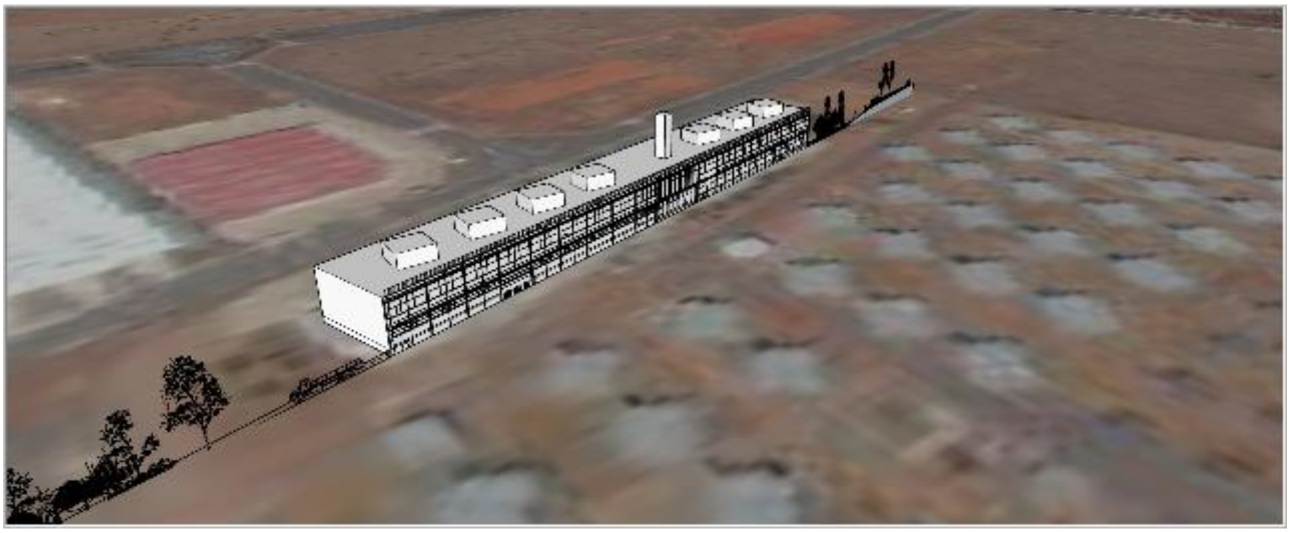


Figure 2.42 Modelling has been made as much realistic as it could be from the existing 2D plans to address BIPV issues (Trimble SketchUp model from EnerBIM)

STEP#1- BIMsolar IMPORTATION – Building settings

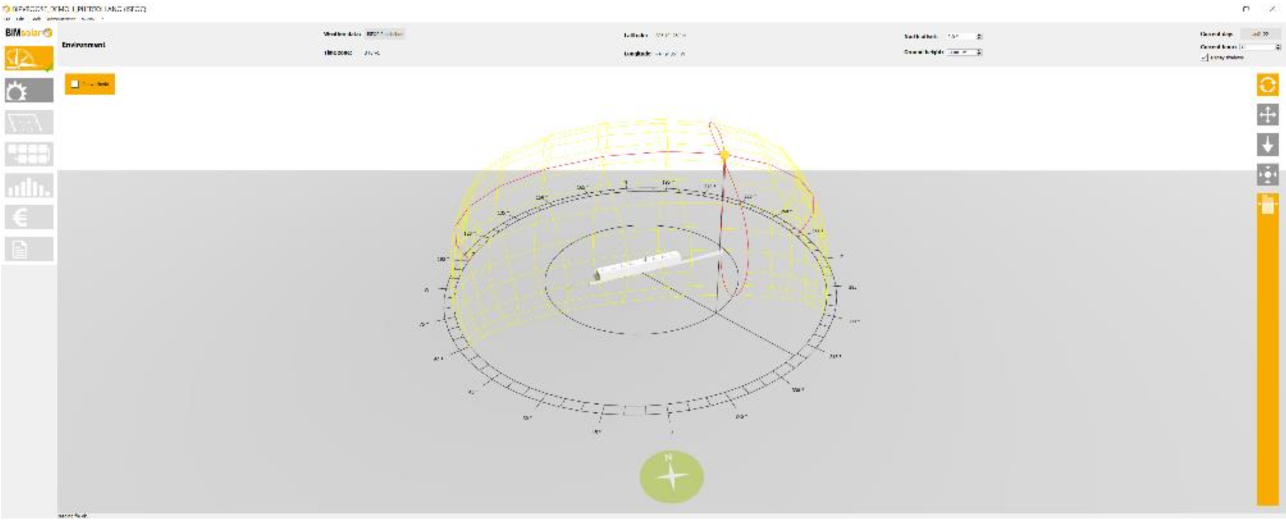


Figure 2.43 Close and far shadowing calculation are made through 3D modelling of realistic buildings - Sun course for full year is displayed at hourly step time

Figure 2.44 Albedo effects (reflected irradiance) are generated selecting groups and types of surfaces 50% as a setup for surroundings and for the building envelop as a general approach

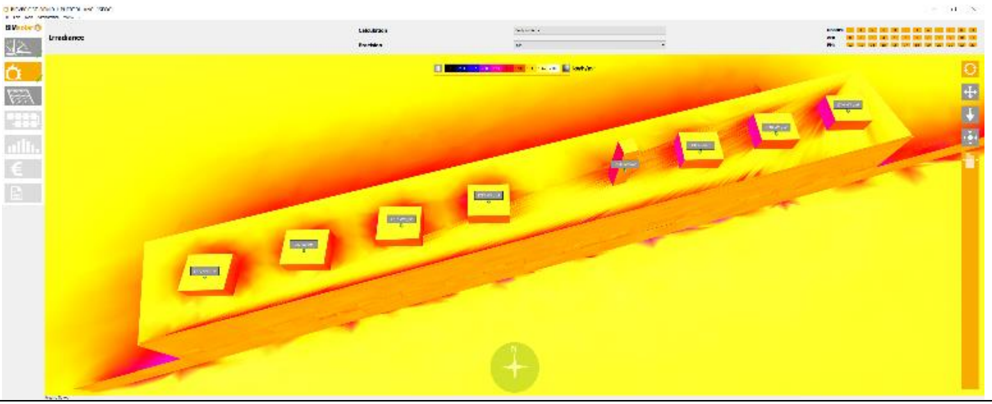
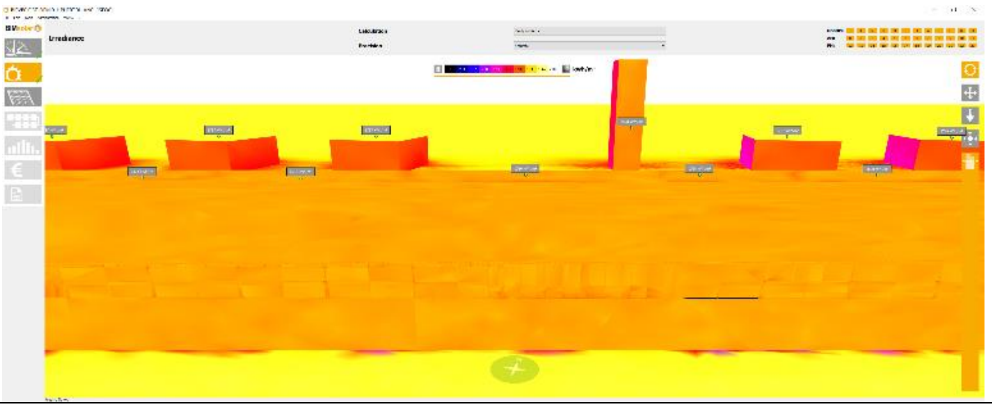
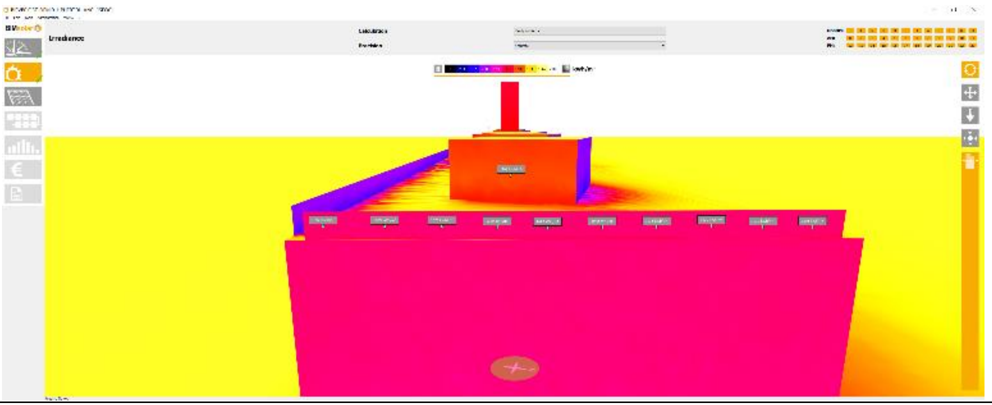
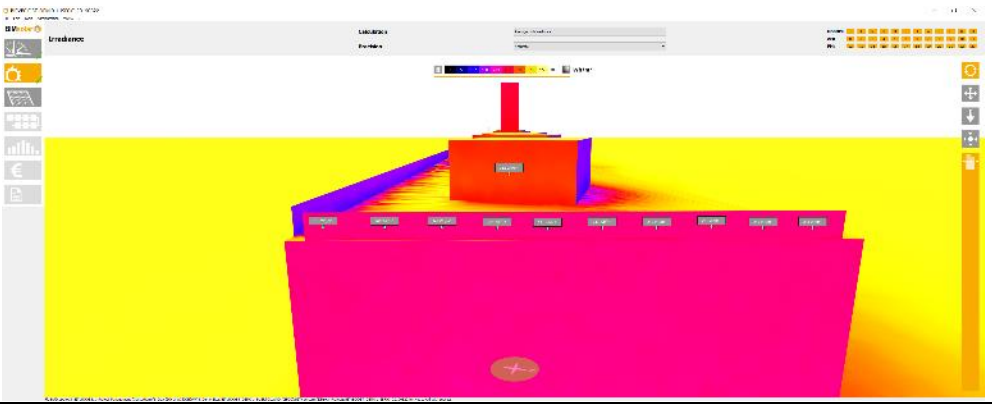
2.7.3.6 Simulation – Results

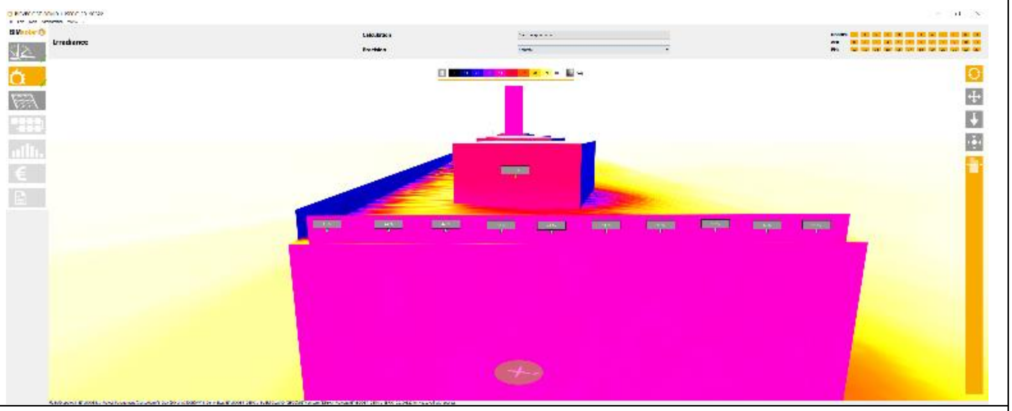
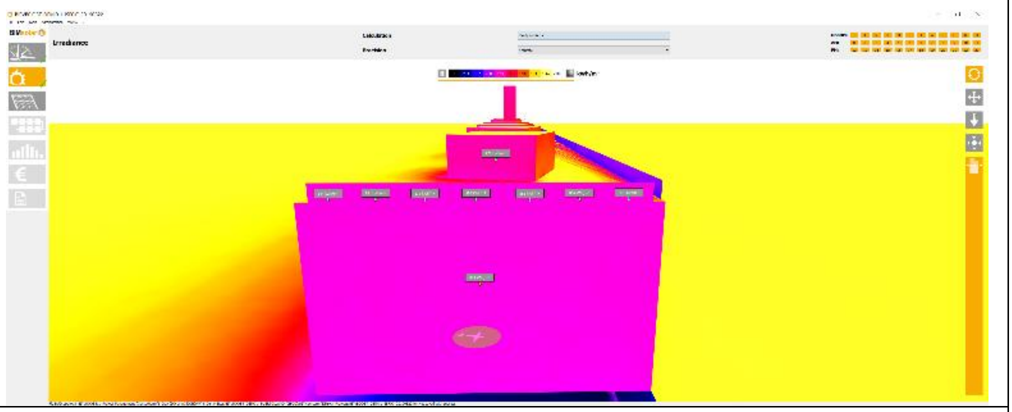
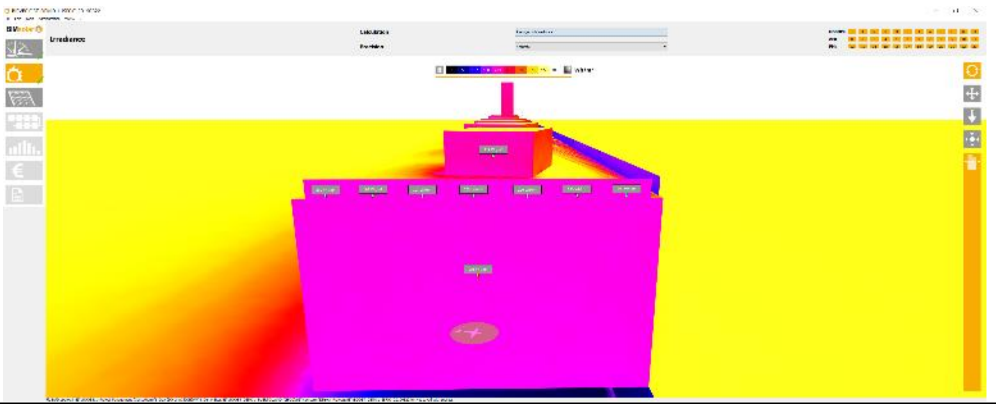
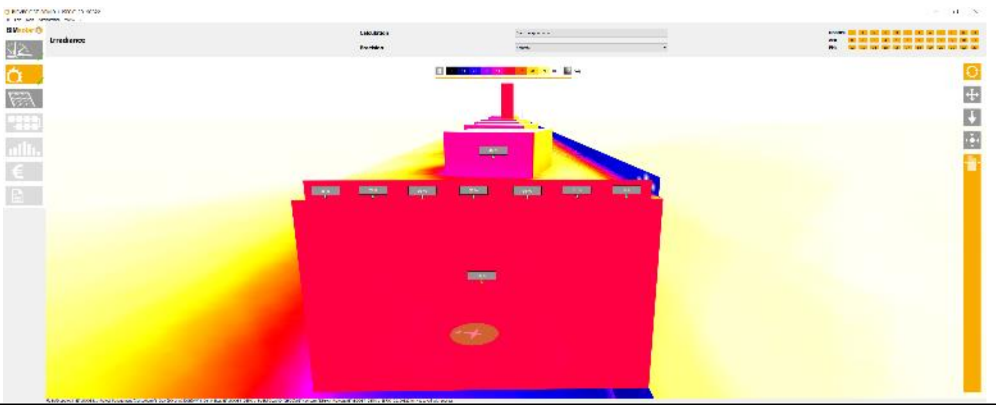
STEP#2-IRRADIATION

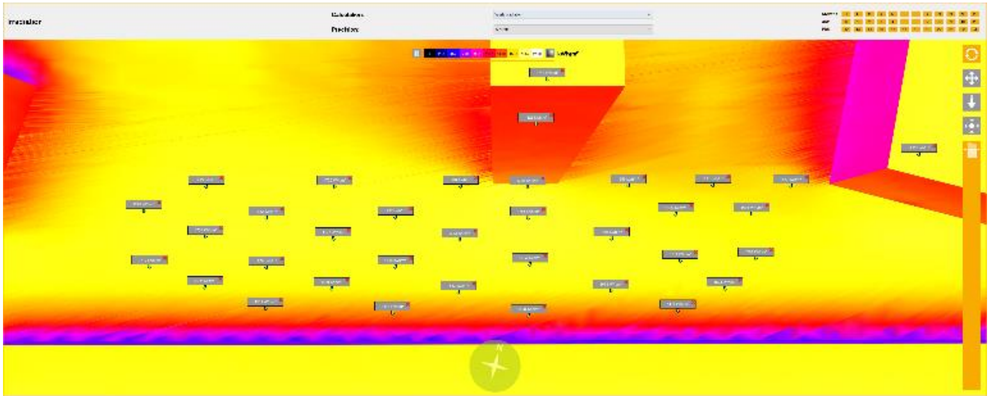
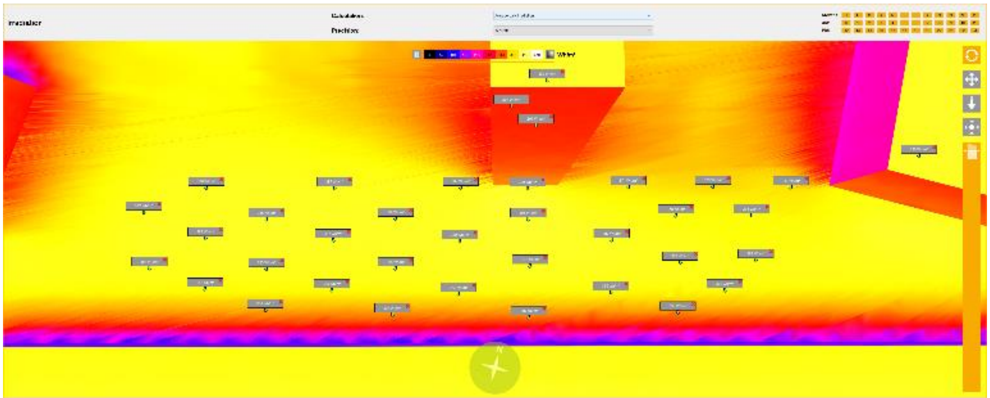
We perform simulation of irradiance with BIMsolar raytracing algorithms to deliver irradiation 3D mapping.

We use markers to record and visualize values.

Sets of data can be exported in CSV files.

Global survey on horizontal surfaces + vertical south Yearly kWh/sqm	
South balustrade Yearly →1515 kWh/sqm recorded	
East balustrade Yearly →1070 kWh/sqm recorded	
East balustrade Average day →240kWh/sqm recorded	

East balustrade Direct ratio →44% recorded	
West balustrade Yearly →880 kWh/sqm recorded	
West balustrade Average day →200kWh/sqm recorded	
West balustrade Direct ratio →55% recorded	

Roof floor Yearly survey 1700 kWh/sqm recorded as average value on the targeted area	
Roof floor Daily survey 385 kWh/sqm recorded as average value on the targeted area	

STEP#3 – BIPV layouts

We use virtual modules set-up from manufacturer's datasheets (see above) to generate BIPV systems. Production, shading losses, temperature losses are calculated in real time from module level to BIPV layout level. Every single module is computed as a system and the software displays individual KPIs.

Detailed results can be obtained at STEP#5 (BIMsolar reference process).

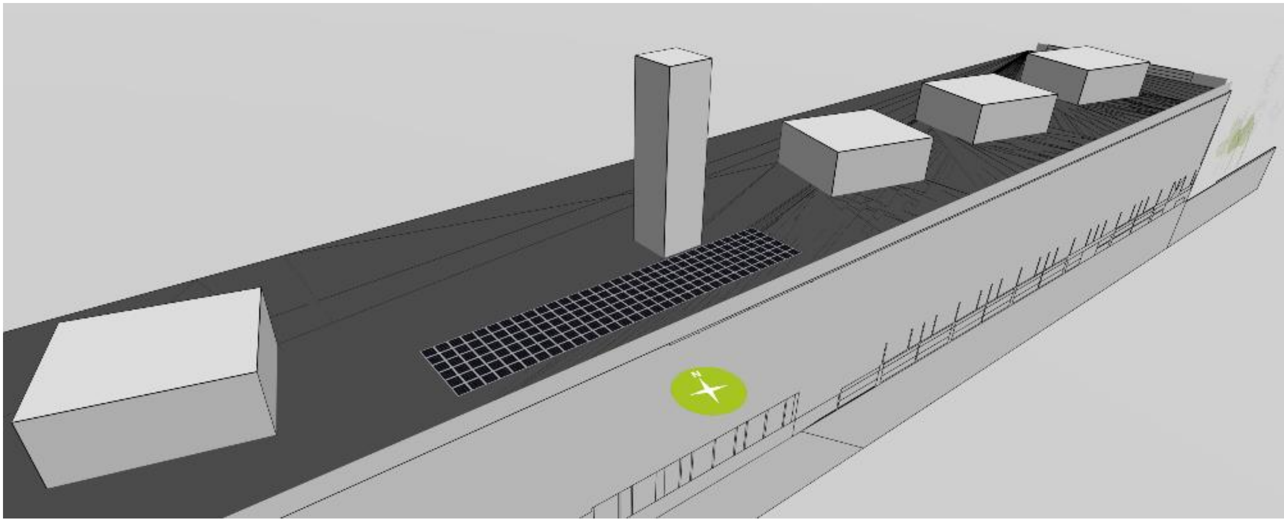


Figure 2.45 c-Si walkable floor=192 modules – Total 9.2kWp / 69.1sqm

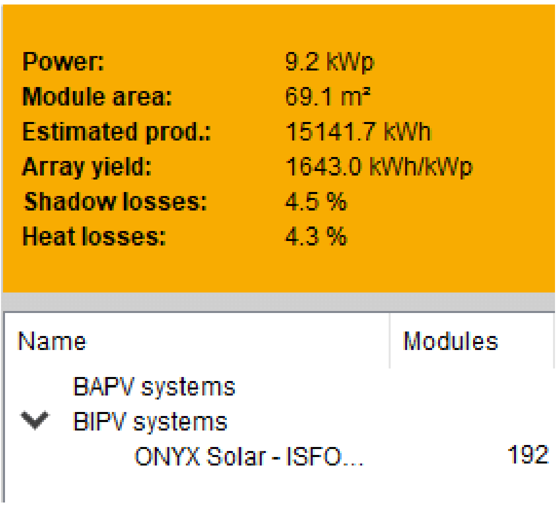


Figure 2.46 Global results at array level – Year#1 - Walkable floor layout

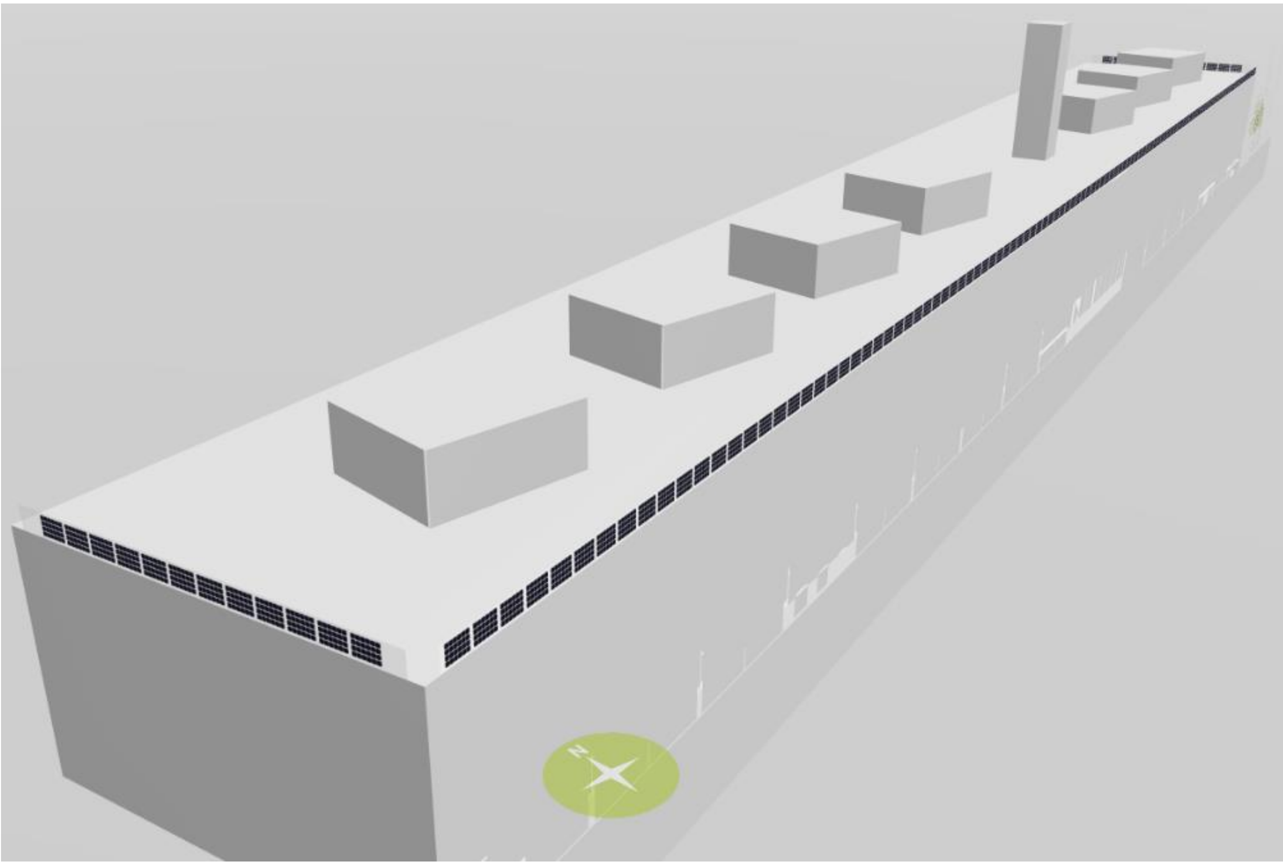


Figure 2.47 Bifacial c-Si south balustrade= 108 modules; bifacial c-Si east + west balustrade= 24 modules – Total 12.8kWp / 125.6sqm

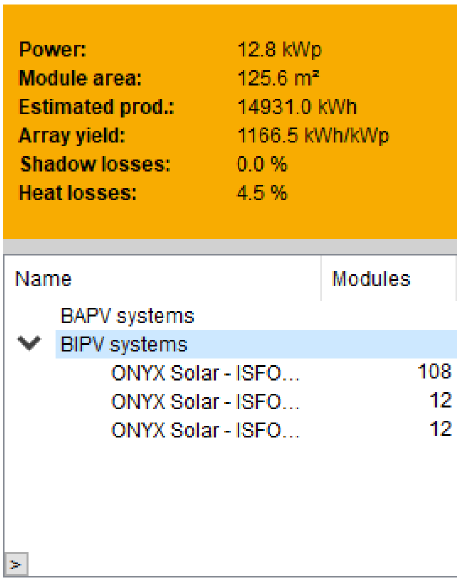


Figure 2.48 Global results at array level – Year#1 - Balustrades layouts

Handling a specific layout is possible as a 'What If' analysis: it was used for the walkable floor to size the shading effects due to the relating position towards the south balustrade. The 'What if' analysis is aimed at supporting design options so we can learn how to mitigate mismatching of irradiance between modules by optimization of the placement of the full array. Then the string strategy is influenced: zoning and selection of groups of modules by irradiance level / expected shading. The choice of the inverter(s) is also supported, as well as cost optimisation together with energy production (in this case 1 single inverter with 2 MPPTs / 4 strings)"

Detailed shading effects are visualized in real time:

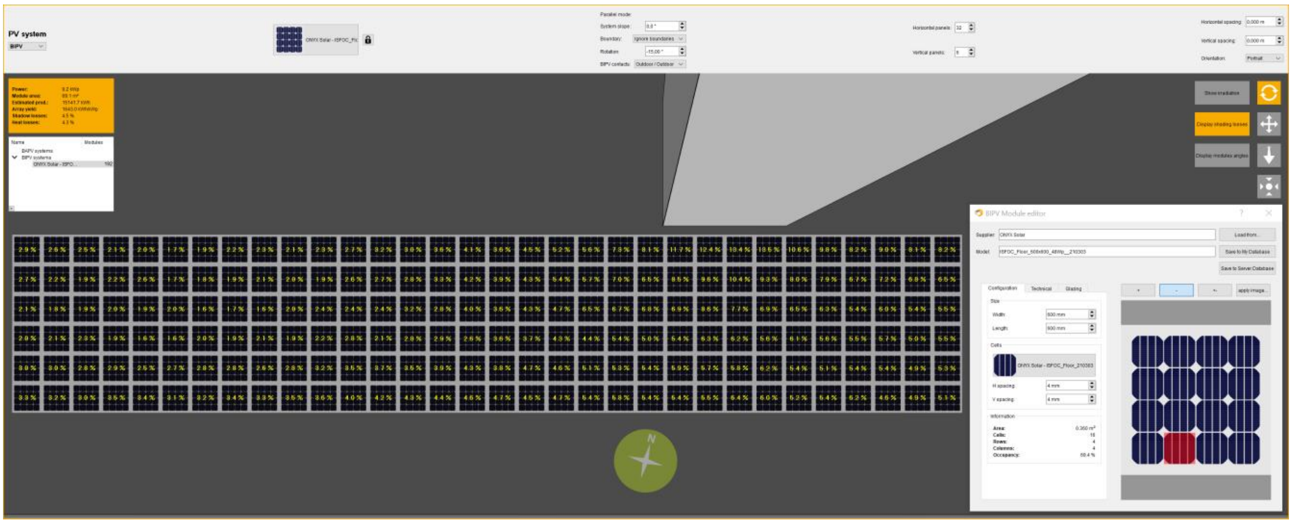


Figure 2.49 Shading computation: walkable floor – Highest losses=13.5% (module 26-6)

STEP#4 – INVERTERS / WIRING

This step consists in building the best strategy for the implementation of inverters and connect to them the strings of modules to optimise the DC and AC productions.

BIMsolar enables considering the mismatching between modules (gaps in irradiance due to shading effects), then proposes the best wiring configuration for each MPPT to maximise the energy production.

Electrical layout specifications from ISFOC:

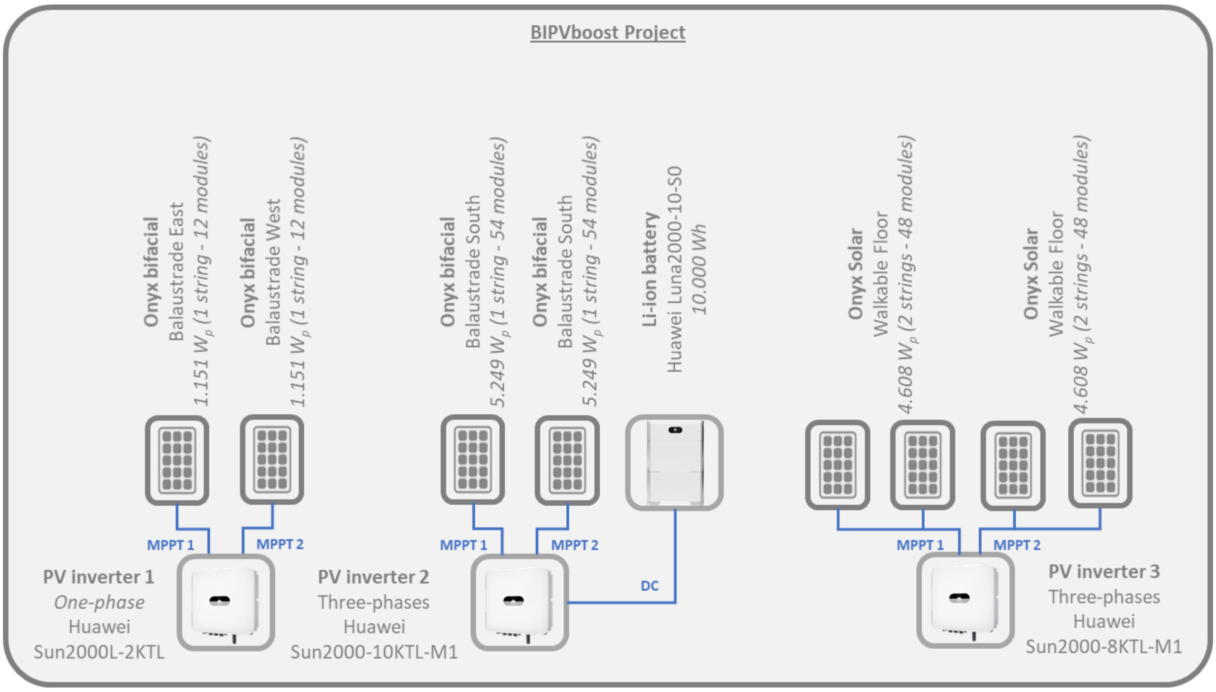


Figure 2.50 Electrical layout

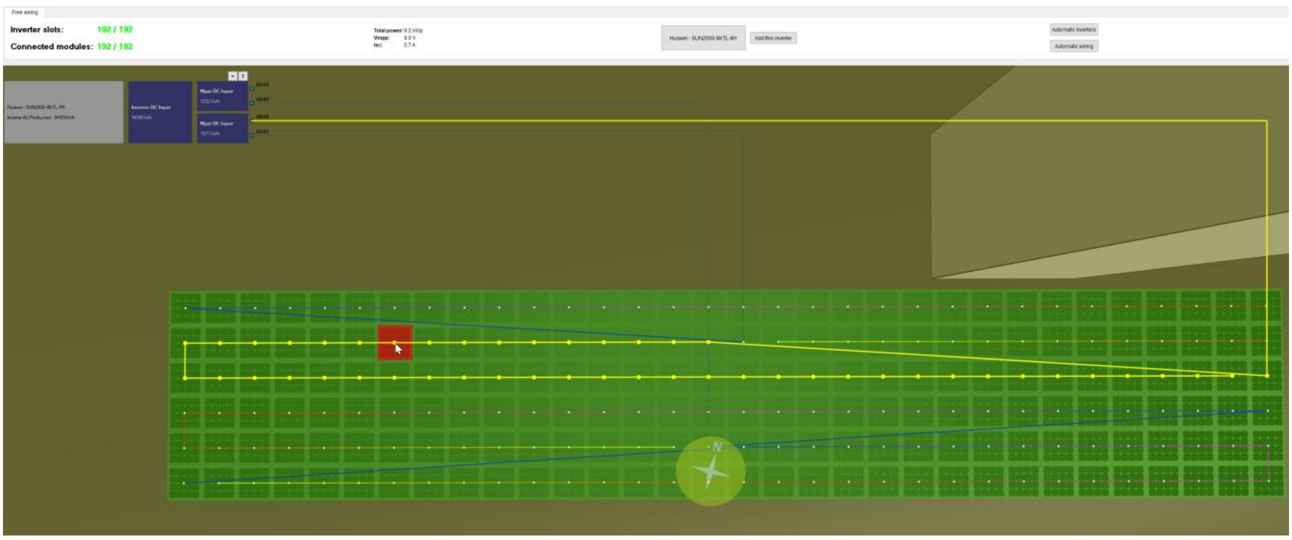


Figure 2.51 INVERTERS and strings configuration in BIMsolar – Walkable floor

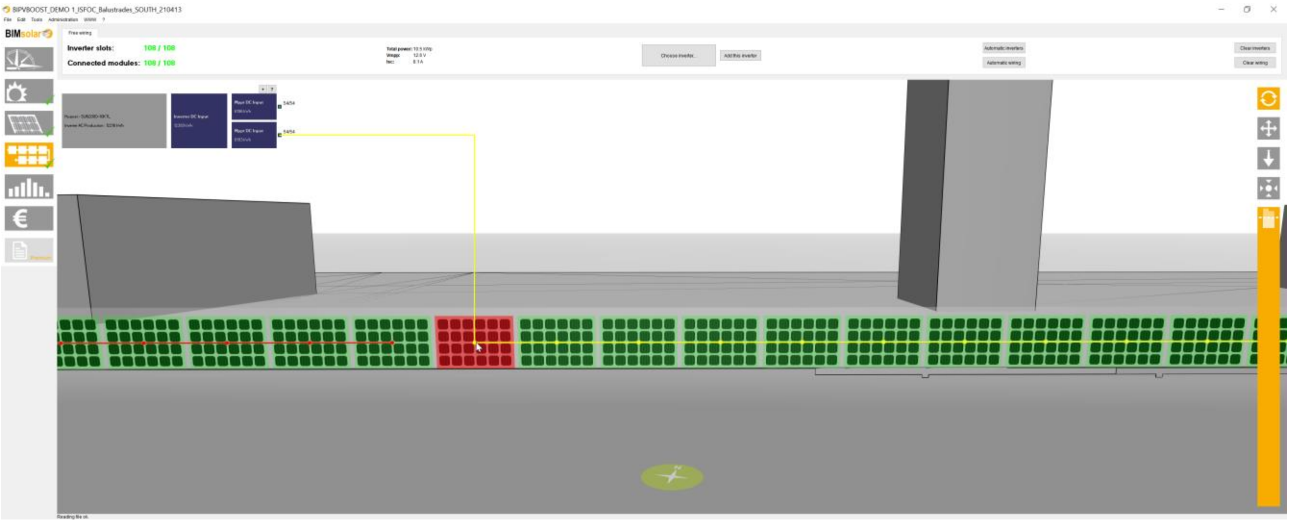


Figure 2.52 INVERTERS and strings configuration in BIMsolar – South balustrade

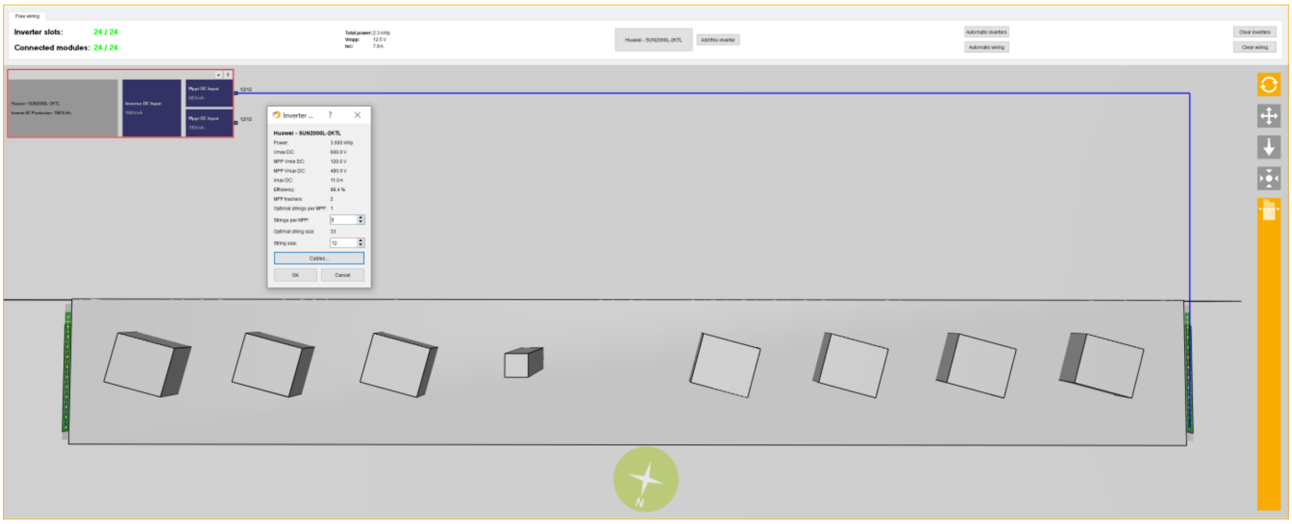


Figure 2.53 INVERTERS and strings configuration in BIMsolar – East & West balustrades

STEP#5 – RESULTS

BIMsolar offers a comprehensive set of detailed results, from yearly to hourly timestep, covering irradiance, shading losses, heat losses, production, yield… from module level to layout level.

Examples:

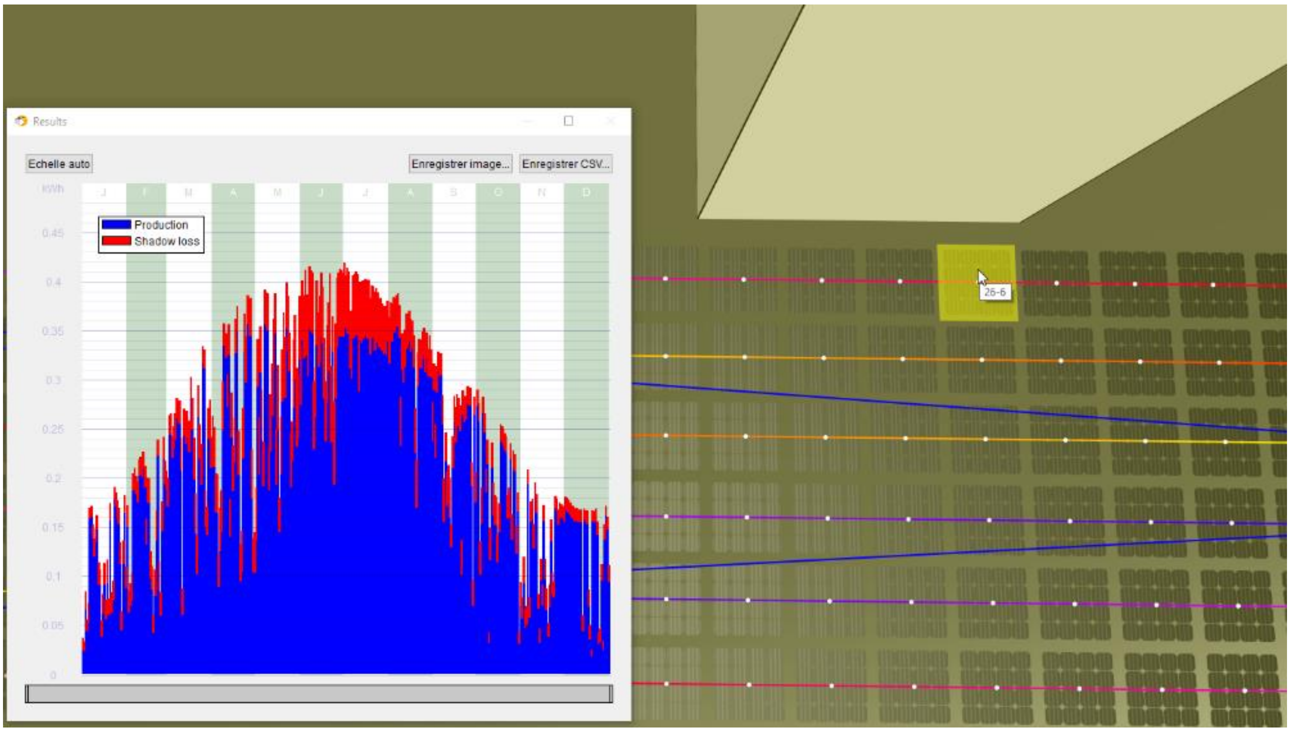


Figure 2.54 PV generation *+ shading: walkable floor (module 26-6)*

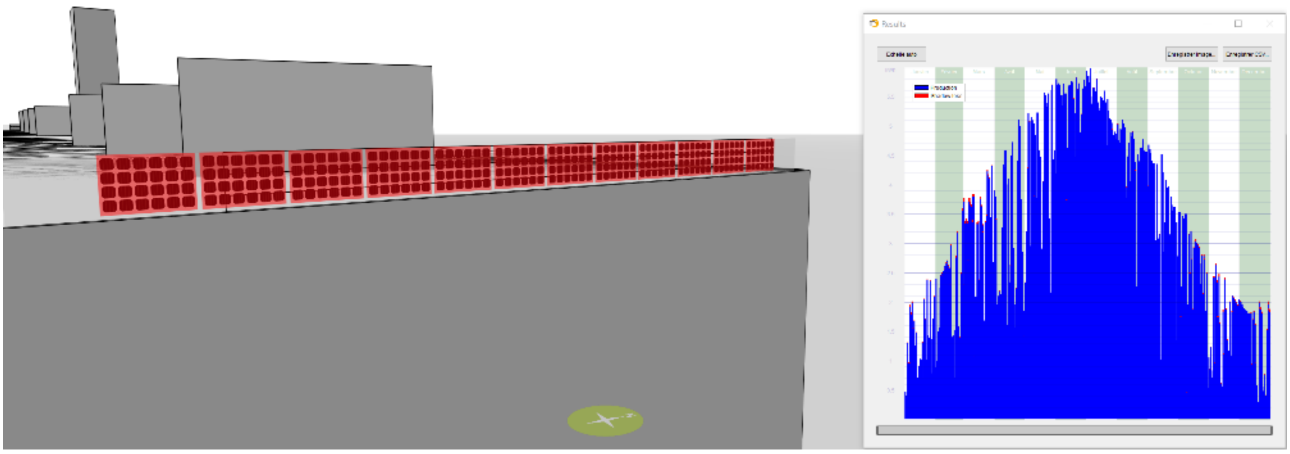
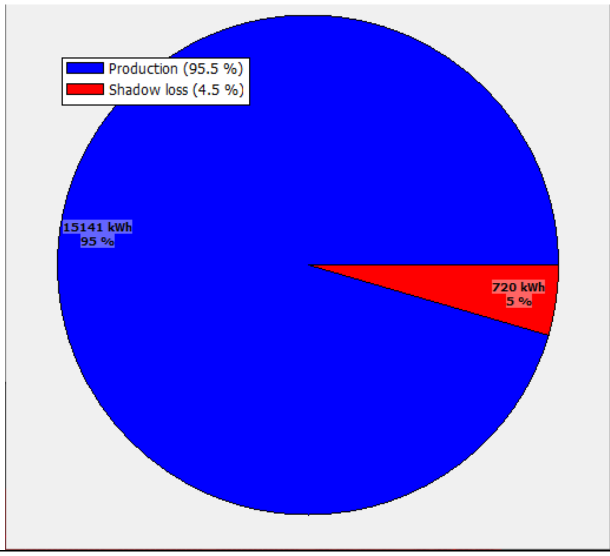
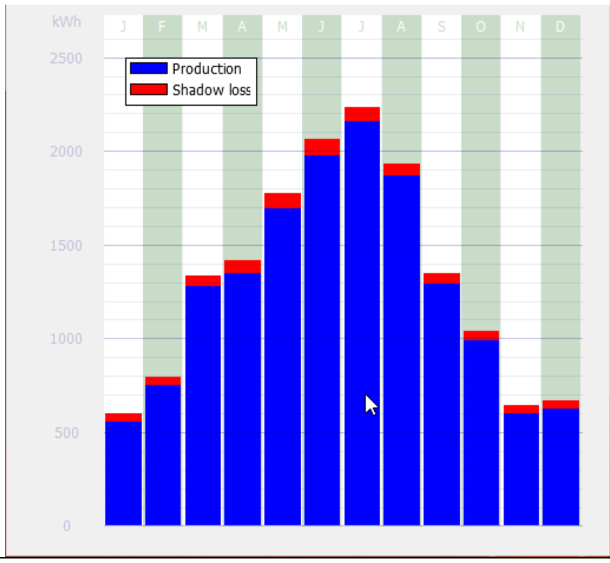
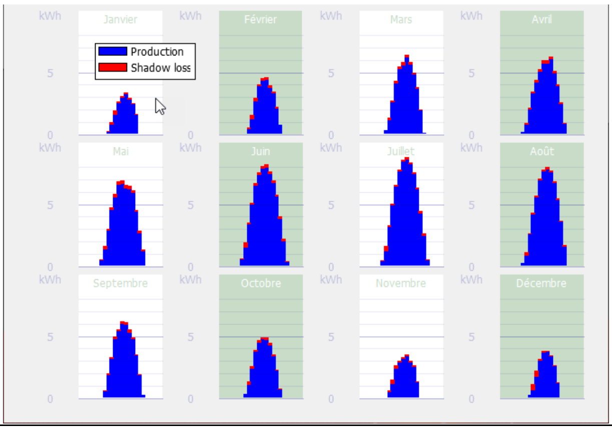
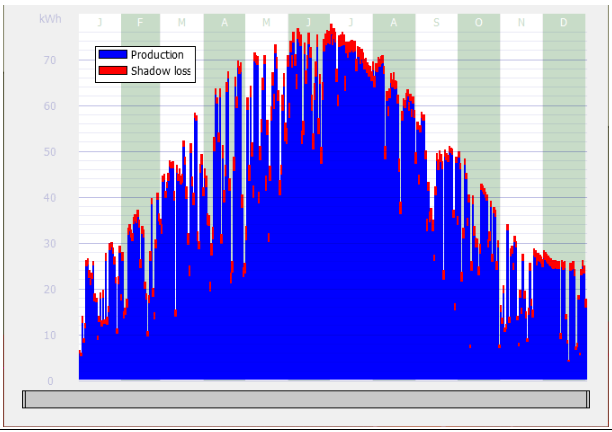
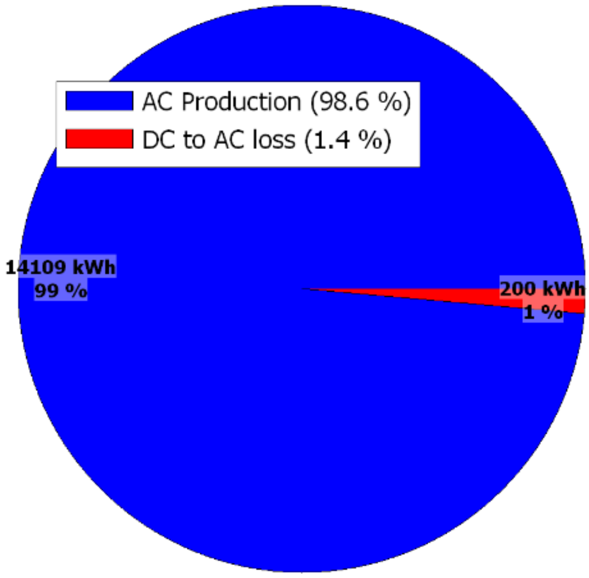
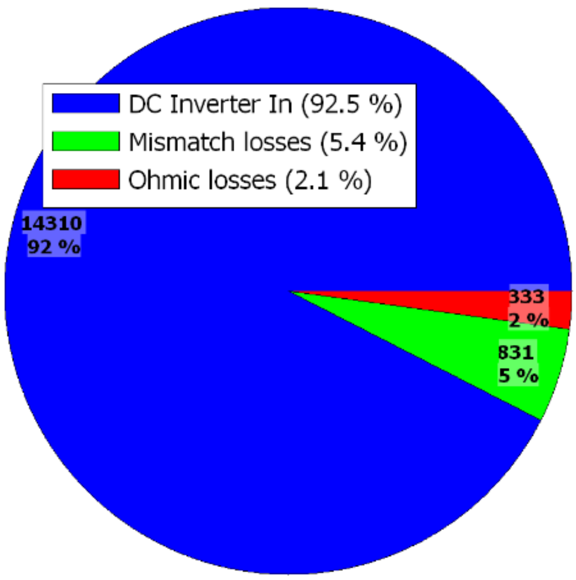


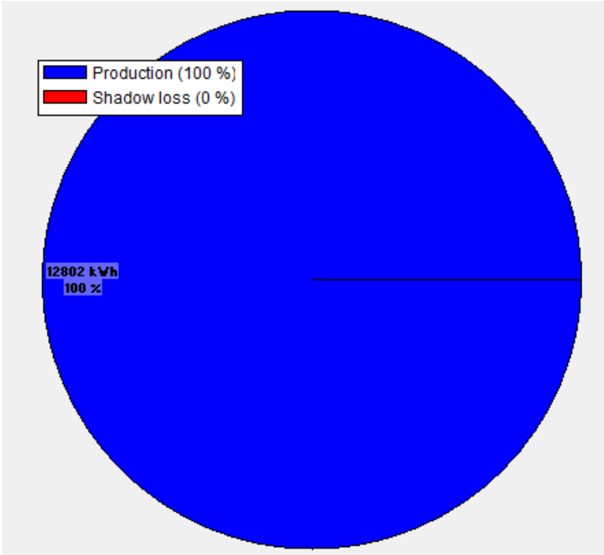
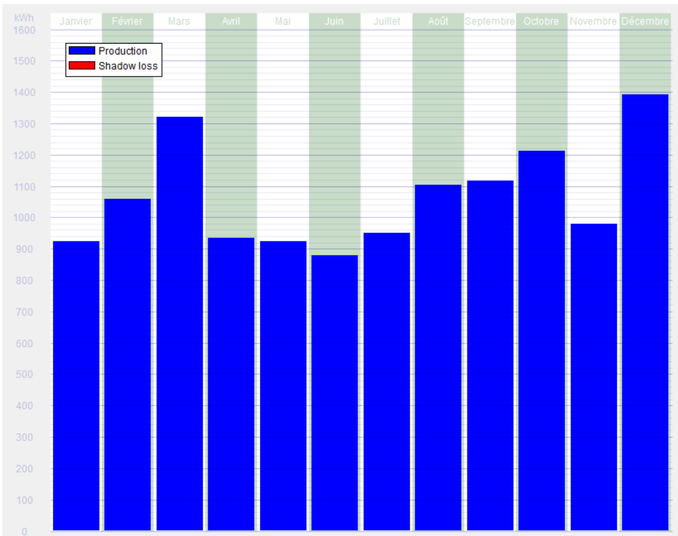
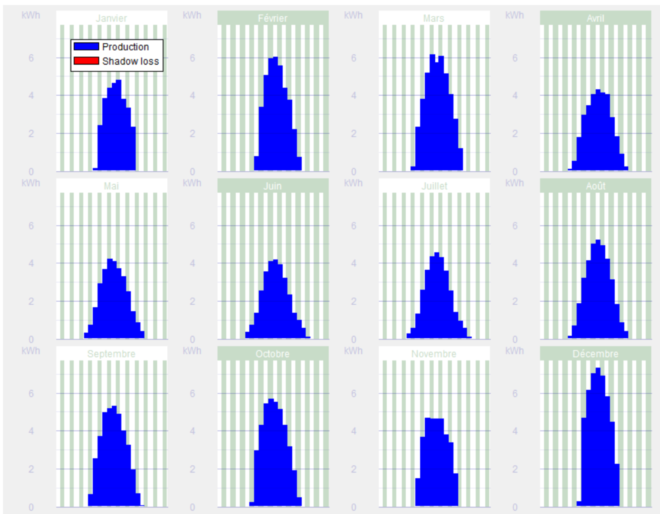
Figure 2.55 PV generation *+ shading: East balustrade (module 3-1)*

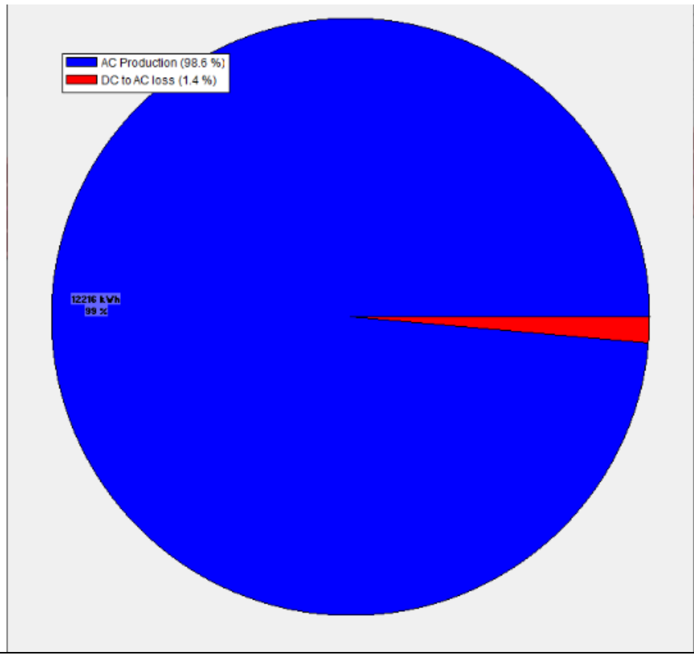
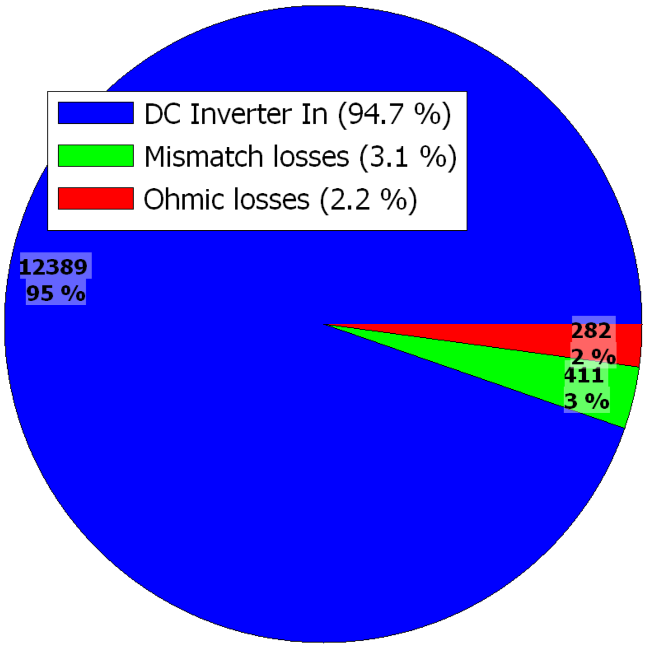
WALKABLE FLOOR - Table of results:

<table>
<tr>
<td>PV Generation – Shading losses
GLOBAL – YEAR #1</td>
<td>
</td>
</tr>
<tr>
<td>PV Generation – Shading losses
MONTHLY</td>
<td>
</td>
</tr>
<tr>
<td>PV Generation – Shading losses
AVERAGE DAY / MONTH</td>
<td>
</td>
</tr>
</table>

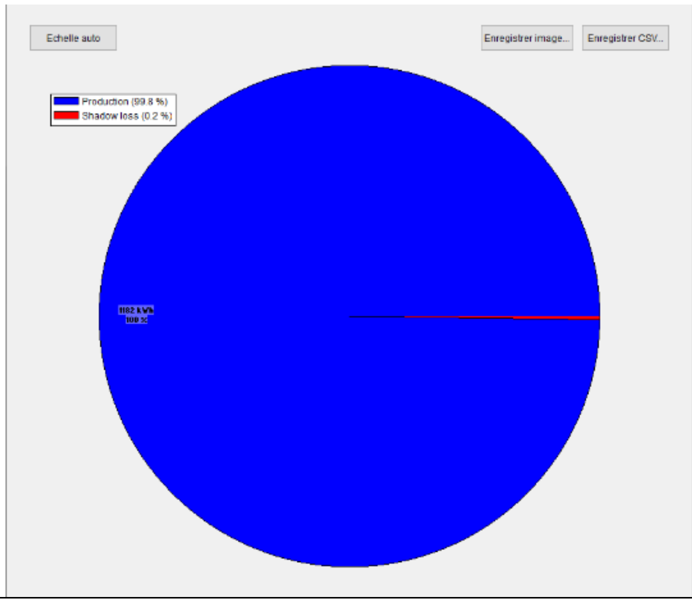
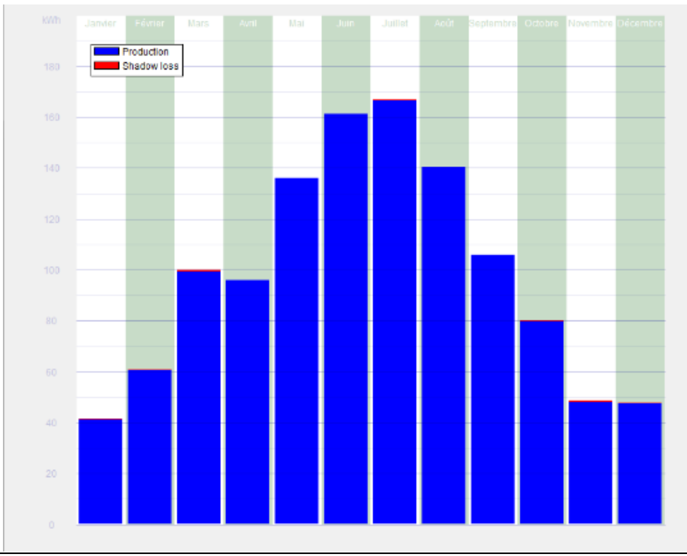
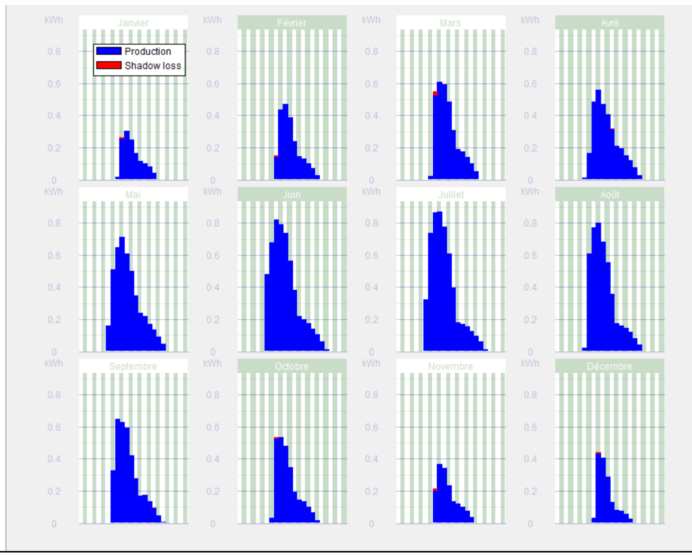
PV Generation – Shading losses DAILY	
AC Production (Inverter Out) – AC/DC ratio GLOBAL Final yield = 1531kWh/kWp	
Electrical Losses (Inverter OUT) GLOBAL	

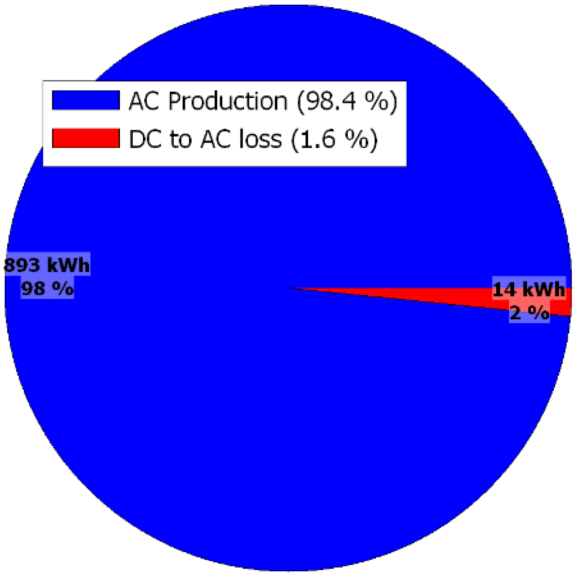
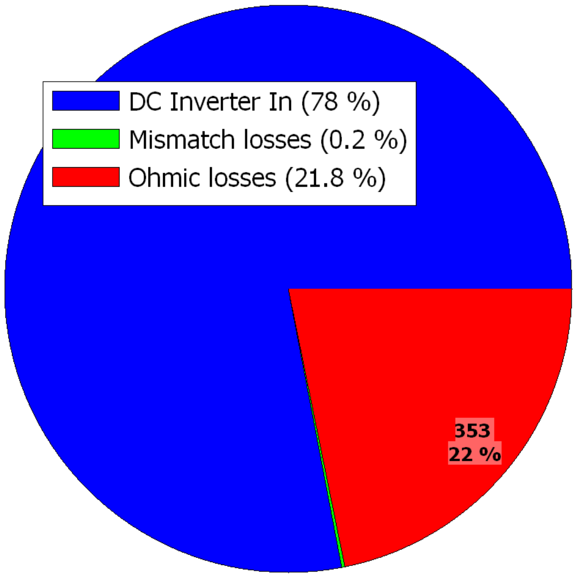
SOUTH BALUSTRADE - Table of results:

PV generation – Shading losses GLOBAL – YEAR #1	
PV Generation MONTHLY	
PV Generation AVERAGE DAY / MONTH	

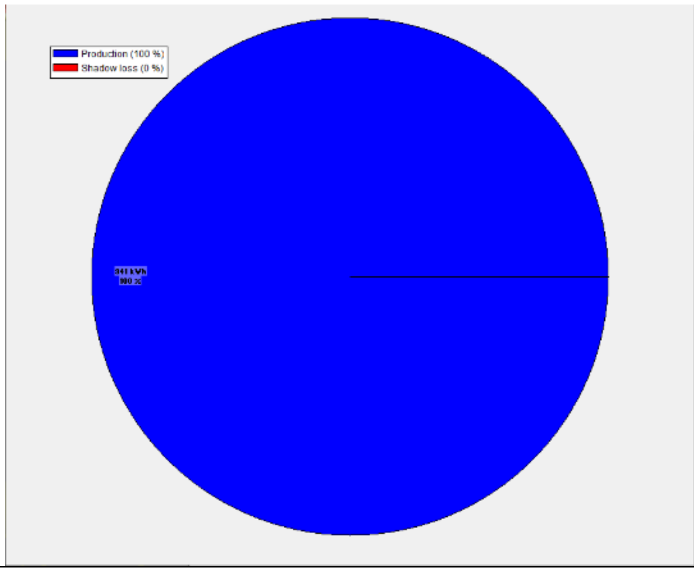
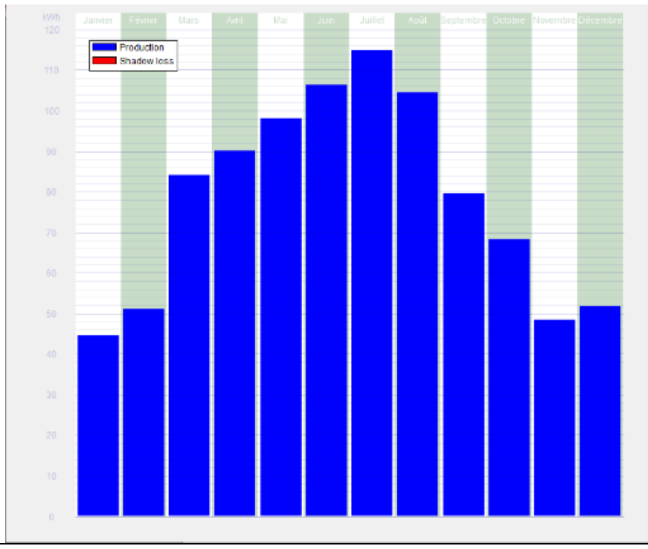
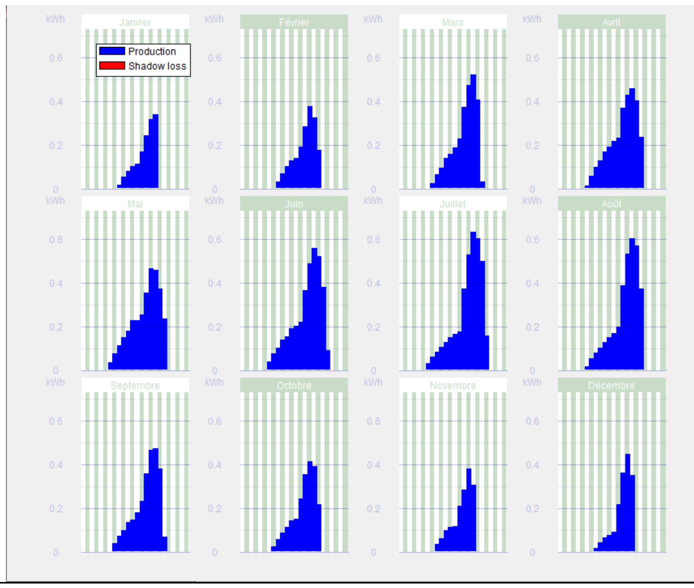
AC/DC Production GLOBAL – YEAR #1 FINAL YIELD (Inverter Out) 1163 kWh/kWp	
Electrical Losses (Inverter OUT) GLOBAL	

EAST BALUSTRADE - Table of results:

PV generation – Shading losses GLOBAL – YEAR #1	
PV Generation MONTHLY	
PV Generation AVERAGE DAY / MONTH	

AC/DC Production GLOBAL – YEAR #1 FINAL YIELD (Inverters Out) 776 kWh/kWp	
Electrical Losses (Inverter OUT) GLOBAL	

WEST BALUSTRADE - Table of results:

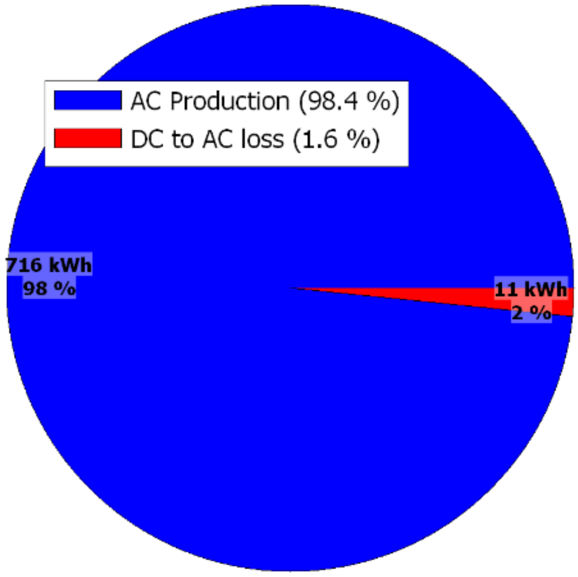
PV generation – Shading losses GLOBAL – YEAR #1	
PV Generation MONTHLY	
PV Generation AVERAGE DAY / MONTH	

AC/DC Production

GLOBAL – YEAR #1

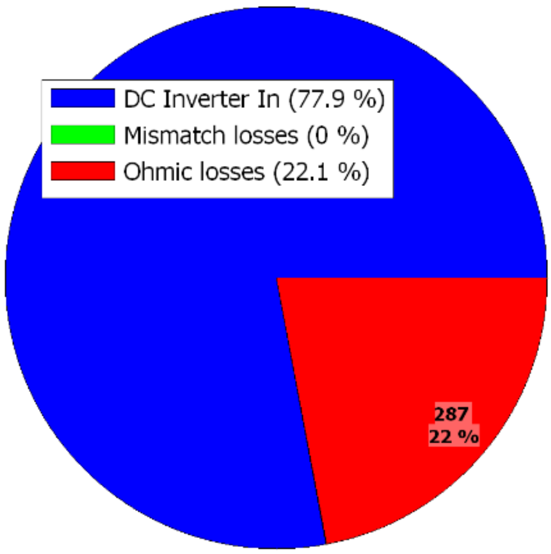
FINAL YIELD (Inverters Out)

662 kWh/kWp



Electrical Losses (Inverter OUT)

GLOBAL



2.7.4 Summary of the results

		Array							
Unit	kWh						°	kWh	
	Irradiation					Panel orientation		PV generation	
		Floor	South Balustrade	East Balustrade	West Balustrade		Azimut*	Floor	Balustrades
	Direct	77 537	82 409	6 987	4 745	East	-105		1 182,8
	Diffuse	37 409	31 102	3 386	3 323	South	-15,0	15 141,7	12 801,7
	Indirect	3 731	17 883	1 772	1 816	West	75,0		941,0
		118 677,0	131 394,0	12 145,0	9 884,0	*South = 0°		15 141,7	14 925,5
TOTAL:	272 100,0							30 067,2	

	Inverters								YIELD	
Unit	kWh		kWh	kWh	%	%	kWh		kWh/kWp	
	DC inverter IN		Losses				AC inverter OUT		AC inverter OUT	
	Floor	Balustrades	Floor	Balustrades	Floor	Balustrades	Floor	Balustrades	Floor	Balustrades
Direct		907,0		17		1,9%		893		776
Diffuse	14 310,0	12 389,0	201,0	173,0	1,4%	1,4%	14 109	12 216	1 531	1 163
Indirect		728,0		12,0		1,6%		716		622
	14 310,0	14 024,0	201,0	202,0	5%	5%	14 109,0	13 825,0	1 531,0	853,7
TOTAL:	28 334,0		403,0				27 934,0			

2.7.5 Conclusions

At the current stage of the performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are positive and converging towards expectations.

In particular:

- The impact of albedo is promising to consider the BIPV floor layout: gains for reflected irradiance from the tower enable to maintain a correct yield for the modules below this close obstacle,
- The balustrades have no shading losses and receive reflected irradiance from the ground,
- Spring, autumn months and December are profitable for the south balustrade.

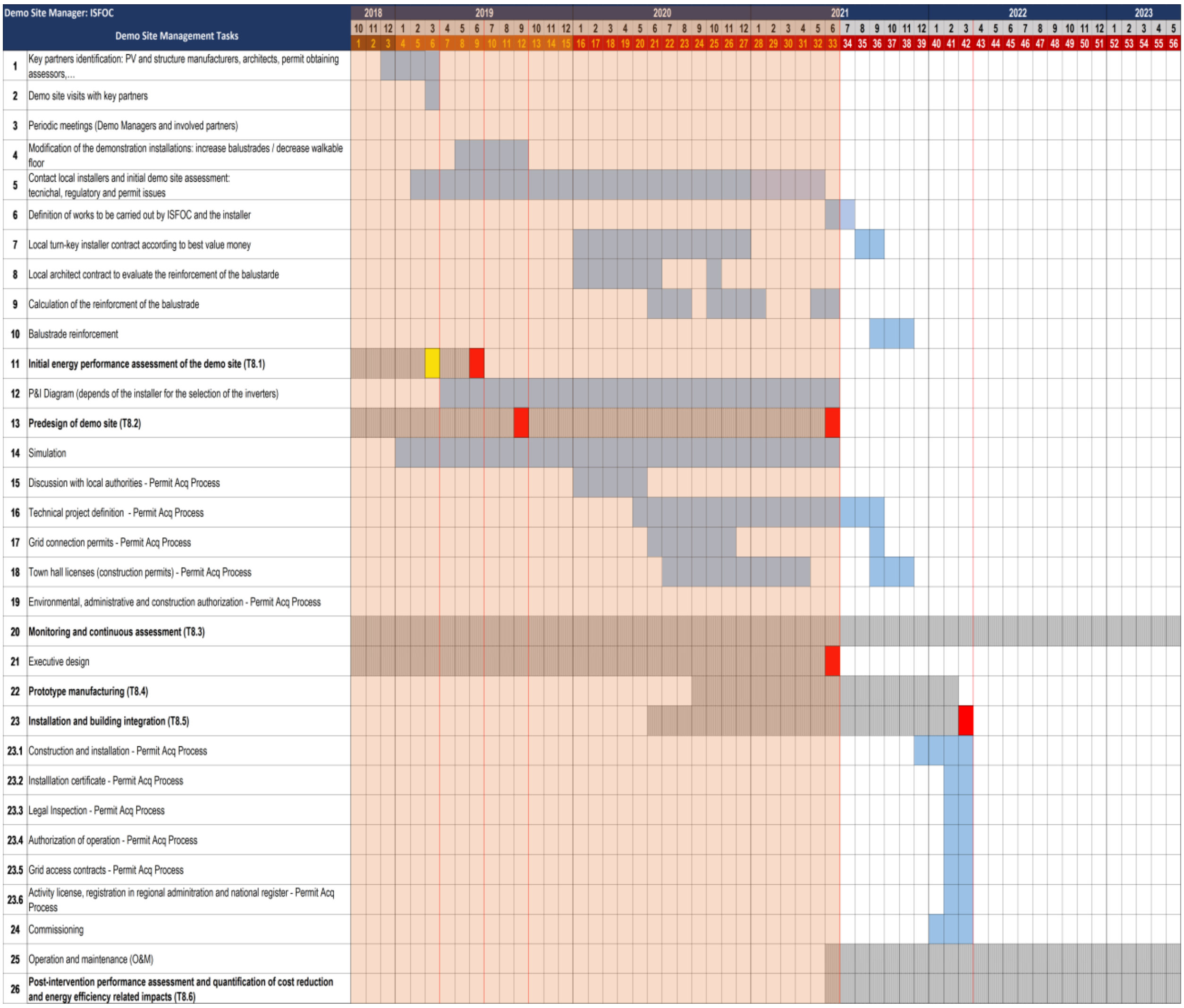
We did not face critical difficulties in the process except difficulties in converting 2D plans into 3D model (geometrical issues to get a readable 3D mesh).

Considering bifacial gains, we could not proceed with proper simulation in this phase because of missing parameters. But we could assume that a gain in production outcomes between 15% and 25% is realistic.

Next steps will be:

1. Update of the building 3D model, related to final BIPV integration (demo site manager),
2. Implementation of BIFACIAL simulation (rear irradiance calculation on every single cell depending on elevation and orientation is crucial to perform reliable computation) with bifacial outcomes and settings from the testing phase of the modules,
3. BIM upgrade of the modules following ONYX Solar and ISFOC specifications, to enable technical design of the system,
4. Comparison between measurement and simulation as soon as the real modules will be integrated and monitoring available.

2.8PLANNING TIMELINE



3 DEMO SITE 2: MASS

3.1 DEMO-SITE BUILDING DESCRIPTION

MASS demo site, located in Aretxabaleta (Spain), corresponds to the headquarters and factory of Mondragón Assembly. The building is connected to the general electrical grid and PV panels are already installed on the roof with nominal power of 100kW.

Figure 3.1: Google maps top view of the factory.

3.1.1 General topology

The building, an industrial pavilion, is divided into two different factories, the external dimensions of the MASS factory are 103,4 m long and between 51 and 66,6 m wide resulting in a ground floor area of about 5700 m^2. From those 5700 m^2, 790 m^2 are divided in three heights where the offices are located, the remaining 4.910 m^2 is a workshop with a height between 11 and 12 meters.

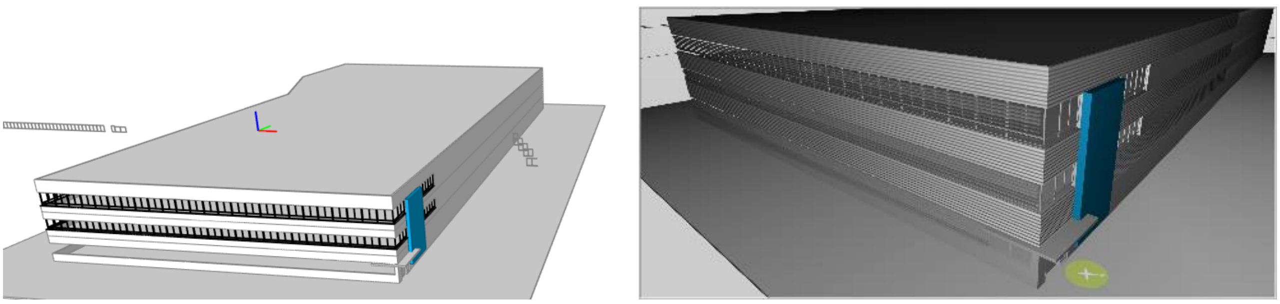


Figure 3.2: CAD rendering of the pavilion.

3.2 ARCHITECTURAL BIPV DESIGN

The BIPV installation will partially cover the South-East façade of the building. The solution will consist of glass-glass panels and c-Si technology, manufactured by Onyx, using the line developed by MASS within WP2. The BIPV modules will be installed using Tulipps' lock-&-go mounting system.

Figure 3.3: East façade of MASS building

For this demo, the final design has been selected between two different configurations, 1 with 114 panels of 2mx0.667 m and another composed of 228 panels of 1.02m x 0.667 m.

Demo 2	
MASS	
SCEN. 1 2m panels	**SCEN. 2** 1,02m panels
Glass-glass c-Si modules with different configurations (ONYX). Façade structure (TULIPPS)	
Ventilade façade	
SE	
152 m^2	155 m^2
21,6 kWp	22,2 kWp

Figure 1.4 Different configurations for Demo2

Since both designs, the 2 m panel and the 1.02 m panel, met the project specifications and met what MASS as the final owner required in aesthetic and production terms, the decision to select the design of 2m panels was taken, due to the fact that the economic valuation raised both by the local installer and by the project partners, was more economical than the option of 1.02 m panels.

Turn-key installation quotation for a demo-site				
		Scenario 1,02 m (4+4)	Scenario 2m (6+6)	Scenario 2m (4+4) ***
1. Materials			Price [€]	Price [€]
1.1	Fastening and mounting system	29.302,00 €	20.817,00 €	20.475,00 €
1.2	BIPV modules	50.651,20 €	53.378,30 €	42.309,12 €
1.3	Cabling	1.200,00 €	1.200,00 €	1.200,00 €
1.4	Inverters	4.750,00 €	4.750,00 €	4.750,00 €
1.5	Monitoring system			
1.6	Electrical installation materials	3.100,00 €	3.100,00 €	3.100,00 €
1.7	Battery System	6.200,00 €	6.200,00 €	6.200,00 €
MATERIALS SUBTOTAL		95.203,20 €	89.445,30 €	78.034,12 €
2. Labor		Price [€]	Price [€]	Price [€]
2.1	Permit obtaining	2.500,00 €	2.500,00 €	2.500,00 €
2.2	Detailed Executive Project	9.000,00 €	9.000,00 €	9.000,00 €
2.3	Structural and mechanical installation	66.500,00 €	66.500,00 €	66.500,00 €
2.4	Electrical installation	5.500,00 €	5.500,00 €	5.500,00 €
2.5	Certification of the installation	8.500,00 €	8.500,00 €	8.500,00 €
2.6	Operation and Maintenance (optional)	0,00 €	0,00 €	0,00 €
LABOR SUBTOTAL		92.000,00 €	92.000,00 €	92.000,00 €
TOTAL TURN-KEY INSTALLATION:		187.203,20 €	181.445,30 €	170.034,12 €

Figure 1.5 Economic table for different options of Demo2

With those data the selected option is the variant 38 designed by Viriden, from now on “demo 2 selected design”.

3.2.1 Demo 2 selected design

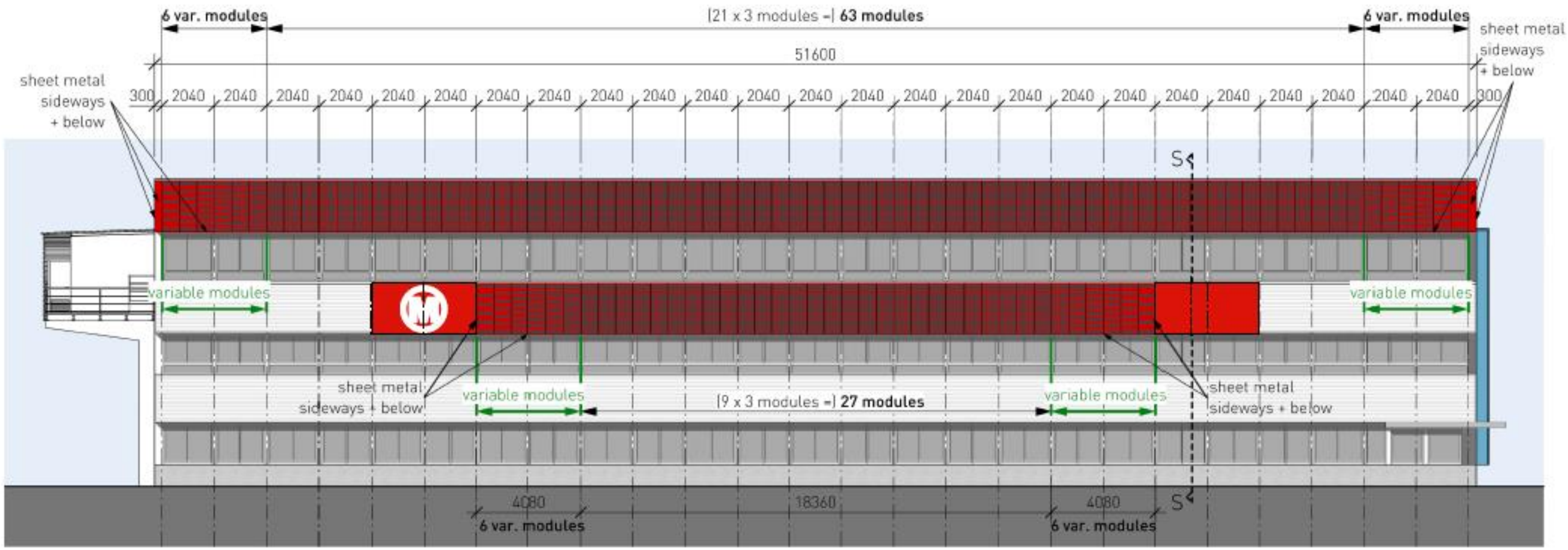


Figure 3.6: Demo 2 final design

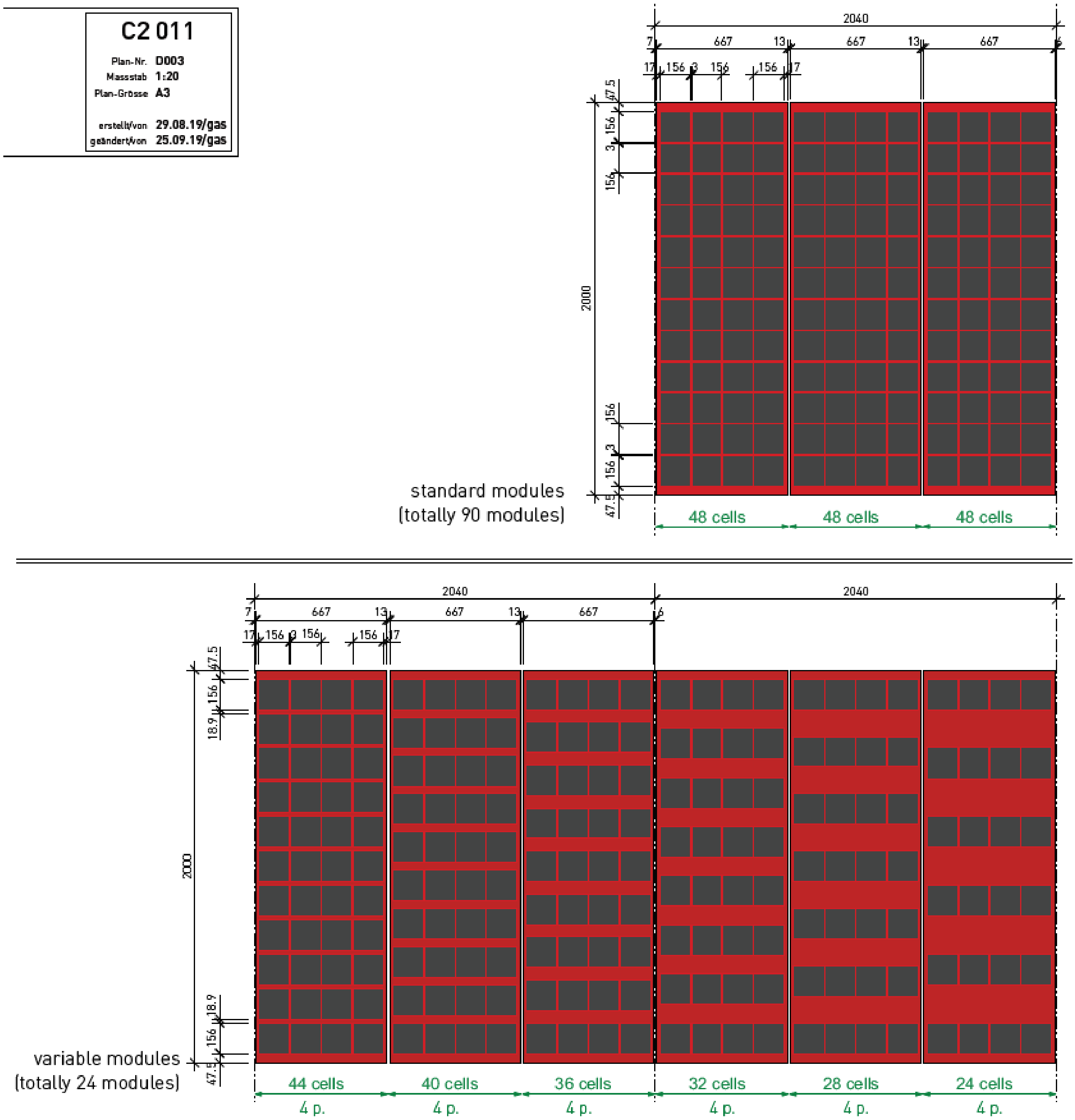


Figure 3.7: detail of the variable module design

3.3 BIPV STRUCTURE DESIGN

The façade structure design can be divided into in two parts, on the one hand, the necessary structure able to tie the modules to the existing building, whose designer has been AGM, as a local installer hired by MASS and a second structure, which is properly fixed to the BIPV module that has been designed by Tullips as part of the project.

3.3.1 Building to module structure.

For the structure necessary to be able to place the panels for this demo the following documents of the Technical Building Code (CTE) have been taken into account:

DB SE: Structural safety

DB SE AE: Actions in the building

DB SE C: Foundation

DB SE A: Steel

DB SE SI: Fire Safety

In addition, the following regulations in force have been taken into account:

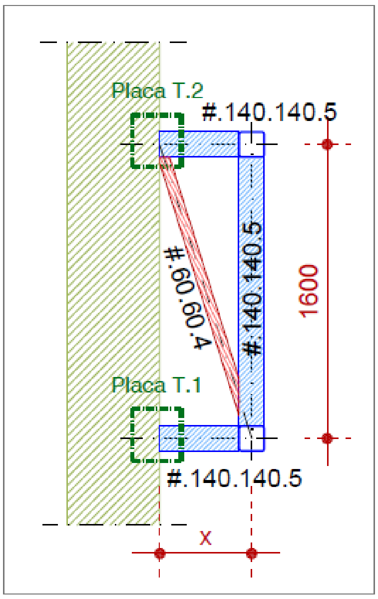
EHE-08: Structural Concrete Instruction.

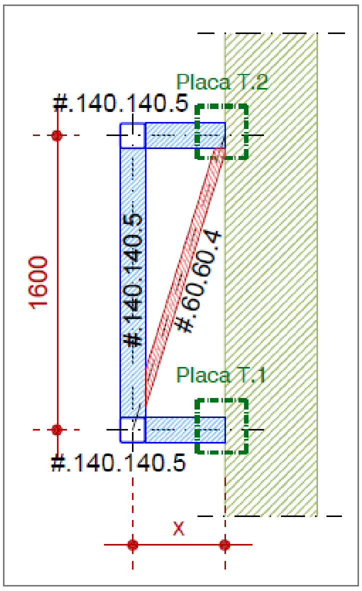
EAE: Structural Steel Instruction

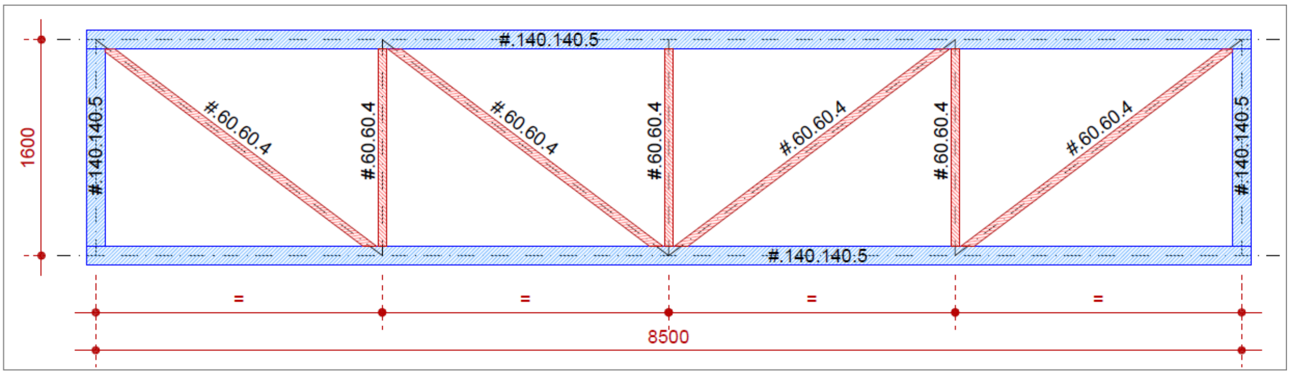
NSCE-02: Seismic resistant construction standard: general part and edification.

RC-08: Instruction for the reception of cements

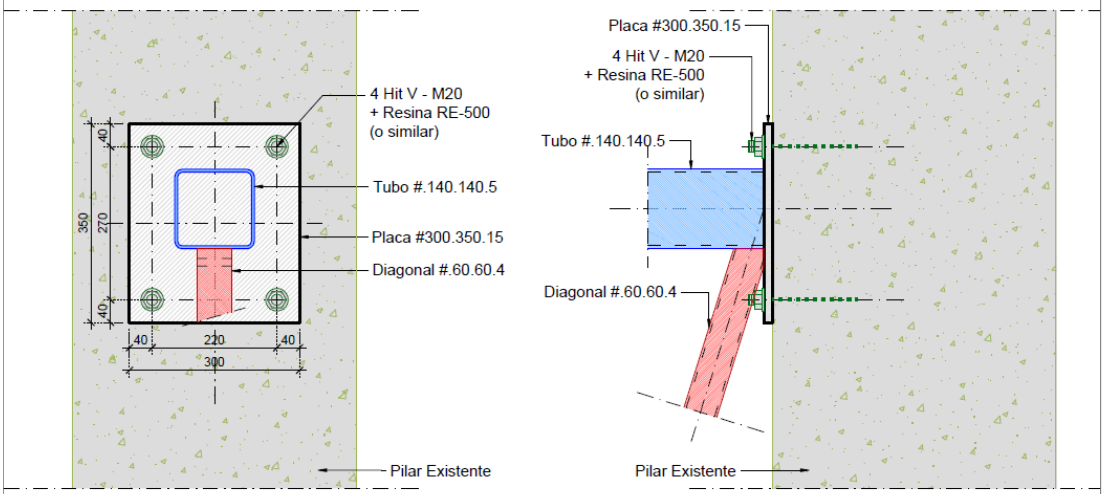
For the structural parts, Rolled steel in S-275-JR profiles built by welding in the workshop and on site by electrode E.43.3.B in two phases with surface treatment by blasting SA 2.5 and application in the workshop of a coat of anticorrosive primer of ZINC PHOSPHATE with a thickness of 40 microns are used. Anchor plates for support and fixings to existing structural elements (with studs, pins, tubular elements, plates, HIT-V 5.8 dowels of different metrics, HIT-RE 500 resin, all according to detail of structure drawings), losses, bushings, layout, auxiliary means and cleaning, according to CTE, DB-SE-AE and DB-SE-A.





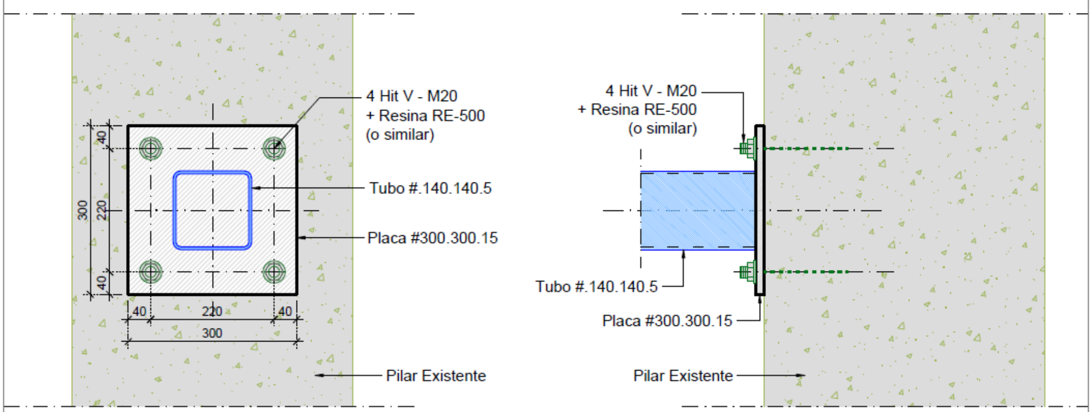


Detalle placas T2. escala 1/10
dimensiones placa = 300.350.15 mm (S275)



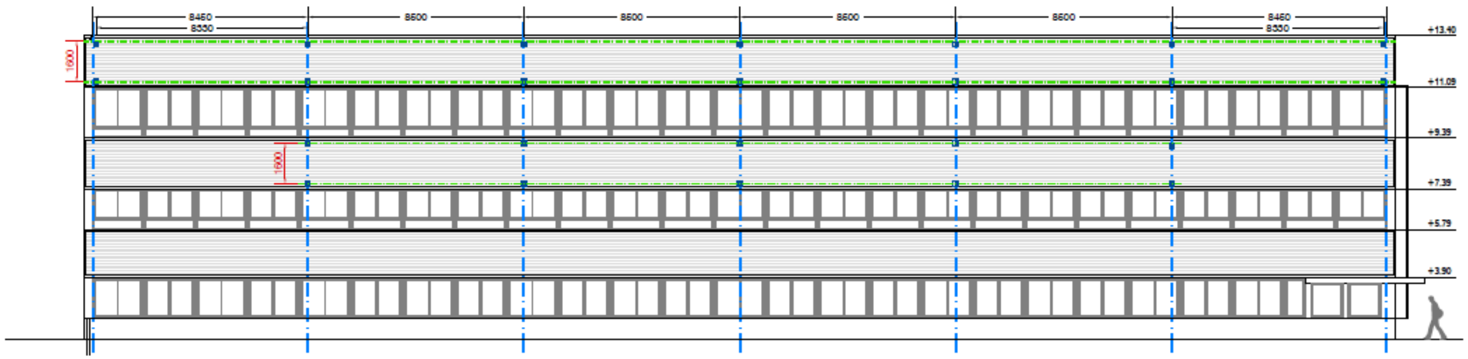
Espesor placa base: 15 mm

Detalle placas T1. escala 1/10
dimensiones placa = 300.300.15 mm (S275)

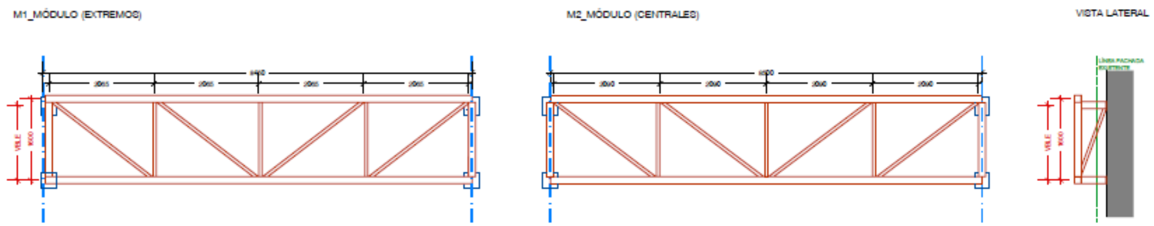


Espesor placa base: 15 mm

ALZADO ESTE CON ANCLAJES A PILARES
E 1:100



SUBESTRUCTURA DE SUJECIÓN DE PANELES SUPERIORES
E 1:50



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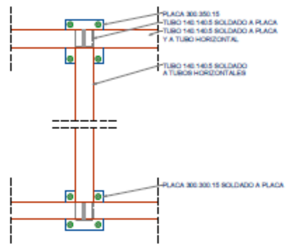
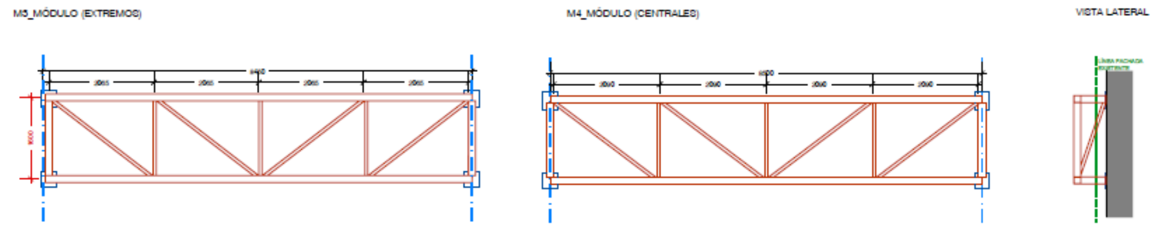
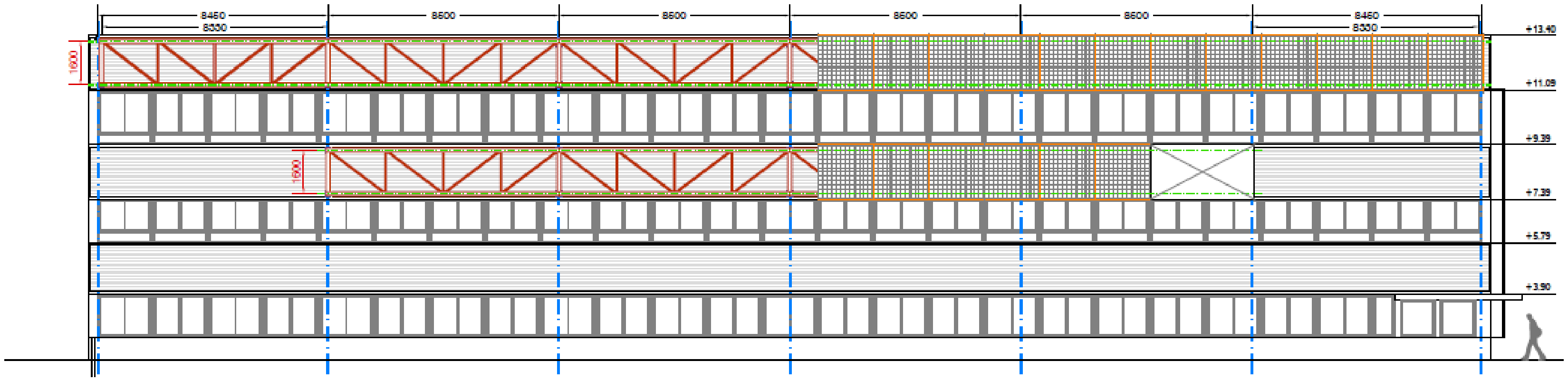
E 1:25



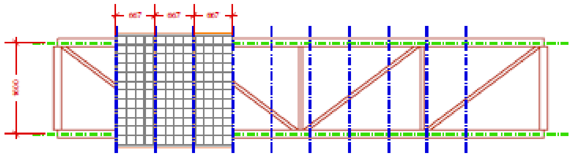
SUBESTRUCTURA DE SUJECIÓN DE PANELES INFERIORES
E 1:50



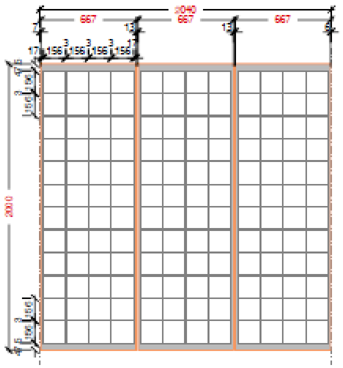
ALZADO ESTE
E 1:100



ESTRUCTURA DE SUJECIÓN DE PANELES
E 1:50



MÓDULO FOTOVOLTAICO
E 1:20



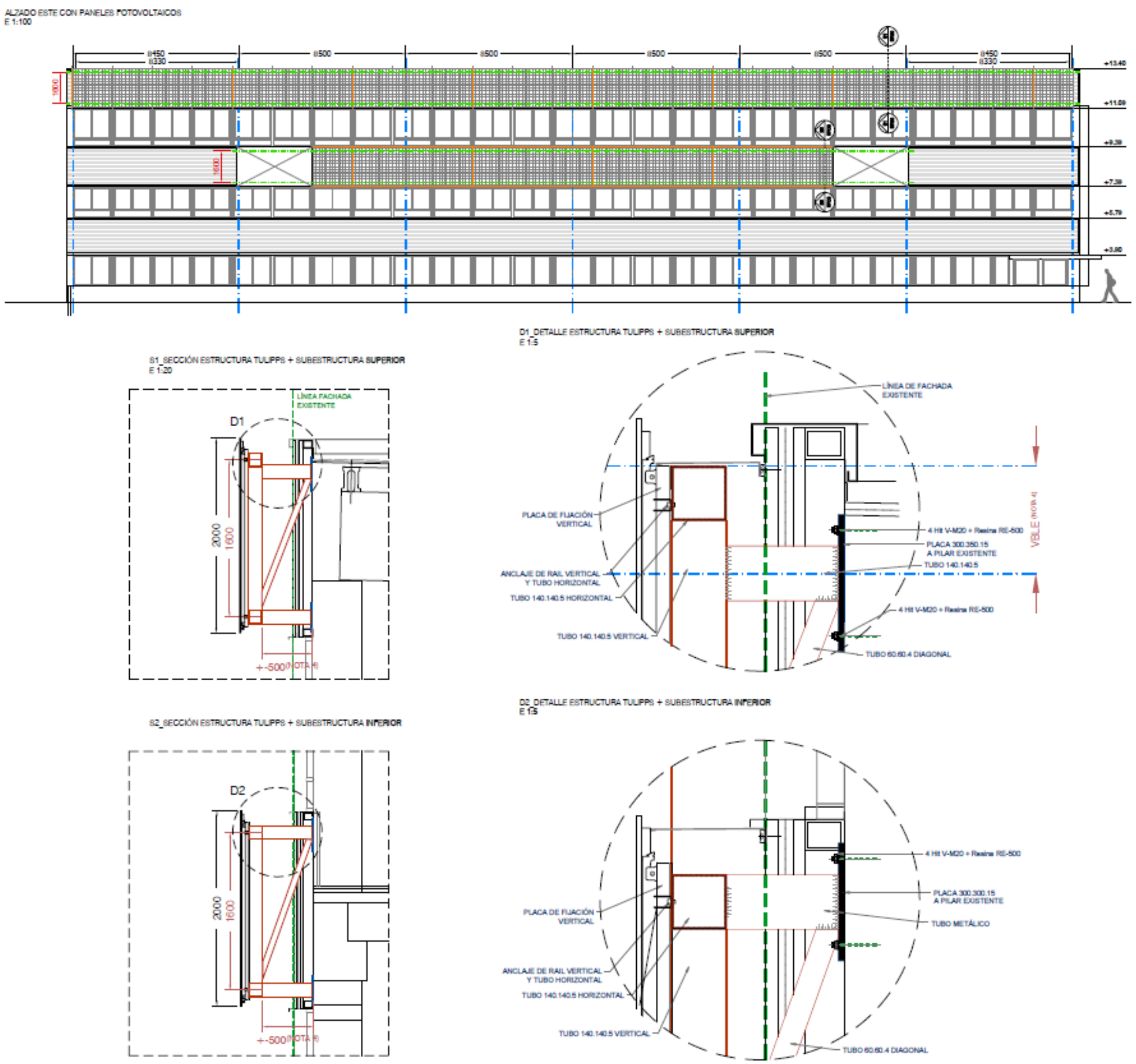


Figure 3.8: MASS substructure for Tulipps framing assembly

3.3.2 Module fixing structure

The frame for the demo design has been done by Tulipps, which has worked towards demonstrating a significant cost reduction through adjustments in the substructure design and components towards lower bill of materials, flexibility in sizing, ultra-easy installation processes.

This system consists of a distinctive click-&-go technology which is mounted in a rail system installed in the wall., with 1600 mm pitch distance. The system is presented in the public deliverable *D4.3. Functional samples of cost effective glass façade systems complying with specifications*.

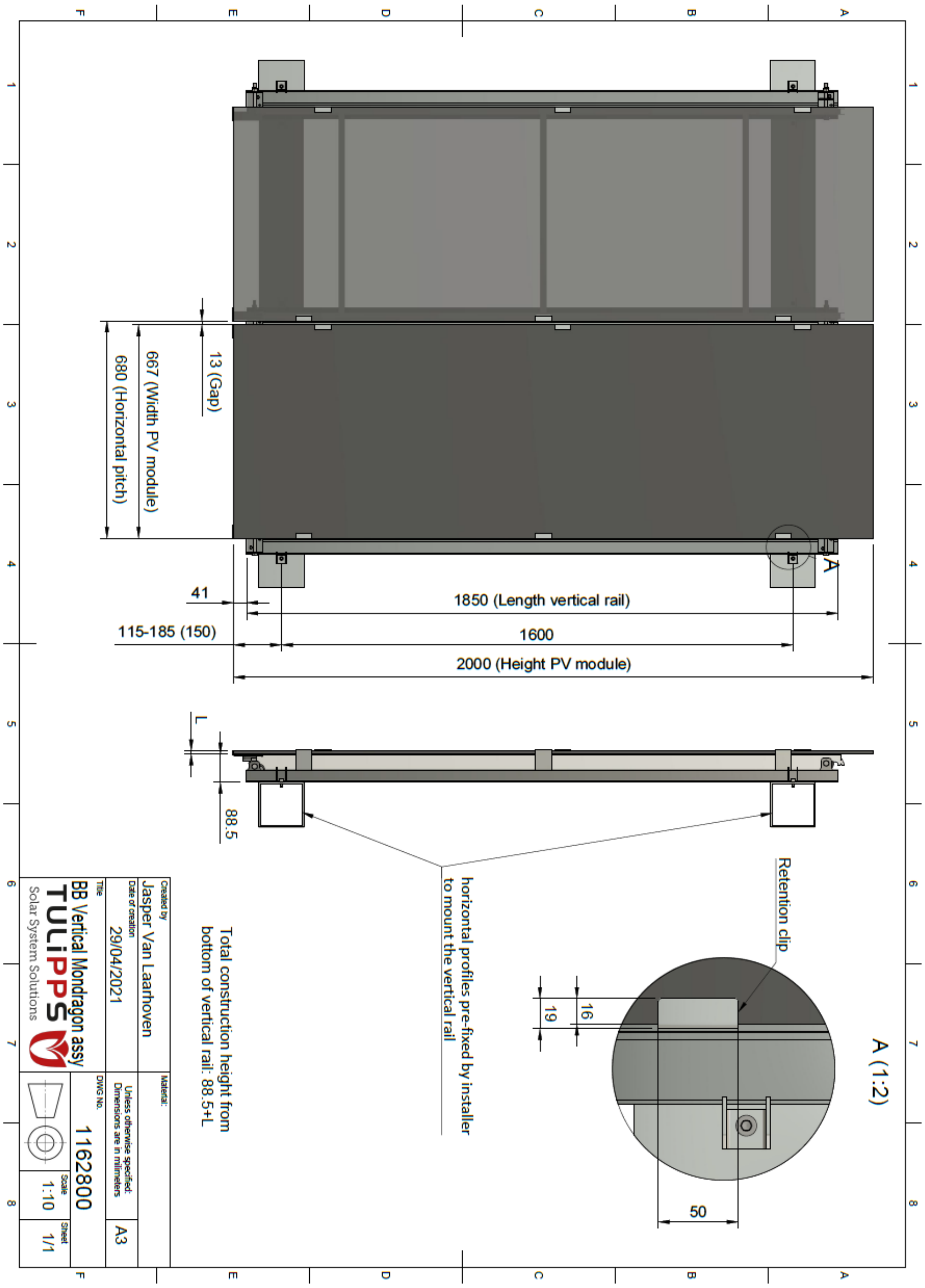
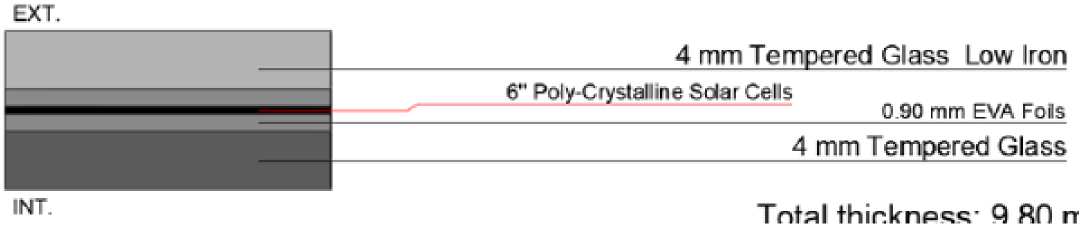


Figure 3.9: Framing provided by Tulipps

3.4 BIPV MODULE DESIGN

For this demo2, the panels will be manufactured by Onyx. The initial design of the same will consist on the geometry shown in the following image where there will be a transparent front glass of 4 mm, 6 "and 5 BB cells, 2 foils of 0.9 mm EVA to make the seal and rear glass with colour RAL 3020, which will give the selected aesthetic to the whole of the façade. Regarding this design, it remains to be validated in the WP5 that the dimensions of 4 + 4 mm of glass is sufficient.



(RAL 3020)

Figure 3.10: Composition of the panels

As an example, the first module manufactured in Onyx with the specifications of this demo2 is shown.

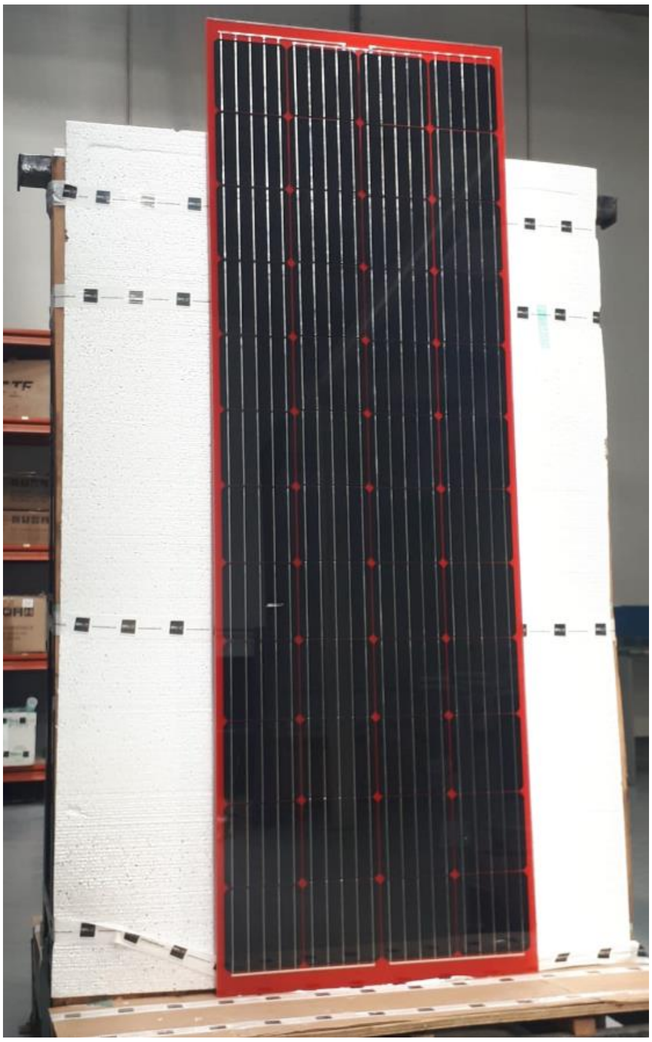


Figure 3.11: 2000m x 667 mm with 48 cells module manufactured by Onyx

3.4.1 BIPVBOOST module/s

The panels to be manufactured for this demo2 in terms of geometry and quantity, as can be seen in Section 3.2 where the design of the facade is exposed, would be the following:

- 90 modules of 2000mm x 667 mm and 48 cells
- 4 modules of 2000mm x 667 mm and 44 cells
- 4 modules of 2000mm x 667 mm and 40 cells
- 4 modules of 2000mm x 667 mm and 36 cells
- 4 modules of 2000mm x 667 mm and 32 cells
- 4 modules of 2000mm x 667 mm and 28 cells
- 4 modules of 2000mm x 667 mm and 24 cells

Each of the designs is detailed below. In all cases the module configuration is composed by the following materials:

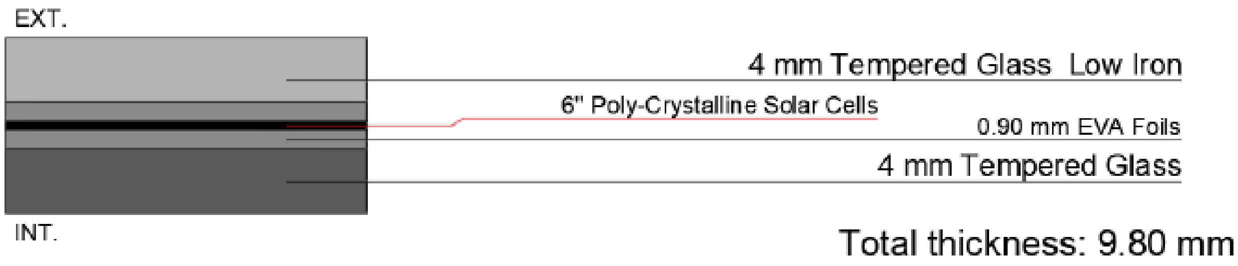


Figure 3.12: Glass-glass laminate composition for demo prototypes

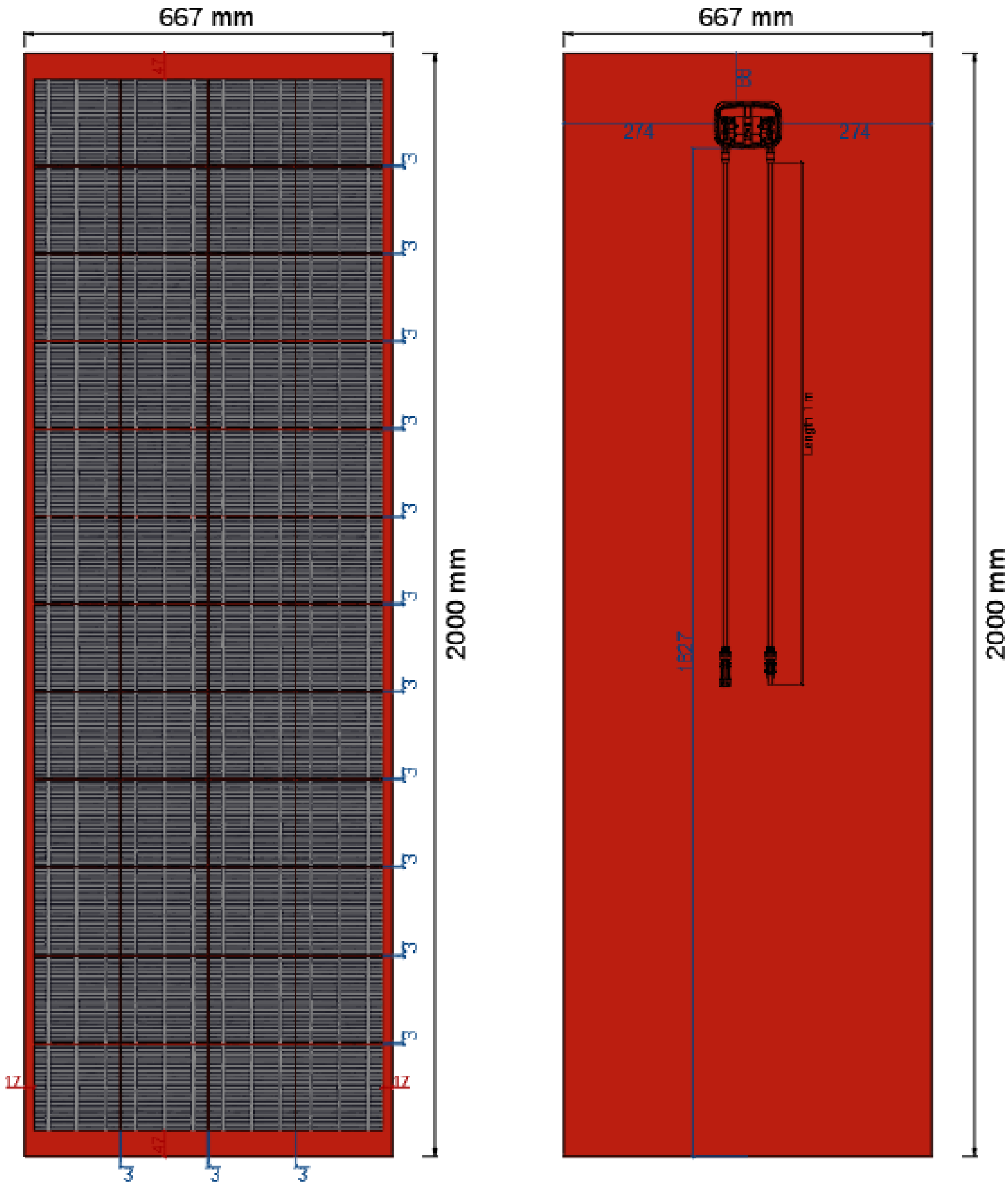


Figure 3.13: Façade glass-glass with 48 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.1: Data sheet of glass-glass module with 48 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 48 cells	2.000 x 6" Poly	667 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

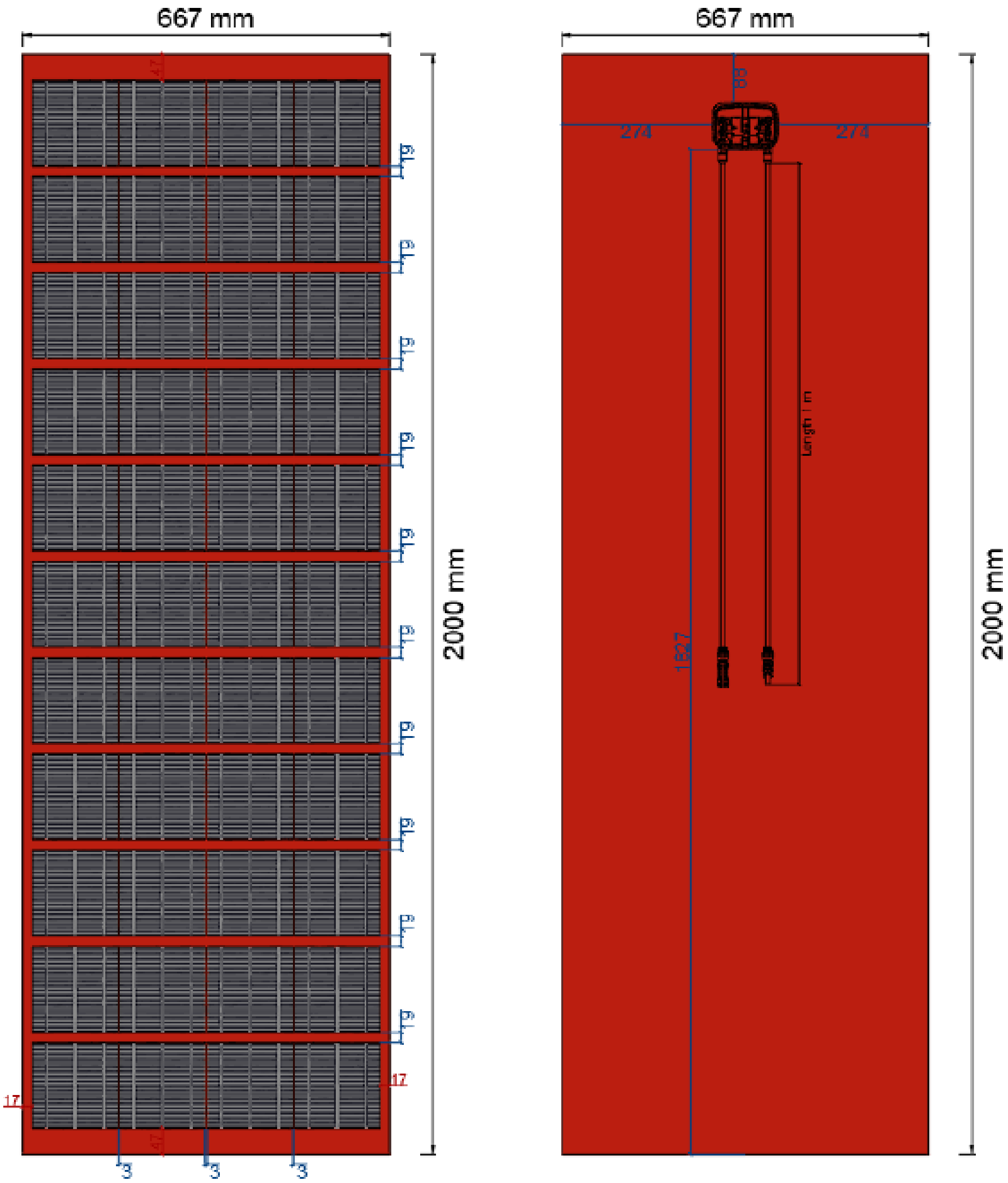


Figure 3.14: Façade glass-glass with 44 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.2: Data sheet of glass-glass module with 44 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 44 cells	2.000 x 6" Poly	667 Crystalline
Electrical data test conditions (STC)		
Nominal peak power	185	P_{mpp} (Wp)
Open-circuit voltage	28	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	24	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	44	20%
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	20%
U-value [W/sqm.K]	5,4
Peak Power [Wp/sqm]	138,6

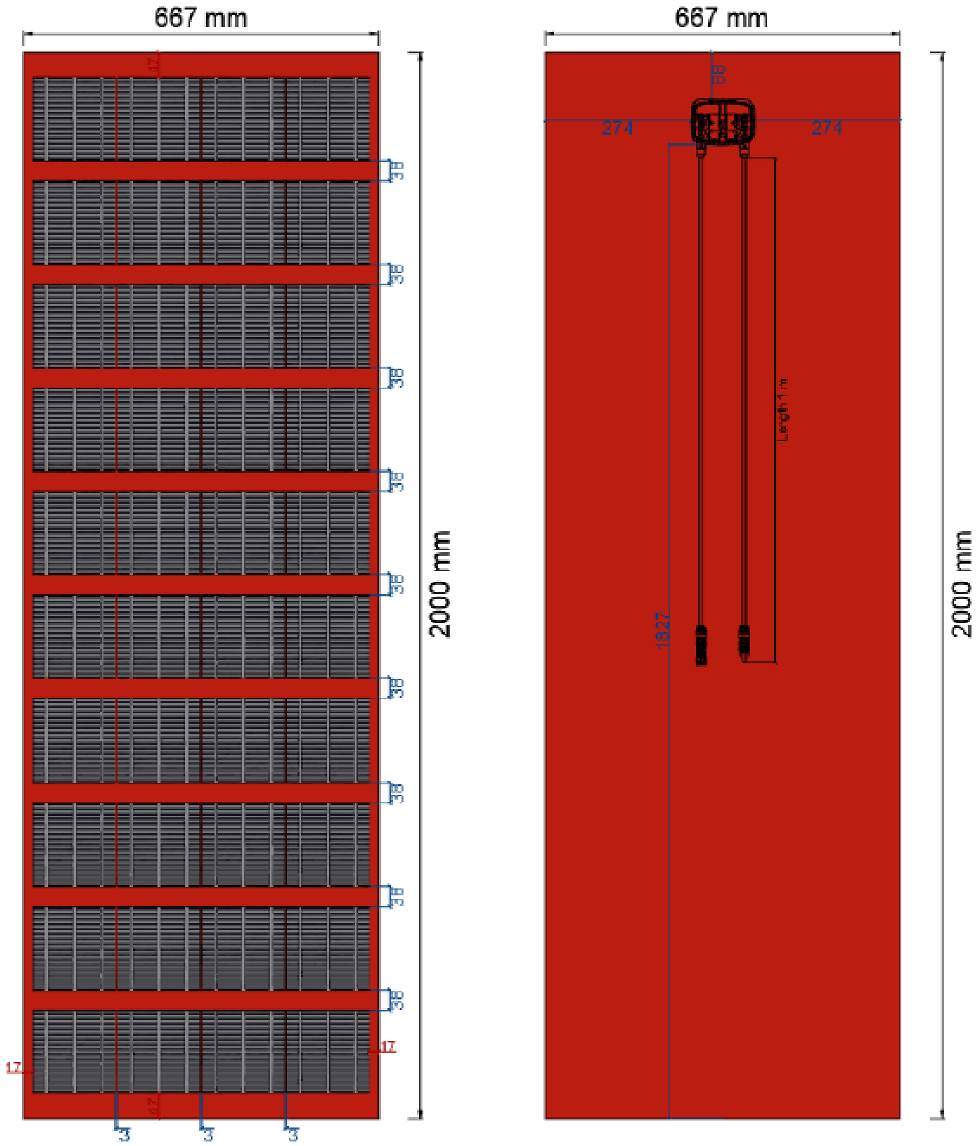


Figure 3.15: Façade glass-glass with 40 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.3: Data sheet of glass-glass module with 40 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 40 cells	2.000 x 6" Poly	667 Crystalline
Electrical data test conditions (STC)		
Nominal peak power	168	P_{mpp} (Wp)
Open-circuit voltage	26	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	22	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	40	27%
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	**27%**
U-value [W/sqm.K]	**5,4**
Peak Power [Wp/sqm]	**126,0**

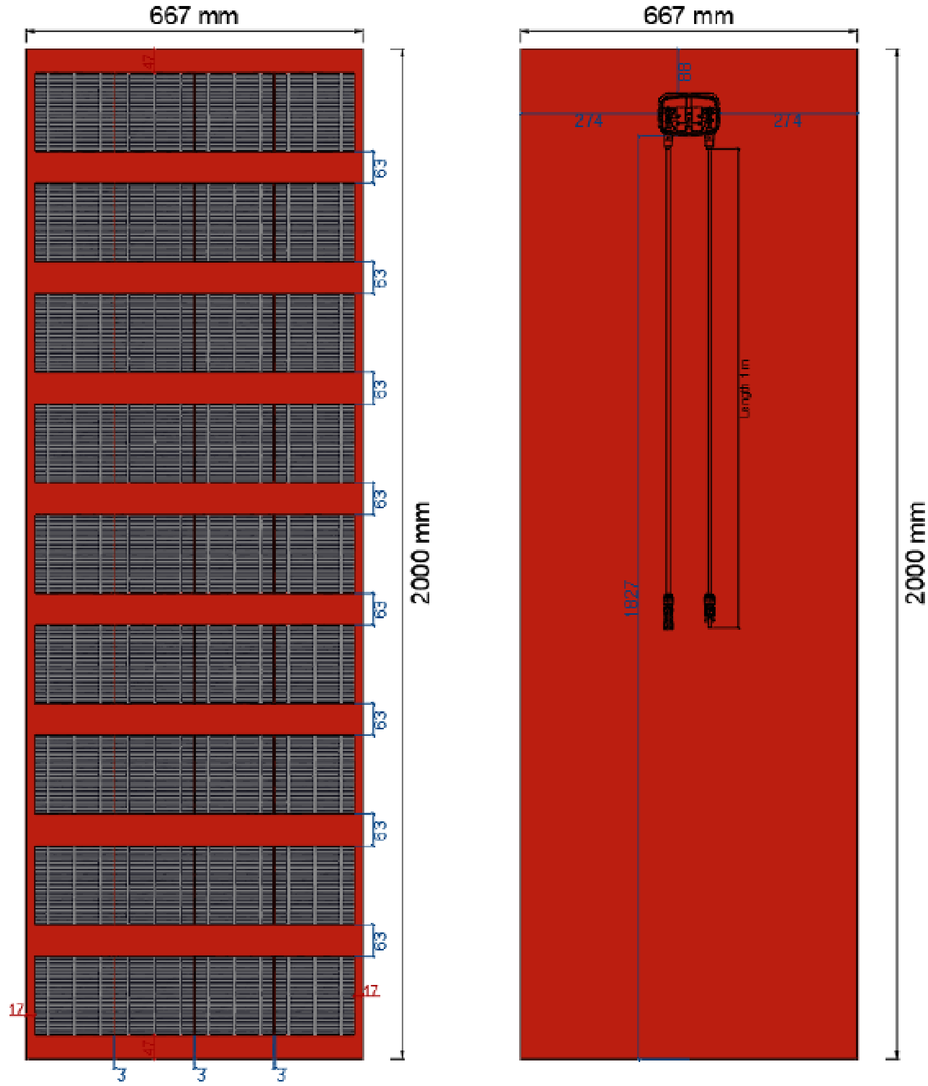


Figure 3.16: Façade glass-glass with 36 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.4: Data sheet of glass-glass module with 36 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 36 cells	2.000 x 6" Poly	667 Crystalline
Electrical data test conditions (STC)		
Nominal peak power	151	P_{mpp} (Wp)
Open-circuit voltage	23	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	19	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	36	34%
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	34%
U-value [W/sqm.K]	5,4
Peak Power [Wp/sqm]	113,4

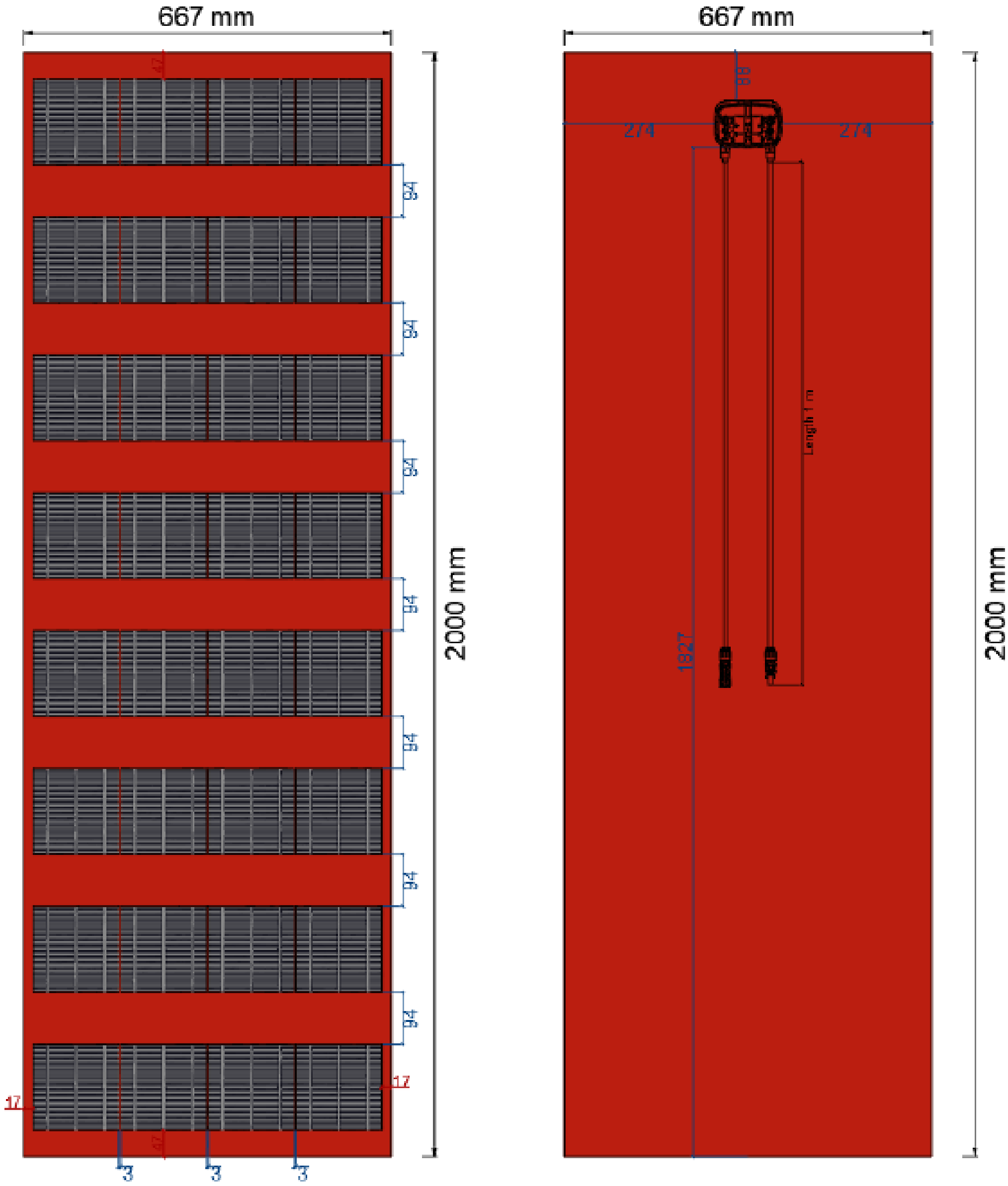


Figure 3.17: Façade glass-glass with 32 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.5: Data sheet of glass-glass module with 32 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 32 cells	2.000 x 667 6" Poly	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	134	P_{mpp} (Wp)
Open-circuit voltage	20	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	17	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	32	42%
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	34%
U-value [W/sqm.K]	5,4
Peak Power [Wp/sqm]	113,4

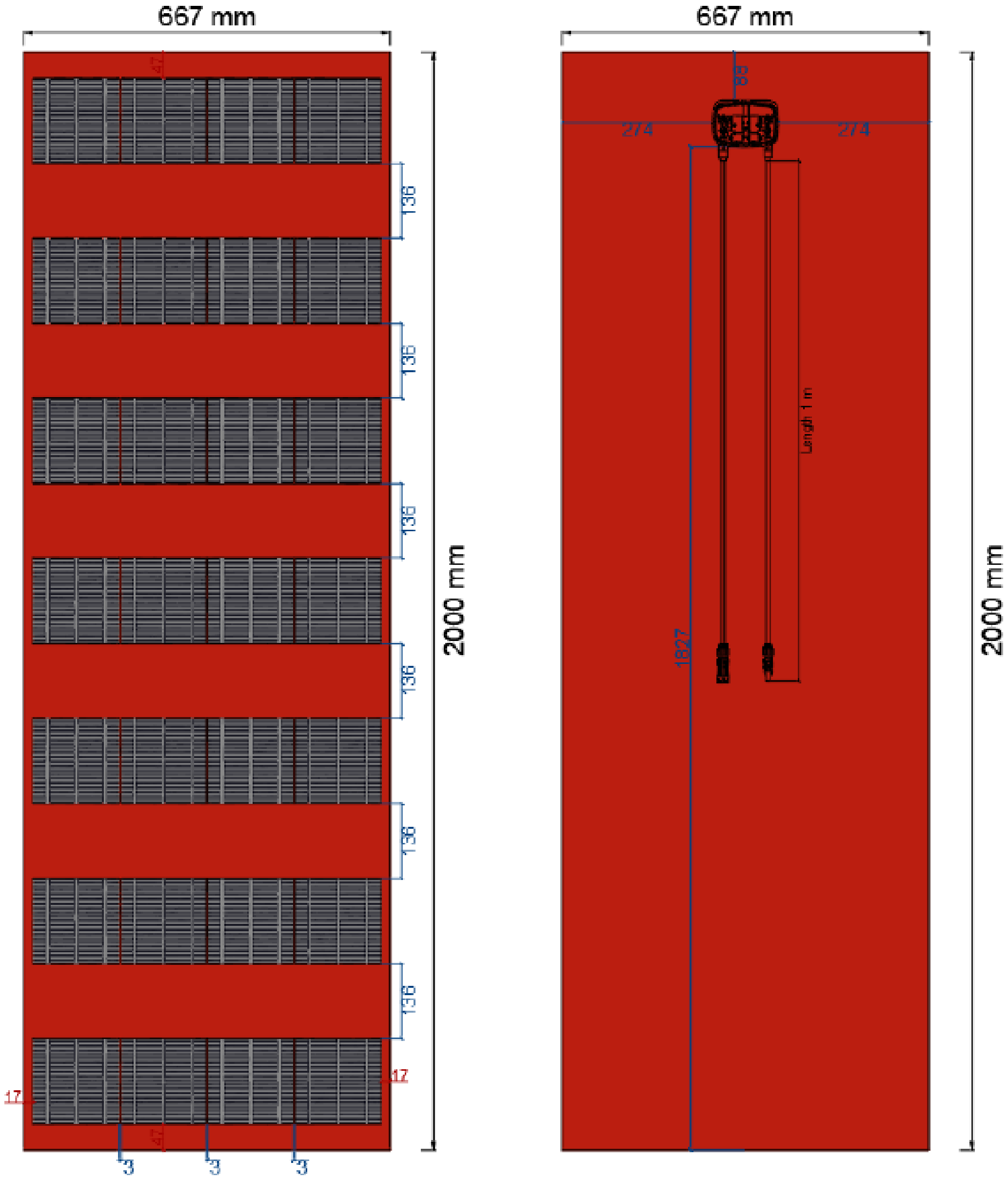


Figure 3.18: Façade glass-glass with 28 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.6: Data sheet of glass-glass module with 28 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 28 cells	**2.000 x** **6" Poly**	**667** **Crystalline**
Electrical data test conditions (STC)		
Nominal peak power	118	P_{mpp} (Wp)
Open-circuit voltage	18	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	15	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	28	49%
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	**49%**
U-value [W/sqm.K]	**5,4**
Peak Power [Wp/sqm]	**88,2**

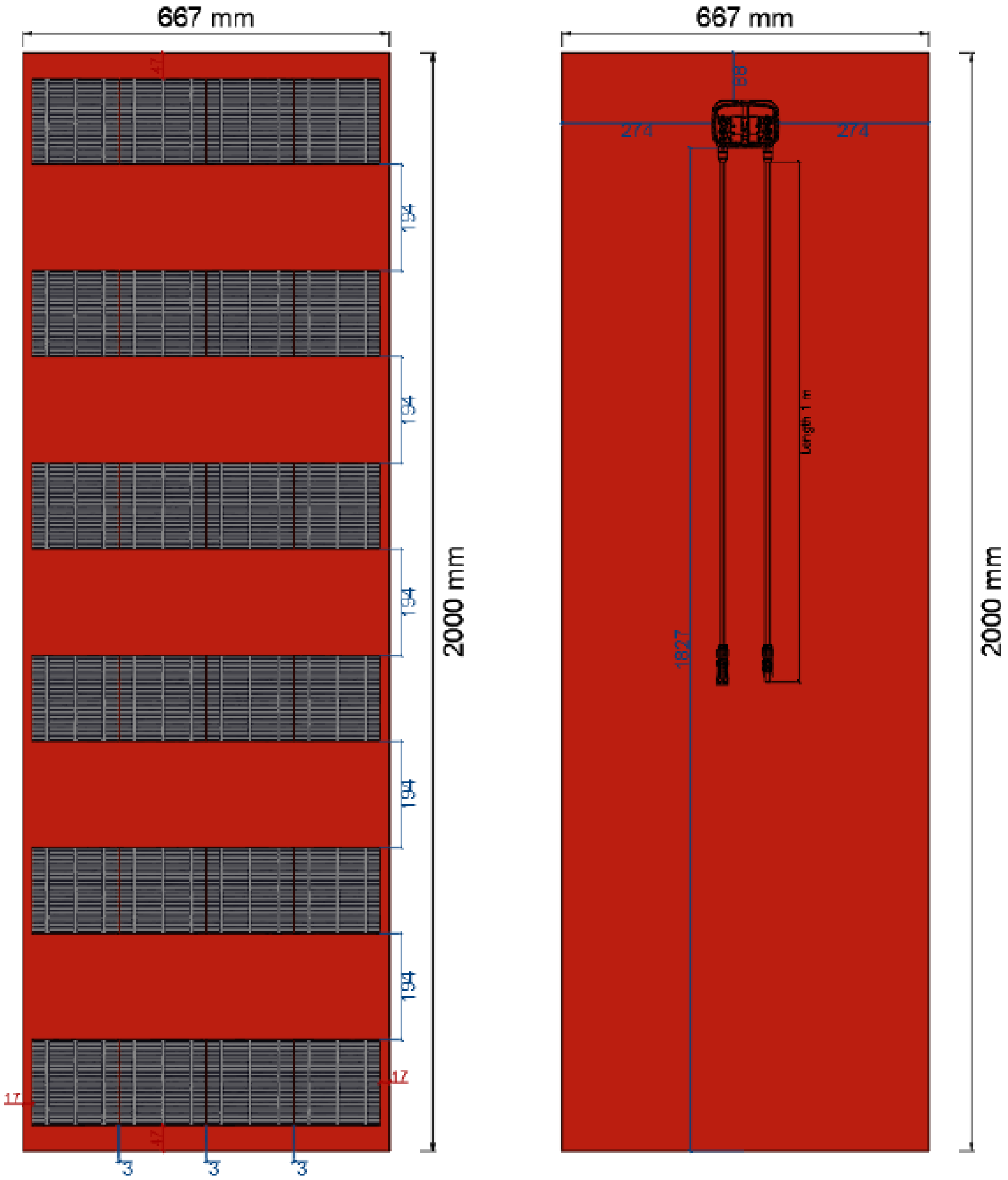


Figure 3.19: Data sheet of glass-glass module with 24 poly-crystalline cells and tempered rear glass RAL 3020

Table 3.7: Data sheet of glass-glass module with 24 poly-crystalline cells and tempered rear glass RAL 3020

PHOTOVOLTAIC GLASS 24 cells	2.000 x 6" Poly	667 Crystalline
Electrical data test conditions (STC)		
Nominal peak power	101	P_{mpp} (Wp)
Open-circuit voltage	15	V_{oc} (V)
Short-circuit current	8,27	I_{sc} (A)
Voltage at nominal power	13	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	24	56%
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	56%
U-value [W/sqm.K]	5,4
Peak Power [Wp/sqm]	75,6

To connect the solar panels as well as to offer all the advantages that a J-box offers, such as avoiding the entry of water, the following option was selected.

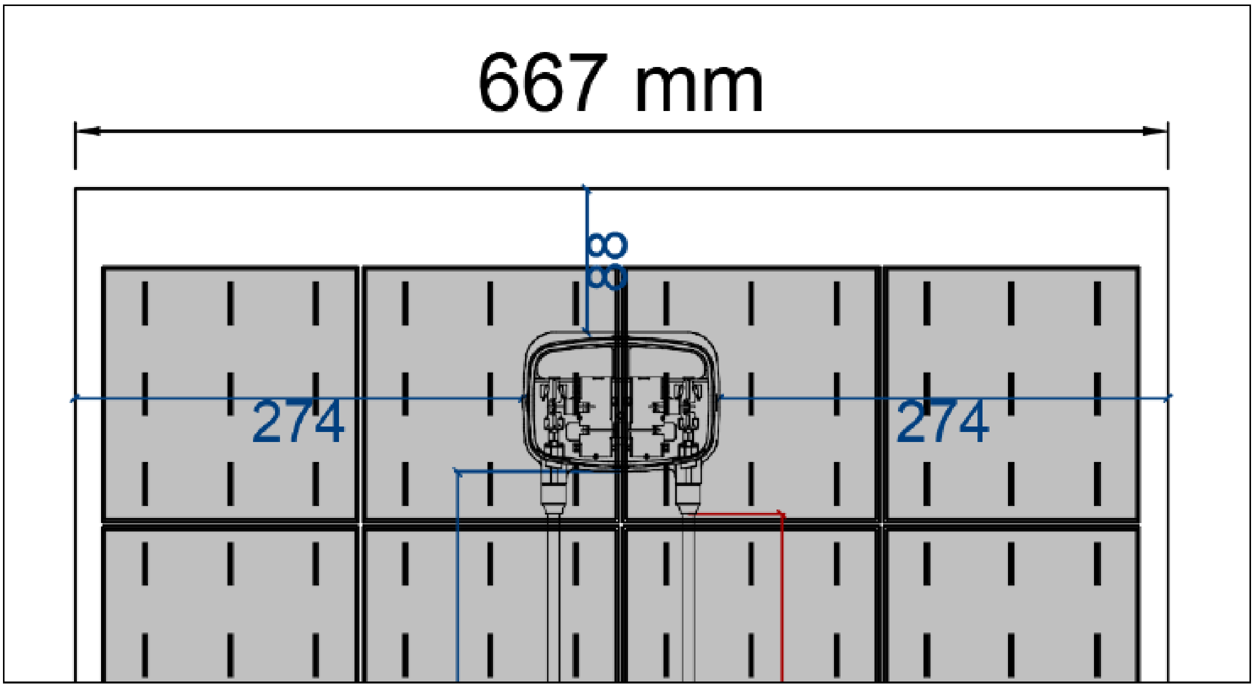


Figure 1.16 JB approximate location (equal to all the variants)

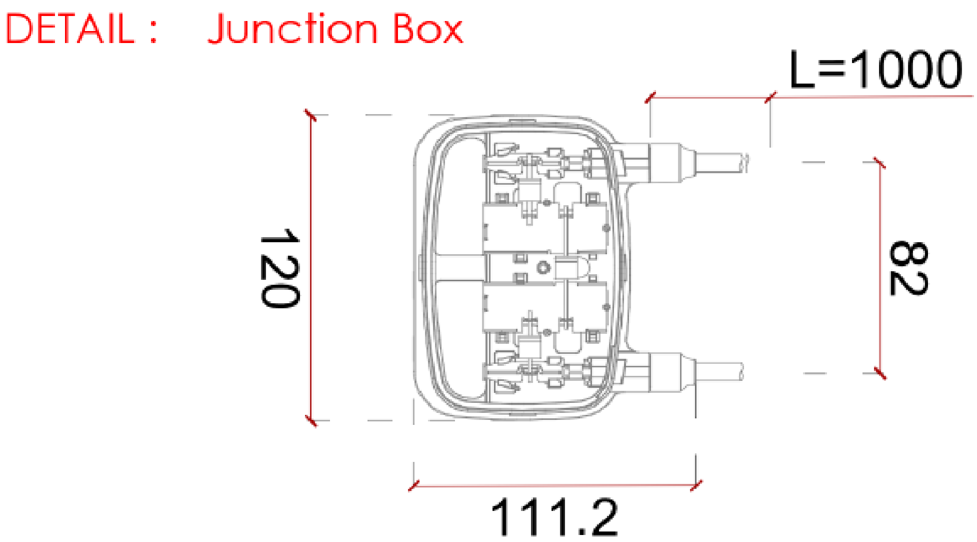


Figure 1.17 PV-JB/WL-V MC (4 spring clamps) junction box

All the junction boxes of these variants use MC4 connectors

3.5 BIPV ELECTRICAL SYSTEM DESIGN

3.5.1 BIPVBOOST electrical diagram

Electrical diagram for demo 2 selected design is defined by Ekilor, MASS local installer, which has proven experience in the installation of solar panels, including those that are currently on the roof of MASS

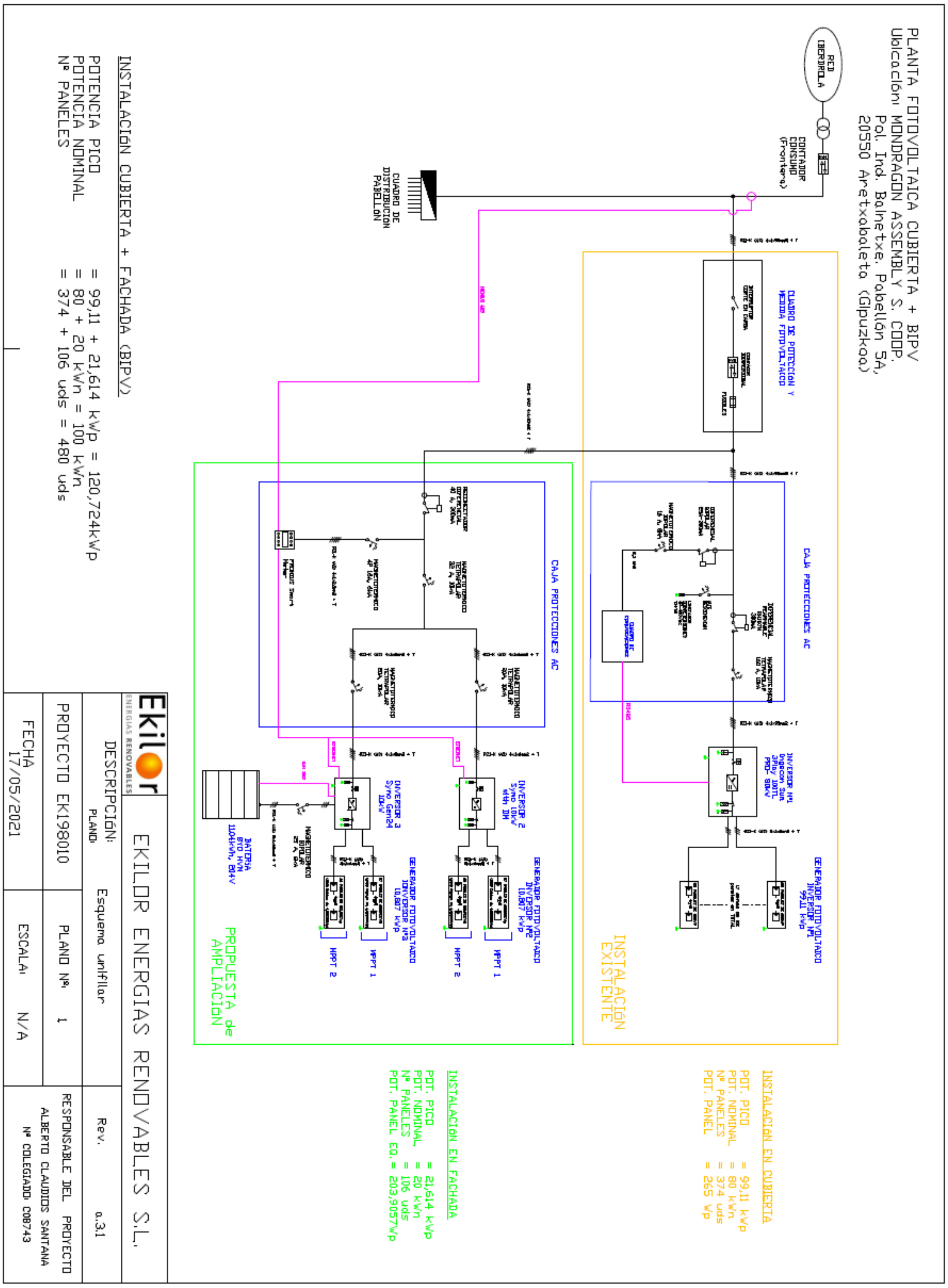


Figure 3.20: Electrical diagram provided by Ekilor

3.6 BIPV MONITORING DESIGN

3.6.1 Definition of monitoring objectives: BIPV performance validation, economic viability and progress towards NZEB requirements

As described previously in this document the Mondragon assembly demo site will be equipped with a BIPV ventilated facade and new BEMS system. The objective of the monitoring system is to measure and verify the energy performance of the BIPVBOOST project developments and implementation in Mondragon assembly demo site. In this context the energy performance is understood as the non-used energy (energy savings), the self-consumption ratio, the reduction in the energy bill and the performance ratio. Next the implementation of monitoring system is presented.

3.6.2 Definition of variables to be monitored

In order to achieve the monitoring system objectives, the monitored variables have been selected following the monitoring guidelines defined in deliverable 8.3. The following figure 3.9 shows in a graphical way the main variables that will be measured, and the table 3.1 summarised the measured variables, the monitoring instruments and the required accuracies. These variables will be aqcuired in two-time steps, the pre-intervention (In red font in figure 3.9) period and the post intervention period (inside the red box in figure 3.9)

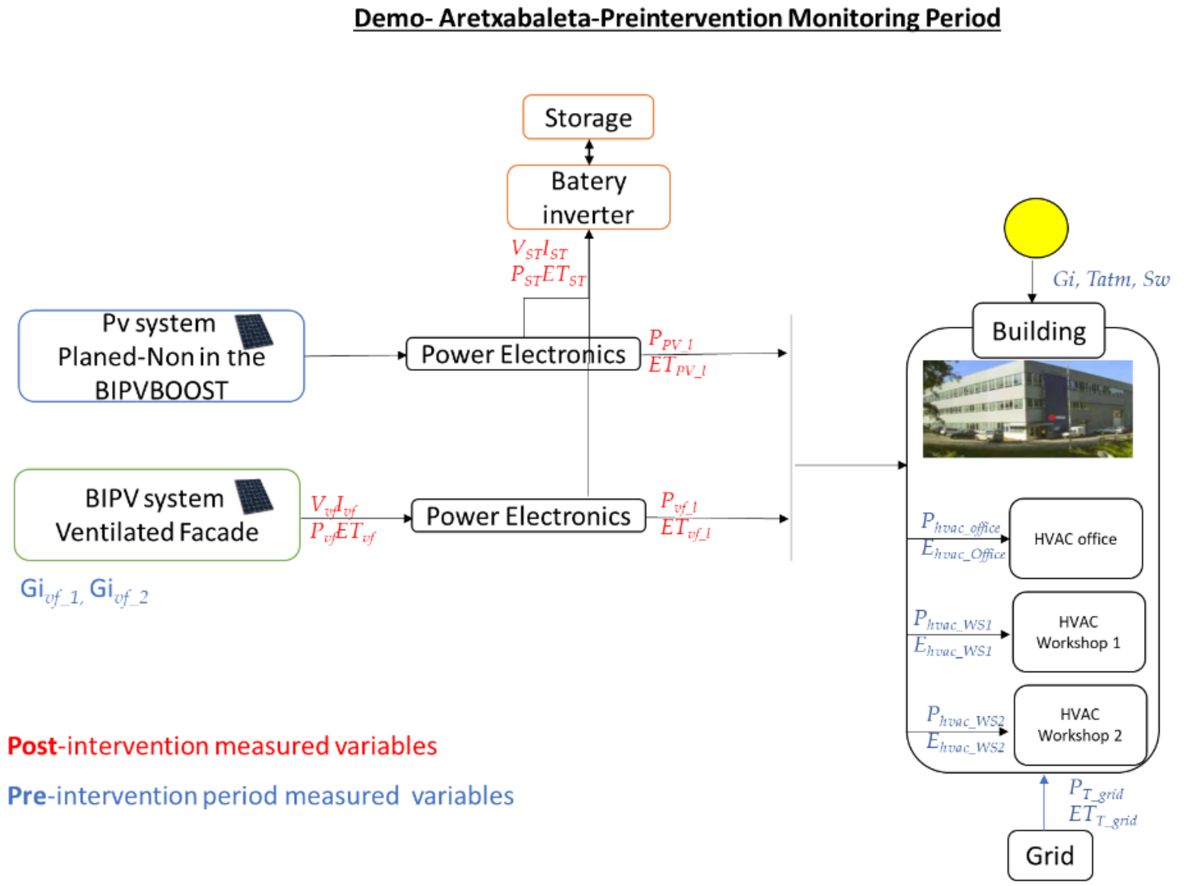


Figure 3.21: Main measuring variables of Aretxabaleta demo site

Table 3.8: Aretxabaleta demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	Description	instrument	Range	Units	Time Resolution	Accuracy
BIPV components						
Ventilated facade						
Meteo	-					
Gi_{vf}	*Irradiance in the ventilated facade plane*	Reference cell	0-1200	w/m2	<1min	5% of the Reading
Tm_{vf}	*Temperature of the reference cell*	Thermocouple type T	0-100	ºC	<1min	1K
DC	-					
I_{vf}	Intensity DC	Amperimeter		A	<1min	1% of the Reading
V_{vf}	Voltage DC	Voltimeter		V	<1min	1% of the Reading
P_{vf}	Power DC	Power meter	24	kW	<1min	2% of the Reading
ET_{vf}	Energy DC	Energy meter		kW/h	<1min	
AC	-					
P_{vf_I}	Power AC	Power meter	24	kW	<1min	2% of the Reading
ET_{vf_I}	Energy AC	Energy meter		kW/h	<1min	
Storage	-					
Imput	-					
$I_{\_st}$	Intensity	Amperimeter		A	<1min	1% of the Reading
$V_{\_st}$	Voltage	Voltimeter		V	<1min	1% of the Reading
$P_{\_st}$	Power	Power meter	24	kW	<1min	2% of the Reading
$ET_{\_st}$	Energy	Energy meter		kW/h	<1min	
Building						
Gi	*Global irradiance*	Pyranometer	0-1200	w/m2	<1min	5% of the Reading
T_{amb}	*Ambient temperature*	Thermocouple type T	0-50	ºC	<1min	1K
S_w	*Wind Speed*	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
HVAC						
Office						
I_{hvac_office}	Intensity	Amperimeter		A	<1min	1% of the Reading
V_{hvac_office}	Voltage	Voltimeter		V	<1min	1% of the Reading
P_{hvac_office}	Power	Power meter		kW	<1min	2% of the Reading
ET_{hvac_office}	Energy	Energy meter		kW/h	<1min	
WorkShop 1						

I_{hvac_WS1}	Intensity	Amperimeter		A	<1min	1% of the Reading
V_{hvacc_WS1}	Voltage	Voltimeter		V	<1min	1% of the Reading
P_{hvacc_WS1}	Power	Power meter		kW	<1min	2% of the Reading
ET_{hvacc_WS1}	Energy	Energy meter		kW/h	<1min	
WorkShop 2						
$I_{hvac\_c\_WS2}$	Intensity	Amperimeter		A	<1min	1% of the Reading
V_{hvacc_WS2}	Voltage	Voltimeter		V	<1min	1% of the Reading
P_{hvacc_WS2}	Power	Power meter		kW	<1min	2% of the Reading
ET_{hvacc_WS2}	Energy	Energy meter		kW/h	<1min	
Existing PV field						
AC	-					
P_{pv_I}	Power AC	Power meter	89	kW	<1min	2% of the Reading
ET_{pv_I}	Energy AC	Energy meter		kW/h	<1min	
Grid						
P_{gr}	Power from the grid	Power meter		kW	<1min	2% of the Reading
ET_{gr}	Energy from the grid	Energy meter		kW/h	<1min	

3.6.3 Existing monitoring system

Mondragon assembly has already a PV plant installed on the building's roof. This PV plant is not part of the BIPVBOOST project, but it has an impact in the self-consumption ratio of the building during the project period. Therefore, the monitoring of the production of this plant is important to evaluate the project KPIs. Fortunately, the energy produced by this existing PV plant is being monitoring by the existing a monitoring system and the data are shared with TECNALIA.

3.6.4 BIPVBOOST monitoring system

The monitoring system is composed by all the instruments required to measure the variables listed in Table 3.8 connected to a data logger (via Modbus). Figure 3.22 shows the preintervention period connection diagram between all the instruments and the main board where the data logger is installed. The installation of all these instruments was carried out before August 2020. The installation lay out can be divided in two main groups: The roof installation and the indoor installation.

The instruments installed on the roof (near to the pre-existing PV plant) are devoted to measure the meteorological data (See Figure 3.23).

- Reference cell to measure the irradiance in the ventilated facade plane
- Pyranometer to measure the global irradiance
- PT100 to measure the ambient temperature, protected from sun radiation and wind.
- Anemometer to measure the wind speed.

Moreover, the instrument devoted to measure de building climatization consumption (HVAC) were installed indoor in the workshop 1, workshop 2 and the offices.

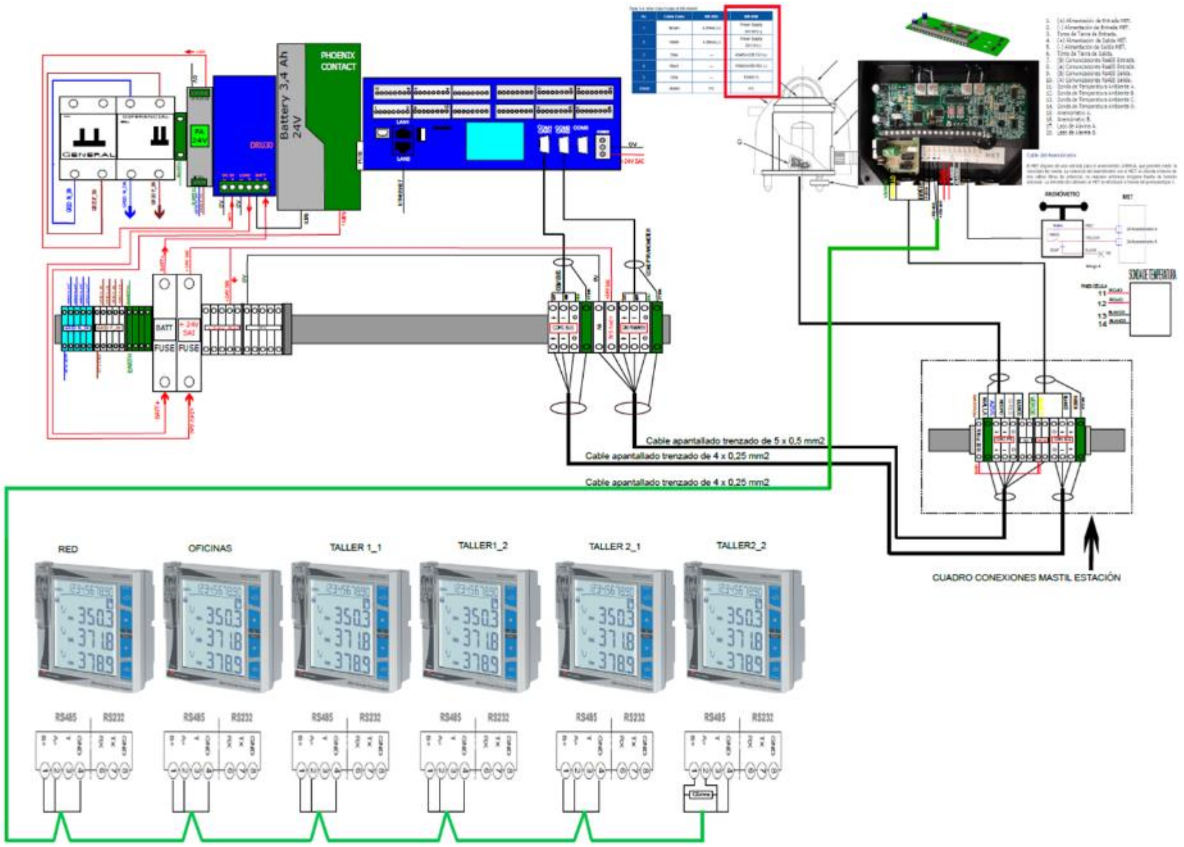


Figure 3.22: Pre-intervention monitoring system connection schema

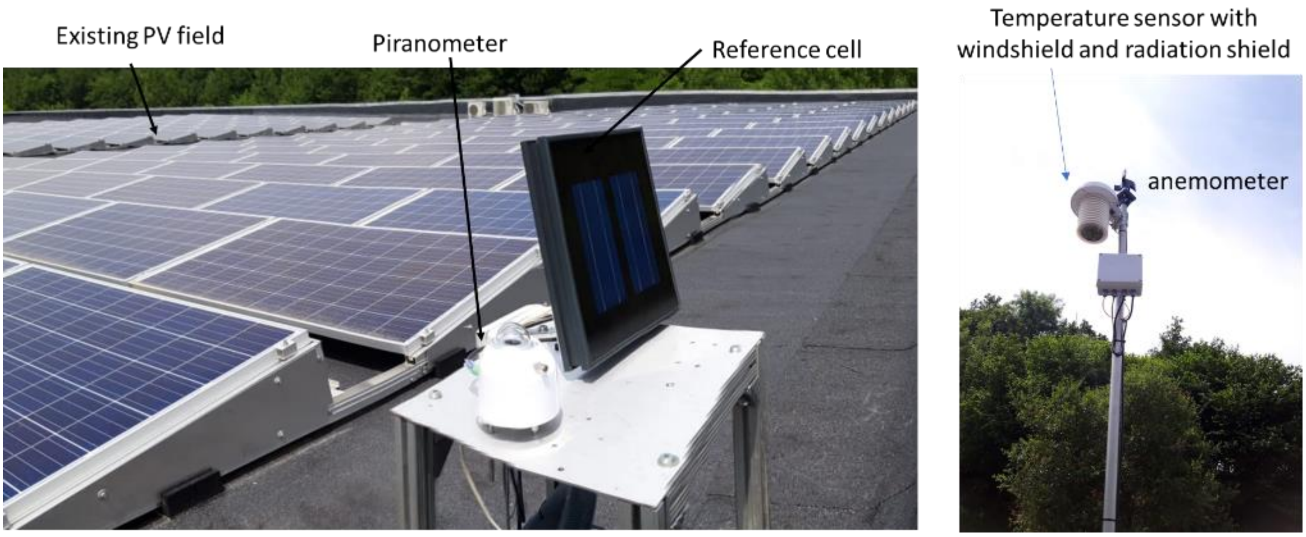


Figure 3.23: Roof installation of the instruments devoted to meteorological data.

Regarding the data collection, the gathered data are sent to TECNALIA via internet connection (provided by Mondragon Assembly) and the data of the pre-existing PV plant will be sent to TECNALIA. The data can be checked online in the website prepared for this purpose (see next figure).

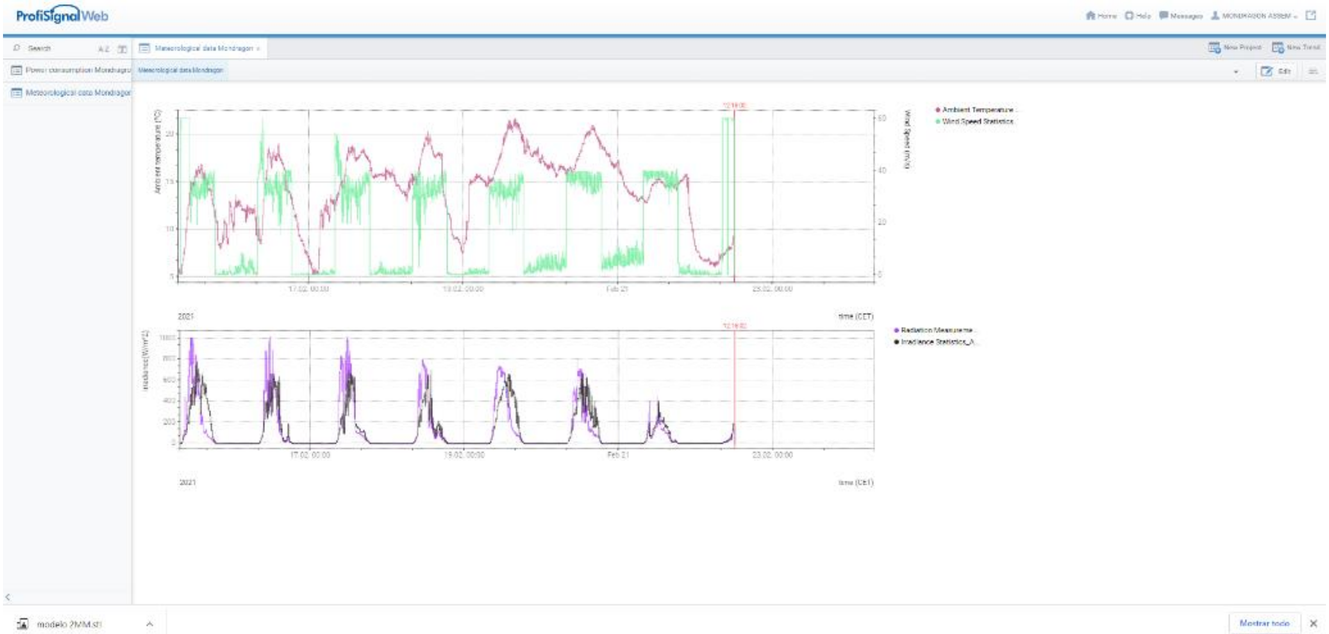


Figure 3.24: Screenshot of the web datalogger.

3.7 BIPV MODELLING AND PERFORMANCE SIMULATION

EnerBIM, as WP6 leader and BIMsolar tool developer, has completed BIPV systems digital modelling and simulation works as a pre-study.

3.7.1 Element level to building level methodology using 3D modelling and simulation tools

3.7.1.1 Overall methodology

The same methodology presented in Section 2.7.1.1 has been used.

3.7.2 Modelling strategy retained for transparent and opaque BIPV

The software is being developed to fit with ONYX Solar and TULIPPS combined strategies regarding BIPV glass modules to integrate cladding systems. The BIPV module configurator is based on 4 editors:

- Cell editor
- Pattern editor
- Transparent Glass editor
- Glazing editor

To design a transparent BIPV system, we have fixed the following steps:

<u>BIPV Layout</u>

<u>Balance of System (downstream studies)</u>

As a pre-study approach - conceptual design - for cladding systems without advanced BIPV considerations at this stage, the module builder is based on 2 editors working as a BAPV configurator:

- Cell editor
- Module editor

We have fixed the following steps:

<u>BAPV Layout</u>

3.7.3 DEMO#2 – MASS building, 3D design from 2D plans, simulation with BIMsolar

3.7.3.1 Hypothesis

BIPV modules have been set up from ONYX Solar datasets.

COLOURED modules: the development of these specific innovations for BIPV is not completed for BIMsolar software at this stage (WP6 T6.3 – M48). We use a first level of optical properties related to BIPV glass quality and modules resultant efficiency (from lab tests by ONYX Solar).

To run first simulations, we have selected mono crystalline cells and glass modules from ONYX Solar standard modules datasheets in accordance with Viridén+Partner's variant ref.38 (25.09.2019) amended during the 5th General Assembly (05.05.2021).

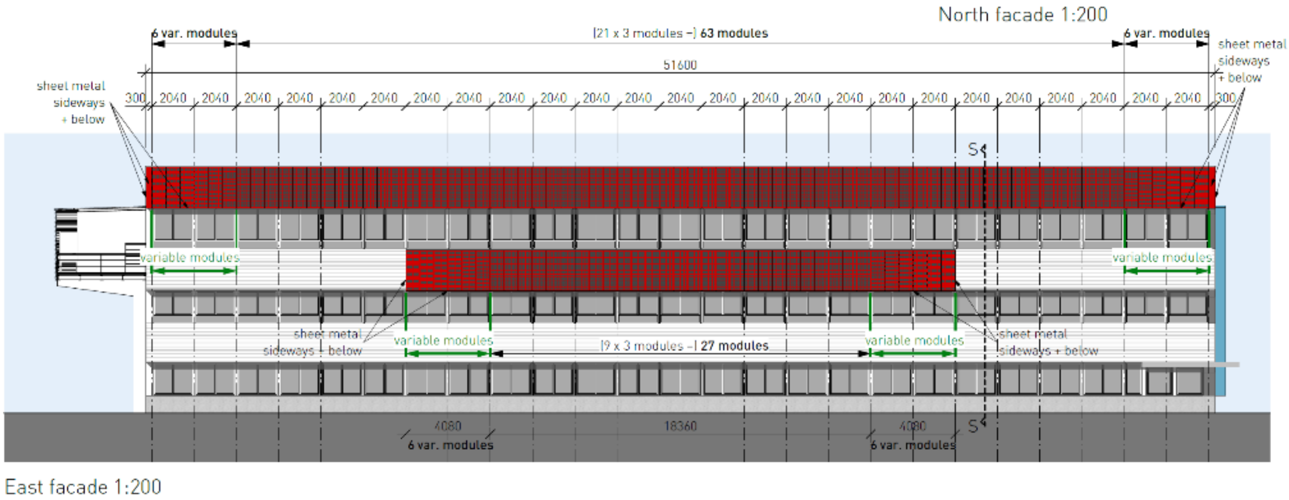


Figure 3.25: Viriden+Partner – Project East Façade – Variant 38 design (vertical configuration)

ONYX Solar has set up single sized modules as defined below, where only the cell density is changed in certain modules:

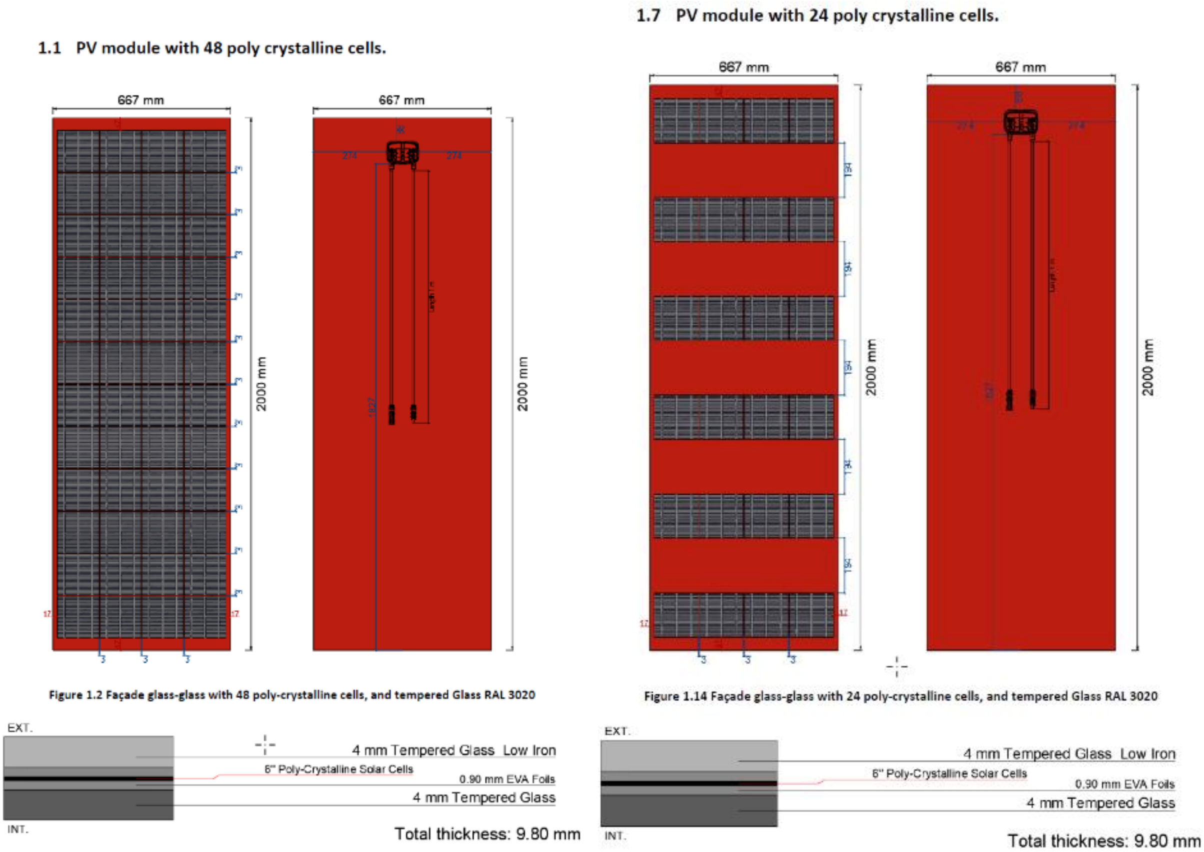
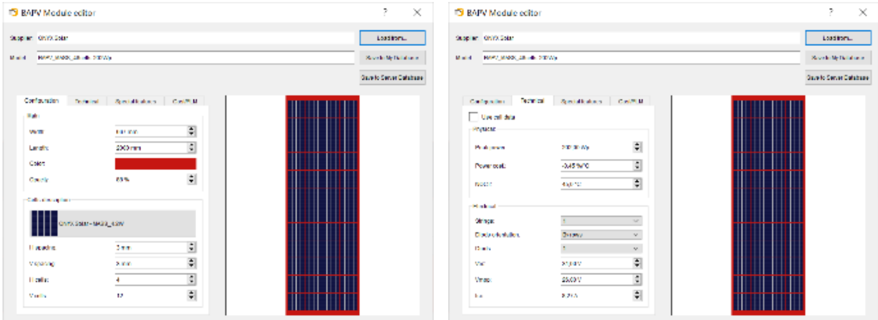
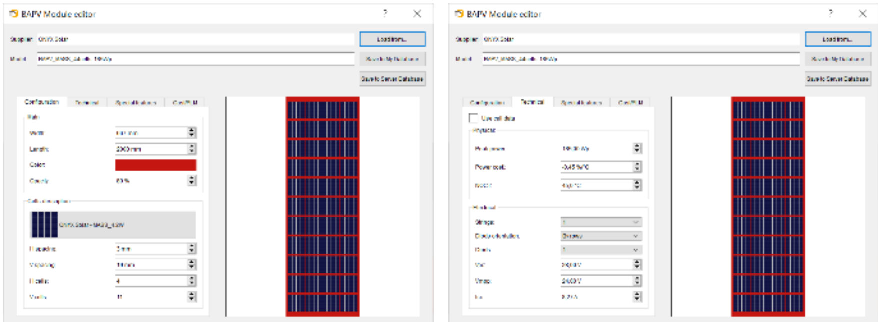
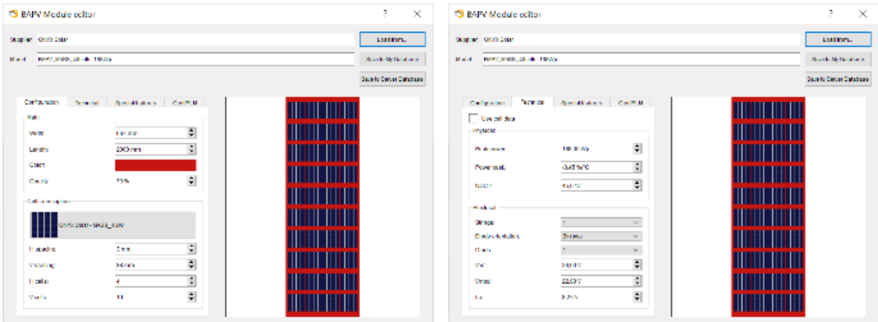
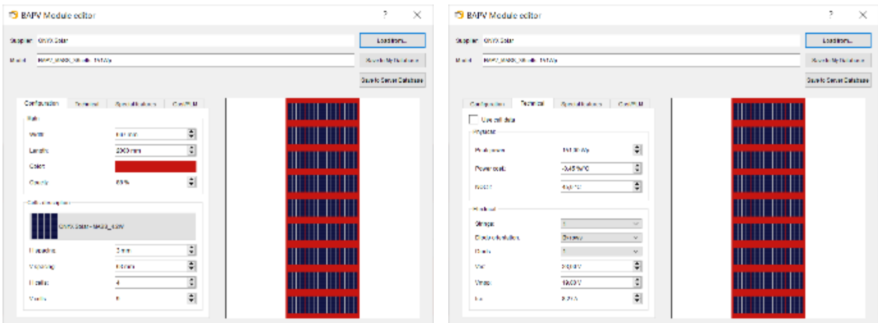
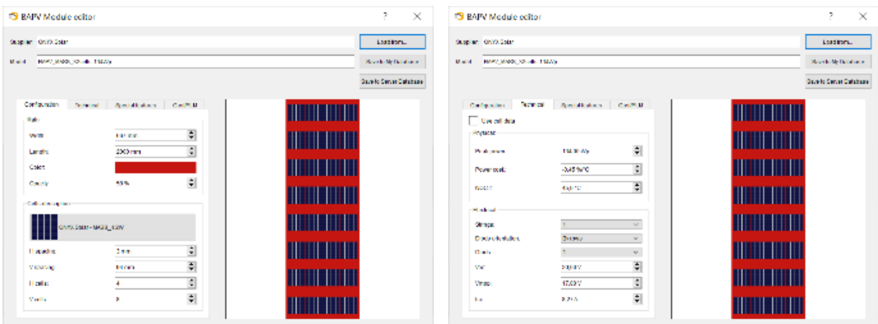


Figure 3.26: Onyx Solar – Detailing modules – Double sized (final choice)

3.7.3.2 CLADDING MODULES VARIANT 38 – BAPV features

BIPV equivalent MODULES (source ONYX Solar) 48 cells / 202Wp 667mm x 2000mm	
BIPV equivalent MODULES (source ONYX Solar) 44 cells / 185Wp 667mm x 2000mm	
BIPV equivalent MODULES (source ONYX Solar) 40 cells / 168Wp 667mm x 2000mm	
BIPV equivalent MODULES (source ONYX Solar) 36 cells / 151Wp 667mm x 2000mm	
BIPV equivalent MODULES (source ONYX Solar) 32 cells / 134Wp 667mm x 2000mm	

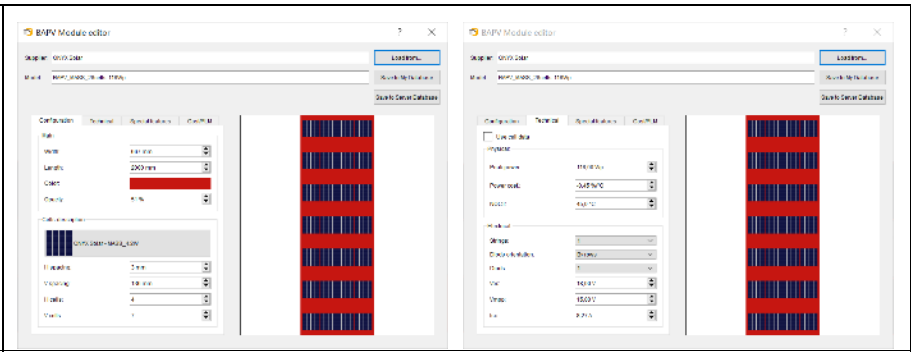
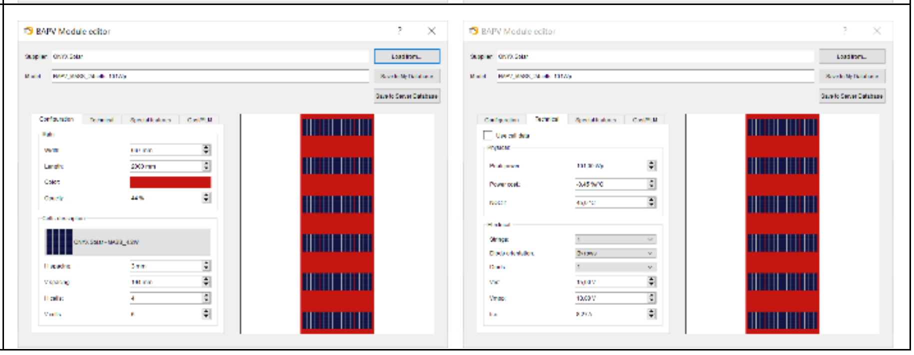
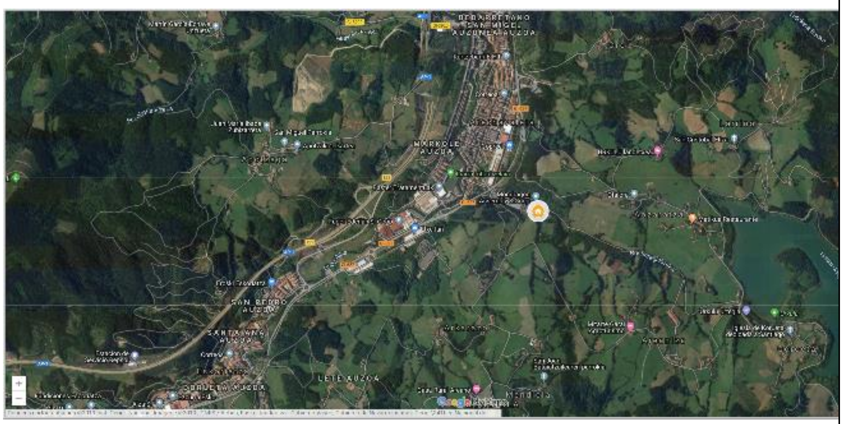
BIPV equivalent MODULES (source ONYX Solar) 28 cells / 118Wp 667mm x 2000mm	
BIPV equivalent MODULES (source ONYX Solar) 24 cells / 101Wp 667mm x 2000mm	

Figure 3.27: Configuration of ONYX Solar V38 modules

3.7.3.3 WEATHER DATA and IRRADIATION MODELING

We chose to use the European open access reference tool PVGIS to generate meteorological + site data at the exact location of the demo site. Visualization from satellite enable considering terrain modelling, albedo evaluation and masking effects.

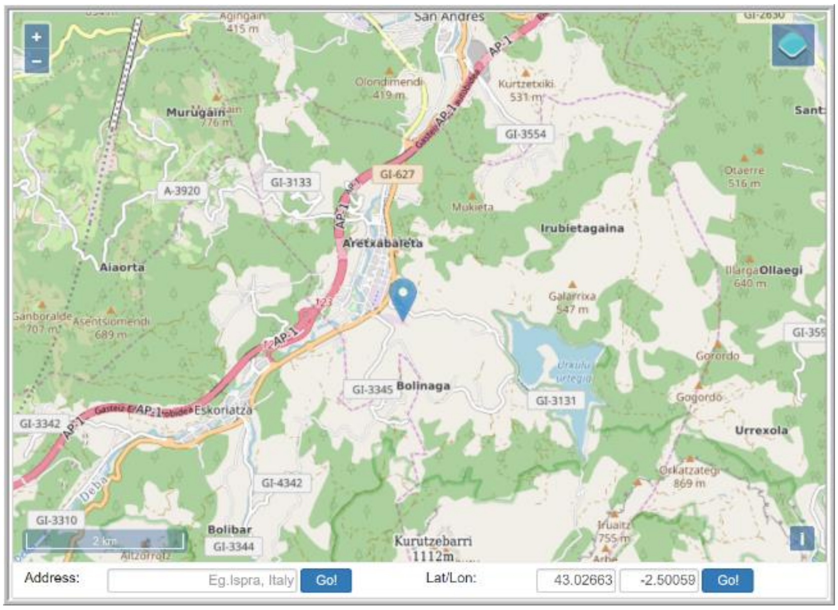
GEO LOCATION ➔ Google Maps	
➔ PVGIS	

ALBEDO

- ➔ 20% for surroundings (grass)
- ➔ 50% for building (metal)

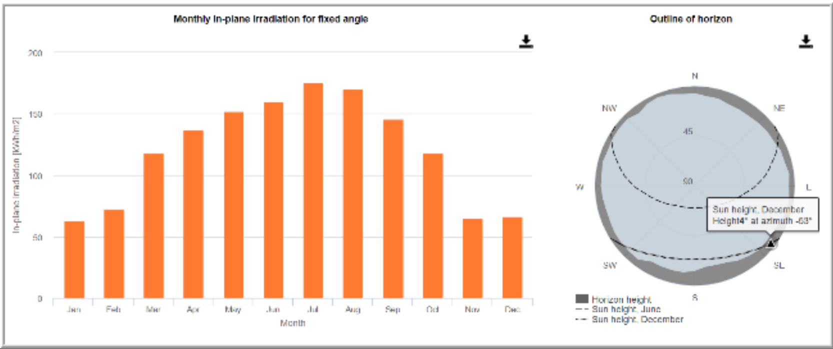
ORIENTATION

- ➔ +30° from picture interpretation



HORIZON IN PLANE IRRADIATION for typical 35° PV angle

- ➔ Masking at winter for PV production

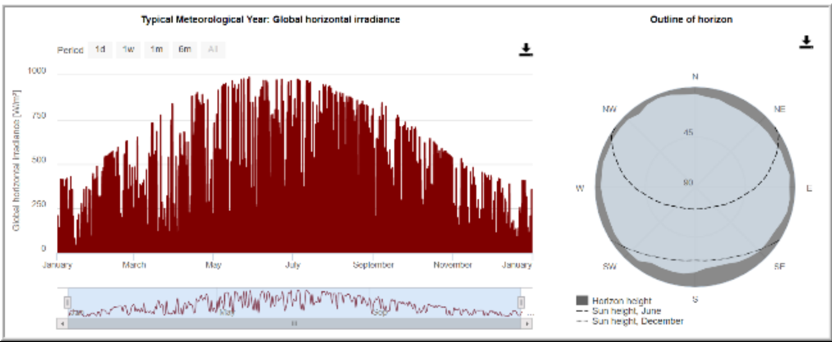


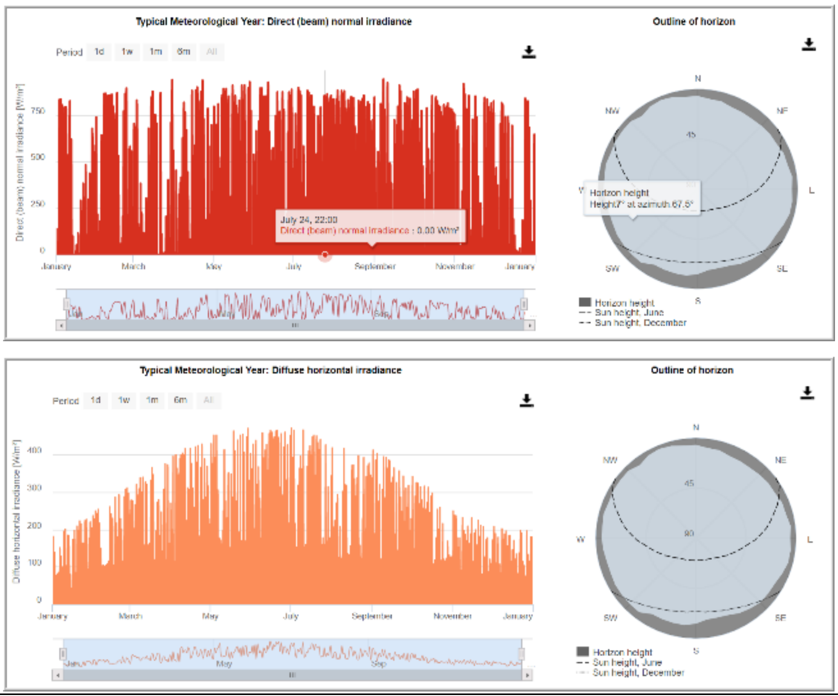
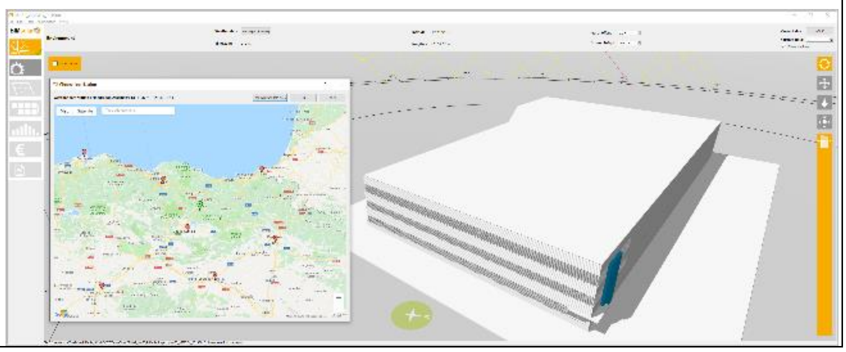
IRRADIANCE

TMY data to generate weather file as input for BIMsolar (epw)

TMY Period: 2007-2016

Time step: hourly



	
BIMsolar epw importation Sun course / heliodon	

3.7.3.4 3D MODELING - SETUP- EXISTING BUILDING

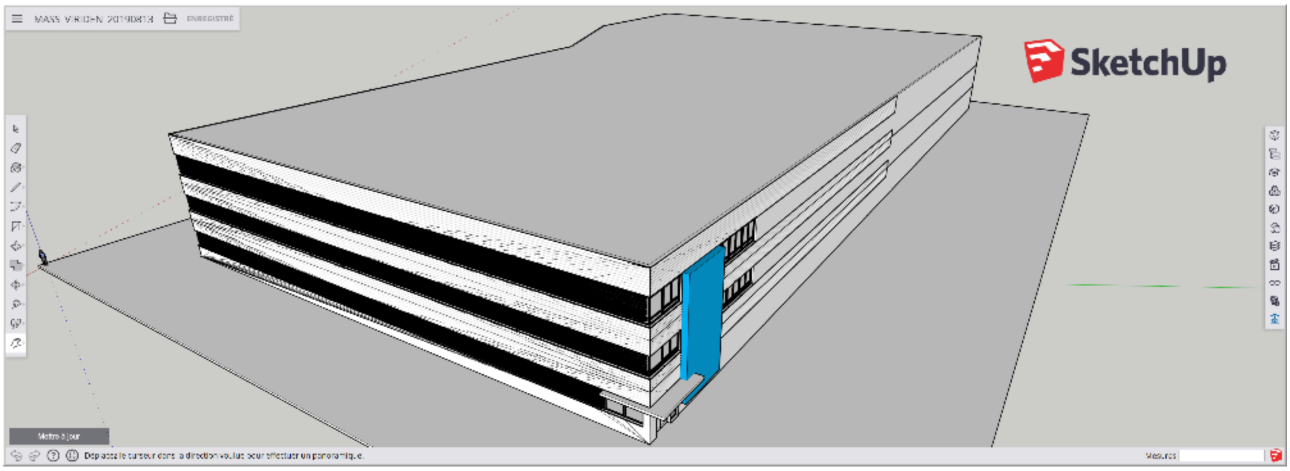


Figure 3.28: Modelling has been made as much realistic as it could be from the existing 2D plans to address BIPV issues (Trimble SketchUp model from Viridén+Partner)

STEP#1-BIMsolar IMPORTATION – Building settings

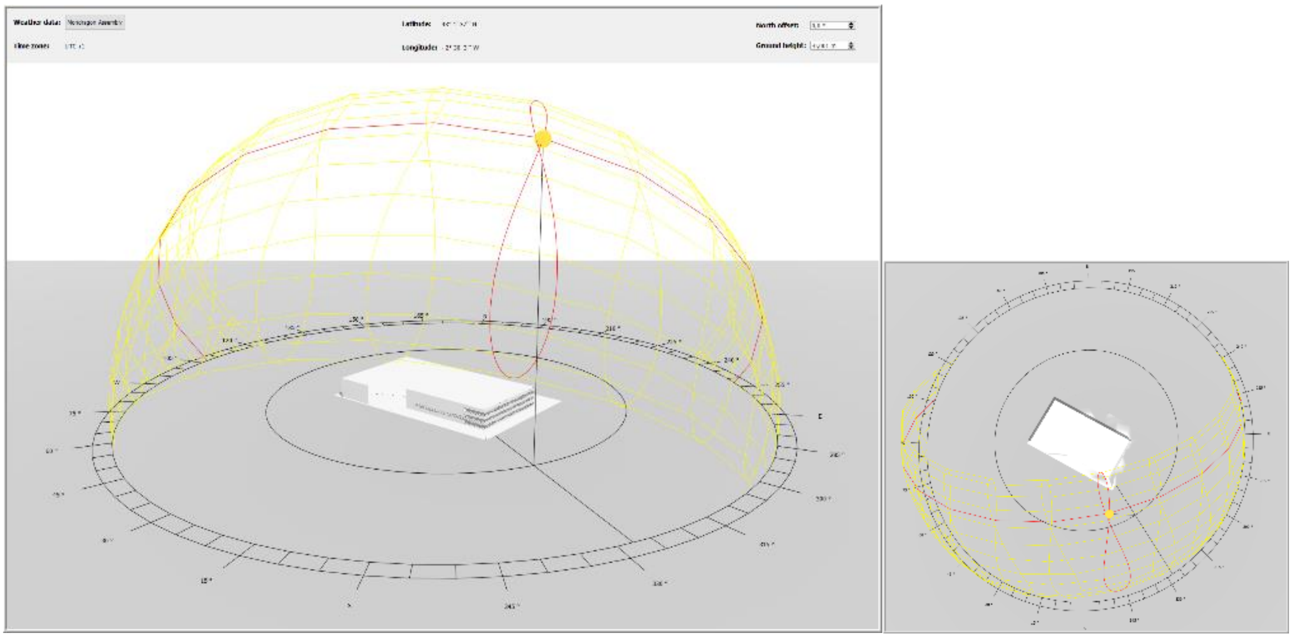
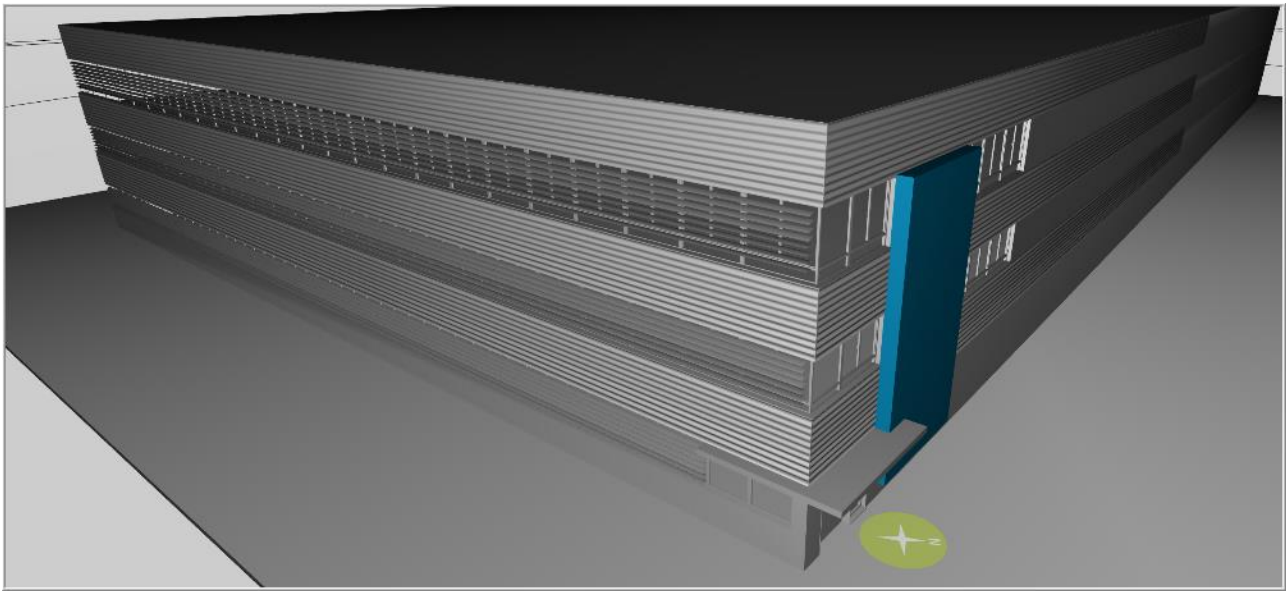


Figure 3.29: Close and far shadowing calculation are made through 3D modelling of realistic buildings - Sun course for full year is displayed at hourly step time



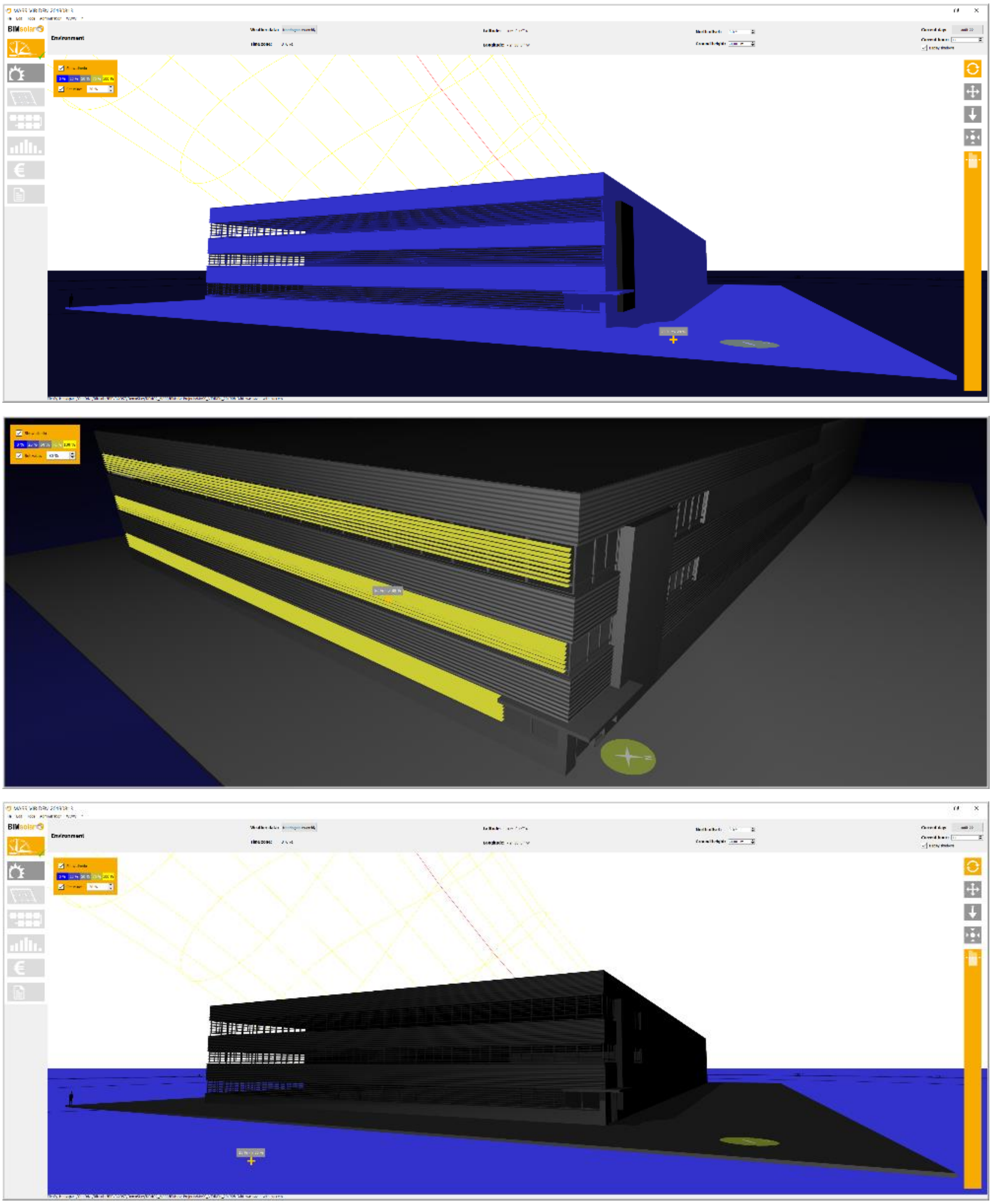


Figure 3.30: Albedo effects (reflected irradiance) are generated selecting groups and types of surfaces 20% for surroundings; 50% for the building envelop; 80% for cladding as a general approach

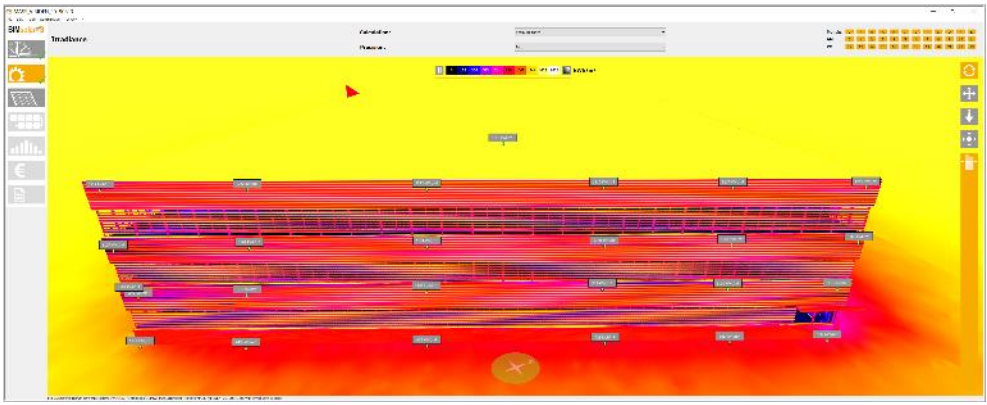
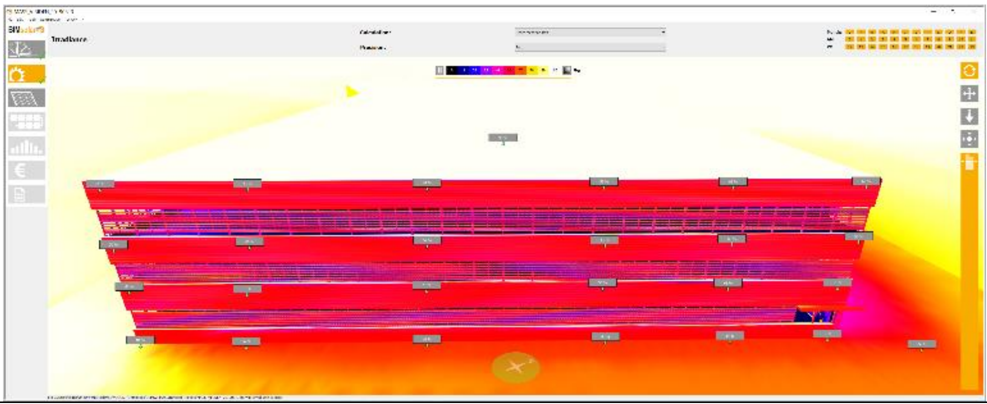
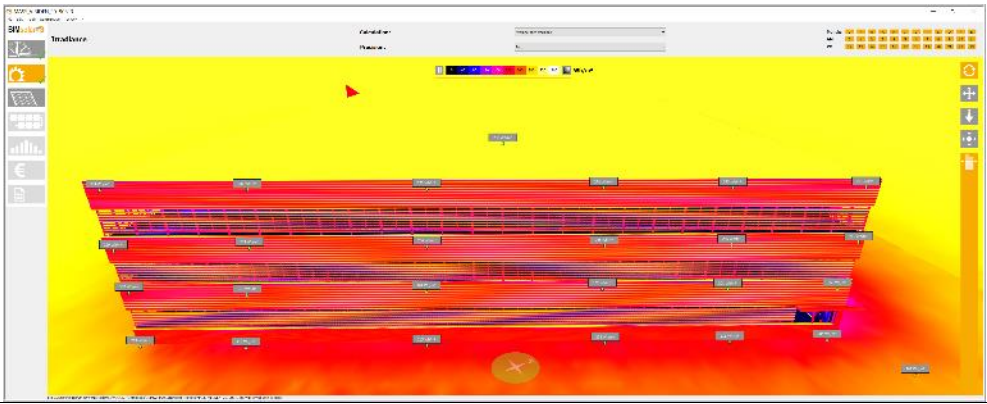
3.7.3.5 Simulation – Results

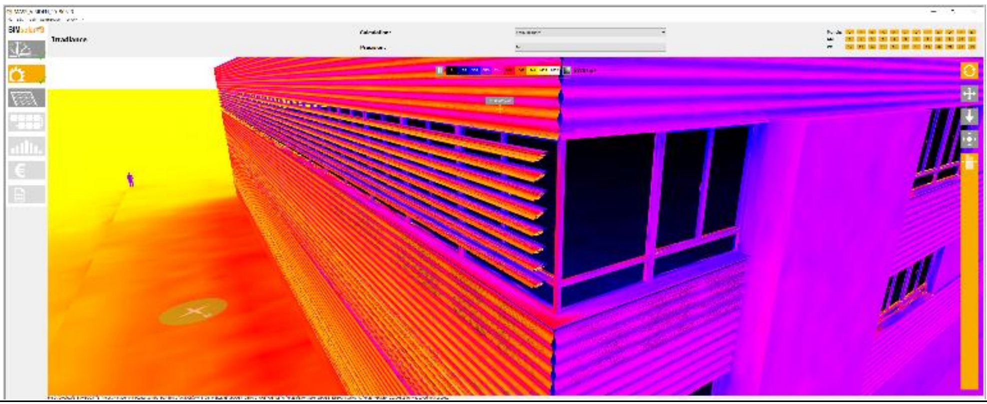
STEP#2-IRRADIATION

We use markers to record and visualize values. We compared 2 versions of the building 3D model: with cladding detail (corrugated surface) and without

Sets of data can be exported in CSV

Corrugated cladding version – Mapping at maximum potential

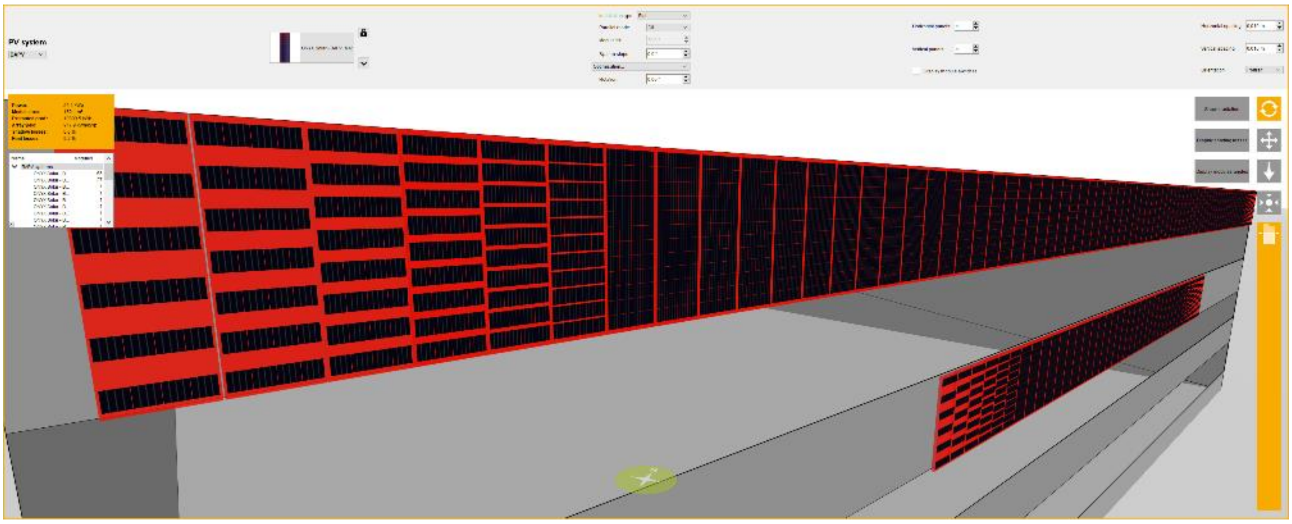
Global survey on East facade Yearly kWh/sqm Some discrepancies may be due to complex surfaces (corrugated cladding) →1200 kWh/sqm minimum recorded on top row	
Global survey on East facade Direct reception ratio →60% recorded	
Global survey on East facade Average daily irradiance →270 kWh/sqm minimum recorded on top row	

Detail on on East and North facades Yearly kWh/sqm	

STEP#3 – BIPV layouts

We use virtual modules set-up from manufacturer's datasheets (see above) to generate BAPV systems. PV generation, electrical production, shading losses, temperature losses and other performance indicators are calculated in real time from module level to BIPV layout level. Every single module is computed as a system and the software displays individual KPIs.

Detailed results can be obtained at STEP#5 (BIMsolar reference process).



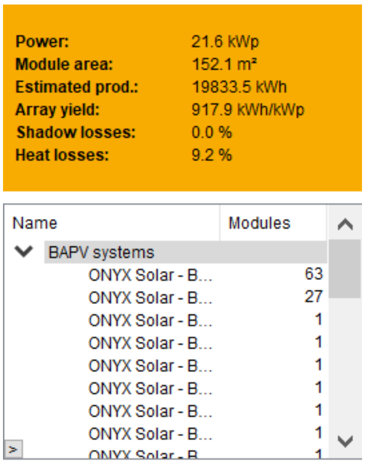


Figure 3.31: Global results – All layouts – V38 version – non tilted BAPV modules

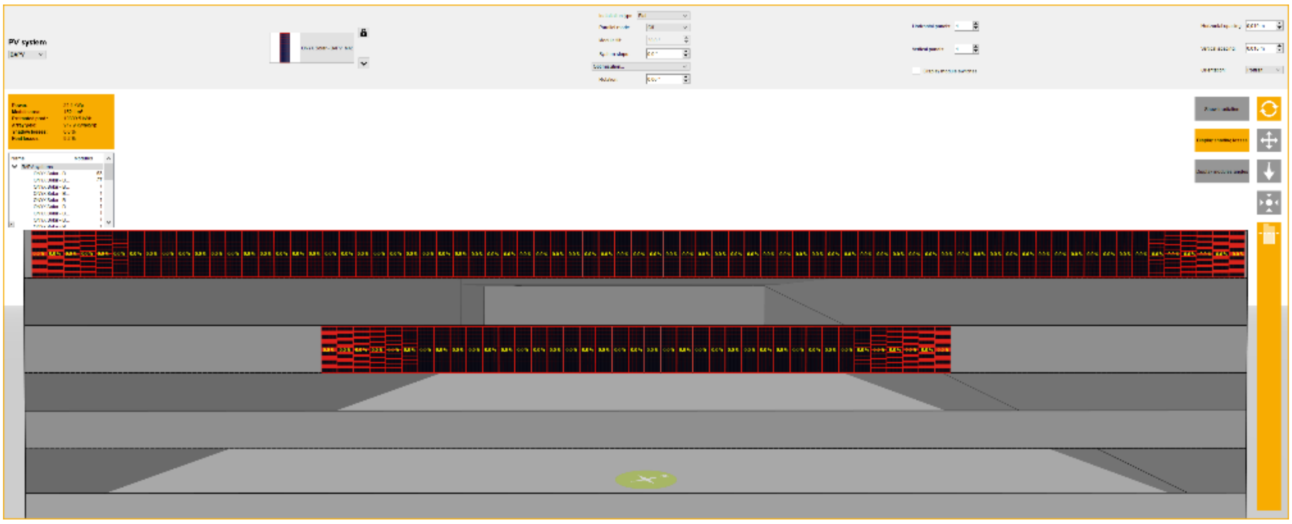


Figure 3.32: Mapping of shading losses – No issue – No significant shading

STEP#4 – INVERTERS / WIRING

This step consists in building the best strategy for the implementation of inverters and connect to them the strings of modules to optimise the DC and AC productions.

BIMsolar enables considering the mismatching between modules (gaps in irradiance due to shading effects), then proposes the best wiring configuration for each MPPT to maximise the energy production.

We used this functionality to deliver representative KPIs at pre-study stage before the selection of the final inverter.

For this study, we selected a typical SMA Solar string inverter: Sunny Tripower 15000TL-30

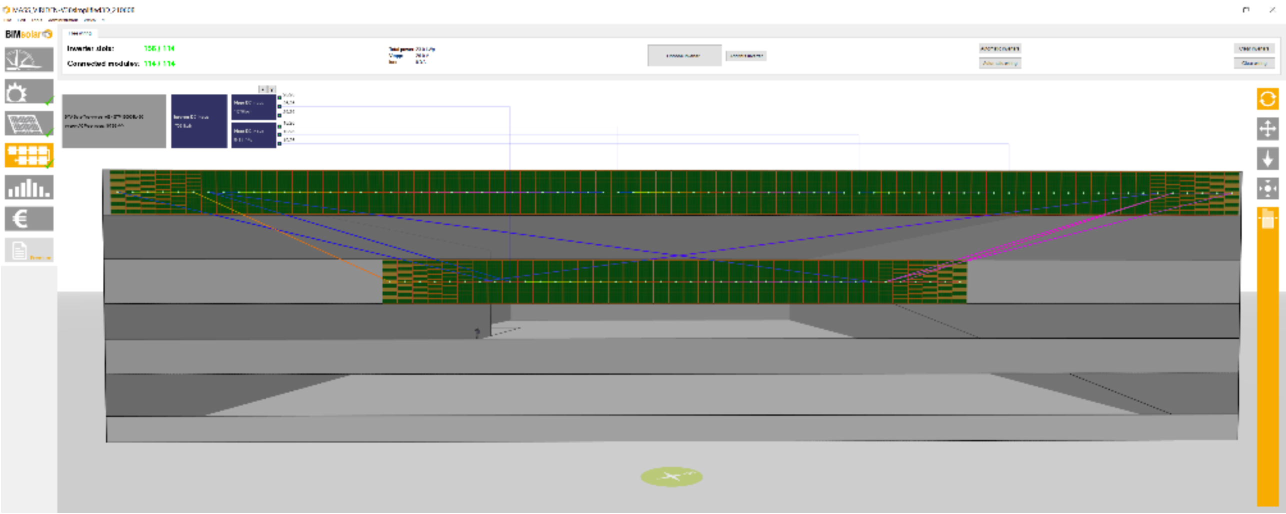


Figure 3.33: Inverter selection and optimized wiring – 1 string inverter / 2 MPPTs

STEP#5 – RESULTS

BIMsolar offers a comprehensive set of detailed results, from yearly to hourly timestep, covering irradiance, shading losses, heat losses, production, yield… from module level to layout level.

Example:

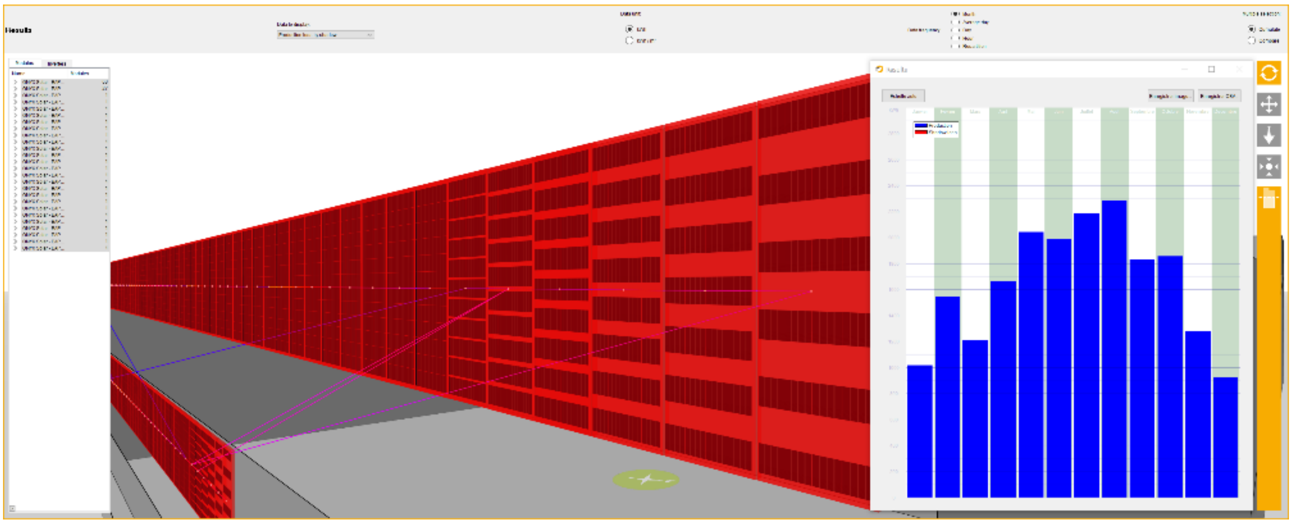
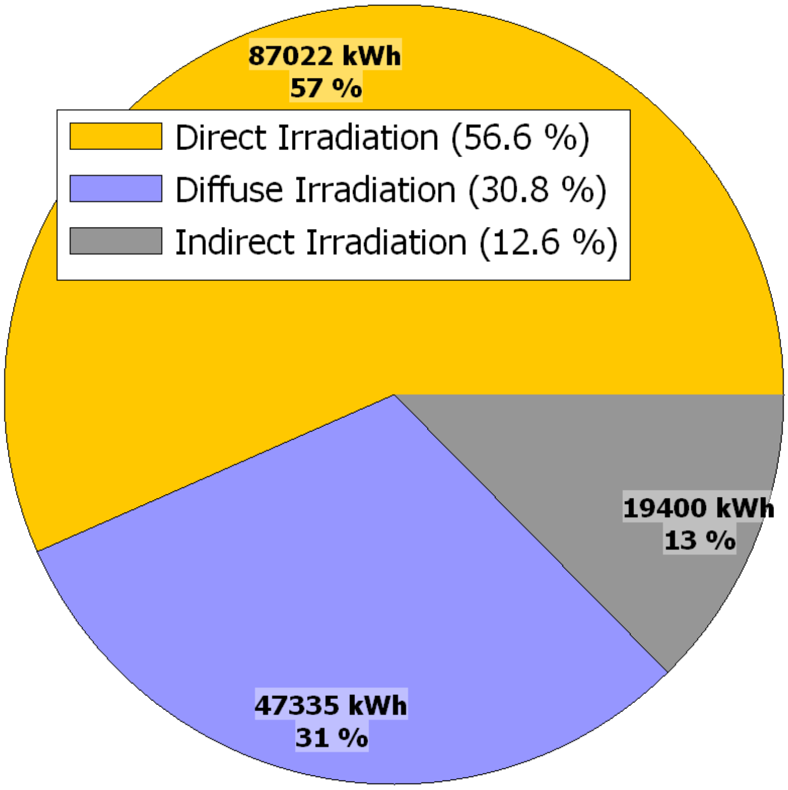
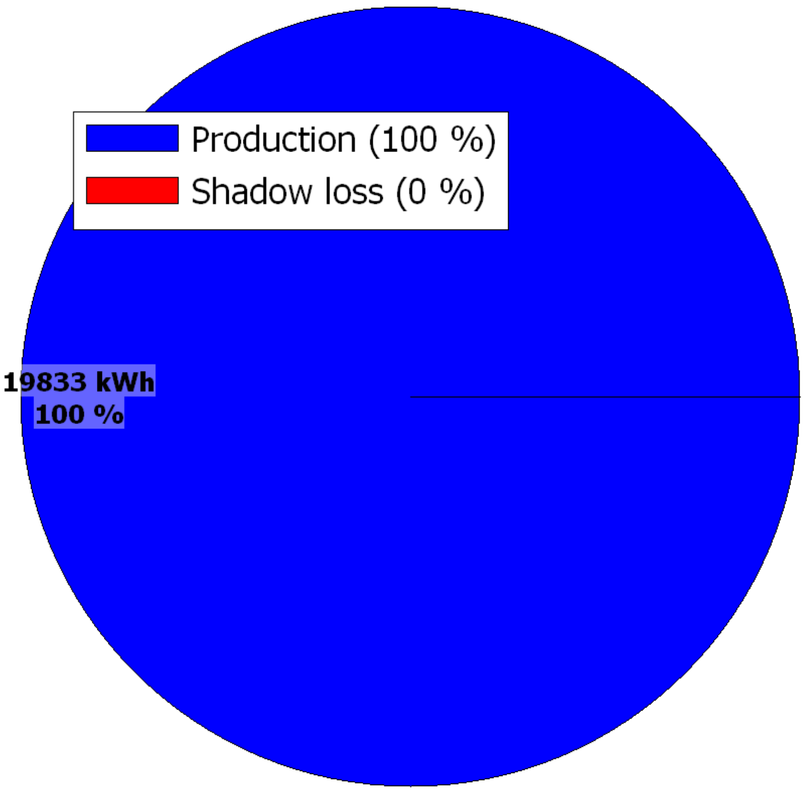
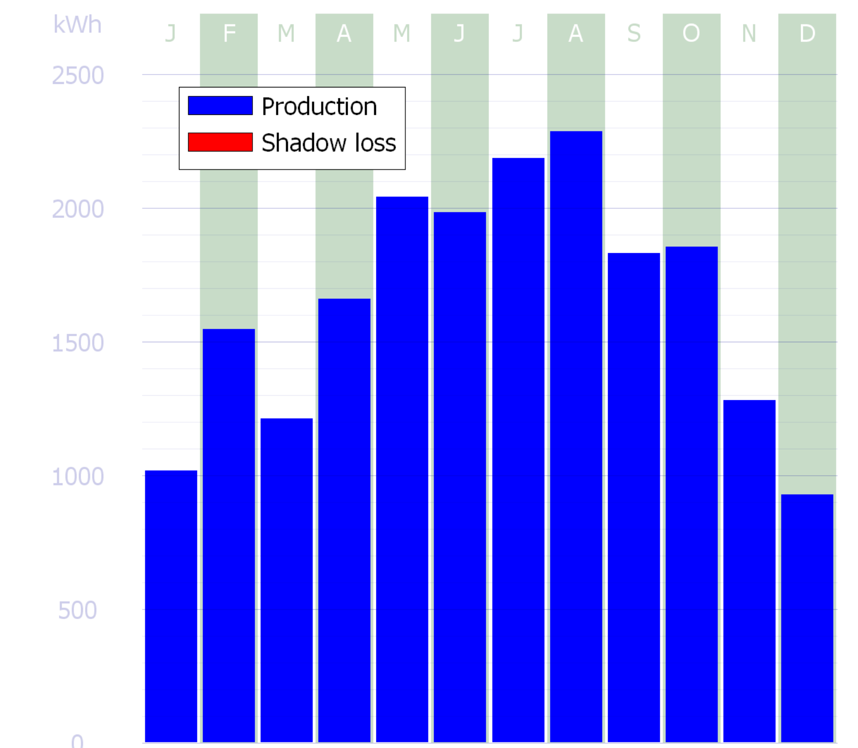
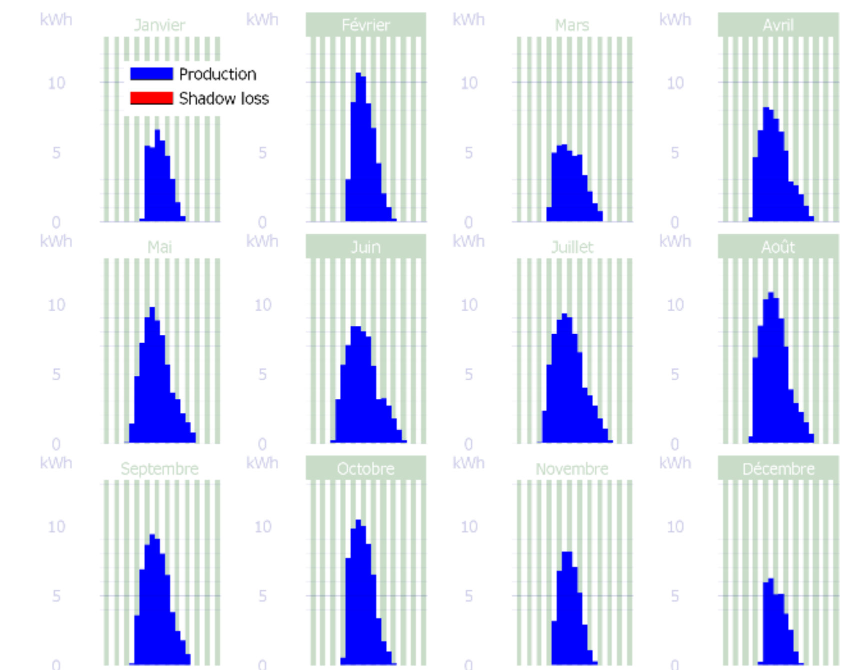
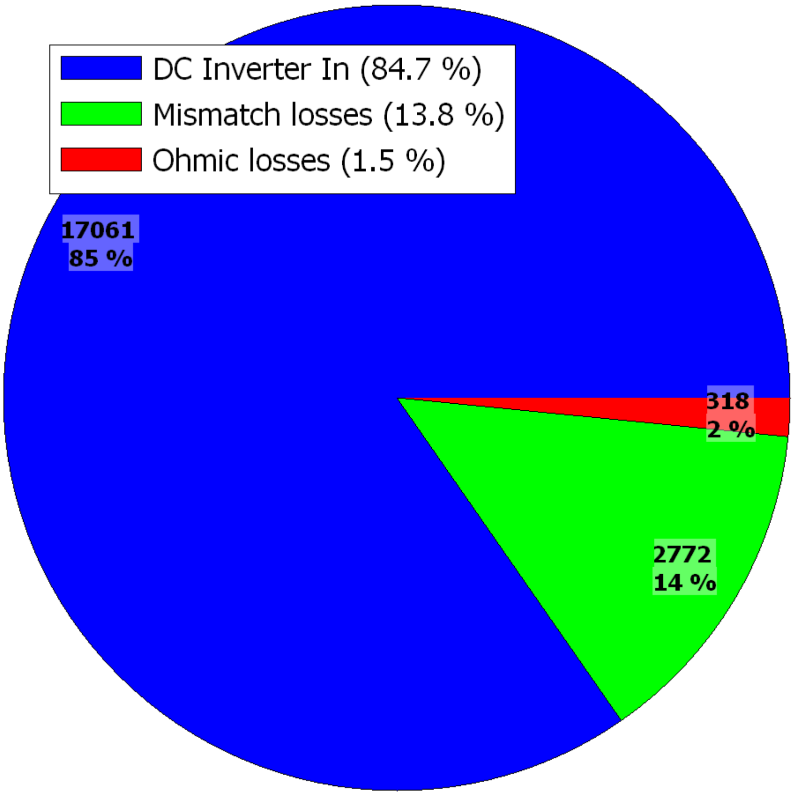


Figure 3.34: Monthly AC generation + ohmic losses: inverter output

EAST FAÇADE – Variant 38 - non tilted modules - Table of results:

IRRADIATION share - Annual GLOBAL BAPV ARRAY	
PV Generation – Shading losses GLOBAL – Year #1 →19 833 kWh No shading issue Array Yield = 918 kWh/kWp	

PV Generation – Shading losses MONTHLY No losses August is the top production month	
PV Generation – Shading losses AVERAGE DAY / MONTH →best months Feb, Aug & Oct 10:00AM, over 10kWh	

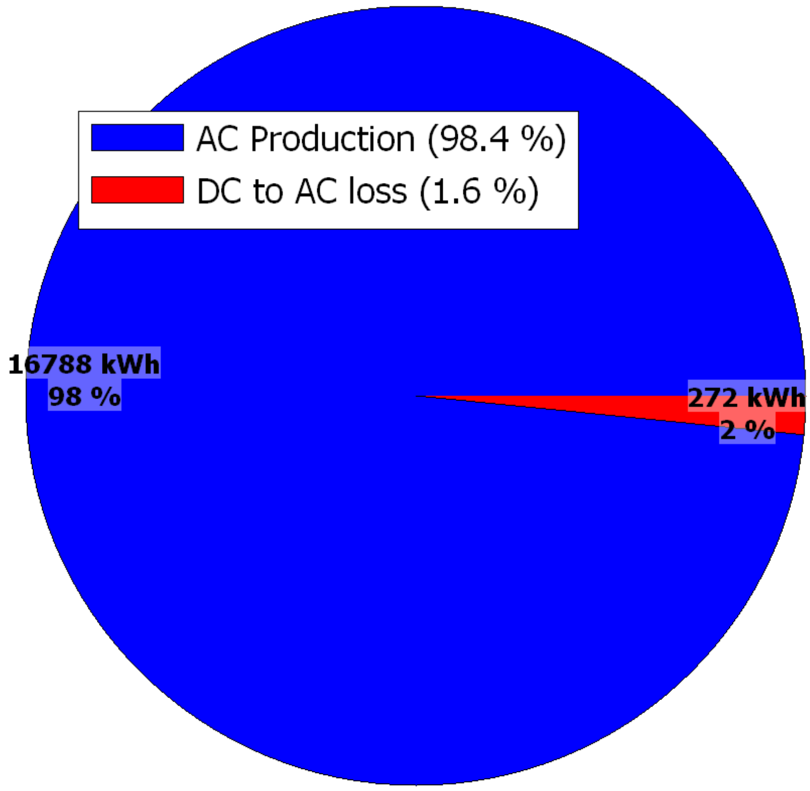
DC Production (Inverter IN) Year #1 = 17 061 kWh Losses (strings) Significant mismatch losses (from wiring)	

AC Production (Inverter OUT)

Year #1 = 16 788 kWh

Losses (strings)

Final Yield = 776 kWh/kWp



3.7.4 Summary of the results

	Array							Inverter			Yield
Unit	kWh		degree			kWh	kWh	kWh	%	kWh	kWh/kWp
	Irradiation		Panel orientation			PV generation	DC inverter IN	Losses		AC inverter OUT	AC inverter OUT
		East facade		Azimut*	Tilt	East facade	East facade	East facade	East facade	East facade	East facade
	Direct	87 022	East	-60,0	90,0	19 833,0	17 061,0	273	1,6%	16 788,0	776,0
	Diffuse	47 335									
	Indirect	19 400									
		153 757,0	*South = 0°			19 833,0	17 061,0	273,0	0,0	16 788,0	776,0
TOTAL:	153 757,0					19 833,0	17 061,0			16 788,0	MEAN VALUES

3.7.5 Conclusions

At the current stage of the validated performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are exploitable and converging towards performance expectations. Even if we did not face critical difficulties in the process, discussions must be engaged to fix the electrical strategy so to work in detail on the string/inverter calculation. Some key points about this pre-study:

- East façade (before modules integration) is homogeneous regarding irradiance mapping. Simulation seems to perform correctly, with 10 years based Typical Meteorological Year file from PVGIS,
- No shading issues, no irradiation mismatching,

- Direct reception ratio seems correct (60%),
- Array yield: 918 kWh/kWp,
- PV generation seems to be quite well balanced within a full year period (January production is 43.5% of August),
- The AC production could be optimized with a stronger strategy mitigating the mismatching for strings and more technical studies on the inverter side. Final yield is 776 kWh/kWp.

Next steps will be:

1. Update of the building 3D model, related to final and detailed BIPV studies (demo site manager + partners),
2. Implementation of COLOURED BIPV modules expert configurator and simulation models (T6.3) into BIMsolar,
3. Final set up of the modules and the mounting structure following ONYX Solar and TULIPPS manufacturing specifications,

Comparison between measurement and simulation as soon as the real modules will be integrated

3.8 PLANNING TIMELINE

Below is the planning timeline for the MASS demonstration site at the time of writing. The Gantt chart is a living document and available via the BIPVBOOST shared platform.

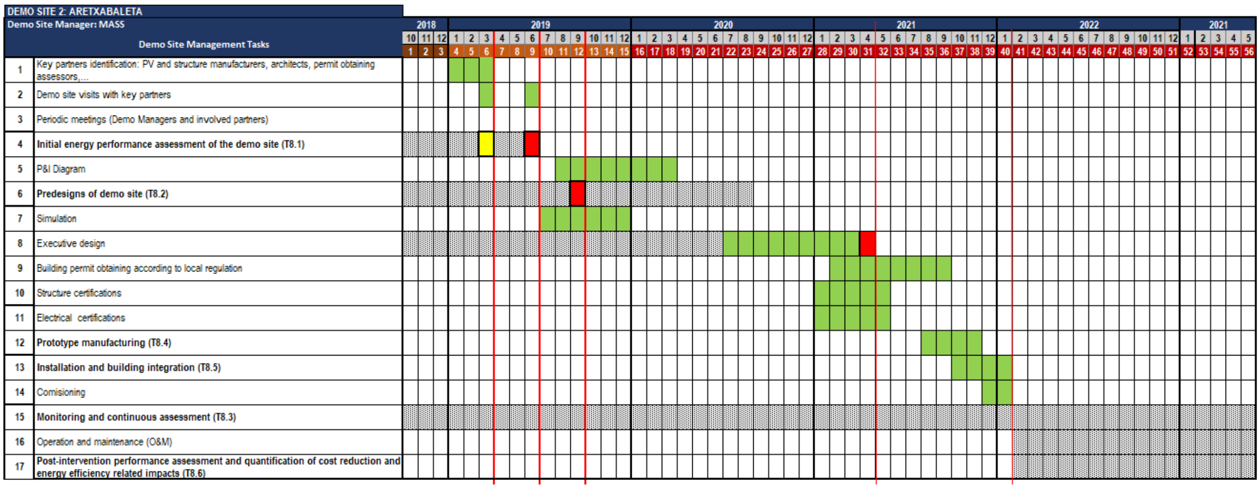


Figure 3.35: MASS *Demo-site Gantt Chart*

4 DEMO SITE 3: OPTIMAL

4.1 DEMO-SITE BUILDING DESCRIPTION

4.1.1 Building description

The house is in Belgium, Saint-Denis (close to the town of Mons), which is located close to the French border (Lat. 50°28'). The building is a residential family house for a family of 5 persons constructed in 1997 (Figure 4.2). Next to this building there is a small office and a kitchen room added in 2011 (Figure 4.313). The main house is constructed in blocs and bricks while the office is constructed in wood with a beam structure and a very good insulation level with triple glazing.

Figure 4.1: Google and CAD view of the whole building

The building is connected to the electrical public grid network with a single-phase connection and a 40 A meter. The building is also connected to the gas network in order to feed the gas boiler.

4.1.2 General topology

The external dimensions of the main house are 13.4 m long and 8.8 m wide resulting in a ground floor area of 118 m^2. At the first floor the area is a little bit smaller and equal to a value of 92.4 m^2. The dimensions of the added rectangular office are 10 m long and 4.3 m wide providing a ground floor area of 43 m^2. The kitchen room area is 17 m^2. Therefore, the total floor area of the building including the external walls is 270 m^2.

The house contains a cellar and ventilated room of smaller height under its total surface making it an ideal place to install the batteries. There is a good technical connection between the roof and the cellar in order to place the wiring between the roof and the batteries including any monitoring devices.

Figure 4.2: Picture of the house with the front view (left) and the back view (right)

Figure 4.3: Picture of the office next to the house (left) and top view of the whole building (right)

4.1.3 Grid connection & Equipment

The building is connected to the electrical public grid network with a 2 phases connection and a 40 A meter. The building is also connected to the gas network in order to feed the gas boiler. In order to support the increased power brought by the BIPVBOOST panels, the general meter will require to be upgraded to 3 phases connection of a power of 13,9 kVA.

The **main building** is equipped with 2 heating systems: a gas boiler of a power of 21 kW to heat the water radiator and to produce the Domestic Hot Water (DHW). The building is also equipped with a HVAC air/air HP of a power of 8 kW and capable to heat or cool the main house building. This HVAC in the main building is controllable. This will require to buy a device making the interface between BEMS system and the HVAC equipment. The internal HVAC unit is a Toshiba RAV-SM806BTP-E and an interface IntesisBox TO-RC-KNX-1i or similar (IntesisBox TO-RC-MBS-1 or IntesisBox TO-RC-BAC-1).

The **office** attached to the main building is equipped with a small HVAC Heat Pump (HP) capable to produce heat in winter and to cool the office in summer. The power of this HP is 2.5 kW. This HP cannot be controlled.

This setup offers various possibilities to control the building temperature mainly by using either the HVAC of 8 kW or the gas boiler to heat the main house.

In the scope of the BIPVBOOST project, this demonstration site will be equipped also with electric batteries.

There are already PV panels: 3.5 kWp on the west roof slope and 1.4 kWp on the flat roof next to the main building. The plan is to replace the one on the roof slope (3.5 kWp) with the one coming from BIPVBOOST.

4.1.4 Energy consumption

The electricity contract is a dual Day and Night meter. The night schedule is from 10pm until 7 am and also includes the weekend. The electricity tariff increased a lot in the last year. In 2016, the 'Night' tariff was around 4 c€ / kWh and the 'Day' tariff was around 7 c€ / kWh. In 2017, the 'Night' tariff was around 5 c€ / kWh and the 'Day' tariff was around 6.5 c€ / kWh. Additionally, there are also other costs to be added: the network cost (including the distribution and transportation costs), the fixed cost and the green energy cost.

For the gas, the price was between 2.2 c€ and 2.4 c€ / kWh (2017), while it was 1.8 c€ in 2020. As for the electricity there is also several other cost such as the network cost (including the distribution and transport costs) and a fixed cost in addition

The history of electrical consumptions of the house is available for many years. An extract of these available data is provided in **Figure 4.4**. A second table is provided containing the daily measure of the current building during the month of December 2017 (Figure 4.5).

DUAL RATE METER			
Year	Yearly Total Consumption (kwh)	Yearly 'Day' Consumption (kwh)	Yearly 'Night' Consumption (kwh)
2020	8198	4186	4012
2019	8144	4433	3711
2018	8164	4440	3724
2017	8941	4934	4007
2016	6442	3259	3184
2015	6049	3078	2970
2014	5839	3255	2583
2013	6143	3368	2774
2012	6589	3760	2829
2011	5166	3059	2107
2010	3869	2167	1702
2009	4126	1911	2215
2008	3542	1490	2052
2007	3687	1702	1985

Figure 4.4: Yearly electrical consumption of the house

		Total Building			House		Office				Weather
Date	Day	Electricity 'Day' [kwh]	Electricity 'Night' [kwh]	Electricity Total [kwh]	Gas [m^3]	Electricity All Consumption [kwh]	Electricity All ([kwh]	Electricity Light [kwh]	Electricity Plugs [kwh]	Electricity HVAC [kwh]	External temperature [°C]
3/12/17 15:30	Sunday	0,7	11,5	12,2	4,2	8,2	4	0	4	0	0
4/12/17 8:00	Monday	21,6	5,3	26,9	4,1	13,9	13	1	8	4	1
5/12/17 9:30	Tuesday	16,3	5,1	21,4	5,2	11,4	10	0	8	2	4
6/12/17 7:30	Wednesday	18,3	6,9	25,2	5,8	13,2	12	1	8	3	6
7/12/17 8:30	Thursday	16,3	6,0	22,3	3,8	11,3	11	1	8	2	4
8/12/17 8:00	Friday	15,7	6,0	21,7	6,6	13,7	8	0	6	2	3
9/12/17 8:30	Saturday	0,0	17,2	17,2	10,3	11,2	6	0	5	1	-1

Figure 4.5: Measure of daily electrical and gas consumption of the current building

4.1.5 BIPV system to be installed

BIPV panels will be installed on the roof of the main building (residential house). This will consist of metal-based roofing shingles. The product will be the FLISOM CIGS module with Schweizer roof structure. The implementation will consist of a retrofitting of the current roof.

There are 2 slopes to the roof one with an orientation East and one with an orientation West. The dimension of each slope of the roof are 5.84 m large by 13.8 m long resulting in an area of 2 * 80.5 m^2 = 161 m^2 for the 2 roof slopes. From this surface, the useful area must be reduced by the ridge, the 5 roof windows, and the chimney. This provides a useful area between 140 and 150 m^2 to setup the PV panels. The new panels will be installed on both roof slopes.

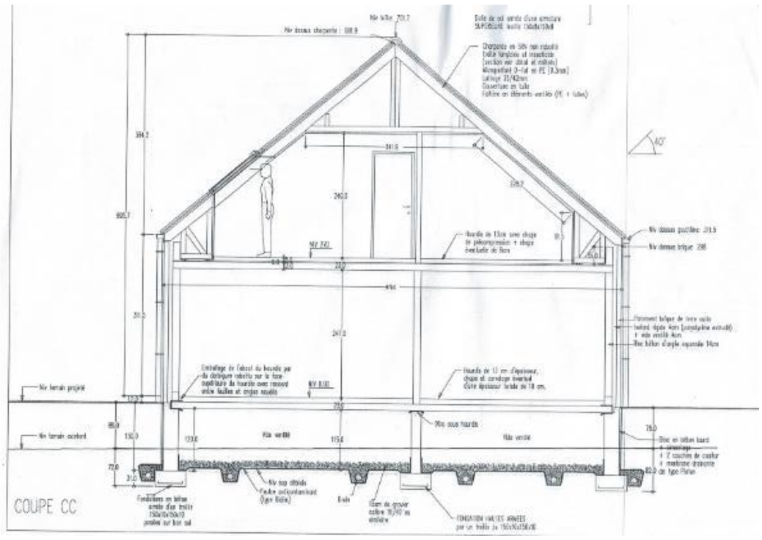


Figure 4.6: Cross section of the house showing the roof slope and dimensions

4.1.6 Monitoring system

As of 2019, before the project starts, there is no monitoring system installed in the house. Setting up the monitoring system will be part of the BIPVBOOST project.

The house is equipped with a normal residential internet connection. So, it will be possible to access or push data outside.

Regarding the weather data, there is a weather station on the residential house in Belgium used during the BFIRST project. The distance between the houses is about 4 km.

4.2 ARCHITECTURAL BIPV DESIGN

4.2.1 Existing demo-site building

Figure 4.7: Demo-site 3 building, east and west side

Table 4.1: Available roof area

	Roof east	Roof west	Total roof
Roof area (m^2)	81.48	79.23	160.71
Obstacles (m^2)(roof windows, chimney, canopy)	6.46	5.91	12.38

4.2.2 Architectural BIPVBOOST Design Options

Two initial possible design options have been elaborated with different objectives. The first one foresees to maximize the power of the installation (10.2 kWp) while the second one tries to have the best possible architectural integration, while slightly scarifying PV performance (9.3 kWp).

Moreover, for the maximum power option, three different scenarios have been established and studied in detail.

In these scenario, 3 types of panel format have been used. They are called 1V, 2V and 3V. They are approximatively 1 unit large, 2 unit large and 3 unit large.

4.2.2.1 Design option 1.1 ("Max Power")

This option is represented in Figure 4.8. In this scenario 2V modules are mainly used because they offer the best compromise between maximizing the cell area per roof surface area. These 2V modules are completed by 1V modules in order to fill in as much as possible the usable roof surface. The number of each type of0 module is summarized in Table 4.2. The total power of this configuration is 10.2 kW.

4.2.2.2 Design option 1.11 ("Max Power")

With the option (Figure 4.9: Scenario 1.11 (Max power).: East (top), West (bottom), one row of 1V panel is added inside the east roof and 2 rows of 1V panel on the west roof in order to gain a little more power. The total power is 10.38 kW.

4.2.2.3 Design option 1.12 ("Max Power")

This option (Figure 4.10) is identical to the previous one except that no active panels are placed on the east roof in the small triangular part in the centre. The total power is 10.26 kW.

4.2.2.4 Design option 1.2 ("Max Power")

With the option (Figure 4.11), 3V panels are used in order to check if the panels offering the highest power density but smaller geometrical flexibility could bring more power. However, the total power is smaller than the previous options mainly because spaces is lost on the left and right part of the roof slopes. The total power is 9,81 kW.

4.2.2.5 Design option 2 ("Best architectural integration")

The two inclined roofs are completely implemented in the roof area with frameless modules (Figure 4.12). With the color-coordinated sheet steel, profiles and modules, the roof can be perceived as a total area. With dummy modules, the remaining areas can be connected to the existing skylights and the chimney as well as the porch.

Option 2, unlike option 1, is based on two types of modules. The main part of the roof area is provided with the narrow, vertical module types (1V). Only on the edge do the broad module types occur. By this division, a uniform image is generated, despite the different location of the existing skylights, which cut through the roof surface. The total power is 9.42 kW.

Table 4.2: Summary of panel placement options and their power

	East				West				
	1V modules	2V modules	3V modules	kWp	1V modules	2V modules	3V modules	kWp	Total
Option 1.1	15	80	0	5,25	11	77	0	4,95	10,2
Option 1.11	12	83	0	5,34	22	73	0	5,04	10,38
Option 1.12	12	81	0	5,22	22	73	0	5,04	10,26
Option 1.2	6	23	41	5,25	9	16	37	4,56	9,81
Option 2	162	0	0	4,86	144	4	0	4,56	9,42
Option1.11 (refined)	24	75	0	5,22	19	70	0	4,77	9,99

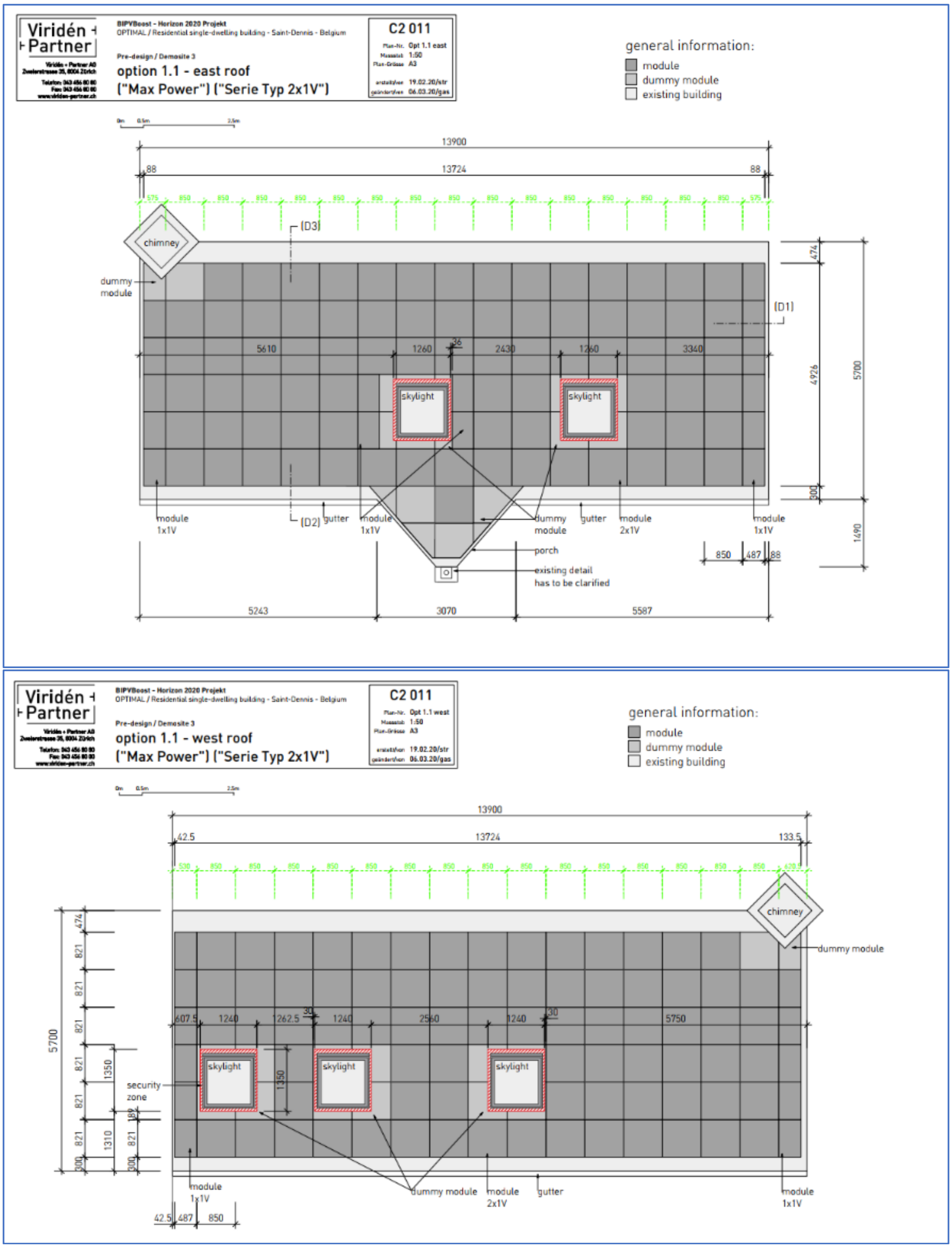
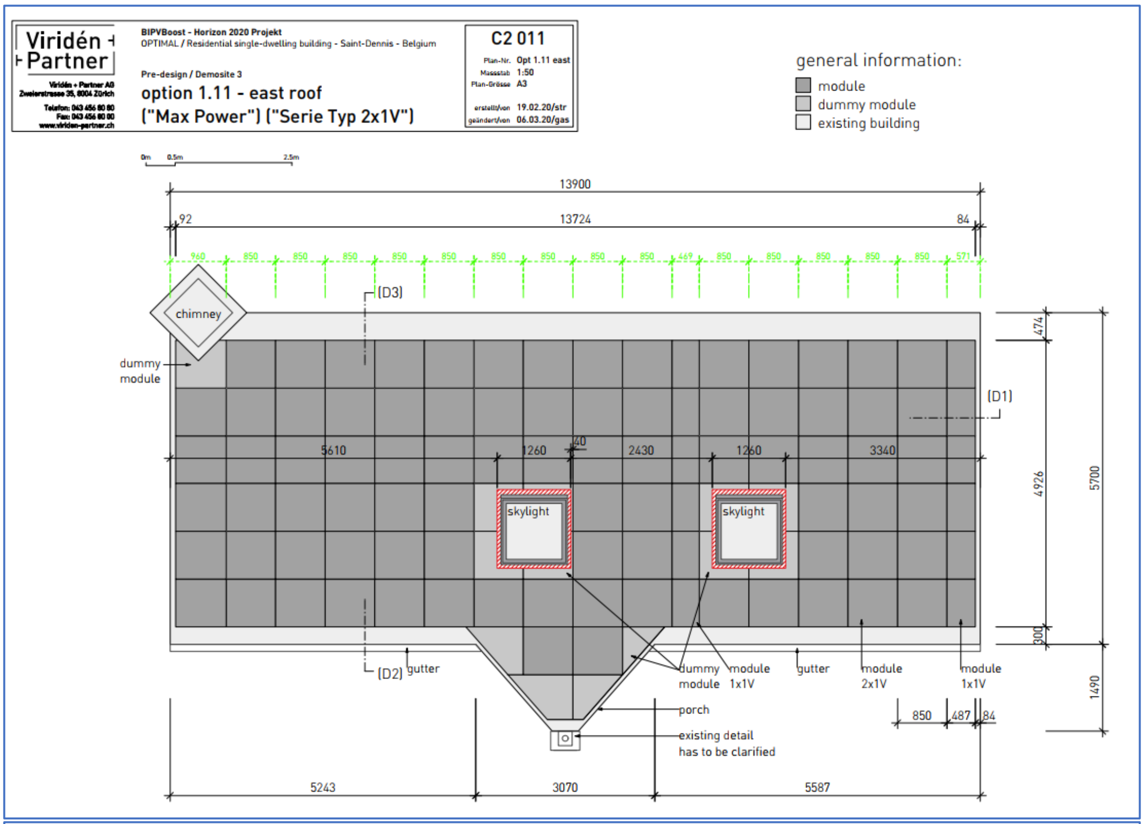


Figure 4.8: Scenario 1.1 (Max power). East (top), West (bottom)



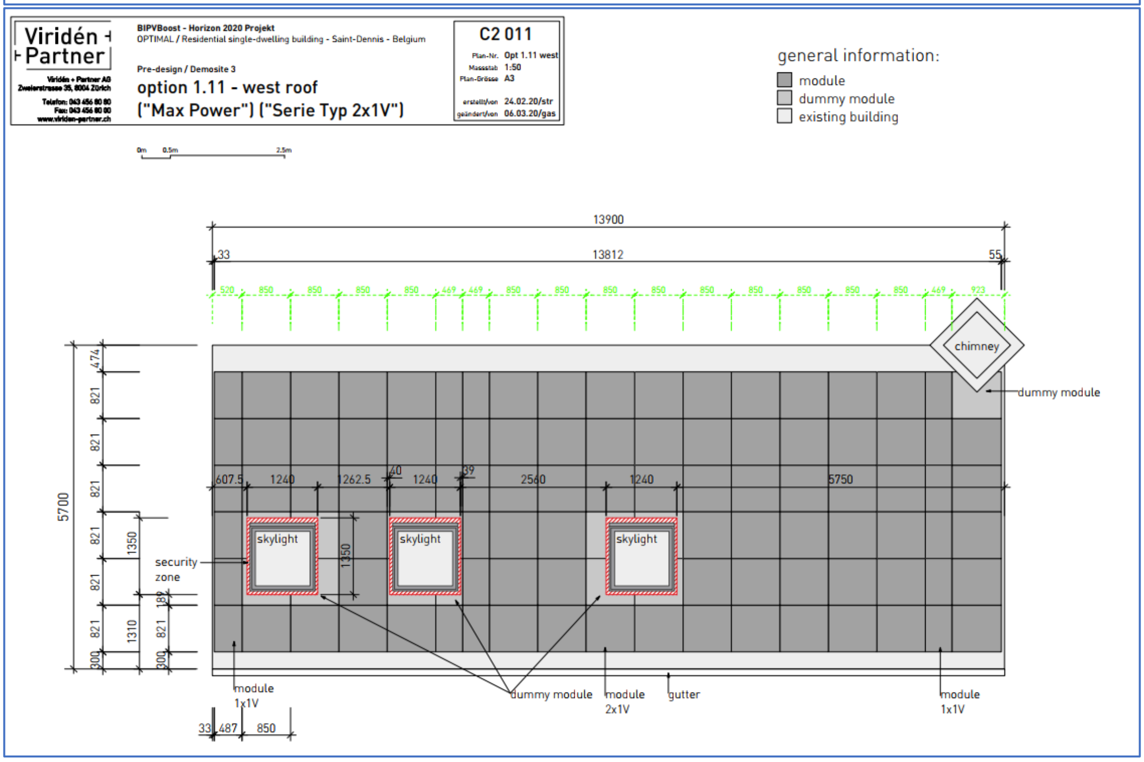


Figure 4.9: Scenario 1.11 (Max power).: East (top), West (bottom)

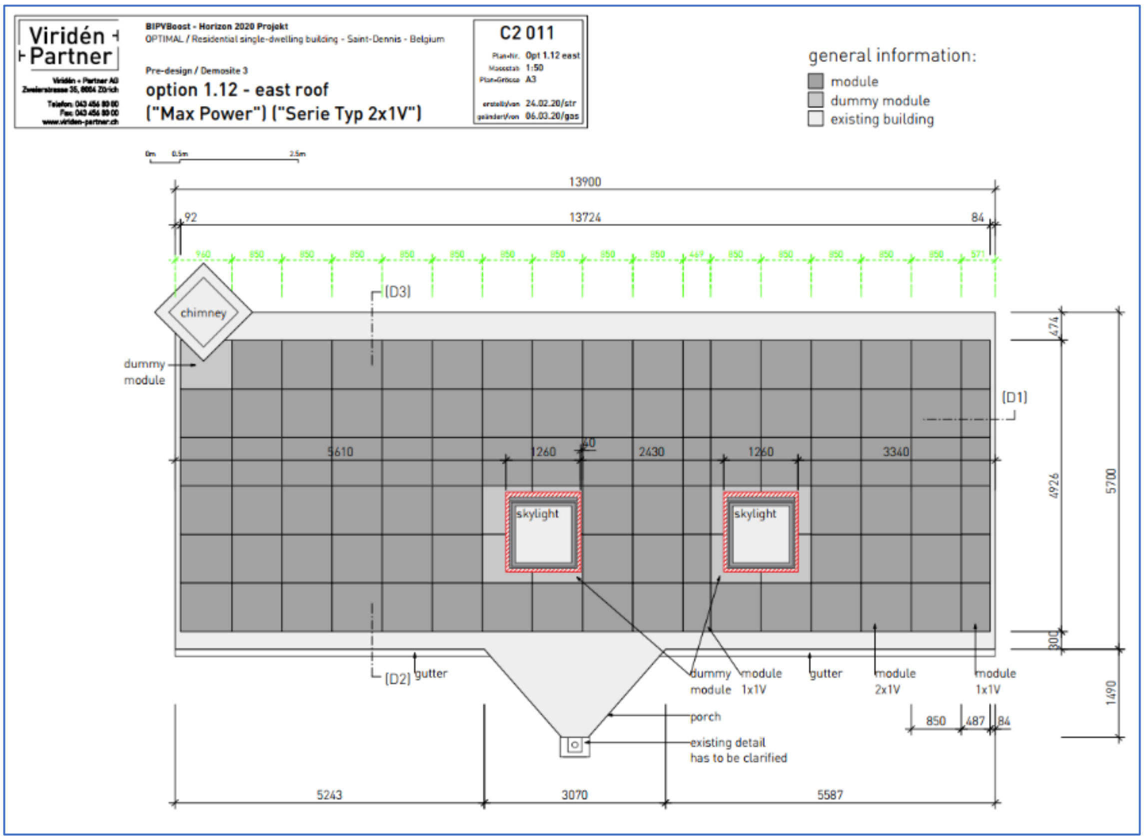


Figure 4.10: Scenario 1.12 (Max power). Alternative option for the East roof

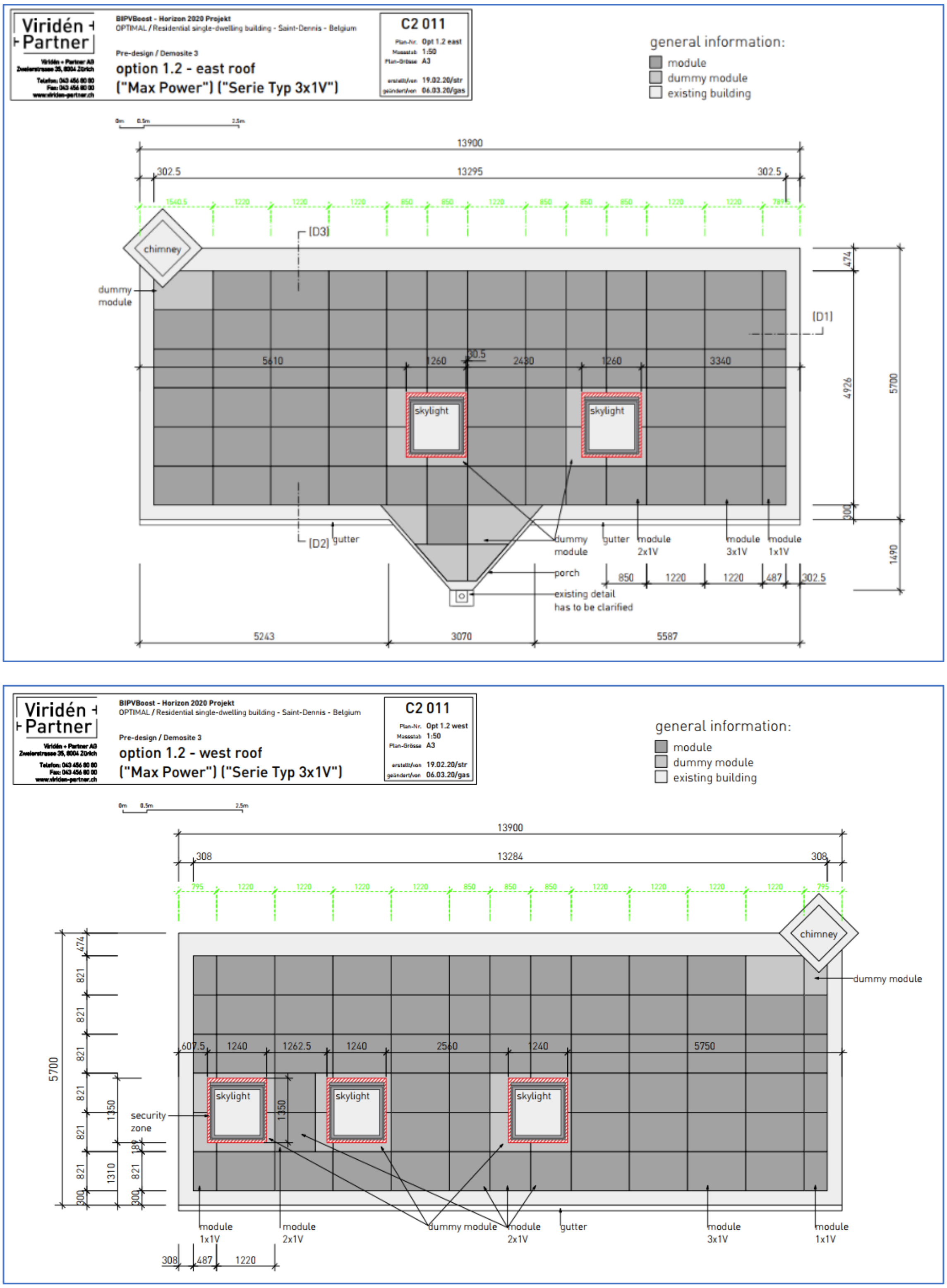


Figure 4.11: Scenario 1.2 (Max power). East (top), West (bottom)

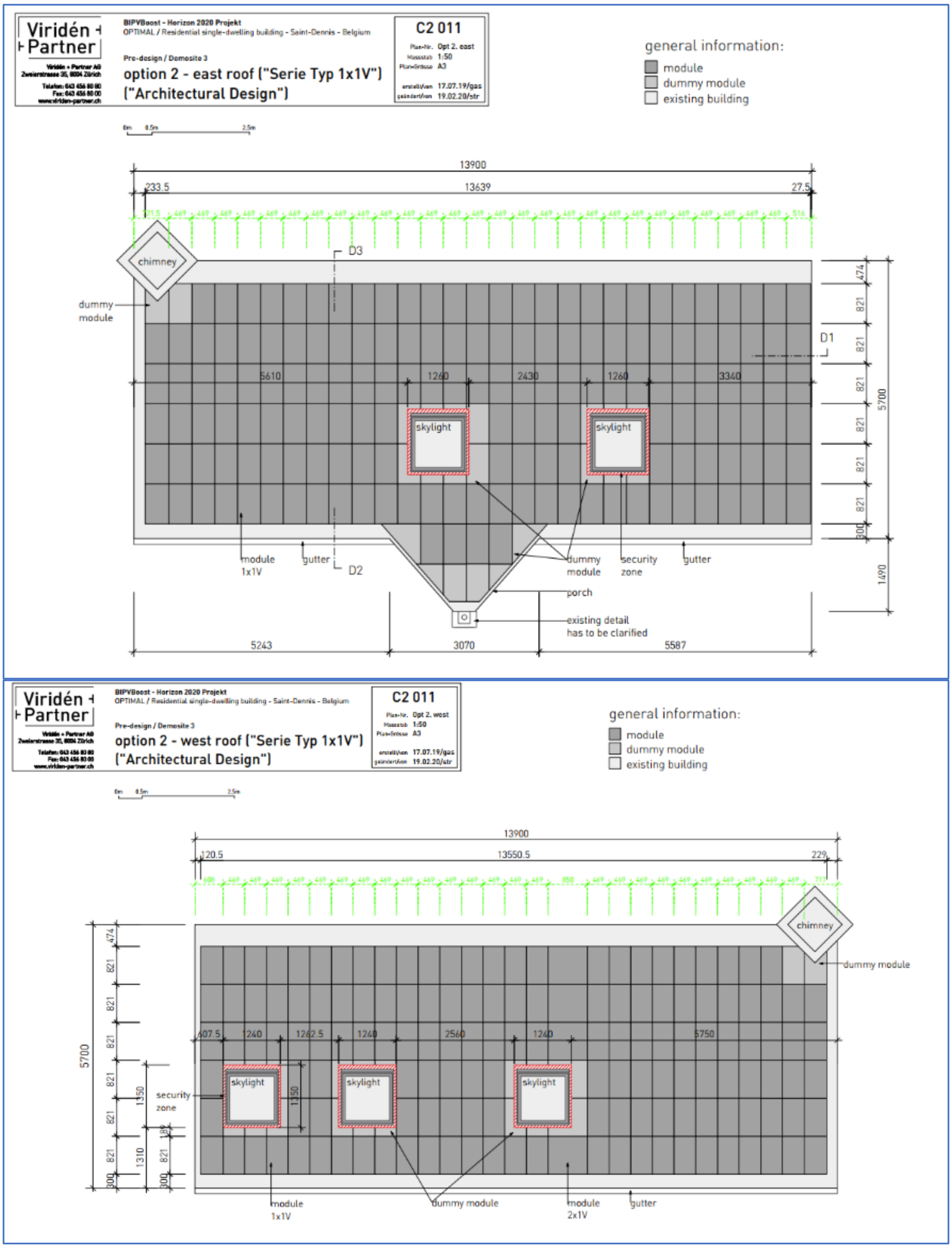


Figure 4.12: Scenario 2 (Architectural Design). East (top), West (bottom)

4.2.3 Detailed selected architectural design

4.2.3.1 Final Design

All these scenarios present preliminary designs of different options. However, the final setup requires to consider placing flashing material at the top, the edge, the bottom and in the small triangular part of the east roof.

The evaluation of buying and installing the panels together with the flashing material all around the panel perimeters was then performed (Figure 4.13). The cost of buying the flashing material is evaluated to 10000 € while the labour cost is 4800 €. This was evaluated based on a cost per square meter rule of the flashing material provided by the local architect.

This makes the cost of the flashing material quite expensive and therefore it was decided to minimize this cost as much as possible. The solution was to use dummy panels as much as possible and to use 2V panels equipped with only one active cell in order to be able to 'cut' these specific dummy panels at the exact dimension. These panels will be produced on specific dimension in order to provide a proper overlap with the sheeting of the roof windows. Only the special shapes around the chimney and the bay will be cut on site. Also, dummy panels or onsite flashing will be used at the junction between the panels surface and the bottom gutter. This will reduce a lot the extra cost of the flashing material required initially.

This leads to the final design presented in Figure 4.14. This setup has a power of 9.99 kWp. The power is a little smaller than the initial option 1.11 (10.38 kWp) but it will reduce the cost of the flashing material required around the panel surface.

			Common	Scenario 1.1	Scenario 1.11	Scenario 1.12	Scenario 1.2	Scenario 2	
Turn-key installation quotation for a demo-site									
1.		**Materials**		**Price [€]**	**Price [€]**	**Price [€]**	**Price [€]**	**Price [€]**	**Remarks**
	1.0	**Removing / preparing**							
		Setup + security	1000						
		Removing existing tiles + removing underlayer + removing underlating (*)	2000						
		New wood sub-structure (*)	2000						Is the underlating different for one Scenario to another?
		New sublayer (*)	1500						
		Gutter placed back (*)	500						
	1.1	Fastening and mounting system (FCA Switzerland)		1.563,96	1.581,29	1.581,29	1.356,36	1.622,95	Structure not included: Structure provided by TULIPPS/SCHWEIZER. Battery limits of provided material to be defined.
	1.2	BIPV modules (FCA Switzerland)		46.469,44	47.257,16	47.257,16	45.107,13	49.921,32	Modules not included: Modules provided by ONYX/FLISOM/PIZ. Battery
	1.3	Cabling							This is an **actual cost for CC Cable only**. Total cost can only be calculated after finalization of the elctrical design for demosite. This
	1.4	Inverters	2000						Based on Fronius Galvo solution (inverter with transformer): 2 * 3 kWp inverters
	1.5	Monitoring system							Cabling included. Monitoring equipment not included: Monitoring equipment to to be provided by TECNALIA. Battery limits of provided
	1.6	Electrical installation materials	500						We can provide this information only after the choice of right scenario
	1.7	Battery System	9000						Budget of 6000 € for the batteries and 3000 € for the inverter
	1.8	**Flashing + Velux windows (*)**		**10.000,00**	**7.500,00**	**10.000,00**	**10.000,00**	**10.000,00**	**There will be some difference in material surface and therefore on material cost but cannot be determined at this stage. Estimated to**
		MATERIALS SUBTOTAL	**18500**	**58.033,39**	**56.338,45**	**58.838,45**	**56.463,50**	**61.544,27**	
2.	**Lab or**			**Price [€]**	**Price [€]**		**Price [€]**	**Price [€]**	**Remarks**
	2.1	Permit obtaining	250						This is an Estimated Cost.
	2.2	Detailed Executive Project							We can provide this information only after the choice of right scenario.
	2.3	Structural and mechanical installation		3.200,00	3.200,00	3.200,00	3.200,00	4.000,00	We can provide this information only after the choice of right scenario. Estimated to 4 days / 2 persons + 25% for the option 2
	2.4	Electrical installation	1600						Estimated to 1 day, 1 person + Upgrade of the GRD connection
	2.5	Certification of the installation	250						
	2.6	Operation and Maintenance (optional)							
	2.7	Flasing + Velux windows		4.800,00	4800	4800	4800	4800	Estimated to 6 days / 2 persons
		LABOR SUBTOTAL	**2100**	**8.000,00**	**8.000,00**	**8.000,00**	**8.000,00**	**8.800,00**	
		TOTAL TURN-KEY INSTALLATION:	**20.600,00 €**	**66.033,39 €**	**64.338,45 €**	**66.838,45 €**	**64.463,50 €**	**70.344,27 €**	

Figure 4.13: Cost evaluation

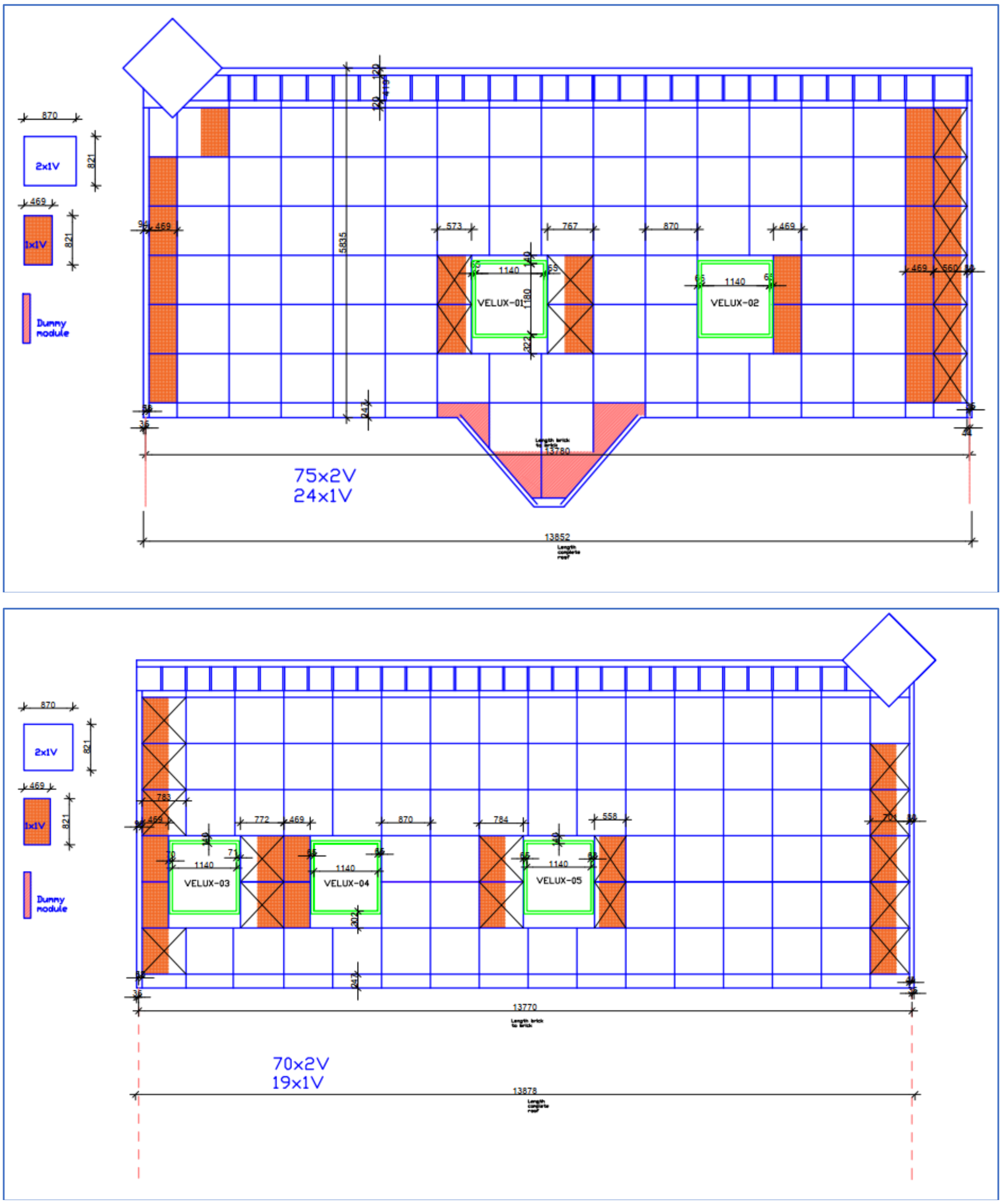


Figure 4.14: Final design

This final design also considers the following details (which might still get slightly modified until the final production):

- The details in order to place the Velux flashing material and how the panels are connected at the top, the bottom (Figure 4.15, Figure 4.16) and the side of the Velux (Figure 4.17)
- the placement of the roof top (Figure 4.18)
- The junction of the panels with the bottom gutters (Figure 4.19)
- The design of the triangular part of the east slope
- The design of the roof edge (Figure 4.20)

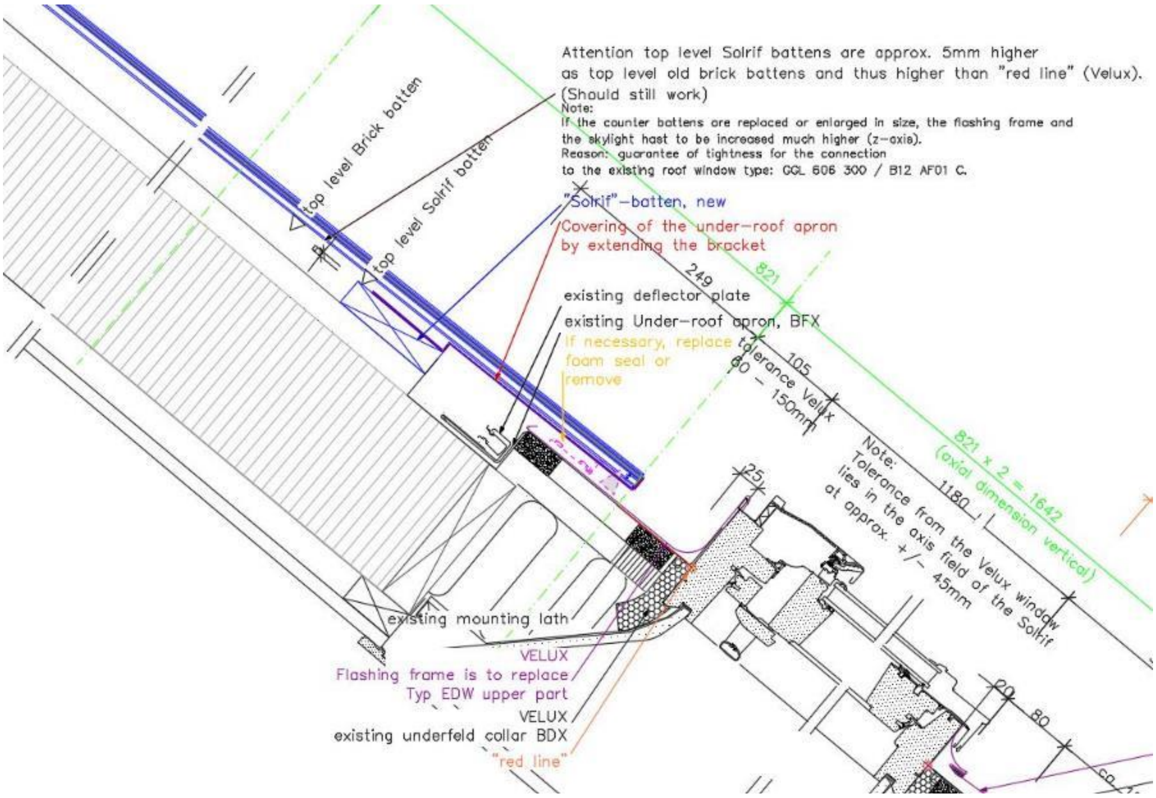


Figure 4.15: Junction details at the top of the Velux

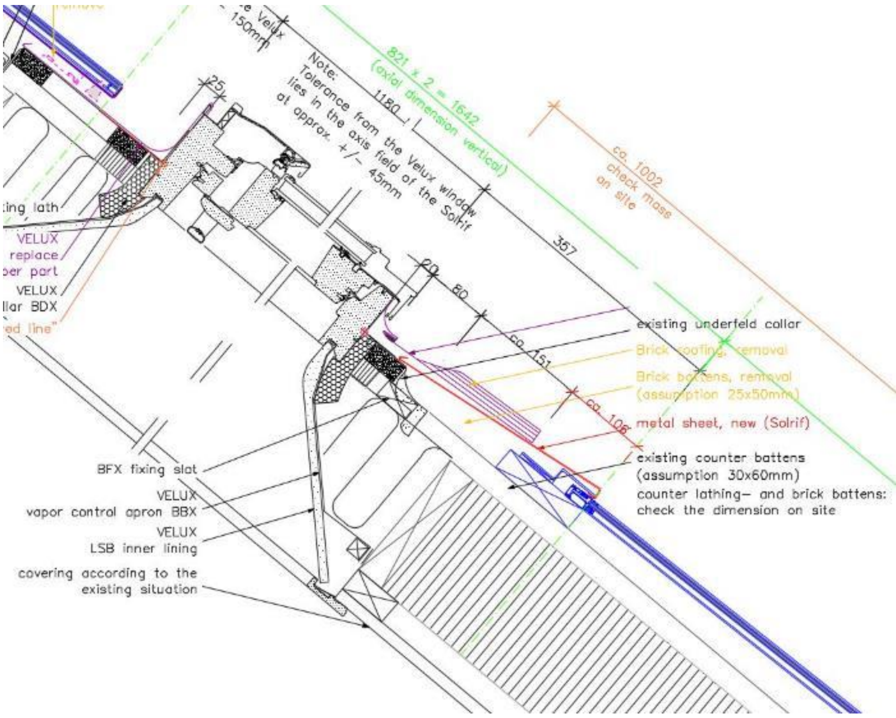


Figure 4.16: Junction details at the bottom of the Velux

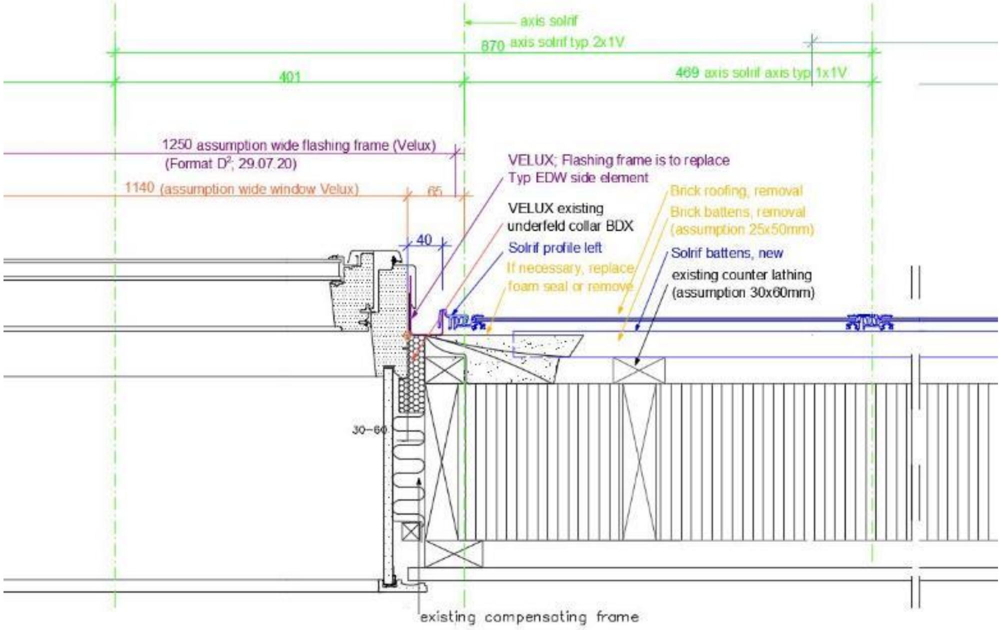


Figure 4.17: Junction details on the side of the Velux

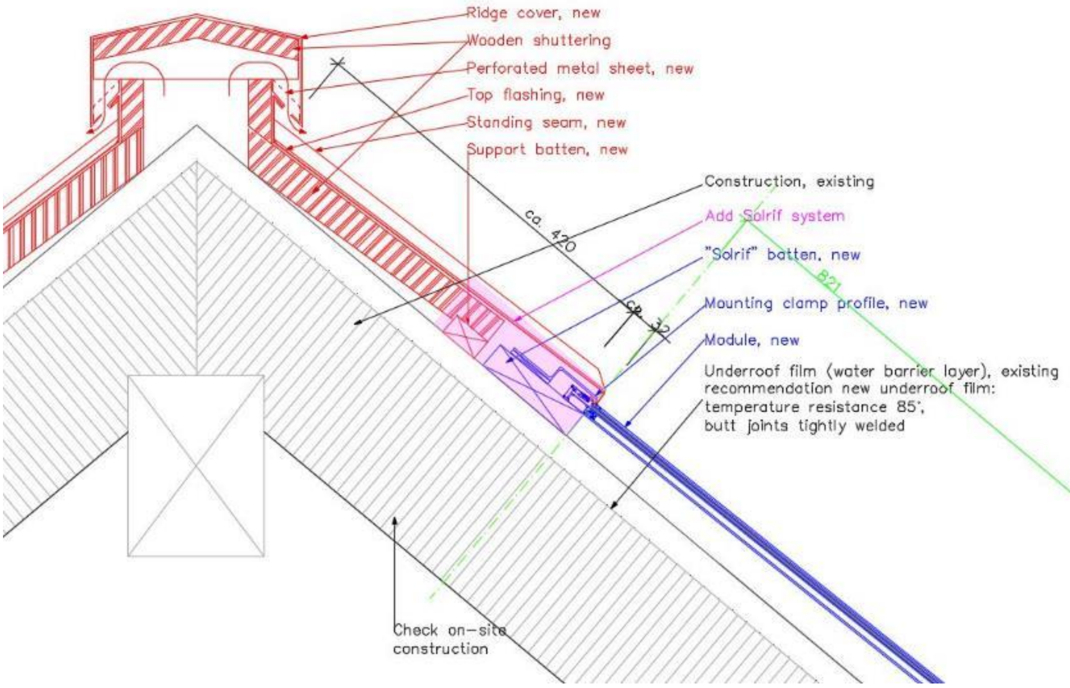


Figure 4.18: Ridge details

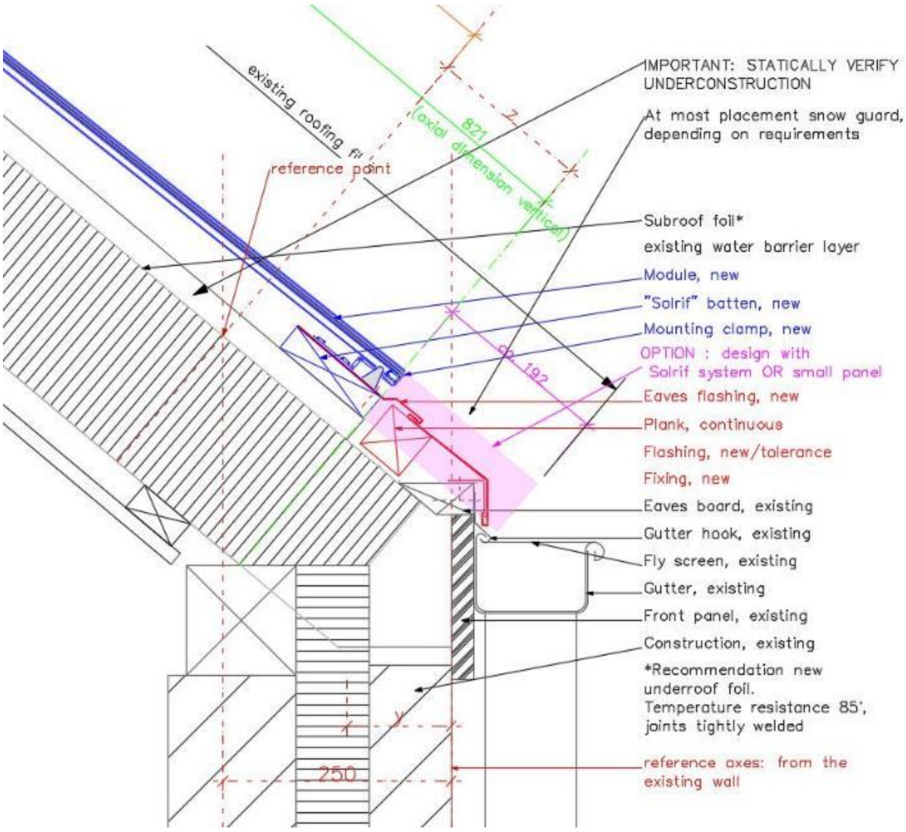


Figure 4.19: Details at the bottom junction with the gutter

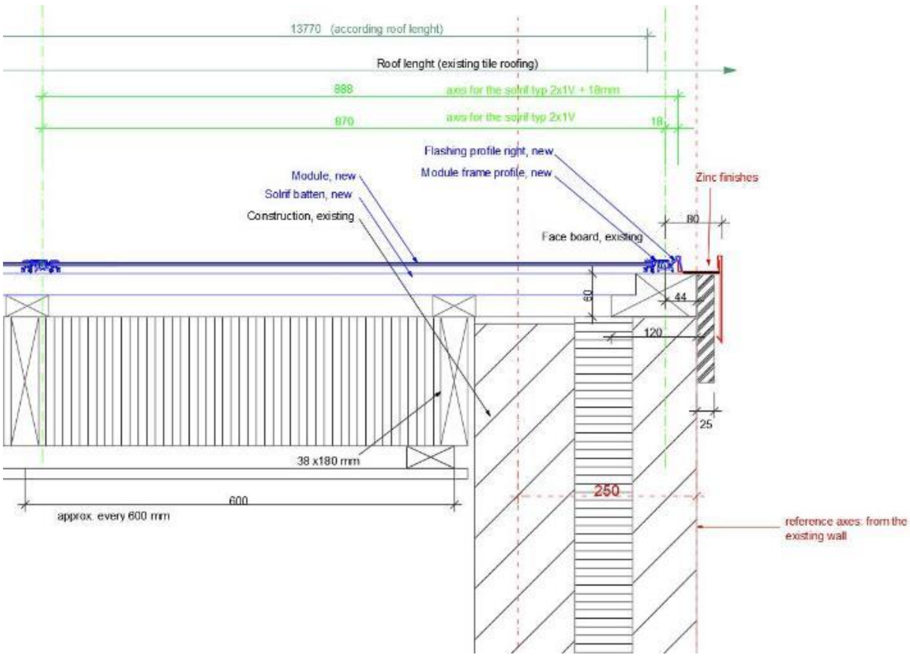


Figure 4.20: Details at the side edge of the roof

Finally, a summary of all the type of features and type of panels are summarized in

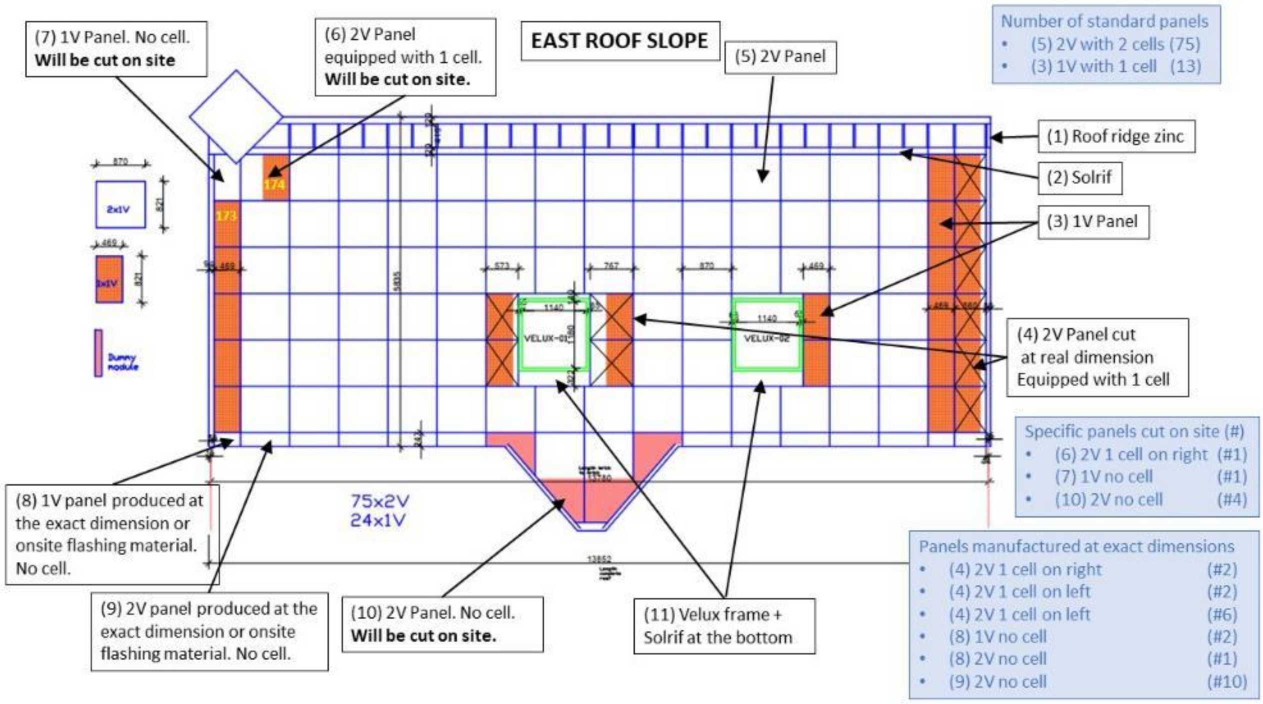


Figure 4.21: East roof details

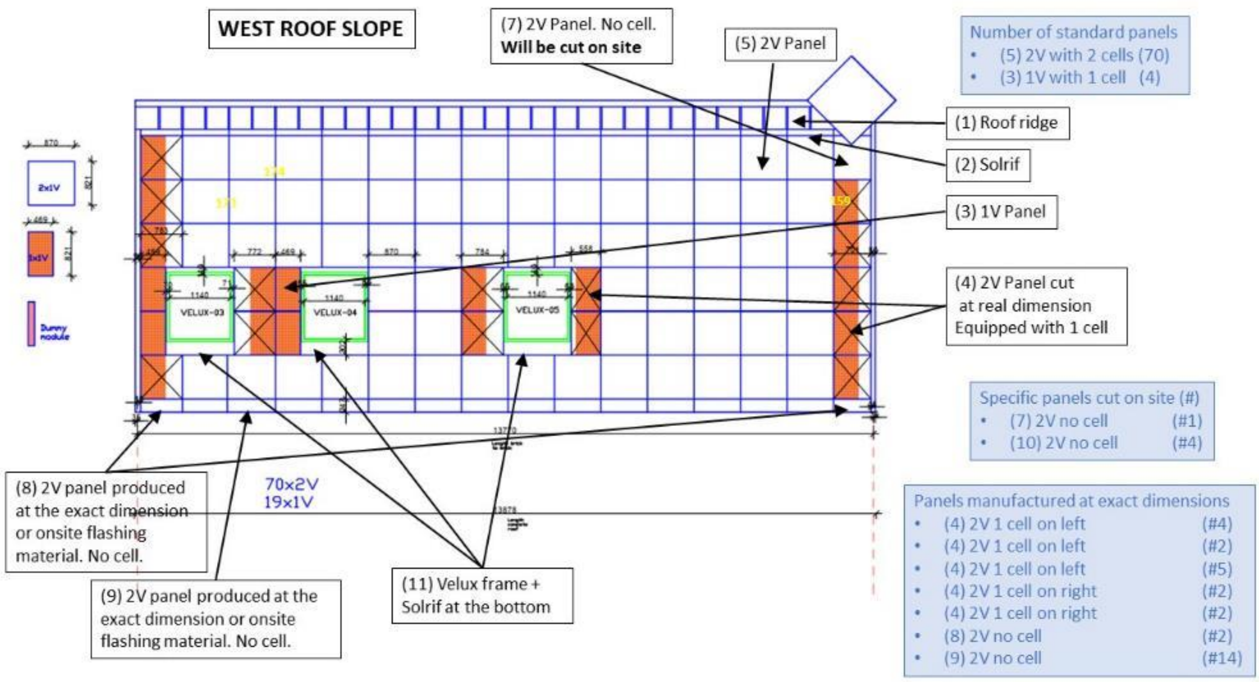


Figure 4.22: West roof details

The building permit was obtained in August 2020 (Figure 4.23).

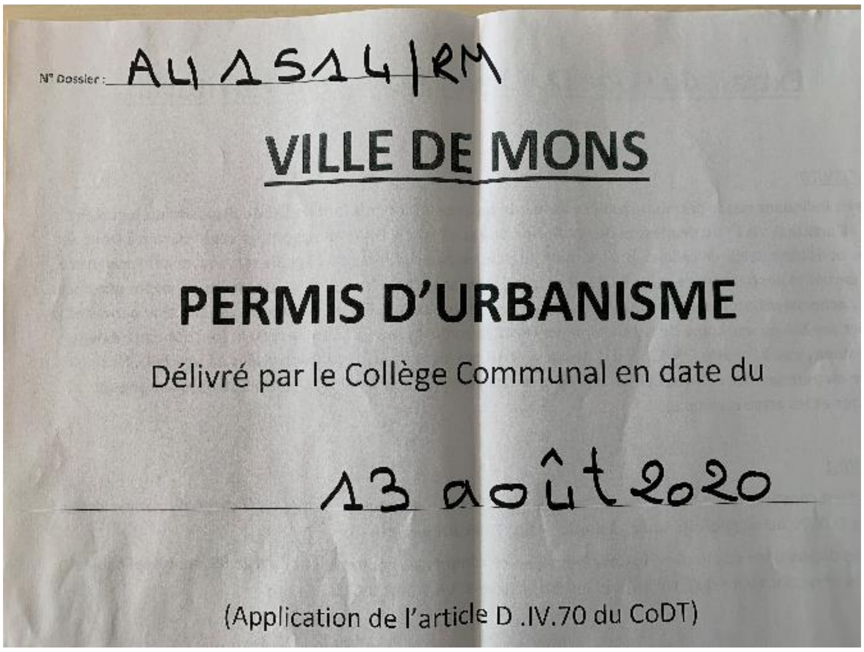


Figure 4.23: Building permit

4.3 BIPV STRUCTURE DESIGN

4.3.1 Existing building structure (roof)

The basic roof structure consists of a wooden beam structure overarching the walls of the building. The roof structure seems to be around 200 mm thick. The insulation sits within the vertical beams and is covered and protected by a plastic sheet (see Figure 4.24 and Figure 4.25)

Figure 4.24: Existing roof structure of Demo-site 3

The lath for the tiles is 30 mm in height and with the same width (see Figure 4.25). At the eaves lead the tiles lead directly into the gutter.

Figure 4.25: Details at the eves of Demo-site 3 roof.

4.3.2 BIPVBOOST roof/tile structure

It has been decided by the Demo-site owner, that the basic structure of the roof should not be changed (e.g. additional insulation). However, the roof structure for mounting Solrif® based BIPV roof modules will require some changes to the original roof structure:

- Width of the tile lath: Must be 100 mm in order to mount the clamps for the modules.
- The protective plastic sheet must withstand 80°C, otherwise it must be changed.
- The detail at the eaves to the gutter must be adapted (detail see proposal Viridén + Partner).

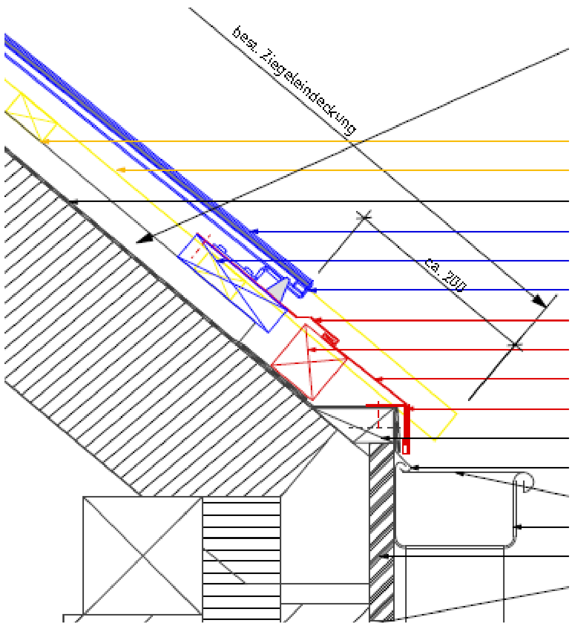


Figure 4.26: Vertical section detail eaves and gutter.

4.4 BIPV MODULE DESIGN

For cost reasons, the largest possible PV module size should be used for BIPV complete roofs. For small roofs and roofs with obstacles, this is often a challenge in terms of layout. Large modules often lead to too much unused roof area.

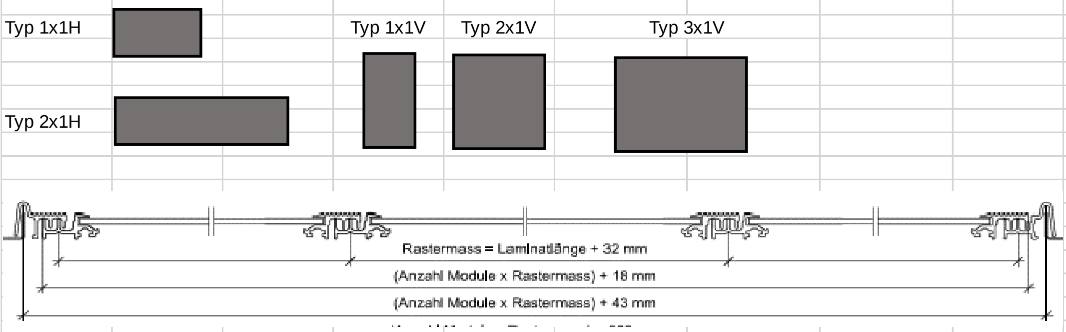
It has been shown that by using a "module family" with two to three compatibles, but differently sized modules, the flexibility for the complete roof covering is significantly greater and thus the roof surfaces can be optimally used for solar power.

4.4.1 BIPVBOOST module/s

In the framework of BIPVBOOST WP4 (T4.2) two module families have been developed. They differ in the orientation of the CIGS subcells (vertical/portrait and horizontal/landscape).

CIGS on metal module options | Version 5.0 | (21.7.2020)

Type	Lver [mm]	Lhor [mm]	Rver [mm]	Rhor [mm]	LverTotal [mm]	LhorTotal [mm]	net area [m2]	power [W[
1x1H	430	820	430	852	462	870	0.366	30
2x1H	430	1650	430	1682	462	1700	0.723	60
1x1V	821	437	821	469	853	487	0.385	30
2x1V	821	838	821	870	853	888	0.714	60
3x1V	821	1220	821	1252	853	1270	1.028	90



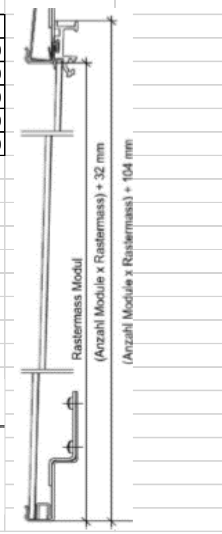


Figure 4.27: Structural design of the CIGS on metal roof module families (vertical and horizontal oriented CIGS subcells)

4.4.2 BIPVBOOST module/s electrical Design

Solrif® CIGS on metal BIPV roof modules				Version	5.1	(7.9.2020)	
Module Type			1x1H	2x1H	1x1V	2x1V	3x1V
Dimensions							
Width total	LhorTotal	[mm]	870	1700	487	888	1270
Height total	LverTotal	[mm]	462	462	853	853	853
Width grid	RhorTotal	[mm]	852	1682	469	870	1252
Heigt grid	RverTotal	[mm]	430	430	821	821	821
Thickness at module frame		[mm]	17				
Thickness at J-Box		[mm]	23 ± 1				
Weight (prelimiary estimation)		[kg]	4.0	7.0	4.0	7.0	10.0
area (based on layout grid)			0.4	0.7	0.4	0.7	1.0
Electrical characteristics at STC[1]							
Nominal Power	P_{MPP}	[W]	30	60	30	60	90
Short Circuit Current	I_{SC}	[A]	0.97	1.91	0.97	1.94	2.91
Open Circuit Voltage	V_{OC}	[V]	46	48	46	46	46
MPP Current	I_{MPP}	[A]	0.88	1.66	0.88	2x0.88	3x0.88
MPP Voltage	V_{MPP}	]V]	34	36	34	34	34
Solar Cell Efficiency (subcell)	η_c	[%]	12				
Module Efficiency	η_m	[%]	9.1	9.2	8.7	9.4	9.8
Power Output Tolerance			-0%/+5%				
Maximum Revere Current			10 A				
Maximum System Voltage			1000 V				

Figure 4.28: Preliminary datasheet of the CIGS on metal modules, part 1

Thermail charactersistics							
Temperature coeffficient	Voc	[%/°C]	-0.3				
Temperature coeffficient	Isc	[%/°C]	0.01				
Temperature coeffficient	PPmpp	[%/°C]	-0.35				
Operating conditions							
Temperature range		[°C]	-40 to 85				
Max. mechanical load [Pa]			open				
Additioal data							
Cell type			CIGS				
Junction Box			Back side including bypass diode, IP 67, MC4 type / MC4 connectors STC1				
No. of junction boxes			1	1	1	2	tbd
Cable lenght ($4mm^2$)		[mm]	tbd	tbd	900	900	tbd
Encapsulation			Fluorpolymer front sheet / back plate: aluminium 3 mm black anodized				
Warranty & certification							
Performance guarantee			10 years on 90% of Pmpp under STC1 and 20 years on 80% of Pmpp under				
Warranty			5 years' workmanship after delivery date				
Certification			EN IEC 61646; EN IEC 51730-1 & 2				
Fire safety class			according to hard roofing (B root T1, Euroclass) (attempted)				

Figure 4.29: Preliminary datasheet of the CIGS on metal modules, part 2

Note: The fire safety tests need to be performed prior to the final design and production of the Demo-site 3 installation.

4.5 BIPV ELECTRICAL SYSTEM DESIGN

In this section the choice of the inverter, the panels connection wiring, and the electric board will be described.

However, first it is important to review the current existing legislation in Belgium which will drive some of our choices hereafter.

As now (2021), the electricity can be injected back on the public network and the main general meter counts in the reverse side when the electricity is injected into the public network. However this is changing and it is becoming mandatory to install a general meter that will count both the energy used from the network and the energy feed in into the network. Based on this new meter and new regulation, there will be 2 options to pay the energy bill:

(1) The first option will be to pay a flat tax depending on the installed power together with the net consumption (energy taken from the network minus energy feed in into the network). This plat tax is based on the minimum of the following 2 powers: panels installed power and inverter total power. So a good solution to minimize the cost of this scenario is to minimize the power of installed inverters.

(2) The second option will be to pay only the energy taken from the network. In that case the electricity feed in to the network is not at all taken into account for the bill. This energy is send completely free to the energy provider.

Based on the power that is scheduled to be installed using the BIPVBOOST panel (10.8 kWp) and the installation of batteries, it is very strongly desired to base the future scenario on the option (2) and to minimize the energy taken from the public network.

This will put a large pressure on self-consumption for the Belgian demonstration site.

4.5.1 PV Inverter

The design of the electrical system is not an easy task for the Optimal demonstration site. This is because this design must meet several constraints. The 3 major ones are summarized here after:

1. In order to be considered as a prosumer in Belgium the size of the installed inverters must not exceed 10 kWp. If the power of inverters (sum of all inverter installed) exceeds this limit, the installation is considered as a producer. Being a producer imposes to face additional administrative tasks. As stated in section 4.1.6 there are already 2 inverters installed (1.4 kWp and 3.5 kWp). This leaves ‘only’ the possibility to install an additional inverter of 5.1 kWp (if the building must remain prosumer).
2. The second point is the new TAX imposed since the end of 2020 as summarized in 4.5.Ggoing for the flat TAX based on the installed PV power would lead to an annual TAX of around 1200 € which is probably as much as the energy saving price. This is not an option. As stated in that section, the goal is to minimize the cost of exploitation of the PV installation and therefore to limit the TAX imposed on the PV inverter power. To achieve that a new meter will be set up that is capable to measure the electricity consumed from the network and the electricity fed into the network. Having that will allow to pay ‘only” for the electricity that is consumed from the public network.
3. Installing inverter for a total peak power between 5 and 10 kWp imposes to use a tri-phase electricity supply although the building is currently equipped with a single-phase supply.
4. Having CIGS modules has some consequences on current leaks imposing to make sure that the inverter as a good galvanic insulation.

For the first constraint here above, there are several possible scenarios:

1. Being a producer and therefore do not consider the limit of 10 kWp for the total power of all inverters.
2. Install an inverter < 5.1 kWp
3. Replace the existing inverter with slightly lower power in order to be able to use an inverter of or around 6.0 kWp for the BIPVBOOST panels.

However, the specificity of this demonstration site is that the panels are almost equally distributed on 2 roof slopes having 2 orientations at 180 deg. (East and West). This means that the panels production on each slope will not be maximum at the same time. The East roof will have its maximum peak power around 10-11 am while the west side around 14-16 pm. Moreover, none of the slope are oriented towards the South meaning that the peak power will never reach the theoretical maximum power of the panels.

This means that the total daily production of the field will be smaller than for an equivalent south oriented field of PV panels. However, this also means that the electricity production will start earlier in the morning and will produce more in the evening than for a south oriented field (Figure 4.30). Therefore, this offers the possibility to install an inverter of lower peak power that the 9.9 kWp of the PV systems.

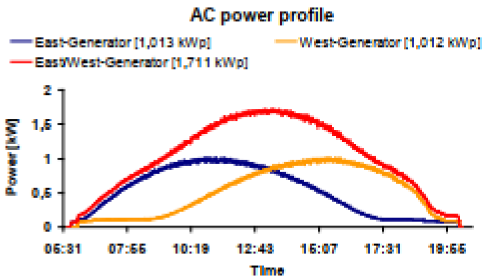


Figure 4.30: Comparison PV Field South and East-West oriented (from Fronius: "Efficient East-West Oriented PC Systems with one MPP tracker")

The East-West orientation could suggest installing one inverter per roof slope. However, that would mean to install 2 inverters of around 3 to 4kWp each leading to 6 - 8 kWp. That would not allow to reach the limit of 10 kWp of installed capacity.

However, installing only one inverter (with one or 2 MPPT entry) will allow to use a lower max power inverter. Some simulations have been performed while design the roof set up. These simulations were performed during the first year project in order to validate the concept and to forecast the electricity meter adaptation. These simulations were performed with PVSyst free edition. The first simulation uses 2 inverters of 3kWp, one for each roof slope. The second configuration study the use of a single inverter of 5 kWp for both roof slopes. For these simulations we have considered 170 1V panels on the west roof and 160 1V panel on the West roof. The main results are:

- For the 2 inverters case (2*3 kWp):
  - Electricity produced in one year = 3’282 + 4’259 = 7‘541 kWh
  - Losses due to overpower inverter east: 4.36 %
  - Losses due to overpower inverter west: 4.75 %
- For the 1 inverter case (5 kWp):
  - Electricity produced in one year: 7’270 kWh
  - Losses due to overpower : 7,49%

This simulation shows that there are only 3.5 % of different in the annual electricity amount produced. However, in the simulation, it can be noted that on the single inverter case, there are 8.65% losses called “Global incident on the plane of the PV cells”. This is not clear in this output and we could not figure out the meaning for that.

On the page 3 bottom, of the 3 simulations, it can be noted that there are some productions which are lost due to the overpower of the PV production compared to the power of the inverter. This is particularly visible for the 2 inverters case.

These simulations allow to validate the possibility to use a single inverter of a lower total power without losing annual production.

The search for inverters was not an easy task for the reasons exposed above and because it was required to have first the final count of the number of PV panels installed on each slope of the roof.

Based on the precise definition of the panels presented in section 4.2.3.1 a first price request was performed to a reseller of SMA inverters. This was also important for us to have a third-party validation of our design and conclusions. This reseller proposes us to use SMA STP4.0 or STP5.0 inverters (Figure 4.33). The Figure 4.31 shows that with 170 1V equivalent panels on the east roof slope and 154 1V equivalent panels on the west roof slope, the total annual production is 7 772 kWh so even better than with our simulation above.

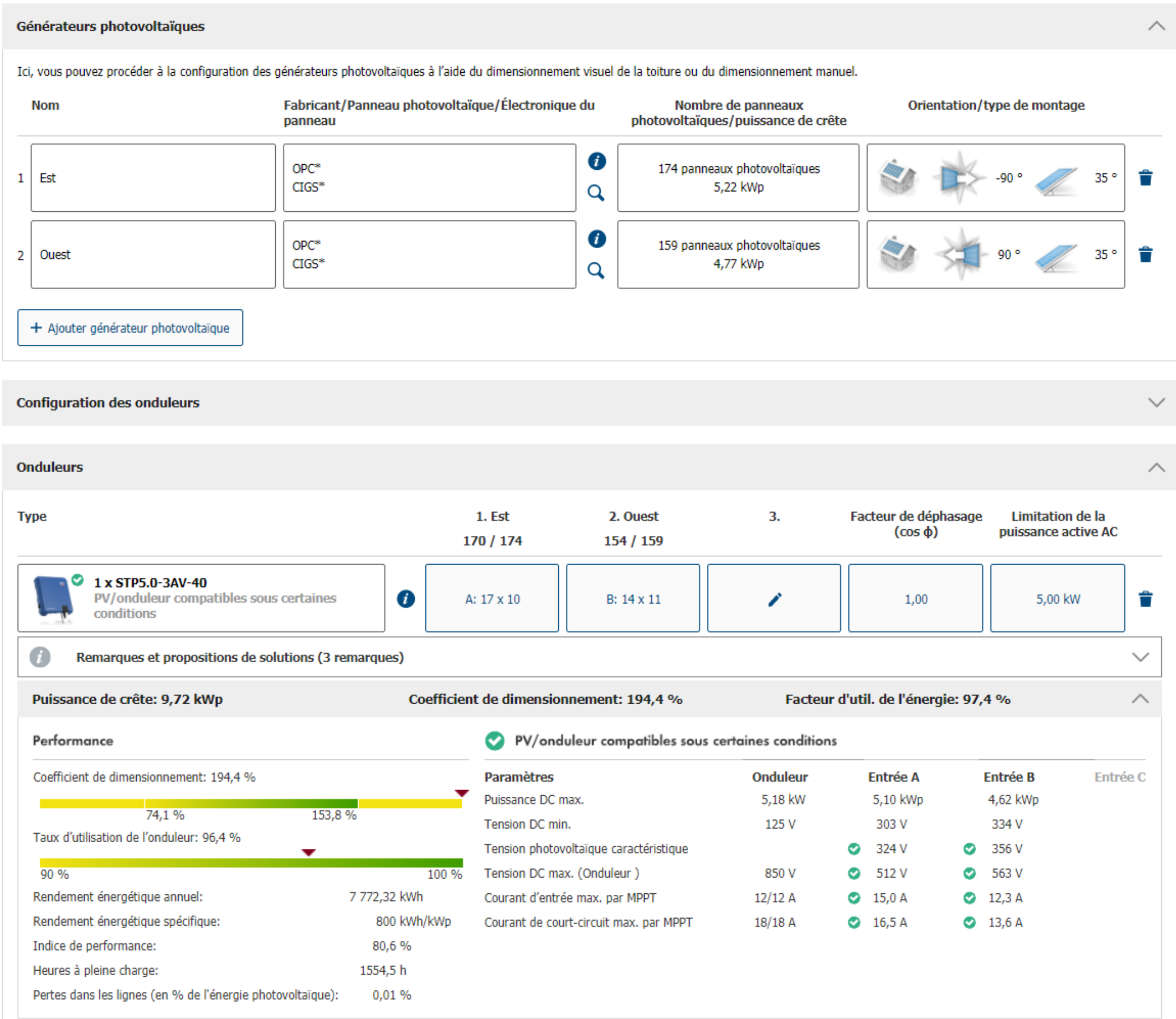


Figure 4.31: SMA simulation provided by a third-party SMA reseller.

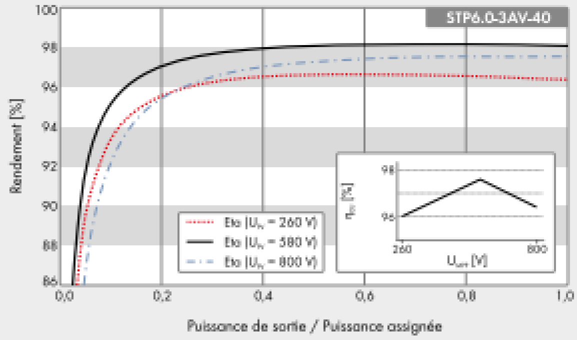
Another aspect that must also be taken into account is the string connection. In the simulation above, each string was composed of 9 x 1V equivalent panels. So the East roof is composed of 17 strings and the West roof of 14 strings. This leads to 170 / 174 panels used on the East roof and 154/159 panels on the West roof.

The options to connect the panels together, to create string are calculated on the Figure 4.32: Options to connect the panels and design the strings

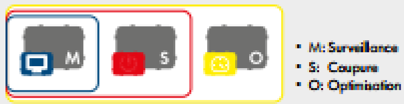
	Options to design the Strings											
Number of cells per string	9	10	11	12	13	14	15	16	17	18	19	20
	East Face											
Total number of 1V modules	**174**											
Number Strings	19	17	15	14	13	12	11	10	10	9	9	8
Total number of connect 1V panels	171	170	165	168	169	168	165	160	170	162	171	160
Unconnected panels	-3	-4	-9	-6	-5	-6	-9	-14	-4	-12	-3	-14
Nominal Power (W)	5130	5100	4950	5040	5070	5040	4950	4800	5100	4860	5130	4800
Short Circuit Curren (A)	18,4	16,5	14,6	13,6	12,6	11,6	10,7	9,7	9,7	8,7	8,7	7,8
Open Circuit Voltage (V)	414	460	506	552	598	644	690	736	782	828	874	920
MPP Current (A)	16,7	15,0	13,2	12,3	11,4	10,6	9,7	8,8	8,8	7,9	7,9	7,0
MPP Voltage (V)	306	340	374	408	442	476	510	544	578	612	646	680
	West Face											
Total number of 1V modules	**159**											
Number Strings	17	15	14	13	12	11	10	9	9	8	8	7
Total number of connect 1V panels	153	150	154	156	156	154	150	144	153	144	152	140
Unconnected panels	-6	-9	-5	-3	-3	-5	-9	-15	-6	-15	-7	-19
Nominal Power (W)	4590	4500	4620	4680	4680	4620	4500	4320	4590	4320	4560	4200
Short Circuit Curren (A)t	16,5	14,6	13,6	12,6	11,6	10,7	9,7	8,7	8,7	7,8	7,8	6,8
Open Circuit Voltage (V)	414	460	506	552	598	644	690	736	782	828	874	920
MPP Current (A)	15,0	13,2	12,3	11,4	10,6	9,7	8,8	7,9	7,9	7,0	7,0	6,2
MPP Voltage (V)	306	340	374	408	442	476	510	544	578	612	646	680

Figure 4.32: Options to connect the panels and design the strings

Courbe de rendement



Accessoires (en option)



● Équipement de série ○ En option — Non disponible
Données valables en conditions nominales
Version 07/2020

Caractéristiques techniques	Sunny Tripower 3.0	Sunny Tripower 4.0	Sunny Tripower 5.0	Sunny Tripower 6.0
Entrée (DC)				
Puissance max. du générateur photovoltaïque	6000 Wc	8000 Wc	9000 Wc	9000 Wc
Tension d'entrée max.	850 V	850 V	850 V	850 V
Plage de tension MPP	140 V à 800 V	175 V à 800 V	215 V à 800 V	260 V à 800 V
Tension d'entrée assignée	580 V			
Tension d'entrée min. / tension d'entrée de démarrage	125 V / 175 V			
Courant d'entrée max. entrée A / entrée B	12 A / 12 A			
Courant de court-circuit max. entrée A / entrée B	18 A / 18 A			
Nombre d'entrées MPP indépendantes / strings par entrée MPP	2 / A:1; B:1			
Sortie (AC)				
Puissance assignée (pour 230 V, 50 Hz)	3000 W	4000 W	5000 W	6000 W
Puissance apparente AC max.	3000 VA	4000 VA	5000 VA	6000 VA
Tension nominale AC	3/N/PE; 220 V / 380 V 3/N/PE; 230 V / 400 V 3/N/PE; 240 V / 415 V			
Plage de tension AC	180 V à 280 V			
Fréquence du réseau AC / Plage	50 Hz / 45 Hz à 55 Hz 60 Hz / 55 Hz à 65 Hz			
Fréquence de réseau assignée / tension de réseau assignée	50 Hz / 230 V			
Courant de sortie max.	3 x 4,5 A	3 x 5,8 A	3 x 7,6 A	3 x 9,1 A
Facteur de puissance à la puissance assignée / facteur de déphasage réglable	1 / 0,8 inductif à 0,8 capacitif			
Phases d'injection / Phases de raccordement	3 / 3			
Rendement				
Rendement max. / Rendement européen	98,2 % / 96,5 %	98,2 % / 97,1 %	98,2 % / 97,4 %	98,2 % / 97,6 %
Dispositifs de protection				
Dispositif de déconnexion côté entrée	●			
Surveillance du défaut à la terre / surveillance du réseau	● / ●			
Protection inversion de polarité DC / résistance aux courts-circuits AC / séparation galvanique	● / ● / –			
Unité de surveillance du courant de défaut, sensible à tous les courants	●			
Classe de protection (selon IEC 61140) / catégorie de surtension (selon IEC 60664-1)	I / III			
Caractéristiques générales				
Dimensions (L/H/P)	435 mm / 470 mm / 176 mm (17,1 pouces / 18,5 pouces / 6,9 pouces)			
Poids	17 kg (37,4 lb)			
Plage de température de fonctionnement	−25 °C à +60 °C (−13 °F à +140 °F)			
Émissions sonores, typiques	30 dB(A)			
Autoconsommation (nuit)	5,0 W			
Topologie / Système de refroidissement	Sans transformateur / Convection			
Indice de protection (selon IEC 60529)	IP65			
Classe climatique (selon IEC 60721-3-4)	4K4H			
Valeur maximale admise pour l'humidité relative de l'air (sans condensation)	100 %			
Équipement				
Raccordement DC / raccordement AC	SUNCLIX / fiche AC			
Affichage via smartphone, tablette, ordinateur portable	●			
Interfaces : WLAN / Ethernet / RS485	● / ● / ●			
Protocoles de communication	Modbus (SMA, Sunspec), Webconnect, SMA Data, TS4-R			
Gestion de l'ombrage : SMA ShadeFix (intégrée) / TS4-R	● / ○			
Garantie : 5 / 10 / 15 ans	● / ○ / ○			
Certifications et homologations (autres sur demande)	AS 4777, C10/11, CE, CEI 0-21, DIN EN 62109-1/IEC 62109-1, DIN EN 62109-2/IEC 62109-2, EN 50438, G59/3, G83/2, NEN-EN 50438, ÖVE / ÖNORM E 8001-4-712, PPDS, PPC, RD 1699, SI 4777, TR 3.2.1, UTE C15-712, VDE-AR-N 4105, VDE0126-1-1, VFR 2014, RfG compliant			
Certifications et homologations (en projet)	DEWA 2016, EN 62116, IEC 61727, IE-EN 50438, NBR 16149, NRS 097-2-1			
Pays de disponibilité de SMA Smart Connected	AU, AT, BE, CH, DE, ES, FR, IT, LU, NL, UK			
Désignation du type	STP3.0-3AV-40	STP4.0-3AV-40	STP5.0-3AV-40	STP6.0-3AV-40

Figure 4.33: SMA Sunny Tri-power

4.6 BIPV MONITORING DESIGN

4.6.1 Definition of monitoring objectives: BIPV performance validation, economic viability and progress towards NZEB requirements

As mentioned earlier in this document, Optimal demo site will be equipped with a BIPV roof retrofitting and new BEMS system that will optimise the thermal inertia use of the building, the optimal use of produced energy by shifting some loads and optimal use of batteries. The objective of the monitoring system is to measure and verify the effect of this implantation in the overall building performance. In this context the energy performance is understood as the non-used energy (energy savings), the self-consumption ratio, the reduction in the energy bill and the performance ratio. Next, the implementation of the monitoring system is presented.

4.6.2 Definition of variables to be monitored

In order to demonstrate the project objectives, the monitored variables have been selected following the monitoring guidelines defined in Deliverable 8.3. The following Figure 4.34shows the variables to be monitored, and the Table 4.3 summarises the measured variables, instruments and required accuracies. These variables have been divided in two-time steps, the pre-intervention (Inside the Blue box in Figure 4.34) period and the post intervention period (inside the red box in Figure 4.34). As can be seen the selected variables are related with the energy balance of the demo; energy production (by the existing PV field and the one to be installed), the energy consumption from the grid, energy consumed by HVAC system, gas boiler and movable charges and meteorological data.

The variables of the pre-intervention period are being measured since August 2020 and the post-intervention variable will be monitored after the new BIPV roof and BEMS interventions have been carried out.

Demo Optimal

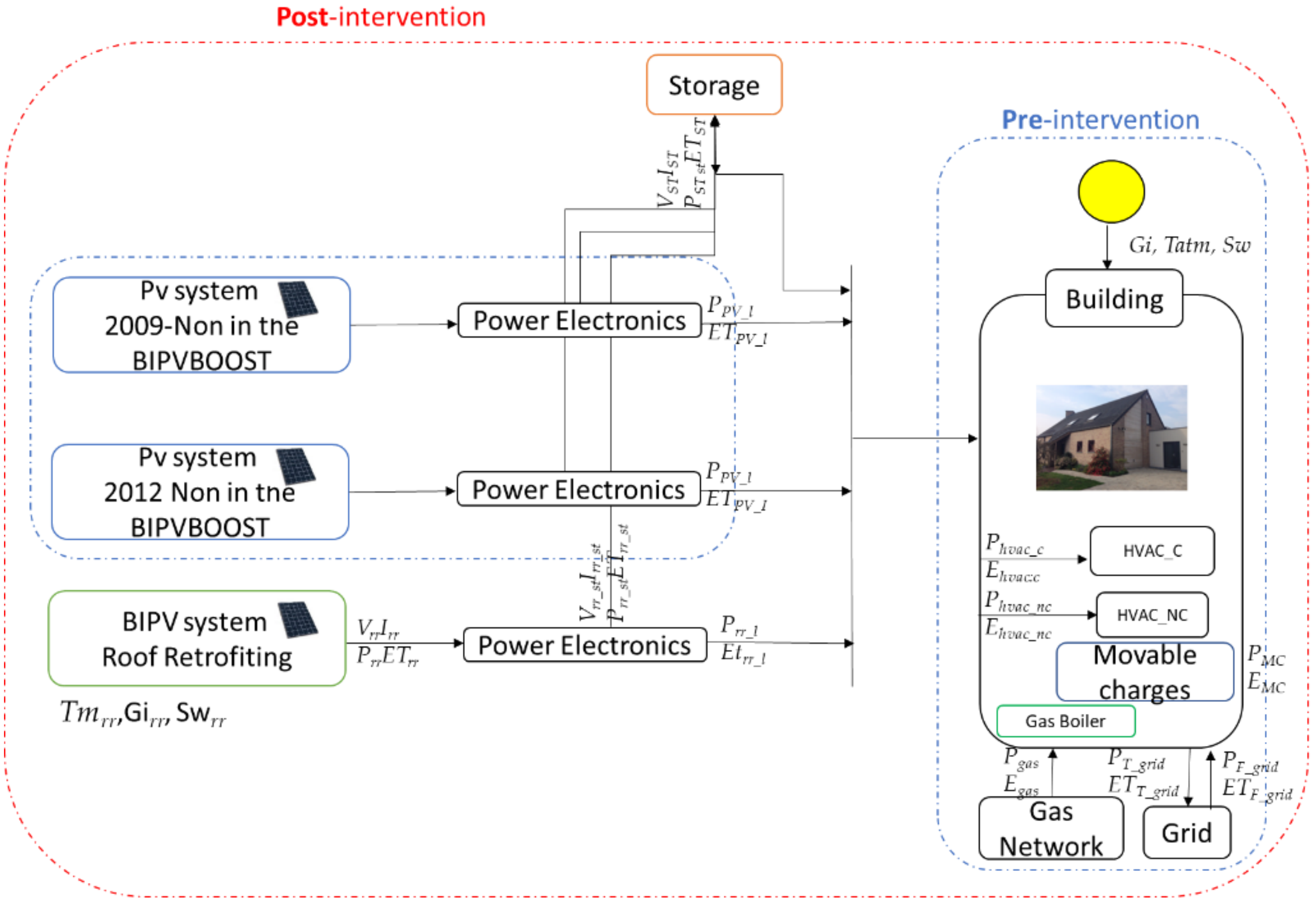


Figure 4.34.Measured variables on optimal demo site. In Blue the variables measured during the preintervention period and in red the variables that will be also measured during the postintervention period.

Table 4. 3.Optimal demo site variables measurement information: required instruments, range, units, Time resolution and accuracy

Variable	_	instrument	Range	Units	Time Resolution	Accuracy
BIPV components						
Roof retrofiting						
Meteo	_					
Gi_{rr}	*Irradiance in the roof retrofiting*	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{rr}	*Temperature of the reference cell*	Thermocouple type T	0-100	ºC	<1min	1K
DC	_					
I_{rr}	BIPV generated Intensity DC	Amperimeter		A	<1min	1% of the reading
V_{rr}	BIPV generated Voltage DC	Voltimeter		V	<1min	1% of the reading
P_{rr}	BIPV generated Power DC	Power meter	15	kW	<1min	2% of the reading
ET_{rr}	BIPV generated Energy DC	Energy meter		kW/h	<1min	
AC	_					

P_{rr_I}	BIPV generated Power AC	Power meter	15	kW	<1min	2% of the reading
ET_{rr_I}	BIPV generated Energy AC	Energy meter		kW/h	<1min	
Storage						
Imput						
I_{rr_st}	Intensity flux of storage system	Amperimeter		A	<1min	1% of the reading
V_{rr_st}	voltage of storage system	Voltimeter		V	<1min	1% of the reading
P_{rr_st}	Power flux of storage system	Power meter		kW	<1min	2% of the reading
ET_{rr_st}	Energy flux of storage system	Energy meter		kW/h	<1min	
Building						
Gi	*Global irradiance*	Pyranometer	0-1200	w/m2	<1min	5% of the reading
T_{amb}	*ambient temperature*	Thermocouple type T	0-50	ºC	<1min	1K
S_w	*Wind speed*	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
HVAC controled by de BEMS						
I_{hvac_c}	Intensity	Amperimeter		A	<1min	1% of the reading
V_{hvac_c}	Voltage	Voltimeter		V	<1min	1% of the reading
P_{hvac_c}	Power	Power meter		kW	<1min	2% of the reading
ET_{hvac_c}	Energy	Energy meter		kW/h	<1min	
HVAC Not controled by de BEMS						
I_{hvac_nc}	Intensity	Amperimeter		A	<1min	1% of the reading
V_{hvac_nc}	Voltage	Voltimeter		V	<1min	1% of the reading
P_{hvac_nc}	Power	Power meter		kW	<1min	2% of the reading
ET_{hvac_nc}	Energy	Energy meter		kW/h	<1min	
Existing gas Boiler						
P*gas*	Thermal Power	Gas flow meter		kg/s	<1min	
E*gas*	Thermal energy	water calorimeter		kW	<1min	
Existing PV field 2009						
AC	-					
P_{pv09_I}	Power	Power meter	3,4	kW	<1min	2% of the reading
ET_{pv09_I}	Energy	Energy meter		kW/h	<1min	
Existing PV field 2012						
AC	-					
P_{pv12_I}	Power	Power meter	1,35	kW	<1min	2% of the reading

ET_{pv12_I}	Energy	Energy meter		kW/h	<1min	
Grid						
P_{gr}	Power	Power meter		kW	<1min	2% of the reading
ET_{grid}	Energy	Energy meter		kW/h	<1min	
Movable charges						
$E_{\text{whasing machine}}$	Whasing machine energy consumption	Energy meter		kW/h	<1min	
$E_{\text{Swining poll heat pump and pump}}$	Ssining pool energy consumption	Energy meter		kW/h	<1min	
$E_{dishwasher}$	Dish washer energy consumption	Energy meter		kW/h	<1min	

4.6.3 BIPVBOOST monitoring system

The pre-intervention period instruments have been installed in the building as detailed in the following figures:Figure 4.35, Figure 4.36, Figure 4.37..

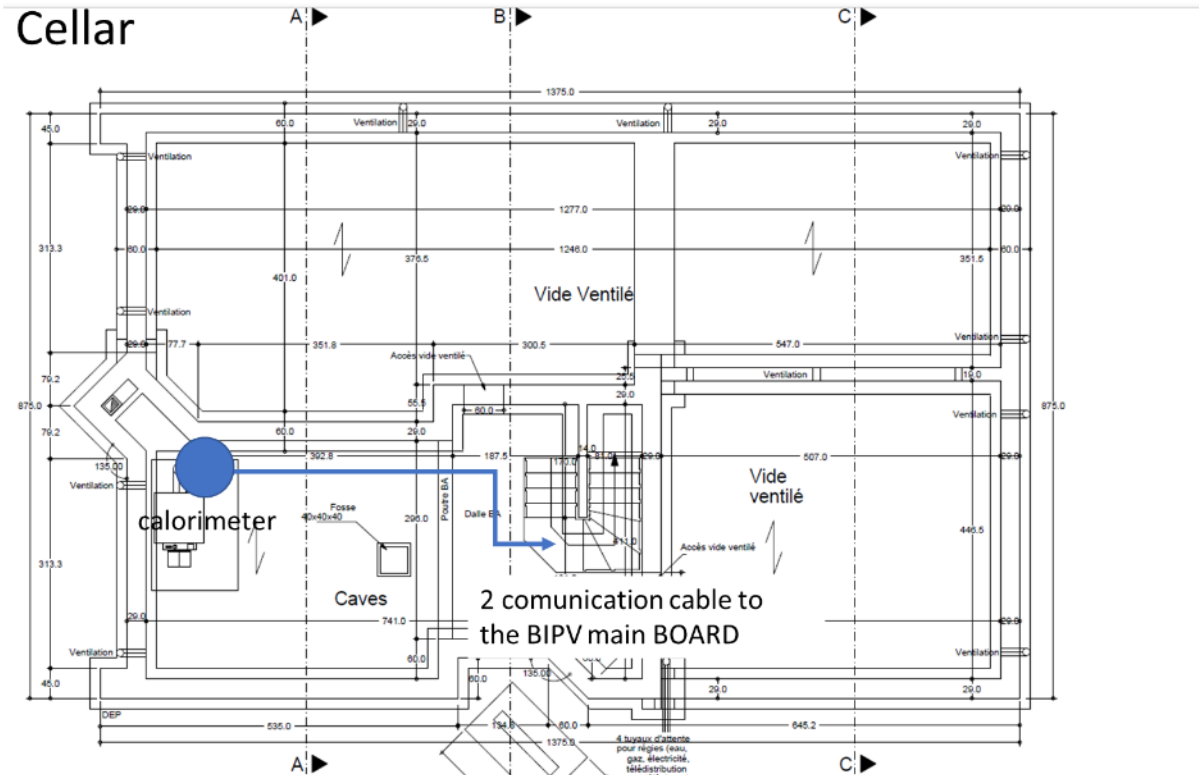


Figure 4.35. Monitoring system elements located in the Cellar.

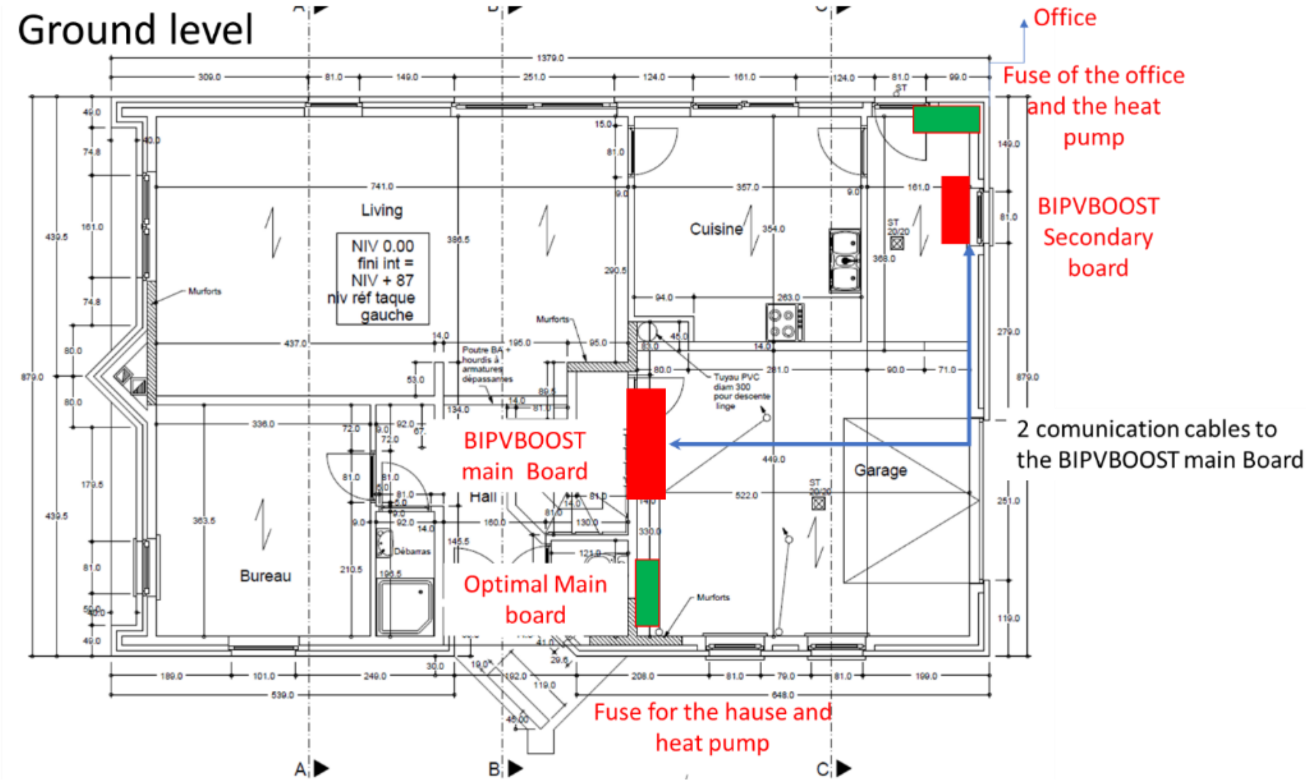


Figure 4.36 Monitoring system elements located in the ground level.

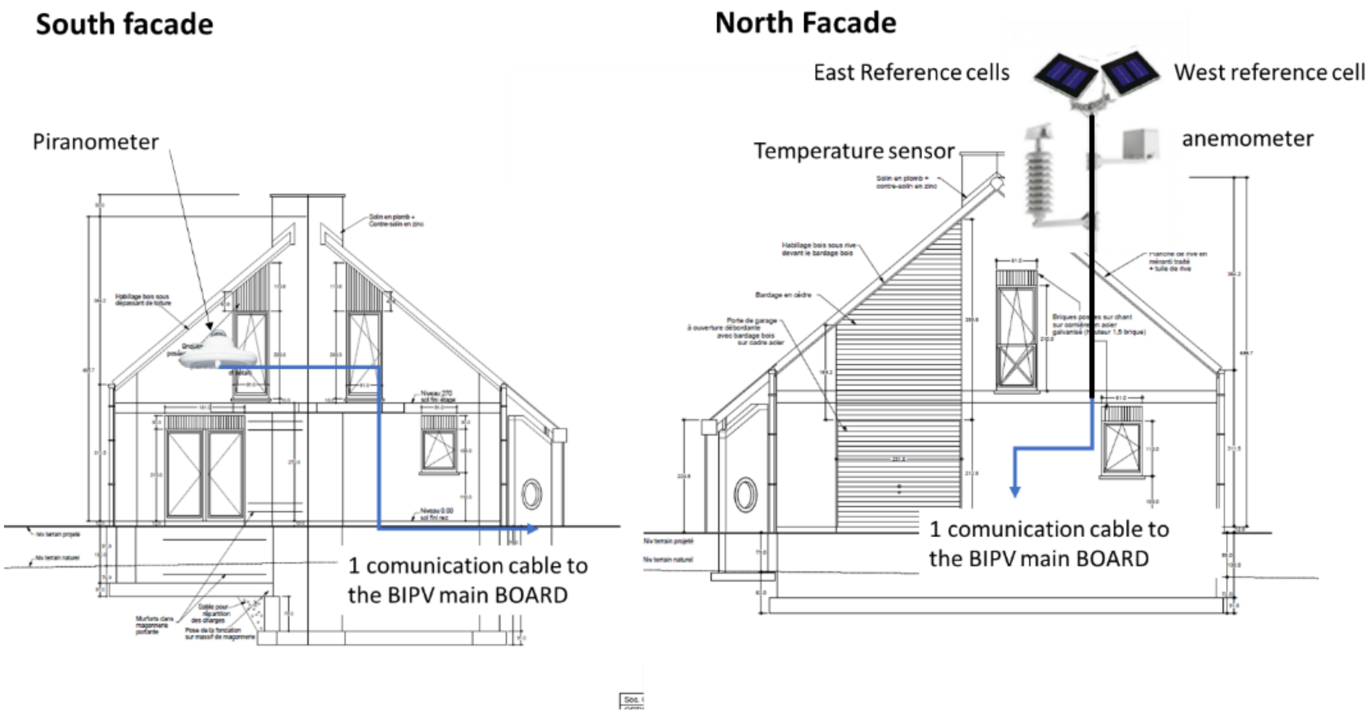


Figure 4.37. Monitoring system elements located in the south and north facades.

Starting from the cellar, it has been installed just one instrument, the calorimeter that it is measuring the thermal energy produced by the existing gas boiler for heating the house (not the domestic hot water). See the installation schema in theFigure 4.38.

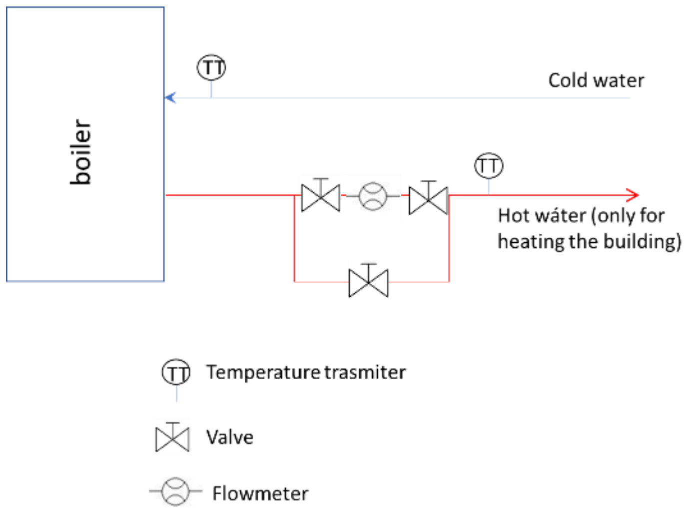


Figure 4.38. Calorimeter installation schema

Next, at ground level, the main BIPV board and the secondary board have been installed. On one hand, the main board contains the data acquisition system and 6 energy meters that measure the energy consumption from the grid, the swimming pool, the HVAC system controlled by the BEMS, and the energy production from the 2 existing PV fields. On the other hand, the secondary board contains the energy meters that measure the energy consumption of the HVAC system not controlled by the BEMS and the Dishwasher. Figure 4.39and Figure 4.40 show the main board and secondary board components, layout and connections.

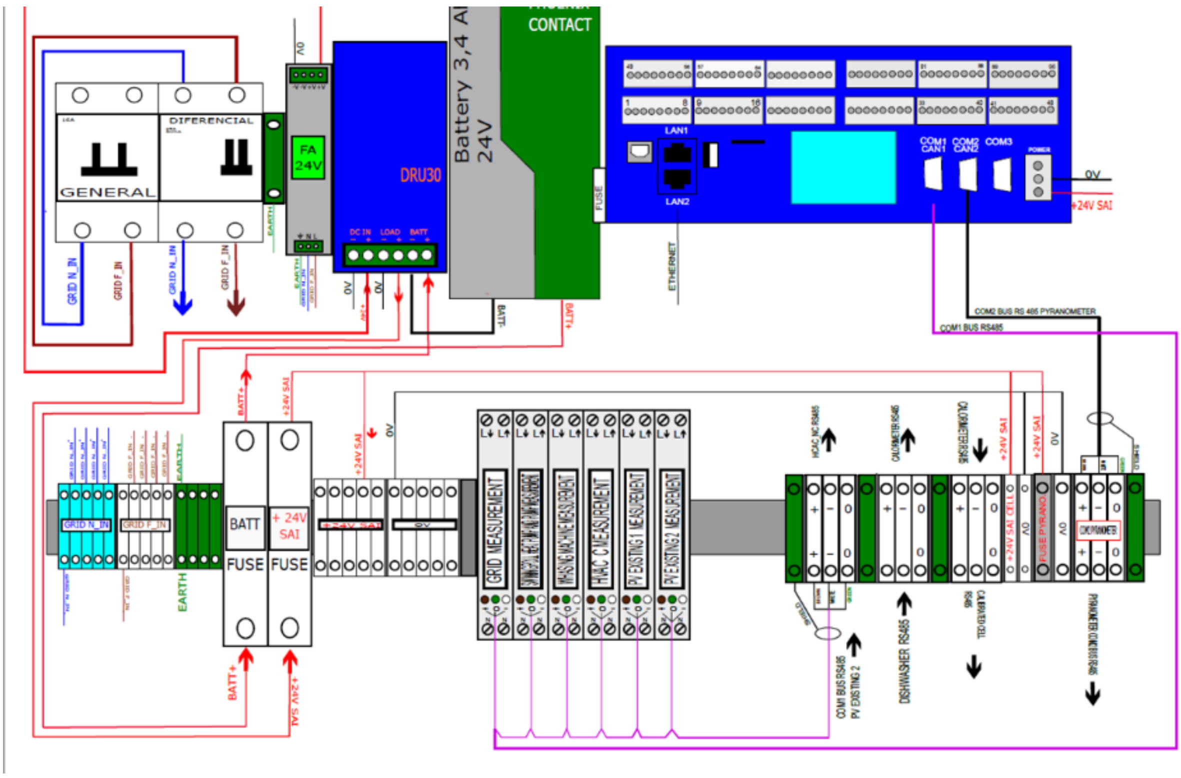


Figure 4.39. Main board components, lay-out and connections.

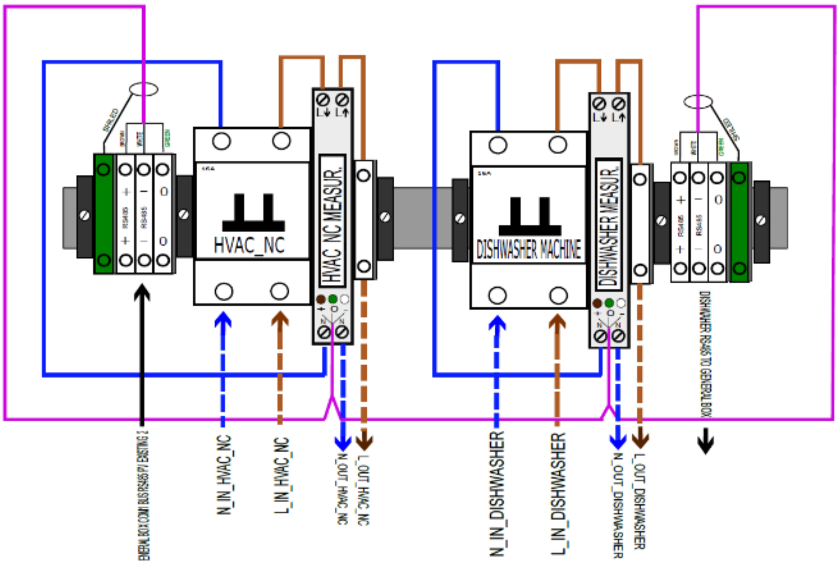


Figure 4.40. Secondary board components, lay-out and connections.

Finally, the meteorological instruments (pyranometer, temperature sensor, reference cell and anemometer) have been installed in the North and South façades, as shown in the next figure.

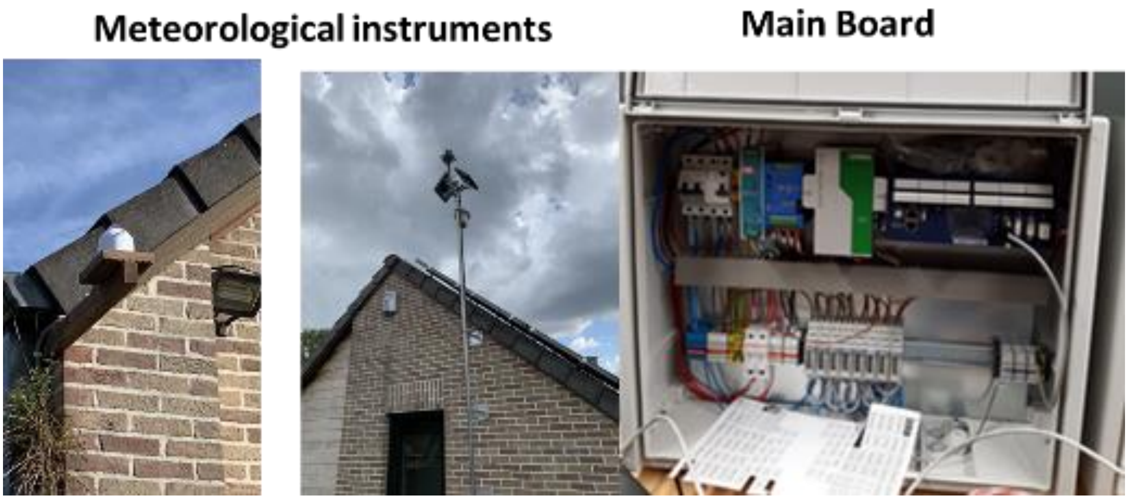


Figure 4.41. Monitoring system installed components; meteorological instruments and main board.

4.7 BIPV MODELLING AND PERFORMANCE SIMULATION

EnerBIM, as WP6 leader and BIMsolar tool developer, has completed BIPV systems digital modelling and simulation works as a pre-study.

4.7.1 Element level to building level methodology using 3D modelling and simulation tools

4.7.1.1 Overall methodology

The same methodology presented in Section 2.7.1.1 has been used.

4.7.2 Modelling strategy retained for CIGS films mounted on roof tiles (integrated system by SCHWEIZER) – Opaque BIPV

The software is being developed to fit with SCHWEIZER/FLISOM© strategies regarding CIGS PV technologies mounted on metal substrate (steel, aluminum) to generate cladding modules and roof tiles. As a pre-study approach, the module builder is based on 2 editors working as a BAPV configurator:

- Cell editor
- Module editor

To design a CIGS roof tile system, we have fixed the following steps:

<u>BIPV Layout</u>

<u>Balance of System</u>

4.7.3 DEMO#3 – OPTIMAL building, 3D design from 2D plans, simulation with BIMsolar

4.7.3.1 Hypothesis

BIPV modules have been set up from SCHWEIZER datasets (final revision). Layouts options decided by VIRIDEN & FD2 (as architects) and OPTIMAL (as the demo site owner).
To run first simulations, we have set-up selected CIGS cells and CIGS modules from FLISOM© standards (known from PVSITES sister project) and set up features from SCHWEIZER datasheets and recommendations.

4.7.3.2 CIGS ROOF TILES

Specifications from SCHWEIZER

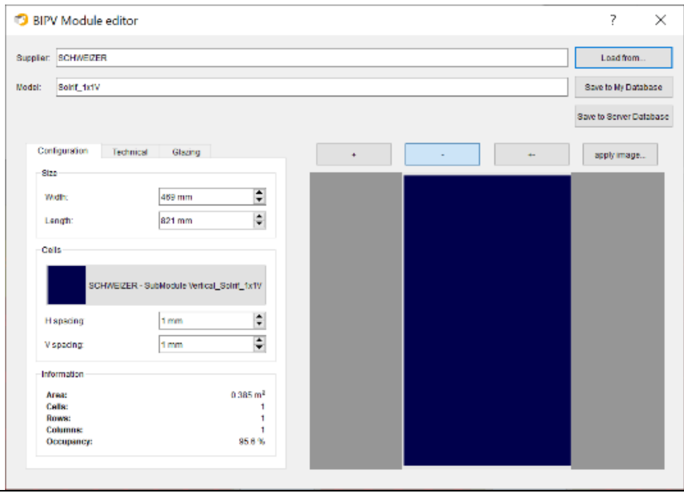
Solrif® CIGS on metal BIPV roof modules Version 5.0 (21.7.2020)

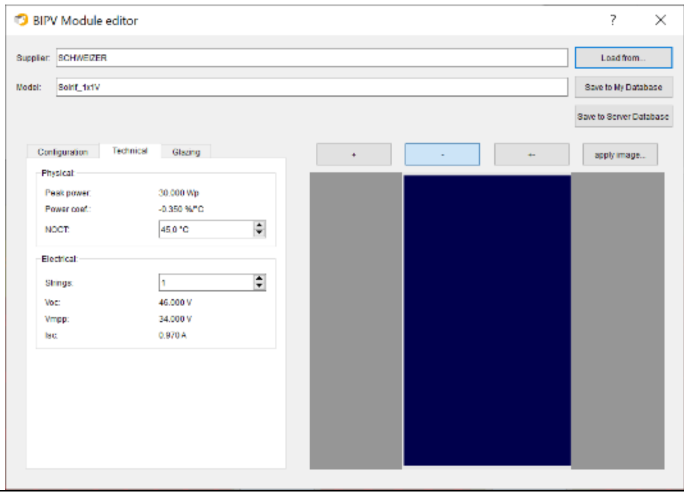
Module Type			1x1H	2x1H	1x1V	2x1V	3x1V
Dimensions							
Width total	LhorTotal	[mm]	870	1700	487	888	1270
Height total	LverTotal	[mm]	462	462	853	853	853
Width grid	RhorTotal	[mm]	852	1682	469	870	1252
Heigt grid	RverTotal	[mm]	430	430	821	821	821
Thickness at module frame		[mm]			17		
Thickness at J-Box		[mm]			23 ± 1		
Weight (prelimiary estimation)		[kg]	4.0	7.0	4.0	7.0	10.0
area (based on layout grid)			0.4	0.7	0.4	0.7	1.0
Electrical characteristics at STC[1]							
Nominal Power	P_{MPP}	[W]	30	60	30	60	90
Short Circuit Current	I_{SC}	[A]	0.97	1.91	0.97	1.94	2.91
Open Circuit Voltage	V_{OC}	[V]	46	48	46	46	46
MPP Current	I_{MPP}	[A]	0.88	1.66	0.88	2x0.88	3x0.88
MPP Voltage	V_{MPP}	[V]	34	36	34	34	34
Solar Cell Efficiency (subcell)	η_c	[%]			12		
Module Efficiency	η_m	[%]	9.1	9.2	8.7	9.4	9.8
Power Output Tolerance					-0%/+5%		
Maximum Revere Current					10 A		
Maximum System Voltage					1000 V		
Thermail charactersistics							
Temperature coeffficient	Voc	[%/°C]			-0.3		
Temperature coeffficient	Isc	[%/°C]			0.01		
Temperature coeffficient	PPmpp	[%/°C]			-0.35		
Operating conditions							
Temperature range		[°C]			-40 to 85		
Max. mechanical load [Pa]					open		
Additioal data							
Cell type					CIGS		
Junction Box			Back side including bypass diode, IP 67, MC4 type / MC4 connectors STC1				
No. of junction boxes			1	1	1	2	tbd
Cable lenght (4mm²)		[mm]	tbd	tbd	900	tbd	tbd
Encapsulation					Fluorpolymer front sheet / back plate (open)		
Warranty & certification							
Performance guarantee			10 years on 90% of Pmpp under STC1 and 20 years on 80% of Pmpp under				
Warranty					5 years' workmanship after delivery date		
Certification					EN IEC 61646; EN IEC 51730-1 & 2		
Fire safety class					according to hard roofing (B roof T1, Euroclass) (attempted)		

Configuration of virtual modules into BIMsolar

1X1V MODULE

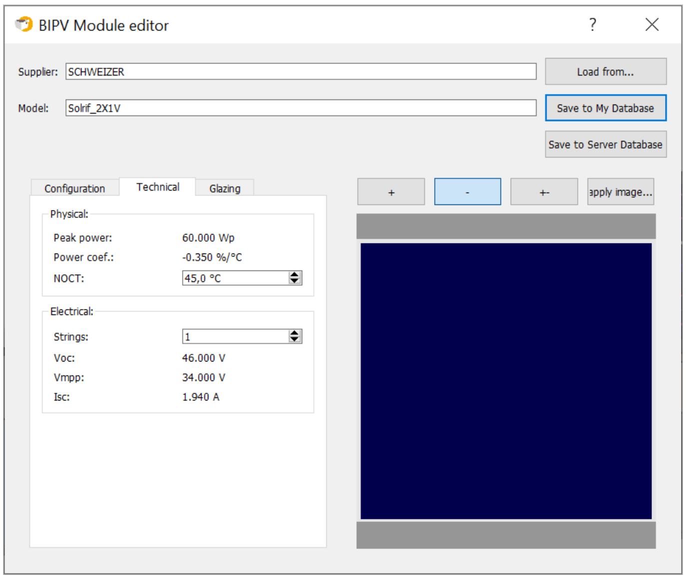
Technical specifications

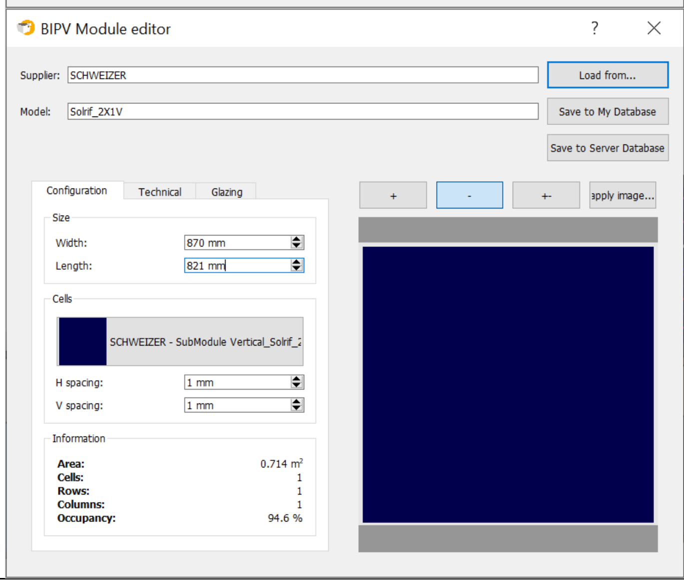




1X2V MODULE

Technical specifications





4.7.3.3 WEATHER DATA and IRRADIATION MODELING

We chose to use the European open access reference tool PVGIS to generate meteorological + site data at the exact location of the demo site. Visualization from satellite enable considering terrain modelling, albedo evaluation and masking effects

GEO LOCATION

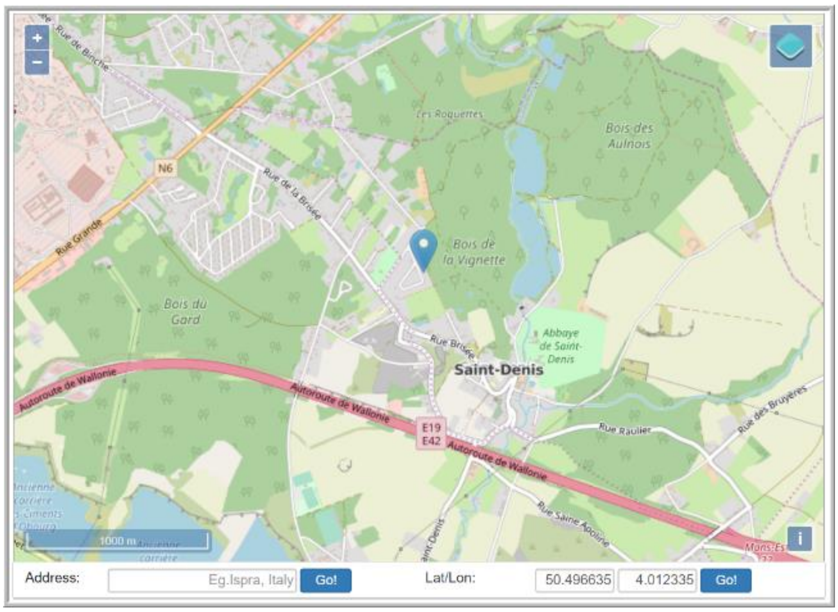
- ➔ Google Maps
- ➔ PVGIS

ALBEDO

- ➔ 20% for vegetation
- ➔ 50% for buildings

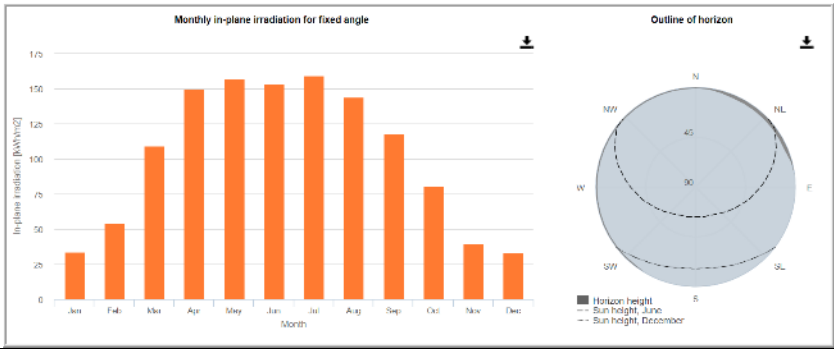
ORIENTATION

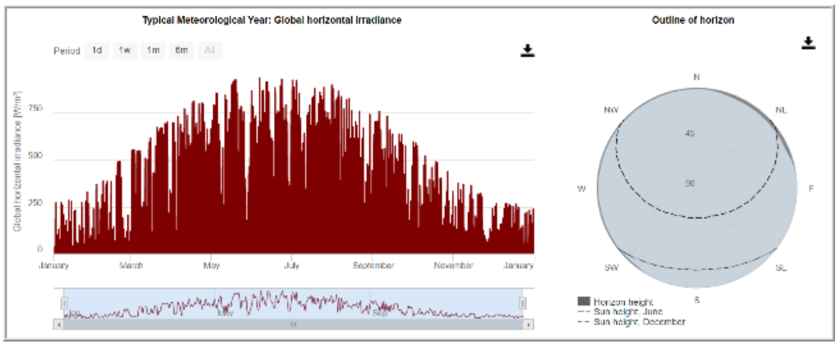
- ➔ Set-up from architectural design and urban integration

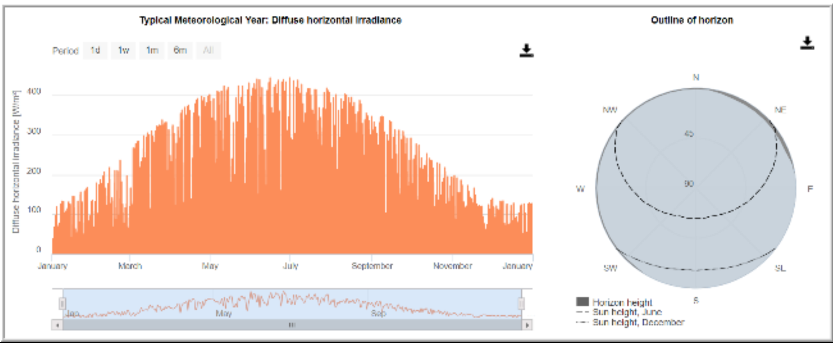


<table>
<tr>
<td>HORIZON

IN PLANE IRRADIATION for typical 35° PV angle

➔ No masking for PV production</td>
<td>
</td>
</tr>
<tr>
<td>IRRADIANCE

TMY data to generate weather file as input for BIMsolar (epw)</td>
<td>


</td>
</tr>
</table>

4.7.3.4 3D MODELING - SETUP- EXISTING BUILDING

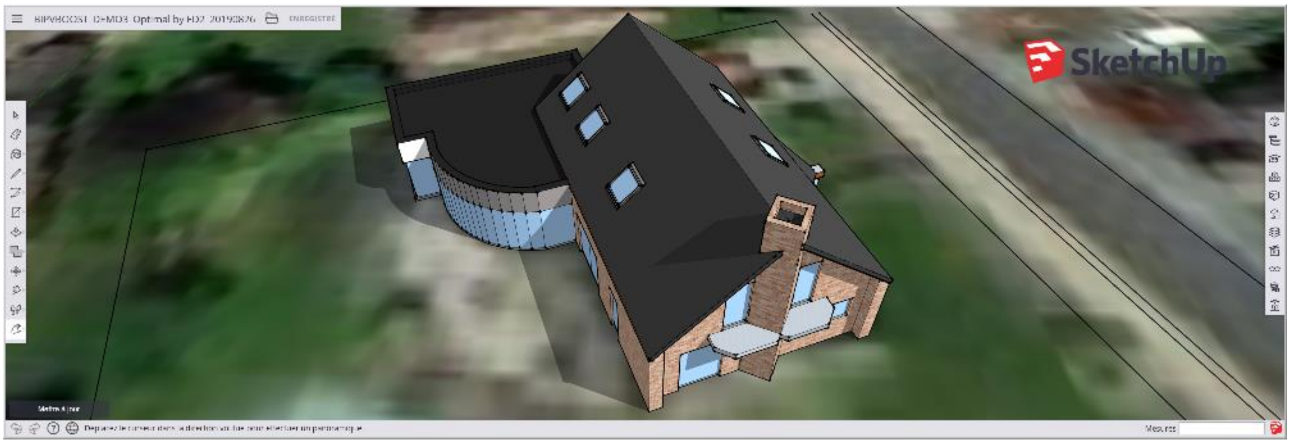


Figure 4.42: Modelling has been made as much realistic as it could be from the existing 2D plans to address BIPV issues (Trimble SketchUp model from FD2 Architecture)

STEP#1-BIMsolar IMPORTATION

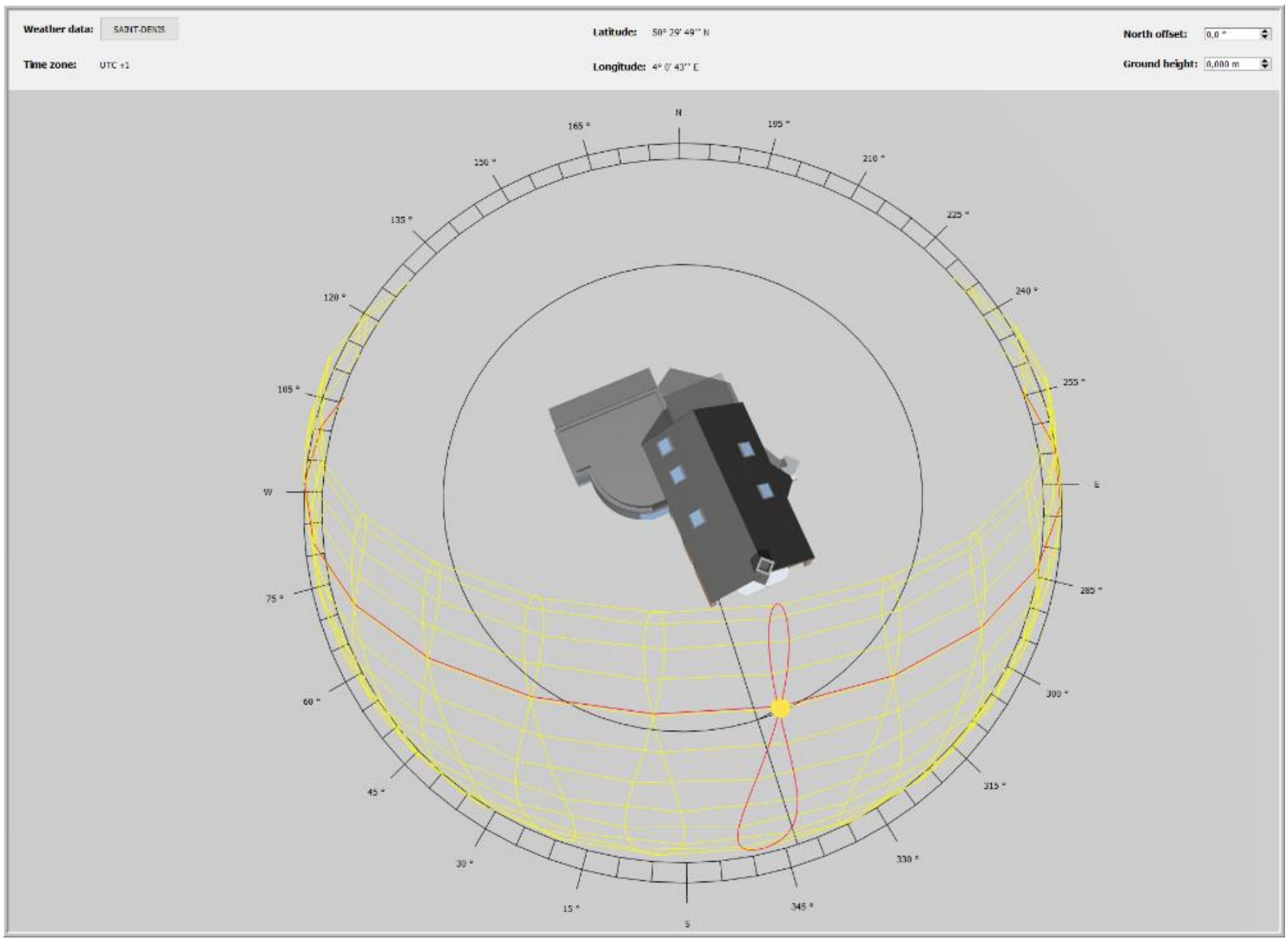


Figure 4.43: Close and far shadowing calculation are made possible through 3D modelling of realistic buildings - Sun course for full year is displayed at hourly step time

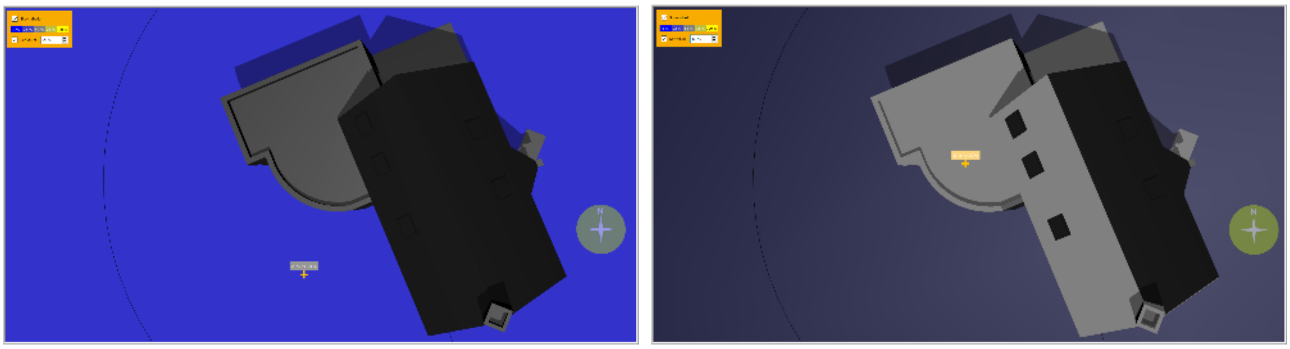


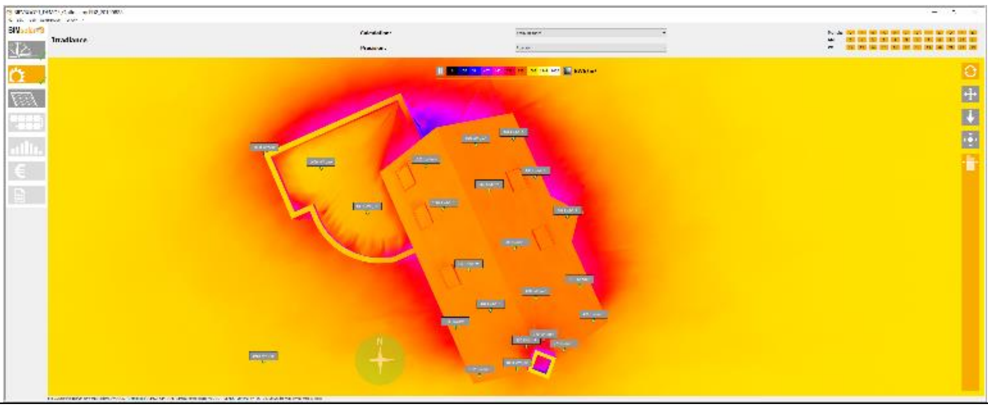
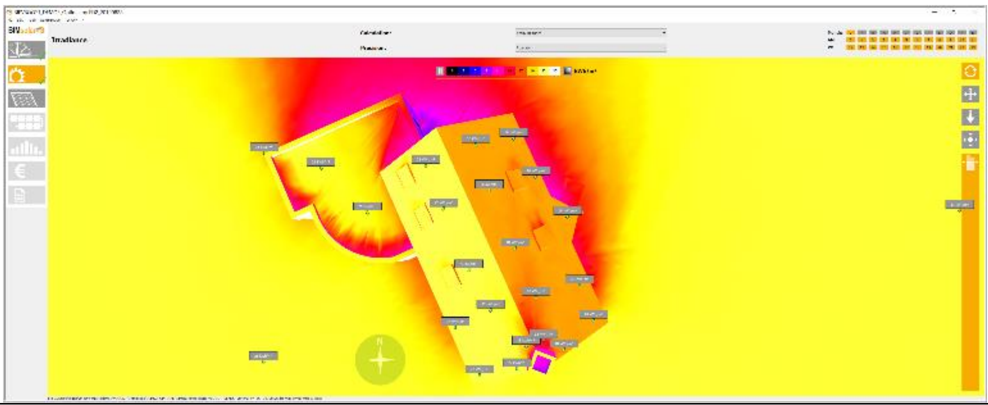
Figure 4.44: Albedo effects (reflected irradiance) are generated selecting groups and types of surfaces 20% as a setup for surroundings and 50% for the building itself and other buildings

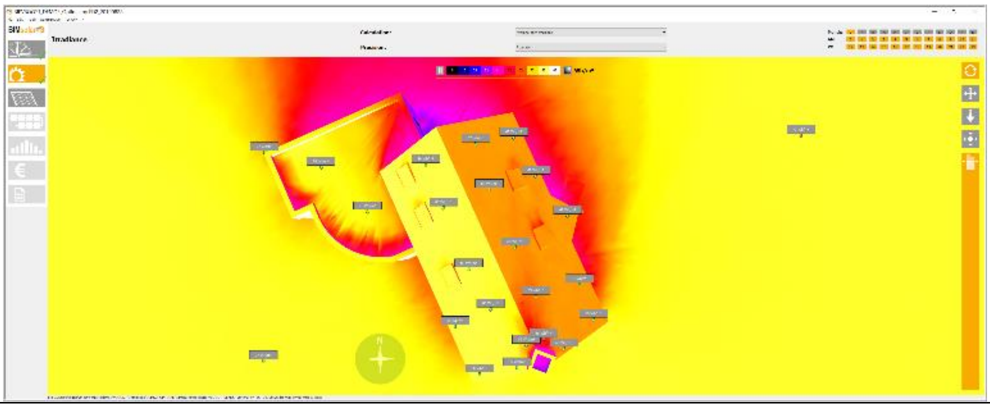
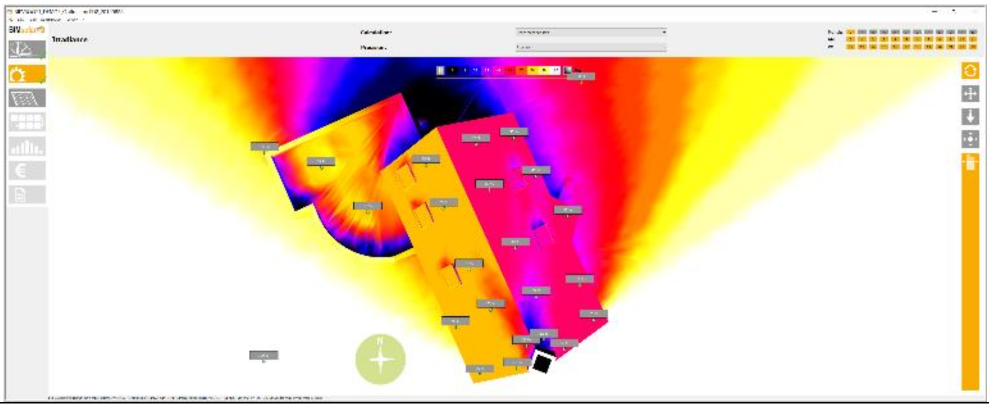
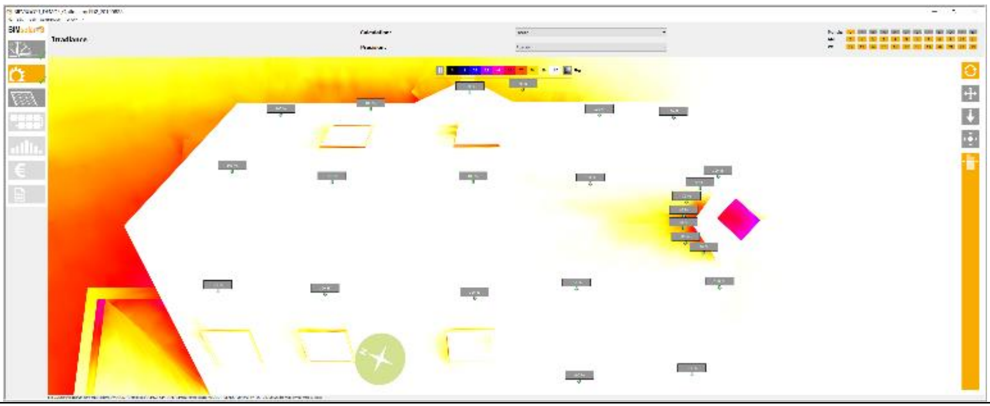
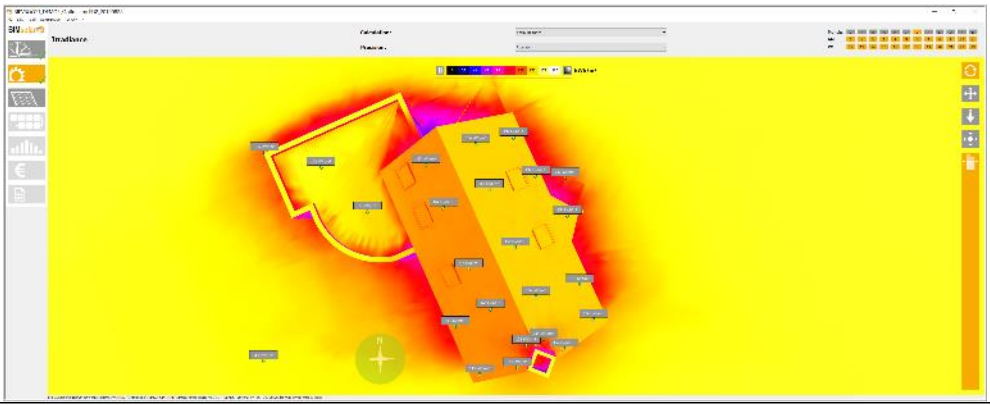
4.7.3.5 Simulation – Results

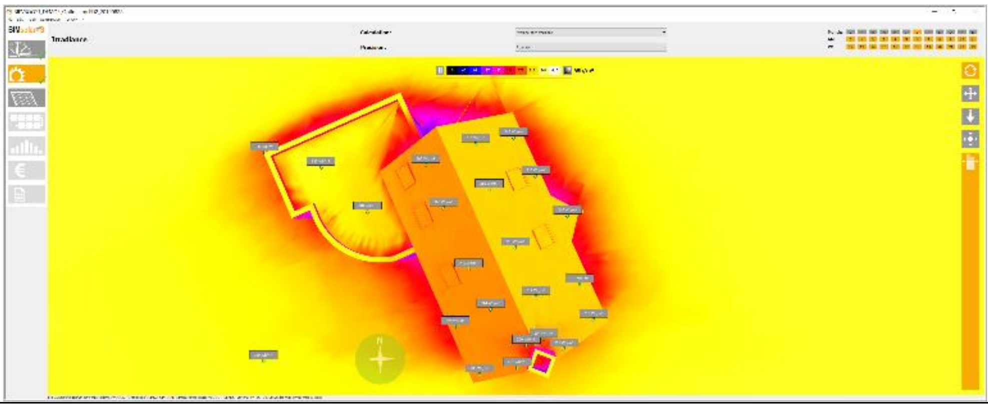
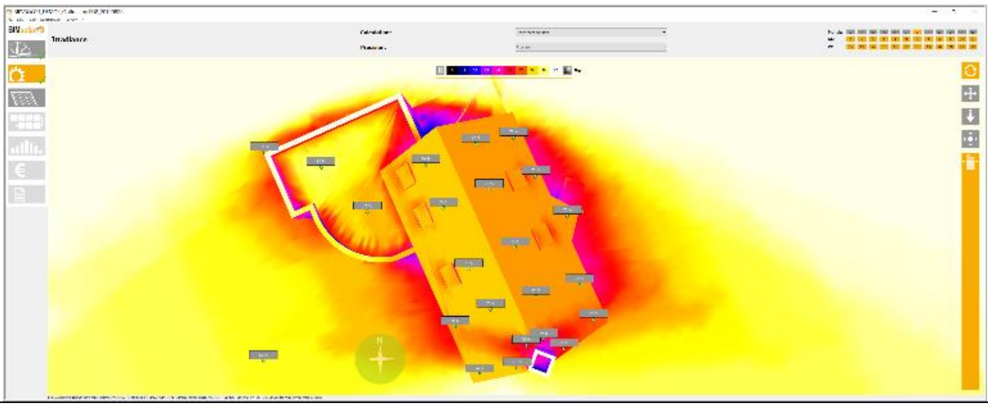
STEP#2-IRRADIATION

We use markers to record and visualize values.

Sets of data can be exported in CSV.

Global survey on roof Yearly kWh/sqm Max=1002 Min=775 (shading from chimney)	
January Worst case kWh/sqm Max=22 Min=13 (shading from chimney)	

Average day for January Wh/sqm Max=80 Min=48 (shading from chimney)	
Direct ratio for January % Max=75 Min=12 (shading from chimney)	
Roof Shading survey January (worst case) No shading issue except on chimney area	
July Best case kWh/sqm Max=154 Min=122 (shading from chimney)	

Average day for July Wh/sqm Max=316 Min=250 (shading from chimney)	
Direct ratio for July % Max=76 Min=40 (shading from chimney)	
Roof Shading survey July (best case) No shading issue except on chimney area	

STEP#3 – BIPV layouts

We use virtual modules set-up from manufacturer’s datasheets (see above) to generate BIPV systems:

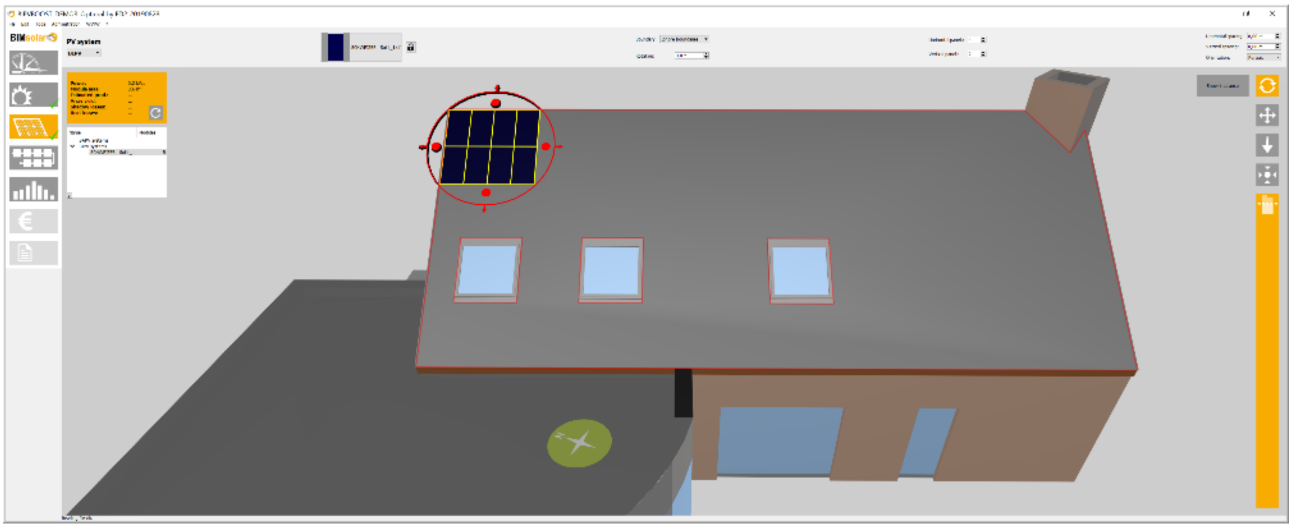


Figure 4.45: Layout generation within 3D interface using BIPV BIM objects (from BIMsolar®)

Production, shading losses, temperature losses are calculated in real time from module level to BIPV layout level.Every single module is computed as a system and the software displays individual KPIs.

Detailed results are obtained at STEP#5 (BIMsolar reference process)

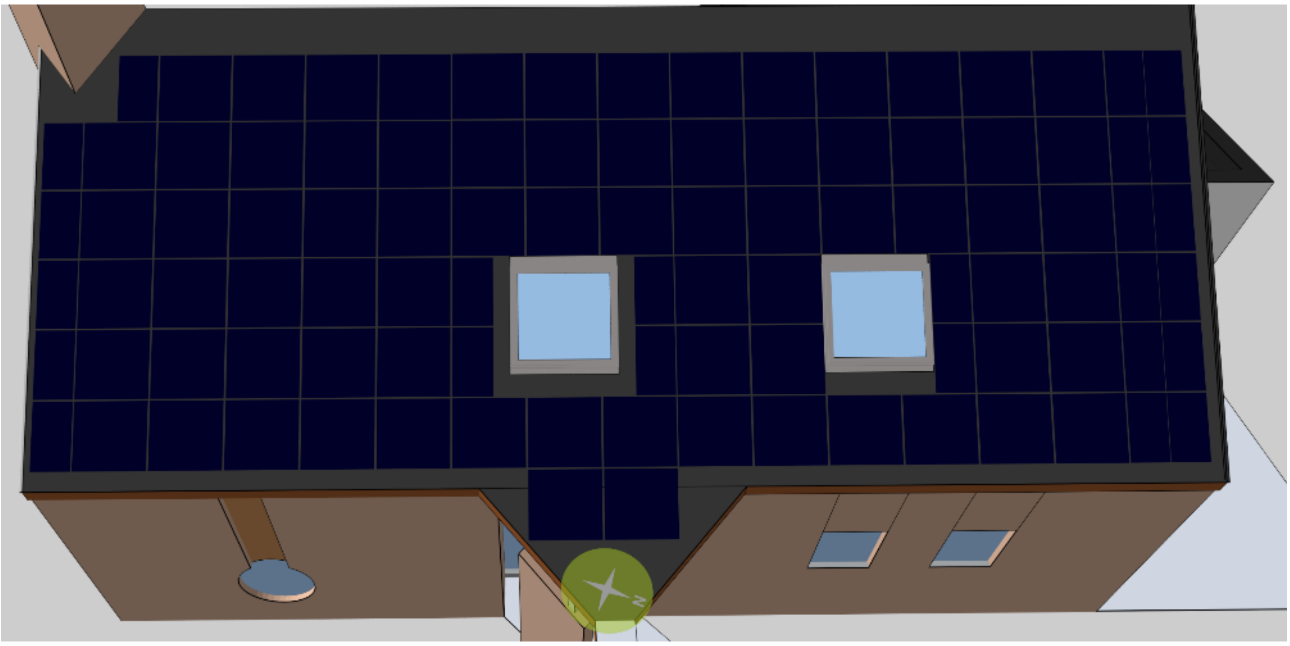


Figure 4.46: East roof for Solrif© modules combination following architect + demo owner requirements. Total 5.2kWp / 62.8 sqm

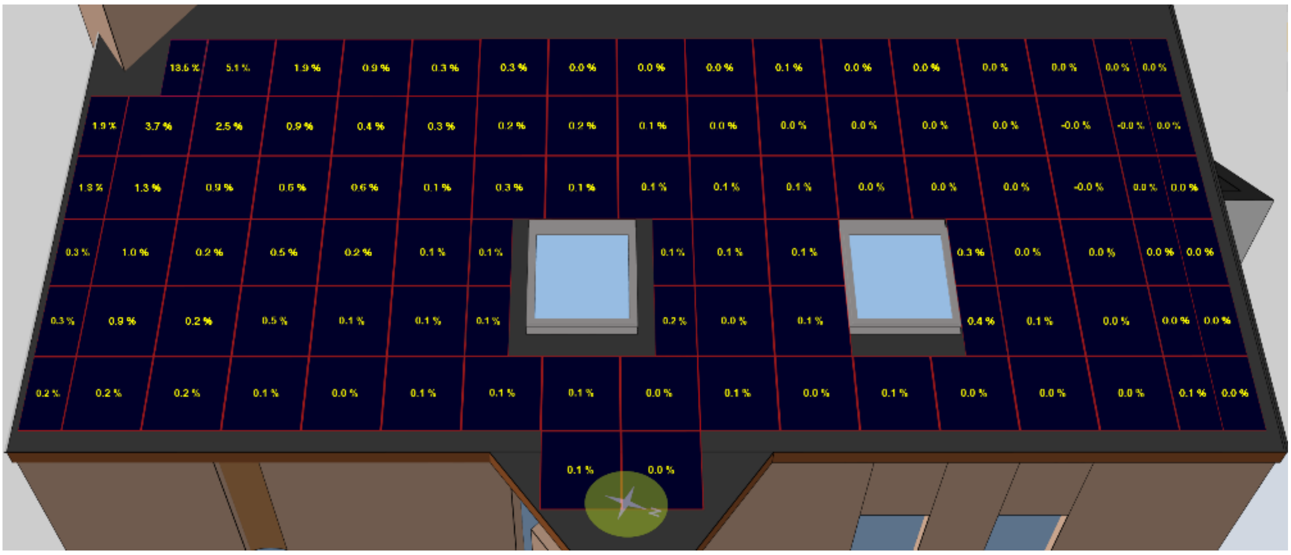


Figure 4.47: East roof – Shading losses at module level

Note: skylights are not perfectly positioned in the original 3D model. For that reason, the BIPV modules layouts may enter in collision with the geometry which generates local shading.

Dummy modules are not created for simulation. 2x1V modules equipped with one cell are set-up as 1X1V modules.

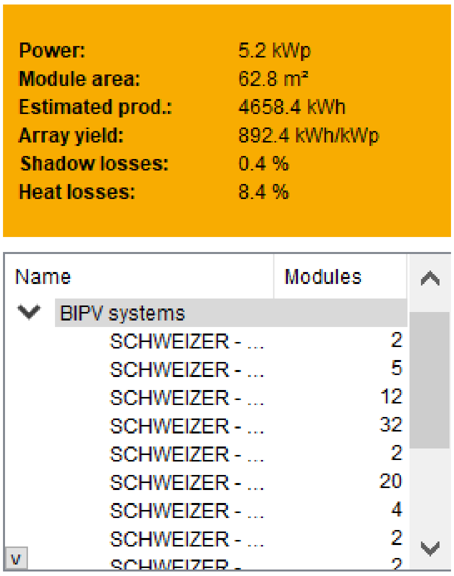


Figure 4.48: East roof – Global results – Array level

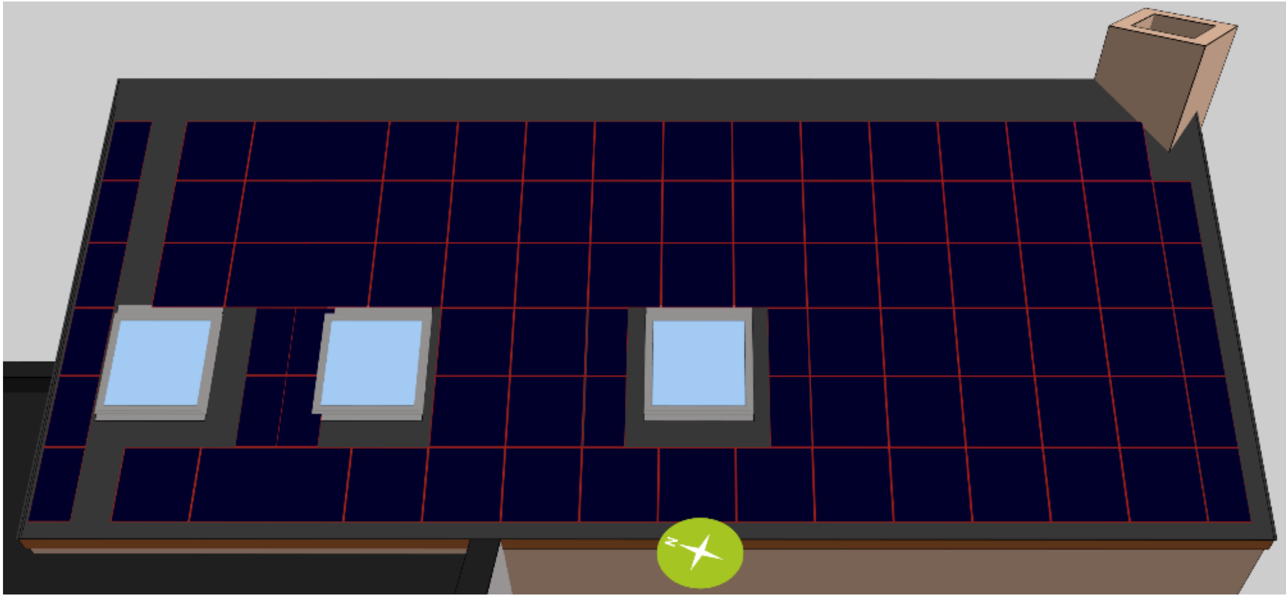


Figure 4.49: West roof for Solrif© modules combination following architect + demo owner requirements.*Total 4.8kWp / 62.8 sqm*

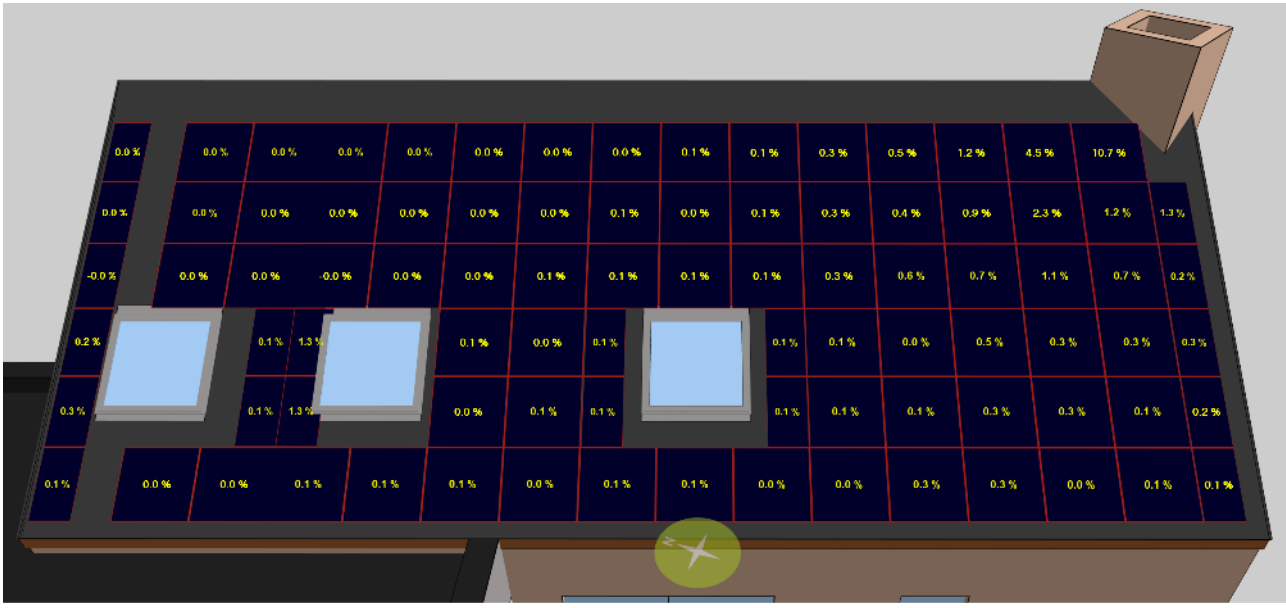


Figure 4.50: West roof – Shading losses at module level

Note: skylights are not perfectly positioned in the original 3D model. For that reason, the BIPV modules layouts may enter in collision with the geometry which generates local shading.

Dummy modules are not created for simulation. 2x1V modules equipped with one cell are set-up as 1X1V modules.

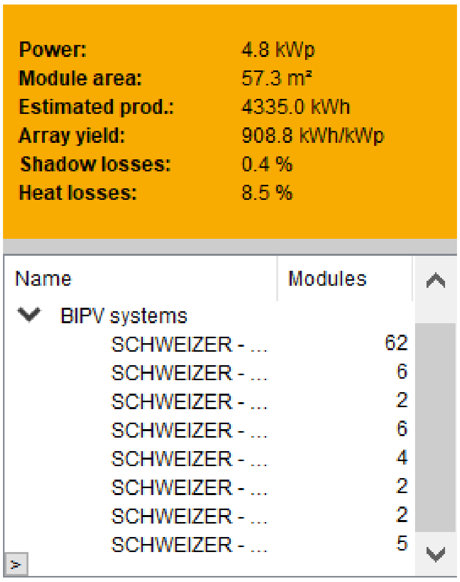


Figure 4.51: East roof – Global results – Array level

STEP#4 – INVERTERS / WIRING

This step consists in building the best strategy for the implementation of inverters and connect to them the strings of modules to optimise the DC and AC productions.

BIMsolar enables considering the mismatching between modules (gaps in irradiance due to shading effects), then proposes the best wiring configuration for each MPPT to maximise the energy production.

Methodology for simulations:

Because the 1X1V and 2x1V modules are different in size to fit with the architectural grid configuration, we need to address only individual cells to set-up connections of modules to build strings and to meet inverters input requirements (same Isc values to connect in series).

For these reasons we rebuilt the 3D models with one cell equivalent modules.

This allows to count the exact number of cells and to connect the appropriate ones to meet the electrical engineering strategy.

Electrical layout specifications from OPTIMAL:

As presented above (section 4.5.1 "PV inverter"), OPTIMAL chose to limit the total power input for the inverter. This means disconnect 3 cells on each roof.

BIMsolar allows mismatching of modules analysis to support wiring strategies. This is useful to build well balanced strings to be connected on the inverter's MPPTs.

In this way we let the software build the strings of 9 modules for the two roofs and we disconnected the most shaded modules (nb=6 around the chimney).

We obtain a total of 327 cells connected to the SMA INVERTER.

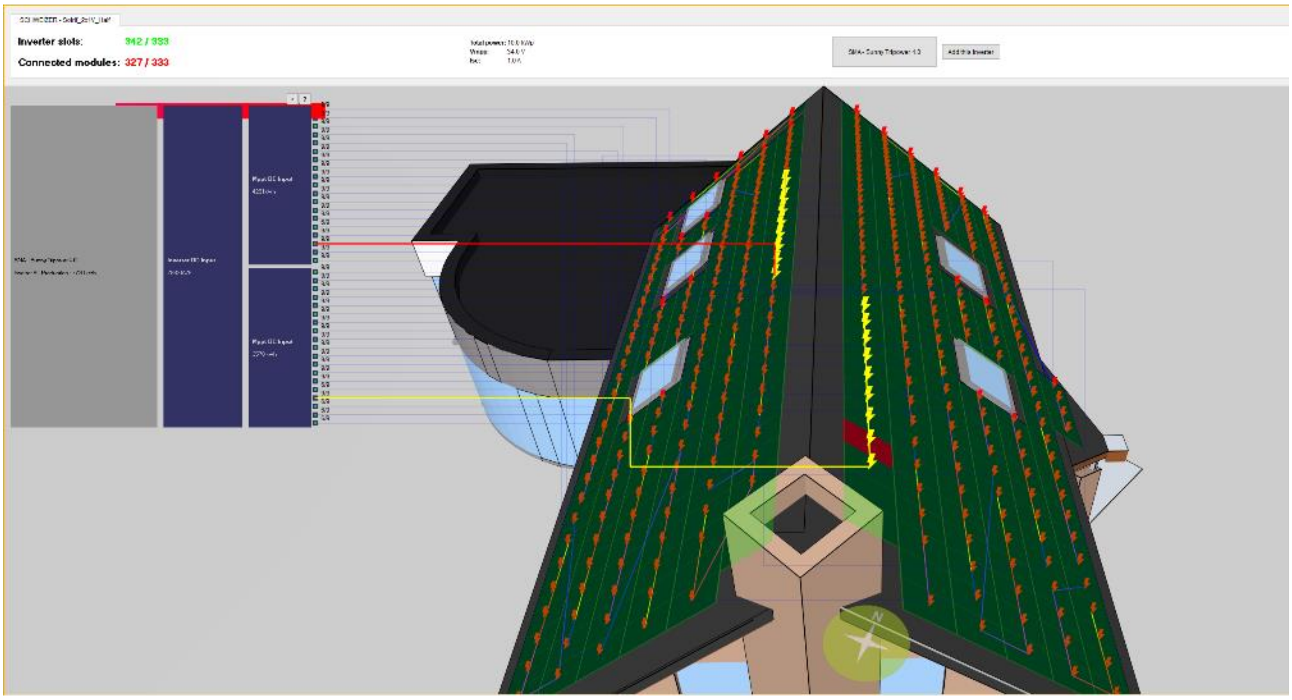


Figure 4.52: SMA SUNNY TRIPOWER 4.0 INVERTER and strings configuration in BIMsolar

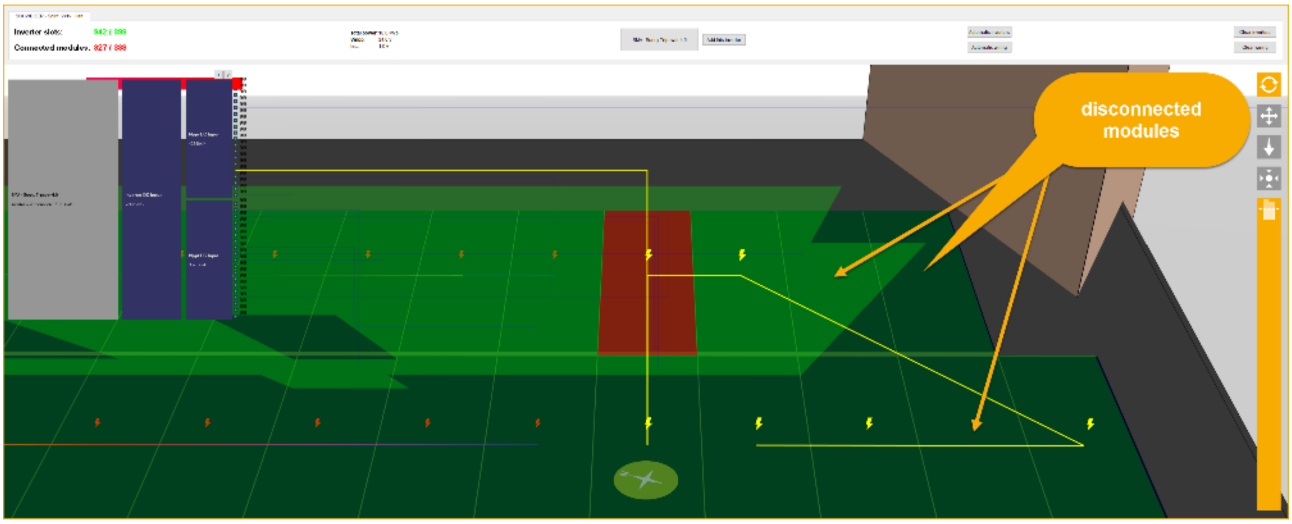
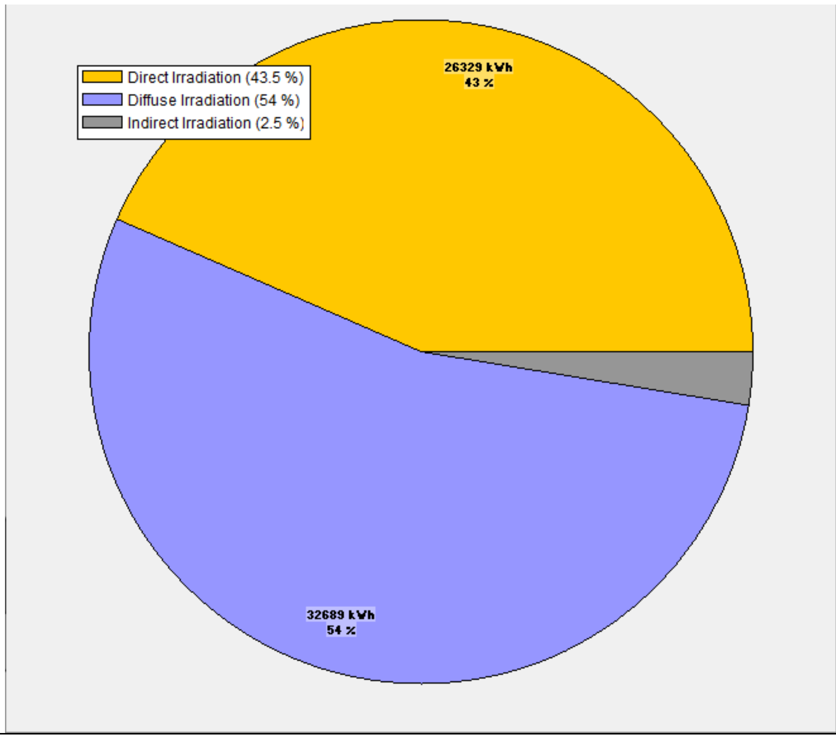
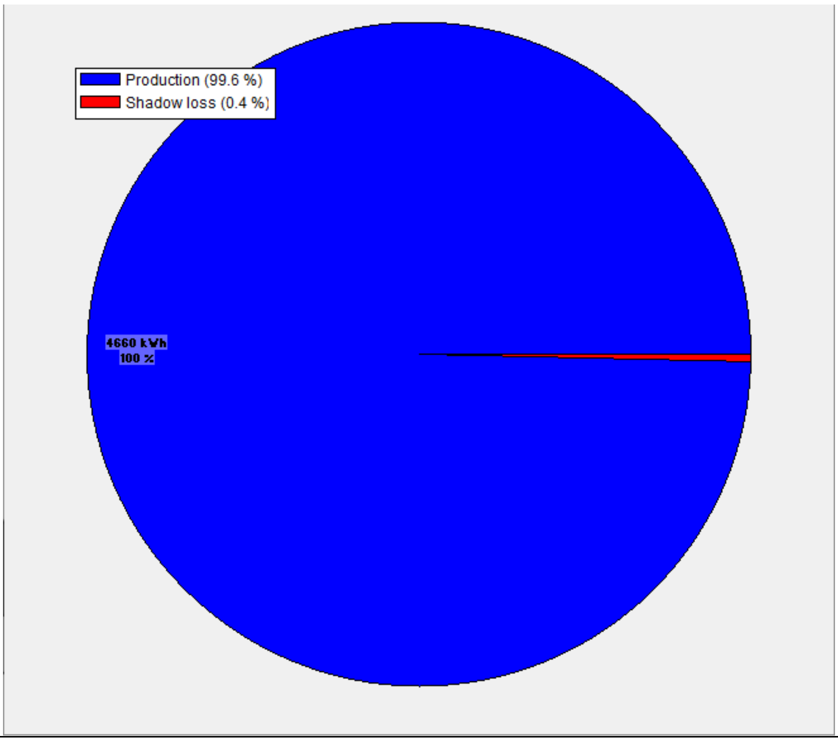


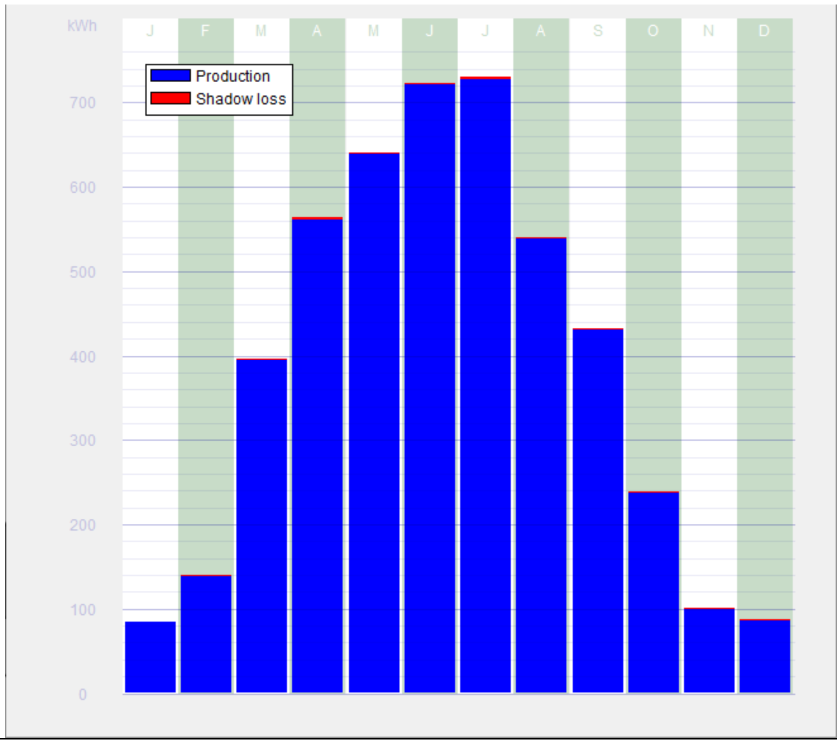
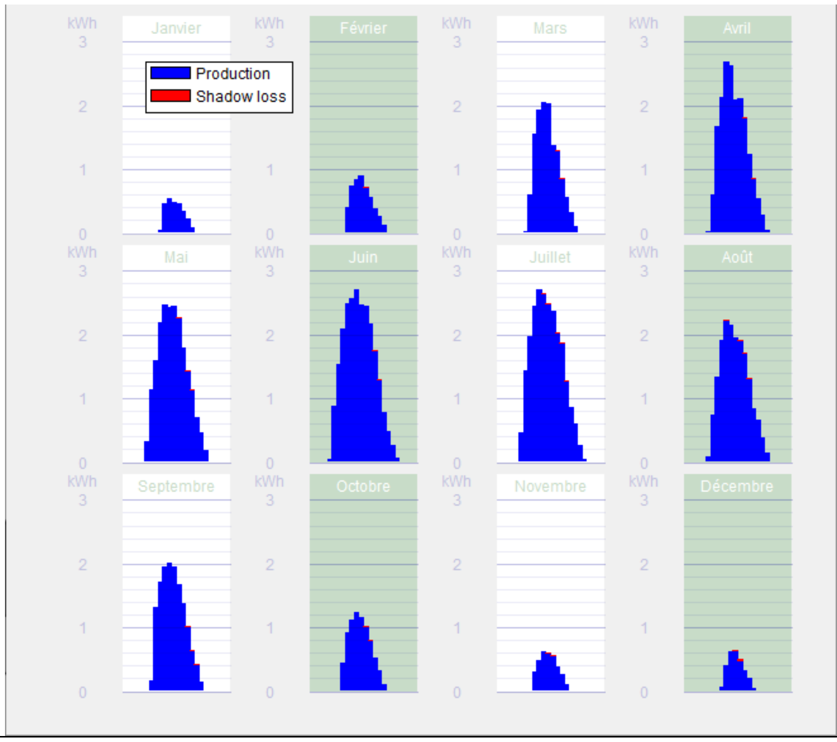
Figure 4.53: disconnection of modules following the demo site manager's strategy

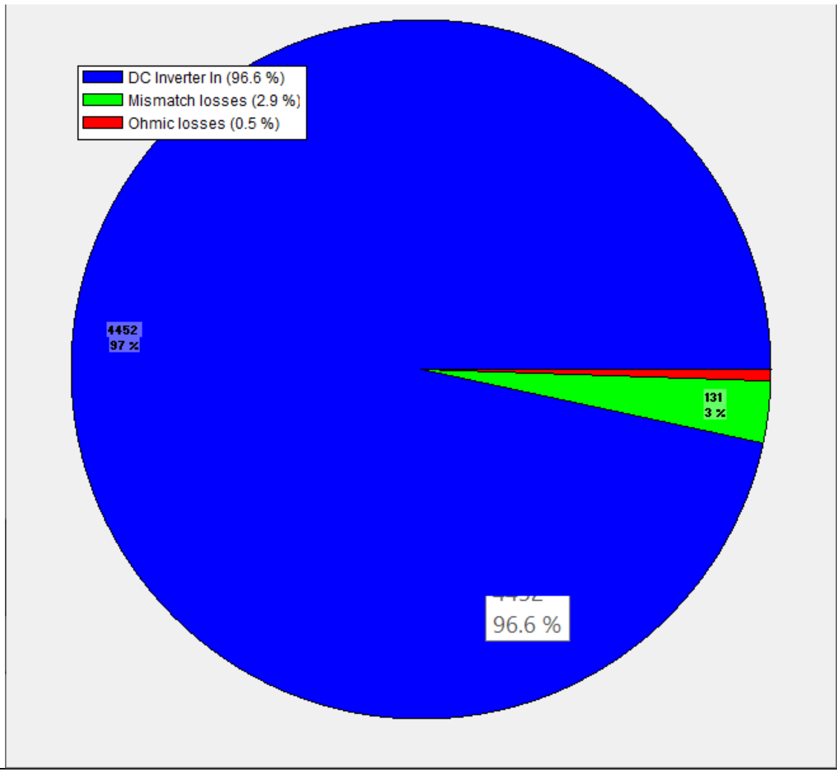
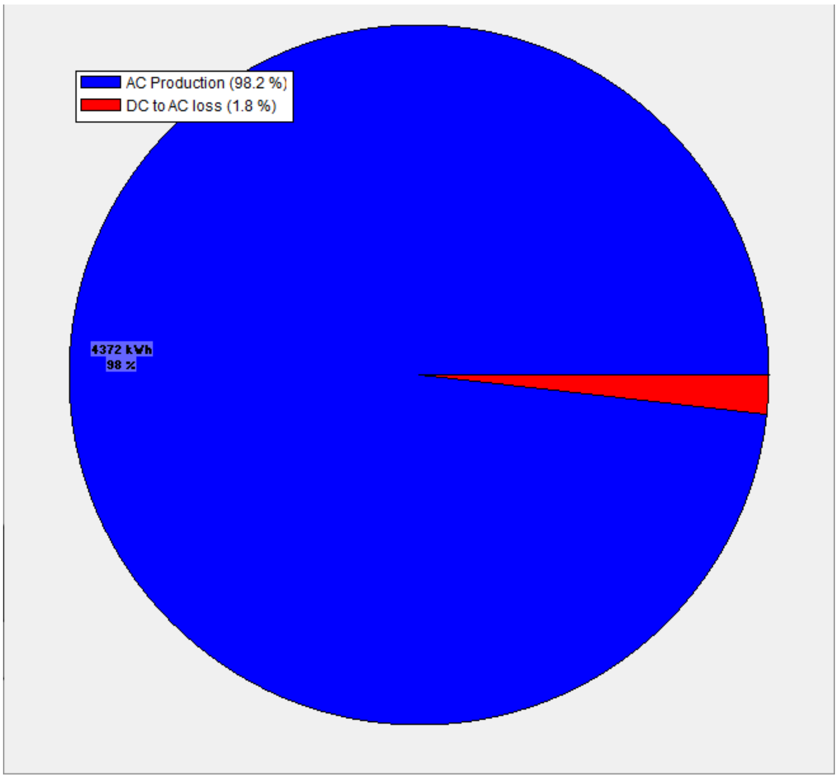
STEP#5 – RESULTS

BIMsolar offers a comprehensive set of detailed results, from yearly to hourly timestep, covering irradiation distribution, shading survey, heat losses, production, yield… from module level to layout level.

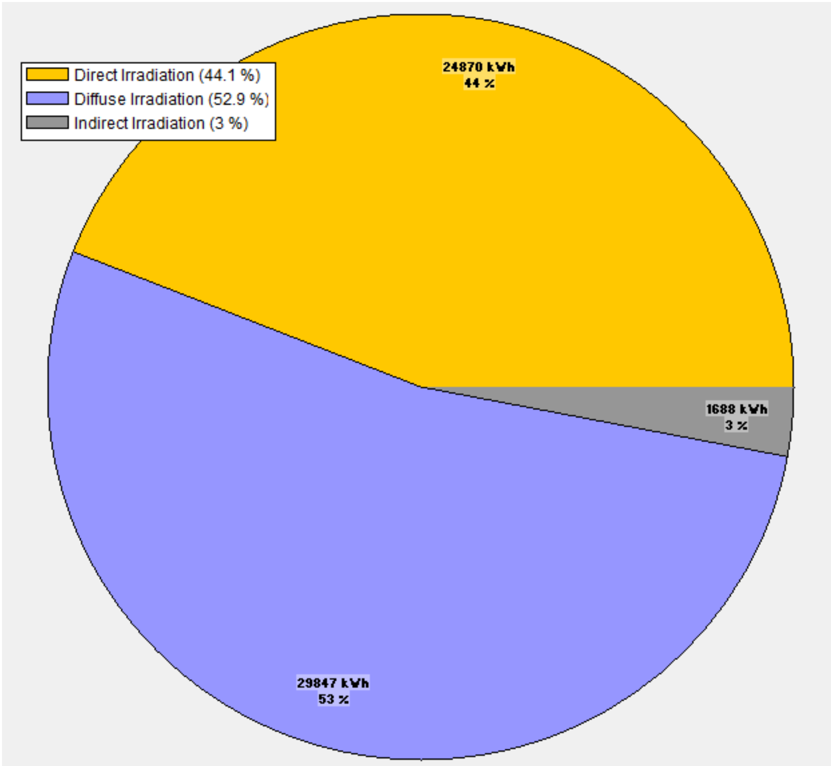
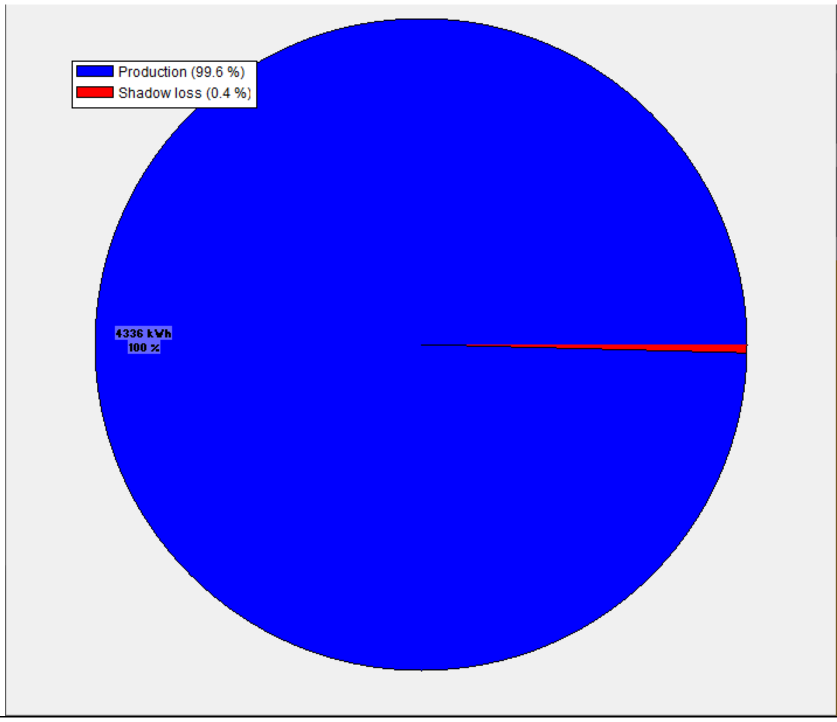
EAST roof - Table of results:

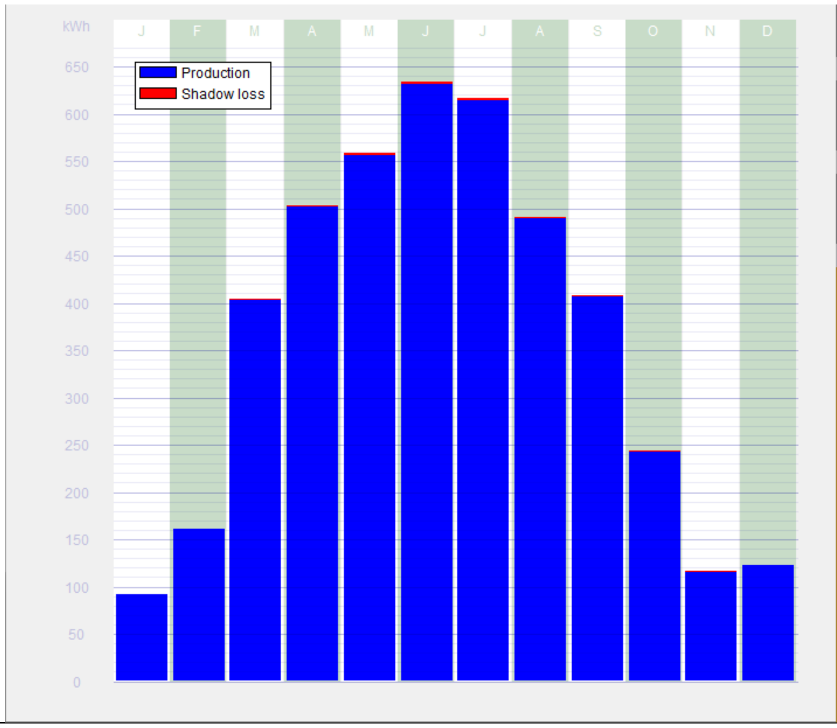
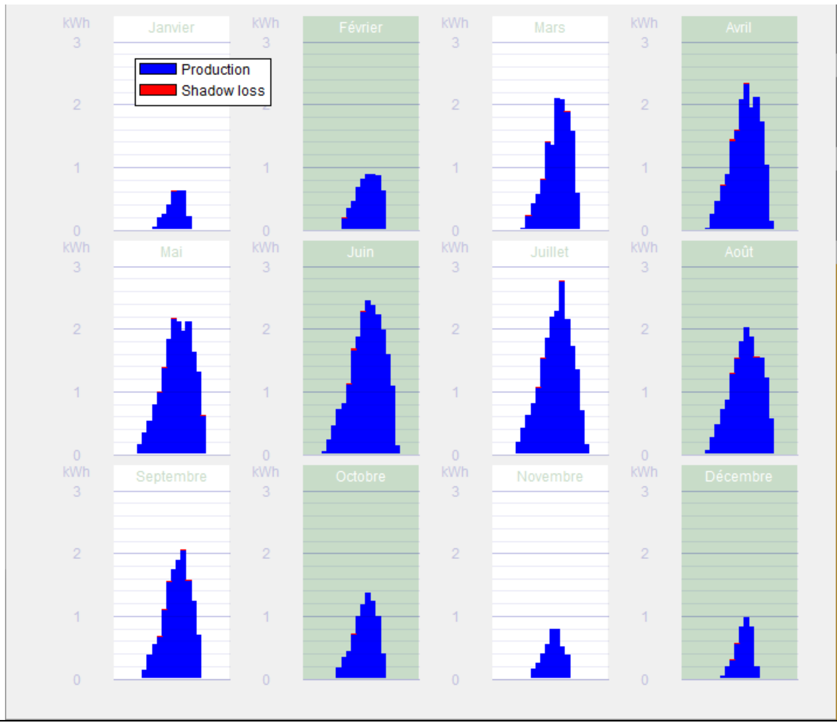
IRRADIATION share - Annual GLOBAL BIPV ARRAY	
Production – Shading losses Year #1 GLOBAL BIPV ARRAY	

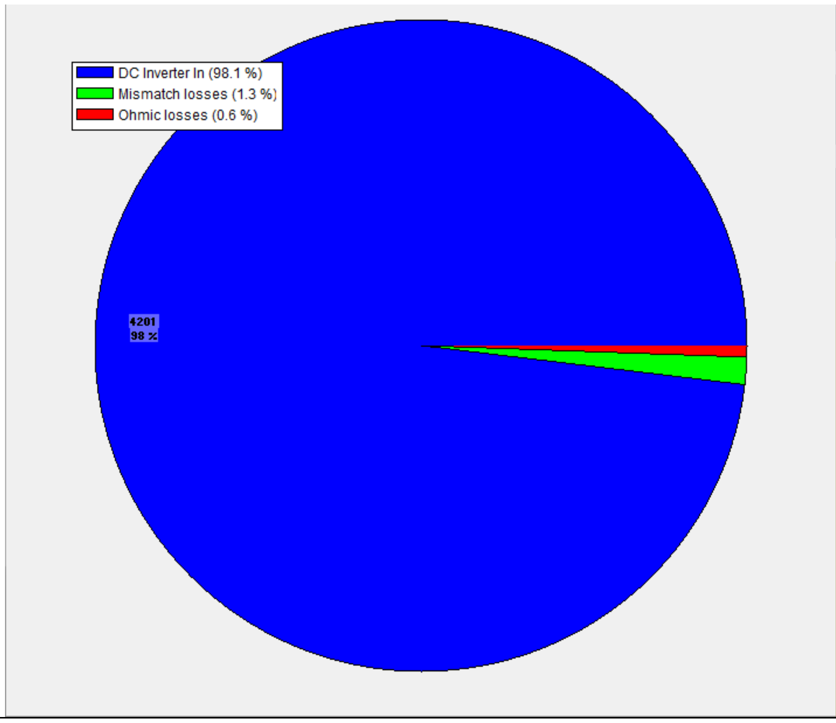
PV Generation – Shading losses MONTHLY	
PV Generation – Shading losses AVERAGE DAY / MONTH	

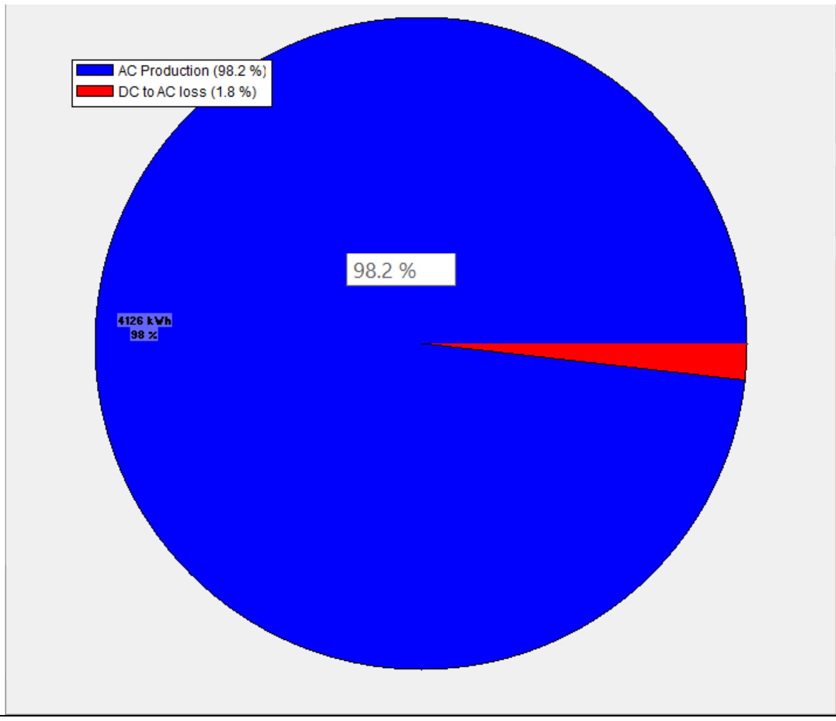
DC Production (Inverter IN) Year #1 = 4 452 kWh Losses (strings)	
AC Production (Inverter OUT) Year #1 = 4 372 kWh Final Yield = 881 kWh/kWp	

WEST roof - Table of results:

IRRADIATION share - Annual GLOBAL BIPV ARRAY	
Production – Shading losses Year #1 GLOBAL BIPV ARRAY	

PV Generation – Shading losses MONTHLY	
PV Generation – Shading losses AVERAGE DAY / MONTH	

<table>
<tr><td>DC Production (Inverter IN)
Year #1 = 4 201 kWh
Losses (strings)</td><td>
</td></tr>
<tr><td>AC Production (Inverter OUT)
Year #1 = 4 126 kWh

Final Yield = 881 kWh/kWp</td><td>
</td></tr>
</table>

4.7.4 Summary of the results

	Array											Yield
Unit	kWh			degree			kWh	kWh	kWh	%	kWh	kWh/kWp
	Irradiation			Panel orientation			PV generation	DC inverter IN	Losses		AC inverter OUT	AC inverter OUT
		East Roof	West Roof		Azimut*	Tilt	House	House	House	House	House	House
	Direct	26 329	24 870	East	-112,9	39,4	4 660,0	4 452,0	80	1,8%	4 372,0	852,0
	Diffuse	32 689	29 847									
	Indirect	1 565	1 688	West	69,1	39,4	4 336,1	4 201,0	75,0	1,8%	4 126,0	881,0
		60 583,0	56 405,0	*South = 0°			8 996,1	8 653,0	155,0	0,0	8 498,0	866,5
TOTAL:	116 988,0						8 996,1	8 653,0			8 498,0	MEAN VALUES

4.7.5 Conclusions

At the current stage of the validated performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are positive and converging towards expectations. We did not face critical difficulties in the process except difficulties in positioning the virtual objects with the highest accuracy into layouts to fit with 2D drawings and 3D original model provided by the BIPV designers.

The two roofs seem to be well balanced in final yield. Connected to the same inverter, the strings do not show unacceptable mismatching.

5 months (OCT-FEB) reveal low expected production due to meteorological conditions and the important share of diffuse irradiation.

Next steps will be:

1. Update of the building 3D model, related to final BIPV integration (demo site manager),
2. Implementation of enhanced features to generate BIPV BIM objects related to virtualization of SOLRIF© systems and enabling accurate positioning on the 3D model,
3. Comparison between measurement and simulation as soon as the real modules will be integrated and monitoring available.

4.8 PLANNING TIMELINE

Below is the planning timeline for the Optimal demonstration site at the time of writing. The Gantt chart is a living document and available via the BIPVBOOST shared platform.

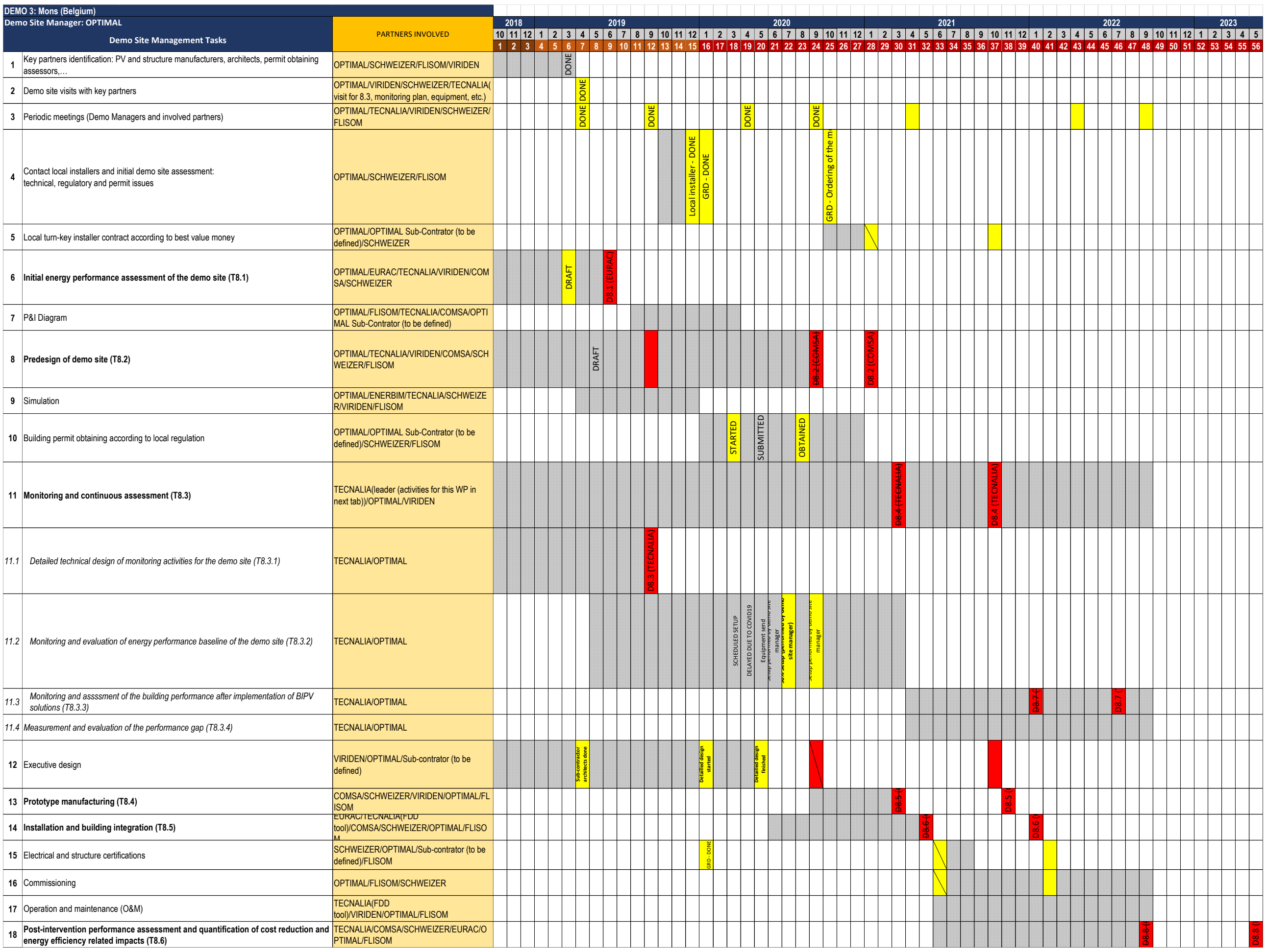


Figure 4.18: Optimal Demo-site Gantt Chart

The next big steps for the demonstration site setup are:

- August 2021: ordering of the PV inverter.
- September 2021: delivery of the PV inverter.
- October 2021: Delivery of the panels and equipments
- November 2021: Panel placement

5 DEMO SITE 4: PIZ

5.1 DEMO-SITE BUILDING DESCRIPTION

The demosite at which BIPV modules will be installed is located in the town of Morbegno situated in the North of Italy. It is a residential complex consisting of twin buildings separated from each other. The buildings were built in 2007 and are multi-family residential complex consisting of 17 residential units and 4 commercial spaces. Commercial spaces are located on the ground floor and are intended for office use. Both buildings have been constructed of bricks with the mainframe structure of reinforced concrete beams and pillars. Building facades have been realized with PIZ H89 panel which provides a good level of insulation. Images of the building are shown in Figure 5.2 and Figure 5.3.

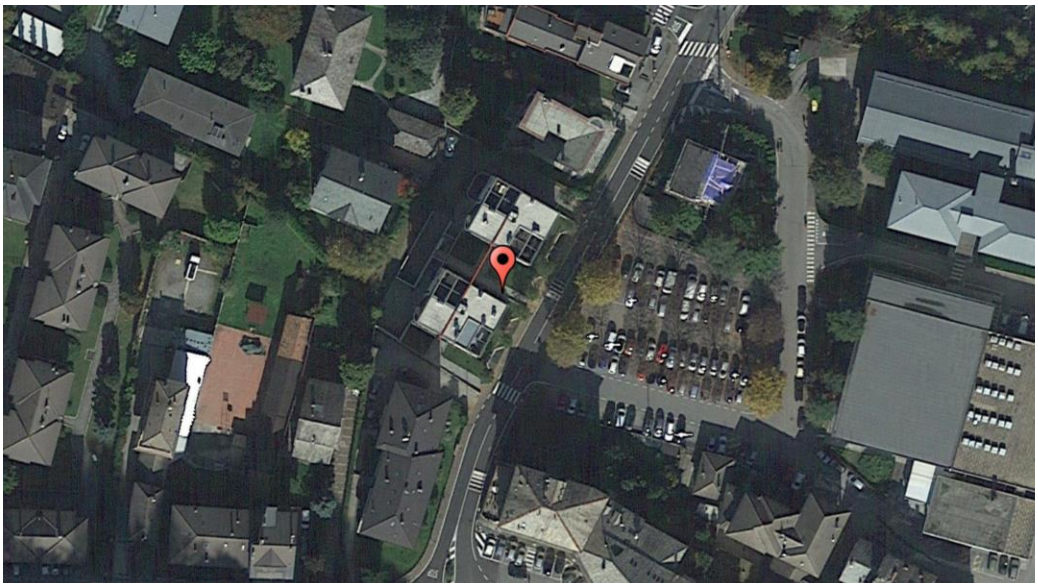


Figure 5.1: Satellite view of demosite 4, Latitude 46°7´54´´ Longitude 9°33´64´´ (Source: google earth)

Figure 5.2: Demo-site 4, Images of the building

Figure 5.3: Demo-site 4, Building's image from 1st underground level

The electricity produced by the BIPV installation will be consumed primarily to power common light points and elevators. If there is any excess electricity produced during the day, it will be used to control common heat pump for the hot/cold water of the building.

5.2 ARCHITECTURAL BIPV DESIGN

5.2.1 Existing demo-site building

The Demo-site consists of two adjacent buildings, both buildings have an identical cube-like shape. Each building consists of 5 floors above ground and 2 underground levels. The area of each floor is about 200 m^2. The underground level comprises car garages and common areas (metering room, heat pump room). The components of the building electrical system are present in the metering room on the 2nd underground level. All building facades have been realized with the PIZ H89 panel. 3D drawing of the demo site can be seen in Figure 5.5 and Figure 5.5.

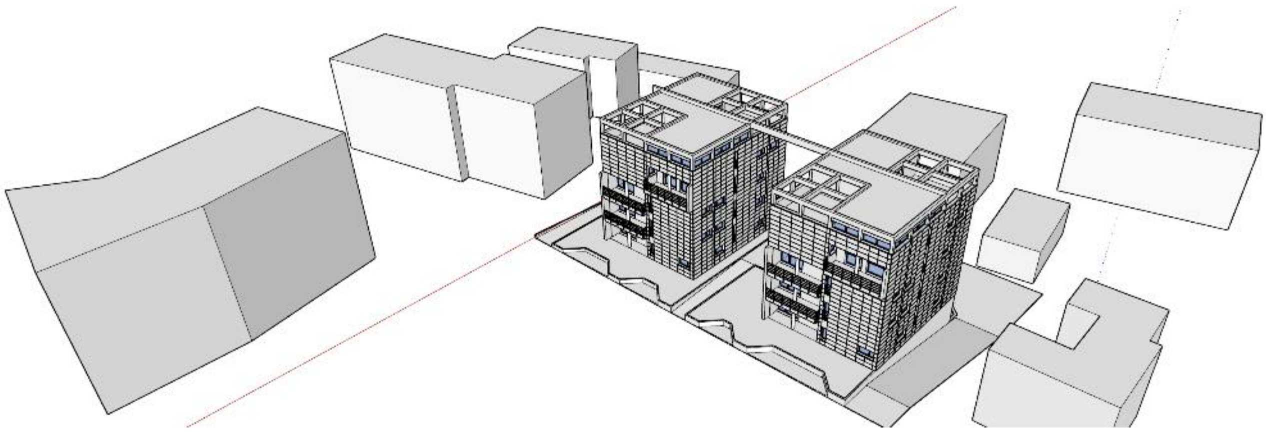


Figure 5.4: Demo-site 4, 3d drawing of the existing building

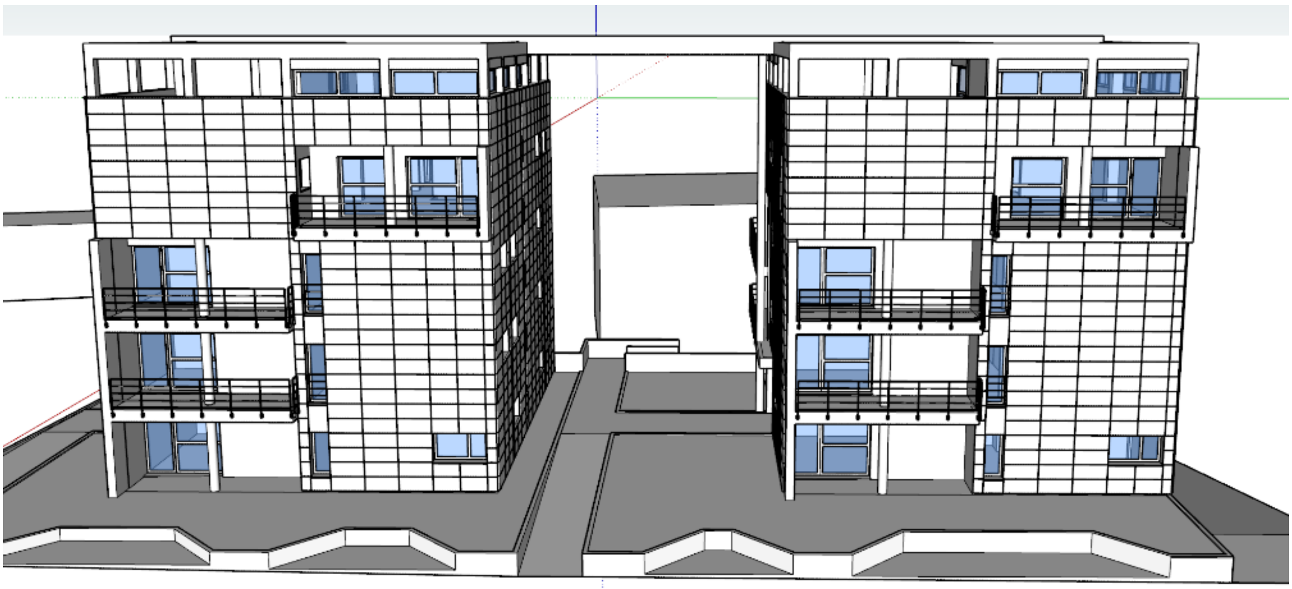


Figure 5.5: Demo-site 4, 3d drawing of the existing building

5.2.2 Architectural BIPVBOOST Design

In the initial design stages, two architectural designs were prepared with different purposes, first one focused on maximizing the power installation (10,9 KWp) whereas the second one aimed at the best architectural integration while slightly compromising the energy production (10,2 KWp).

5.2.2.1 Design option A1 and A2 (best architectural integration)

The design is shown in Figure 5.6. In this design top two rows of PIZ cladding panels are replaced by two rows of ePIZ glass-glass BIPV modules in all four facades of each building. The new installation runs in a wreath shape thereby covering all four facades of each building. This design option integrates well with the existing building design. In total 120 m^2 of ePIZ BIPV cladding would be installed which would generate 10,2 KWp of energy. The design option A is further divided into category A1 (three number of three-phase inverters for each building) and A2 (4 number of monophase inverters for each building) based upon the type of inverter used.

5.2.2.2 Design option B (maximum power)

The design is shown in Figure 5.7. In this design top three rows of PIZ cladding panel are replaced by three rows of ePIZ glass-glass BIPV modules in all facades except the North-West façade. This design has four dummy modules for each building at the position of emergency overflows. In total 140 m^2 of ePIZ BIPV cladding would be installed which would generate 10,9 kWp of energy. This option generates more power output compared to option A but the design doesn’t blend in well with the existing building design.

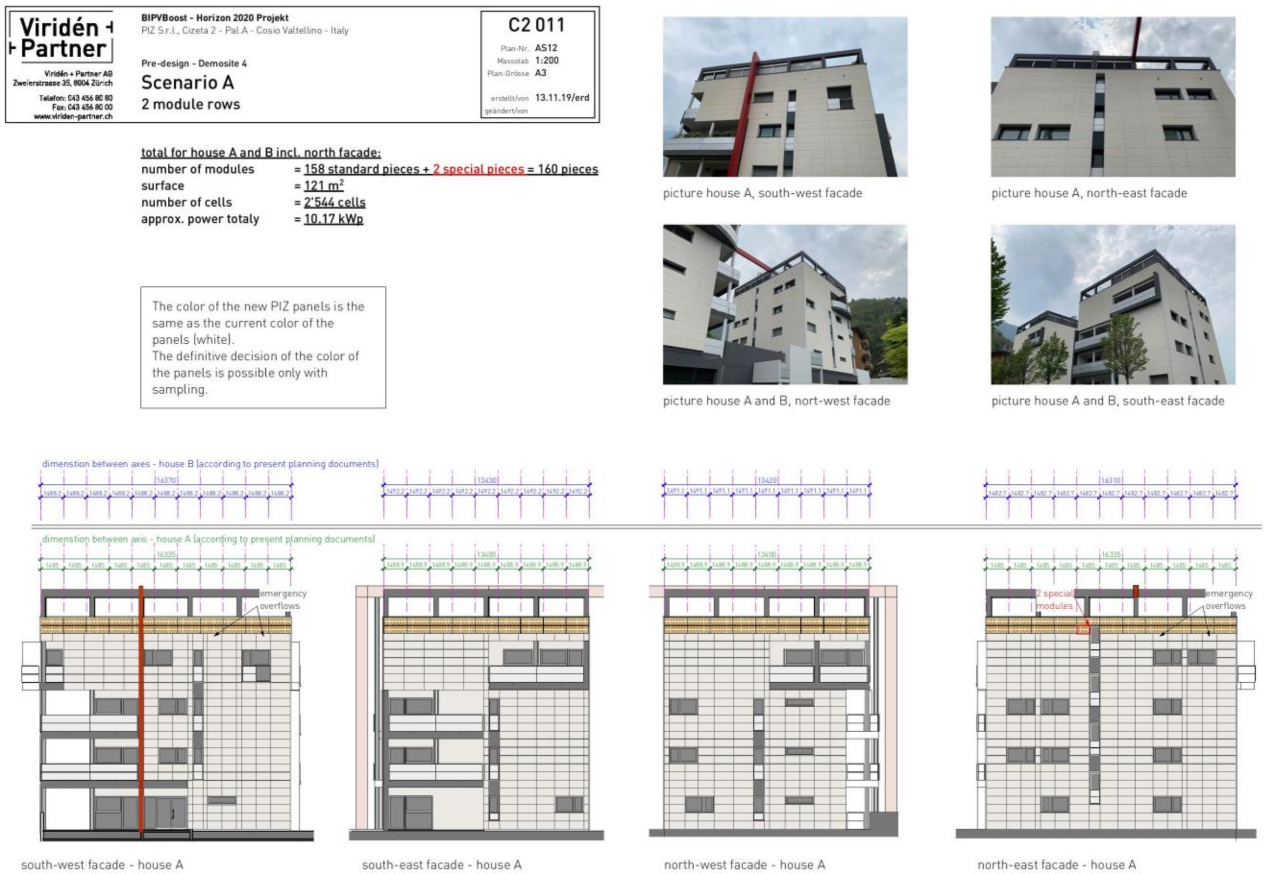


Figure 5.6: Design option A (best architectural integration)

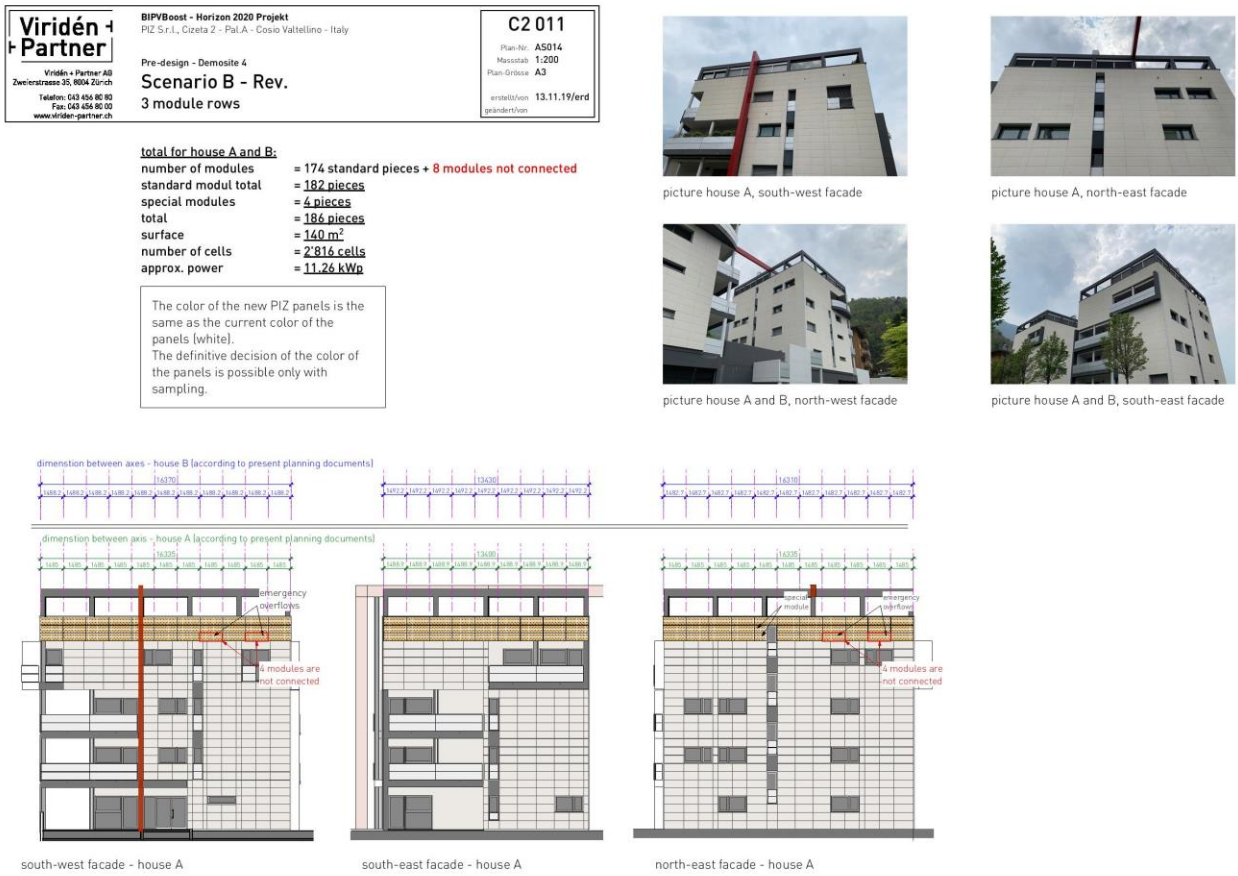


Figure 5.7: Design option B (maximum power)

5.2.2.3 Choice of final design

For the final choice of architectural design, both design options A and B were presented and discussed in the local municipality office. The office was requested to choose one of the two presented design options. Municipality accepted design option A because this design blends in well with the current cladding design of the building and the difference in power output is not much when compared to design option B.

A cost estimation analysis as seen in Figure 5.8 was carried out for all design options in order to support the final design choice based upon best value for money rule. It can be seen that architectural design A has been further divided into two categories A1 (three number of three-phase inverters for each building) and A2 (4 number of monophase inverters for each building) based upon the type of inverter used.

Design A2 turned out to be the best option because the architectural layout is accepted by the municipality, has the least cost among the three options and uses monophase inverter for every façade of each building. Therefore, it was decided to study this design option A2 in detail and make further improvements in the design.

Turn-key installation quotation for a demo-site						
			Scenario A2	Scenario A1	Scenario B	
1.	Materials		Price [€]	Price [€]	Price [€]	Remarks
	1.1	Fastening and mounting system	1.500,00 €	1.500,00 €	1.600,00 €	For demosite-4 structure is not provided by TULIPPS/SCHWEIZER. Partial cost of fastening system is already included in price of BIPV module. This is the estimated cost of additional componenets to be purchased.
	1.2	BIPV modules	79.779,14 €	79.779,14 €	87.001,74 €	This cost is sum of the cost of modules provided by ONYX and PIZ. This cost is estimated considering current production process for both ONYX and PIZ.
	1.3	Cabling	740,00 €	1.290,00 €	1.290,00 €	Cable distances are calculated from pre-design. Cost is estimated from quotation recieved on 04/12/2019. Price may change over time.
	1.4	Inverters	2.392,00 €	2.092,00 €	3.138,00 €	The cost of the invertors taken from the quotation recieved on 04/12/2019. Price may change over time.
	1.5	Monitoring system	200,00 €	200,00 €	200,00 €	Cabling included. Monitoring equipment not included: Monitoring equipment to to be provided by TECNALIA.
	1.6	Electrical installation materials	500,00 €	3.000,00 €	3.248,00 €	This is an estimated cost of all required material. A Part of this cost is taken from quotation received on 4/12/2019 and a part is estimated based on previous experience.
	1.7	Battery System				Not Applicable for Demosite4
	MATERIALS SUBTOTAL		85.111,14 €	87.861,14 €	96.477,74 €	
2.	Labor		Price [€]	Price [€]	Price [€]	Remarks
	2.1	Permit obtaining	4.000,00 €	4.000,00 €	4.000,00 €	This is an estimated cost.
	2.2	Detailed Executive Project	2.000,00 €	2.000,00 €	2.000,00 €	This is an estimated cost.
	2.3	Structural and mechanical installation	8.000,00 €	8.000,00 €	8.660,00 €	Cost estimated based on previous experience. It includes disinstallation cost of PIZ, installation cost of new BIPV system and platform rental cost.
	2.4	Electrical installation	4.800,00 €	6.400,00 €	6.928,00 €	Cost estimated after consulting electrical installer.
	2.5	Certification of the installation	1.000,00 €	1.000,00 €	1.000,00 €	Cost estimated for certification of only electrical installation of the system (not for the complete BIPV system).
	2.6	Operation and Maintenance (optional)				
	LABOR SUBTOTAL		19.800,00 €	21.400,00 €	22.588,00 €	
TOTAL TURN-KEY INSTALLATION:			104.911,14 €	109.261,14 €	119.065,74 €	

Figure 5.8: Cost estimation analysis of Design option A1, A2 and B

5.2.2.4 Design option E, final design (Improved version of design option A2)

The design is shown in Figure 5.9 and Figure 5.10, it is an improved version of design option A2 and is the final design. In this architectural design, the top three rows of the PIZ cladding panel are replaced with the two rows of ePIZ glass-glass BIPV modules and two small rows of conventional PIZ H89 modules. ePIZ glass-glass BIPV modules are placed in between the two small rows of conventional PIZ H89 modules in order to avoid production losses due to the shadow of flashing elements in the top row.

In this design, 178m^2 of façade cladding is replaced with 110m^2 of ePIZ BIPV cladding and 68m^2 of PIZ H89 cladding. 204 standard ePIZ BIPV modules and 8 special ePIZ BIPV modules are required for this installation. All ePIZ BIPV modules have the same width and solar cells will be evenly distributed in the individual BIPV module which gives a raster image look overall. The approximate power of this PV installation is 9,8 kWp.

An emergency water overflow in the BIPV installation area exists, located on the North-East façade of each building which will be redirected to the lower row of conventional PIZ H89 modules during the installation process. The new ePIZ panels will be of white color same as the existing PIZ cladding panels of the building. The solar cells are of sparkling-gold color, contrast in colors with sparkling gold PV cells is more balanced compared to black or blue solar cells. Overall, the design of the demo site integrates well with the building surrounding. Figure 5.11 shows rendered images of the demo-site building before and after BIPV installation.

The cost comparison analysis of all the design options can be seen in Figure 5.12. The increase in cost of design option E compared to design option A2 is due to addition of 68m^2 of PIZ H89 cladding in the design which is required in order to avoid power losses due to shadowing effect.

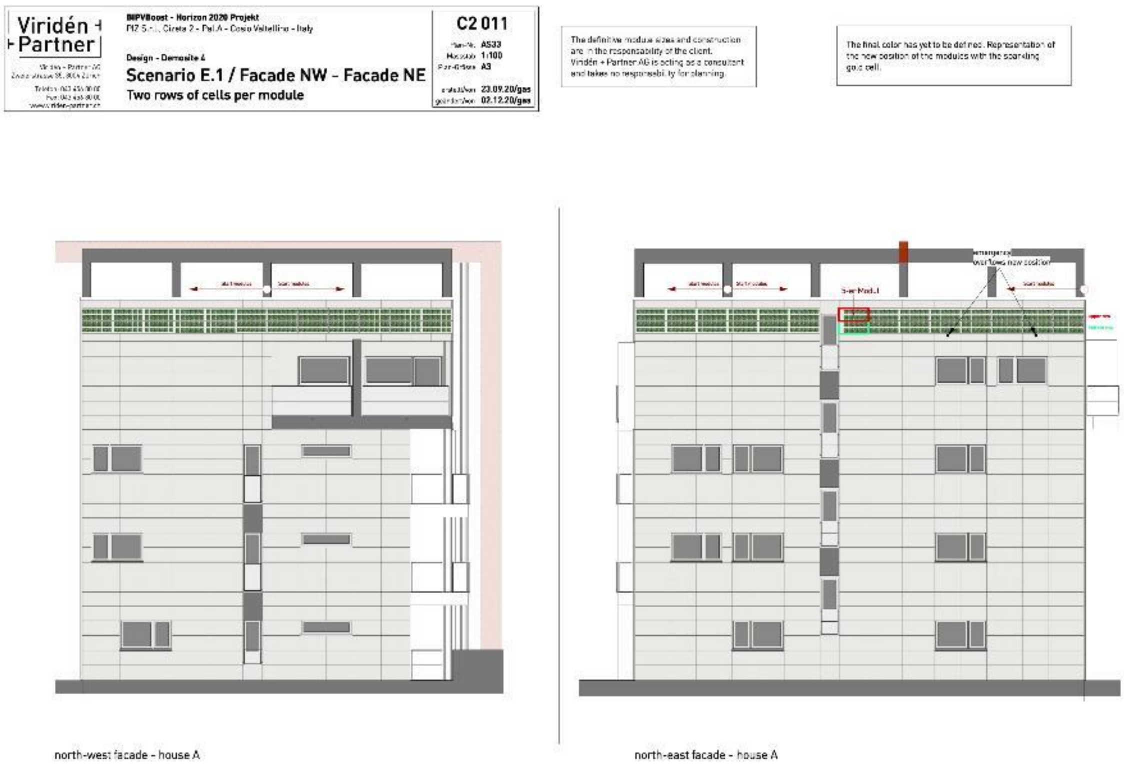


Figure 5.9: Demo-site 4, North-west and north-east facade

Figure 5.10: Demo-site 4, south-west and south-east facade design

Figure 5.11: Demo-site 4, 3D design of demo-site building design with and without ePIZ BIPV modules

Turn-key installation quotation for a demo-site							
			Scenario A2	Scenario A1	Scenario B	Scenario E	
1.	Materials		Price [€]	Price [€]	Price [€]	Price [€]	Remarks
	1.1	Fastening and mounting system	1.500,00 €	1.500,00 €	1.600,00 €	1.500,00 €	For demosite-4 structure is not provided by TULIPPS/SCHWEIZER. Partial cost of fastening system is already included in price of BIPV module. This is the estimated cost of additional componenets to be purchased.
	1.2	BIPV modules	79.779,14 €	79.779,14 €	87.001,74 €	79.779,14 €	This cost is sum of the cost of modules provided by ONYX and PIZ. This cost is estimated considering current production process for both ONYX and PIZ.
	1.3	Cabling	740,00 €	1.290,00 €	1.290,00 €	740,00 €	Cable distances are calculated from pre-design. Cost is estimated from quotation recieved on 04/12/2019. Price may change over time.
	1.4	Inverters	2.392,00 €	2.092,00 €	3.138,00 €	2.392,00 €	The cost of the invertors taken from the quotation recieved on 04/12/2019. Price may change over time.
	1.5	Monitoring system	200,00 €	200,00 €	200,00 €	200,00 €	Cabling included. Monitoring equipment not included: Monitoring equipment to to be provided by TECNALIA.
	1.6	Electrical installation materials	500,00 €	3.000,00 €	3.248,00 €	500,00 €	This is an estimated cost of all required material. A Part of this cost is taken from quotation received on 4/12/2019 and a part is estimated based on previous experience.
	1.7	Battery System					Not Applicable for Demosite4
	1.8	PIZ H89 cladding modules				5.916,00 €	
	MATERIALS SUBTOTAL		85.111,14 €	87.861,14 €	96.477,74 €	91.027,14 €	
2.	Labor		Price [€]	Price [€]	Price [€]		Remarks
	2.1	Permit obtaining	4.000,00 €	4.000,00 €	4.000,00 €	4.000,00 €	This is an estimated cost.
	2.2	Detailed Executive Project	2.000,00 €	2.000,00 €	2.000,00 €	2.000,00 €	This is an estimated cost.
	2.3	Structural and mechanical installation	8.000,00 €	8.000,00 €	8.660,00 €	8.000,00 €	Cost estimated based on previous experience. It includes disinstallation cost of PIZ, installation cost of new BIPV system and platform rental cost.
	2.4	Electrical installation	4.800,00 €	6.400,00 €	6.928,00 €	4.800,00 €	Cost estimated after consulting electrical installer.
	2.5	Certification of the installation	1.000,00 €	1.000,00 €	1.000,00 €	1.000,00 €	Cost estimated for certification of only electrical installation of the system (not for the complete BIPV system).
	2.6	Operation and Maintenance (optional)					
	LABOR SUBTOTAL		19.800,00 €	21.400,00 €	22.588,00 €	19.800,00 €	
TOTAL TURN-KEY INSTALLATION:			104.911,14 €	109.261,14 €	119.065,74 €	110.827,14 €	

Figure 5.12: Cost estimation analysis of Design option A1, A2, B and final design E

5.3 BIPV STRUCTURE DESIGN

5.3.1 Existing building structure

The building walls have been constructed in bricks and the facades have been realized with PIZ H89 cladding system. The existing PIZ H89 cladding panels are in white colour with photocatalytic behaviour, rough surface finish, 0 mm vertical and 0 mm horizontal joint. The PIZ H89 cladding panel as shown in Figure 5.13 consists of mortar combined with an insulating layer. The panel has a total thickness of 89 mm and is made up of 9 mm external mortar skin and 80 mm insulation. The mortar is reinforced with alkaline resistant fiberglass and contains modified cement with metal oxide coloured pigments which are resistant to atmospheric agents. This mortar is joined with a layer of NEOPOR which is synthesized polystyrene with retarded expansion. Overall, the thickness of the installed system with mounting rails is 92 mm.

The PIZ cladding product is CE certified and follows ETAG 017. It has a lower specific thermal conductivity and very low water absorption capacity. It shows good resistance under wind suction test, a good resistance under impact test and a great resistance under fire test. PIZ system is a breathable system with open joints, so it has good water vapor permeability.

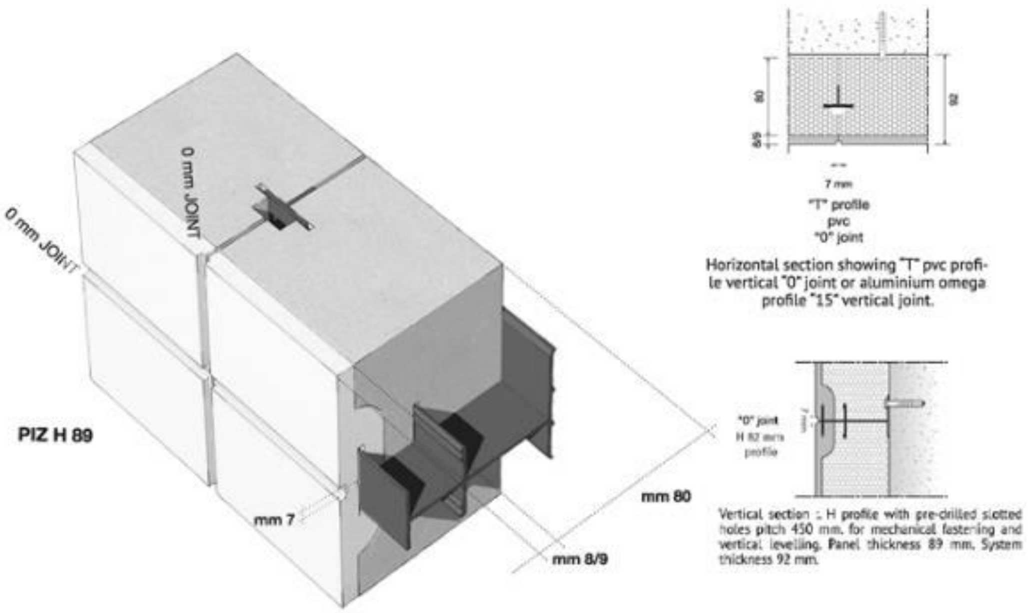


Figure 5.13: Demo site 4, PIZ H 89 cladding system

PIZ panels can be mounted using a special profile mounting system specific to PIZ product. This mounting system makes installation of panels easier and less time consuming. It consists of horizontal profiles in aluminum (start profiles, H-profile and top profile), vertical T spacer profile in PVC and corner profiles in aluminum. Aluminium profiles are secured to the substructure using expansion plug distanced at 90 cm. These profiles are fixed in the grooves prepared on the horizontal and vertical edges of the panels. Over Horizontal edges, mortar is thickened and grooved to allow insertion of continuous extruded aluminium profile and on vertical edge rockwool is grooved to allow insertion of PVC T spacer profile.

5.3.2 BIPVBOOST structure

ePIZ can be mounted on substructure using the same fastening and mounting system as traditional PIZ panels. The mounting system will comprise the same profile system as explained in the previous section. Horizontal profiles will be fixed to the walls using metal expansion plugs. The pitch between the expansion plugs will be 45 cm. The modules will be installed with 0 mm vertical joint and 15 mm horizontal joint. Additional aluminium safety clamps will be used to provide extra protection to the glass. Safety clamps are recommended considering the behavior of polymeric materials under high temperatures. In ePIZ modules, EVA encapsulant and silicone are the polymeric materials. These materials could melt in case of fire and result in glass detachment therefore safety clamps can enhance protection in such a scenario.

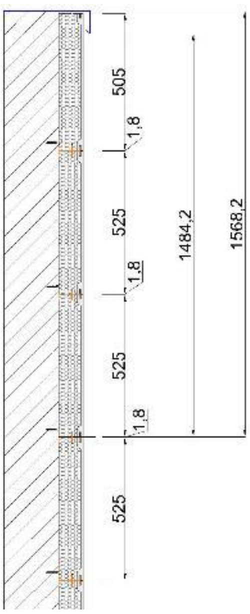


Figure 5.14: Demo-site 4, typical wall section before BIPV installation

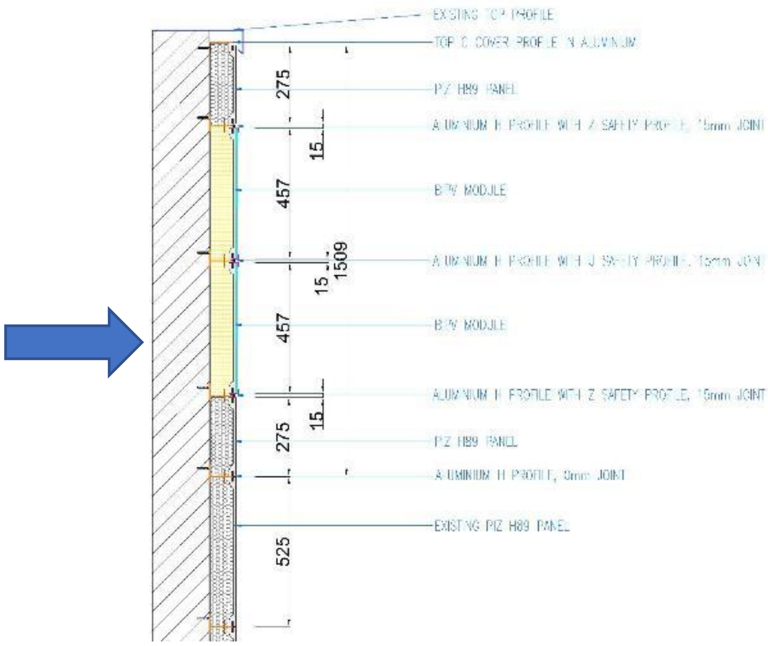


Figure 5.15: Demo-site 4, typical wall section after BIPV installation

Typical wall sections before and after BIPV installation is shown in Figure 5.14 and Figure 5.15 respectively. Three rows of PIZ H89 cladding panels will be replaced by two rows ePIZ BIPV panels and two small rows of conventional PIZ H89 cladding panel.

5.4 BIPV MODULE DESIGN

5.4.1 ePIZ glass-glass module description

ePIZ consists of a composite element, obtained by integrating PIZ cladding product with different photovoltaic (PV) technologies. The main concept of combining PIZ product with a PV element was to have a BIPV cladding system that can offer energy production, a high level of thermal insulation and a good level of acoustic insulation within one product along with an easy installation process. In the BIPVBOOST project, two different ePIZ products were prepared by integrating the PIZ rock metabio H89 panel with ONYX glass-glass PV module and FLISOM CIGS modules.

For the demo-site installation, it was decided to use ePIZ prepared with ONYX glass-glass PV module, functional prototype is shown in Figure 5.16. PIZ rock metabio H89 consists of 8-9 mm thick mortar external skin joined with 80 mm thick wool rock insulation that has a density of 135 kg/m^3. The mortar is reinforced with alkaline resistant fiberglass and contains modified cement with metal oxide coloured pigments which are resistant to atmospheric agents. The glass-glass PV laminate consists of two layers of 3.2 mm thick glass with PV cells packed in between the two layers through EVA encapsulant sheets. A Junction Box (JB) is attached at the back of the module containing all necessary electrical components. Silicone adhesive was used to join the surface of the mortar with the rear glass surface of the glass-glass PV module. Silicone was applied only behind the solar cells and along the edges.

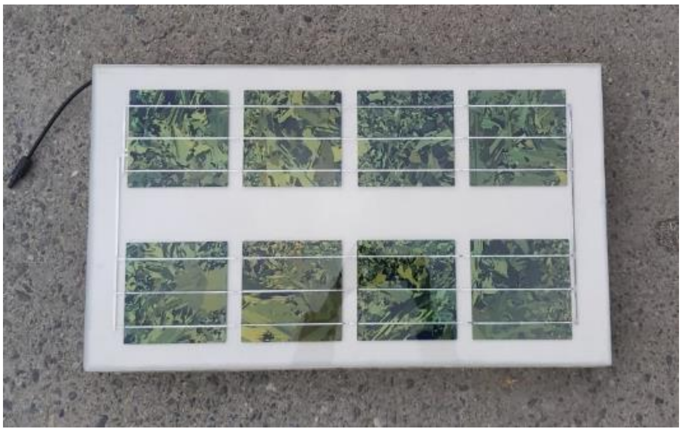


Figure 5.16: Demo-site 4, ePIZ prototype with glass-glass PV module (color of the cells is different from the one that will be installed)

Figure 5.17: Demo-site 4, Aluminum H-profile placed inside the upper horizontal grooves

The vertical edges of the wool rock are grooved to allow the insertion of a PVC "T" profile for the "0" mm gap joint. Top horizontal edge of the wool rock is grooved as shown in Figure 5.18 to create a passage for the electrical wiring thus providing a defined path for wiring inside the module. A hollow cavity of 102 mm diameter is created inside the PIZ module to accommodate JB. Horizontal edges of mortar are thickened and grooved to allow insertion of aluminium H-profile as depicted in Figure 5.17.

Figure 5.18: Demo-site 4, Groove created on the top horizontal edge to provide cable passage

Figure 5.19: Demo-site 4, Middle safety clamp

Figure 5.20: Demo-site 4, ePIZ prototypes with glass-glass PV laminate mounted on wall

Prototypes in golden-brown and sparkling-gold color solar cells were prepared for the Architect VIRIDEN Partner in order to make the right design choice for the demo-site building. Architect chose sparkiling gold color cell and white color PIZ mortar surface with rought finish for demo-site building.

5.4.2 Demo-site module/s design

Architectural design of demo-site is shown in Figure 5.9 and Figure 5.10, we have six different module designs in total; two standard modules and four special modules which will be used to adjust spaces at building corners. Design of all demo-site modules is shown In Figure 5.21, Figure 5.24, Figure 5.23, Figure 5.24, Figure 4.21 and Figure 4.22.

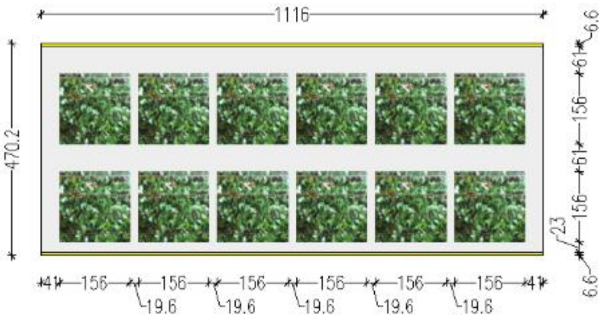


Figure 5.23: Demo-site 4, front view of standard ePIZ module A1

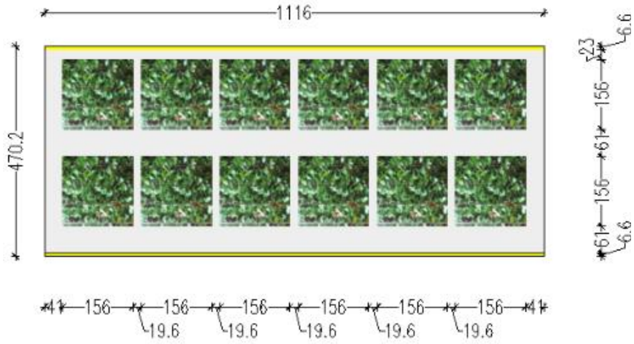


Figure 5.24: Demo-site 4, front view of standard ePIZ module A2

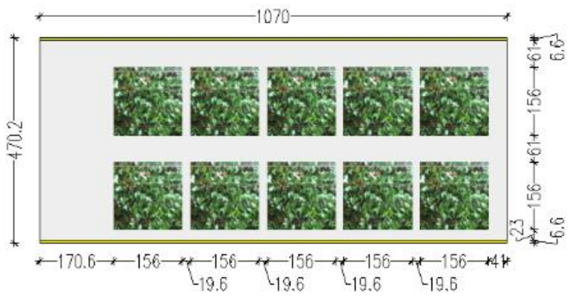


Figure 5.25: Demo-site4, front view of special ePIZ module B1

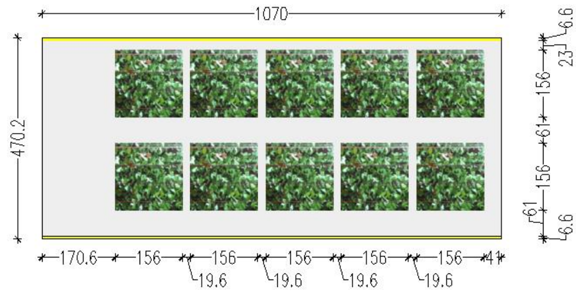


Figure 5.26: Demo-site 4. front view of standard ePIZ module B2

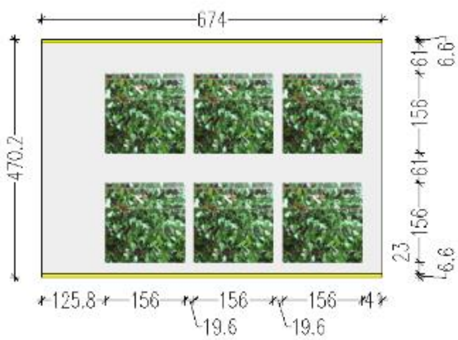


Figure 5.27: Demo-site 4, front view of special ePIZ module C1

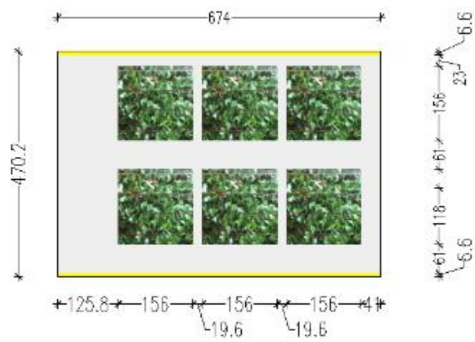


Figure 5.28: Demo-site 4, front view of special ePIZ module C2

Table 5.1 Total number of BIPV modules required for demo-site 4 installation

Type	Required Numbers
Standard module - A1	102
Standard module - A2	102
Special Module - B1	2
Special Module - B2	2
Special Module - C1	2
Special Module – C2	2

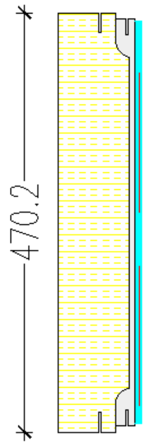


Figure 5.29: Demo-site 4, Lateral view of standard ePIZ module

Table 5.1 shows total number of modules required to complete the demo-site BIPV installation.

5.4.3 BIPVBOOST module/s electrical Design

This section provides data sheet and design of glass-glass PV modules provided by ONYX. Data sheets can be seen in Table 5.2, Table 5.3 and Table 5.4, it contains all necessary details of the PV modules that will be integrated with PIZ panel to manufacture BIPV modules. The design of the PV modules can be seen if Figure 5.31, Figure 5.32, Figure 5.33, Figure 5.34 and Figure 5.35

Table 5.2 Demo-site 4, technical data sheet of ONYX PV module type A1 and A2

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	ºC
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

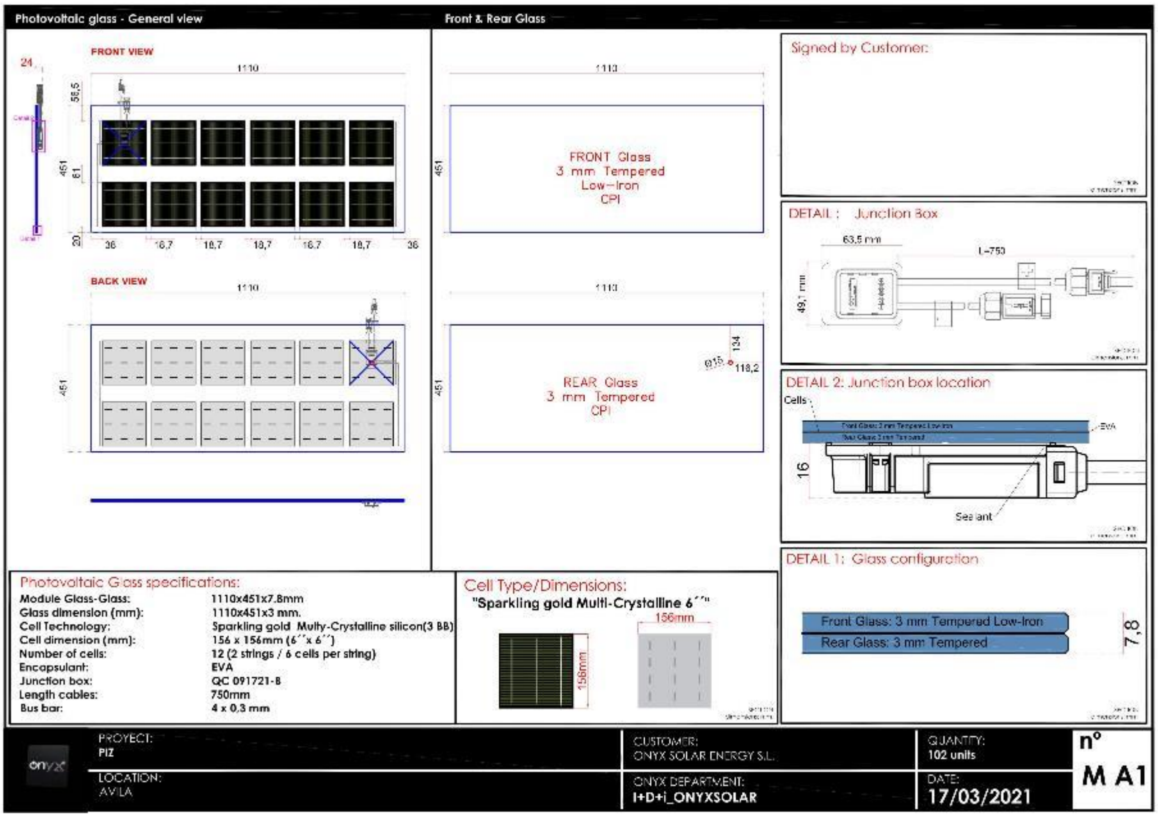


Figure 5.30: Demo-site 4, design of ONYX PV module, type A1

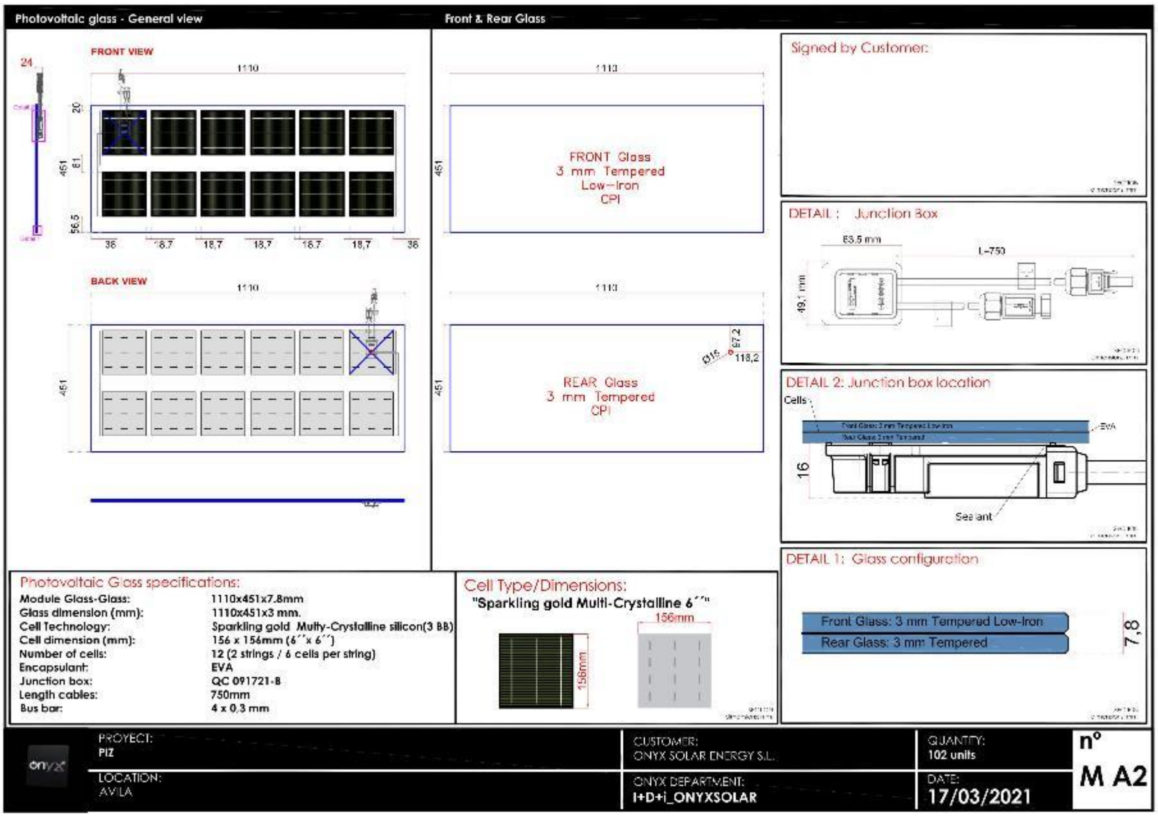


Figure 5.31: Demo-site 4, design of ONYX PV module, type A2

Table 5.3 Demo-site 4, technical data sheet of ONYX PV module type B1 and B2

PHOTOVOLTAIC GLASS	1.064 x	451
Sparkling gold 16.3-16.1%	6" Poly Color	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	39	P_{mpp} (Wp)
Open-circuit voltage	6	V_{oc} (V)
Short-circuit current	8,22	I_{sc} (A)
Voltage at nominal power	5	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	1064	mm
Width	451	mm
Thickness	7,8	mm
Surface area	0,48	sqm
Weight	7,2	Kgs
Cell type	6" Poly Color	Crystalline sparkling gold
No PV cells / Transparency degree	10	49%
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	$2{,}5\ mm^2$ or	$4{,}0\ mm^2$
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	**49%**
U-value [W/sqm.K]	**-**
Peak Power [Wp/sqm]	**81,5**

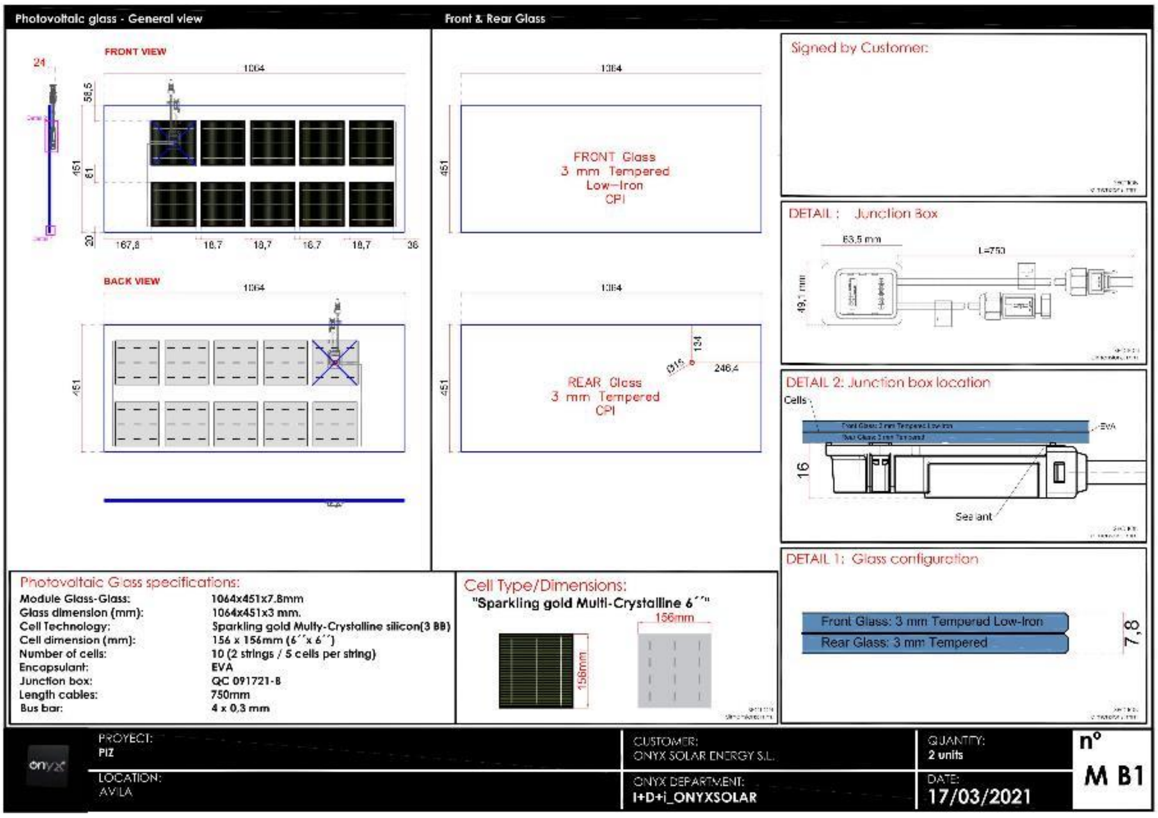


Figure 5.32 Demo-site 4, design of ONYX PV module, type B1

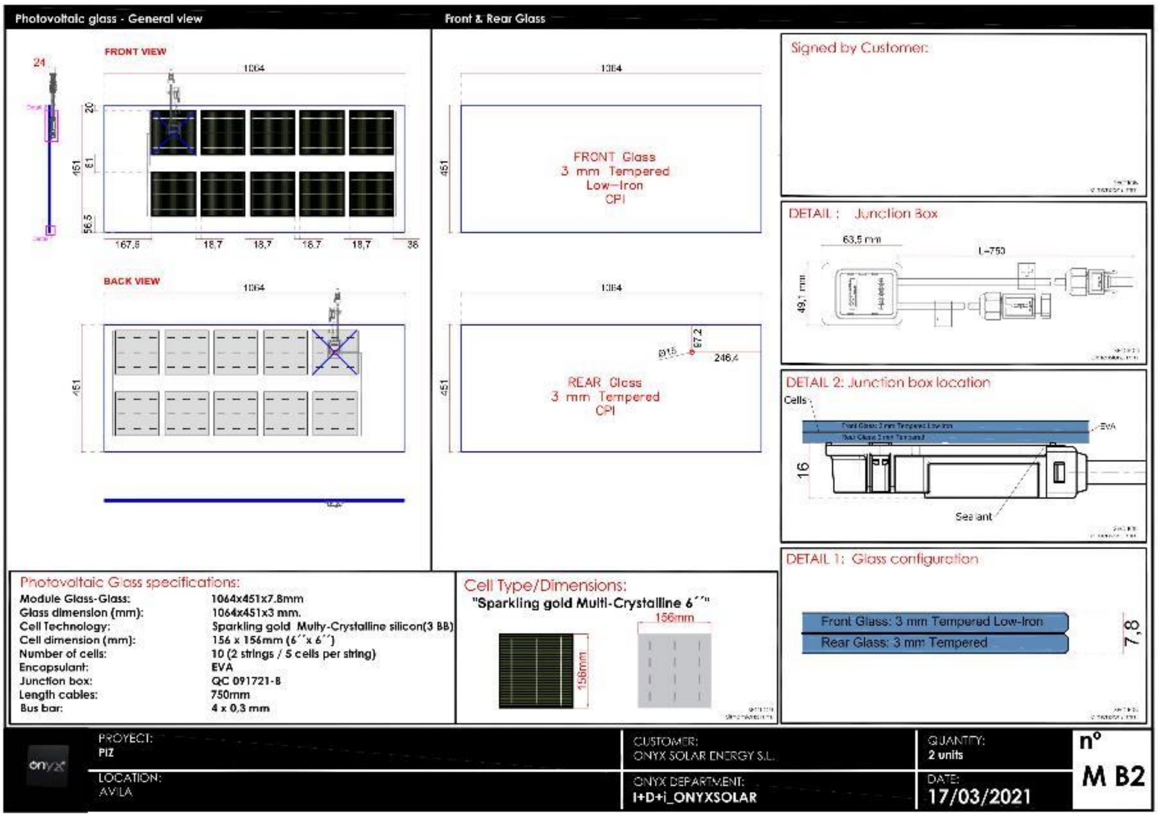


Figure 5.33 Demo-site 4, design of ONYX PV module, type B2

Table 5.4 Demo-site 4, technical data sheet of ONYX PV module type C1 and C2

PHOTOVOLTAIC GLASS	668 x 451	
Sparkling gold 16.3-16.1%	6" Poly Color	Crystalline
Electrical data test conditions (STC)		
Nominal peak power	23	P_{mpp} (Wp)
Open-circuit voltage	4	V_{oc} (V)
Short-circuit current	8,22	I_{sc} (A)
Voltage at nominal power	3	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	668	mm
Width	451	mm
Thickness	7,8	mm
Surface area	0,30	sqm
Weight	4,5	Kgs
Cell type	6" Poly Color	Crystalline sparkling gold
No PV cells / Transparency degree	6	52%
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	$2{,}5\ mm^2$ or $4{,}0\ mm^2$	
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	52%
U-value [W/sqm.K]	-
Peak Power [Wp/sqm]	77,9

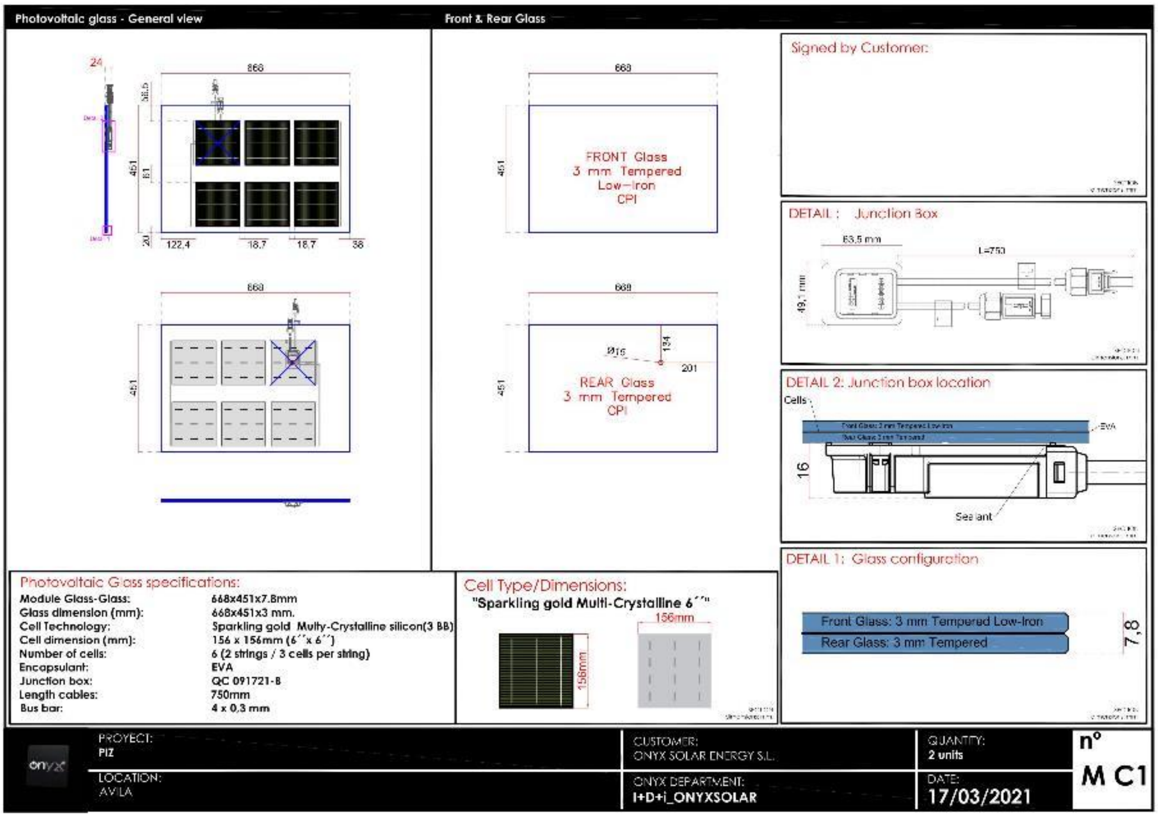


Figure 5.34 Demo-site 4, design of ONYX PV module, type C1

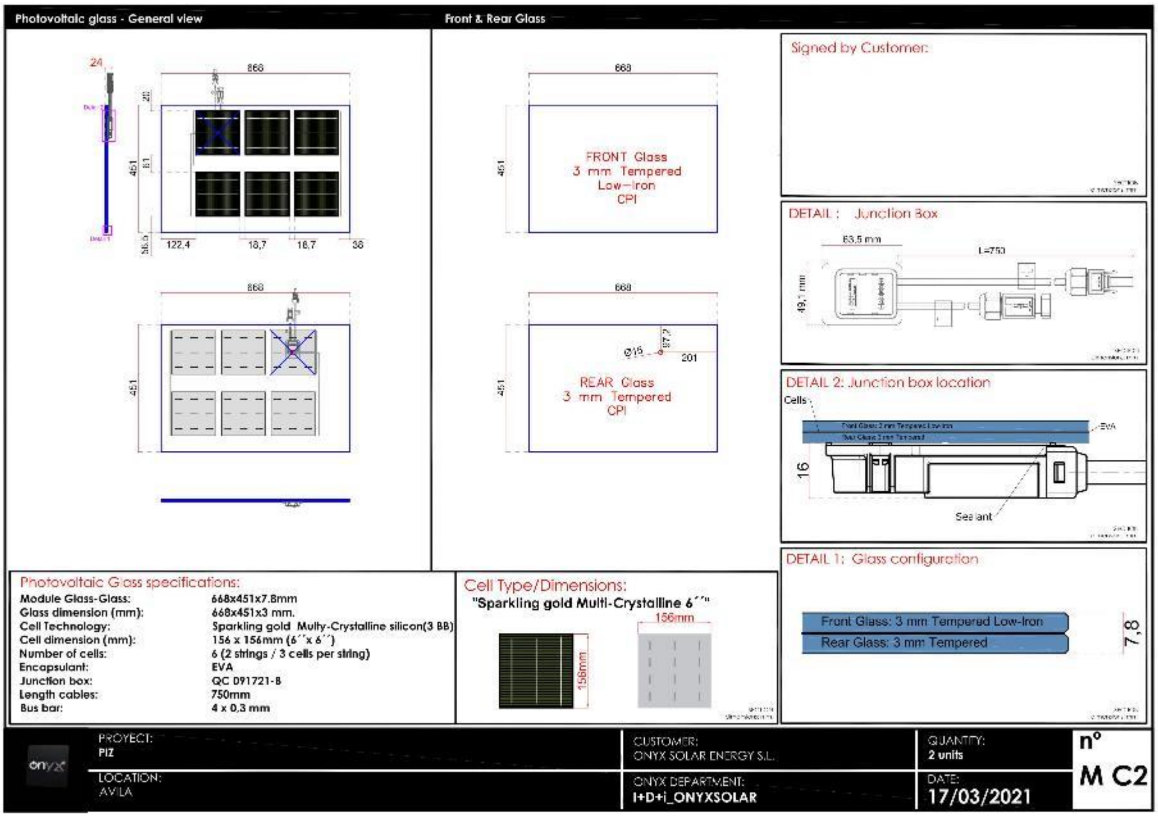


Figure 5.35: Demo-site 4, design of ONYX PV module, type C2

5.5 BIPV ELECTRICAL SYSTEM DESIGN

5.5.1 BIPVBOOST system components

The electrical design of the system was studied in detail and all electrical components were selected accordingly. It was decided to realize the PV installation using a mono phase inverter for every façade as each façade is oriented in different direction and generates different power. Electrical components required for demo-site installation are listed in Table 5.5. Figure 5.36 provides technical data sheet of the inverter.

Table 5.5 Demo-site 4, list of electrical components

SR. NO.	ITEM	QTY.
1	"QE-A" / "QE-B" ELECTRICAL PANEL	2 units
2	"QE-PAR" ELECTRICAL PANEL	1 unit
3	GENERAL CIRCUIT BREAKER TO BE INSTALLED ON AN EXISTING FRONT ELECTRICAL PANEL	1 unit
4	PARALLEL CIRCUIT BREAKER TO BE INSTALLED ON “QE-A” AND “QE-B”	2 units
5	CABLE TYPE H1 Z2Z2-K RED 1 X6MMQ	220 m
6	CABLE TYPE H1 Z2Z2-K BLACK 1 X6MMQ	220 m
7	FG1 6OR1 6 5G6 TYPE CABLE	45 m
8	CATEGORY 6 U / FTP DATA CABLE	90 m
9	INVERTER ZCS AZZURRO 1 1 00TL-WS	8 units
10	EMERGENCY CIRCUIT BREAKER FOR EACH INVERTER	8 units
11	WATERPROOF SWITCHBOARD GEWISS TYPE EMERGENCY SYSTEMS - GW42201	1 unit

TECHNICAL DATA	1100TL	1600TL	2200TL	2700TL	3000TL
DC Input data					
Typical DC power	1200W	1800W	2400W	2900W	3300W
No. of independent MPPTs/No. of strings per MPPT	1/1				
Maximum DC input voltage	450V		500V		
Activation voltage	100V		120V		
Nominal DC input voltage	360V				
MPPT range of DC voltage	80-450V		100-500V		
DC voltage range at full load	110-450V	165-450V	170-500V	200-500V	
Maximum input current for each MPPT	10A		13A	13.5A	15A
AC output data					
Nominal AC power	1000W	1550W	2100W	2600W	3100W
Maximum AC power	1000VA	1550VA	2100VA	2600VA	3100VA
Maximum AC Current	4.5A	7A	9.5A	11.5A	13A
Type of connection/nominal grid voltage	Single-phase L/N/PE / 220V,230V,240V				
Grid Voltage range	180~270V (according to the local grid standards)				
Grid nominal frequency	50/60Hz				
Grid frequency range	45~53 / 57~63 Hz (according to the local grid standards)				
Total current harmonic distortion	<3%				
Power factor	1 (programmable +/-0.8)				
Active Power adjustable range	0~100%				
Grid feed-in limitation	Feed in adjustable from zero to the nominal power value*				
Efficiency					
Maximum efficiency	97%			97.1%	97.2%
Weighted efficiency (EURO)	95.2%	95.9%	96.1%	96.4%	96.5%
MPPT efficiency	>99.9%				
Night-time consumption	<1W				
Protections					
Safety protections	Anti islanding, RCMU, Ground Fault Monitoring				
DC reverse polarity protection	Yes				
DC switch	Optional (only WS models)				
Surge protection	Yes				
Protection class/Surge category	I/III				
Integrated dischargers	AC/DC MOV: Type III standard				
Standard					
EMC	EN 61000-6-1/2/3/4,				
Safety standard	IEC 62116, IEC 61727, IEC 61683, IEC 60068-1/2/14/30, IEC 62109-1/2				
Grid connection standard	AS 4777, VDE V 0124-100, VDE V 0126-1-1, VDE-AR-N 4105, EN50438, G83/2, C10/11, RD1699, CEI 0-21				
Communication					
Communication interfaces	Wi-Fi (only WS models), RS485 (proprietary protocol), SD card				
Additional inputs or connections	Input for current sensor connection				
Data storage on SD	25 years				
General information					
Permissible ambient temperature range	-25°C...+60°C (power limitation above 45°C)				
Topology	Transformerless				
Environmental protection rating	IP65				
Permissible relative humidity range	0%.....95% senza condensazione				
Maximum operating altitude	2000m				
Noise	< 25dB @ 1mt				
Weight	11kg		12kg		
Cooling	Natural ventilation				
Dimensions (H*L*D)	405mm*314mm*135mm				
Display	LCD				
Warranty	10 years				

*Possible by connecting a current sensor (ZST-ACC-TA)

Figure 5.36: Technical data sheet of inverter Azzurro 1100TL

5.5.2 BIPVBOOST electrical diagram

The electrical scheme of the demo-site BIPV installation is shown in Figure 5.37:

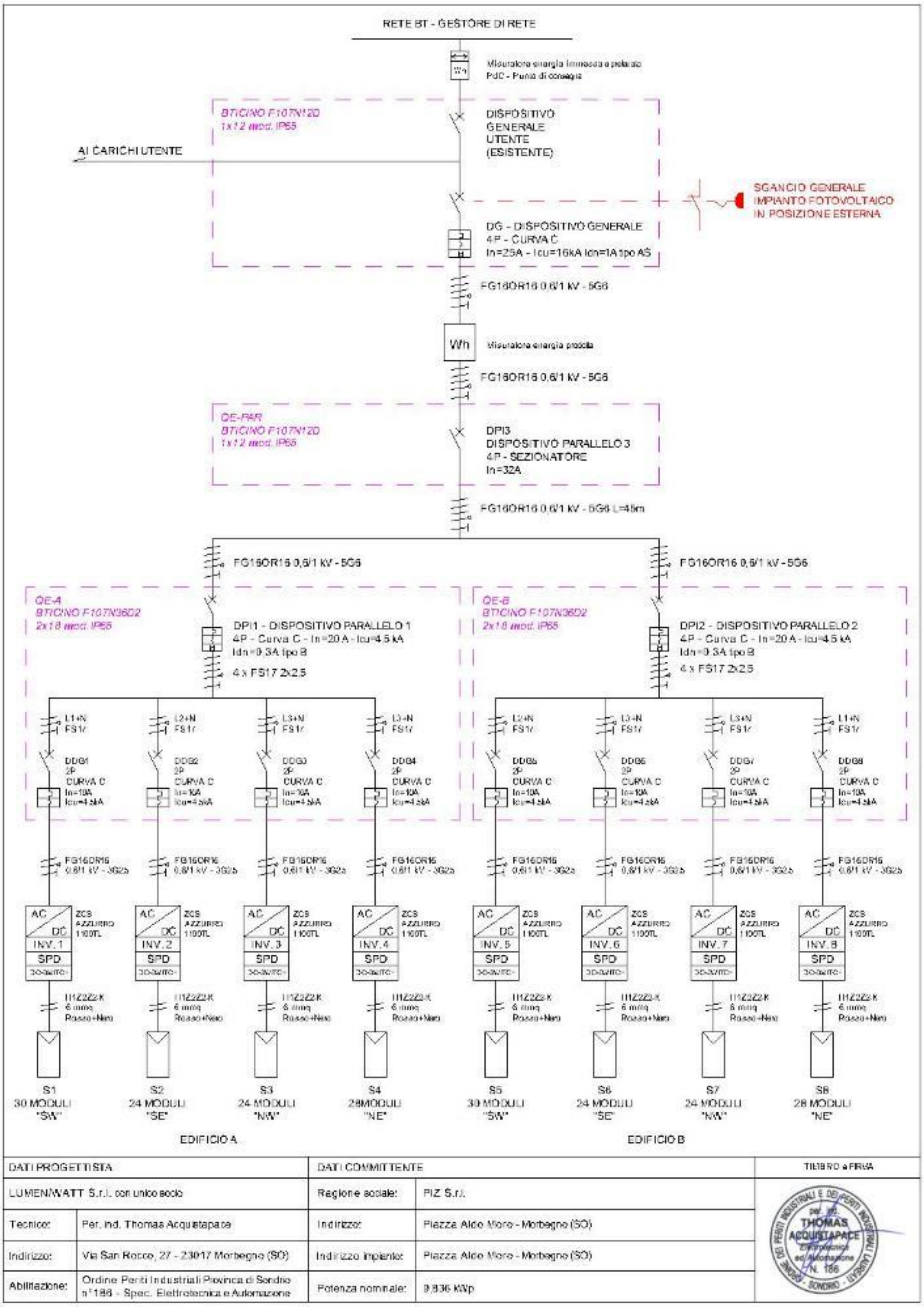


Figure 5.37: Electrical diagram for the demo-site installation

5.6 BIPV MONITORING DESIGN

5.6.1 Definition of monitoring objectives: BIPV performance validation, economic viability and progress towards NZEB requirements

The main objective of the monitoring system is to verify and validate the Energy performance of the BIPV installation at the demo-site through the measurement of key variables. The measurement methodology and key variables to be measured were defined in Deliverable 8.3. The monitoring methodology described in Deliverable 8.3 is based in the inter-comparison of two monitoring periods, defined as the pre-intervention period (base line) and the post intervention period.

The implementation of pre-intervention period monitoring system has been finished in July 2020 and measurements are being gathered since August 2020.The post-intervention monitoring system will be implemented after the intervention described in this document in September 2021.

Next, the pre-intervention period monitoring system is presented and later this document will be updated with the implementation of e post-intervention monitoring system.

5.6.2 Definition of variables to be monitored

The monitoring objectives will be reached thought the measurement of the energy variables shown in Figure 5.38. Table 5.6 enlists short definition of the variables depicted in Figure 5.38 and additional information about instruments used for the measurements. In Table 5.6, variables that are being monitored during preintervention period are in blue and the variables that will be monitored during the post intervention period variables written in red.

It can be seen that during the pre-intervention period variables are related to the meteorology, building energy consumption from the grid and energy consumption by the heat pump. Moreover, during the post intervention period, energy production of BIPV modules will also be measured.

Demo PIZ

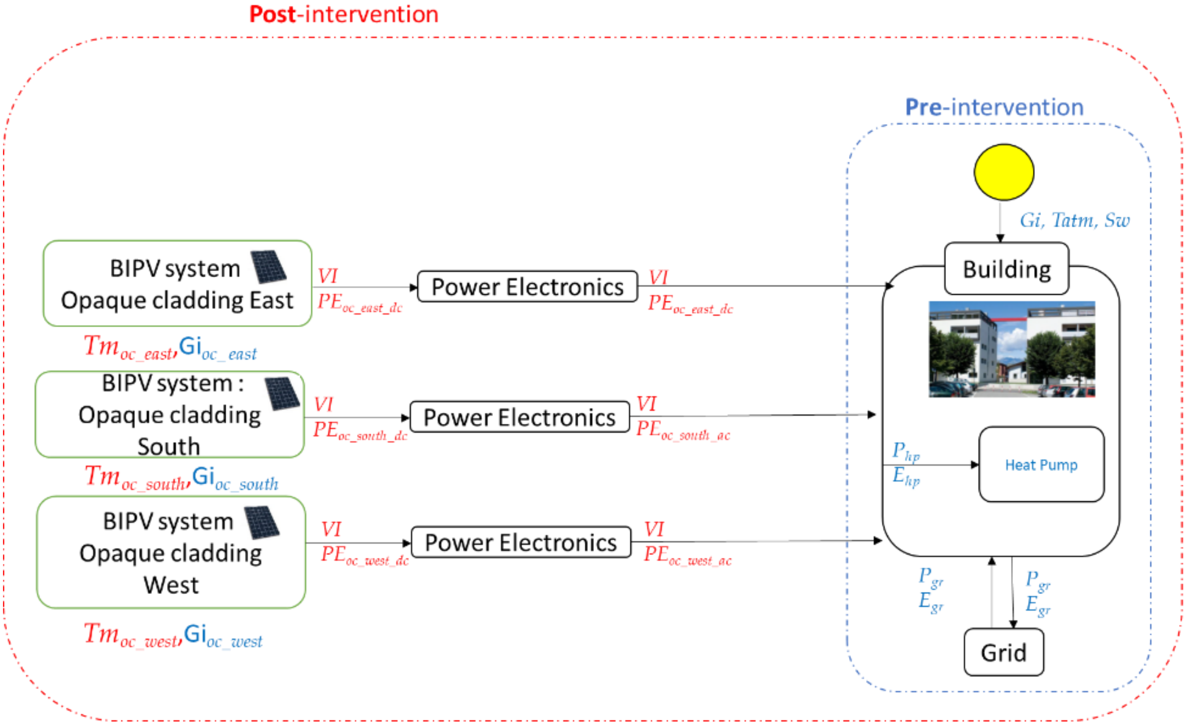


Figure 5.38: Main measuring variables of PIZ demo site. Blue variables are being monitored since the start of preintervention year and the red variables will be monitored afterwards postintervention period.

Table 5.6. Description of the variables shown in Figure 5.38 and the intruments used for the measurements.

Variable	Desciption	Instrument	Range	Units	Time Resolution	Accuracy
BIPV components						
Opaque cladding						
East						
Meteo						
G_{oc_east}	Irradiance East plane	Reference cell	0-1200	w/m2	<1min	5% of the reading
Tm_{oc_east}	Module temperature	Thermocouple type T	0-100	ºC	<1min	1K
DC						
$I_{\_oc\_east\_DC}$	DC Intensity	Amperimeter		A	<1min	1% of the reading
$V_{\_oc\_east\_DC}$	DC Voltage	Voltimeter		V	<1min	1% of the reading
$P_{\_oc\_east\_DC}$	DC Power	medidor de potencia	10	kW	<1min	2% of the reading
$ET_{\_oc\_east\_DC}$	DC Energy	Energy meter		kW/h	<1min	
AC						
$P_{\_oc\_east\_AC}$	AC Power	Power meter	10	kW	<1min	2% of the reading
$ET_{\_oc\_east\_AC}$	AC Energy	Energy meter		kW/h	<1min	
South						
Meteo						
$G_{\_oc\_South}$	Irradiance south plane	Reference cell	0-1200	w/m2	<1min	5% of the reading
$Tm_{\_oc\_South}$	Module temperature	Thermocouple type T	0-100	ºC	<1min	1K
DC						
$I_{\_oc\_South\_DC}$	DC Intensity	Amperimeter		A	<1min	1% of the reading

$V_{\_oc\_South\_DC}$	DC Voltage	Voltimeter		V	<1min	1% of the reading
$P_{\_oc\_South\_DC}$	DC Power	medidor de potencia	10	kW	<1min	2% of the reading
$ET_{\_oc\_South\_DC}$	DC Energy	Energy meter		kW/h	<1min	
AC						
$P_{\_oc\_South\_AC}$	AC Power	Power meter	10	kW	<1min	2% of the reading
$ET_{\_oc\_South\_AC}$	AC Energy	Energy meter		kW/h	<1min	
West						
Meteo						
$G_{\_oc\_West}$	Irradiance west plane	Reference cell	0-1200	w/m2	<1min	5% of the reading
$Tm_{\_oc\_West}$	Module temperature	Thermocouple type T	0-100	ºC	<1min	1K
DC						
$I_{\_oc\_West\_DC}$	DC Intensity	Amperimeter		A	<1min	1% of the reading
$V_{\_oc\_West\_DC}$	DC Voltage	Voltimeter		V	<1min	1% of the reading
$P_{\_oc\_West\_DC}$	DC Power	medidor de potencia	10	kW	<1min	2% of the reading
$ET_{\_oc\_West\_DC}$	DC Energy	Energy meter		kW/h	<1min	
AC						
$P_{\_oc\_West\_AC}$	AC Power	Power meter	10	kW	<1min	2% of the reading
$ET_{\_oc\_West\_AC}$	AC Energy	Energy meter		kW/h	<1min	
Building						
Meteo						
$G_{\_iHorizontal}$	Horizontal Irrradiance	Pyranometer	0-1200	w/m2	<1min	5% of the reading
T_{amb}	ambient temperature	Thermocouple type T	0-50	ºC	<1min	1K
Sw	Wind speed	Ultrasonic anemometer	0-100	m/s	<1min	Sw<5m/s--->0,5m/s;Sw>5m/s--->10% of the reading
Grid						
P_{gr}	AC Power	Power meter		kW	<1min	2% of the reading
E_{gr}	AC Energy	Energy meter		kW/h	<1min	
Heat Pump						
P_{hp}	AC Power	Power meter		kW	<1min	2% of the reading
E_{hp}	AC Energy	Energy meter		kW/h	<1min	

5.6.3 BIPVBOOST monitoring system

The installation of the pre-intervention monitoring system was carried out in two main group of components; Meteorological station and the main board.

The meteorological station was installed on the roof and consist of the following components (see Figure 5.39 and Figure 5.40);

- 1 anemometer for measuring wind speed (Sw)
- 3 references cells in the equivalent plane that will be installed the opaque cladding BIPV modules for measuring the irradiance ($Gi_{oc\_ east}$, $Gi_{oc\_ south}$, $Gi_{oc\_ west}$)
- 1 pyranometer for measuring the horizontal global irradiance (Gi)
- 1 temperature sensor (PT-100) for measuring the ambient temperature.

Roof installation

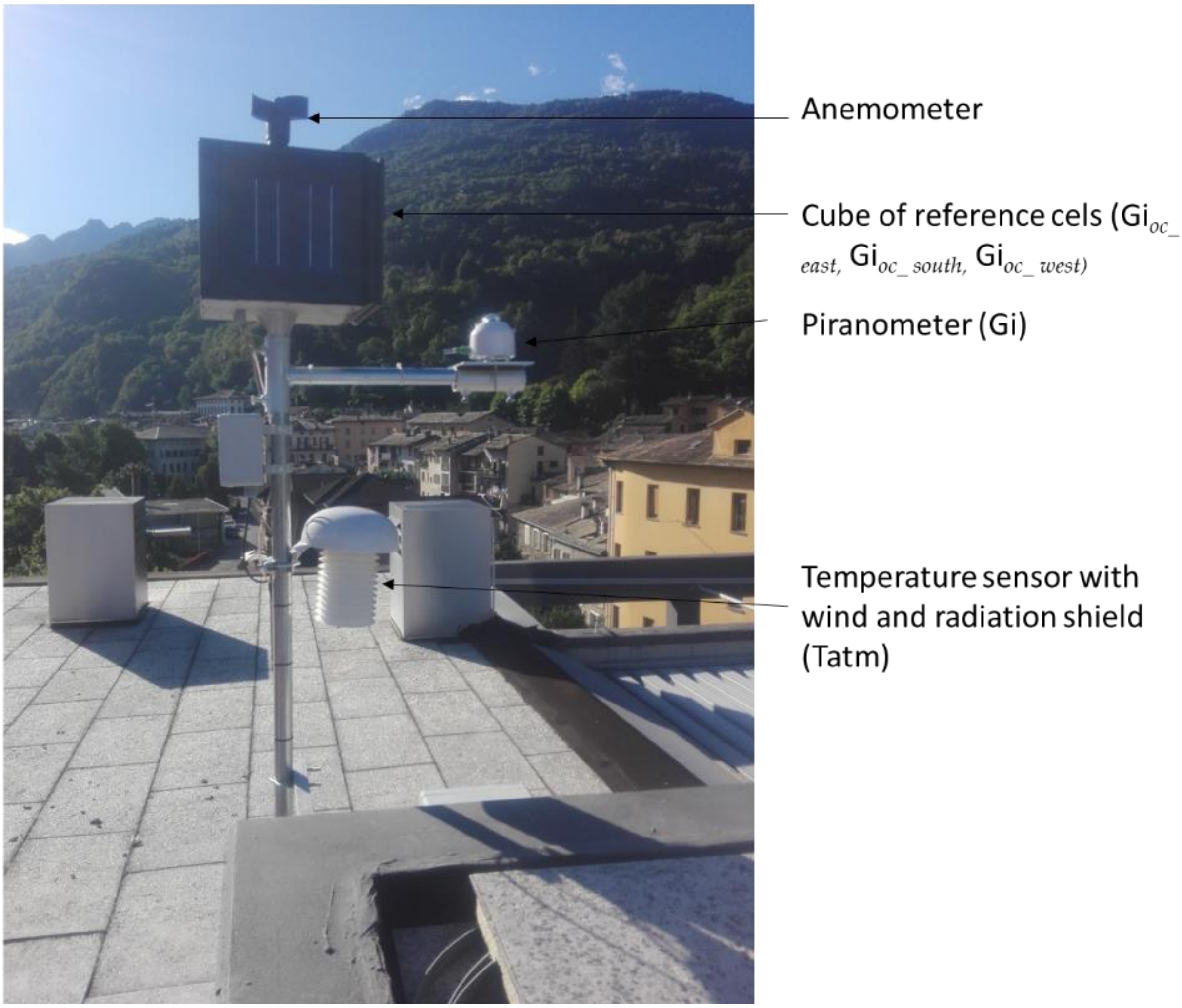


Figure 5.39: pre-intervention monitoring system meteorological station installed on the roof.

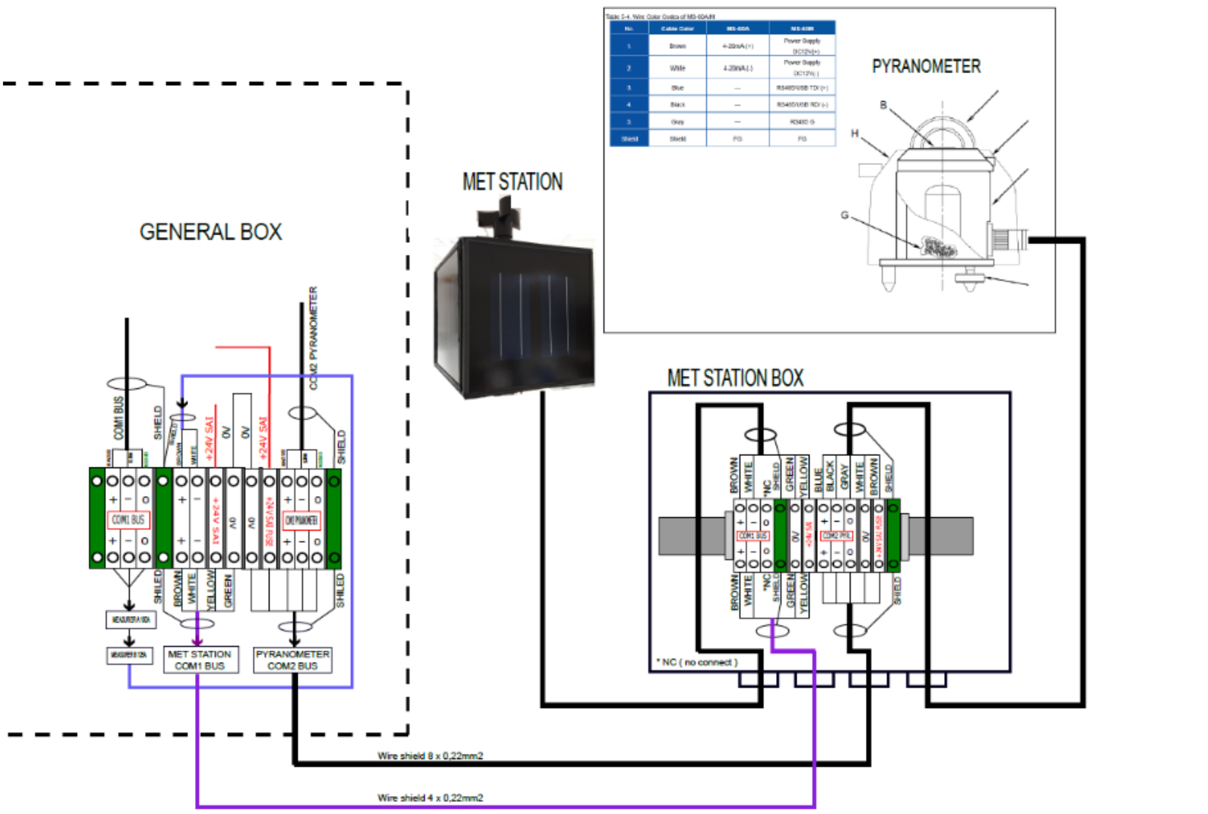


Figure 5.40: Pre-intervention monitoring system meteorological station connections diagram.

On the other hand, the main board was installed in the metering room as seen in Figure 5.41 and Figure 5.42. It contains following components.

- The data logger
- The heat pump energy meter to measure heat pump consumption (P_{hp},E_{hp}).
- The grid connection energy meter for measuring the building energy consumption. (P_{gr},E_{gr})

Monitoring system main board

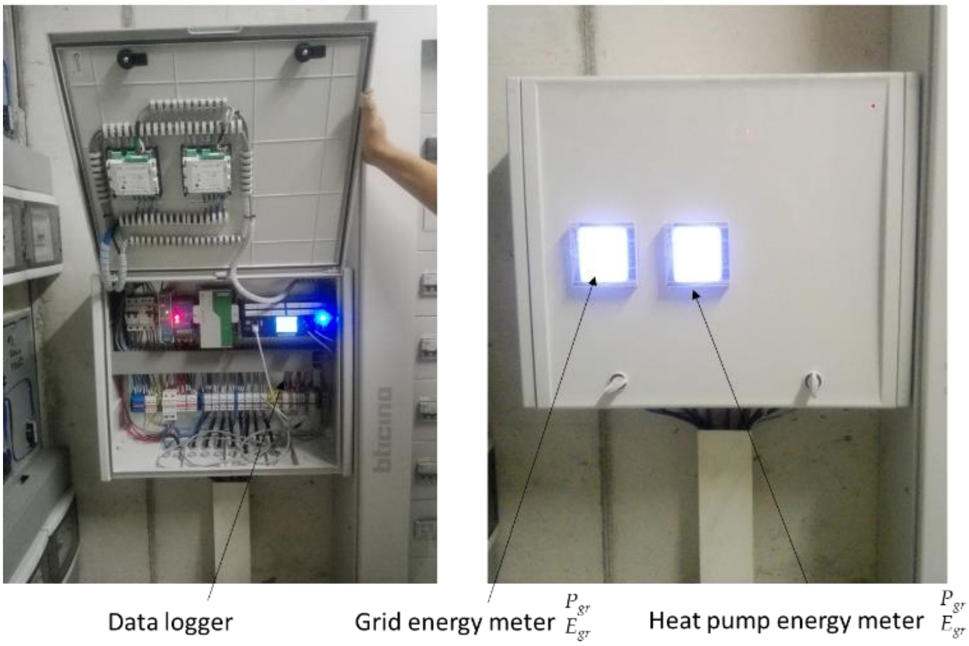


Figure 5.41: Monitoring system main board installed in the counter room.

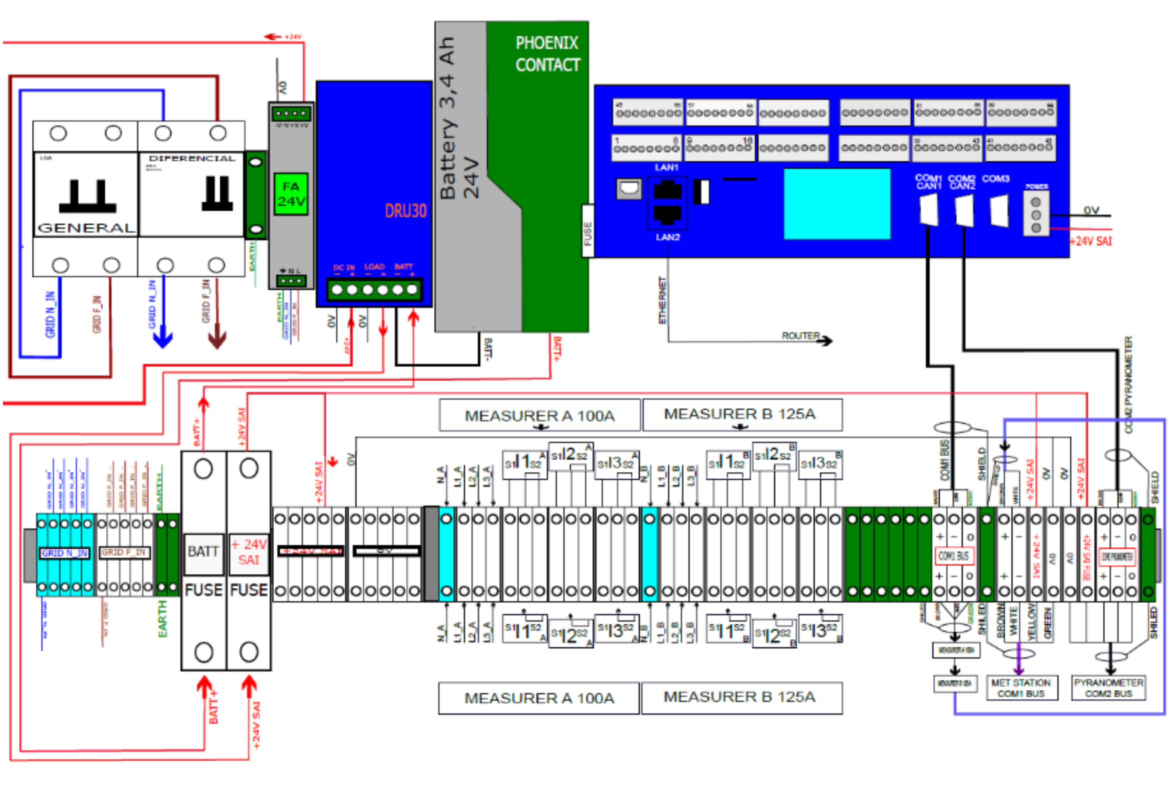


Figure 5.42: Monitoring system main board connections diagrams.

Data collection

The measurements of the sensors are collected by the data logger via Modbus and sent to Tecnalia headquarters through internet connection using a modem integrated in the monitoring system. Data gathered by the monitoring system can be checked online on the web datalogger prepared for this purpose, screenshot of online web datalogger is shown in Figure 5.43

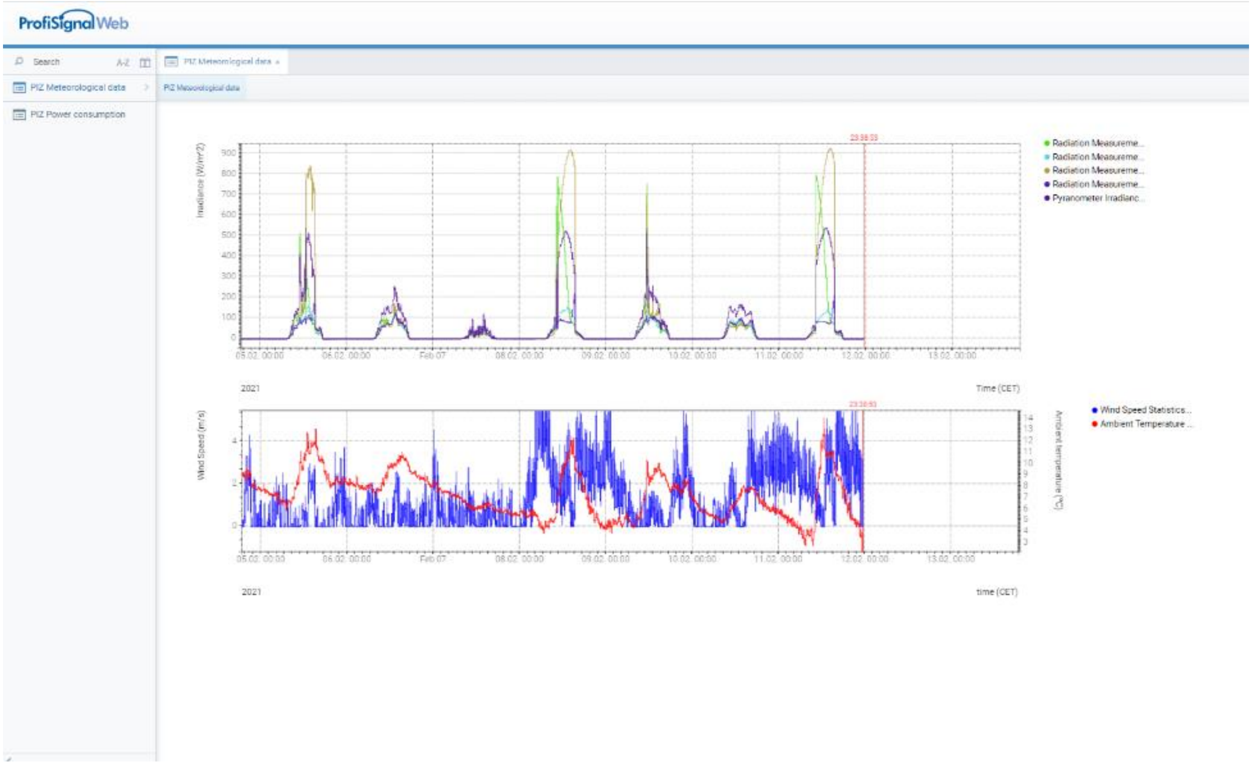


Figure 5.43: Screen shot of the web datalogger.

5.7 BIPV MODELLING AND PERFORMANCE SIMULATION

EnerBIM, as WP6 leader and BIMsolar tool developer, has completed BIPV systems digital modeling and simulation work as a pre-study.

5.7.1 Element level to building level methodology using 3D modeling and simulation tools

5.7.1.1 Overall methodology

The same methodology presented in Section 2.7.1.1 has been used.

5.7.2 Modeling strategy retained for transparent and opaque BIPV

The software is being developed to fit with ONYX Solar strategies regarding glazing systems and transparent BIPV products. The BIPV module configurator is based on 4 editors:

- Cell editor
- Pattern editor
- Transparent Glass editor
- Glazing editor

To design a transparent BIPV system, we have fixed the following steps:

BIPV Layout

Balance of System (downstream studies)

5.7.3 DEMO#4 – PIZ building, 3D design from 2D plans, simulation with BIMsolar

5.7.3.1 Hypothesis

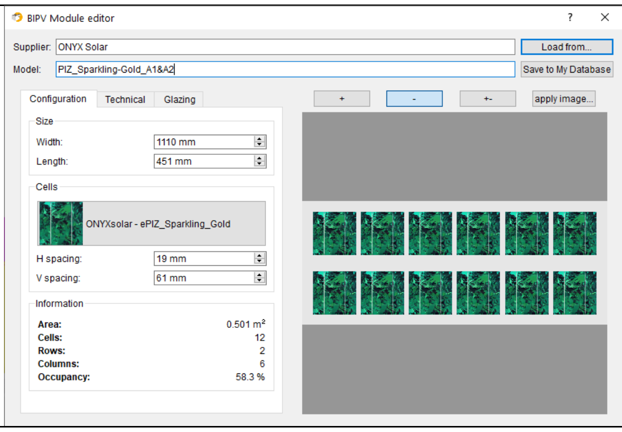
BIPV modules have been set up from ONYX Solar and PIZ datasets (up to date version).

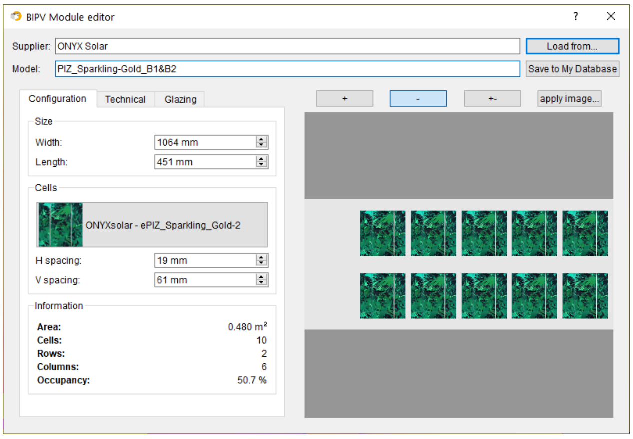
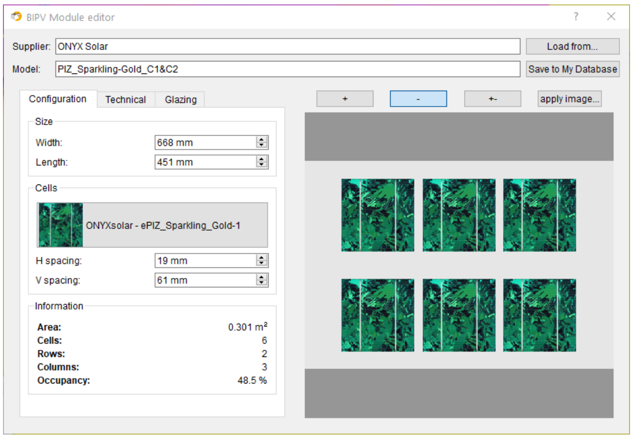
COLOURED cells: the development of these specific cells and patterns databases for BIPV with adequate models is not completed for BIMsolar software at this stage (WP6 T6.3 – M48)

To run first simulations, we have selected mono crystalline cells and glass modules from ONYX standards and set up features from ONYX Solar modules datasheets.

5.7.3.2 FACADE CLADDING MODULES – ONYX Solar BIPV glass for simulation

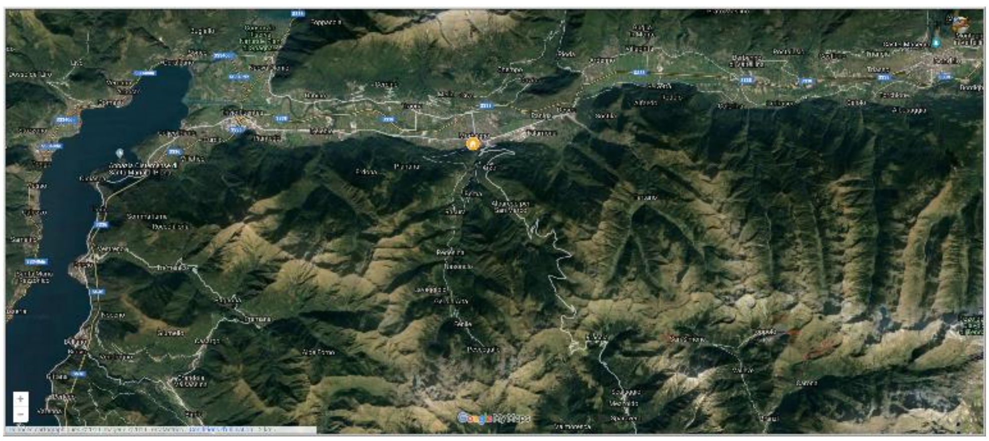
Table 5.7 Configuration of ONYX Solar Cladding modules

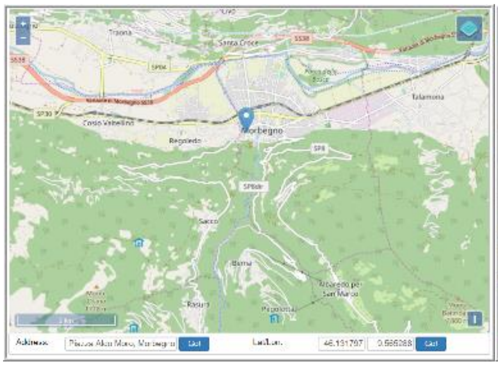
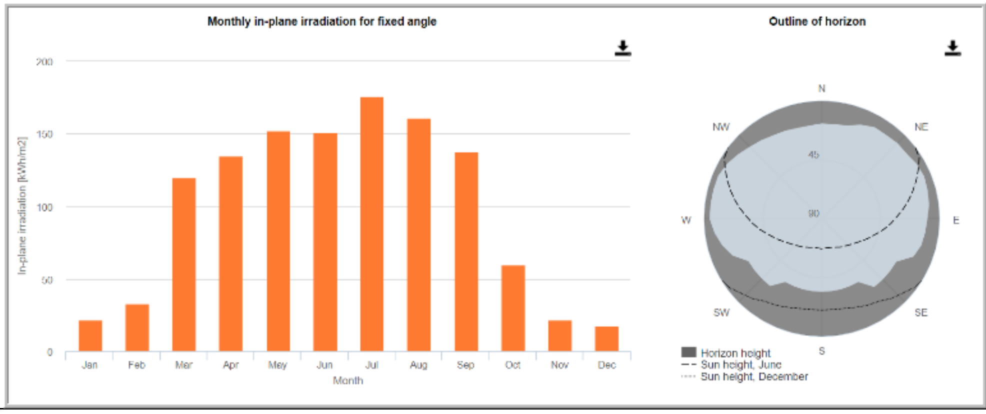
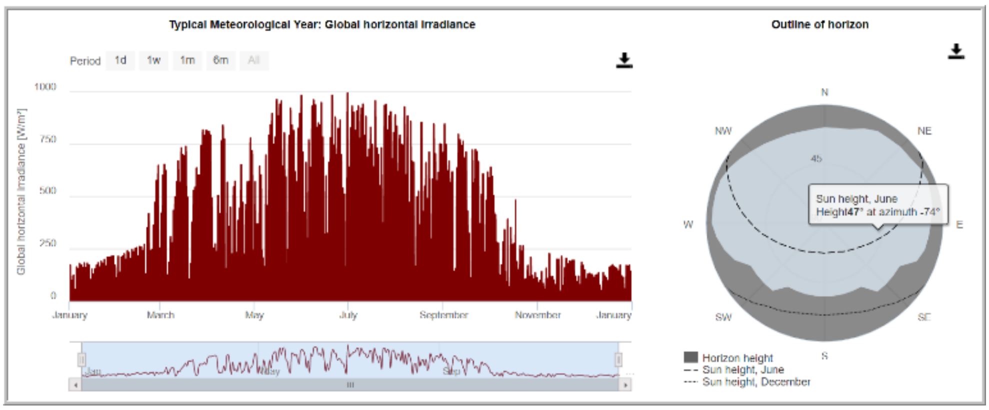
A1 & A2 BIPV MODULES 1110mm x 451mm Cell color : Sparkling gold 102 panels distributed over all the contours Total : 204 panels	

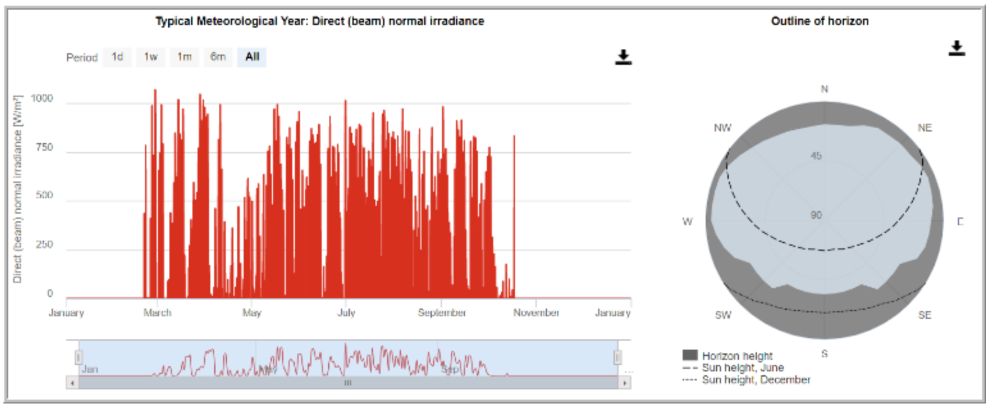
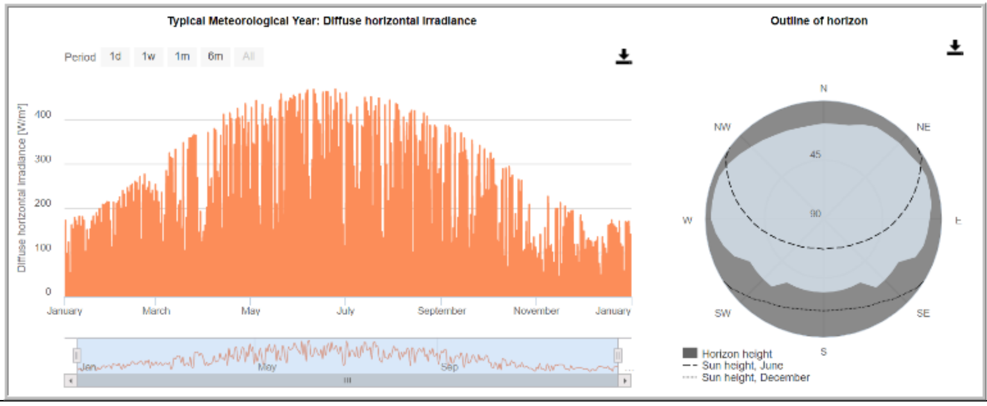
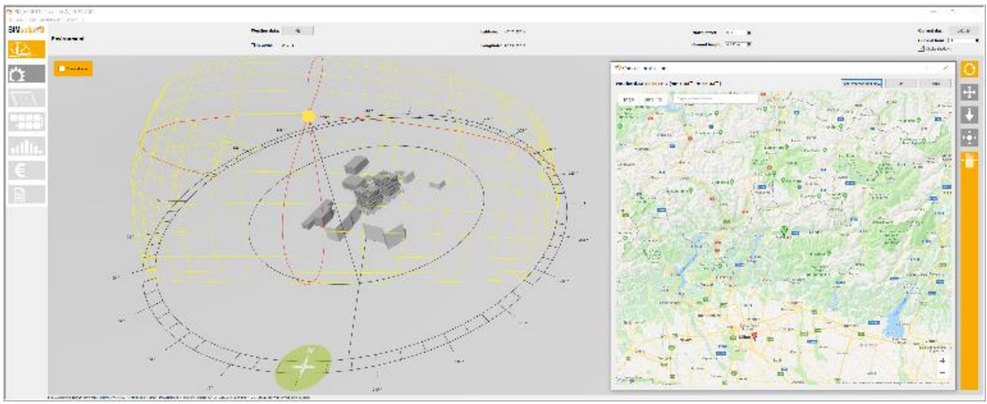
B1 & B2 BIPV equivalent MODULES 1064mm x 451mm Cell color : Sparkling gold 2 panels on North-East façade of each building. Total : 4 panels	
C1 & C2 BIPV equivalent MODULES 668mm x 451mm Cell color : Sparkling gold 2 panels on South-West façade of each building. Total : 4 panels	

5.7.3.3 WEATHER DATA and IRRADIATION MODELING

We chose to use the European open access reference tool PVGIS to generate meteorological + site data at the exact location of the demo site. Visualization from satellite enable considering terrain modelling, albedo evaluation and masking effects.

GEO LOCATION ➔ Google Maps	

➔ PVGIS ORIENTATION ➔ +30° from Google Maps interpretation ALBEDO ➔ 20% ground ➔ 50% buildings	  
HORIZON IN PLANE IRRADIATION for typical 35° PV angle ➔ Severe masking for PV production during winter	
IRRADIANCE TMY data to generate weather file as input for BIMsolar (epw) TMY Period: 2007-2016 Time step: hourly ➔ Horizontal mask effects at winter	

→no direct irradiance at winter	 
BIMsolar epw importation Sun course / heliodon	

5.7.3.4 3D MODELING - SETUP- EXISTING BUILDING

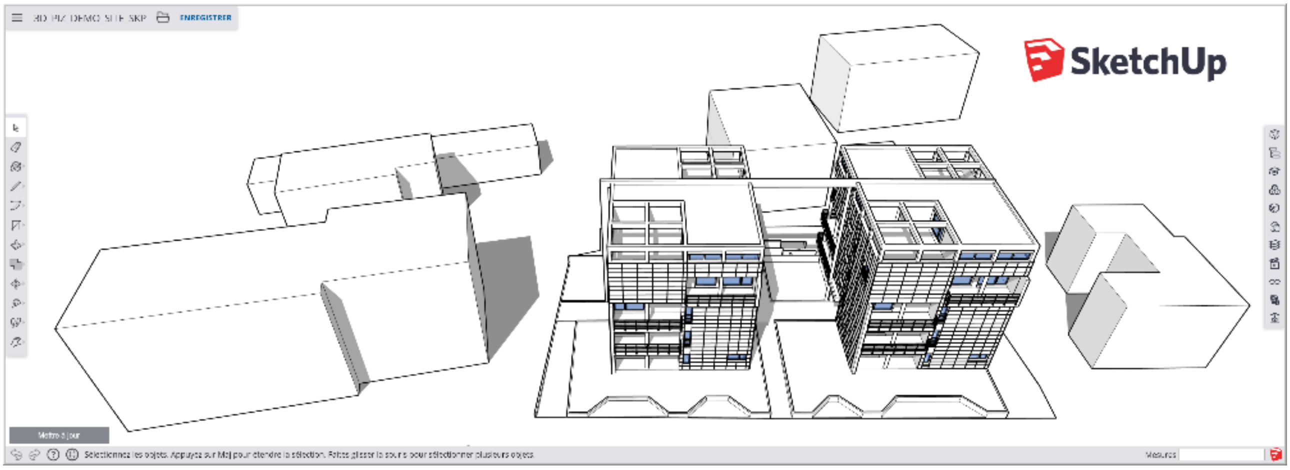
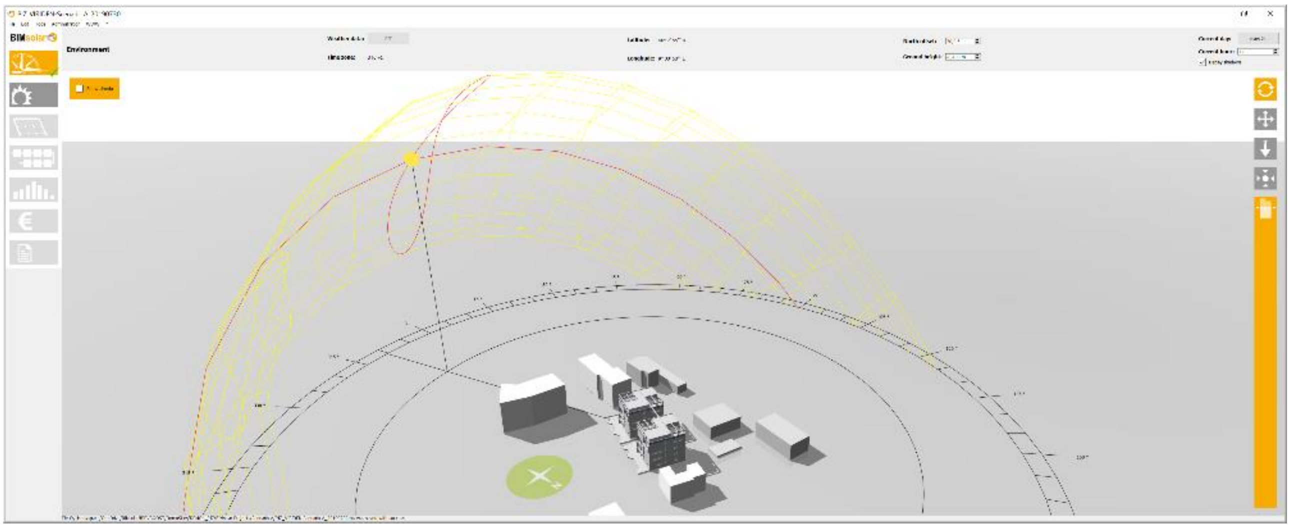
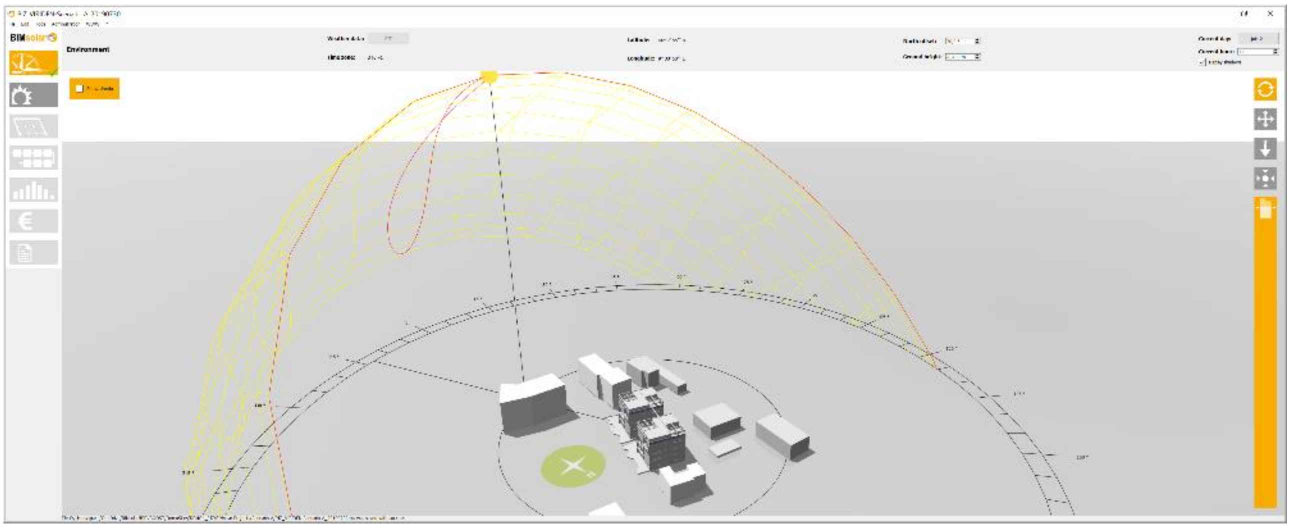


Figure 5.44: Modelling has been made as much realistic as it could be from the existing 2D plans to address BIPV issues (Trimble SketchUp model from PIZ)

STEP#1- BIMsolar IMPORTATION – Building settings





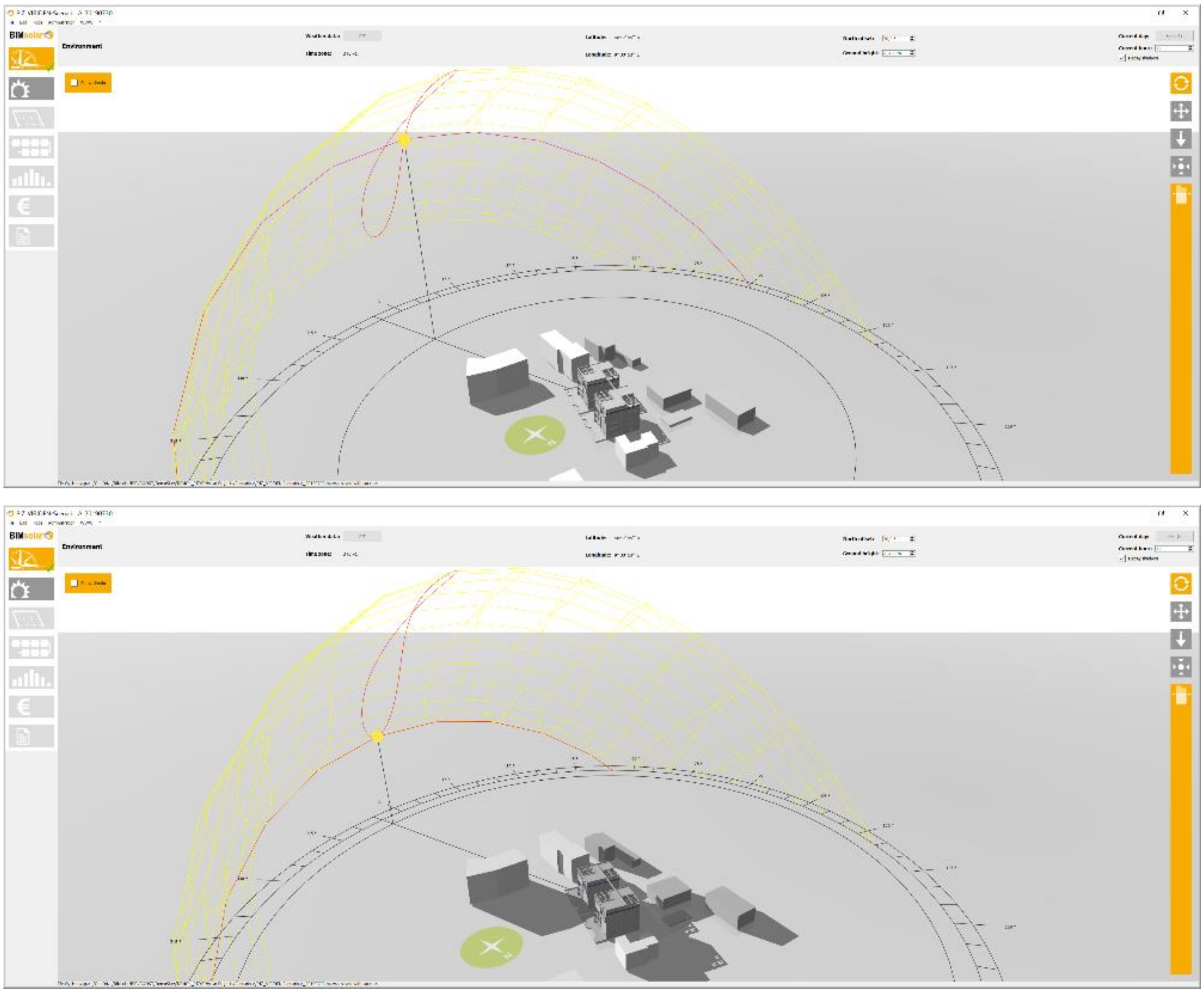
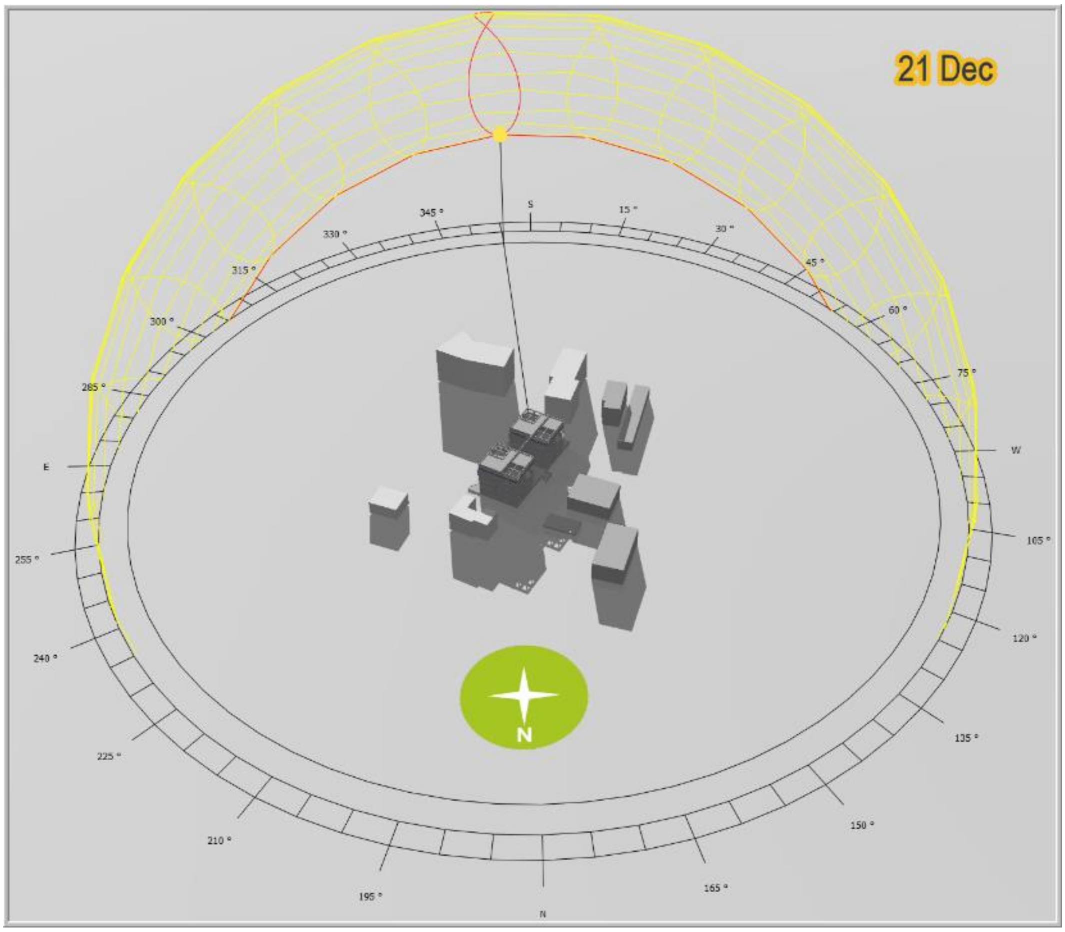


Figure 5.45: Close and far shadowing calculation are made through 3D modelling of realistic buildings - Sun course for full year is displayed at hourly step time – 4 seasons illustration



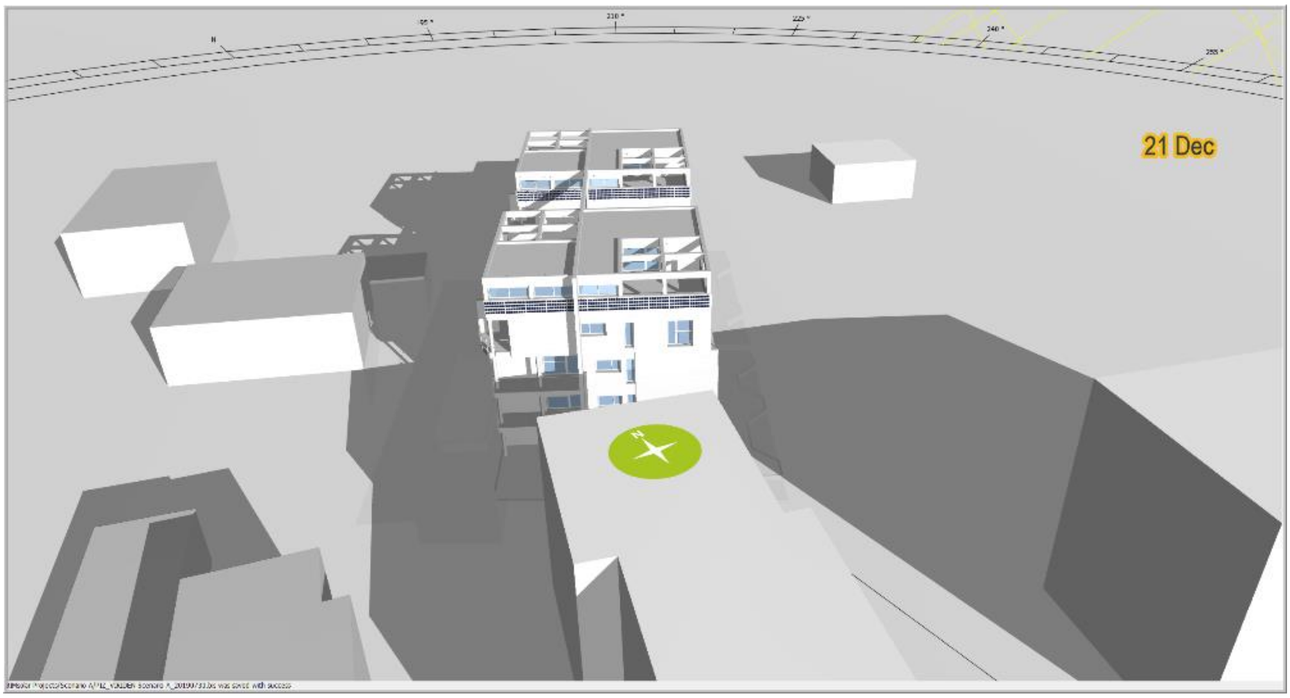


Figure 5.46: Close and far shadowing calculation – Specific illustration – DEC 21st – 12:00

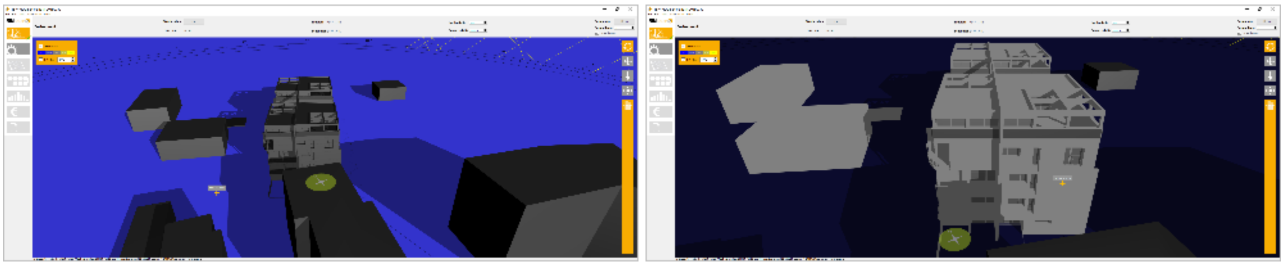


Figure 5.47: Albedo effects (reflected irradiance) are generated selecting groups and types of surfaces

20% as a setup for surroundings and 50% for the buildings envelops as a general approach

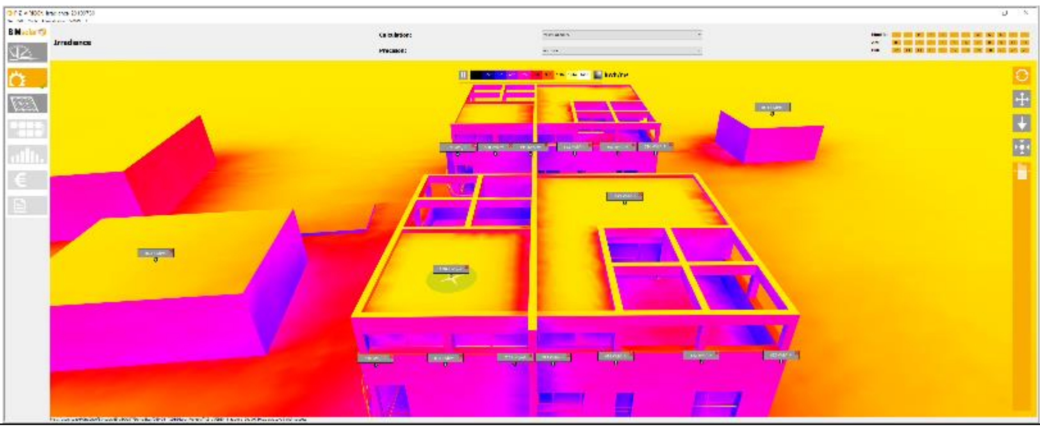
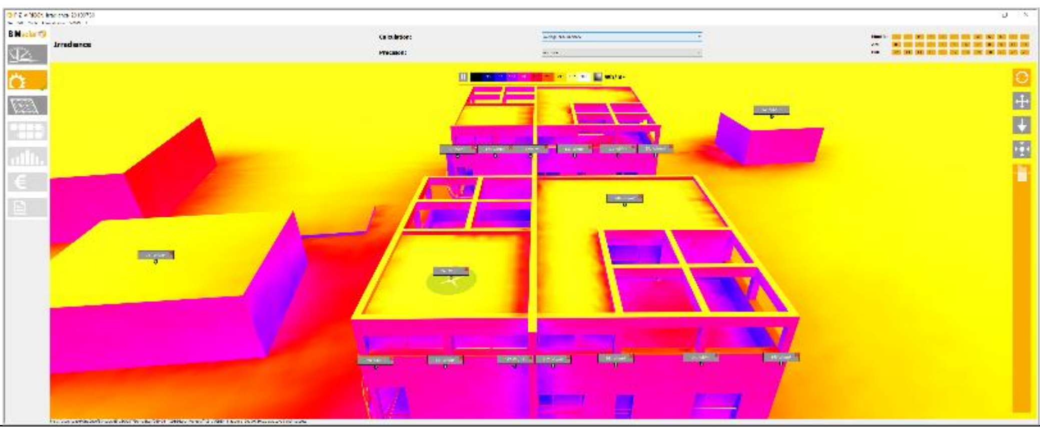
5.7.3.5 Simulation – Results

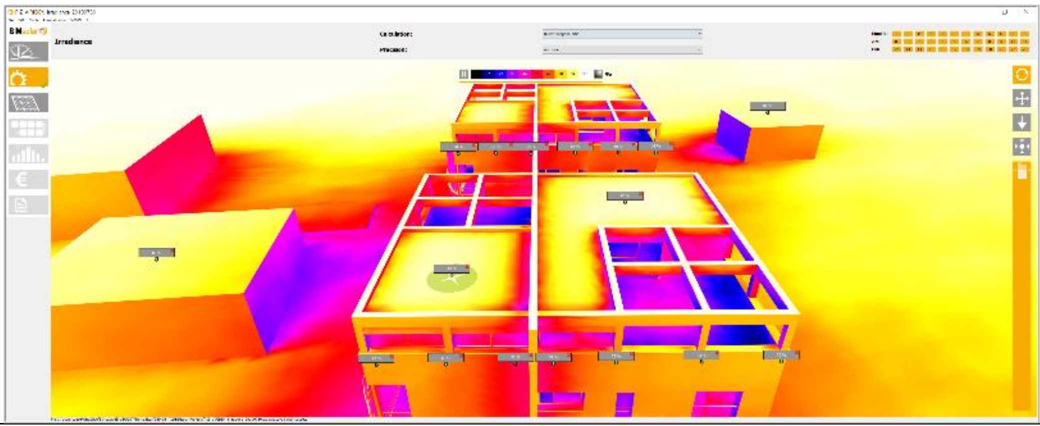
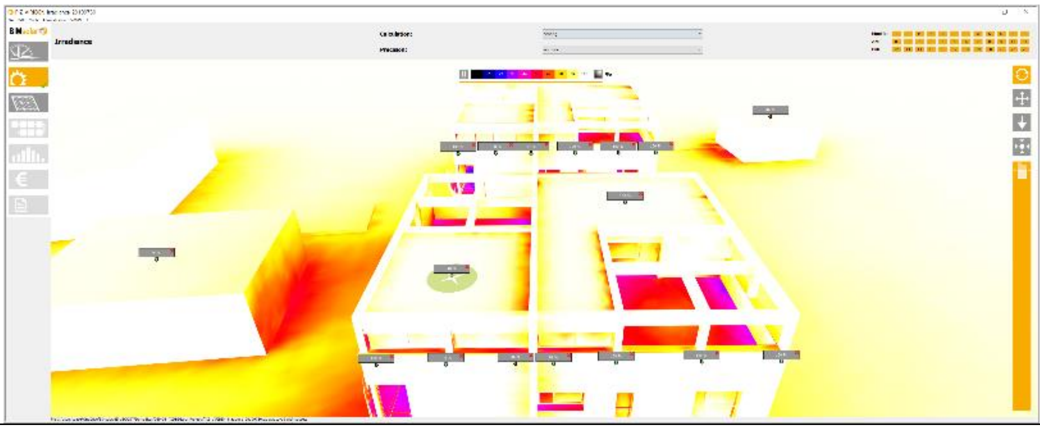
STEP#2-IRRADIATION

We use markers to record and visualize values

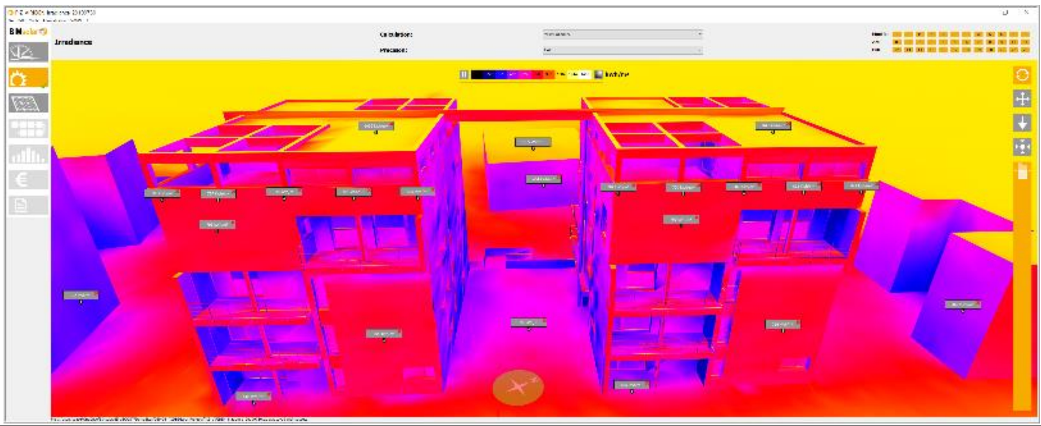
Sets of data can be exported in CSV

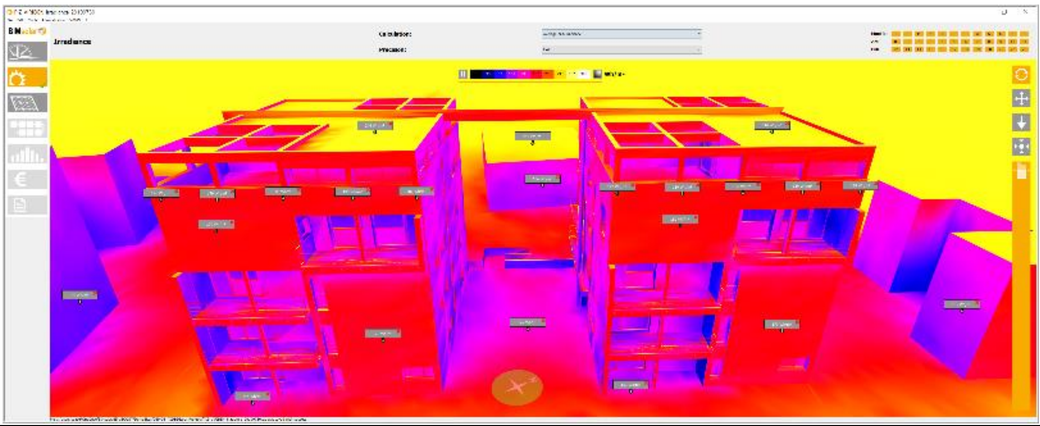
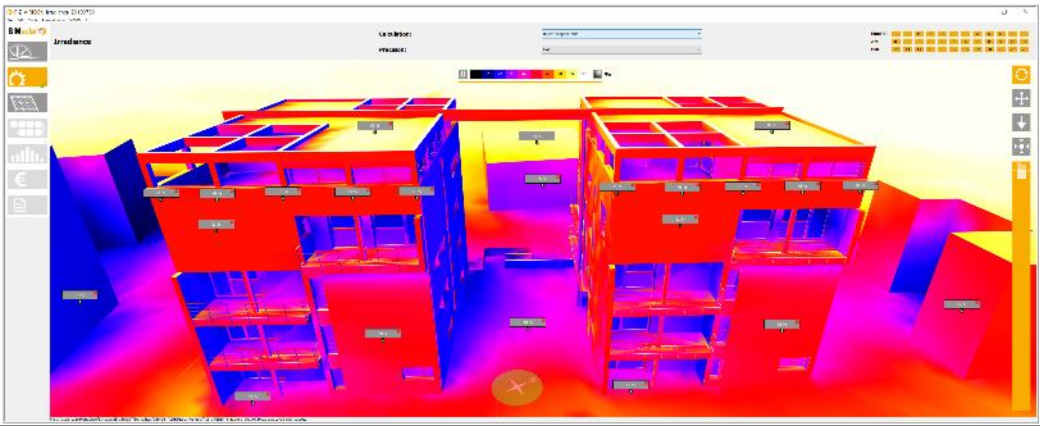
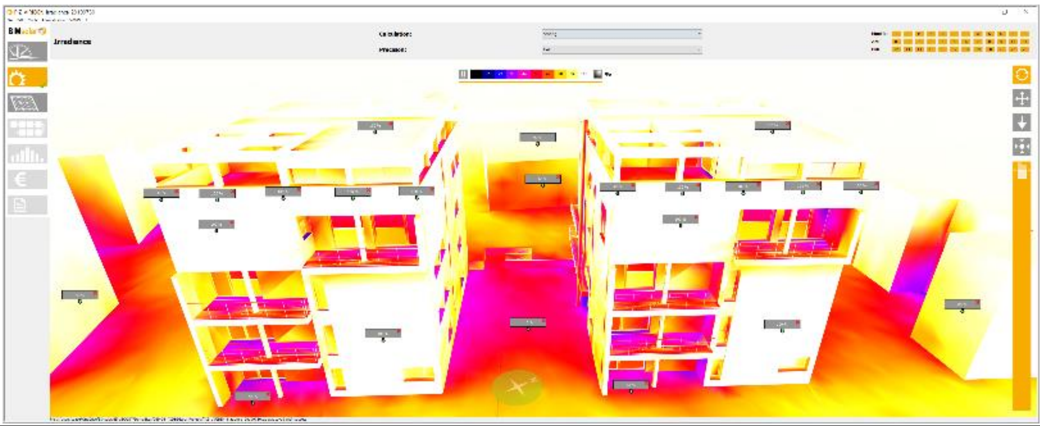
SOUTH FACADES mapping & survey

Yearly kWh/sqm →620kWh/sqm recorded for facade A →570kWh/sqm recorded for facade B (exclusion of shading issue due to beam)	
Average day 140kWh/sqm recorded for facade A →128kWh/sqm recorded for facade B (exclusion of shading issue due to beam)	

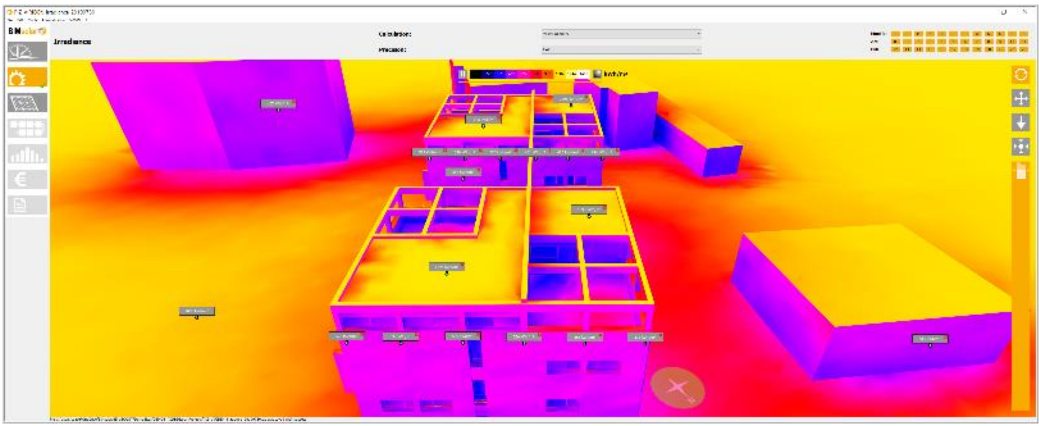
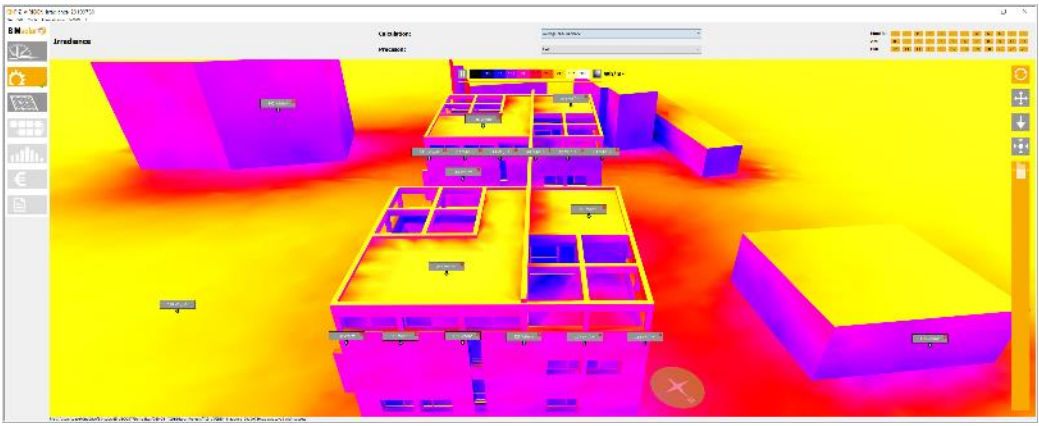
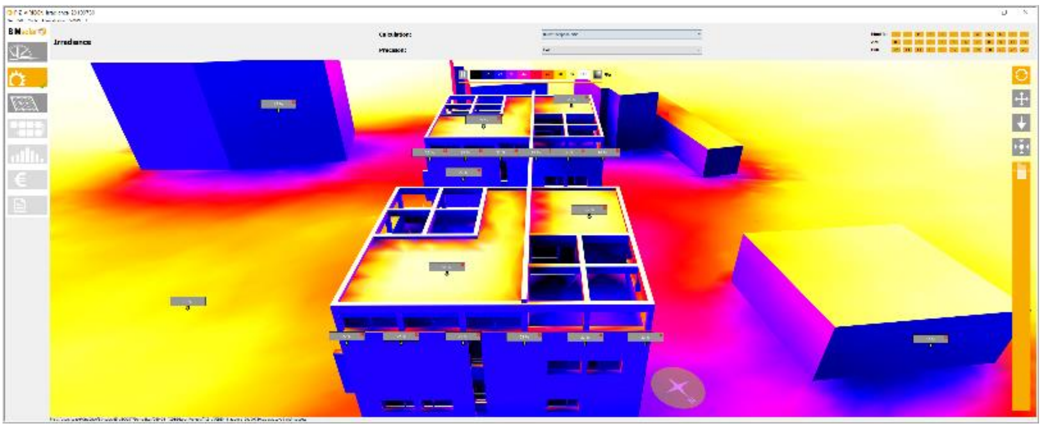
Direct ratio →70% recorded for façade A →68% recorded for façade B (exclusion of shading issue due to beam)	
Shading →only external beam generates shading issues	

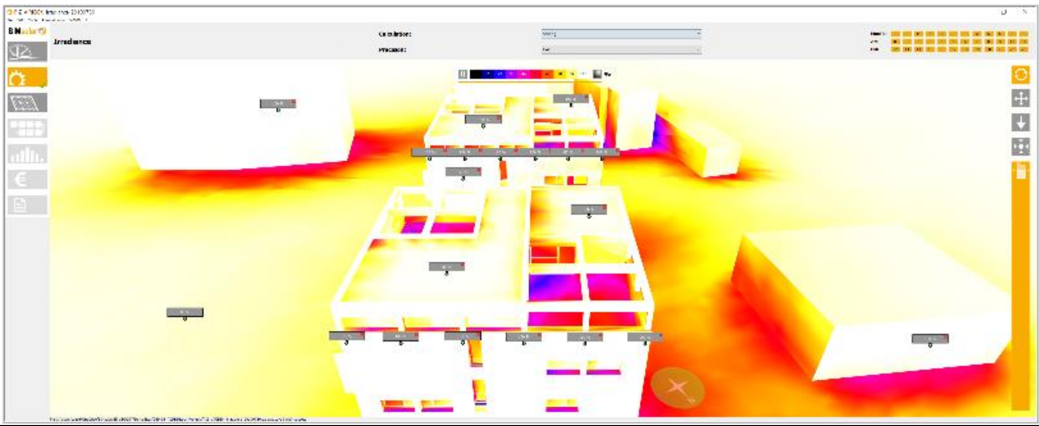
EAST FACADES mapping & survey

Yearly kWh/sqm →800kWh/sqm recorded as average value	

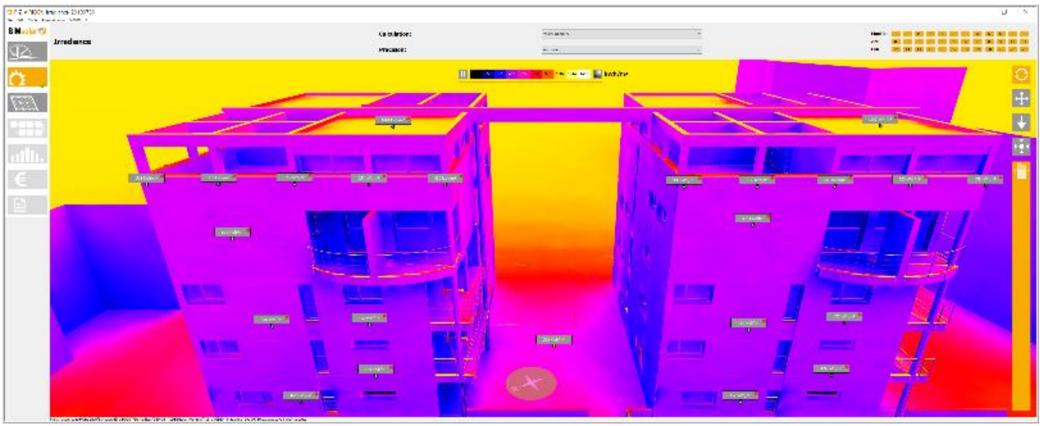
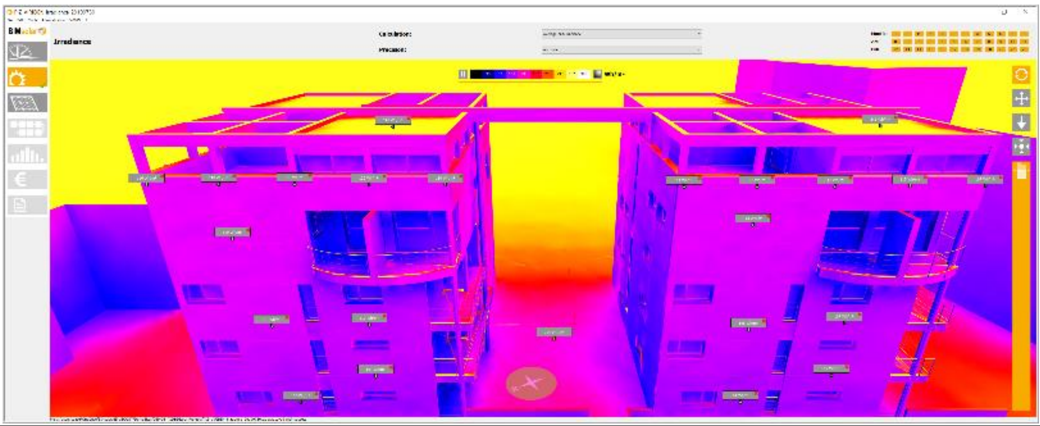
Average day 180kWh/sqm recorded as average value	
Direct ratio →61% recorded	
Shading →no issue	

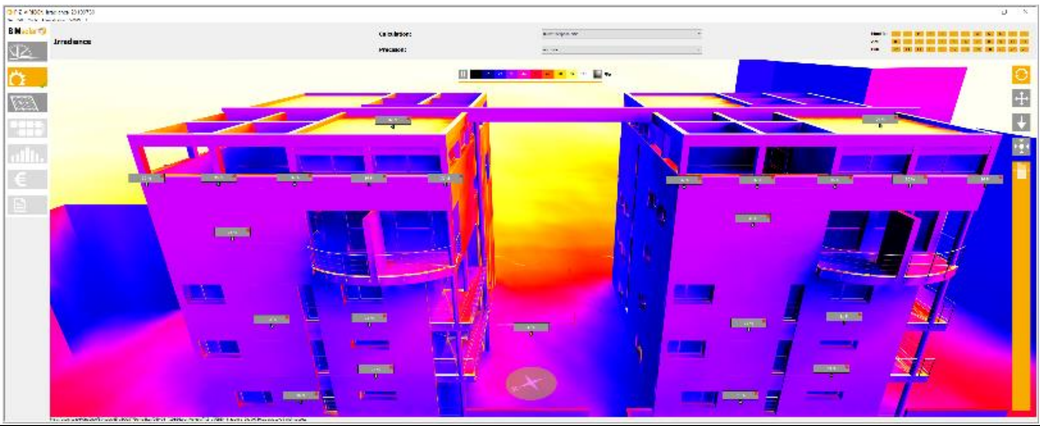
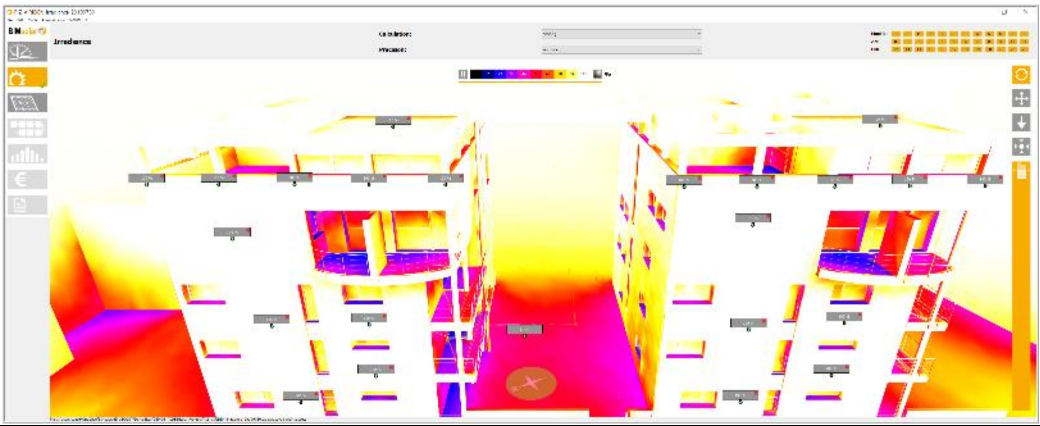
NORTH FACADES mapping & survey

Yearly kWh/sqm →530kWh/sqm recorded for facade A East side →430kWh/sqm minimum for facade A West side →550kWh/sqm recorded for facade B as a minimum	
Average day →119kWh/sqm recorded for facade A East side →102kWh/sqm minimum for facade A West side →123kWh/sqm recorded for facade B	
Direct ratio →22% recorded for facade A East side →16% recorded for facade A East side →22% recorded for facade B	

Shading →no issue	

WEST FACADES mapping & survey

Yearly kWh/sqm →500kWh/sqm recorded as average value for façade A →530kWh/sqm recorded as average value for façade B	
Average day →113kWh/sqm recorded as average value for façade A →119kWh/sqm recorded as average value for façade B	

Direct ratio →36% recorded	
Shading →no issue	

STEP#3 – BIPV layouts

We use virtual modules set-up from manufacturer's datasheets (see above) to generate BIPV systems. Production, shading losses, temperature losses are calculated in real time from module level to BIPV layout level. Every single module is computed as a system and the software displays individual KPIs.

Detailed results can be obtained at STEP#5 (BIMsolar reference process).

Building A

Figure 5.48: Building A – 2 rows of 1110x451mm (=102 modules) on South, East, West and North facades + 2 rows 668x451mm (=2 modules) on South-West + 2 rows of 1064x451mm (=2 modules) on North-East facades – Total 4.9kWp / 52.6sqm

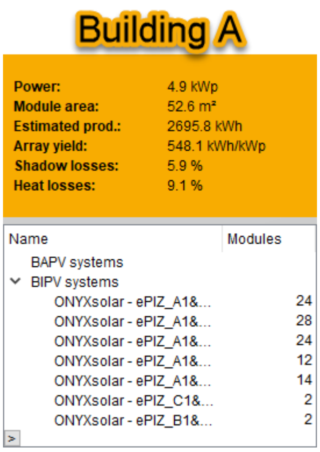


Figure 5.49: Global results building A – All layouts

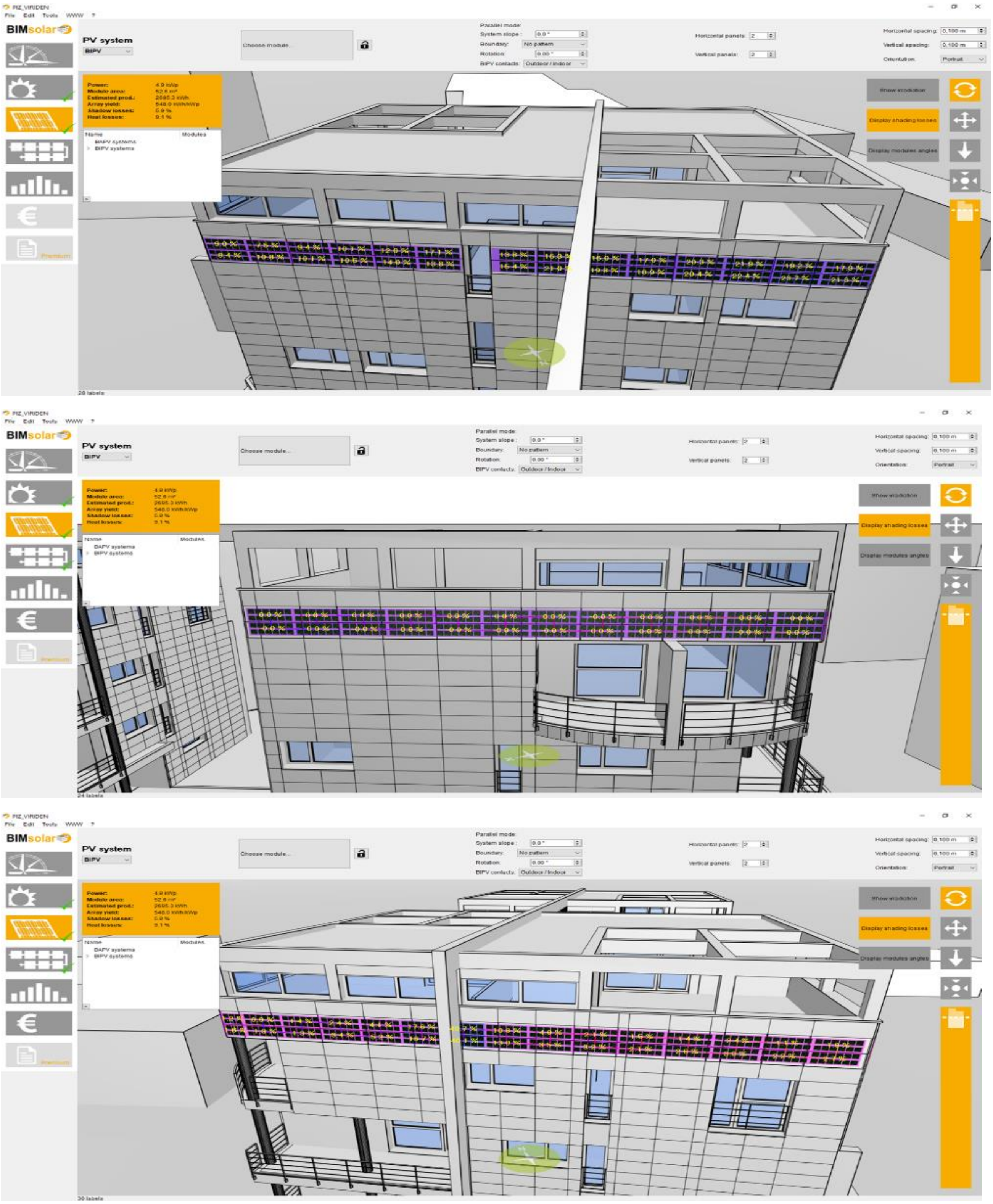


Figure 5.50: Shading mapping at module level – Main issue is shading from external beam (south, 70% on 2 modules)

Building B

Figure 5.51: Building B – 2 rows of 1110x451mm (=102 modules) on South, East, West and North facades + 2 rows of 668x451mm (=2 modules) on South-West + 2 rows of 1064x451mm (=2 modules) on North East facades – Total 4.9kWp / 52.6sqm

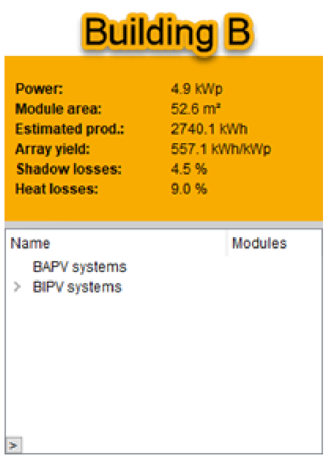


Figure 5.52: Global results building B – All layouts

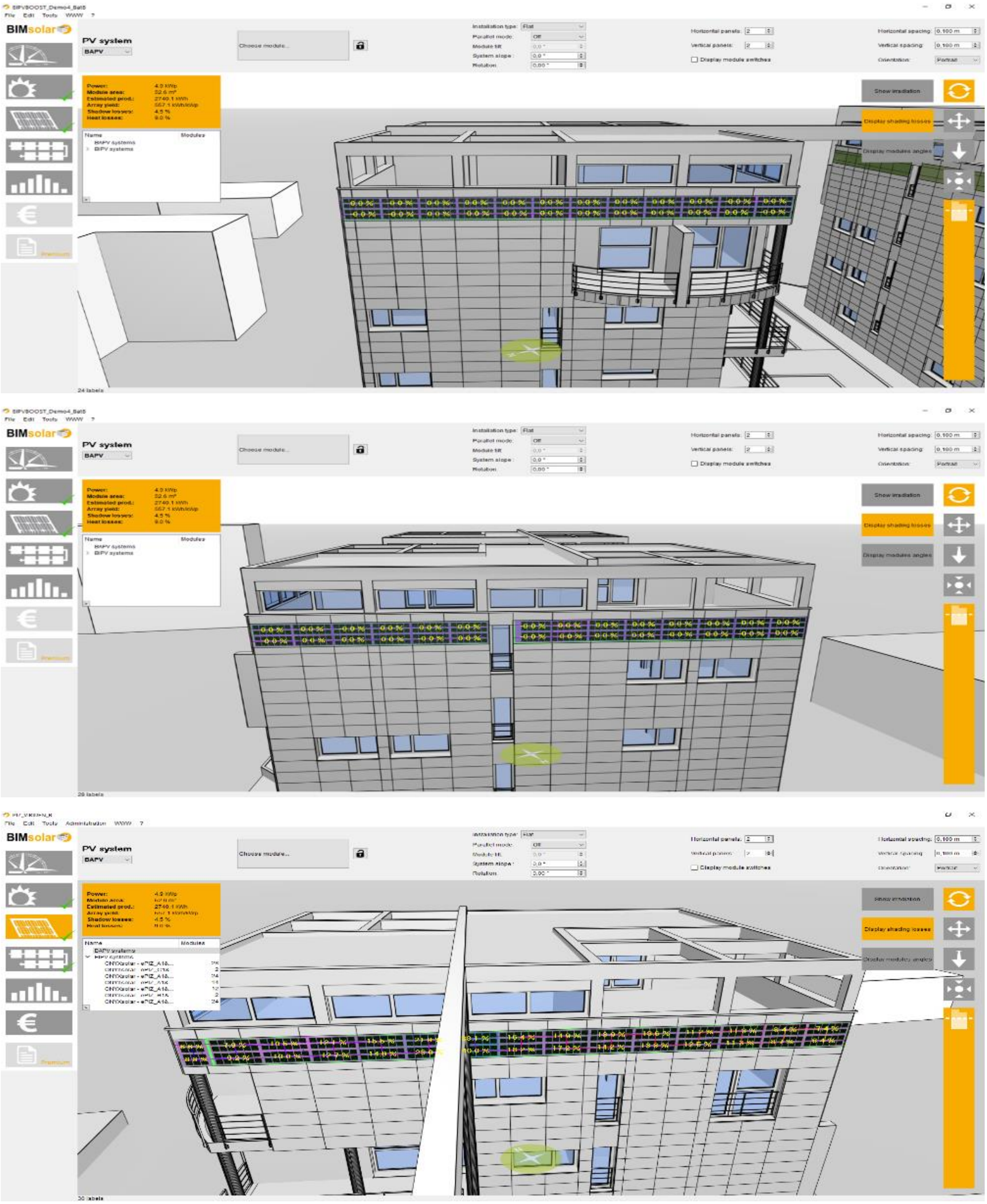


Figure 5.53: Shading mapping at module level

STEP#4 – INVERTERS / WIRING

We have implemented the inverters as listed on the single line diagram:

- Azzuro-1100-TL: 30 panels
- Azzuro-1100-TL: 24 panels
- Azzuro-1100-TL: 24 panels
- Azzuro-1100-TL: 28 panels

Building A

Figure 5.54: Building A - 1 inverter on each façade for all the panels (=4 inverters Azzuro-1100-TL), there is 102 module types A1&A2, 2 module types B1&B2 and then 2 C1&C2

Building B

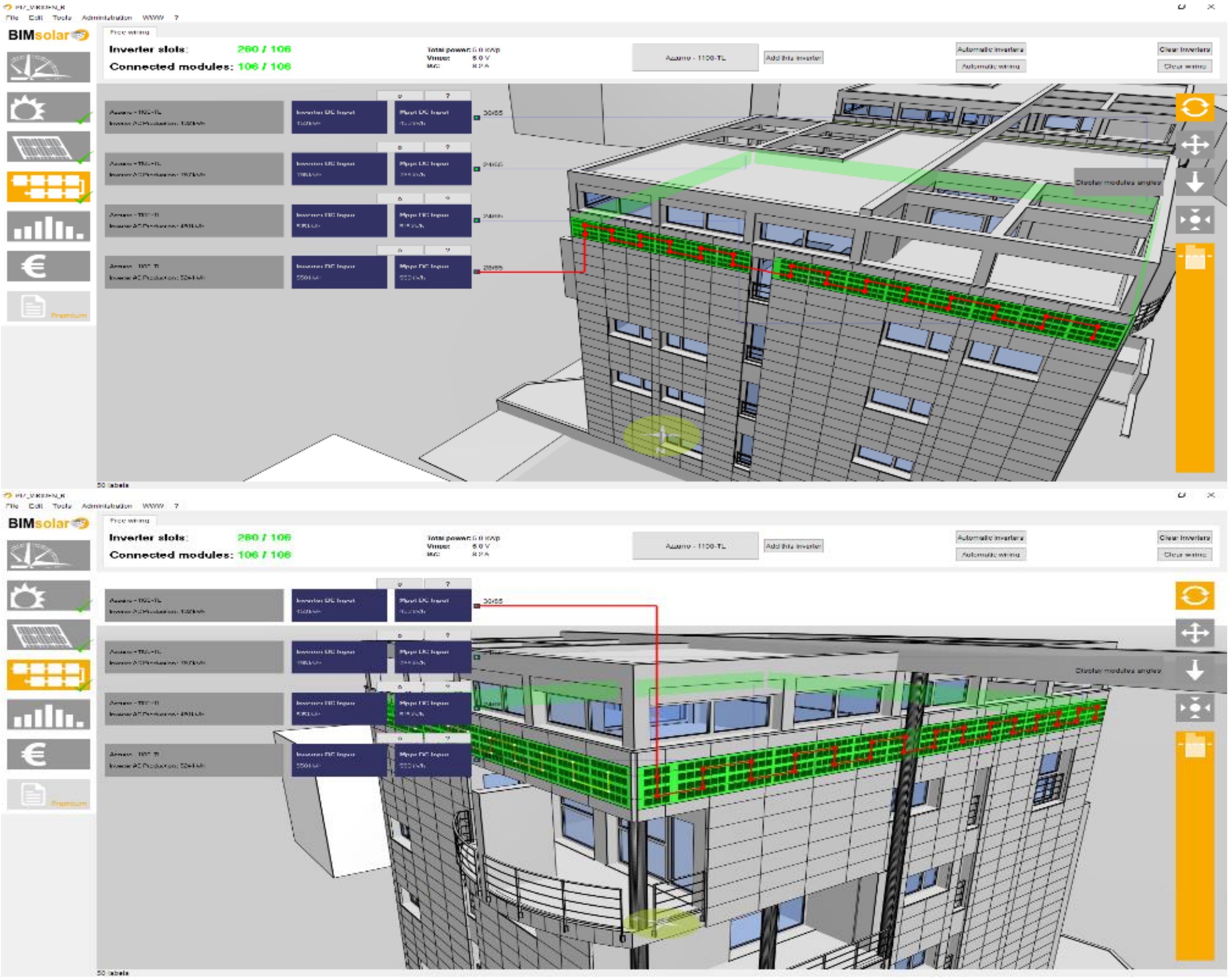


Figure 5.55: Building B – 1 inverter on each façade for all the panels (=4 inverters Azzuro-1100-TL), there is 102 module types A1&A2, 2 module types B1&B2 and then 2 C1&C2

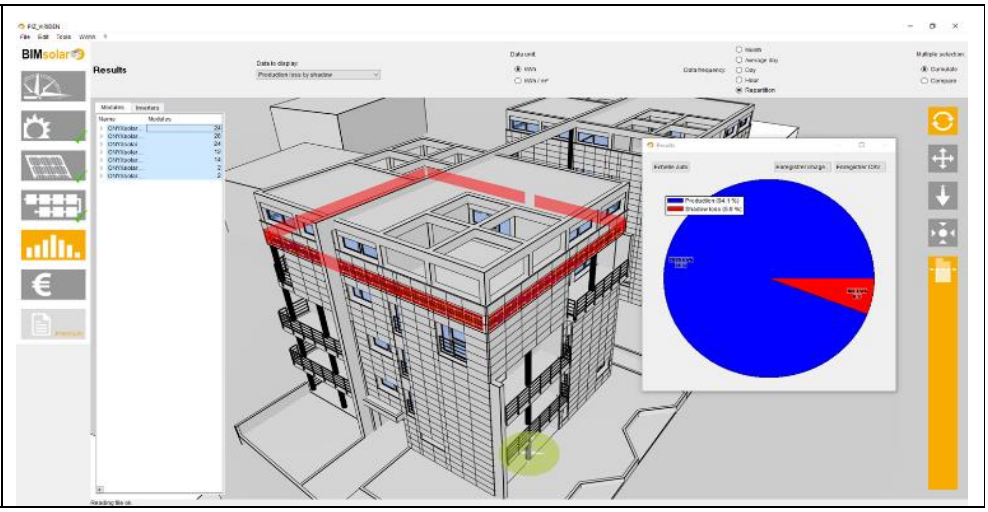
STEP#5 – RESULTS

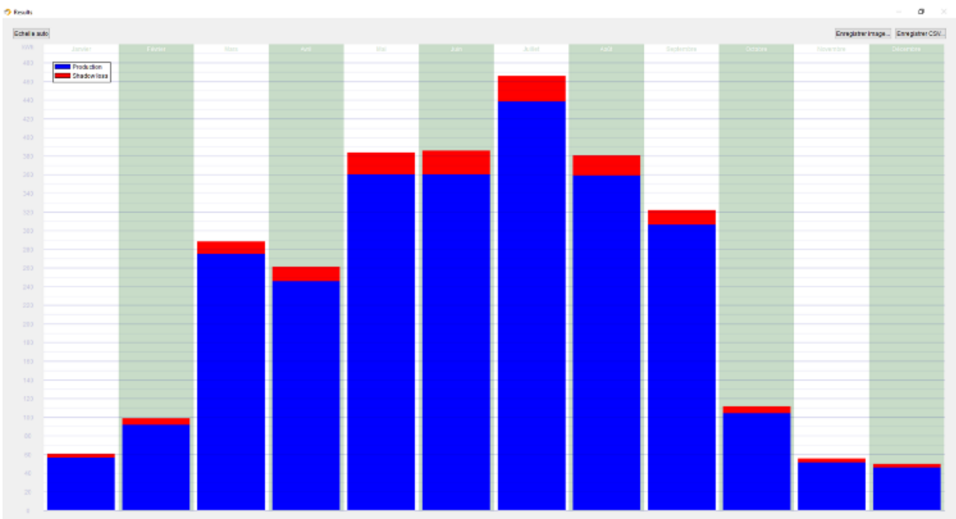
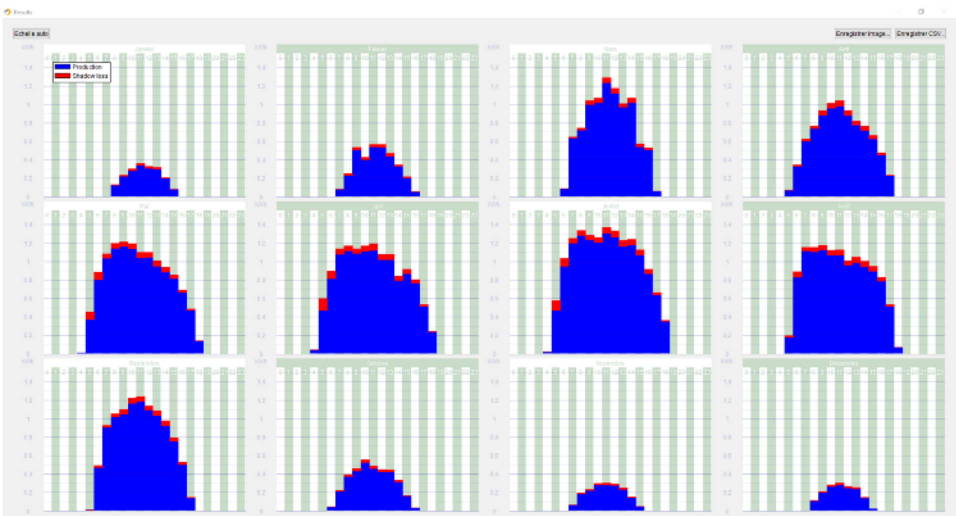
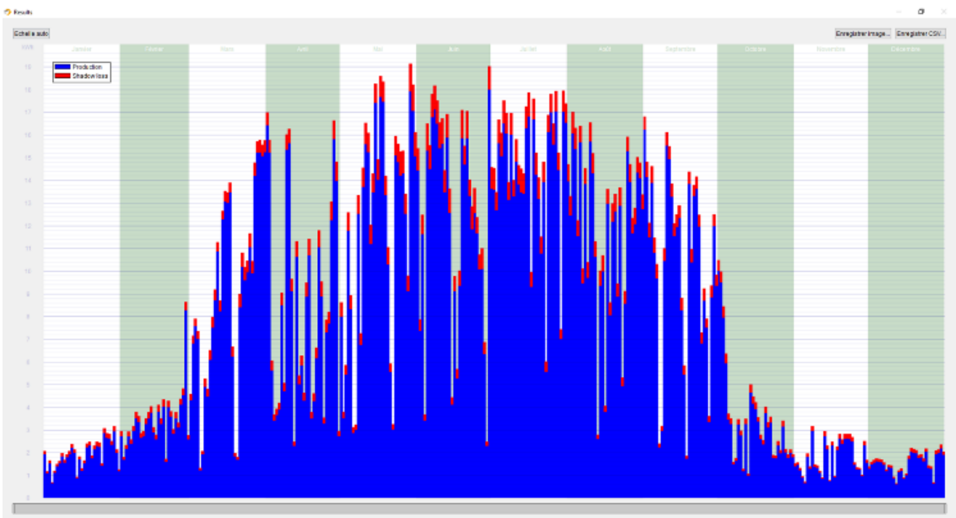
BIMsolar offers a comprehensive set of detailed results, from yearly to hourly timestep, covering irradiance, shading losses, heat losses, production, yield… from module level to layout level.

Example on building A:

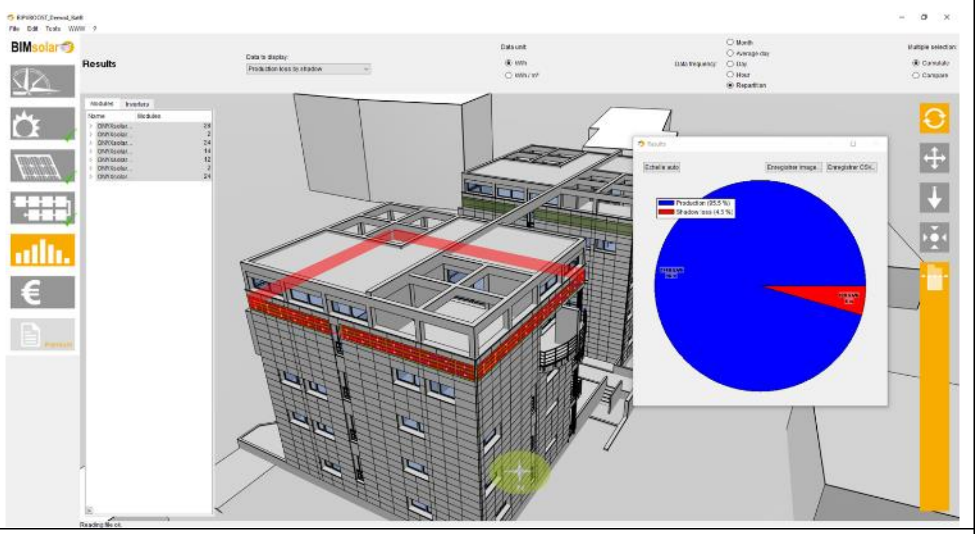
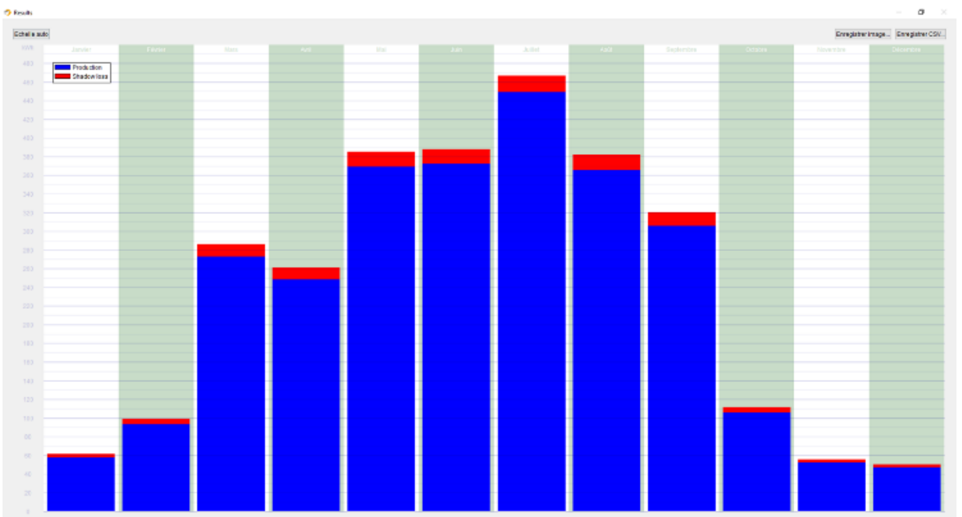
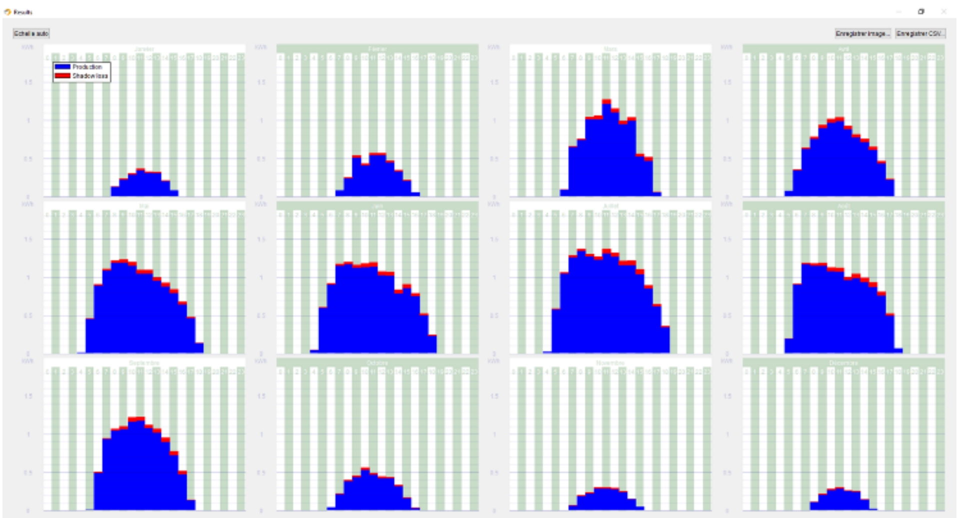
Figure 5.56: Production + shading losses: building A – Monthly analysis

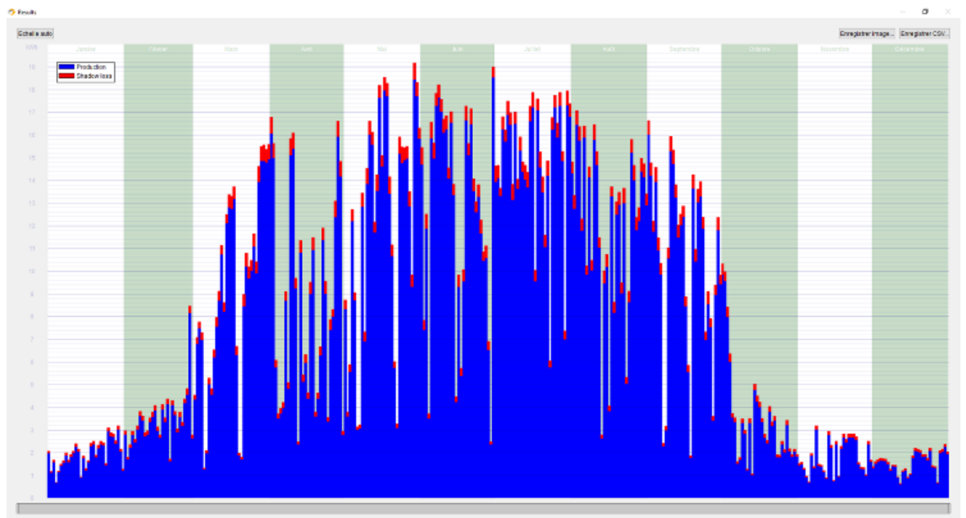
Building A - Table of results:

Production – Shading losses GLOBAL →Production= 2 695kWh (94%) →Shading losses= 168kWh (6%)	

Production – Shading losses MONTHLY →strong discrepancy due to horizontal masking, low season →7 months are well balanced and July is the most productive	
Production – Shading losses AVERAGE DAY / MONTH	
Production – Shading losses DAILY	

Building B - Table of results:

Production – Shading losses GLOBAL →Production= 2 740kWh (96%) →Shading losses= 128kWh (4%)	
Production – Shading losses MONTHLY →strong discrepancy due to horizontal masking, low season →7 months are well balanced and July is the most productive	
Production – Shading losses AVERAGE DAY / MONTH	

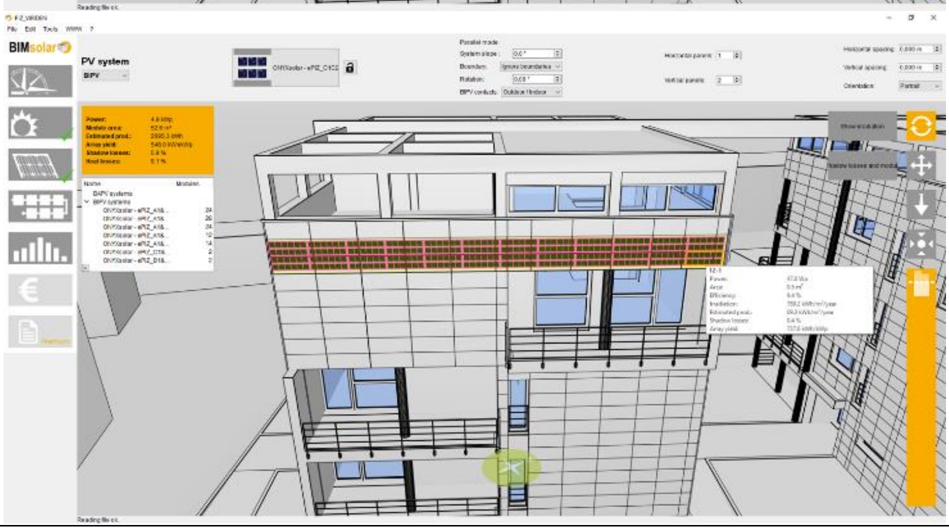
Production – Shading losses DAILY	

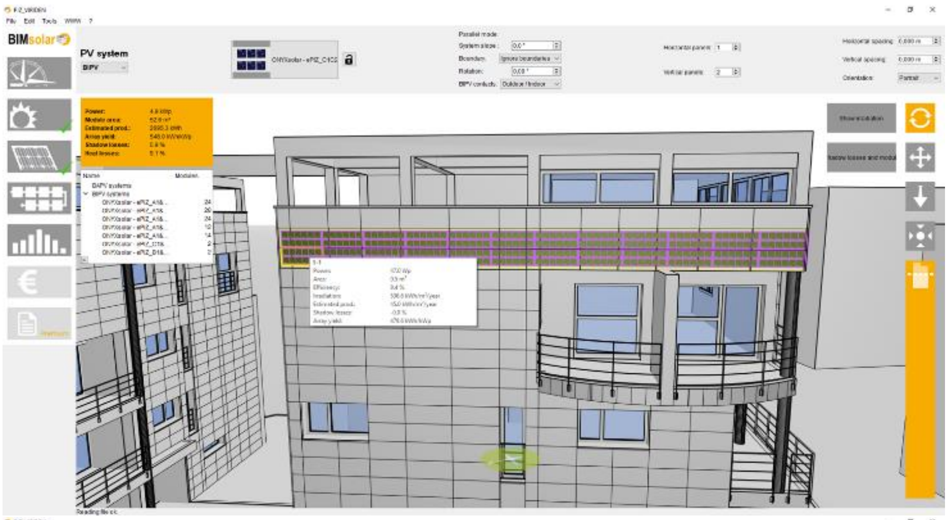
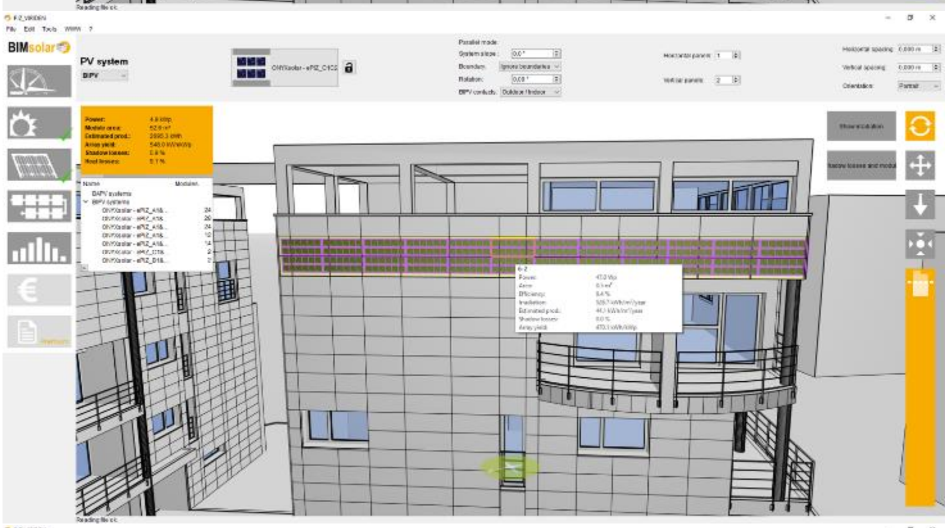
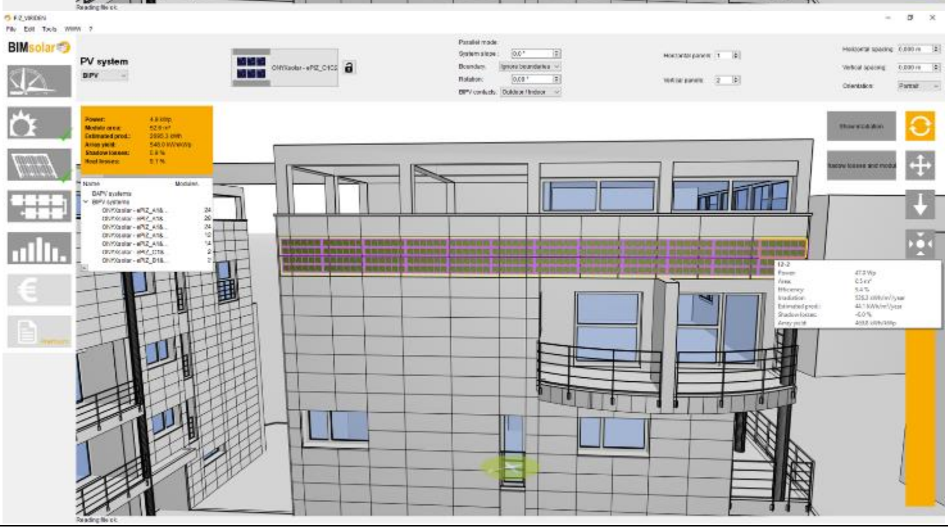
Building A - Layouts YIELD survey & mapping

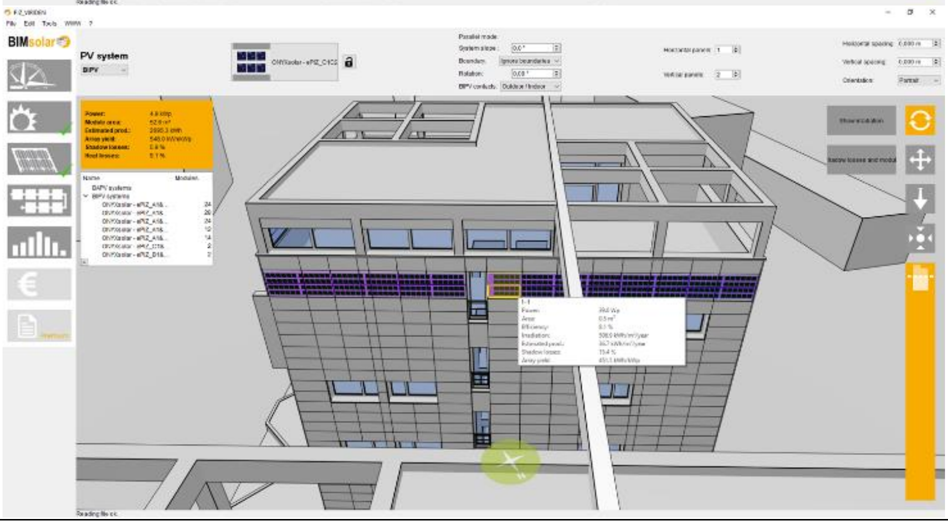
Array yield and KPIs displayed at module level

SOUTH-WEST FACADES	
SOUTH-WEST FACADES	

SOUTH-WEST FACADES	
SOUTH-WEST FACADES	

SOUTH-EAST FACADES	
SOUTH-EAST FACADES	
SOUTH-EAST FACADES	

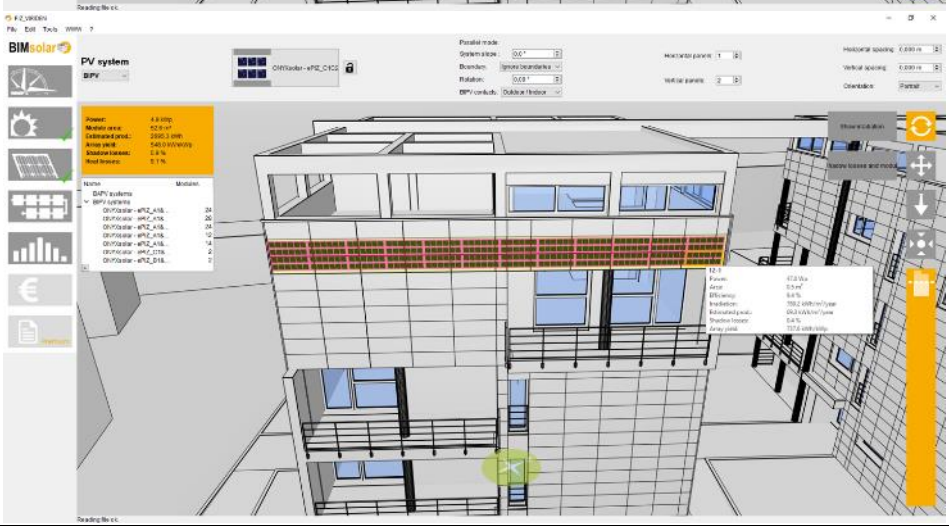
NORTH-WEST FACADES	
NORTH-WEST FACADES	
NORTH-WEST FACADES	

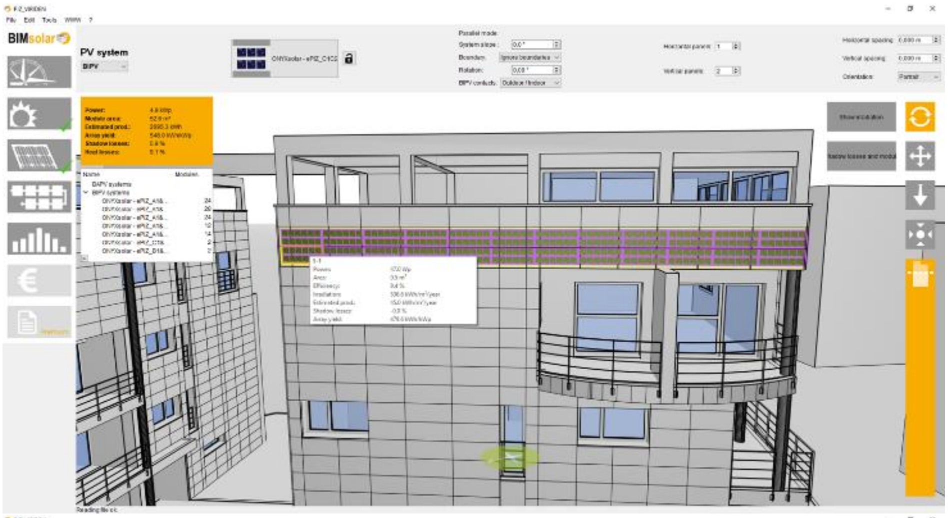
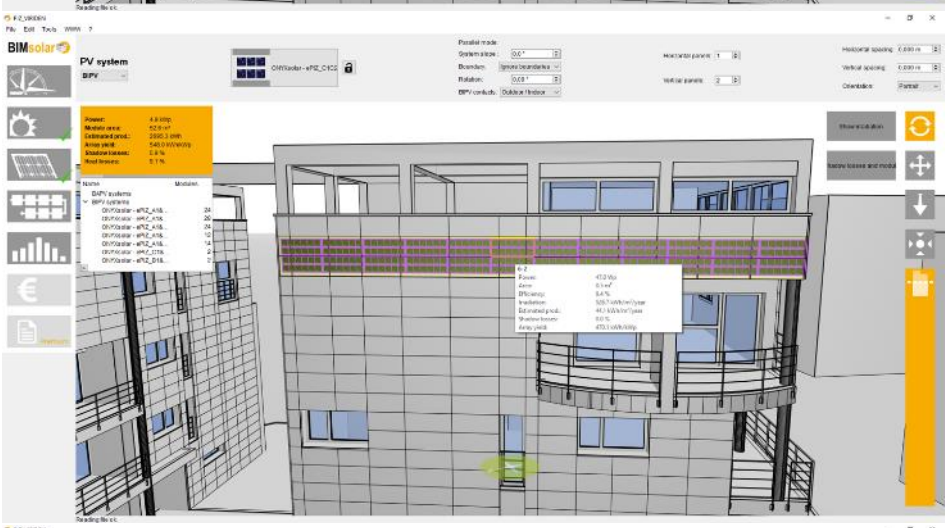
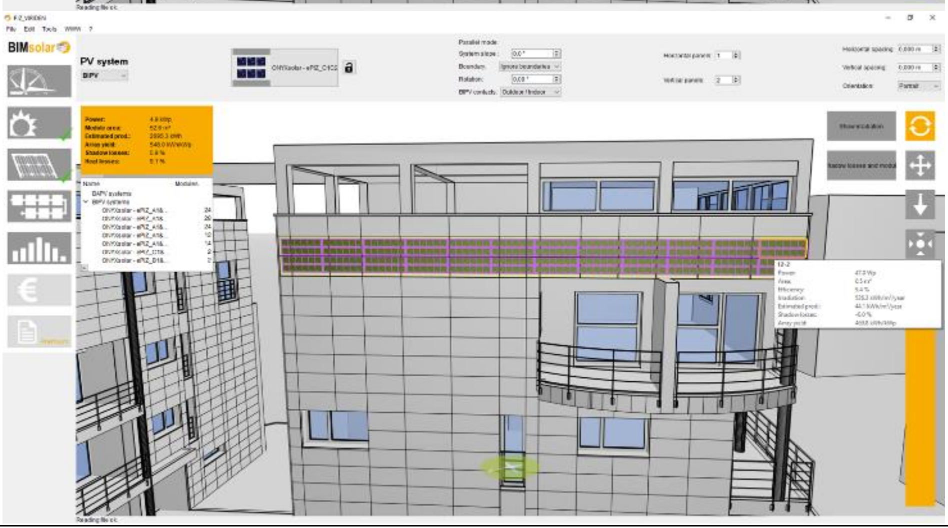
NORTH-EAST FACADES	
NORTH-EAST FACADES	
NORTH-EAST FACADES	

Building B - Layouts YIELD survey & mapping

SOUTH-WEST FACADES	
SOUTH-WEST FACADES	

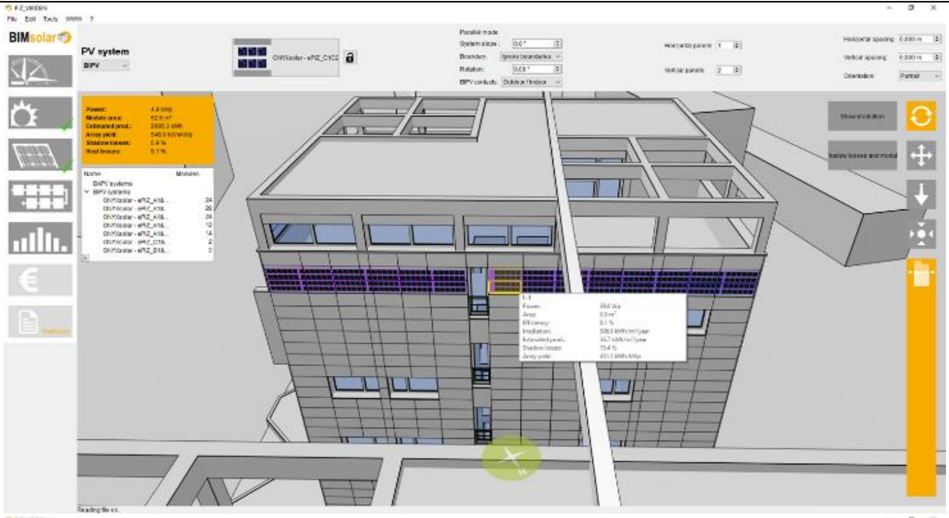
SOUTH-WEST FACADES	
SOUTH-WEST FACADES	

SOUTH-EAST FACADES	
SOUTH-EAST FACADES	
SOUTH-EAST FACADES	

NORTH-WEST FACADES	
NORTH-WEST FACADES	
NORTH-WEST FACADES	

NORTH-EAST FACADES	
NORTH-EAST FACADES	

NORTH-EAST FACADES



NORTH-EAST FACADES

5.7.4 –Summary of the results

	Array							Inverter								Yield	
Unit		kWh			°	kWh		kWh		kWh	kWh	%	%	kWh		kWh/kWp	
		Irradiation		Panel orientation		PV generation		DC inverter IN		Losses				AC inverter OUT		AC inverter OUT	
		Building A	Building B		Azimut*	Building A	Building B	Building A	Building B	Building A	Building B	Building A	Building B	Building A	Building B	Building A	Building B
	Direct	10 289	10 460	East	-60	824,9	834,5	784,0	795,0	37	38	4,8%	4,8%	747,0	757,0	661,0	671,0
	Diffuse	15 016	15 349	South	30	765,1	729,0	427,0	453,0	20	21	4,8%	4,8%	407,0	432,0	298,0	317,0
	Indirect	6 406	6 406	West	120	536,3	549,4	497,0	515,0	23	24	4,8%	4,8%	474,0	491,0	419,0	435,0
				North	150	569,4	627,5	462,0	550,0	22	26	4,8%	4,8%	440,0	524,0	338,0	403,0
		31 711,0	32 215,0	*South = 0°		2 695,7	2 740,4	2 170,0	2 313,0	102,0	109,0	4,8%	4,8%	2 068,0	2 204,0	429,0	456,5
TOTAL:		63 926,0				5 436,1		4 483,0		211,0				4 272,0		MEAN VALUES	

5.7.5 Conclusions

At the current stage of the validated performance of the software and provided the fact that products and project are submitted to updates we consider that the first results are positive and converging towards expectations. We did not face critical difficulties in the process.

- Shading issues: potential discrepancies with electrical production on south layouts due to shading effects from the external beams / poles. Up to 40% of shading for two modules, 20% for four modules, may create mismatching effects and lowering of the MPP for the entire string (modules are connected in series, 1 string per facade),

- Direct reception ratio discrepancy to be considered (max 70% south, min 16% maximum North); the fact that each façade is independent with its own inverter avoids the mismatching between strings,
- Production seems to be quite well balanced within a 7-month period. Winter should be very low (less than 20% of the summer production) because of the lack of irradiation due to the horizontal masking (valley effect)
- July is the most productive period for both buildings,
- Building B is more productive than building A. For both buildings, the East facades are the most productive, the South facades the less.

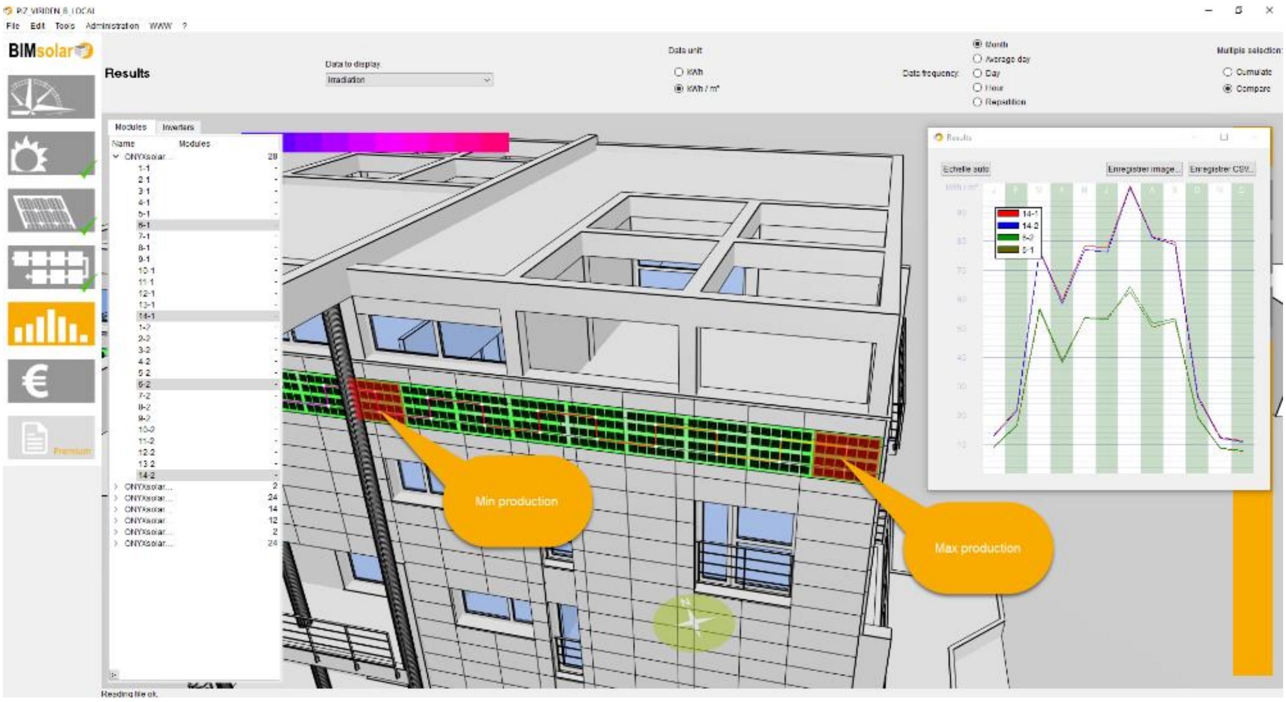


Figure 5.57: Highlight of mismatching of irradiation between extreme modules

<u>Next steps will be</u>:

1. Update of the building 3D model, related to the final BIPV integration (demo site manager),
2. BIM upgrade of the modules following ONYX Solar and PIZ specifications, to enable technical design of the system,
3. Comparison between measurement and simulation as soon as the real modules will be integrated and monitoring available.

5.9 PLANNING TIMELINE

Below is the planning timeline for the PIZ demonstration site at the time of writing. The Gantt chart is a living document and available via the BIPVBOOST shared platform.

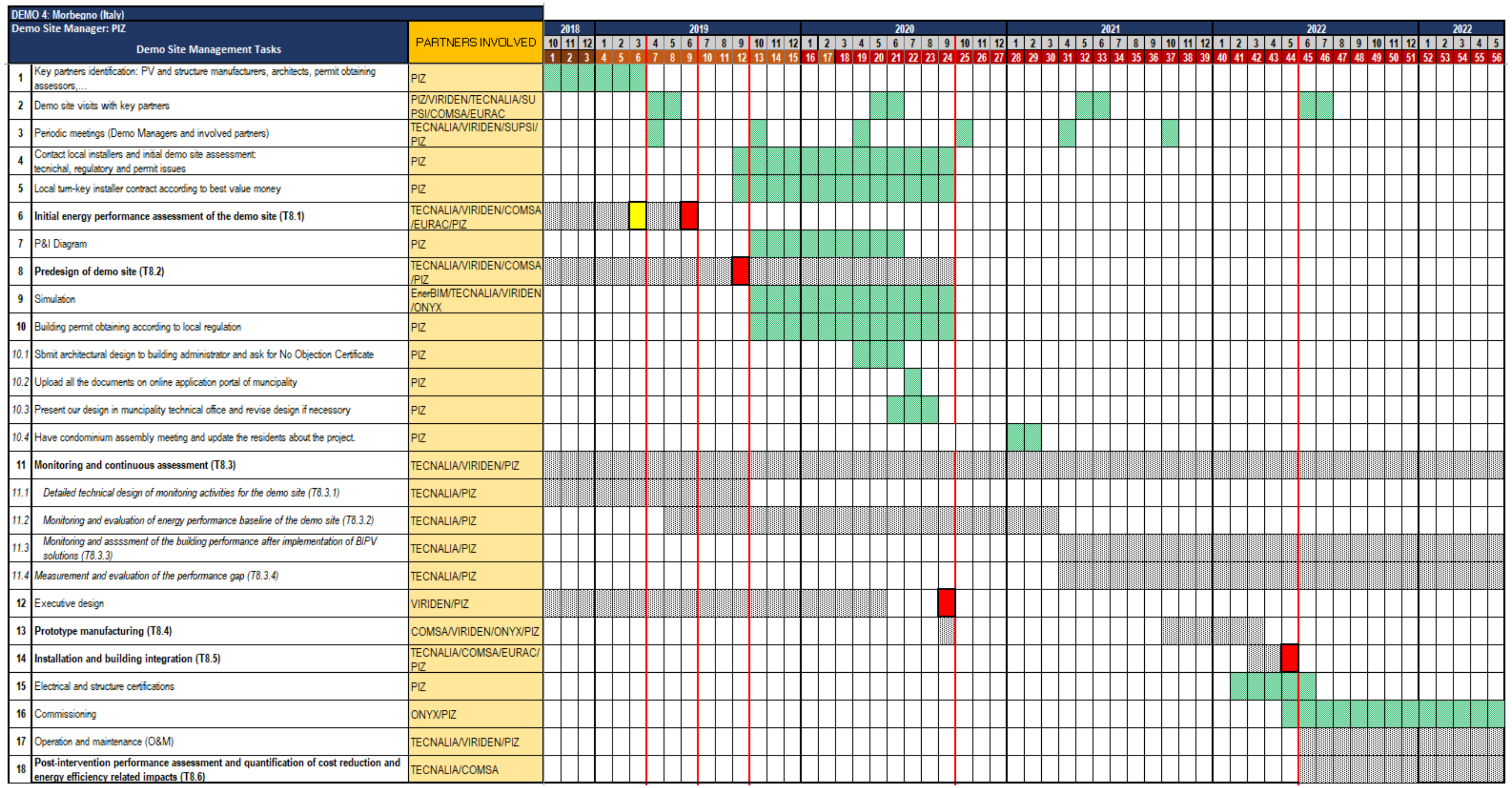


Figure 5.59: PIZ Demo-site Gantt Chart

6 NEXT STEPS

The following steps are focused to the validation of the design of the prototypes for each demo-site according to the test results performed in WP5. Once the design is completely validated and accepted by the demo-owners, the partners of the consortium will start with the manufacturing of the BIPV modules and structure.

In the following months it has been planned to install all the equipment and prototypes for the BIPVBOOST installation in the four demo-sites according to the design and Gantt chart detailed in the present deliverable.

The monitoring installation will continue with the data acquisition before and after the BIPVBOOST installation. This task will be performed until the end of the project.

The baseline of each demonstration site will be evaluated according to monitoring data gathered from each demo-site. This will allow to define the energy demand baseline to be compared with the demand after the BIPVBOOST installation.

Each demo-site is being developed aligned to project objectives, and a post-intervention performance assessment and quantification of cost reduction and energy efficiency related impacts will be performed for each demo.