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D8.11: Public report summarizing lessons learnt, approaches, actions, results and experiences of the demonstration activities

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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

Summary

This report deliverable describes a summary on the architectural, energy efficiency, operational, economic and environmental assessment of the BIPV solutions developed in BIPVBOOST project and implemented in the four building demo-sites. The analysis and presentation of the five BIPV implementations is described for decision makers as designers, technology providers and building owners, in order to reinforce post-project building operation activities, further technical developments, sales strategies, etc.

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Disclaimer

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1 EXECUTIVE SUMMARY

1.1 DESCRIPTION OF THE DELIVERABLE CONTENT AND PURPOSE

The deliverable describes a summary on the architectural, energy efficiency, operational, economic and environmental assessment of the BIPV solutions developed in BIPVBOOST project and implemented in the four building demo-sites. The analysis and presentation of the five BIPV implementations is described for decision makers as designers, technology providers and building owners, in order to reinforce post-project building operation activities, further technical developments, sales strategies, etc. The work contained in this deliverable has been performed in task T8.6.

1.2 RELATION WITH OTHER ACTIVITIES IN THE PROJECT

The work performed in task T8.6 is related to the analysis of the BIPVBOOST implementations in the four demo-sites focusing on the performance assessment and quantification of cost reduction and energy efficiency related impacts.

The work is based on the results obtained in task T8.1 focused on the pre-audit of demonstration installations, task T8.2 related to the simulation of demo installations, task T8.3 focused on the monitoring data gathering of the demo-sites and its evaluation and assessment and T8.5 related to the implementation commissioning and assessment.

2 BIPV IMPLEMENTATIONS

This document describes the result of the five innovative architectural solutions developed in the BIPVBOOST project and applied to four demonstrators in different climatic zones of Europe, in order to demonstrate the architectural integration of photovoltaic modules to the envelope of different building typologies, and show the benefits obtained in the operation of the BIPV installations in terms of economic and environmental aspects.

The five BIPVBOOST technological solutions developed in the project were embodied in five products: Glass-glass bifacial modules, Glass-glass back contact modules from automated tabber, Glass-glass c-Si modules with different configurations, CIGS modules and Multifunctional BIPV element with integrated insulation.

These developed photovoltaic products were tested and installed on balustrades, walkable floors, ventilated façade, roof retrofitting and opaque cladding. The design phase, including the design of the modules and the adaptation of the building elements for their installation, took place between 2019 and 2021. The designed was closed in 2021. More information can be found in the following deliverables:

- D8.2 “Report on the design and simulation of PV and energy performance of each demonstration installation”. In this case the installation was carried out following the design described in D8.2.
- D8.6 “Results of the installation and commissioning process. Lessons learnt during the process and related guidelines”. This report D8.6 also presents a detailed description of the installation of the modules, the inverter, the DC and AC wiring, the monitoring, the BEMS… and as conclusions the lessons learnt during the installation and some installation guidelines.
- D8.10 “Architectural, EE, operational, economic and environmental assessment. In this case, more information about BIPV Implementations Design can be found, although it is confidential.

The BIPVBOOST technological implementations are described in the following sections.

2.1 BIPV BALUSTRADE

2.1.1 BIPV Solution Design

In this demonstration the objective was to integrate the BIPV modules developed in the BIPVBoost project in the existing balustrade of the rooftop at ISFOC building.

The design of the installation was performed in collaboration mainly between ISFOC, the demo owner, and ONYX Solar, the manufacturer of the BIPV modules. With the support of Viriden, the architects of the consortium, EnerBIM for the simulations and Tecnalia and COMSA for the inverters selection, advice and support during the design phase and the monitoring (Tecnalia). ISFOC also had the support of:

- ENAR (ENvolventes ARquitéctonicas) is a Spanish technical consultancy and engineering specialized in building facades. ENAR was in charge of the design of the solution to integrate the BIPV modules in the balustrade, including the reinforcement of the existing structure, and the establishment of the minimum structural requirements that must fulfil the BIPV modules.
- COSFYM is a construction and installation company. COSFYM manufactured the reinforcement elements of the balustrade and the assembly elements for the bifacial modules in the balustrade. COSFYM also carried out the works for the reinforcement of the balustrade.
- VALVCAT is a Spanish company in the renewable energy sector whose main purpose is the promotion, development, project management and paperwork, construction, operation and maintenance of PV installations. VALCAT made the installation of the bifacial modules and all the

electrical works (DC wiring, inverters, electrical cabinets and AC wiring) to the connection to the grid point. ISFOC personnel did also participate in this activity.

The design phase, including the design of the modules and the adaptation of the building elements for their installation, took place between 2019 and 2021.

Pictures from Figure 2.1 to Figure 2.5 show the result of the BIPV balustrade at ISFOC building.

Figure 2.1. Demonstration site 1 – BIPV balustrade. South and east facades view from the ground level

Figure 2.2. South balustrade view from the rooftop

Figure 2.3. South – East (left) and South – West (right) balustrade view from the rooftop

Figure 2.4. Detail of the view of the balustrades on one corner of the rooftop

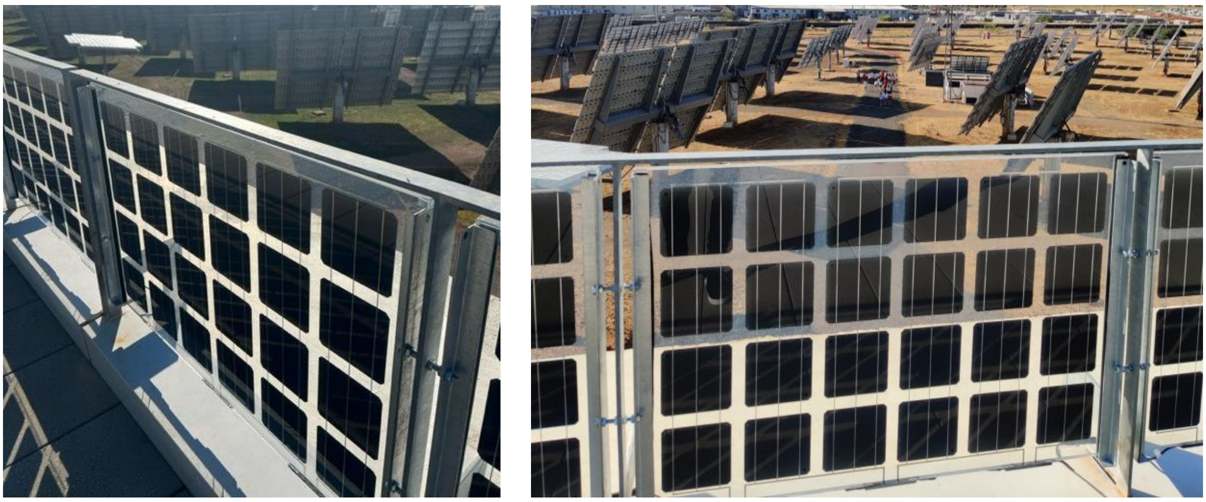

Figure 2.5. Detail of the BIPV modules installed in the balustrade

2.1.1.1 BIPV module technology

ONYX has been the partner involved in the development of the BIPV module for balustrade application.

The most extended PV technology used so far is the monocrystalline silicon technology, but in the last years, an updated (version) is being used more and more due to the advantage to increase energy production, the bifacial PV cells. Bifacial PV modules look the same as traditional crystalline silicon technology PV modules, but with the advantage of having the ability to produce energy on both sides of the cells. This technology is perfectly well suited for balustrade application

Thus, a semitransparent glass-glass balustrade based on bifacial BIPV modules has been installed, replacing the current solution in the South, East and West facades of the ISFOC demonstrative building located in Puertollano (Spain). In total, 125.6 m^2 distributed in the South, East and West orientations and a power of 12.8 kWp have been installed.

For the ISFOC demonstrative located in Puertollano (Spain), two different BIPV modules dimensions have been manufactured and implemented, depending on the location on the balustrade:

- On the south area of the balustrade, 24 bifacial cells of 6" have been laminated between two panes of tempered glass of 10 mm. The dimensions of these panels are 1180 mm x 810 mm. A total of 108 units + 3 spare units have been manufactured:

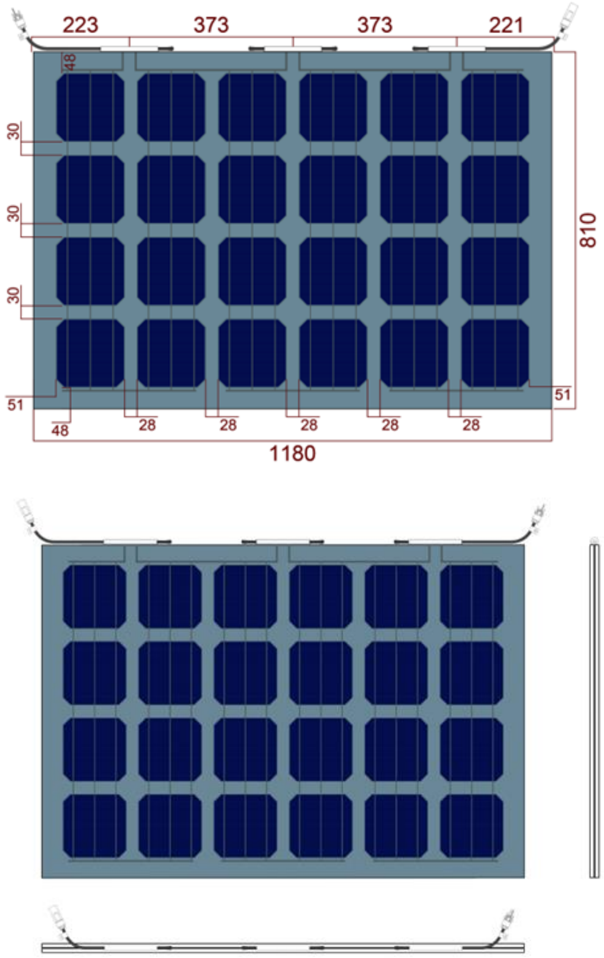

Figure 2.6. BIPV glass-glass bifacial modules for south balustrade. Front side (left) rear side (right)

- On the east and west areas of the balustrade also 24 bifacial cells of 6” have been laminated between two panes of tempered glass of 10 mm. However, the dimensions of these panels are 1150 mm x 810 mm. In total, 24 units + 2 spare units have been manufactured:

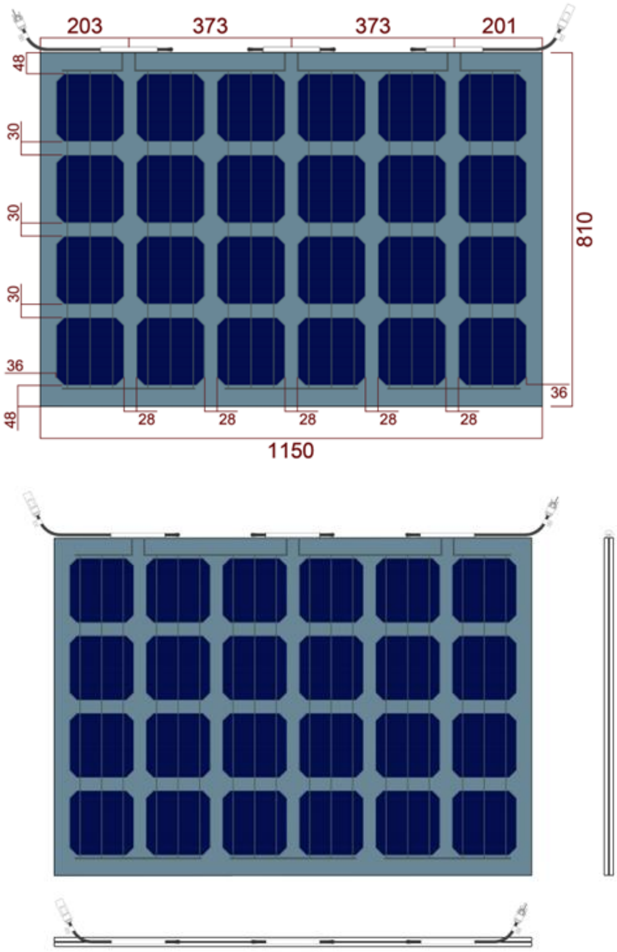

Figure 2.7. BIPV glass-glass bifacial modules for east and west balustrade. Front side (left) rear side (right)

Figure 2.8. Example of a glass-glass BIPV module of the ISFOC demonstrative

2.1.1.2 Installation Capacity

At the end, the installation in the BIPV balustrade is of 12.8kWp in 126m². Table below collects the numbers of the walkable floor at the building rooftop to cover with BIPV modules.

-

Table 2.1: BIPV balustrades characteristics

BIPV BALUSTRADE at ISFOC			
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		

The balustrades are connected to 2 independent inverters:

- The east and west balustrades (strings of 12 modules in series) are connected to the one-phase **HUAWEI SUN2000-2KTL inverter**. Each string will be connected to one MPPT of the inverter.
- The south balustrade is connected in two serial strings of 96 modules, each one connected to one MPPT of the three-phases **HUAWEI SUN2000-10KTL-M1 inverter**.

The installation 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.**

The details of the electrical design and the installation are described in detail in D8.2 “Report on the design and simulation of PV and energy performance of each demonstration installation” and D8.6 “Results of the installation and commissioning process. Lessons learnt during the process and related guidelines”.

2.2 BIPV WALKABLE FLOOR

2.2.1 BIPV Solution Design

In this demonstration the objective was to integrate the BIPV modules developed in the BIPVBoost project into the existing walkable floor of the rooftop at ISFOC building.

The design of the installation was performed in collaboration mainly between ISFOC, the demo owner, and ONYX Solar, the manufacturer of the BIPV modules. With the support of Viriden, the architects of the consortium, EnerBIM for the simulations and Tecnalia and COMSA for the inverters selection, advice and support during the design phase and the monitoring (Tecnalia). ISFOC also had the support of:

- ENAR (ENvolventes ARquitéctonicas) is a Spanish technical consultancy and engineering specialized in building facades. ENAR was in charge of the design of the solution to integrate the BIPV modules in the existing floor and the establishment of the minimum structural requirements that must fulfil the BIPV modules.
- VALVCAT is a Spanish company in the renewable energy sector whose main purpose is the promotion, development, project management and paperwork, construction, operation and maintenance of PV installations. VALCAT built on site the frame needed for the installation of the walkable modules, made the installation of the walkable floor modules and all the electrical works (DC wiring, inverters, electrical cabinets and AC wiring) to the connection to the grid point. ISFOC personnel also participated in this activity.

The design phase, including the design of the modules and the adaptation of the building elements for their installation, took place between 2019 and 2021.

Pictures from Figure 2.9 to Figure 2.11 show the result of the BIPV balustrade at ISFOC building.

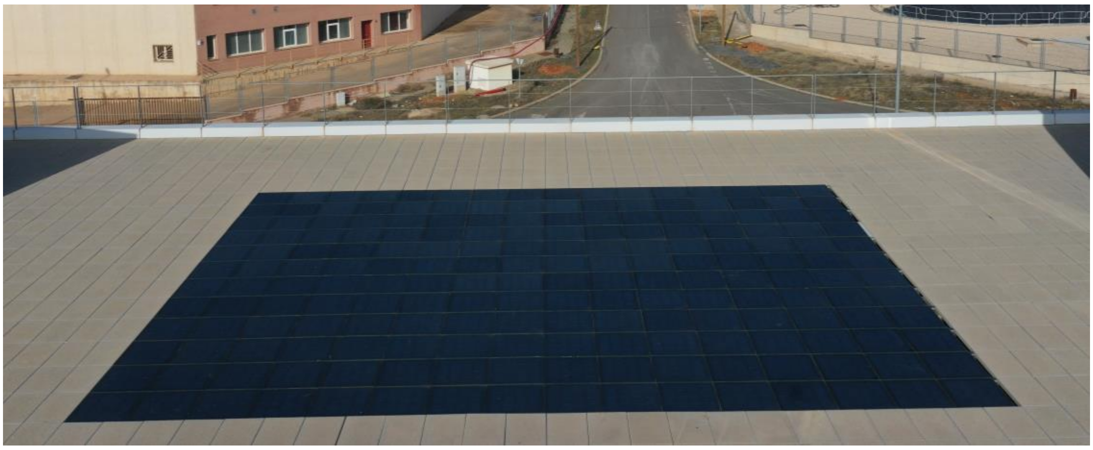

Figure 2.9. Demonstration site 1 – BIPV walkable floor. View from a drone

Figure 2.10. General view of ISFOC's rooftop, walkable floor location

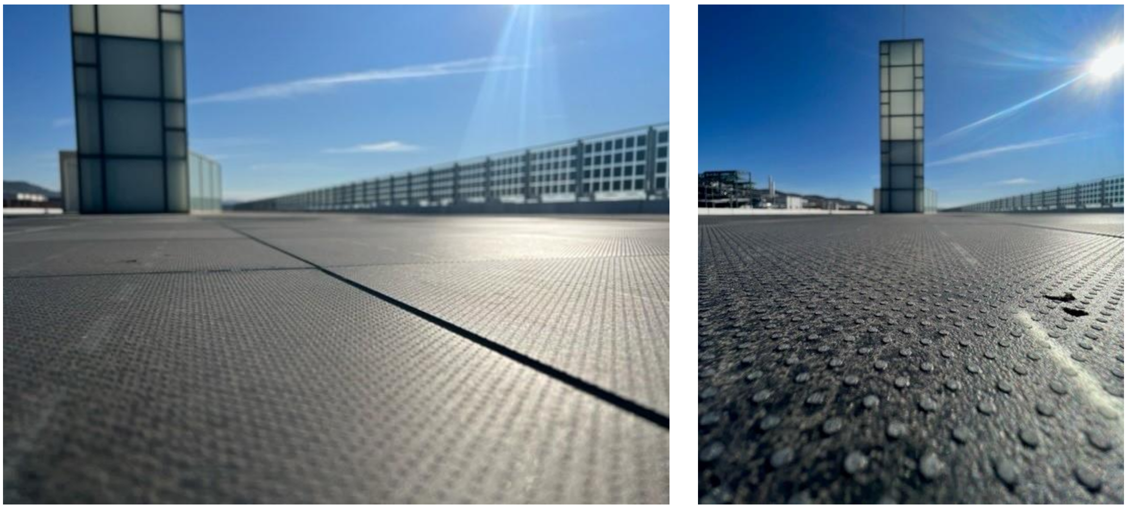

Figure 2.11. Details of the walkable floor modules and the non-slip surface finish

2.2.1.1 BIPV module technology

A BIPV walkable floor solution has been also designed and developed by ONYX to be demonstrated in the ISFOC building. The walkable floor solution developed and implemented is based on 16 back contact cells of 5" laminated between two panes of tempered glass of 10 mm. The front glass has anti-slip ending and the rear glass has been treated with a black ceramic frit to enhance the aesthetics of these modules. The dimensions of these units are 600 mm x 600 mm.

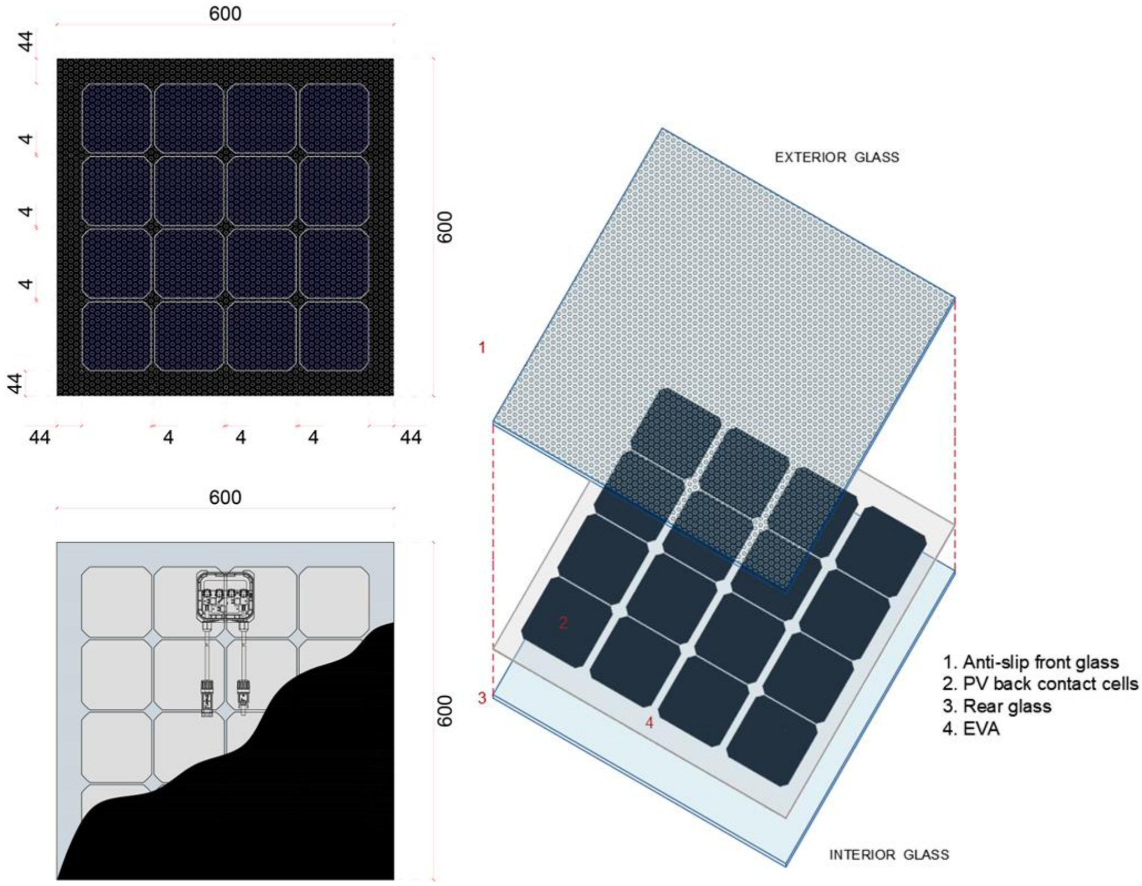

Figure 2.12. BIPV Glass-glass back contact modules for walkable floor

2.2.1.2 Installation Capacity

At the end, the installation in the BIPV balustrade is of 9.22kWp in 69m^2. Table below collects the numbers of the three balustrades of the building rooftop to cover with BIPV modules.

Table 2.2: BIPV walkable floor characteristics

WALKABLE FLOOR at ISFOC	
	Option 3
Dimensions	600x600mm^2
Tiles Nº	192
Power	**9.22kWp**
Area	**69.12 m^2**

All the walkable floor is connected to the 3-phases HUAWEI SUN2000L-8KTL-M1 inverter. The modules are connected in four serial strings of 48 modules, the inverter has 2 MPPT, so 2 strings connected in parallel are connected to each MPPT.

The installation 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.**

The details of the electrical design and the installation are described in detail in D8.2 “Report on the design and simulation of PV and energy performance of each demonstration installation” and D8.6 “Results of the installation and commissioning process. Lessons learnt during the process and related guidelines”.

2.3 VENTILATED FAÇADE

2.3.1 BIPV Solution 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 the latest TULiPPS’ Click&Go (Mk2) mounting system.

Figure 2.13 East façade of MASS building

For this demo, the final design has been selected a configurations with 114 panels of 2mx0.667m due to the fact that the economic valuation raised both by the local installer and by the project partners, was the most economic.

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

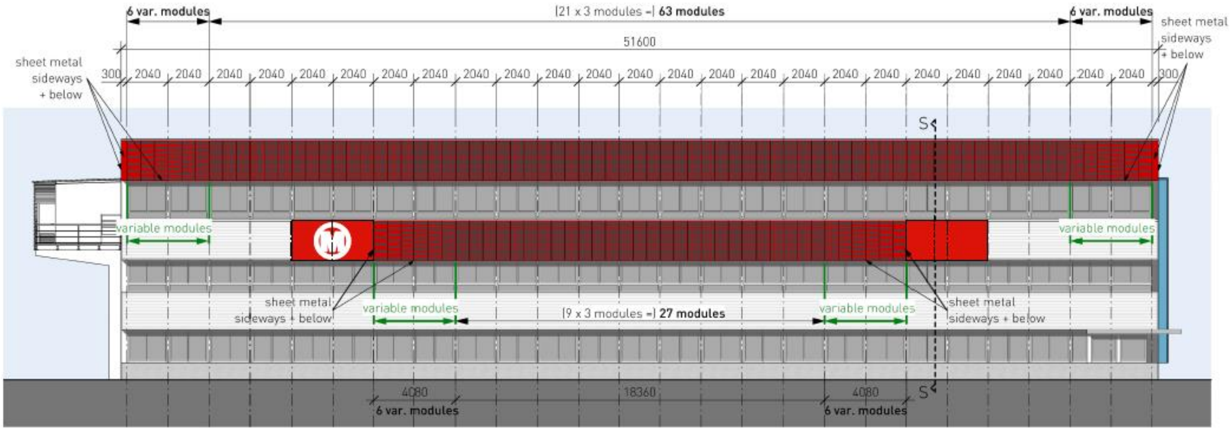

Figure 2.14 Demo 2 final design

2.3.1.1 BIPV module technology

A BIPV facade solution has been designed and developed by ONYX. This façade solution has been implemented on a MASS building. Thus, for the MASS demo-site located in Aretxabaleta (Spain), seven different BIPV module variants with the same dimensions have been manufactured and implemented on the façade.

- Type 1: 48 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 90 units + 3 spare units have been manufactured:

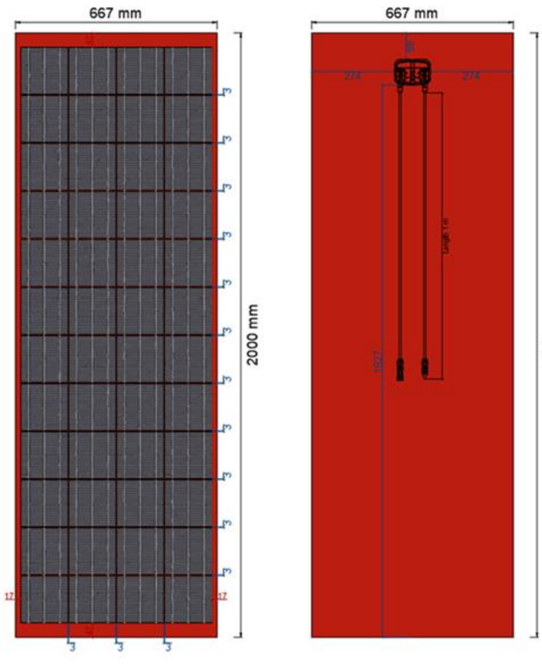

Figure 2.15 BIPV Glass-glass c-Si modules. 48 cells

- Type 2: 44 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

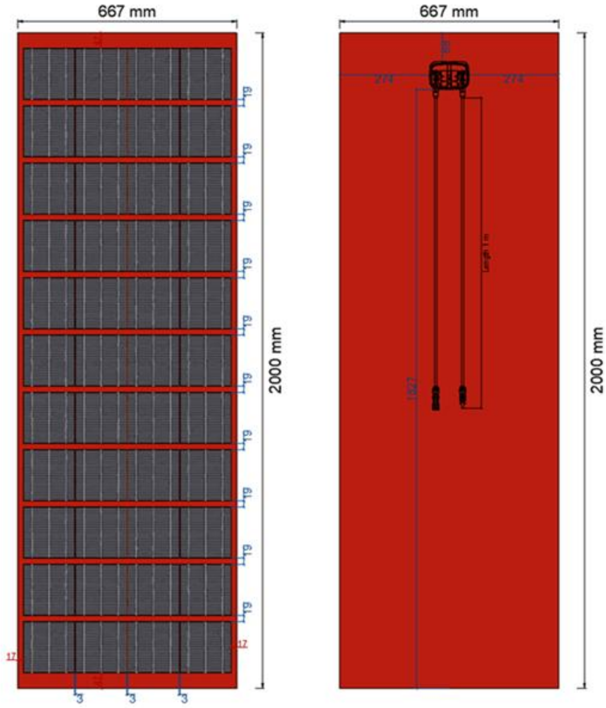

Figure 2.16 BIPV Glass-glass c-Si modules. 44 cells

- Type 3: 40 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

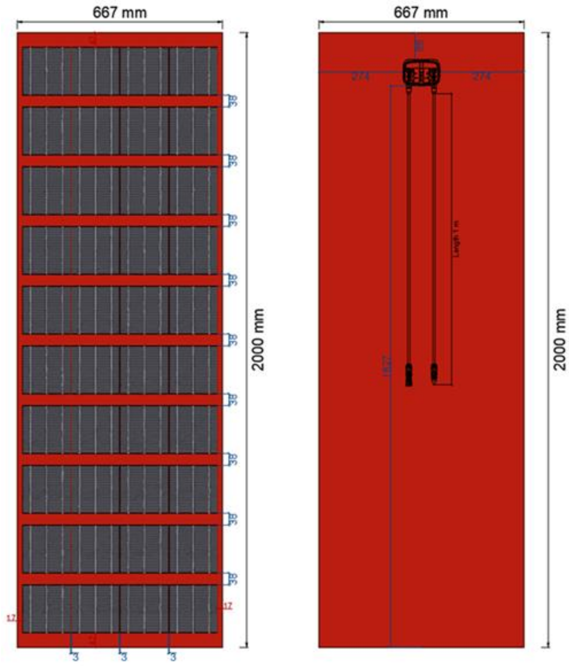

Figure 2.17 BIPV Glass-glass c-Si modules. 40 cells

- Type 4: 36 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

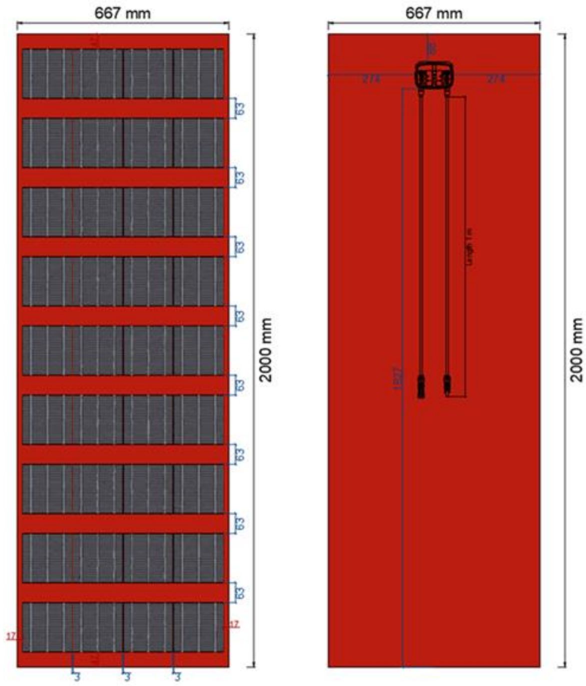

Figure 2.18 BIPV Glass-glass c-Si modules. 36 cells

- Type 5: 32 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

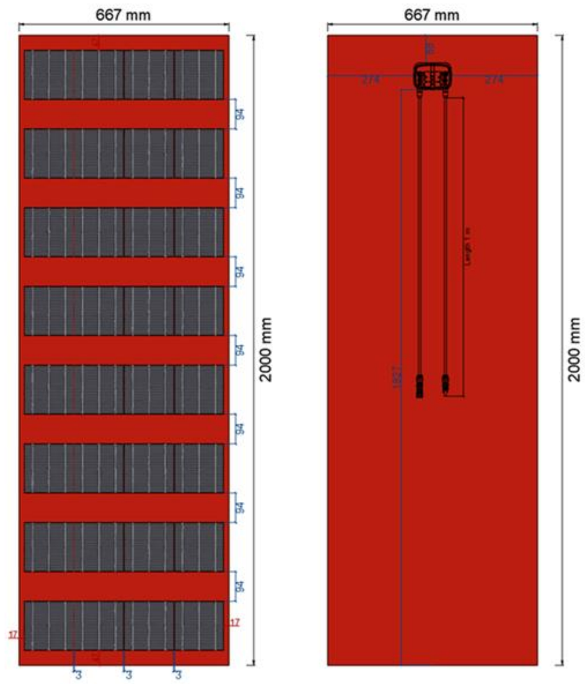

Figure 2.19 BIPV Glass-glass c-Si modules. 32 cells

- Type 6: 28 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

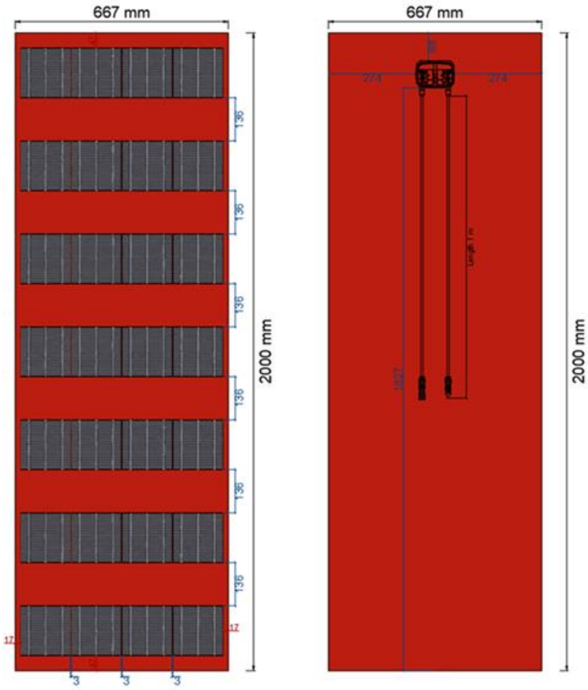

Figure 2.20 BIPV Glass-glass c-Si modules. 28 cells

- Type 7: 24 Mono crystalline cells of 6” have been laminated between two panes of tempered glass of 4 mm (rear glass with ceramic frit RAL 3020). The dimensions of these panels are 2000 mm x 667 mm. A total of 4 units + 1 spare unit have been manufactured:

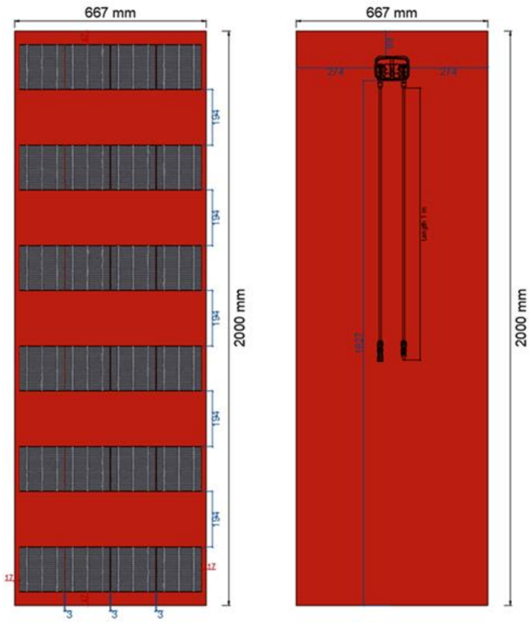

Figure 2.21 BIPV Glass-glass c-Si modules. 24 cells

2.3.1.2 Installation Capacity

Both the square meters and the capacity are defined in the first place from the premises of the BIPVBoost project and after for the design initially selected (variant 38), which has required some aesthetic modification due to the need to tie the substructures to the beams of the building. Leaving the final installation as shown below and with the following specifications.

152 m²
21,6 kWp

Figure 2.22 Final Demo2 FaÇade

2.4 BIPV ROOF

2.4.1 BIPV Solution Design

In this demonstration site the goal was to remove existing roof tiles and replaced them with BIPV component for the 2 faces of the roofs.

The design of the installation was performed in close collaboration between several partners: OPT (the demo owner), SCHWEIZER (the panel and Solrif® structure provider), FLISOM (the solar cell provider), VIRIDEN (the BIPVBOOST architects), FormatD2 (the local architect, sub-contractor of OPT), EnerBIM (simulation) with contribution from many others for the monitoring, inverter selection (TECNALIA, SUPSI, COMSA, CYCLEO, CSTB).

The design phase took place between 2019 and 2021 for the last fine tuning and the conclusions and design details were presented in the D8.2. 95% of the design scheduled in the D8.2 was respected and only a few minor changes had to take place during 2021 and 2022 and during the real installation process.

The deliverable 8.6 provides extensive details regarding the installation phase of the panels, the electricity setup up and installation, the monitoring, the commissioning, the timeline and also lessons learned and installation guidelines.

Figures below show the view on the final setup.

Figure 2.23: Demonstration site 3, East view

Figure 2.24: Demonstration site 3, West view

2.4.1.1 BIPV module technology

One of the biggest challenges in making a thin film module, based on a metal backplate is to ensure proper insulation for DC and AC. AC is also important, as todays inverters do leak an amplitude of about 20V with a frequency of 150 Hz (in case of 3 phases) to the PV array. The modules need to have a low enough capacitance, to avoid a conductive leakage current. In this project the AC and DC insulation were the most challenging.

The solution needs to work with all inverter types to be market ready. In the project a “low capacitance design” was developed, which allowed to use a conventional transformer less 3 phase inverters with no issue. The calculations have finally been proven right by this demo site.

The adhesion of the PV laminate to the backsheet and the adhesion of the different layers inside the module did also need an optimization. In the thermal cycling test a problem with delamination was detected, revealing a material incompatibility. This could be solved by changing the encapsulant material.

Figure 2.25: Delamination in the “new” material stack due to adhesion and thermal expansion problems in the multi-layer stack

After testing the product again, it finally passed all the tests and could be produced for the demo site. Final appearance is shown next pictures.

Figure 2.26: Final appearance of the module with JB on the back, protective foil and front texture imprint for anti-gloss

2.4.1.2 Installation Capacity

The electrical setup was extensively described in the D8.2 and D8.6. Only one inverter is used. The inverter maximum output AC power is 5 kW. This power is much lower than then installed PV power. However, has shown by the simulation, this is not a problem as there are 2 orientations for the panels (East and West) and therefore they do not produce their peak power at the same time during the day. The inverter has 2 MPPT ports, an important criterium for the selection of the inverter. All the panels of the West roof are connected to one MPPT port and all the panels of the East roof are connected to the second MPPT port. The panel cells must be connected in strings in order to match the range of voltage and current accepted by the inverter at the input of each MPPT port. The choice of the number of cells per strings is also a consequence of the objective to connect the maximum number of cells to the inverter. It was decided to use strings of 12 cells for both of the East and West roof. The **Figure 2.27:** show the main electric parameters of the 2 MPPT entries (Entrée A and Entrée B). This resulting in the following quantities:

- A voltage per string of 607 V.
- The East roof has 14 strings while the West roof has 13 strings.
- The max current for the East roof is 12.3 A while for the West roof this is 11.4 A.
- The power for the East roof is 5.04 kWp while for the East roof is 4.68 kWp

These strings are slightly different than the one planned in the D8.2. This was decided in order to decrease the current on each MPPT port while keeping a near optimal (maximal) number of cells connected to the inverter:

- 168 cells (14 * 12) among 174 are connected on the East roof leaving 6 cells un-connected
- 156 cells (13 * 12) among 159 are connected on the West roof leaving 3 cells unconnected.

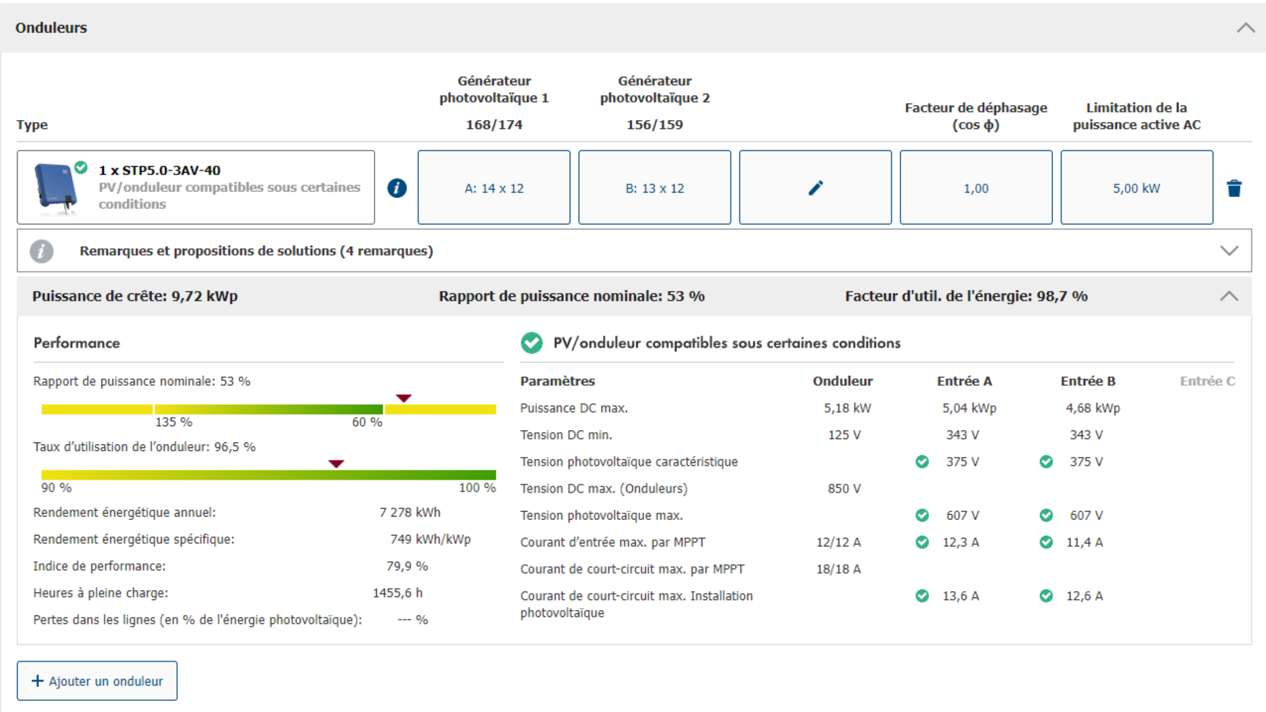

Figure 2.27: Inverter and cell strings

2.5 OPAQUE CLADDING

2.5.1 BIPV Solution Design

At the demonstration site in Morbegno, Italy, the objective was to remove the top three rows of existing cladding on all facades and replace them with 4 rows of new cladding, the middle two rows in BIPV and the other 2 rows with conventional cladding.

The design of the installation was done in close collaboration between several partners: PIZ (the supplier of BIPV panels), ONYX (the supplier of solar cells), VIRIDEN (the architects of BIPVBOOST), EnerBIM (simulation) with input from many others for monitoring, inverter selection (TECNALIA, SUPSI, COMSA,).

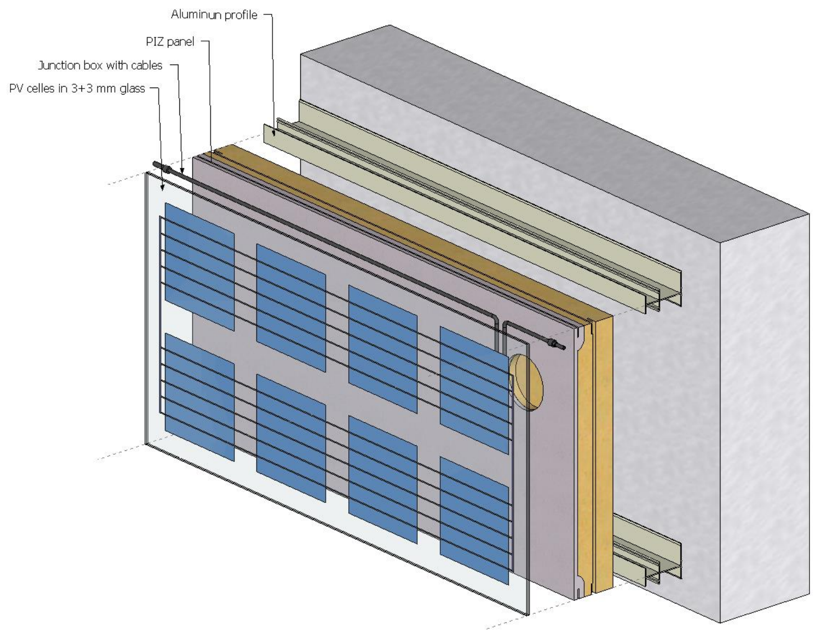

Figure 2.28: 3D split of multifunctional BIPV cladding system

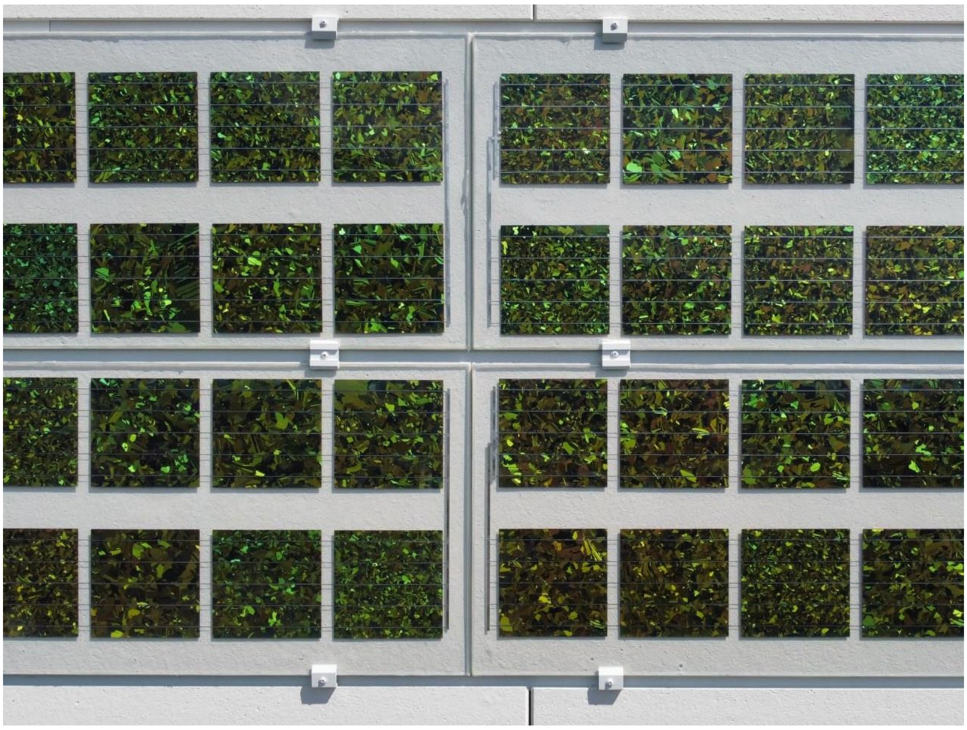

Figure 2.29: Frontal view of multifunctional BIPV cladding system

Figure 2.30: Lateral view of multifunctional BIPV cladding system

Figure 2.31: Corner view of multifunctional BIPV cladding system

Figure 2.32: Demonstration site 4, South-East view

2.5.1.1 BIPV module technology

In the architectural design of PIZ demo site, there are six different types of BIPV glass-glass modules designed and manufactured by ONYX: two standard modules and four special modules.

ONYX 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. The length and width of ONYX glass-glass BIPV module is 8 mm shorter compared to dimensions of BIPV modules (total e-PIZ solution).

- Type A1: It contains 12 6" poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1116 mm x 470 mm

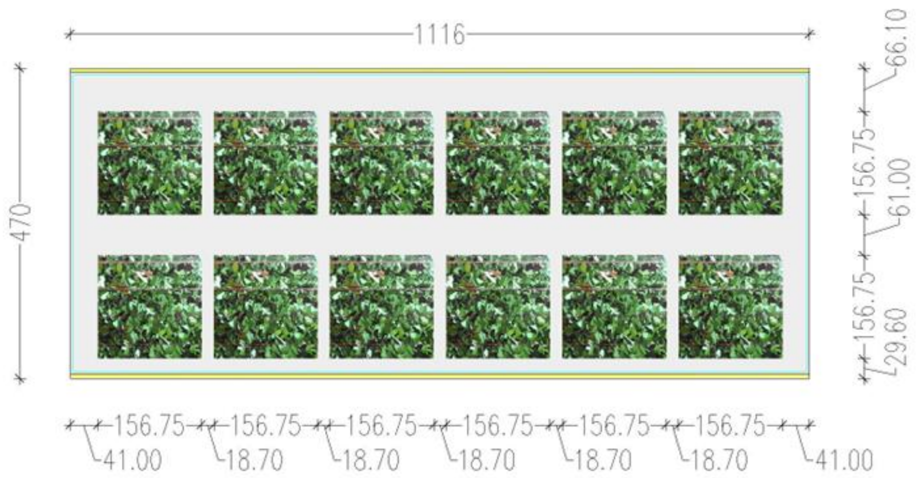

Figure 2.33: ePIZ glass-glass cSi BIPV module with 12 6" colored poly-Si cells – Standard module, type A1

- Type A2: It contains 12 6" poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1116 mm x 470 mm

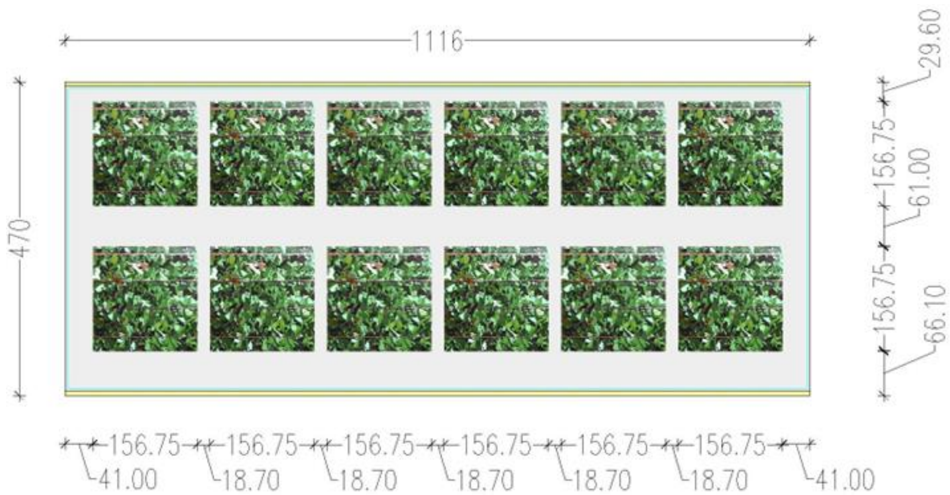

Figure 2.34: ePIZ glass-glass cSi BIPV module with 12 6" colored poly-Si cells – Standard module, type A2

- Type B1: It contains 10 6” poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1070 mm x 470 mm

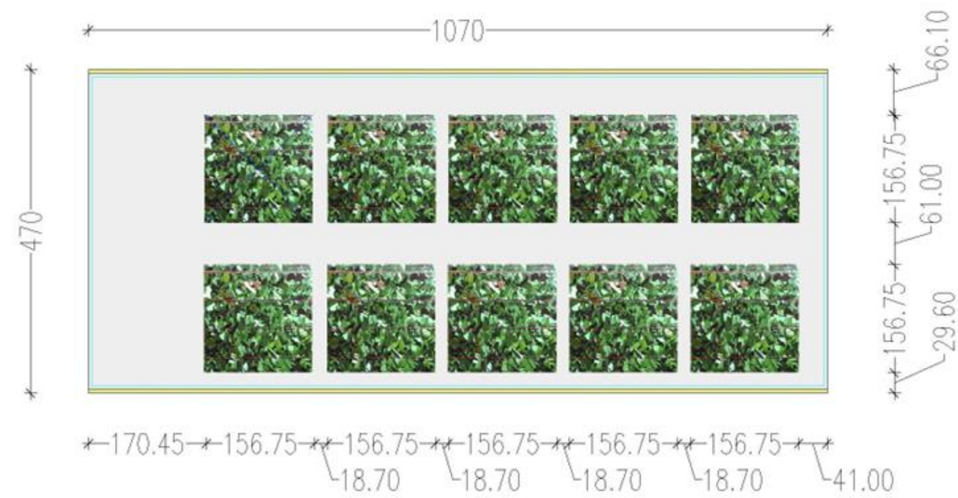

Figure 2.35: BIPV Glass-glass colored poly-Si cells module. Type B1

- Type B2: It contains 10 6” poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1070 mm x 470 mm

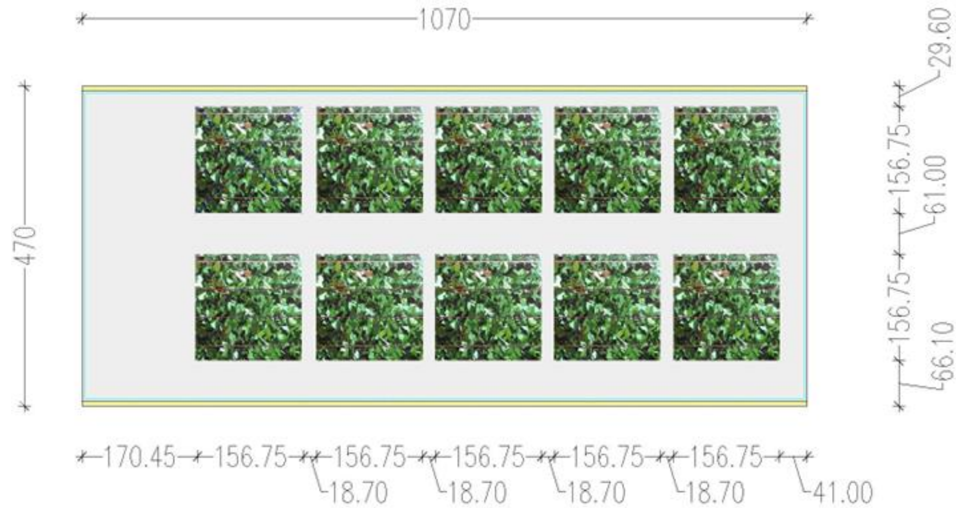

Figure 2.36: BIPV Glass-glass colored poly-Si cells module. Type B2

- Type C1: It contains 10 6” poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1070 mm x 470 mm

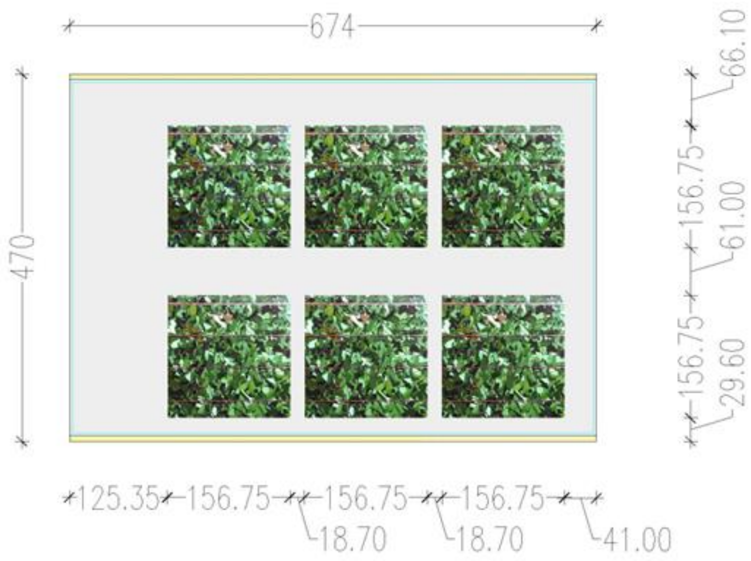

Figure 2.37: ePIZ glass-glass cSi BIPV module with 6 6” colored poly-Si cells – Standard module, type C1

- Type C2: It contains 10 6” poly crystalline sparking gold colored cells, the dimensions of the BIPV module is 1070 mm x 470 mm

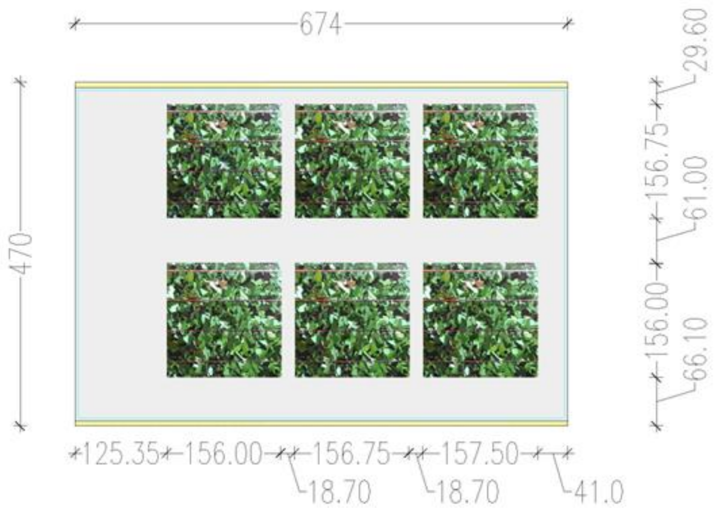

Figure 2.38: ePIZ glass-glass cSi BIPV module with 6 6” colored poly-Si cells – Special module, type C2

2.5.1.2 Installation Capacity

In total, 178m2 of façade cladding was replaced with 110m2 of ePIZ BIPV cladding and 68m2 of PIZ H89 cladding. 204 standard ePIZ BIPV modules and 8 special ePIZ BIPV modules were required for this installation. The total nominal power output of this BIPV installation is 9,8 kWp.

8 single-phase inverters have been installed, one for each facade, as each facade is oriented in a different direction. In the table below the nominal powers for each façade and each inverter.

		Total Power [kW_p]
Building	**Orientation**	4,9
Building A	**- Façade SE**	1,1
Building A	**- Façade SW**	1,4
Building A	**- Façade NW**	1,1
Building A	**- Façade NE**	1,3

Building	**Orientation**	4,9
Building B	**- Façade SE**	1,1
Building B	**- Façade SW**	1,4
Building B	**- Façade NW**	1,1
Building B	**- Façade NE**	1,3

	FINAL TOTAL:	9,8

3 BENEFITS OBTAINED IN THE OPERATION OF THE BIPV INSTALLATION

Once the modules were installed in the architectural envelope of the four-building demo-sites, it has been analysed the performance of the manufactured and installed innovative modules and structure, the energy production of the photovoltaic modules and their contribution to energy saving and the reduction of the carbon footprint of the buildings of the four demonstrators.

In the following sections, the economic benefits obtained in the operation of the BIPV system are evaluated using a holistic competitiveness assessment, following the methodology developed in WP1 and described in the deliverable D1.1. For that purpose, an analysis of the yearly cash-flows associated with the BIPV project is first carried, allowing to estimate all costs (more specifically, the extra costs) and revenues, on its whole lifetime. Then, the net present value of all these yearly cash-flows is calculated, permitting to obtain a metric in €. The final metric obtained is then converted in €/m², which is a metric more commonly used in the construction sector. If positive, it means that the BIPV project is economically attractive, as its owner/user earns money for every m² installed. On the contrary, if this number is negative, investing in such system is not economically attractive as it will cost more money than it will allow to earn on the lifetime of the system. Eventually, this holistic competitiveness assessment can help answer this question: is it worth investing in such electricity generating construction material, compared to a conventional building component?

Different perimeters are considered for the BIPV costs. First the total costs, or as-built costs, are presented. Then, the relevant cost is estimated, to determine the replicable cost that would apply should the BIPV solution be implemented elsewhere. In particular, the specificities of the demo building which would unlikely be encountered elsewhere and which led to higher as-built costs are not included in the relevant cost. Eventually, the extra cost is also determined. To determine the extra cost based on the total or relevant cost breakdown, the same methodology laid out in D1.1 is used. For each cost item, it is determined which share is due to the BIPV system as a building envelope solution, i.e. the fixed costs, and which part is linked to the BIPV system as an electric generating unit, i.e. the extra costs. Electrical installation costs or cabling costs are for example identified as 100% linked to the energy generating function of BIPV (i.e., 100% extra cost). For transport costs for example, the assumption is made that they would be the same, would the installation serve a construction purpose only (i.e., 0% extra cost). Finally, some costs are partly associated to the construction function and partially to the electricity generation function such as the permit obtaining costs or the detailed executive project costs (i.e., 50% extra cost). Eventually, for the BIPV modules, a proxy (the offset construction material) is used for the fixed share of BIPV module cost and is subtracted to eventually determine the amount and share of extra costs.

3.1 BIPV BALUSTRADE

3.1.1 Photovoltaic Power generation

Figure 3.1 shows the energy production of the four BIPV solutions installed in Isfoc:

- South balustrades (PV_BL_Balustrade_South)
- East balustrades (PV_BL_Balustrade East)
- West balustrades (PV_BL_Balustrade West)
- Walkable Floor (PV_Floor)

The measurements were carried out between October 2022 and july2023. In order complete the data until one year it has been considered annual symmetry. The graph shown the measured data and the completed data (estimated). As can be seen the south balustrade is the more energy productive followed by the walkable floor and east and west balustrades.

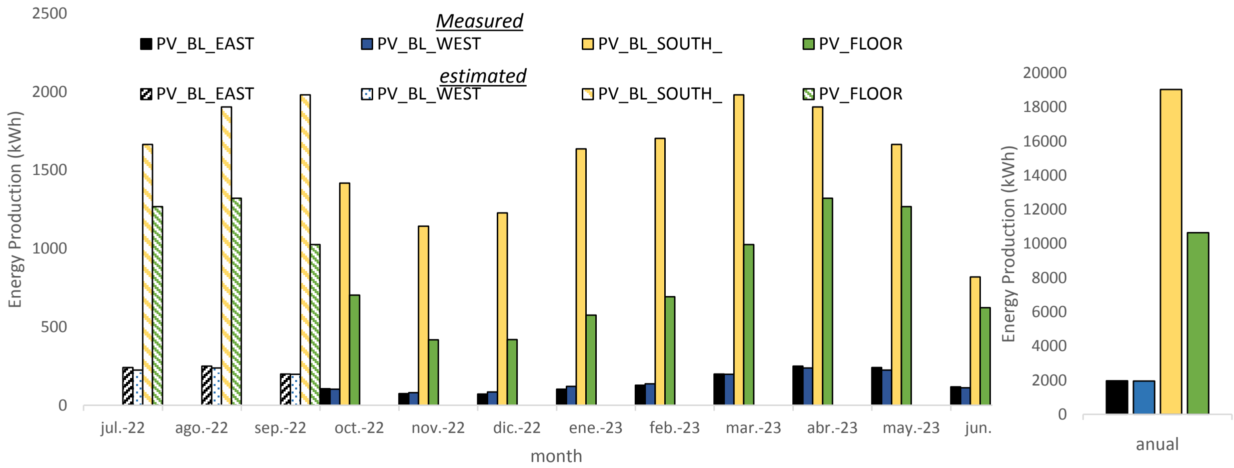

Figure 3.1: ISFOC building BIPV solutions energy production

3.1.2 Investment Cost and Benefits from PV Generation

Investment costs

The presented costs in the figure below are as-built costs which were collected among BIPVBOOST partners which contributed to the demo. The notions of total cost, relevant cost and extra cost are explained in the beginning of Section 2.

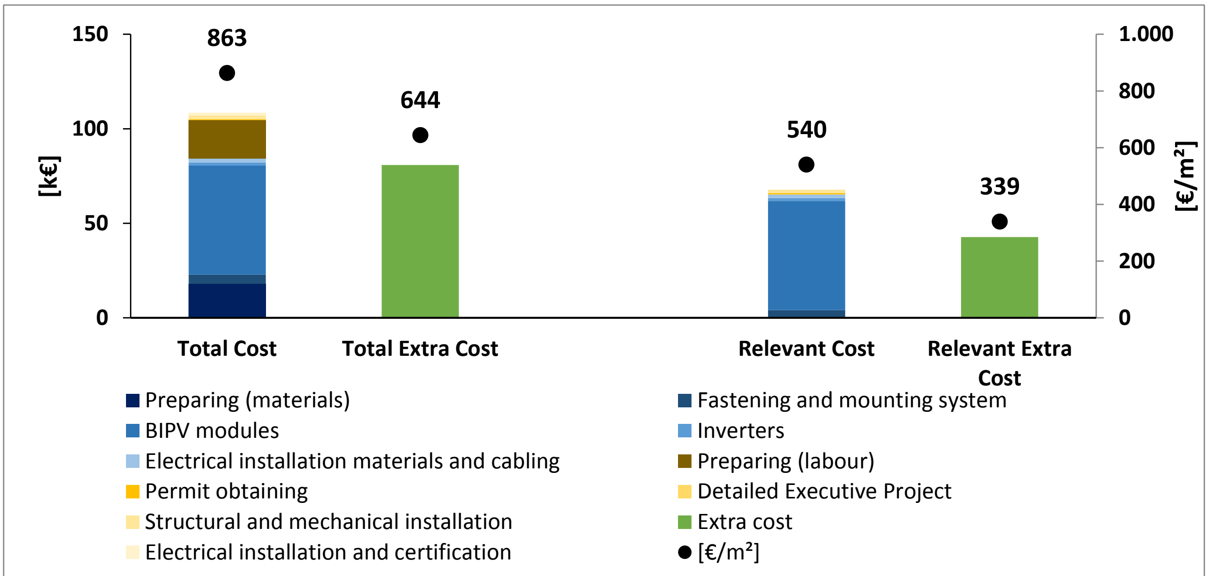

Figure 3.2. Investment cost for the BIPV balustrade (total cost, relevant cost and relevant extra cost)

In the case of the BIPV balustrade, the main difference between the total cost and the relevant cost is associated to preparatory works (materials and labour) which were needed to reinforce the balustrade structure. Eventually **the relevant extra cost for the BIPV balustrade is 43k€ or 339 €/m².**
In addition, a **3,9 k€ battery system** was installed at the ISFOC demo site.

Benefits from PV Generation

The methodology used to evaluate the economic benefit from PV generation is presented in the beginning of Section 2.

The revenues for the BIPV balustrade consist in savings on the electricity bill (0,3 €/kWh compensable retail electricity price in line with prices observed for electricity consumer corresponding to the IA consumption band in Spain) thanks to self-consumption. In this case, the full production was self-consumed. In addition to the initial investment in the BIPV solution (relevant extra cost considered), some operational costs for maintenance, regular visual inspection, and occasional cleaning amounting to 5€/m² are considered. The assumptions taken for the cost of equity, the average annual inflation rate and the corporate tax rate are respectively 4%, 2,5% and 25%. Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is 560 €/m².** The positive value of competitiveness indicates that the investment is profitable.

3.1.3 Life Cycle Assessment (LCA)

The conventional balustrade is divided based on its 2 orientations for the conventional scenario because of the difference in electricity production. The conventional system is always less environmentally beneficial because of the conventional electric production. Thanks to their orientation, the south balustrade presents the highest differences between BIPV systems and conventional solution.
The best illustration of the performances is the BIPV south balustrade versus the Conventional one. Even if the BIPV balustrade as a higher impact (272 kgCo2eq/m^2) than the conventional balustrade (72 kgCO2/m^2), the energy produced by the balustrade avoid the production of 4440 kWh over 30 years avoiding an emission of 1860 kgCO2eq/m^2 of balustrade.

3.2 BIPV Walkable floor

3.2.1 Investment Cost and Benefits from PV Generation

Investment costs

The presented costs in the figure below are as-built costs which were collected among BIPVBOOST partners which contributed to the demo. The notions of total cost, relevant cost and extra cost are explained in the beginning of Section 2.

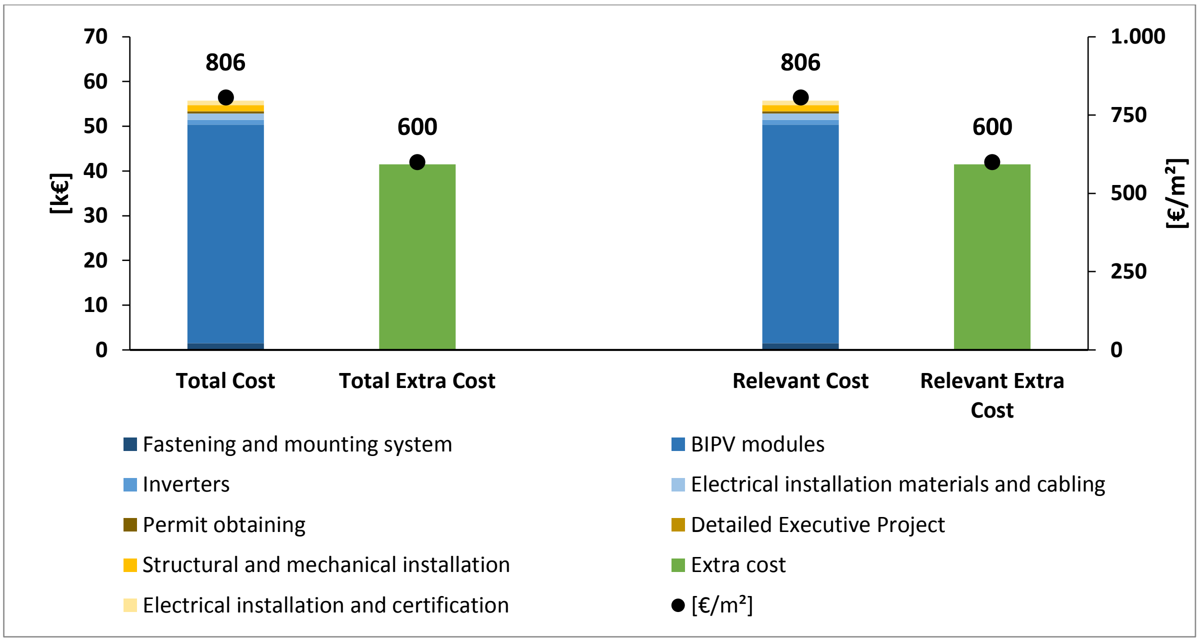

Figure 3.3. Investment cost for the BIPV walkable floor (total cost, relevant cost and relevant extra cost)

In the case of the BIPV walkable floor, there are no differences between the total cost and the relevant cost. Eventually **the relevant extra cost for the BIPV walkable floor is 41k€ or 600 €/m².** In addition, a **3,9 k€ battery system** was installed at the ISFOC demo site.

Benefits from PV Generation

The methodology used to evaluate the economic benefit from PV generation is presented in the beginning of Section 2.

The revenues for the BIPV walkable floor consist in savings on the electricity bill (0,3 €/kWh compensable retail electricity price in line with prices observed for electricity consumer corresponding to the IA consumption band in Spain) thanks to self-consumption. In this case, the full production was self-consumed. In addition to the initial investment in the BIPV solution (relevant extra cost considered), some operational costs for maintenance, regular visual inspection and occasional cleaning amounting to 5€/m² are considered. The assumptions taken for the cost of equity, the average annual inflation rate and the corporate tax rate are respectively 4%, 2,5% and 25%. Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is 198 €/m².** The positive value of competitiveness indicates that the investment is profitable.

3.2.2 Life Cycle Assessment (LCA)

The conventional walkable floor is always less environmentally beneficial because of the conventional electric production. The BIPV floor itself emits 272 kg $CO2/m^2$ and the conventional one 42 $kgCO2/m^2$, but producing a 5245 kWh of electricity over its 30 years of lifetime, the BIPV enable saving nearly 2060 $kgCO2eq/m^2$. The installation of a floor BIPV is nearly 8 time less impacting than a conventional floor.

3.3 VENTILATED FAÇADE

3.3.1 Photovoltaic Power generation

Figure 3.4 shows energy production of BIPV façade installed in Aretxabaleta. The measurements were carried out from October 2020 until July 2023. In order to estimate the annual energy production annual symmetry have been assumed. All the energy produced have been self-consumed.

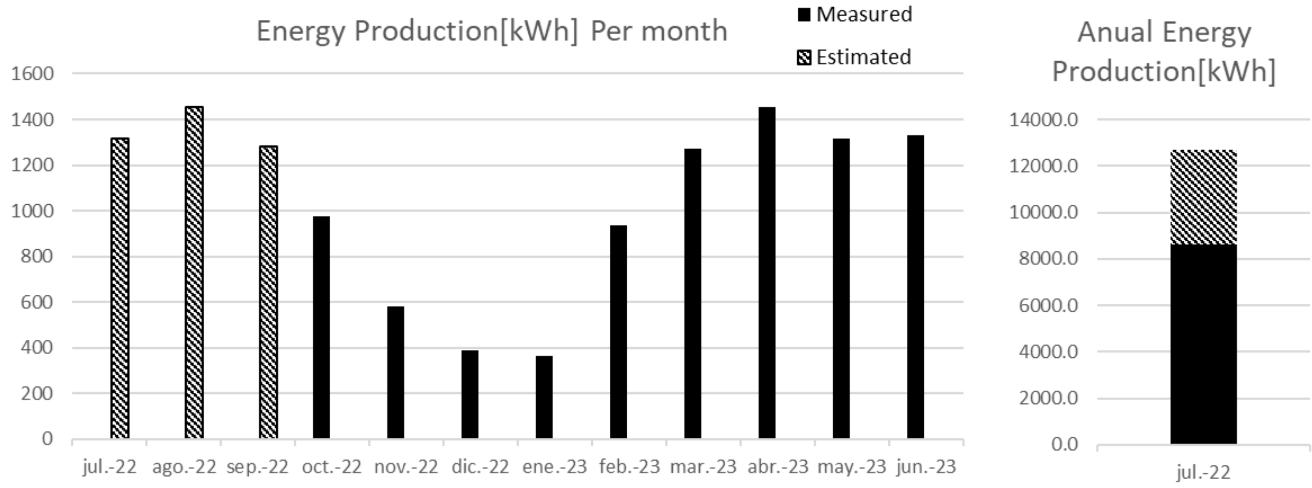

Figure 3.4 Aretxabaleta BIPV façade Energy Production

3.3.2 Investment Cost and Benefits from PV Generation

Investment costs

The presented costs in the figure below are as-built costs which were collected among BIPVBOOST partners which contributed to the demo. The notions of total cost, relevant cost and extra cost are explained in the beginning of Section 2.

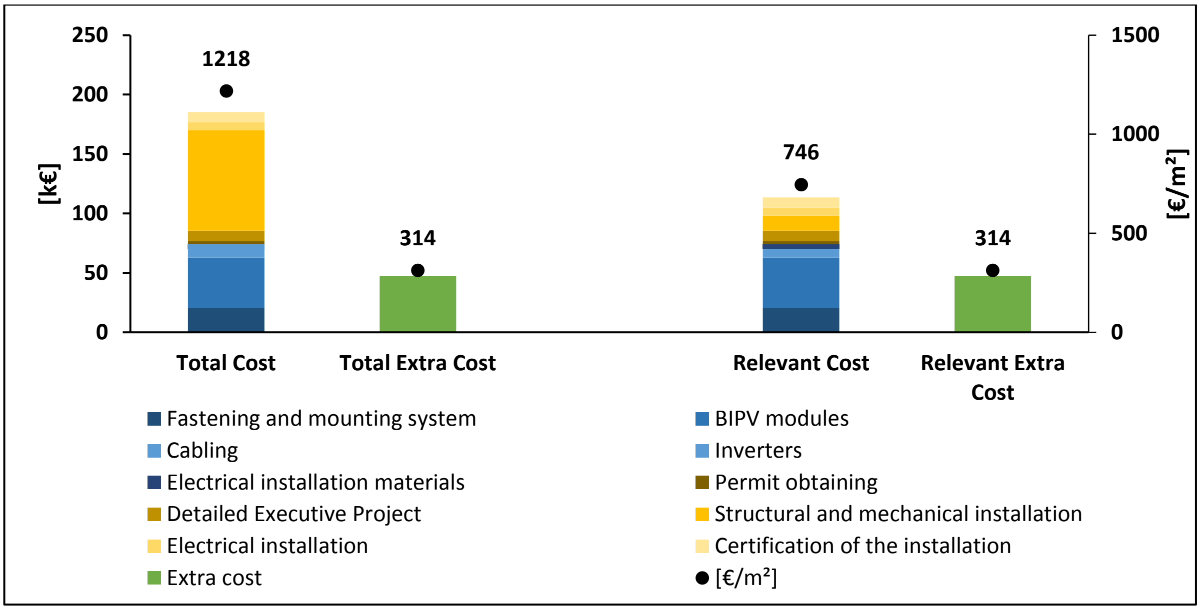

Figure 3.5. Investment cost for the BIPV ventilated facade (total cost, relevant cost and relevant extra cost)[1]

In the case of the BIPV ventilated facade, the main difference between the total cost and the relevant cost is associated to the cost for the super substructure which was necessary to support the weight of the BIPV solution. Eventually **the relevant extra cost for the BIPV ventilated facade is 48k€ or 314 €/m².**

It is worthwhile to mention that the applied super structure is very strong but quite extra-ordinary, attending to the real projects. In the meantime, TULiPPS has developed lower costs support structures available in combination with Click&Go mounting. Moreover, new built projects would unlikely require a super substructure as used in this demonstration. For this reason, today's prefab produced turn-key mounting systems for ventilated facades (so, with the Click-Go substructure included) are significantly more competitive that shown in this example. So, in practice, the competitiveness is better

Benefits from PV Generation

The methodology used to evaluate the economic benefit from PV generation is presented in the beginning of Section 2.

The revenues for the BIPV ventilated facade consist in savings on the electricity bill (0,21 €/kWh compensable retail electricity price in line with prices observed for electricity consumer corresponding to the IC consumption band in Spain) thanks to self-consumption. In this case, the full production was self-consumed. In addition to the initial investment in the BIPV solution (relevant extra cost considered) some

[1] Today's (end of 2023) indicative prices for commercial turn-key Click&Go BIPV systems as a result of the BIPVBOOST project for any facade up to 12 meters high including installation work, DC cables and inverters (excluding AC cables and connection to the main switch board) are as follows:
1) standard framed black solar panels 60 cells or 120 half cut cells + Click&Go mounting, 25 years performance guarantee: € 300/ m² (=> 210 Wp /m²)
2) standard 60 cells aesthetic glass-glass panels without frame, 30 years performance guarantee: + Click&Go mounting about € 400,- /m2 and in case a non-active facade was already planned the EXTRA costs for the PV functionality would be only € 175,- / m²).
3) tailor-made glass-glass modules without colour + Click&Go mounting: € 500 /m²
4) tailor-made glass-glass modules almost any RAL colour + Click&Go mounting: €650 / m² (4.000 colours)
5) tailor-made glass-glass modules with marble-, stone-, brick-, or wood print + Click&Go mounting € 700 - € 750 /m².

operational costs for maintenance, regular visual inspection and occasional cleaning amounting to 5€/m² are considered. The assumptions taken for the cost of equity, the average annual inflation rate and the corporate tax rate are respectively 4%, 2,5% and 25%. Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is -66 €/m².** The value being very close to the competitiveness threshold demonstrate that the investment in such BIPV could be profitable if a slightly more optimal orientation is chosen for example. The results also demonstrate that BIPV solutions with a high aesthetical value can be competitive with conventional construction solutions.

The competitiveness assessment can be complemented by estimating the competitiveness of a BIPV system only composed of the BIPV modules with equal and highest number of cells (a unique BIPV module design with 48 cells instead of 7 different designs from 24 to 48 cells). This would slightly increase the BIPV module price from 42,3 k€ to 43,5 k€ as it incorporates a higher number of PV cells, but would enable a higher installed capacity (24,2 kWp instead of 21,6 kWp) and associated higher electricity production for the same covered area. By assuming that all other cost items and financial assumptions are the same as for the same design, this would lead to an extra relevant cost of 48,9 k€ or 322 €/m². Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is -35 €/m².**

3.3.3 Life Cycle Assessment (LCA)

In this demo case, the conventional façade is impacting more than the BIPV façade for all scenarios. In the best case when 48 cells are installed, the conventional façade reach an impact on climate change impact reaches 1267 kgCo2eq/m^2 (due to nearly 90% to the electricity mix) and the BIPV façade emits only 254 kgCO2eq/m^2 and an electricity production of 2880 kWh over its whole lifetime.

In the worst-case scenario, with the PV module equipped only with 24 cells, the conventional façade emits 700 kg CO2eq/m2 (80 % emissions are due to electricity mix while the corresponding BIPV emits only 180 kg CO2/m^2 with an electricity production of nearly 1440 kWh.

3.4 ROOF RETROFITING

3.4.1 Photovoltaic Power generation

Figure 3.6 shows the energy production at optimal demo site during one operational year. As can be seen the west roof produces more energy than the east roof, but in overall both perform well. This data can be used to estimate the benefits of this BIPV solution.

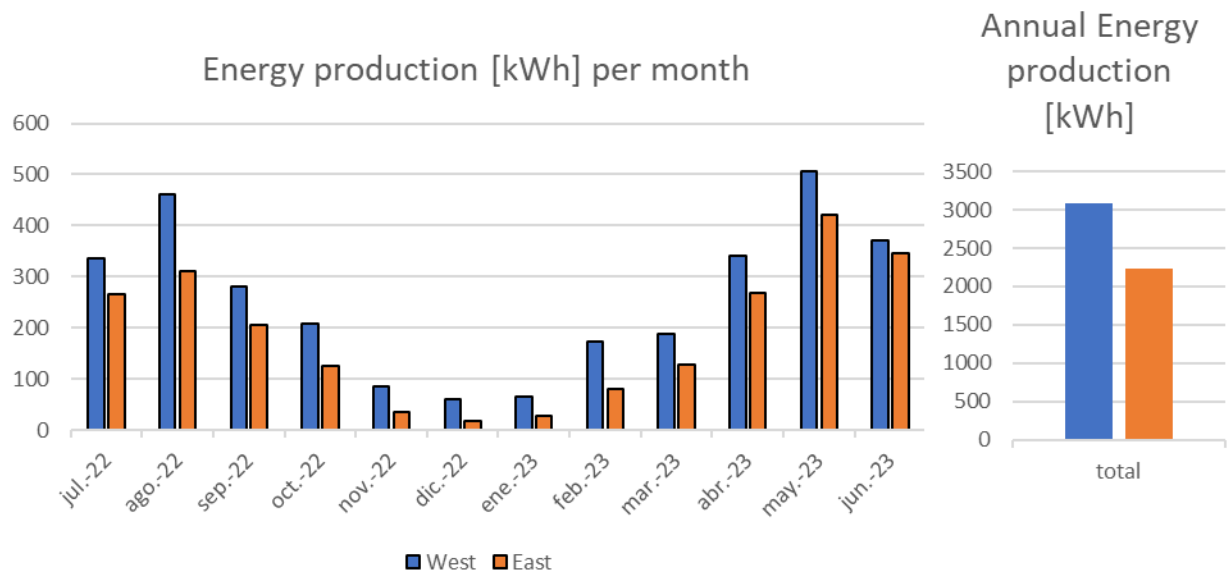

Figure 3.6: Optimal BIPV roof energy production

3.4.2 Investment Cost and Benefits from PV Generation

Investment costs

The presented costs in the figure below are as-built costs which were collected among BIPVBOOST partners which contributed to the demo. The notions of total cost, relevant cost and extra cost are explained in the beginning of Section 2.

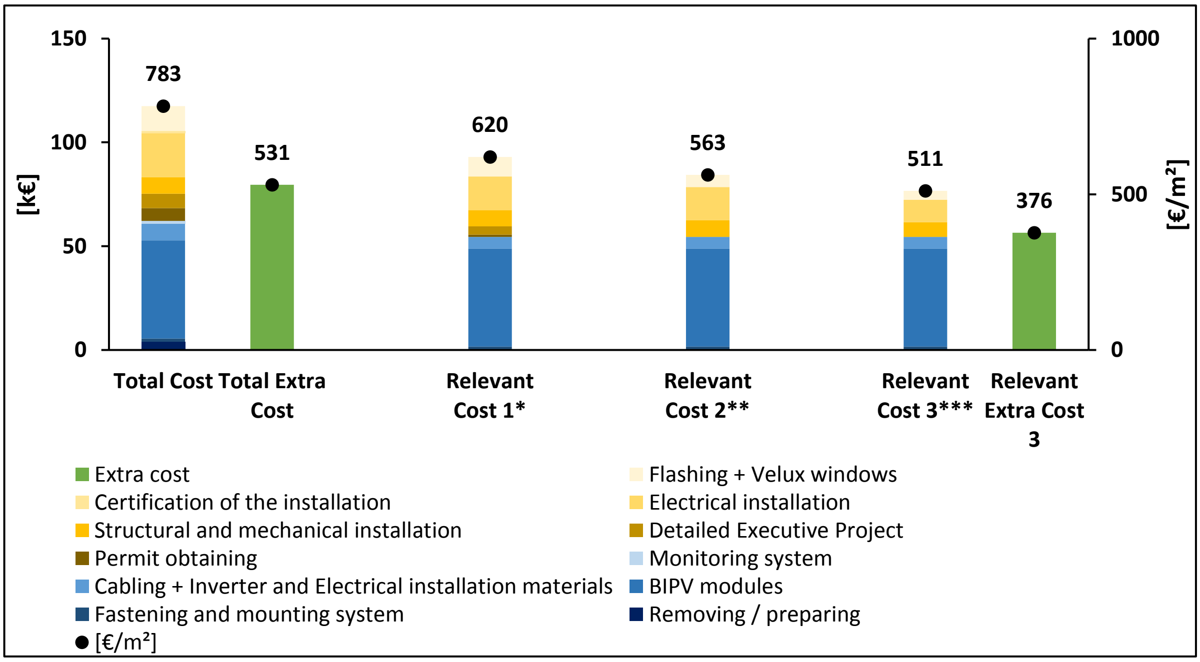

Figure 3.7. Investment cost for the BIPV roof retrofitting (total cost, relevant cost and relevant extra cost)

Notes:
* (no monitoring & no camera & new construction)

** (no monitoring & no camera & new construction + no Velux)
*** (no monitoring & no camera & new construction & no Velux & experience curve)

In the case of the BIPV retrofitting roof, the main difference between the total cost and the relevant cost is associated to the monitoring system cost, to the camera cost, to the removal costs of the prior BAPV system and to higher installation costs due to the roof's characteristics (presence of velux and triangular-shaped roof extension). Eventually **the relevant extra cost for the BIPV ventilated facade is 56k€ or 376 €/m².** In addition, a **7,8 k€ battery system** was installed at the Optimal demo site.

Benefits from PV Generation

The methodology used to evaluate the economic benefit from PV generation is presented in the beginning of Section 2.

The revenues for the BIPV retrofitting roof consist in savings on the electricity bill (0,44 €/kWh compensable retail electricity price in line with prices observed for electricity consumer corresponding to the DC consumption band in Belgium (Wallonia) where retail electricity prices are among the highest in Europe) thanks to self-consumption. Then, electricity injected to the grid has the same value as self-consumed electricity as a yearly net-metering scheme is in force in Wallonia. In addition to the initial investment in the BIPV solution (relevant extra cost considered), some operational costs for maintenance, regular visual inspection and occasional cleaning amounting to 2€/m² are considered. The assumptions taken for the cost of equity and the average annual inflation rate are respectively 2% and 2,5%. Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is 5 €/m².** The positive value of the competitiveness indicates that the investment is profitable.

3.4.3 Life Cycle Assessment (LCA)

Demo site 3 in Belgium addresses a very different PV technology. The module is a thin film module made of CIGS deposited on a flexible polymer membrane. To be considered as a BIPV, the system shall present a function in the building skin, and this can be only achieved by the module after being bonded on an aluminium substrate. Therefore, even if the PV module represents only 12% of the impact of the BIPV system, it cannot be dissociated from the rest and is assessed as a whole. The electricity included in the functional unit is 1692 kWh and corresponds to the production of 1m2 of BIPV during its whole life.

The figure above shows that the conventional roof has a higher impact than the BIPV mainly due to the production of electricity, the total emissions are 430 kgCO2eq/m2. The selected eco-designed solution by Schweitzer is the scenario 5. This scenario (136 kg CO2eq/m2) is a solution which will be possibly developed by Schweitzer since it is mature enough to be handled and it simply requires investments on new tools. This scenario would allow saving 293 kgCo2eq/m2 installed over its whole life, for an installation in Belgium. If the electricity mix substituted corresponds to the EU mix (418 gCO2/kWh based on ecoinvent data), the GHG saved would therefore reach nearly 600 kg CO2eq/m2 installed during 30 years. Nevertheless, during the project, Schweitzer is producing the BIPV 1 since experience and working tool at the company allows testing. Compared to the conventional roof, even with this scenario the GHG emissions are divided by 2 compared to the traditional roof. Among all scenarios explored, the solution which presents the lowest impacts would be the scenario 7 (122 kgCO2eq/m²) but is a very innovative scenario that is not technically feasible on a short-term perspective.

3.5 OPAQUE CLADDING

3.5.1 Photovoltaic Power generation

Next figure shows the energy production during post intervention period for the 4 facades of the 2 buildings.

As can be seen even if both building are supposed to be twin buildings there are some small differences between them, probably due to shadows or different horizon. This data shows clearly the benefit of installing this BIPV solution in real buildings.

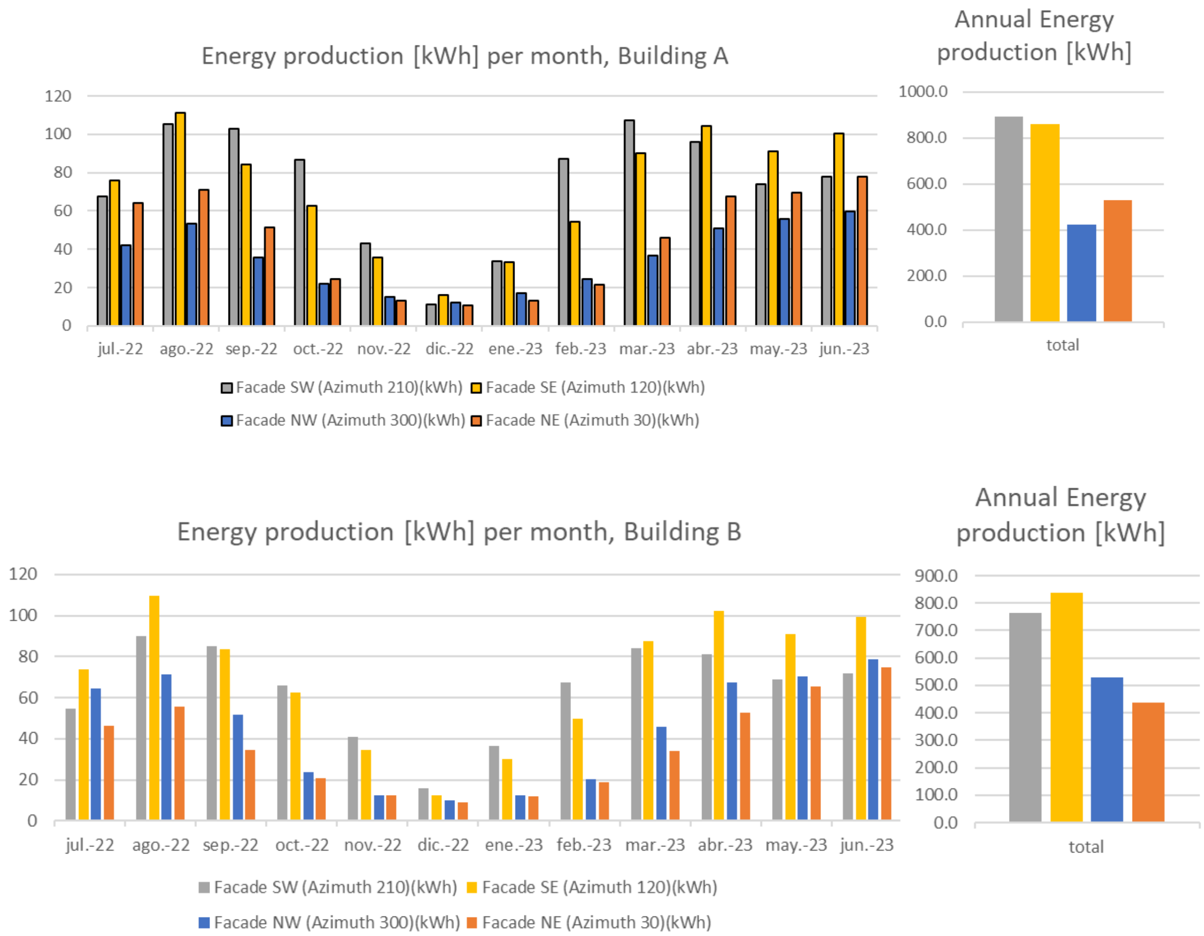

Figure 3.8. PIZ demo site energy production

3.5.2 Investment Cost and Benefits from PV Generation

__Investment costs__

The presented costs in the figure below are as-built costs which were collected among BIPVBOOST partners which contributed to the demo. The notions of total cost, relevant cost and extra cost are explained in the beginning of Section 2.

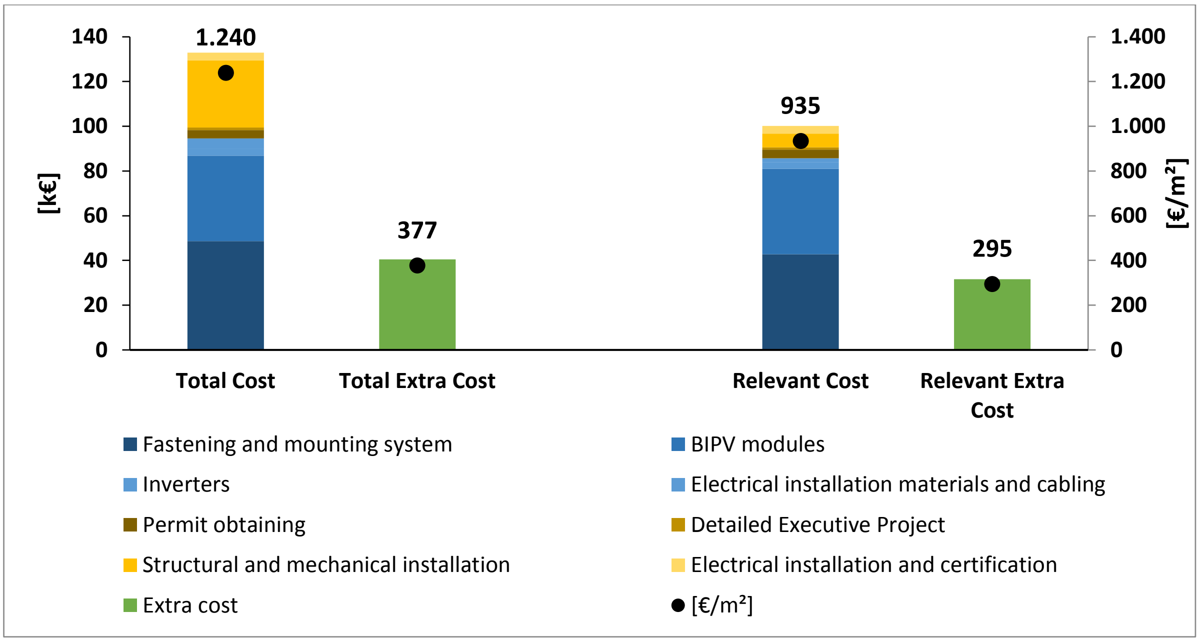

Figure 3.9. Investment cost for the BIPV opaque cladding (total cost, relevant cost and relevant extra cost)

In the case of the BIPV opaque facade, the main difference between the total cost and the relevant cost is associated to structural and mechanical installation costs which were particularly high because the BIPV system was installed on the upper part of the building only. Eventually **the relevant extra cost for the BIPV ventilated facade is 32k€ or 295 €/m².**

<u>**Benefits from PV Generation**</u>

The methodology used to evaluate the economic benefit from PV generation is presented in the beginning of Section 2.

The revenues for the BIPV opaque cladding consist in savings on the electricity bill (0,32 €/kWh compensable retail electricity price in line with prices observed for electricity consumer corresponding to the DC consumption band in Italy) thanks to self-consumption. In this case, the full production was self-consumed. In addition to the initial investment in the BIPV solution (relevant extra cost considered) some operational costs for maintenance, regular visual inspection and occasional cleaning amounting to 5€/m² are considered. The assumptions taken for the cost of equity and the average annual inflation rate are respectively 2% and 2,5%. Eventually, **the competitiveness level reached by such system assuming a 30 years lifetime is 3 €/m².** The value being just above the competitiveness threshold demonstrate that the investment in such BIPV could be more profitable if façade with more optimal orientations are preferred for example. The results also demonstrate that BIPV solutions with a high aesthetical value can be competitive with conventional construction solutions.

3.5.3 Life Cycle Assessment (LCA)

The demosite located in Morbegno (Italy) is a nice demonstration of the advantages of BIPVs to face climate change. First of all, the electricity mix in Italy is very close to the average electricity mix in Europe. The quantification on the environmental benefit of electricity substitution thanks to BIPV is therefore better reflecting an average European situation. Second, BIPVs are installed on the four façades of the two buildings. This is very specific of BIPV compared to BAPV for example. Indeed, for aesthetic reasons, architects designing a building integrates BIPV as a part of the building skin, while BAPV is installed only on the façade sunny façade. Here the façades are all equipped with BIPV and are producing energy. Simulation performed by Enerbim shows that the north oriented façades (NE and NW) are producing 1930 kWh every year and the south oriented ones (SE and SW) 2340. At that place the north oriented façades are producing 45% of the total energy produced. Third observation, the BIPV panel emits 206 kg CO2eq/m2 during its production while the conventional emits 102. Compared to other systems, the difference is not that important. At the end, the GHG emissions of the BIPV system installed in Morbegno enable saving nearly 1500 kgCO2eq/m2 of BIPV installed, considering the whole life of the system.

3.6 Investment Cost and Benefits from PV Generation

Next, the summary of the economic and environmental benefits obtained in the five BIPV implementations developed and demonstrated in building demo-sites: BIPV balustrade, Walkable floor, Ventilated façade, roof and opaque cladding.

The results are directly affected by the environment conditions as climatic area (irradiation, temperature, …), local costs (electricity, labour, …), local regulation and building conditions (orientation, structure, shadows, …) of each building demo-site where the BIPV solution has been implemented.

Table 3.1 Summary of economic benefits from BIPV generation based on competitiveness assessment

BIPV implementation	Key cost and revenues assumptions	30y lifetime competitiveness [€/m²]	Main driver(s) (+) & Main barrier(s) (-)
Balustrade	Relevant extra costs: 339 €/m² Electricity bill savings: 0,3 €/kWh (IA consumption band, Spain)	**560 €/m²**	(+) Important yield due to bifaciality & location (+) 100% self-consumption with relatively high retail electricity
Walkable floor	Relevant extra costs: 600 €/m² Electricity bill savings: 0,3 €/kWh (IA consumption band, Spain)	**198 €/m²**	(+) Important yield due to location (+) 100% self-consumption with relatively high retail electricity
Ventilated façade	Relevant extra costs: 314 €/m² Electricity bill savings: 0,21 €/kWh (IC consumption band, Spain)	**-66 €/m²**	(-) limited yield due to vertical tilt and aesthetical value (+) 100% self-consumption
		-35 €/m² With alternative design (only modules with the highest number of cells)	(-) limited yield due to vertical tilt (+) 100% self-consumption
Roof retrofitting	Relevant extra costs: 376 €/m²	**5 €/m²**	(-) limited yield due to location

BIPV implementation	Key cost and revenues assumptions	30y lifetime competitiveness [€/m²]	Main driver(s) (+) & Main barrier(s) (-)
	Electricity bill savings: 0,44 €/kWh (DC consumption band, Belgium)		(+) 100% self-consumption with very high retail electricity
Opaque cladding	Relevant extra costs: 295 €/m² Electricity bill savings: 0,32 €/kWh (DC consumption band, Italy)	**3 €/m²**	(-) limited yield due to vertical tilt and aesthetical value (+) 100% self-consumption with very high retail electricity

3.7 Life Cycle Assessment (LCA)

Table 3.2 LCA for the different BIPV implementations

BIPV implementation	Life Cycle Assessment (LCA)
Balustrade	1080 kg CO_2/m² saved over 30 years
Walkable floor	2060 kg CO_2eq/m² saved over 30 years
Ventilated façade	1270 kg CO_2eq/m² saved over 30 years
Roof retrofitting	600 kg CO_2eq/m² over 30 years
Opaque cladding	1500 kg CO_2eq/m² saved over 30 years