RE-SKIN

D5.10 - Manufacturing design of the BIPVT roof system II

Funded by the European Union

Deliverable Information Sheet

Version	1.0
Grant Agreement Number	101079957
Project Acronym	RE-SKIN
Project Title	Renewable and Environmental-Sustainable Kit for building Integration
Project Call	HORIZON-CL5-2021-D4-02-02
Project Duration	42
Deliverable Number	D5.10
Contractual Delivery Date	31/01/2024
Actual Delivery Date	31/01/2024
Deliverable Title	Manufacturing design of the BIPVT roof system II
Deliverable Type	R
Deliverable Dissemination Level	PU
Work Package	5
Lead Partner	ZH
Authors	A. Miglioli (ZH), L. Maestri (ZH)
Contributing Partners	POLIMI, GAR, INDRES
Reviewers	A. Vallan (FPM), F. Leonforte (POLIMI)

History of changes

Version	Date	Comments	Main Authors
0.1	30/08/2023	First draft, establishing document structure	L. Maestri (ZH), N. Aste (POLIMI), J. Garcia (GAR)
0.2	12/10/2023	First version, incorporating input from all participants	N. Aste (POLIMI), L. Maestri (ZH)
0.3	15/1/2024	Second version, incorporating input from all participants	L. Maestri (ZH), P. Outon (INDRE), C. Del Pero (POLIMI)
0.3	22/11/2024	Quality review	A. Vallan (FPM), F. Leonforte (POLIMI)
1.0	28/01/2024	Final version addressing all further comments	L. Maestri (ZH), N. Aste (POLIMI)

Table of Contents

List of Figures

Disclaimer

This document reflects the views of the author(s) and does not necessarily reflect the views or policy of the European Commission. Whilst efforts have been made to ensure the accuracy and completeness of this document, the European Commission is not responsible for any use that may be made of the information it contains nor for any errors or omissions, however caused.

1. Executive summary

This document is focused on the solar roof included in the RE-SKIN package. More in detail, it describes the design of a Building Integrated Photovoltaic Thermal (BIPVT) roofing integrating photovoltaic modules, thermal insulation panels and a ventilated air gap.

The BIPVT system forms the outer cladding of the roof and is organised in a matrix pattern, with longitudinal aluminium profiles forming the interface structure with the slab or underlying structure. Between the profiles, from bottom to top, insulating sandwich panels are inserted, a free space is left for air circulation and the photovoltaic modules are installed. The latter, suitably inserted into the structure, in addition to producing electricity, form the roof covering and protection from the weather. The extra solar heat absorbed by the photovoltaic modules is removed by convection within the air gap, with the possibility of being used for heating purposes (e.g. in winter) or dispersed outside (e.g., in summer). Air circulation occurs upwards in the parallel channels formed by the gaps between the profiles, connected to horizontal channels near the eaves and ridge of the roof for supply and return air.

This second release of the document includes the updated of the information of component according to the following points:

- the design of “mullion aluminum profile”,
- the information related to the BIPVT system;
- the installation procedure.

Two other subsequent releases of this report are scheduled for month 19 and month 27. The subsequent deliverables will include further specifications and/or modifications according to the results of the first testing activity in the case studies and the future development during the project.

2. General description

The BIPVT roofing system (Fig. 1) is organized according to a modular matrix structure and is designed in order to be integrated in common sloped roofs, replacing the external covering, waterproof and insulation layers.

The external layer is constituted by PV modules, typically glass-tedlar laminates with an aluminium frame. Since the use of refurbished modules is envisaged, it can be assumed that, from time to time, various types of components will be handled. Therefore, the flexibility of the matrix dimensioning is a critical feature of the system.

The airflow into the gap between PV modules and insulation panels can be generated by using a fan (forced convection) or through buoyancy effect (natural convection). Fresh air removes the heat absorbed by the collector, cooling at the same time the rear of the PV module with the effect of an increment in the electrical conversion efficiency. In the heating season, hot air is used to boost the solar-assisted heat pump.

The installation of the PV modules is provided through recycled aluminium profiles, suitably interspaced according to the modules' size and fixed to the existing slab or roof framework. These profiles constitute the building interface structure of the BIPVT system and perform the functions of housing, fixing, mechanical resistance, structural stability. The PV modules are housed in the profiles and fixed by means of flat upper profiles (pressure plates), fitted with gaskets and a snap-on covers.

Below the air gap, box-shaped sheet metal panels, containing bio-polyurethane foam, act as absorbing plates that increase radiant heat absorption from PV modules and as insulation layer for the building's roof.

In addition to producing solar electricity and heat, the whole system provides thermal insulation, water tightness and airtightness to the building's roof.

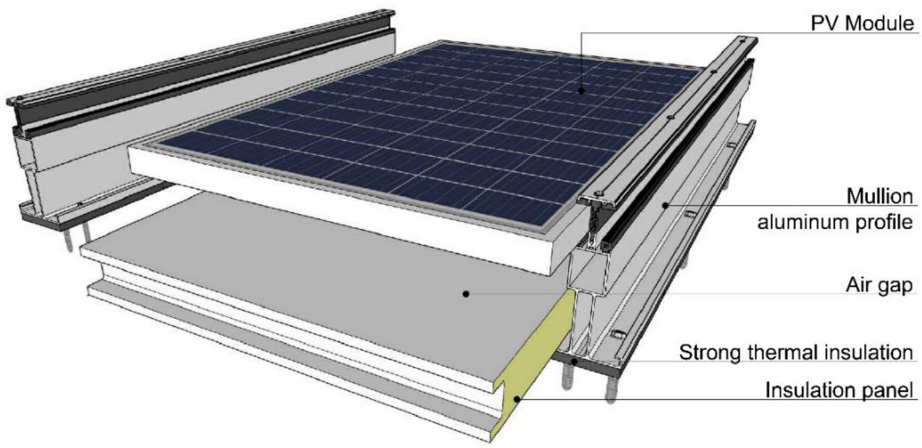

Figure 1. General 3D view of the BIPVT Roof System

3. System/components design

The BIPVT system has been designed so that it can be installed on practically any type of sloped roof (masonry, wood, etc.), overlapping the existing roof structure and replacing the waterproofing and airtightness cladding. Its configuration derives from the merging of curtain wall and ventilated roof concepts. For this reason, although it offers innovative performance, it is based on established technologies, adapted for the specific purpose.

In detail, the system is composed by the following elements:

1) mullion aluminum profile – made with recycled aluminum;
2) refurbished PV module;
3) air gap;
4) thermal insulation panels with biosourced polyurethane;
5) joining, sealing and fixing elements.

The system details are shown in Fig. 2.

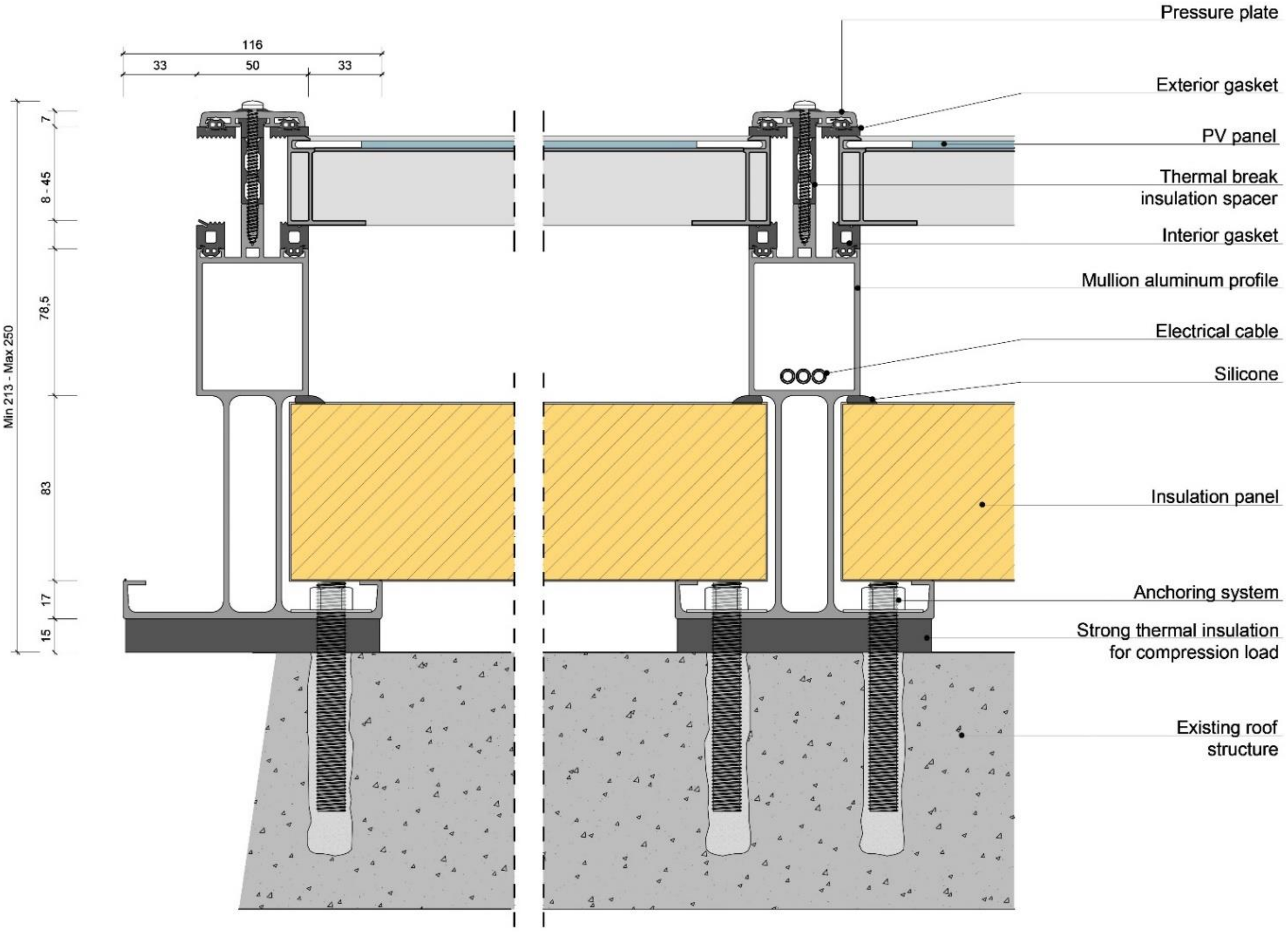

Figure 2. System's cross section with insulation panel

3.1. Aluminium profile

The metal profiles, made of recycled aluminum, constitute the support and building-interface structure and perform the functions of connection between existing roof and the PV modules. The latter are housed in the profiles in the same way as glass facades and the gaskets ensure water tightness and airtightness.
Moreover, the metal profiles also serve as a housing for the electrical wiring of the system, which are thus placed in a protected position (Fig. 3).

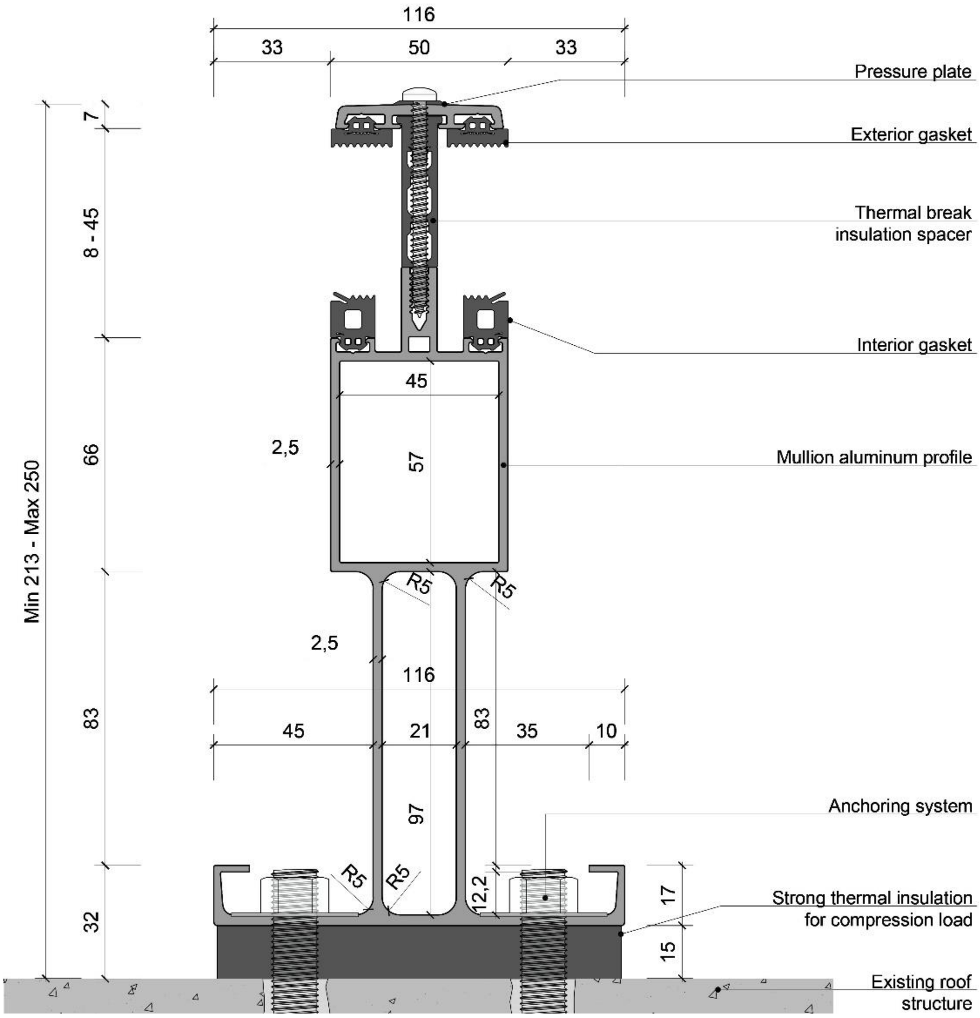

Figure 3. Aluminum profile section

The profile is designed with a cup-shape cross section, specially designed in order to allow in the upper part the housing of the modules by means of pressure plates and gaskets; at the base the installation of the insulating panels and anchoring to the slab or underlying structure; in the intermediate part a ventilated air gap.

The technical data on the mullion aluminium profile is shown in Table 1.

Area (mm^2)	1672
Weight (kg/m)	4,514
TOTAL perimeter (mm)	1256
Exterior perimeter (mm)	805
Interior perimeter (mm)	451
Inertia momentum Ix (cm^4)	97.26
Inertia momentum Iy (cm^4)	659.51

Table 1. Technical data about the mullion aluminum profile

The improvements made in this latest version of the profile are as follows:

1) The profile is manufactured with only 1 extruded piece in order to guarantee stability and resistant from wind, rain and snow;
2) The height of the central part and of the two wings for housing the insulated panels have been modified to host an 8 cm thick insulating panel;
3) A more resistant thermal break insulation of 1.5 cm has been installed on the lower part of the profile to solve the thermal bridge because of only 1 extruded piece of the profile;
4) The snap cover has been removed in order to reduce potential projected shadows on the PV module. Special waterproof screws will be used to prevent water infiltration inside the profile;
5) To allow the sliding and the correct installation of the insulating panels, the interior gaskets have been removed. To guarantee the watertight, silicone (or similar) will be installed after positioning all the insulation panels.

Even if such new configuration characterized by a lower flexibility, since it allows to install only one insulation panel 8 cm thick, it guarantees greater stability and resistance.
According to this configuration, the profile is wider in the upper part, narrower in correspondence of the insulation housing and is equipped with two horizontal side wings at the base, with eyelets for fixing screws to the underlying structure.
The profile is designed to ensure compatibility with different types of PV modules: with regard to module's width, the supporting profiles can be interspaced as required; with regard to length, the profiles can be sized or joined according to need.

Finally, as far as fastening elements to the underlying slab are concerned, there are different variants depending on the specific structure: self-tapping screws for wood, chemical dowels for concrete, nuts and bolts for steel frames.

In the continuation of the research, possible solutions will be examined, with particular reference to the applications envisaged in the case studies.

3.2. Refurbished PV module

Within RE-SKIN, the use of refurbished photovoltaic modules is planned, in line with the project's circular economy approach. Of course, it is not possible to refer to a single standard product, because the reuse logic must be flexible with respect to the specific components available from time to time.

In general, glass-tedlar laminates will be used, with mono- or polycrystalline cells, rear junction box and anodised aluminium perimeter frame.

For the time being, reference is made to the sizes of the most popular modules on the market to date, even if alternatives are not excluded. Although length and width vary slightly, most companies produce solar panels in standard sizes. The most typical size used for residential installations is about 165 x 100 cm (Fig. 4), while the common size for commercial applications is 195 x 100 cm.

The depth of solar panels, due to the height of the frame, varies between about 3.5 - 4.5 cm, although most existing products measure more than 4 cm deep. Note that in general, the higher the frame height, the better the structural stability of the module.

Usually, solar panels for residential applications weigh around 18 kg, while commercial panels for outdoor applications of various types, which are slightly larger, are closer to 22 kg. In any case, a structural analysis is always required before installation to calculate whether the roof can support the additional weight of the solar system, i.e., the profiles, modules, insulation boxes and other sub-components.

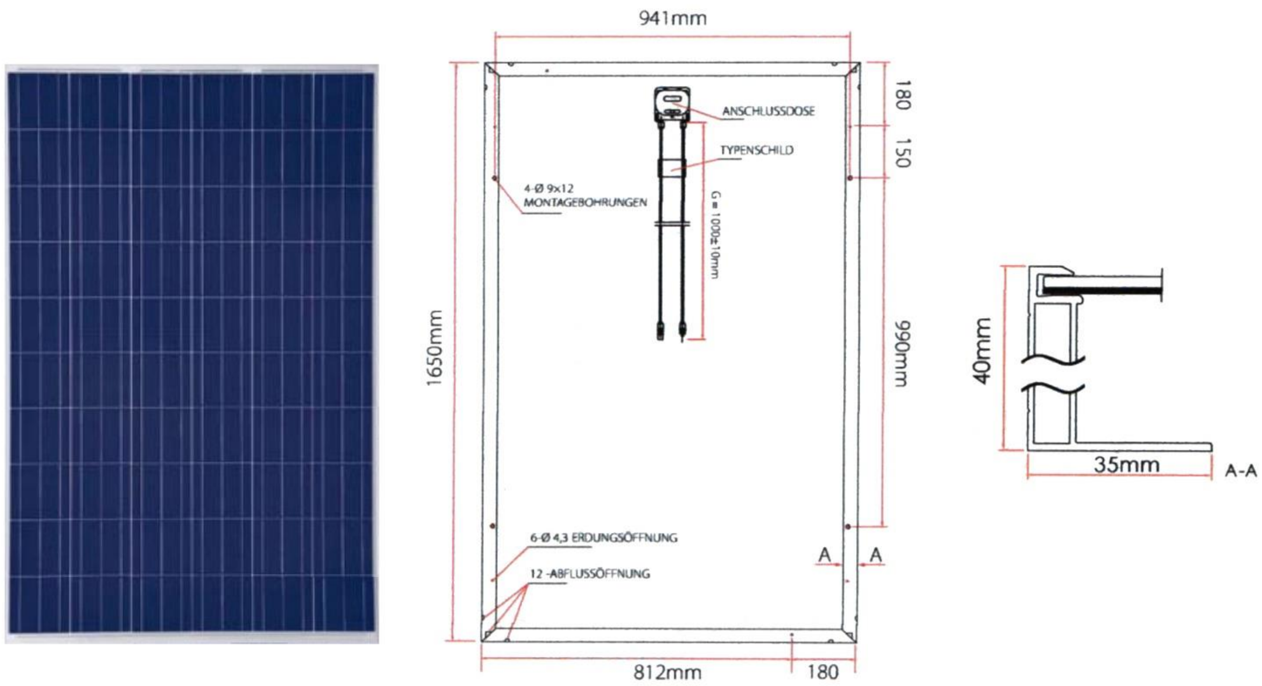

Figure 4. PV module sample

In all the envisaged cases, the BIPVT system can easily fit the modules, although it may be preferable to use the smaller size to allow for greater flexibility in rooftop installation.

3.3. Thermal insulation panel

The thermal insulation panel (Fig. 5) consist in a sandwich panel with a biosourced polyurethane foam core encapsulated in sustainable steel sheet (i.e., special recycled steel).

The insulation panels are inserted into the grooves at the base of the profiles and are interconnected by means of tongue-and-groove joints. Thanks to the interconnection between the panels and appropriate silicon, water tightness is ensured.

A 3D view of the BIPVT roof system is shown in Fig. 6.

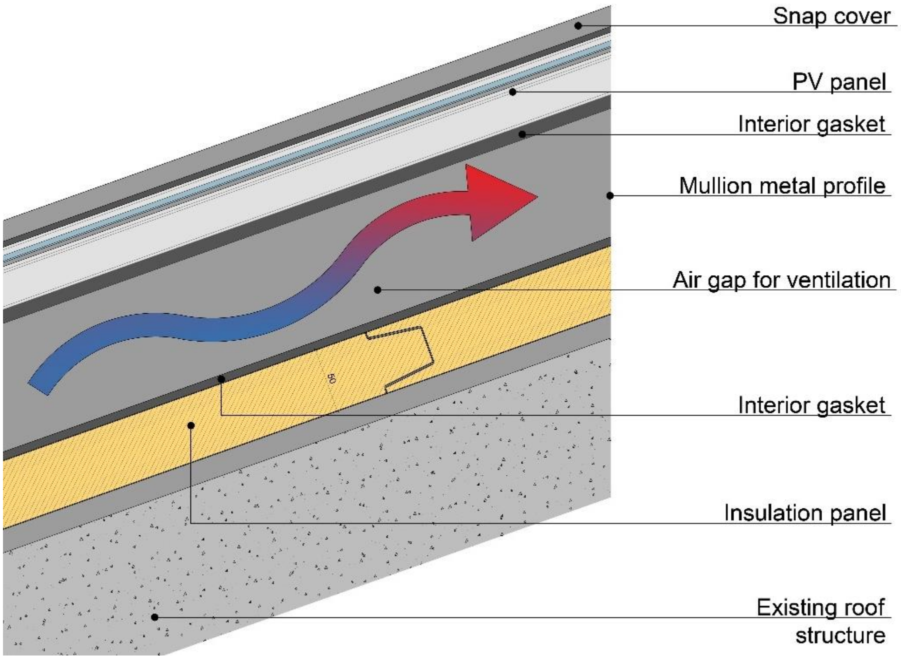

Figure 5. Thermal insulation section

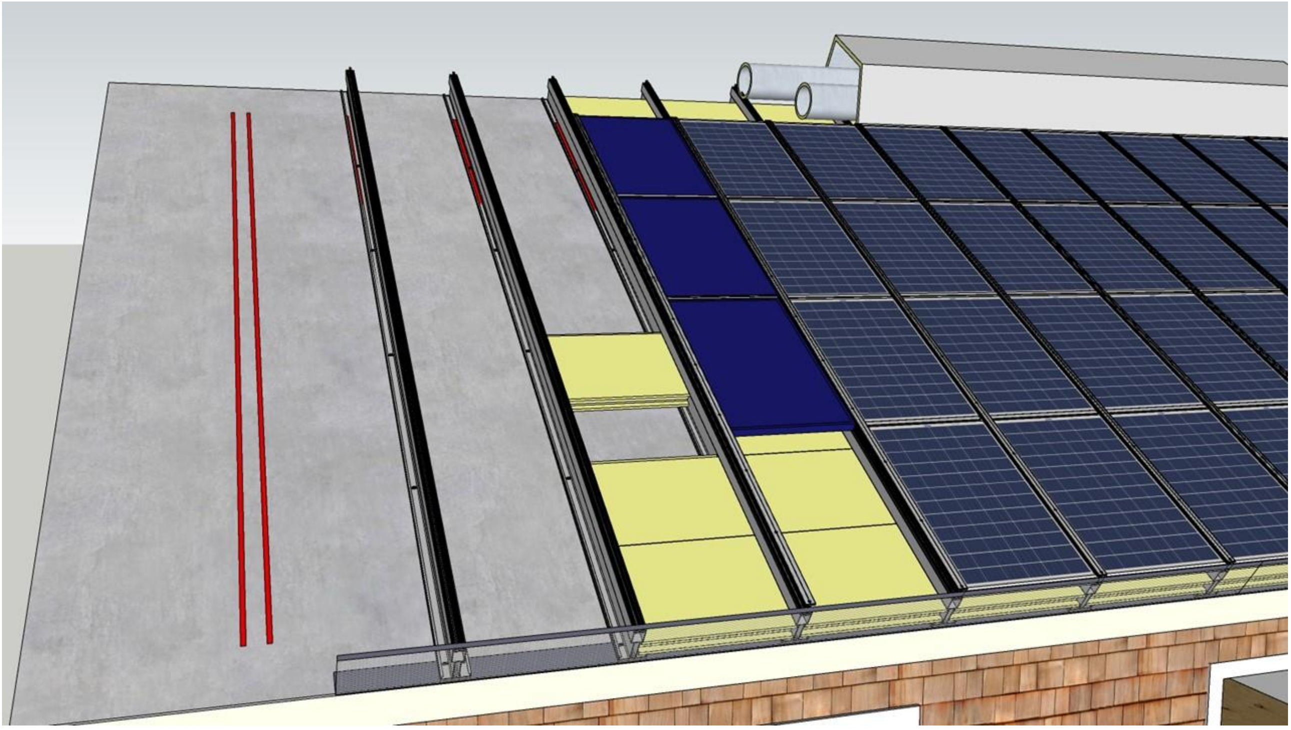

Figure 6. 3D view of the BIPVT roof system divided by phases

3.3.1. Roof thermal insulation panel – testing

The manufacturing test of the insulation panel has been carried out in the manufacturer's laboratory (Fig. 7). The Bio-polyurethane was inflated inside the "aluminum skin frame" in order to create the sandwich panel and make all the mechanical and thermal test in order to verify stability, durability, stress test.


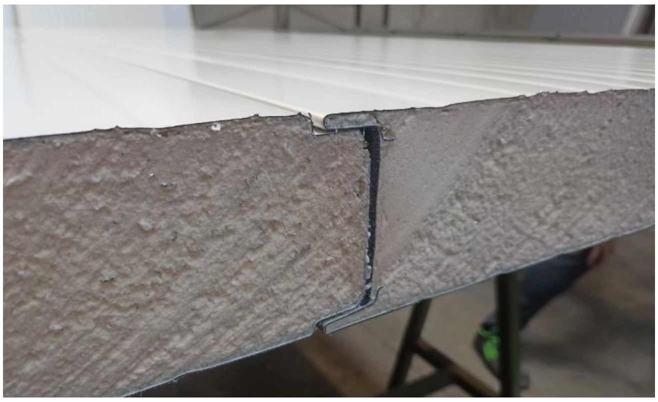

Figure 7. Roof sandwich panel manufacturing

The manufacturing of the first component gave successful results, so the production for the Milan demo case started.
More in detail:

- from the mechanical point of view, these panels are very strong according to the modulus of tension, bending and shear;
- from the thermal point of view, the results are excellent as the value of 0.022 W/mK is lower than the targeted of 0.025 W/mK;
- from the fire resistance point of view, it is necessary incorporate a bit more of fire retardant to improve the results, which now are indeed acceptable since the panel is self-extinguishing.

In the next steps of the research, different solutions will be examined, with reference to the applications envisaged in the case studies.
The main technical features of the panel are reported In Table 2.

Density (kg/m^3)	44.10
Tensile strength (N/mm^2)	0.088
Compression strength (N/mm^2)	0.092
Cutting strength (N/mm^2)	0.119

Thermal conductivity (W/mK)	0.022
Thickness (mm)	80.84

Table 2. Technical data about the roof insulation panel

3.4. Completion modules

To complete the roof system, as shown in Fig. 8, where needed special pieces (called blind panel) will be integrated in the aluminum profiles instead of the PV module on the parts of the roof not intended for BIPVT installation. It consists of a folded recycled metal sheet with an insulating material core, few centimeters thick, manufactured in different sizes to be integrated in the BIPVT roof.

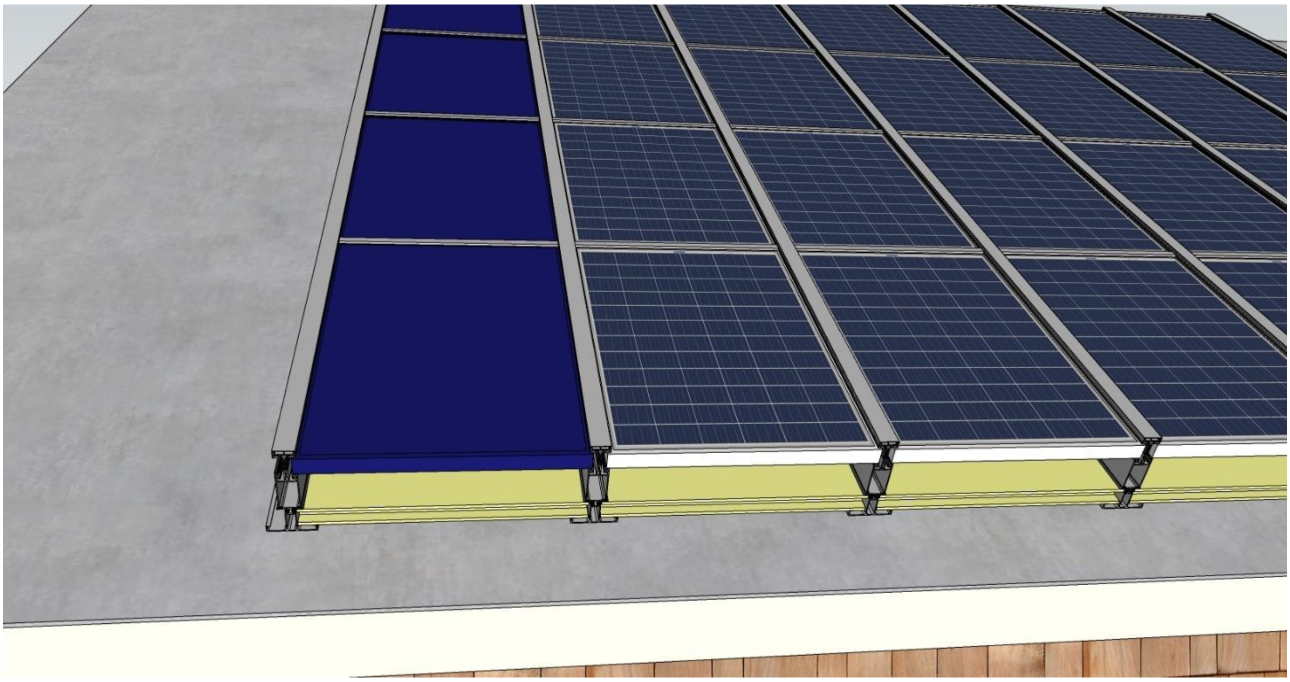

Figure 8. 3D view of the BIPVT roof system with blind panels

3.5. Supply and return channels

In order to allow and balance the ventilation within the BIPVT system, a supply duct will be installed at the eaves of the roof, with grilles for air intake from outside. This horizontal duct will connect in parallel ducts made between the profiles below the photovoltaic modules, which at the top will be connected to a similar return duct near the roof ridge, connected to the heat pump.

It is foreseen that hot air can be expelled when not being utilised.

Composition, sections, shaping and connections of the channels will be studied in detail, possibly according to different variants, during the realisation of the case studies. A schematic drawing of the system is reported in Fig. 9.

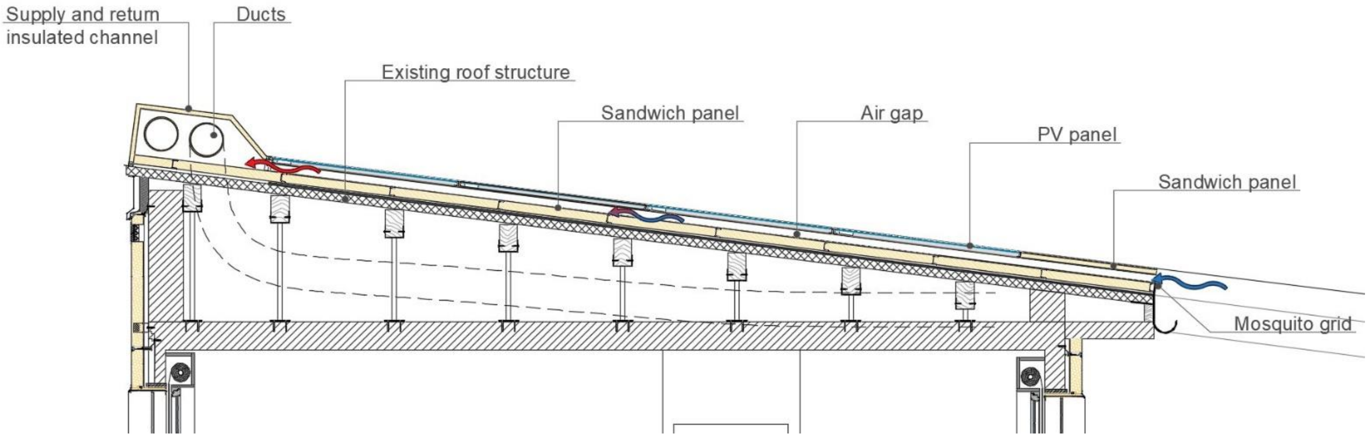

Figure 9. Schematic section of the roof system

4. Installation mode

Before proceeding to install on the existing roof the BIPVT roof system, it is important to check the existing roof status. The installation is divided in 2 phases:

1. **CHECKING EXISTING ROOF STATUS** (Fig. 10)
   1.1. Removal of the current roof covering and the relative substructure.

   1.2. Checking the roof structure layers and materials (concrete slab, predalles, wood, etc.).

   1.3. Carry out a test of the status of cracking and conservation of the roof structure.

   1.4. Carry out a test in order to assess the structural strength and bearing capacity of the roof.

   1.5. Tracking the position of the metal profile on the existing roof structure. The distance between the profiles must be defined considering the dimensions of the PV modules and the existing roof structure.

   1.6. Tracking the position of the electrical cable passage. It is important that all cable routings to the interior of the building are not realized on the structural elements of the existing roof. In the case of the concrete slab, it is necessary for a structural engineer's authorization to proceed.

Figure 10. Phase 1 of installations

2. INSTALLATION OF THE BIPVT ROOF SYSTEM

2.1. Positioning the microperforated metal grid (opening percentage >65%) and fixing on the existing roof structure through appropriate anchoring systems, as shown in Fig. 11.

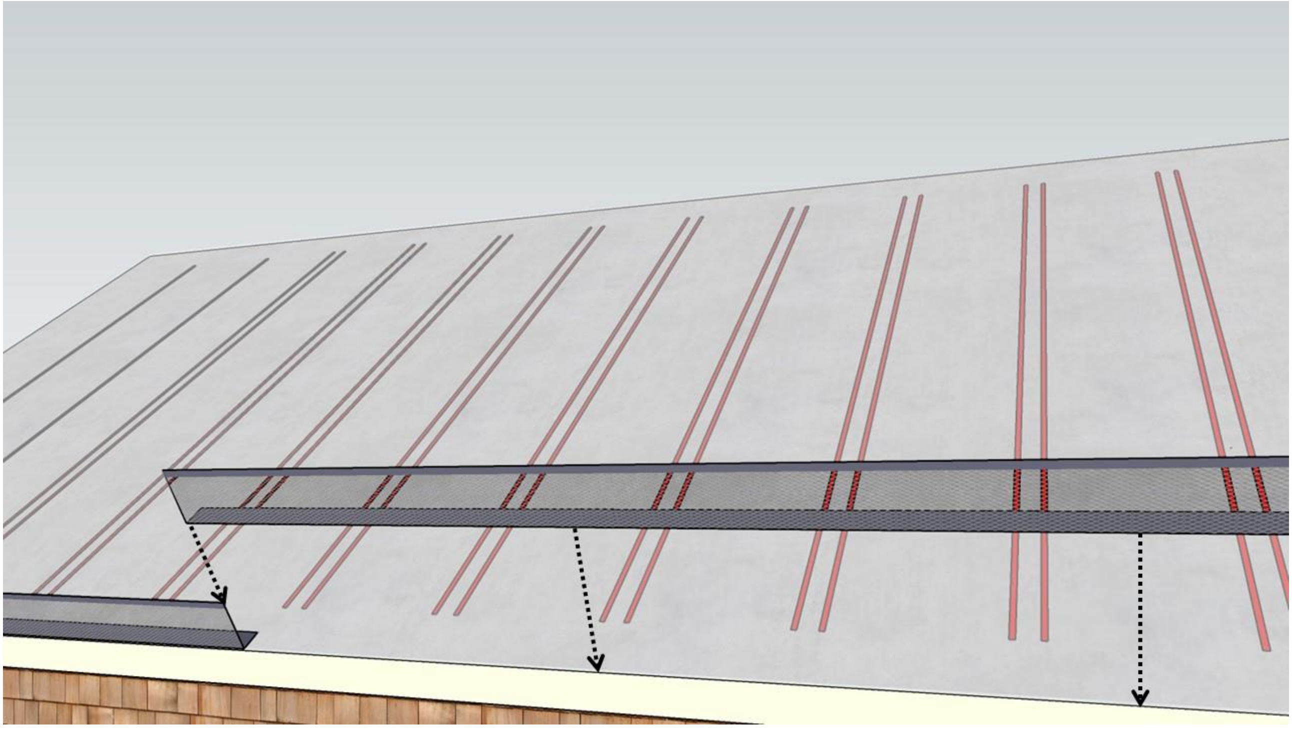

Figure 11. Installation of microperforated metal grid

2.2. Positioning the metal profiles and fixing through the appropriate anchoring systems for the specific underlying structure (Fig. 12).

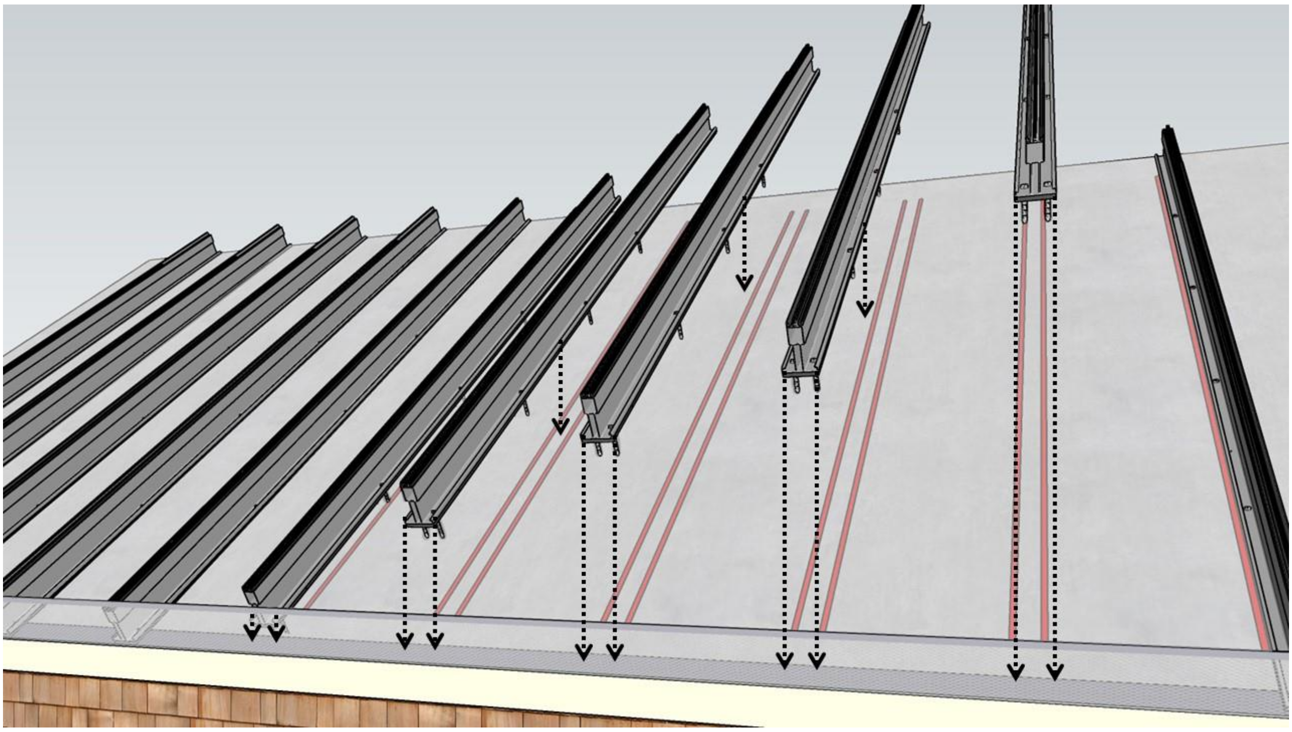

Figure 12. Installation of metal profile

2.3. Starting to positioning the insulation panel between each profile row from the lower to the upper part (Fig. 13).

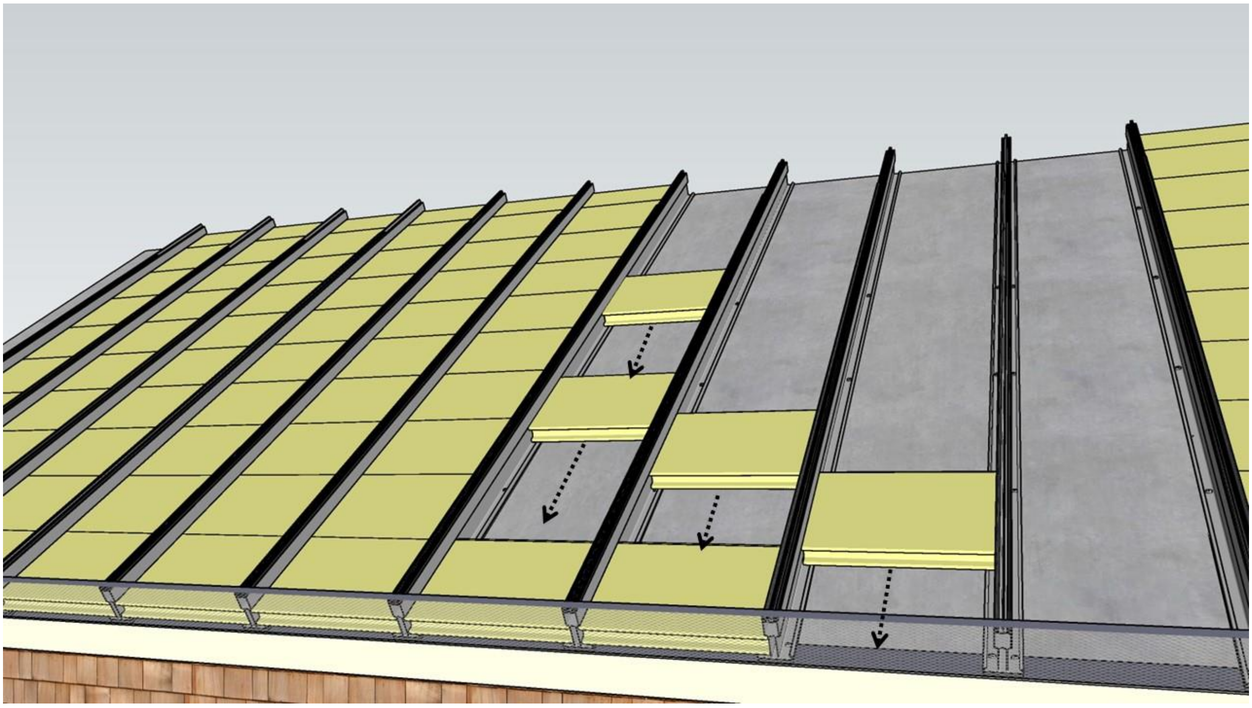

Figure 13. Installation of insulation panels

2.4. Starting to position the PV panel from the lower to the upper part and, consecutively, connecting the electrical cable (Fig. 14).

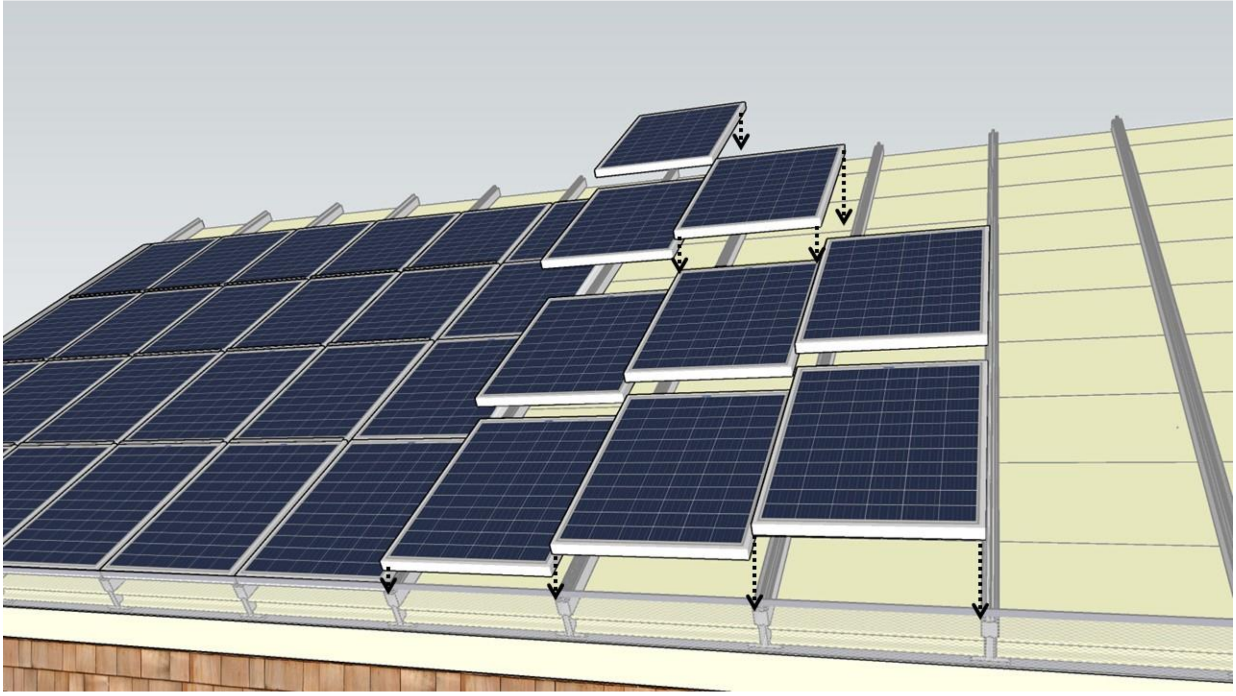

Figure 14. Installation of PV panels

2.5. Mounting the thermal break insulation spacer, sized according to the thickness of the PV panel, and then the pressure plate with the screw (Fig. 15).

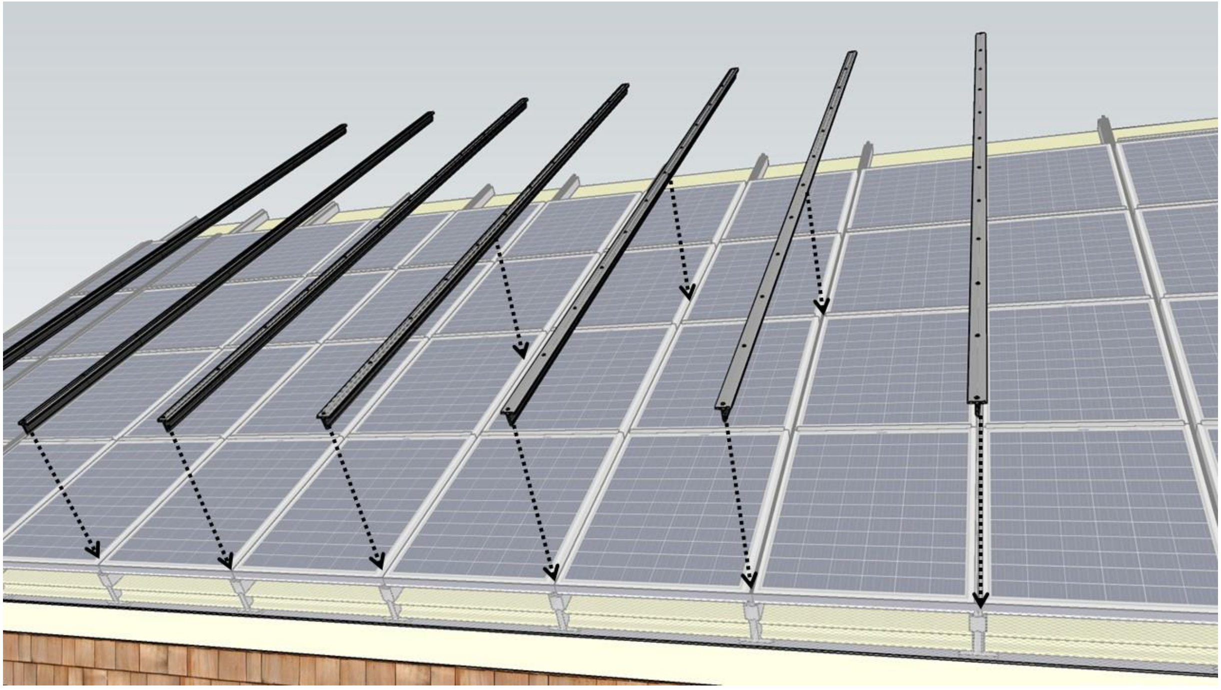

Figure 15. Installation of pressure plate

2.6. In order to guarantee the water tightness and waterproofing, horizontal T shaped frames must be installed between the PV modules, in order to protect against infiltration along the slope direction (Fig. 16).

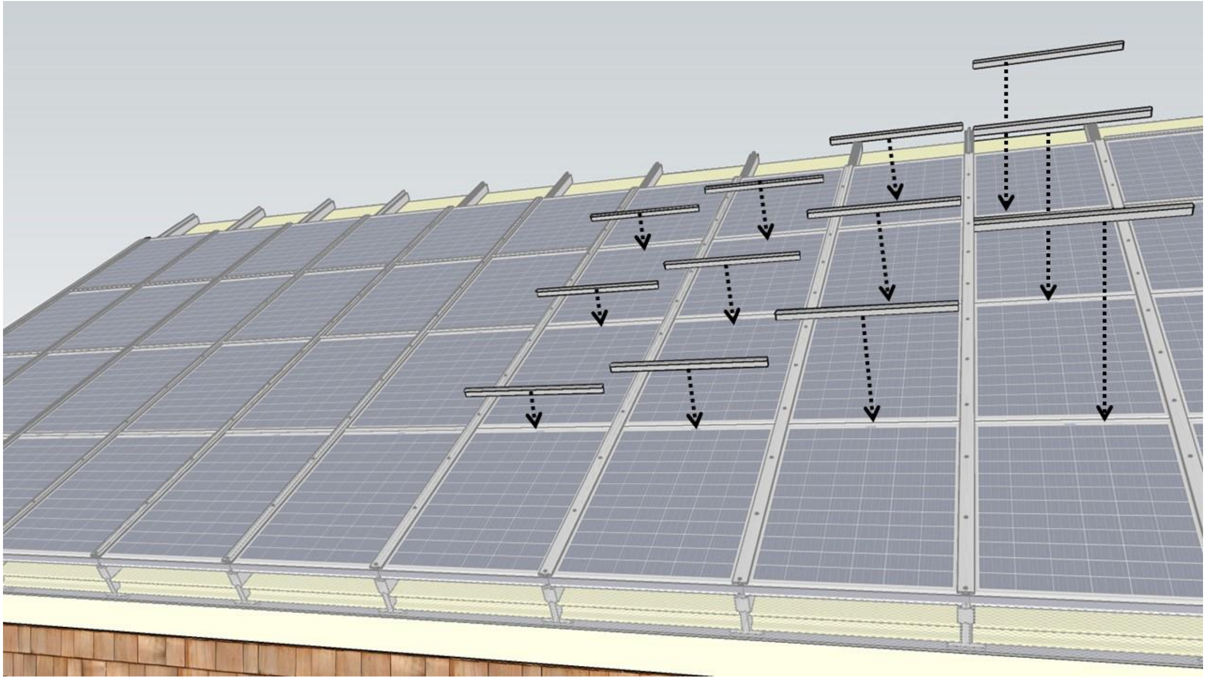

Figure 16. Installation of horizontal frame

2.7. At the end, the snap cover will complete the entire BIPVT roof system, as shown in Figs. 17-18.

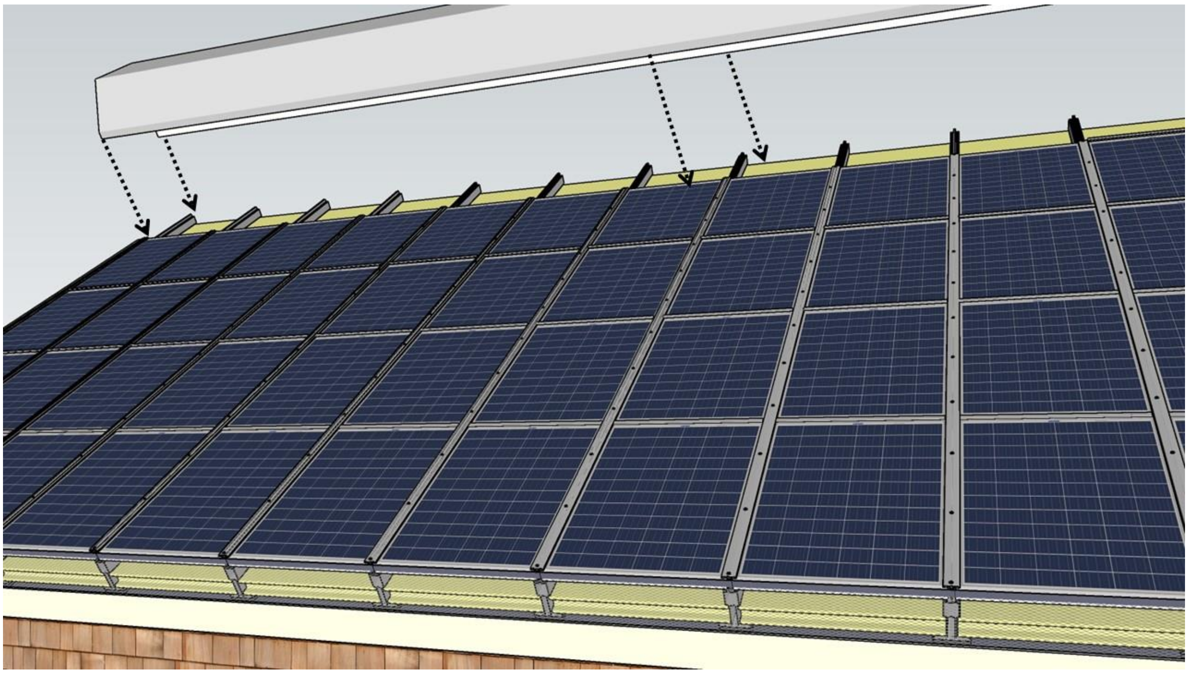

Figure 17. Installation of the supply and return channel

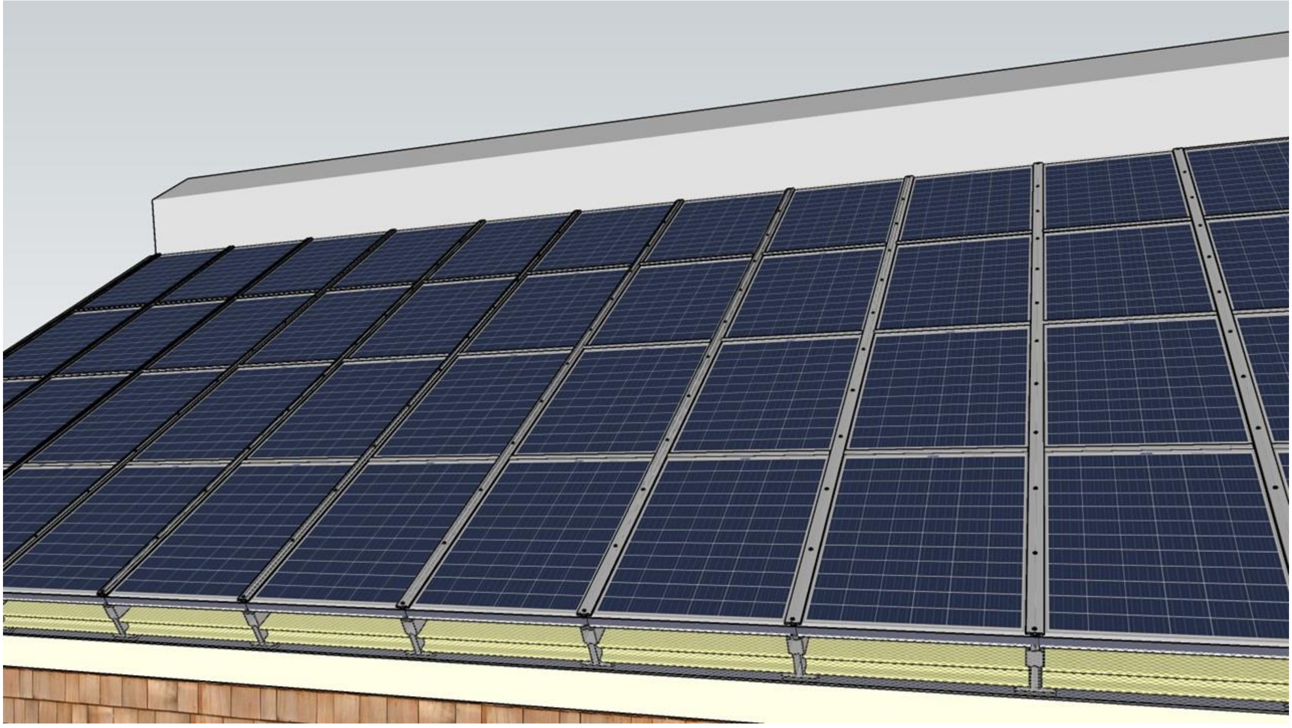

Figure 18. Final roof configuration

5. Operation mode

The PV modules produce DC electricity, while the air circulation beneath the modules (generated by forced-flow or through natural convection) recovers the thermal fraction of captured solar radiation and cools the cells as well (which result is an increment in the PV conversion efficiency).
The modules form a channelled matrix with inside ventilation and thermal insulation at the base.
Air is drawn into the BIPVT system from outside by a supply duct at the eaves, which is equipped with inlet grilles. After flowing through the parallel channels created between the profiles, modules and insulation panels, the air is collected by the upper channel, located at the roof ridge. This channel is connected to the heat pump, which exploits the warm air when heating purposes are required, increasing its efficiency. The heat pump, in fact consist of a solar-assisted air-to-water unit, which can benefit from pre-heating from the PVT roof modules or use the outside air for cooling purposes.
More in detail, the heat pump will be powered in DC, mainly exploiting PV electricity to produce hot or chilled water. The unit will be ducted, allowing indoor installation, and the air heat-exchanger will draw warm air coming from the BIPVT roof when heating or domestic hot water preparation are needed.
When there is no demand, heat circulating in the roof is dispersed outside by natural ventilation through adjustable openings, cooling the envelope. The variable set-up (heat recovery or loss) allows a dynamic insulation, so that the thermal performance can always be adapted to the specific climatic conditions and needs.

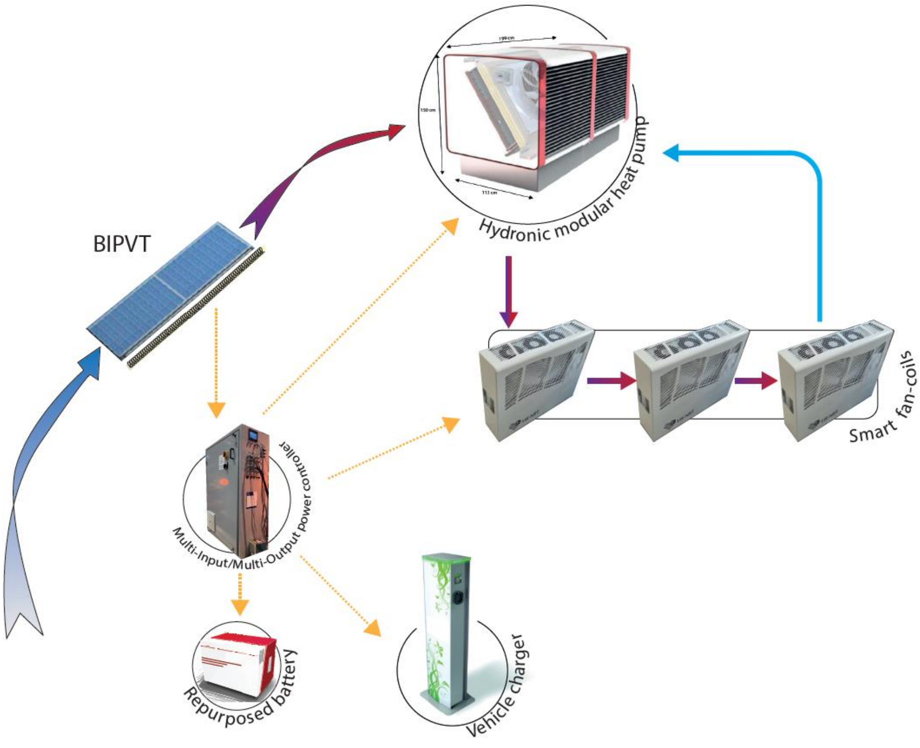

Figure 19. BIPVT operation mode

As previously mentioned, this is a flexible system that may be adapted in according to the dimension of the refurbished PV modules available on the market. For this reason, the dimension and solutions studied are reported on the following features.

Dimensions

- Size of the modular system unit (Width/Height/Thickness) [cm]: 90-120/100-165/21,3-25 (as per refurbished PV modules available on the market)
- Weight [kg/m^2]: 25-30

Technical features

- Sound attenuation in operating conditions [dBA]: ≈ 30
- Water penetration: sealed
- Air tightness: Class A
- Reaction to fire (class): BS3D0
- Thermal transmittance [W/m^{2}K]: 0.6-0.3

Energy performances

- Electric efficiency [%]: 15-20
- Electric power output in STC [W$_p$/ m^2]: 150-200
- Maximum system voltage [V]: ≈ 1000
- Solar thermal power [W/m^2]: 150-200
- Thermal efficiency (UNI 8937) [%]: 20-45

All the dimension and expected performances of this system will be analyzed and confirmed with the first prototype and the test/monitoring.