D3.7 – Best practices handbook and instruction manual for the guided realization, monitoring, maintenance and adaption of the façade energy harvesting modules in a full renovation concept

WP3

Lead Partner: RINA-C

Partner Contributors: EMG, BGT, NSG, AN, TNO

Dissemination Level: Public

Deliverable due date: M30 Actual submission date: M31

Deliverable Version: V0

Horizon 2020
European Union Funding
for Research & Innovation

Project Acronym	ENVISION
Project Title	ENergy HarVesting by Invisible Solar IntegratiON in building skins
Grant Agreement n°	767180
Funding Scheme	Innovation Action
Call	H2020 – EEB - 2017
Topic	EEB-07-2017 Integration of energy harvesting at building and district level
Starting Date	1st October 2017
Duration	54 Months

Executive Summary

The present report constitute D3.7 "Best practices handbook and instruction manual for the guided realization, monitoring, maintenance and adaption of the façade energy harvesting modules in a full renovation concept" of the ENVISION project and its aim is to provide a manual for the correct implementation of the ENVISION concept in a full scale renovation project, explaining in particular how the different technologies developed within the project can be combined into a single integrated solution.

In addition to the technical specifications of each ancillary technology, already included in previous deliverables, this document reports useful information on maintenance aspects, as well as their installation diagrams in order to identify the best solutions for their integration with the existing MEP systems of the building (Chapter 2).

The core of the document (Chapter 3) illustrates a methodology to select the best configuration of the ENVISION module according to the specific building typology targeted by the renovation (**Step 0**). The methodology consists of four main steps, duly described in Chapter 3 subsections, namely

Step 1 - Identification of boundary conditions – i.e. the costraints that may affect the façade design, such as

- Structurals boundaries
- Architectural-distributive boundaries
- HVAC systems.
- Other technical requirements

Step 2 – Identification of baselines, i.e. preliminary design of the modules overall (complying with the boundaries previously identified and including structural scheme, definition of the required performances, position of the technologies)

Step 3 – **Modules design** in which a detailed design of each single module is performed (taking into account also logistic and production aspects)

Step 4 - Identification of the interventions on the building and the existing systems, in which any necessary modification to the building itself is identified, in preparation for the installation of the new envelope system.

Finally, considerations on the maintenance of the modules and on their monitoring are made.

Table of Contents

List of Figures

Abbreviations and Acronyms

[ATO] – Antimony Tin Oxide

[BIVP] – Building Integrated Photovoltaics

[CWO] - Caesium Tungsten Oxide

[HVAC] – Heating, Ventilation, Air Conditioning

[IGU] – Insulating Glass Unit

[KPI] – Key Performance Indicator

[MEP] – Mechanic, electric, plumbing

[NIR] – Near Infrared Radiation

[PV] - Photovoltaic

[RES] – Renewable Energy Sources

1 Introduction

Aside from the difficulties related to the specific development of the new technologies (i.e. NIR solar collectors, the Ventilated window and the PV window), which happens at the component scale, the project has to provide an integrated solution for the façade retrofitting, enabling the efficient assembly and implementation of the necessary maintenance procedures.

The engineering behind the assembly and the architectural detailing of the ENVISION solution are therefore priorities of the project as well, which should allow the achievement of the following objectives.

- To fabricate the system as a modular façade system, from the point of view of an industrialized concept, avoiding onsite installation mistakes and losses of performance.
- To develop the system keeping in mind an easy and affordable access for maintenance jobs of all technologies and components.
- In order to adapt to different scenarios or climate zones, to develop the system with high adaptability degree.
- To design the system from a sustainable point of view enabling an energy efficient production and using materials and components with a high value of life cycle analysis.
- To improve the aesthetic of the rehabilitated building, increasing its economic and social value.
- To Increase the durability of the envelope and raise the life expectancy of the rehabilitated building.

In addition, the solution should ensure the full exploitation of the energy benefits obtained through the new technologies developed in Envision. As a general rule, works involving the installation of renewable energy systems are to be coupled with actions aimed at reducing consumption, i.e. improving the thermal insulation of the envelope and enhancing the efficiency of the existing systems. This in order to minimize the energy demand of the building, and then be able to cover it through on-site renewable energy production.

Beside the above-mentioned targets, it is therefore of primary importance to study the renovation work as a whole, involving the adaptation of the systems and the integration of the MEP system with the new façade, identifying the necessary complementary components to ensure the full operation of the system.

This report is then presenting the schematic procedural approach developed within the project, to be followed in case of deep renovation works involving a modular pre-fabricated timber facade, integrated with the ENVISION technologies, exploring how these can be adapted to the different building target typologies.

2 Façade Harvesting Energy Module

This chapter presents a brief description of the facade energy harvesting module developed within the ENVISION project. It provides a preliminary description and picture of the product (**what**) under development, essential in order to describe, in the next chapter, **how** it should be employed in the context of deep renovation projects.

The facade module is the result of the integration of different components, some developed in ENVISION, others available on the market but essential for the operation of the system.

Among the objectives of this chapter there is also the collection of all the information concerning the installation and maintenance of the individual elements, which may be relevant for the drafting of the guidelines concerning the installation and maintenance of the general system.

2.1 The ENVISION Module – The concept

The product developed in this project is a flexible solution for façade cladding with an optional integrated and invisible solar collector function. The main added value of the product is represented by the wide availability of different colors that can be chosen, which gives a greater degree of freedom to designers or architects willing to retrofit through the use of solar collectors. The cladding can be used in combination with the different façade function such as door and window frames, parts of stone strip façade and other façade cladding materials. In addition, the collector function is integrated in the cladding and therefore "invisible", thus giving the designer the freedom to define which parts of the surface have to be activated to harvest the solar energy with the collector function.

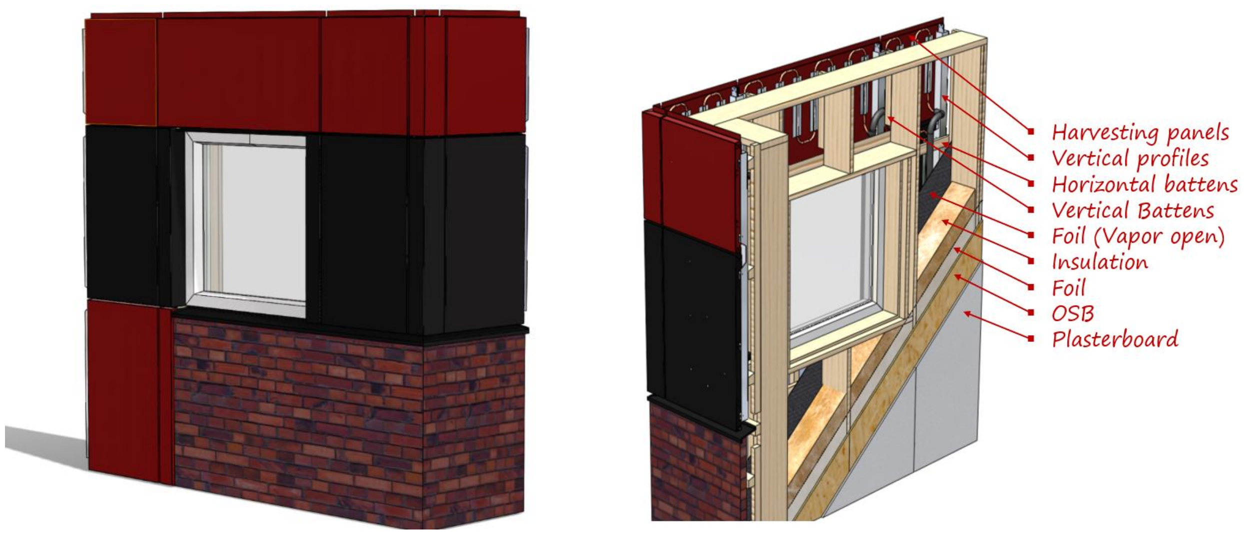


Figure 2.1 – 3D model of demo façade. View from outside (on the left) and inside (on the right) (From Deliverable 3.6)

The key element of the facade system lies in the separation of the facade cladding from the frame through the interposition of wooden battens, which provide the necessary clearance for the positioning of the solar collectors distribution pipes inside the modules.

The wooden battens can be inserted according to the schemes shown in Figure 2.2, depending on whether it is necessary to have only vertical distribution (1), only horizontal distribution (2), or both horizontal and vertical distribution (3) and (4).

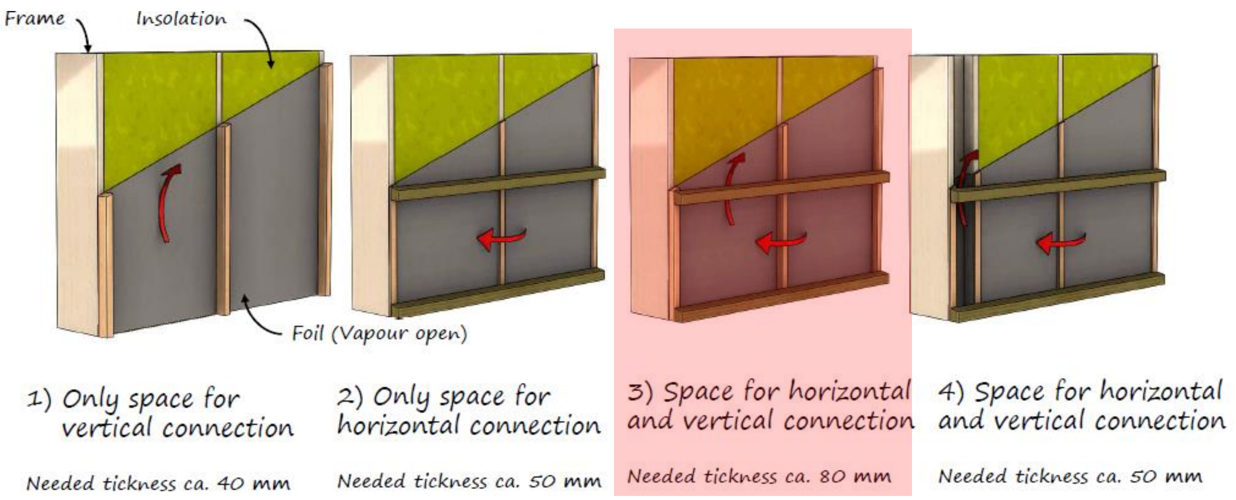


Figure 2.2 – Space for hydraulic coupling

The facade claddings are mounted on the frame by means of U-profiles, as shown in Figure 2.3. The U-profiles are first screwed to the wooden battens used to distance the frame from the cladding.

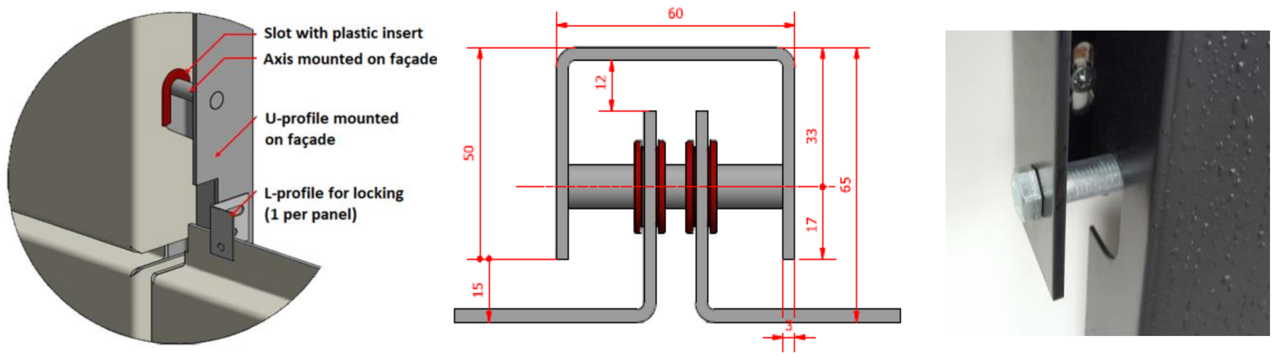


Figure 2.3 – Mounting system of the facade cladding to the frame, by means of U profiles (From Deliverable 3.6)

When façade claddings also serve the purpose of solar collectors, they can be connected in series with a flexible pipe, as shown in Figure 2.4 (on the right). This operation can be carried out in the factory, leaving to the site activities only the connections with the main distributions

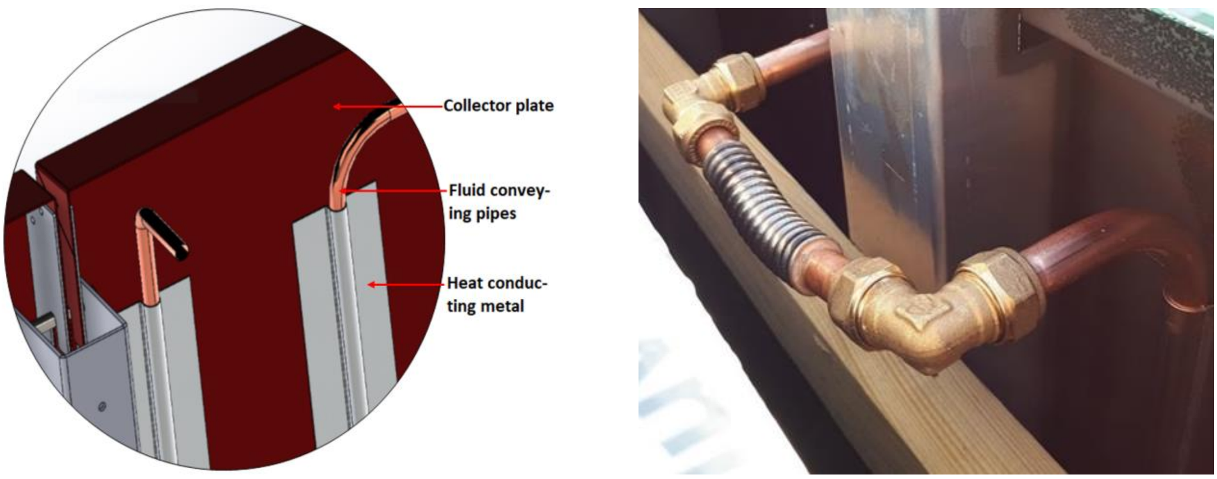


Figure 2.4 – Distribution and detail of the connection between adjacent panels (on the right) (From Deliverable 3.6)

2.2 The ENVISION Module – The innovative technologies

This paragraph briefly presents the technologies developed in ENVISION that are integrated into the modular façade system. As mentioned at the beginning of the chapter, every technology is described providing the necessary information for their maintenance, as well as their installation diagrams in order to identify the best solutions for their integration with the existing MEP systems of the building.

2.2.1 Solar collectors

The solar collectors, both uncovered and covered, developed within ENVISION differ from the commercial ones exclusively for the surface coatings, realised with the purpose of enhancing the absorption capacity of the collectors in the field of Near-Infrared Radiation, seeking a compromise between aesthetic appeal and absorption.

Consequently, compared to traditional collectors, heat production occurs at lower temperatures that, on the one hand, prevents the risk of damage to parts of the system susceptible to high temperatures (>90°), i.e. sheaths, on the other hand, in order to reduce the heating consumption of the building, make necessary to couple the collectors to a low temperature emission system (< 60°), which often entails the use of heat pumps for heat production. Alternatively they can be used to reduce consumption for the production of domestic hot water.

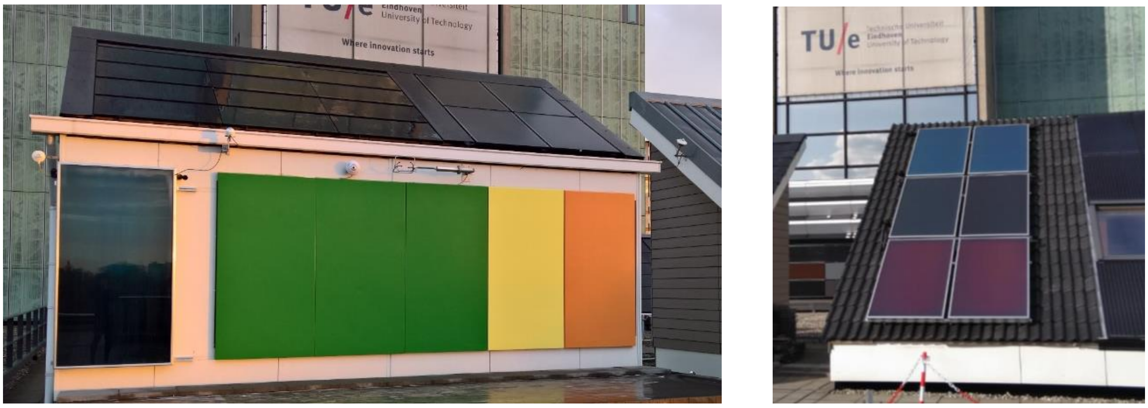


Figure 2.5 – Facade heat collectors series 1, from left to right: green with CWO, with ATO and without NIR absorbing pigments, yellow with ATO, orange with ATO (From Deliverables D3.1 and D3.2)

From a technical point of view, the same considerations applicable to conventional solar collector systems are valid. The installation requires: a heat storage tank, circulation pumps, valves, temperature sensors, a heat exchanger, volume flow meter etc..

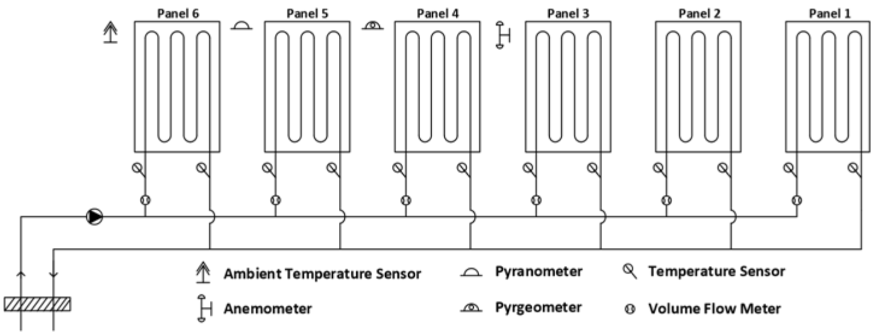


Figure 2-6 - Schematic representation of the solar thermal measurement infrastructure for series 1 (From Deliverables D3.1)

The panels can be connected either in series or in parallel, depending on the temperature and the flow rate required, without any particular constraints imposed by the geometric configuration of the façade (Figure 2-7).

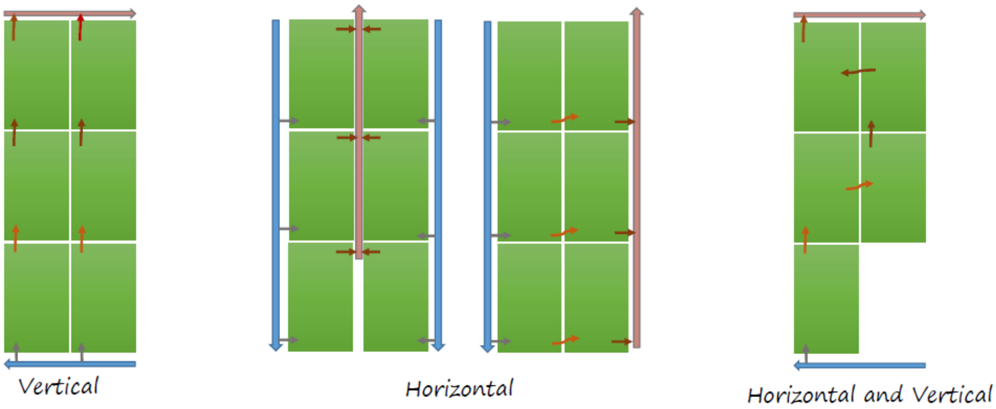


Figure 2-7 - Positioning of solar collectors in the facade and possible distribution schemes

With regard to maintenance, the panels require periodic (yearly) cleaning, not only to preserve the absorption capacity of the facades, but also to comply with aesthetic requirements. Moreover, again on an annual basis, it is necessary to check the pressure of the solar circuit, verify the control and safety devices, as well as undertake the necessary checks in order to prevent changes in pH and of the freezing point of the carrier fluid (the antifreeze liquid must be replaced every 4-6 years).

Compared to traditional panels, due to the relatively low temperatures reached, the interruption of the circulation of the vector fluid consequent to the possible breakage of the control unit or the circulation pump, does not involve the risk of overheating of the panels.

However, it is necessary to control the correct functioning of all elements essential for the operation as well as the control and the monitoring of the hydronic system (circulation pump, temperature probes, modulating valves, flow meters, etc.).

2.2.2 Ventilated window and heat exchanger

The solution is based on integration of a NIR (near infrared radiation) absorbing glass layer in the triple glazed unit, creating a ventilated chamber enabling circulation of air. The air warmed in the cavity between the glass panes can be used for heating purposes or/and for supporting the production of domestic hot water.

During summer, the warm air is funnelled through ducts fixed to the ceiling over an air-water heat exchanger. The heat released to the water can then be piped to a storage tank for domestic hot water production while, in winter mode, heated air is directly distributed inside the building thus supporting heating system.

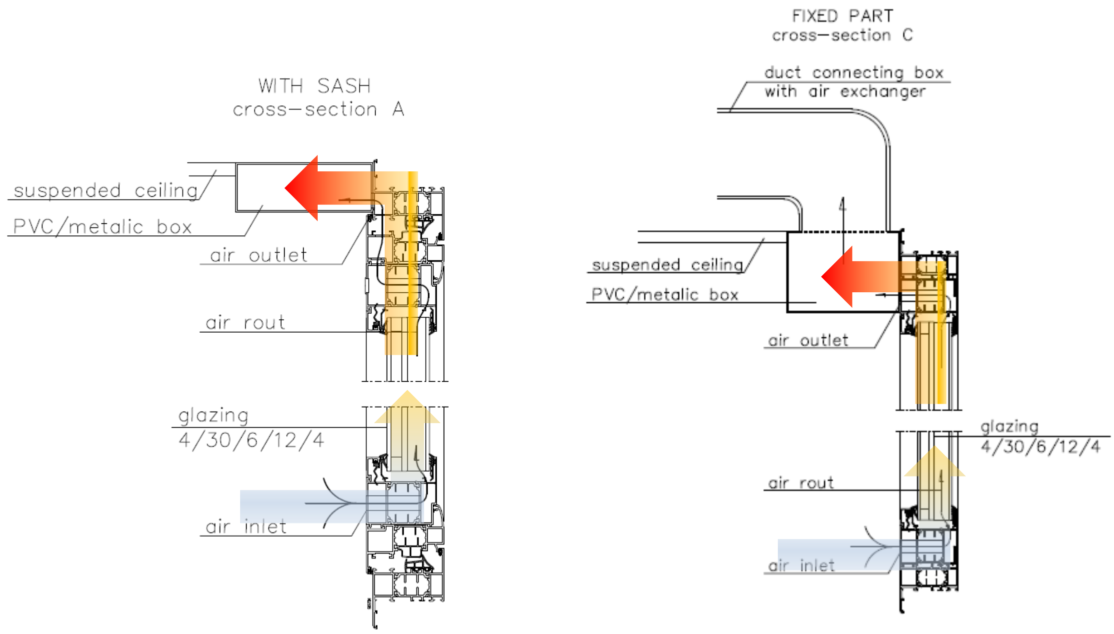


Figure 2-8 - Vertical section – window and duct connection (D2.3 Prototype and report on Ventilated window design)

As for the solar collectors seen in the previous paragraph, heat production occurs at relatively low temperatures. This implies that, in order for the system to be fully exploited and to reduce the heating consumption, it needs to be coupled to an emission system at low temperature (< 55°C). Alternatively, they can be used to reduce consumption for the production of domestic hot water.

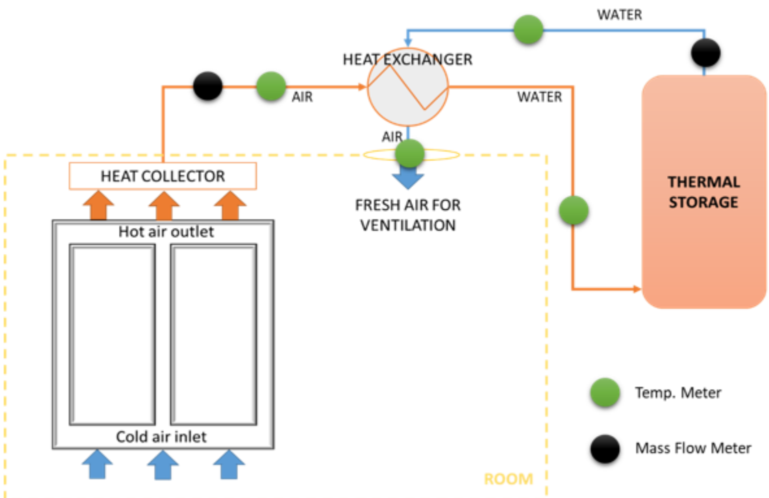


Figure 2-9 – Ventilated window – Summer functional scheme. In winter mode, the warm air is directly introduced into the apartment.

For the proper operation, the system is completed with the following additional components: Fans, Circulating pumps, Throttles, Monitoring devices (temperature sensors and volume flow meter) and a storage water tank.

Figure 2-10 – Ventilated window – Hinged glazing to allow the cleaning of the ventilated cavity

With regard to maintenance, In order to control the temperature sensor and remove any dust deposits and any traces resulting from the condensation, the ventilated cavity is expected to be openable and cleanable (Figure 2-1010).

Similar to what observed for solar collectors, it is necessary to control the correct functioning of all elements essential for the operation and the control and the monitoring of the hydronic and aureulic system (circulation pump, fans, heat exchenager, temperature probes, modulating valves, flow meters, etc.), that have to be easily inspected.

2.2.3 PV active glass

PhotoVoltaic (PV) Harvesting Glass involves the integration of a photovoltaic glass within an Insulating Glazing Unit (IGU). The Insulating Glass Unit can potentially be coupled to most commercial frames, once the necessary modifications to accommodate the cables have been implemented.

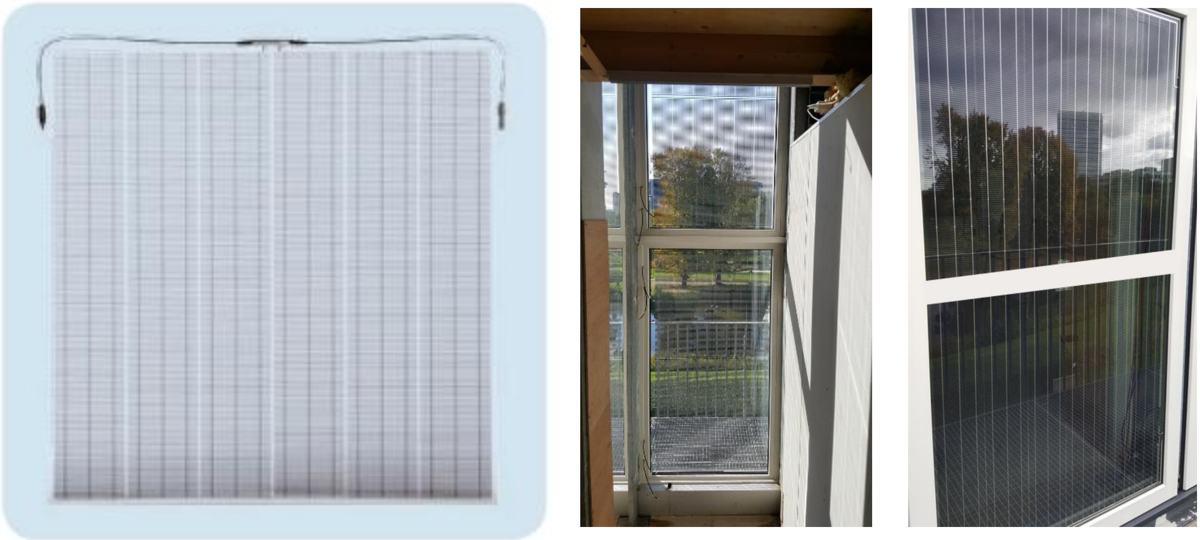


Figure 2-11 – *PhotoVoltaic (PV) Harvesting Glass (From Deliverable D3.4)*

An important aspect to keep in mind, highlighted in Deliverable D3.4, that can seriously affect PV glass performance is the shading due to both the frame (Figure 2-12) and the façade cladding.

In the choice of the frame with which to couple the PV glass, it is essential to prefer those with the smallest thickness. Similarly, when it comes to defining the facade module, it is important to install the photovoltaic window as close as possible to the outer edge of the facade cladding.

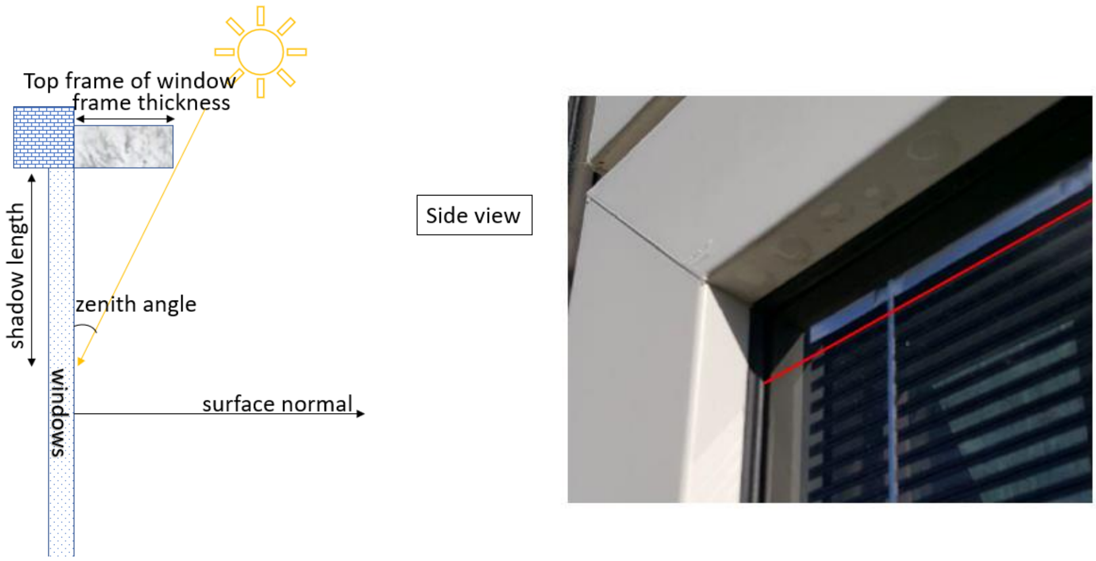


Figure 2-12 - Sketch of side-frame shading length model (From Deliverable D3.4)

With regard to maintenance and cleaning, as the photovoltaic panel is installed in a vertical position, any possible dirt accumulation is not expected to affect the glazing performances. However, based on NSG's experience on BIPV, PV windows should be cleaned at least 1-4 times a year (it depends on a number of parameters like location, orientation and the detailed construction). Should the windows not be openable, cleaning has to be possible from the outside.

In addition to cleaning the PV glass, the inverter is also a crucial element in the operation of the system. It is the device through which solar energy is converted into electricity. In addition, it is responsible of the monitoring of the entire system and ensures that it operates at maximum performance levels. Unless a fault occurs, it has to be checked every ten years.

3 Design approach with the ENVISION system

This chapter aims to describe how the ENVISION system should be used in the context of deep renovation projects. Accordingly, interventions that only involve the installation of individual elements developed within the project will be omitted, to focus instead on the ones requiring the integration of all the technologies within the modular system developed by Emergo, as well as their integration with the existing building and its systems.

After the identification of the building typologies that, given their characteristics, represent the ideal demonstration scenario, the design process for the definition of the best possible configuration of the modular façade system is described. Throughout the individual steps of such process, all the requirements, constraints and issues that represent the drivers for the definition and customization of the facade system, will be addressed and resolved.

3.1 ENVISION concept design process

Once defined the technological system and the components to be embedded in the ENVISION envelope concept (addressed in chapter 2), the next steps have to be taken:

- ✓ Step 0 - Identification of the building object of renovation;
- ✓ Step 1 – Identification of the boundary conditions.

  This phase is aimed to characterize the building, identifying its structural elements and all those relevant factors and requirements that can affect the design of the façade modules and the overall renovation project. Among these are included:

  - Openings;
  - Structural elements (slabs, cavity walls);
  - Load capacity of structural elements (slabls, roof beams)
  - Load-bearing capacity of foundations
  - System requirements

- ✓ Step 2 – Identification of baselines

  This phase identifies baselines for the design of the new envelope system of the building. Based on boundary conditions, the concept design uses these elements as guidelines to design the module that will constitute the ENVISION envelope system (Figure 3.8).

- ✓ Step 3– Modules design

  This phase is articulated in two different sub-phases, to better answer to building boundaries and project expectations, and a third possible moment up to detail the design on the building as well as distance between factory of module manufacturing and site of installation:

  - Phase a - primary modules design

    On the base of the previous phases, the first modules to be designed are the one that depend on the elements that will not change during the renovation process. This is the case of modules that need to be designed on the reference of openings (windows, doors) (Figure 3.14 - a)

  - Phase b - secondary modules design

    Once designed the primary modules, the other modules (defined as secondary) will be designed to complete the envelope. In this context all the modules are designed to be in line with KPI (U value if the envelope, Weighted Sound Reduction Index), expected by the renovation process, the orientation and geo-cluster area of the building (Figure 3.14 - b). Within these modules the following components could be included:

- PV components;
- Solar thermal components;
- HVAC system's ducts
- Other components

- Phase c - modules aggregation design (possibility)

  The modules as defined in the previous phases, can be here aggregated to decrease the number of modules that will be installed on-site. Usually, independently of the dimension of the units, 15/17 units are installed in a daily work. The modules aggregation is mainly related to specific building design solution to be provided or on distance reason. Indeed, manufacturing the module far from site where they will be installed does not make advantageous the logistic management of transport and increase the cost for exceptional transport in case of dimension out of standard truck and vertical transportation of the unit. As a rule, the unit should never be greater than a rectangle of 13 m x 3,8 m in size.

✓ Step 4– Identification of the interventions on the building and the existing systems

In this phase, which occur in parallel to the previous one, any necessary modifications to the building and the existing systems are identified. The integration with ENVISION systems and the placement of additional components in the building as well as the integration of ventilation ducts, pipes and cables in the facade package is defined.

3.1.1 Identification of the building object to renovation

The ideal target of ENVISION are residential buildings characterized by (1) a level of thermal insulation inadequate to current standards, (2) not an excessive degree of complexity of the facades and (3), availability of internal spaces for the installation of the necessary ancillary components to integrate RES with the existing systems (i.e. tank, heat pump..). Single and Terraced houses built before the 1990s are therefore the context that shows the lowest limits to the ENVISION implementation, even though it can still be easily adapted to apartment Block and Multi Family houses, where, on the one hand, the presence of larger facade surfaces can potentially ensure greater benefits, but, on the other, the lack of available interior space can be a major obstacle.

Figure 3-1 –Building typologies across Europe (from TABULA project)

According to the objectives of this chapter, the design process will be described for the case of Terrace Houses with sloping pitched roofs, a widespread typology in Northern and Western Europe.

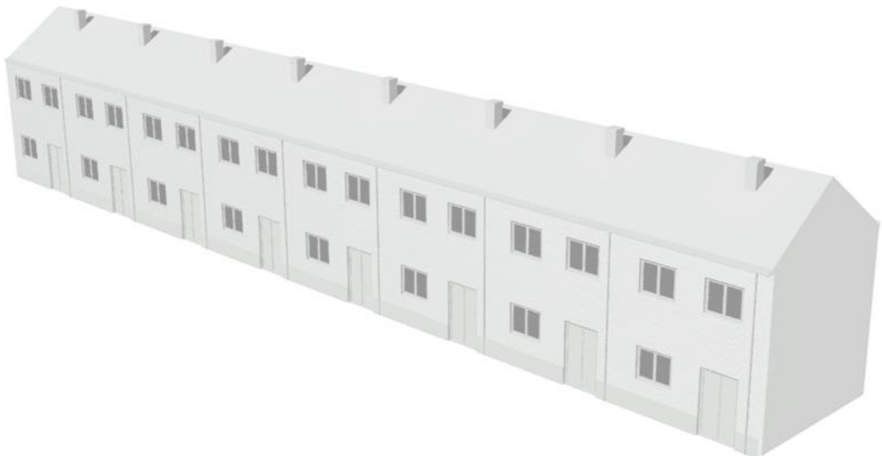


Figure 3.2 – Terraced houses, chosen as ideal building typology on which to show the design approach with Envision

Although regular terraced houses are the ideal housing type to define the guidelines for the application of the system under development, it is however possible to adapt ENVISION also to other types of buildings, keeping the general validity of the process described in this chapter 3.2. Paragraph 0 will show what adjustments and modifications are necessary for this purpose.

3.1.2 Identification of the boundary conditions

This phase, of analysis and investigation of the building, is dedicated to the identification of all the constraints and the requirements that may affect the design of the façade using the ENVISION system. They can be categorized as follows:

- Structural boundaries
- Architectural-distributive boundaries
- HVAC systems requirements
- Other technical requirements

3.1.2.1 Structural boundaries

Structural system has a central part in the envelope design. Before any preliminary study on the envelope solution to be adopted, it is crucial to have the certification on structural stability and the load capacity of the building subject to renovation. The realization of a new cladding system that can include different technological components has its own load and it is important to know if the building can bear this weight. Two different scenarios can be identified:

- the existing structure is able to bear the loads of the new façade system;
- the existing structure is not able to bear the load of the new façade system.

If the existing structure is suitable to support the façade loads, there aren't particular problems in envelope installation except for fixing mechanisms dimensioning and positioning. On the other hand, the case of the existing structure without load bearing capacity needs to be more deeply analyzed, even though it does not exclude the intervention of renovation. In principle, with regard to structural aspects, it is possible to identify two categories of facades (AEE – Institute for Sustainable Technologies, 2010):

- **Façade load on existing structure** – the load capacity of the existing structure is enough to transmit the load of the façade to the foundation. Calculation of foundation capacity should be considered with two possible solutions:
  1. Not reinforced foundation – the existing foundation has the capacity to support the increased load of the new I;
  2. Reinforced foundation – the existing foundation is enlarged to support the increased load of the new façade
- **Self-standing façade** – the load capacity of the existing structure is not enough to transmit the load of the façade. A structure that could support the façade should be designed and realized, unloading on:
  1. Existing foundation – the existing foundation has the capacity to support the load of the new facade;
  2. New foundation – a new foundation for the façade structure is created.

Hereafter (Figure 3.3) both the case of a self-standing I on new foundation and of a I fixed on existing structure are schematically shown.

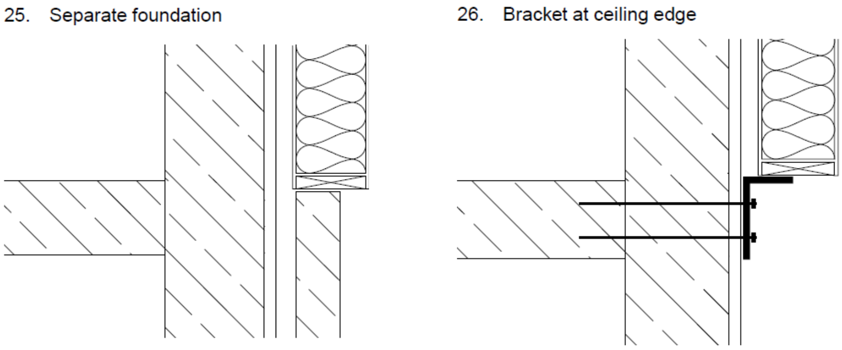


Figure 3.3 – Self-standing I on new foundation (on the left) and I fixed on existing structure (on the right) (Lattke, Larsen, Ott, & Cronhjort, 2011)

It should also be added that, while in the case of a load-bearing outer walls the existing envelope have to necessarily be maintained, which implies the need for the precise measurement of openings, in the case of a frame structure (Skeleton) is even possible to consider the partial or total demolition of the building envelope.

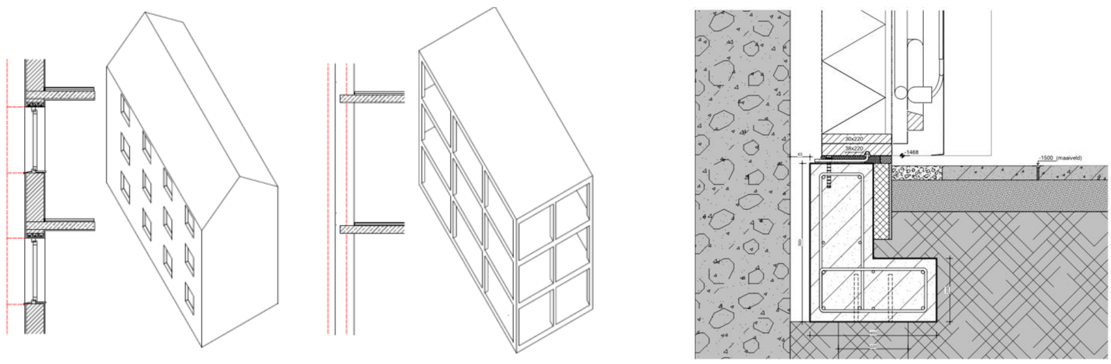


Figure 3.4 – On the left: Comparison between Load bearing outer walls and a skeleton structure with infill (Lattke, Larsen, Ott, & Cronhjort, 2011). On the right: detail of the foundation node for the case under investigation.

For the demonstrative purposes of this report it has been assumed that the existing structure is not suitable to bear the vertical loads imposed by the new façade. It is therefore necessary to create a new foundation (Figure 3.4 – On the right).

The issues arising from the interaction with existing structures have been further explored more in detail in the paragraph 3.1.5.2 (Structural reinforcing interventions and definition of the anchoring elements to the existing structures)

3.1.2.2 Architectural-distributive boundaries

Once the structural constraints have been analyzed, it is necessary to be aware of the distributive architectural constraints that condition the ENVISION system. It is therefore necessary to detect:

With regard to the design of the modules:

- The precise position of the openings
- Any irregularities on the facade
- Any architectural patterns to be preserved

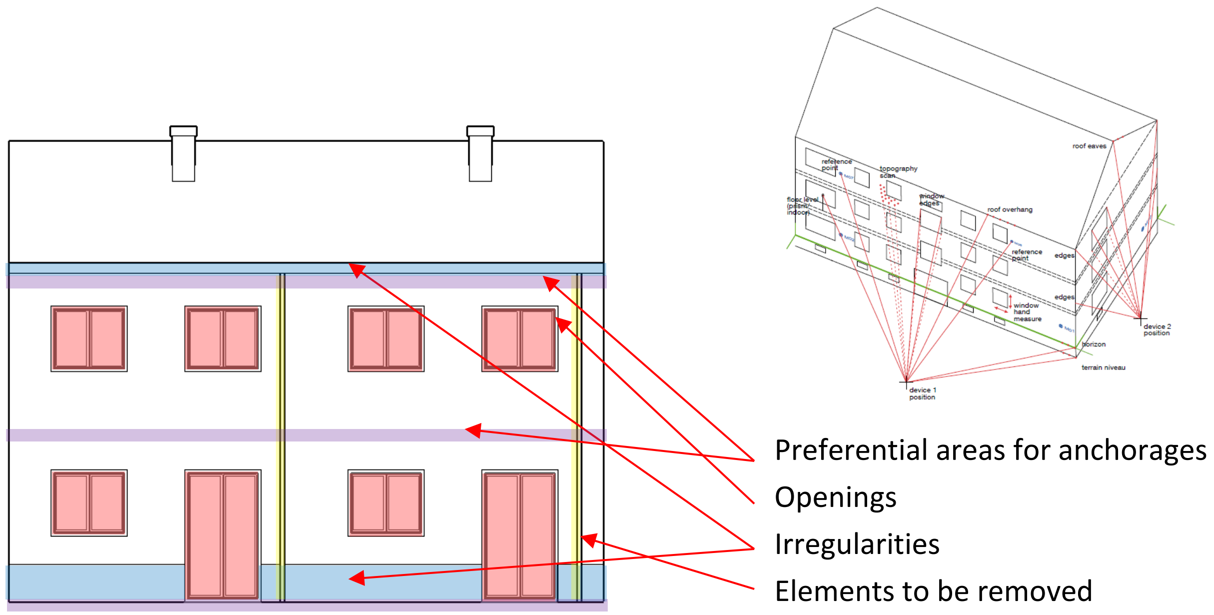
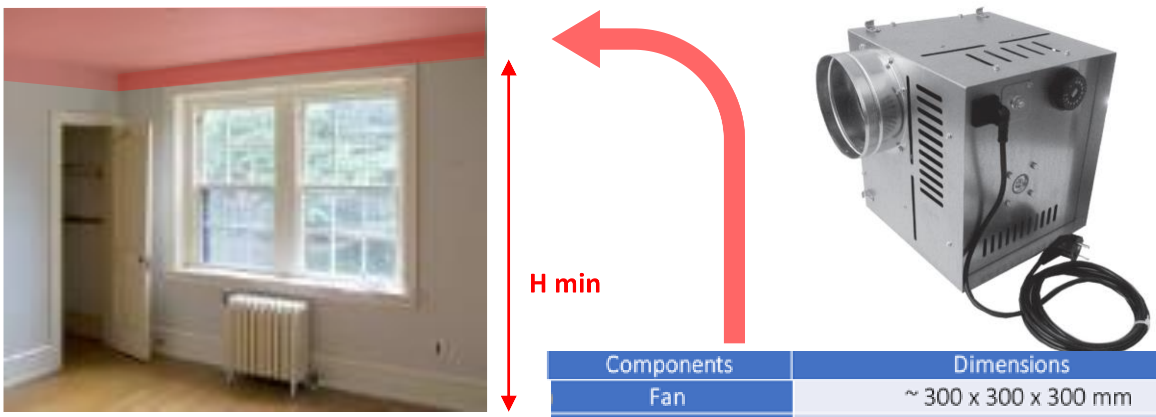


Figure 3.5 – Identification of the boundary conditions and, on the right, critical points of the façade survey

To this end, the façade survey must provide the precise position of all the critical points necessary for the geometric definition of the envelope.

With regard to the installation of the ventilated windows in particular, it is necessary to verify that**:**

- the space between the upper transom of the windows and the ceiling is adequate for the positioning of the elements necessary to deliver the heat recovered from the windows to the heat exchanger. These elements are mainly fans, pipes and throttles whose dimensions are reported in the Deliverable D2.3;
- the resulting ceiling height (H min) after the installation of the above-mentioned ancillary elements are compliant with local hygiene regulations.



Components	Dimensions
Fan	~ 300 x 300 x 300 mm
Heat Exchanger	~ 750 x 600 x 300 mm
Pipes/tubes	d 150/250 mm
Throttle	~300 x 300 x 250 mm

Figure 3.6 – Identification of the boundary conditions for the installation of the ventilated windows

3.1.2.3 Building HVAC system requirements

The application of building integrated solar technologies can reduce or eliminate the fossil fuel needs for energy consumption of buildings. Building integrated solar thermal systems are often part of a more complex heating, ventilation and cooling (HVAC) system, which in turn is part of a larger system, i.e. the building itself.

Hence, when talking about the integration of energy generation technologies in building envelope to achieve high energy efficient buildings, process should take into consideration additional aspects such as:

- buildings existing or needed HVAC system that could benefit from this outcome;
- building space that is needed in order to optimize the energy generation and building energy loads or load matching (space heating, DHW or electrical loads);
- the existence of any district scale energy (thermal/electrical) network were the energy produced by buildings can be consumed;
- existing national regulation about the possibility to deliver to the grid the generated energy (electrical) power.

Briefly, these are the main aspects that should be taken into consideration:

Output temperature range of solar thermal collectors and potential application in building HVAC

Solar thermal collectors deliver heat to a heat transfer fluid, which in the case of building integrated solutions is air or water/water solution. This fluid is heated to a certain temperature depending on the collector technology. In ENVISION, fluid is heated at a relatively low temperature, both in the case of solar collectors and ventilated windows. Consequently, the best strategy to make the most of the heat produced is to store it in a storage tank and then use it as an energy source for the heat pump dedicated to heat the apartment or to produce domestic hot water.

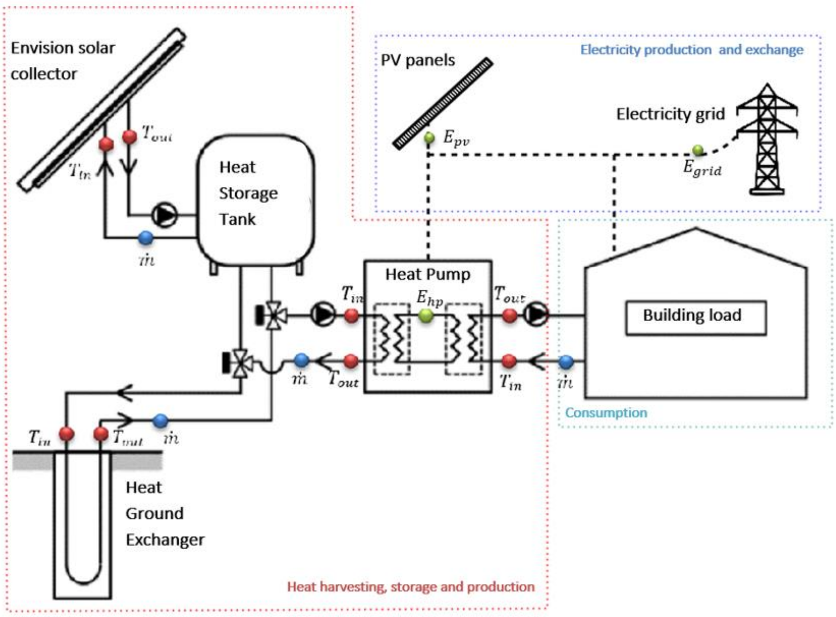


Figure 3.7 – Hypothetical scheme for the integration of the renewable energy systems with the MEP existing system

Typically, in order for heat pumps to work with high COP levels, it is convenient that the heat emission occurs at relatively low temperatures (<55°), which would imply that the use of radiant panels is preferable in comparison to radiators.

Building space availability requirements to deploy the overall system

In order to be able to fully benefit from all the installed technologies, it is necessary to verify the presence of available space in order to allow the integration of the following components:

- hot storage tank for domestic hot water;
- a buffer storage for heating distribution;
- possibly pumps, expansion vessels and tanks for the solar thermal system;
- the inverters of the photovoltaic systems;

Additionally, the installation should consider all the distribution pipes through the building, pumps, etc.., although part of pipes and fittings can be easily placed inside the ENVISON modular façade, avoiding wall trenches inside the building. Hence, in buildings originally designed with decentralized HVAC facilities, installing a central HVAC system without cost-intensive construction costs to modify the building layout is often impossible. Even in buildings already equipped with a central HVAC system, the technical room, which has been designed compatible with the original heating installations, may not offer the space required to install new systems.

3.1.2.4 Technical requirements

Fire prevention – regulated by European standards only partially, it depends largely on national regulations and technical guideline. The most important aspects for ENVISION envelope system are:

- hazard of fire-growth and smoke spreading along façade modules
- hazard of fire-growth and smoke spreading caused by installations, ducts and resulting penetrations of fire-sections.

To face the fire prevention issue, some measures can be studied:

- layout of building (not subject to ENVISION intervention);
- constructional measures (physical structure, materials, etc.)
- technical measures (fire detection systems, sprinkler systems, fire dampers, claps…)

Sound insulation – objective is the prevention of sound transmission between adjoining room, sound from outdoor and sound emission of technical systems installed in façade. The following measures contribute to improve sound insulation:

- massive and heavy components;
- air tightness.

Thermal insulation – the thermal performance is the sum of new envelope solution with the existing façade. The final performances need to be in line with local norms for envelope. Of particular concern is the careful study of condensation and ventilation between old and new façade, that should be subject to specific evaluation.

3.1.3 Identification of baselines

3.1.3.1 Preliminary façade design

At this point, starting from the inputs obtained from the previous phase, it is possible to define the preliminary design of both the façade and the overall harvesting system, which will be the basis for the engineering of the façade system and the definition of each individual prefabricated module, as well as the detail elements.

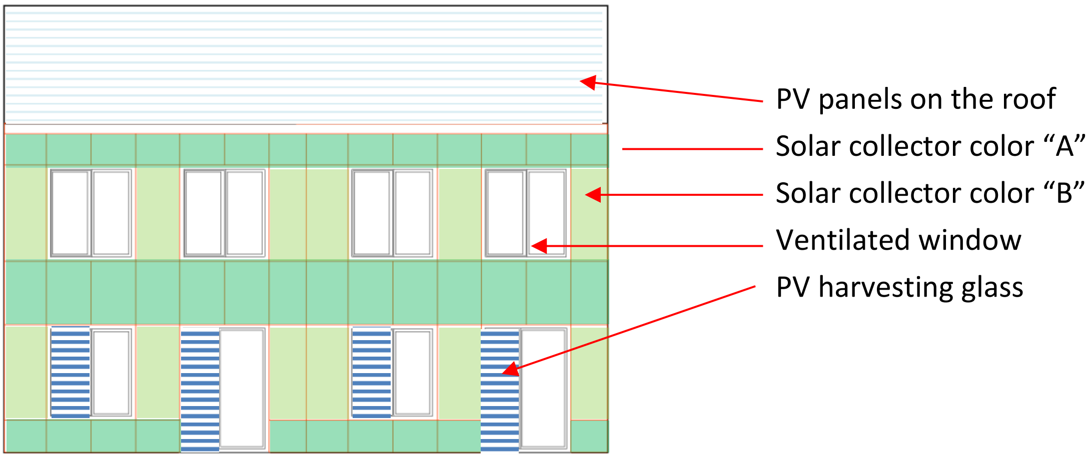


Figure 3.8 – Baseline – Preliminary design of the façade

For the sole purpose of illustrating the process, it is assumed that the building analysis has revealed that each apartment is equipped with an independent heating system with radiant panels and that there is the possibility to obtain, in the basement, the technical space for all the accessory plant components, such as: the heat pump, a buffer storage for heating distribution, pumps, expansion vessels and the tank for the solar thermal system.

The general scheme for the integration of renewable energy systems is shown in Figure 3.12, while the piping distribution in the façade modules is depicted hereafter (Figure 3.9):

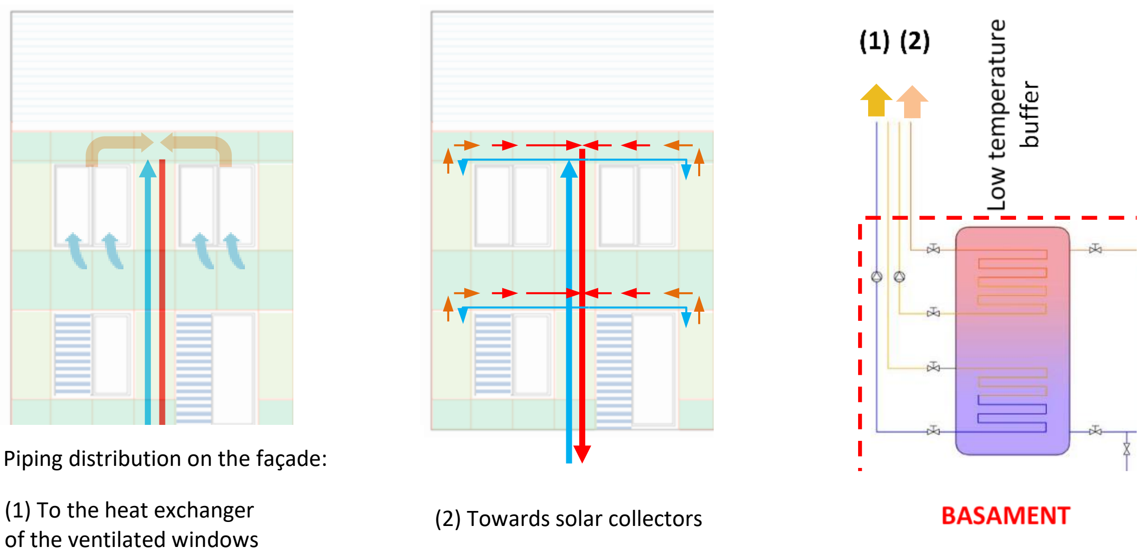


Figure 3.9 –Piping distribution in the façade modules

As previously stated, the preliminary design of the façade defined in this phase is based on all the constraints and requirements identified in the previous step. Therefore, among the aspects that need to be addressed at this stage there are also:

- The definition of the structural scheme and the preliminary verification of the load-bearing elements
- The definition of the required thermal and acoustic insulation, fire protection, water and air tightness performance (KPIs)
- Identification of the appropriate locations for the installation of the photovoltaic panels and solar collectors, also according to the survey of the building's environment conducted at the previous step

It has been assumed that on the ground floor there isn't the necessary height for the duct passages above the windows. Coherently, it has been decided to install the ventilated windows on the first floor and the photovoltaic ones on the ground floor.

3.1.3.2 Preliminary design of the integration with the MEP systems

The project for the integration of RES systems with existing MEPs mainly depends on the layout of the solar collectors and, more generally, on how to exploit the heat produced by them and by ventilated windows (during summer).

Ideally, solar collectors can be used for both heating and domestic hot water production, combined with heat pumps or modulating boilers, in semi-centralized or autonomous centralized systems.

Considering that the water temperature produced by the solar collectors is expected to range between 10 and 30°C, the most promising system is the coupling with a heat pump for low temperature heating systems.

A solution that has become more and more successful in recent years is the connection "in series" between heat pumps and solar systems: the energy collected by the solar collector is stored in an inertial tank in the form of low-temperature heat. When necessary, it is transferred to the evaporator of the machine. This solution has the advantage of lower installation costs compared to geothermal heat pumps, which can be further reduced thanks to the possibility of using low efficiency solar panels.

On the other hand, however, the discontinuity of the solar source has made it necessary to use additional sources: for this purpose, dual source heat pumps (water and air) have been introduced or, in other cases, solar field has been combined with geothermal probes.

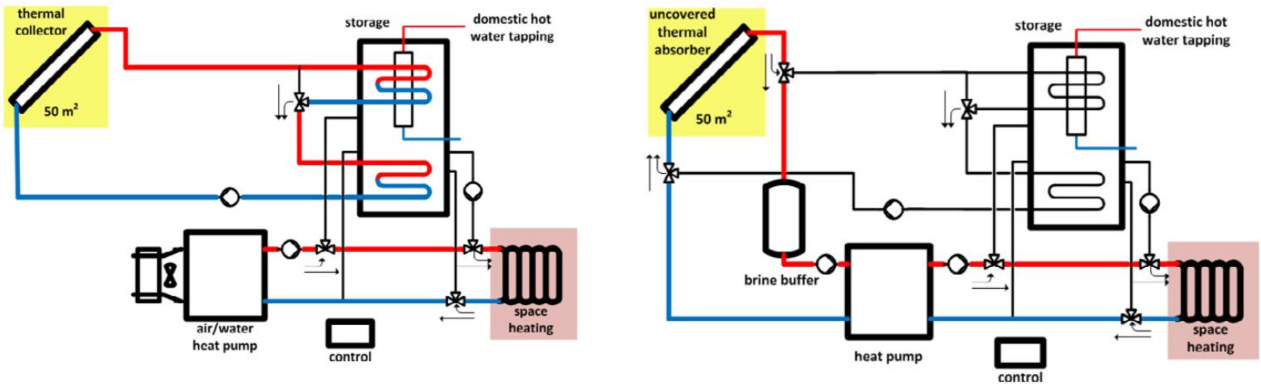


Figure 3.10 – System and hydraulic schemes of combinations heat pump-solar collector for low temperature production (Dott, Genkingera, & Afjeia, 2012). Direct solar heat generation (on the left) and uncovered thermal absorber with heat pump (on the right)

Among the many possibilities analyzed in literature (Dott, Genkingera, & Afjeia, 2012) the latter appears to be the solution that best suits the case of solar collectors developed in ENVISION, precisely because of the low temperature at which the heat is recovered. Since the energy made available by the two sources, solar and air, has the same trend during the year, the performance of the system will be quite low during the winter period, when the heating demand is higher.

For this reason, several studies have treated heat pump systems with geothermal as well as solar sources. One of them (Bakker, Zondag, Elswijk, Strootman, & Jong, 2005) discusses both performance and cost of a hybrid solar system combined with a geothermal heat pump (Figure 3.11).

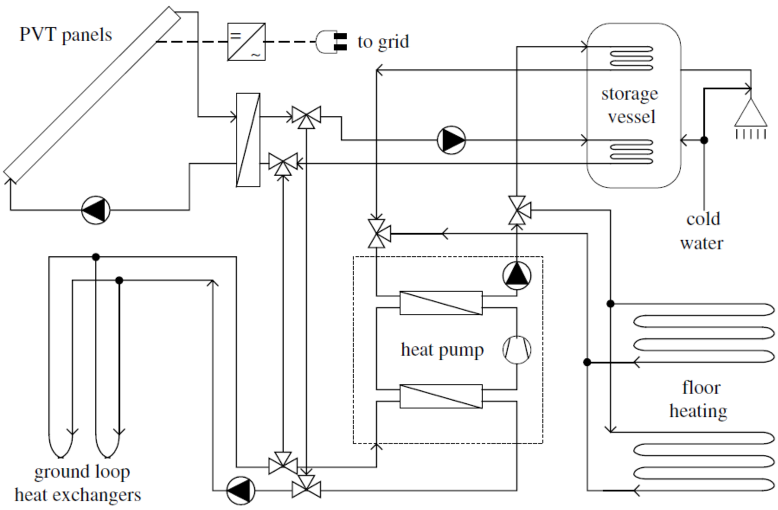


Figure 3.11 –Heat thermal array combined with a ground coupled heat pump (Bakker, Zondag, Elswijk, Strootman, & Jong, 2005)

Similarly, the proposed solution consists in storing the heat absorbed by the solar collectors and the ventilated windows (in summer) in a double serpentine buffer, and then transferred to the ground-source heat pump evaporator, used for heating and production of domestic hot water.

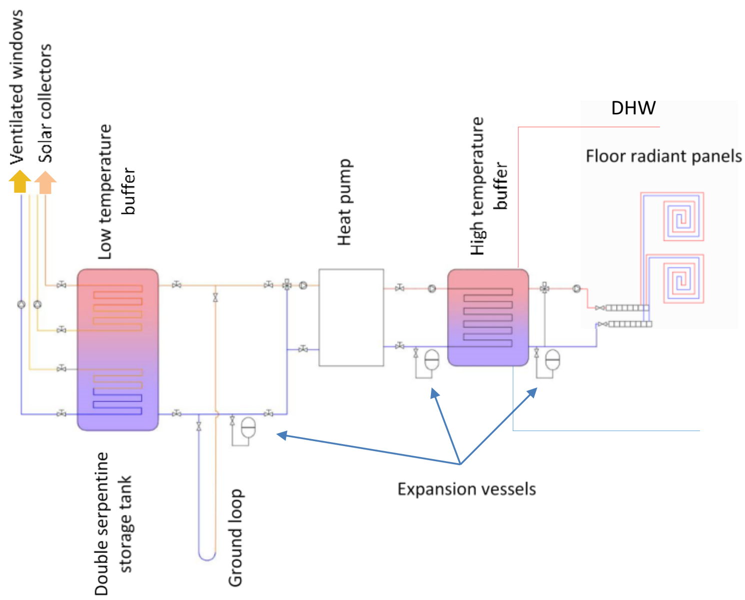


Figure 3.12 – General scheme for the integration of renewable energy systems

The setting of the solar circuit is essentially based on the use of differential temperature controllers. The devices in use are:

- a controller that allows to set the desired temperature difference (ΔT);
- two sensors to detect the temperature of the panels and the storage tank, at the height of the solar circuit coil

If, between the panels and the tank, the sensors register a temperature difference greater than the setpoint (ΔT) of the controller, the solar circuit pump is activated, otherwise it remains off.
For the calibration of differential temperature controllers, it is advisable to use ΔT values variable from 5 to 8°C. Such temperature ranges are necessary to adequately consider:

- of heat losses that occur along the solar circuit pipes;
- the need to have (so that a significant heat exchange occurs) a thermal jump of a few degrees to the storage tank connections;

The circuit (deliverable D2.4) of the system connected to the ventilated windows is adjusted in the same way:

- The fan is activated when a fixed ΔT between the temperature of the glass chamber and the temperature of the heat exchanger is reached.
- The water pumps are activated when a fixed ΔT between the temperature of the heat exchanger and the storage temperature at the height of the lower temperature coil is reached.

After the low temperature storage tank, the evaporator of the heat pump exchanges heat with the ground loop and the storage tank. The amount of flow from both sources is regulated by modulating valves according to the storage and ground loop temperatures.

An interesting alternative, shown in Figure 3.13, foresees the possibility of recharging the ground, if (1) the temperature of the storage tank is higher than 30° and (2) the temperature of the outlet temperature of the solar collector is higher than both the temperature of the storage tank and of the ground.

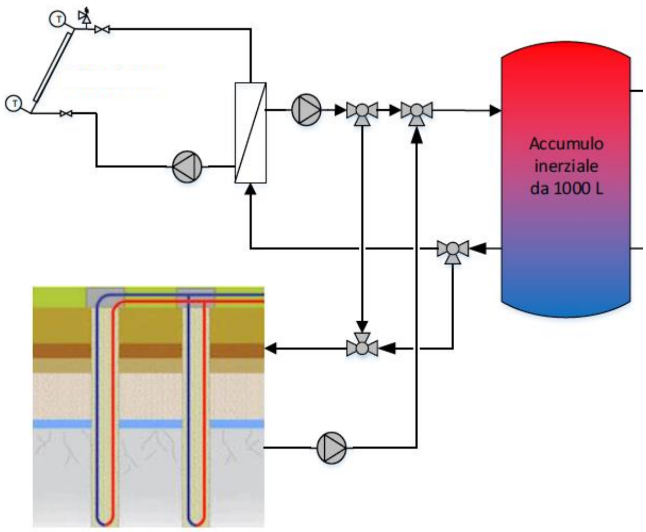


Figure 3.13 – General scheme for the coupling of solar collectors and geothermal probes with ground recharge

3.1.4 Module design

In this phase the individual modules are studied in detail. In order to ensure compliance with the boundary conditions, the façade is first subdivided into minimum units, starting with the definition of the modules that include the openings (primary units – Figure 3.14 - a) and then moving on to the definition of the remaining modules (secondary units – Figure 3.14 - b). The minimum units can then finally be combined to obtain the façade modules, based on the structural and logistical constraints (module aggregation – Figure 3.14 - c)

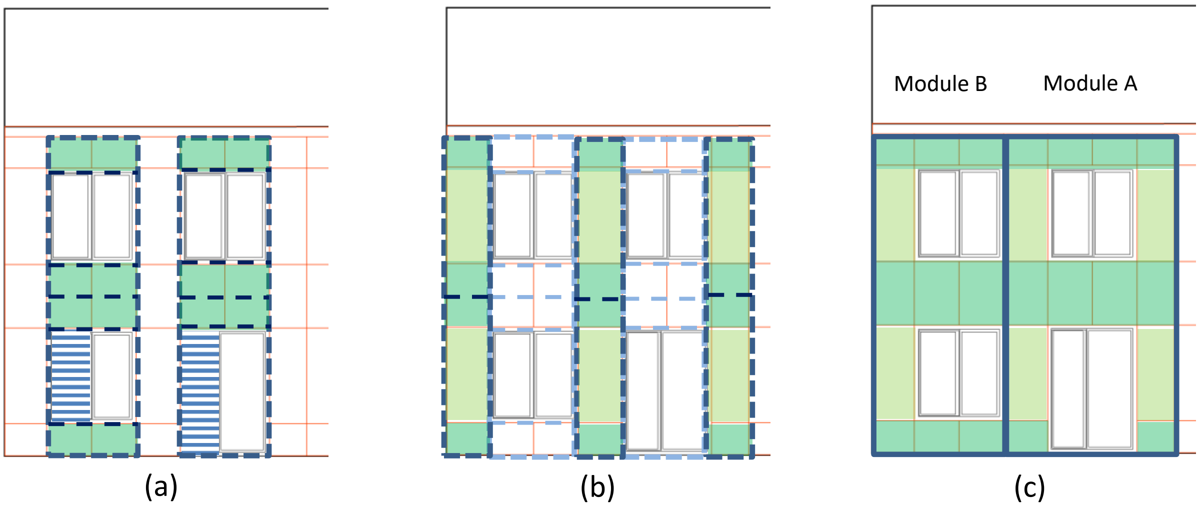


Figure 3.14 – Module design: a) Primary units design, b) Secondary units design, c) Module aggregation

The next step consists of (1) the integration of the system elements (pipes, pumps, valves, cables...) in the façade, which must be consistent with the general design defined in the previous step, and (2) the identification of the panels that have to be easily removable in order to allow the periodic maintenance of such elements.

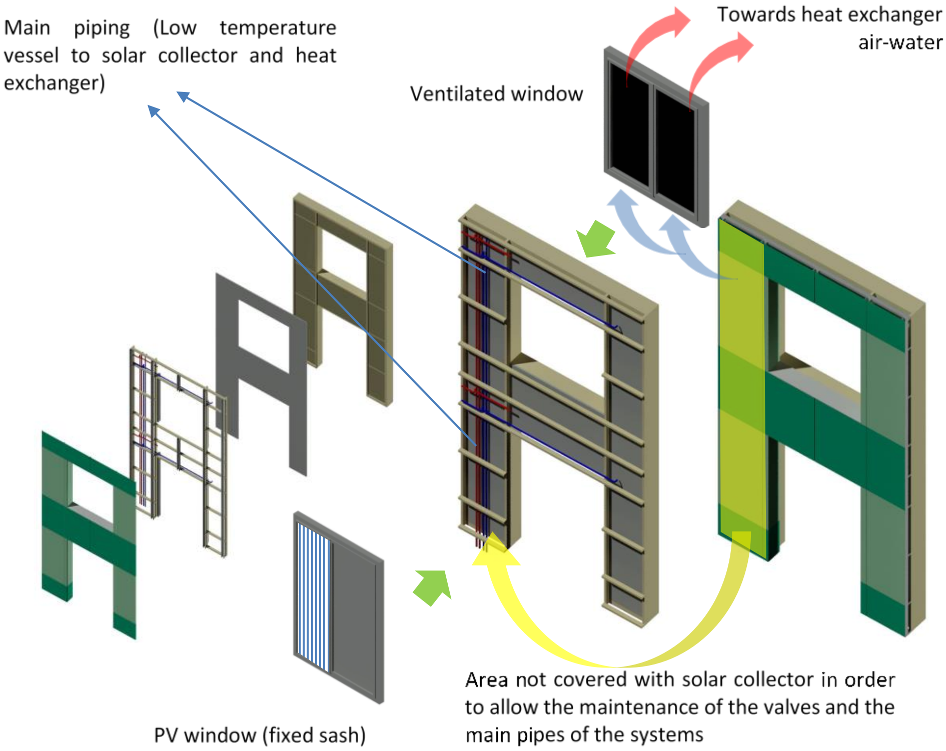


Figure 3.15 – Module A - Identification of the wooden frame, the solar collectors and the main systems components

Figure 3.15 and Figure 3.16 show the positioning of the flow and return pipes for the solar collectors and the water-air exchanger of the ventilated windows. The front panels (highlighted in yellow in Figure 3.15), as they have to be easily removable, are not solar collectors, even though they present the same aesthetic treatment as the other panels.

As we will see below (paragraph 3.2) the assembly of these panels to the facade module is foreseen on site, at the end of the assembly of the modules to the facade and the end of execution of the final tests of the systems. The other panels are expected to be preliminarily assembled at the factory to minimize the operations on site.

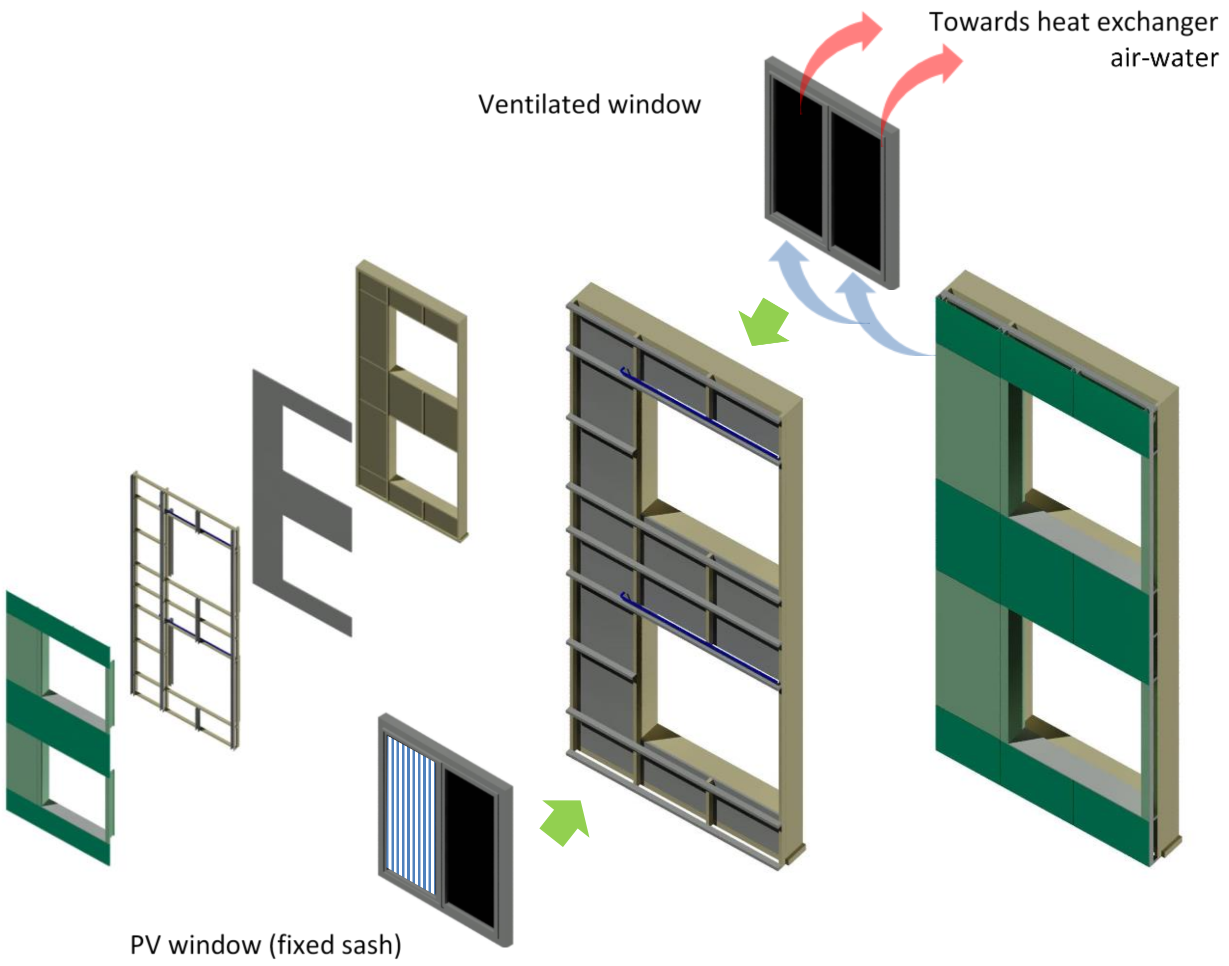


Figure 3.16 – Module B - Identification of the wooden frame, the solar collectors and the main systems components

3.1.5 Interventions on the exiting building and systems

This paragraph is dedicated to the analysis of the interventions to adapt the systems and the existing façade needed to install the ENVISION modular system. As for the façade, the interventions to be carried out, in chronological sequence, are the following:

- Preparation of the envelope surfaces (Paragraph 3.1.5.1)
- Structural interventions (Paragraph 3.1.5.2)
- Holes execution for cable and pipes crossings (Paragraph 3.1.5.3)

Afterwards, the interventions linked to the integration with the existing systems are described in paragraph 3.1.5.4.

3.1.5.1 Preparation of the envelope surfaces

This activity consists in the removal of all irregularities that can affect the coplanarity of the facade, such as plaster swellings on the façade, gutters and decorative bands and it is an essential preliminary activity to the installation of the facade modules.

In order to ensure the minimum tolerance required for the installation of the modules, they are distanced from the facade. The resulting cavity between the existing wall and the TES element needs to be filled by an adaptation layer which can be fixed to the back of the panel before assembly, in which case a compressing force must be applied to the panel during the installation, or blown in once the installation is complete.

Figure 3.17 – Adaptation layer made by a rockwool panel attached on the back of the module (on the left) and through the injection of insulating foam (on the right)

Likewise, in the case of the roof, weak elements and irregularities affecting the coplanarity of the surfaces (tiles, slate sheets) must be removed before the installation of the roof modules.

3.1.5.2 Structural intervention

The structural interventions to be considered are the reinforcing interventions of façade bearing elements and the fixing of the anchor brackets.

Among the objectives of the preliminary survey activity, the structural characterization of the existing building is a priority in order to define any possible reinforcing interventions of the existing structures, the anchorage points and the anchoring system, as well as the size, and therefore the maximum weight, that each single module can have.

Typically, the loads to be considered for the definition of the load-bearing elements and anchors are:

- Vertical loads: own permanent weight (+ snow)
- Horizontal loads: from wind pressure
- Horizontal and vertical - from earthquake, parallel and orthogonal to façade plane
- Loads during the assembly process and different stages of completion

The different typology of mounting of the facade elements can be classified as follows:

- Hanging: elements are hung down from the construction. Vertical loads are collected on top of the building.
- Storey wise mounted: elements are mounted at the head of the ceiling or into the wall.
- Standing: the vertical load of the elements is lead into the existing construction or a separate foundation at the bottom of the building.
- Storey wise standing: the elements stand storey wise on the ceiling.

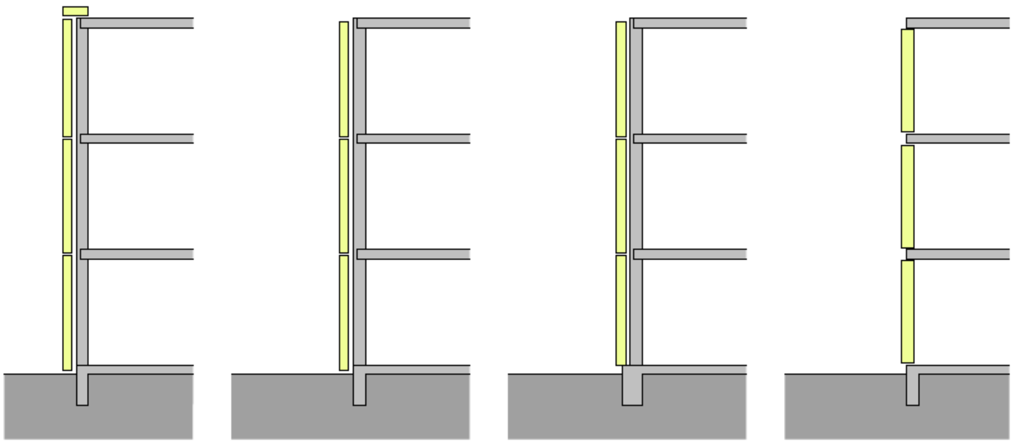


Figure 3.18 – Typology of mounting. From left to right: a) Hanging, b) Storey - wise mounted, c) Standing, d) Storey - wise standing

As already mentioned in paragraph 3.1.2.1, in the case analysed it has been assumed that the loads of the facade modules are transferred to a separated foundation (Figure 3.4) and that modules are anchored to the slab edge of the roof by means of angle brackets.

The following figure shows (a) the simplified static scheme of the Fixing System, (b) the 3d model of the connections and (c) the detail of the module anchorage to the slab edge of the roof.

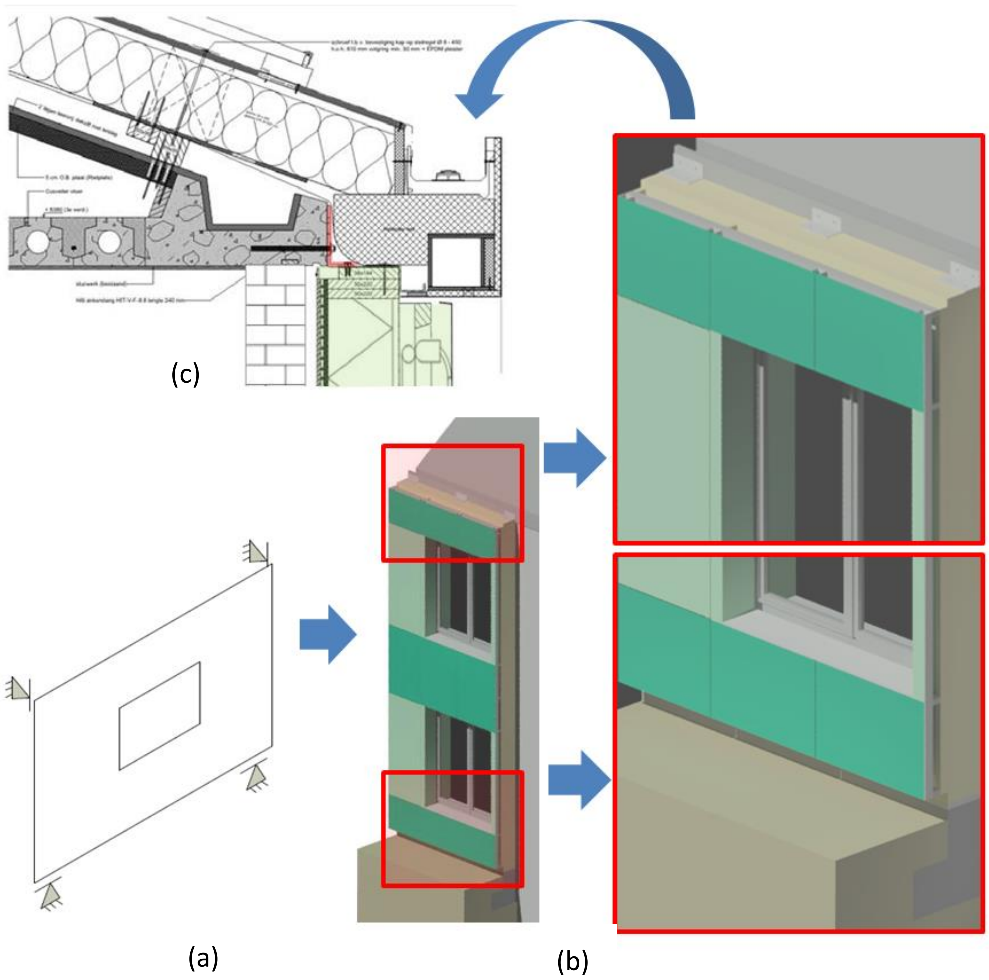


Figure 3.19 – (a) Simplified static scheme of the Fixing System, (b) 3d model of the connections and (c) Detail of the module anchorage to the slab edge of the roof

3.1.5.3 Cable and pipes crossings

Other interventions on the walls to be considered before the installation of the facade modules are the holes executions for cable and pipes crossings. Specifically, it is necessary to consider:

- The holes executions for cable and pipes crossings, close to the air-water heat exchanger for heat recovery from ventilated windows (Figure 3.20 detail n°1)
- The holes executions for cable and pipes crossings, close to the low temperature storage tank in the basement (Figure 3.20 detail n°2)

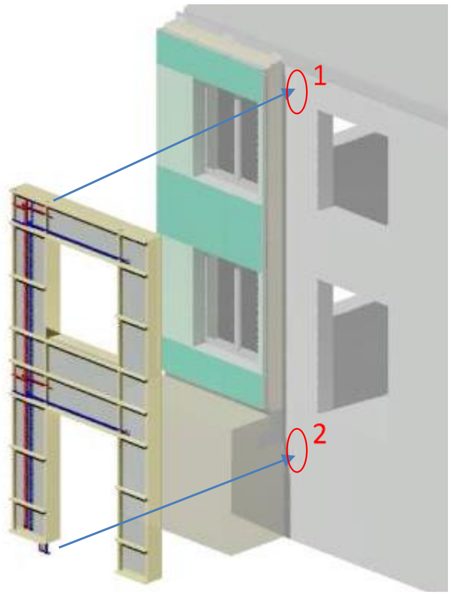


Figure 3.20 – Cable and pipes crossings

3.1.5.4 Modifications to existing HVAC systems

Finally, it is necessary to consider the modifications to be made to the existing systems for their integration with the façade systems. Concerning the electric system, the only peculiarity is related to the connection with the integration of the Photovoltaic panels. The scheme is qualitatively shown in Figure 3.21

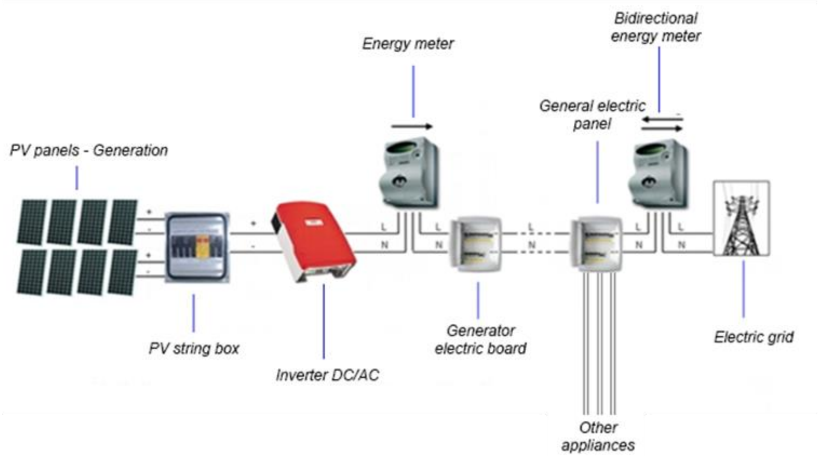


Figure 3.21 – Electrical system – Integration with PV panels

The inverter converts the electricity produced by the solar array from direct current (DC) to alternating current (AC) for domestic use while an energy meter measures the energy produced by the solar array. Then the energy can be either used in the houses or, in case there is no demand for it, sent to the electric grid. Therefore, there aren't any particular changes to be made for this purpose.

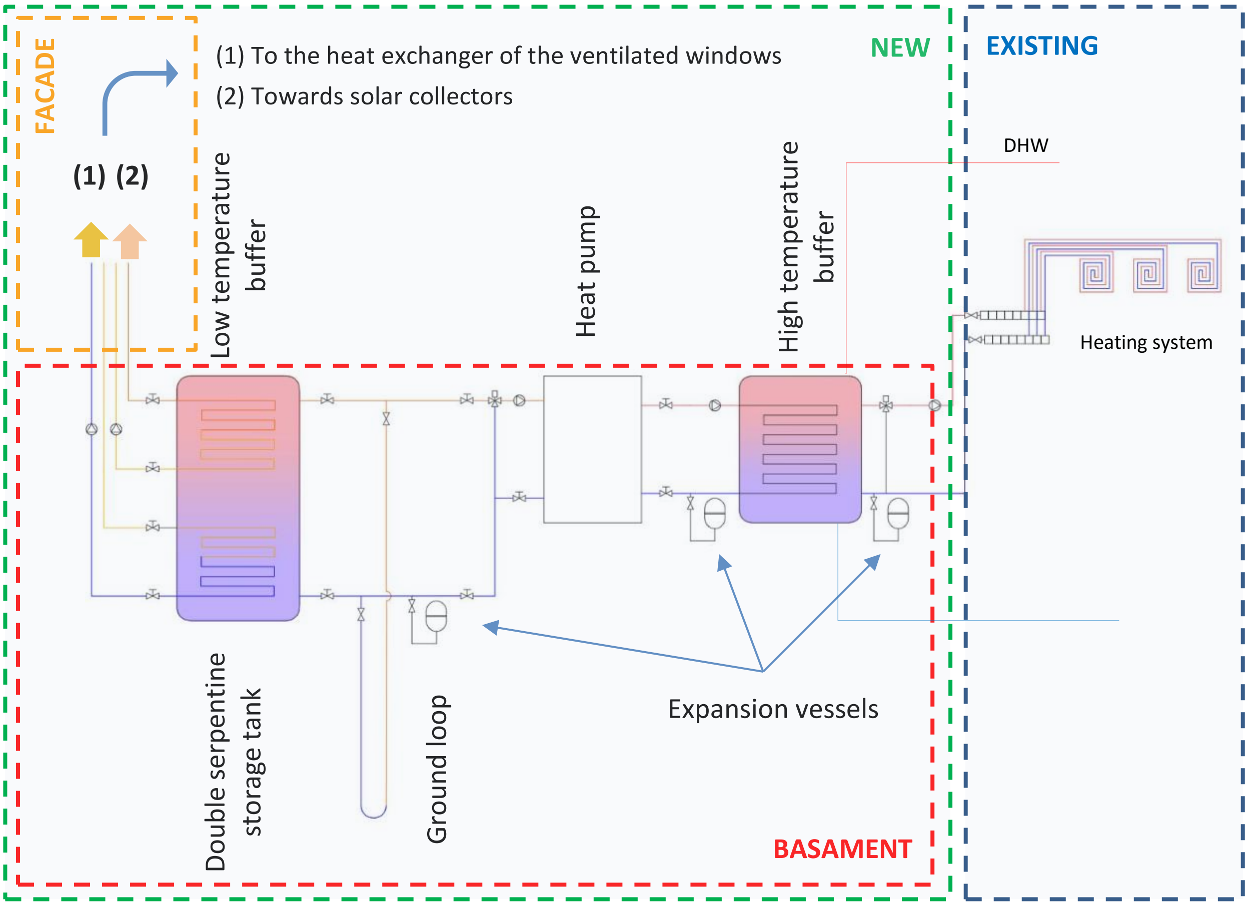


Figure 3.22 – General scheme for the integration of the new RES systems with the existing heating system

As already noted, the integration of solar collectors and ventilated windows presents a greater design degree of discretion. Assuming to be dealing with a heating system that has heat emitters at low temperatures (<55°) the choice that has been proposed here is to store the heat absorbed by the solar collectors and ventilated windows in a double serpentine buffer, which is the low temperature heat source for the heat pump that provides hot water for the heating system (Figure 3.22).

In this case the interventions are:

- the replacement of the generation system
- the realization of the ground loop

In the case the existing heating system involves the use of high temperature emitters (60 - 90°), the intervention should also consider the removal of the radiators and the installation of floor or wall radiant panels.

3.2 The Assembly

This paragraph briefly describes the procedures for the installation of the façade system. The activities can be divided into the following phases:

1. Execution of the interventions on the building and on the existing systems, analysed in paragraph 3.1.5, which are preparatory to the installation of the panels and of the RES systems integrated in the facade, as well as the removal of the existing windows
2. Installation of both the façade and the roof modules
3. Completion of system connections of facade systems and installation of all the ancillary components for the integration with the MEP systems (fans, ducts, heat-exchanger, storage tanks...)
4. Completion with missing facade elements and installation of the finishing elements between the different modules (e.g. finishing elements between façade and roof modules)

Prior to any other activity, scaffolding must be erected in front of the facades where ENVISION panels are to be installed. In order to allow the passage of the panels, it is necessary to maintain a distance of at least 50 cm between the scaffolding and the façade. This means that parapets must also be built on the inner side of the scaffolding. In addition, the scaffolding must be fastened to the ground and braced.

The figure below shows the assembly phases of the main facade modules and the following roof modules.

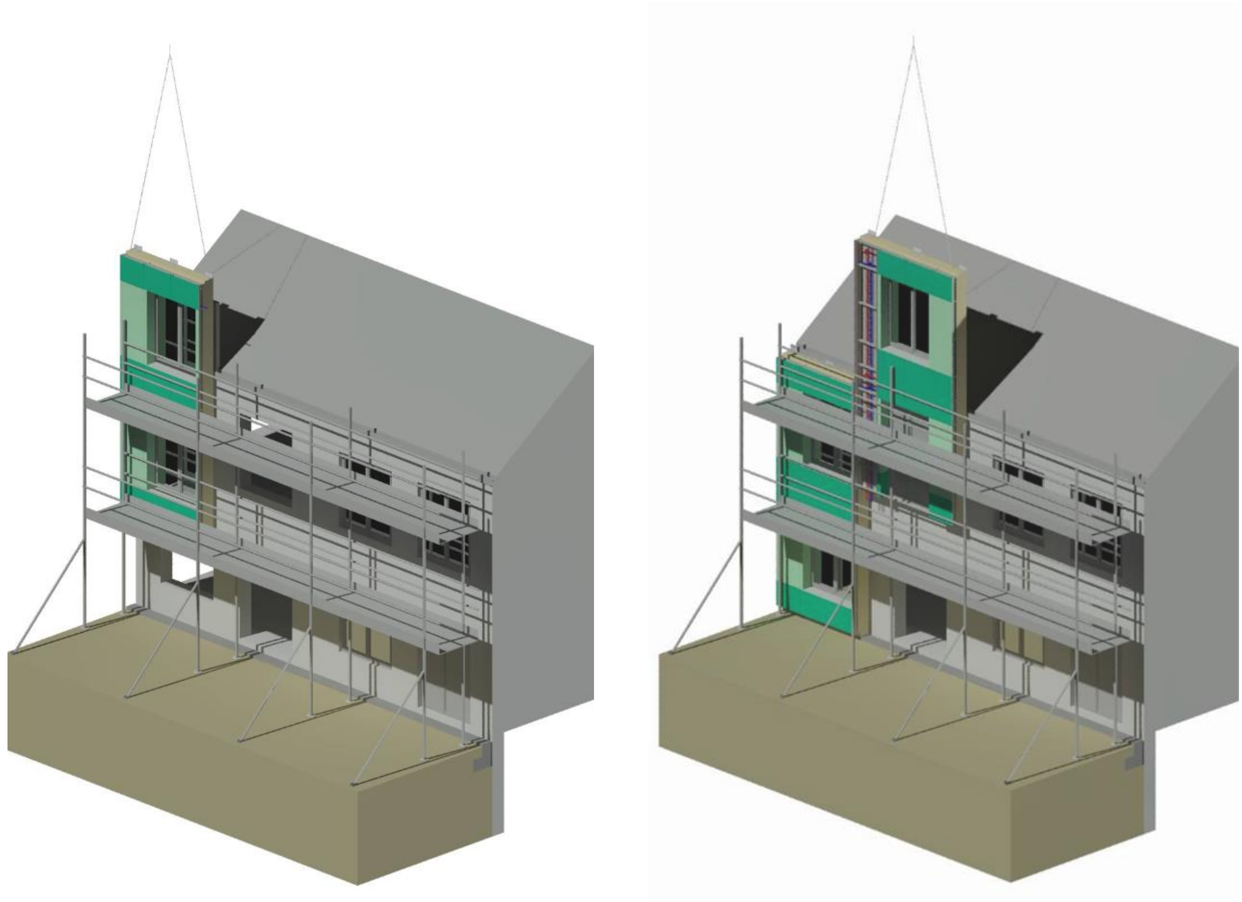


Figure 3.23 – installation of the envision system. mounting of the main facade modules

To ensure that the roof modules can be easily mounted in its correct final position, wooden tracks are first fixed to the existing roof, which prevent the modules from sliding during assembly.

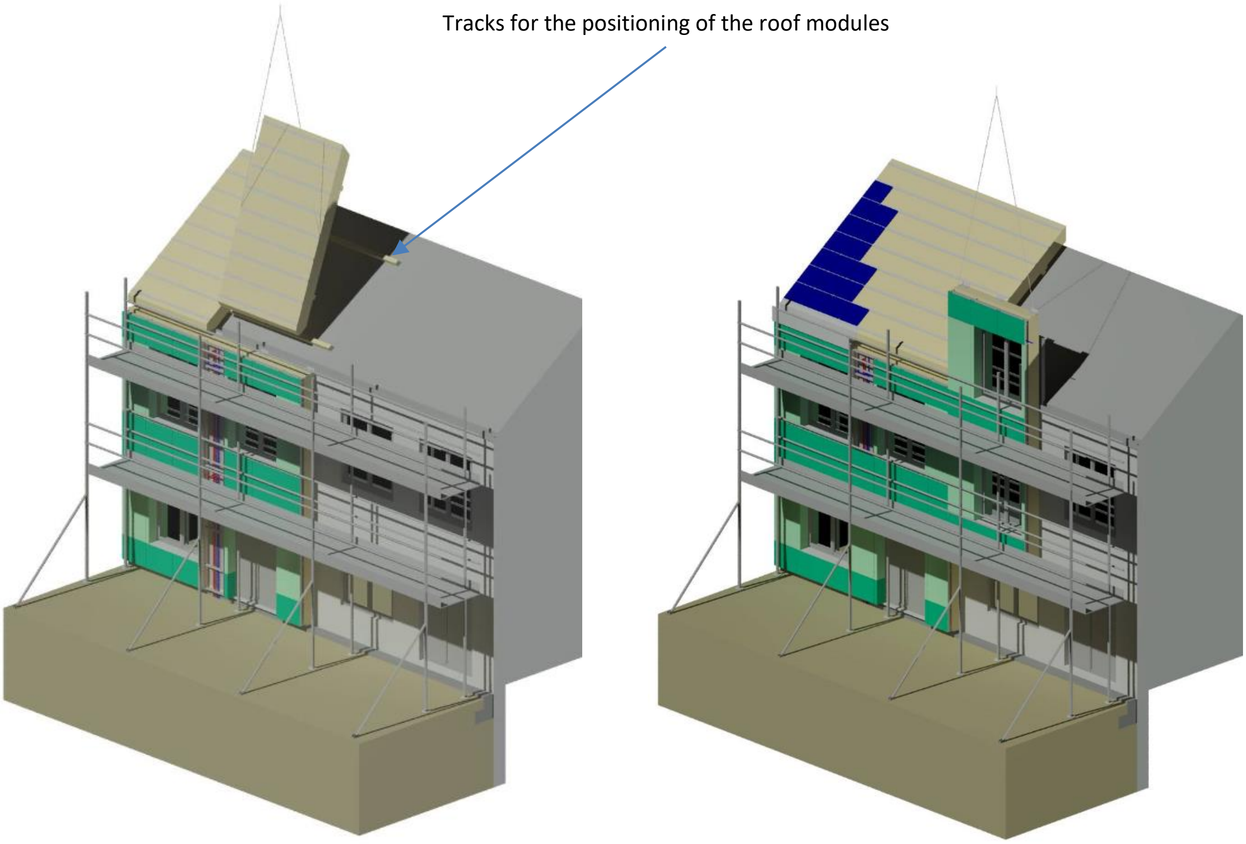


Figure 3.24 – installation of the envision system. mounting of the roof modules and installation of the finishing elements

Once this phase has been completed, it is then possible to complete the system connections, including those located inside the building (installation of ventilation ducts for ventilated windows, fan and heat exchanger installation...) and complete the facade with all the missing finishing elements (i.e. the completion of the roof-facade joint, the photovoltaic panels on the roof and the panels closing the piping distribution).

Figure 3.25 – installation of a timber roof modules (Emergo website)

3.3 Maintenance of the system

In order to maintain the façade system, in line with the specific maintenance requirements of each technology, some facade elements, in particular those covering the main piping distribution, have to be easily removable and to allow the periodic inspection of the more vulnerable components.

All other equipment subject to periodic maintenance and cleaning, located inside the building, either on the ceiling or in the basement, must be easily inspected and reachable.

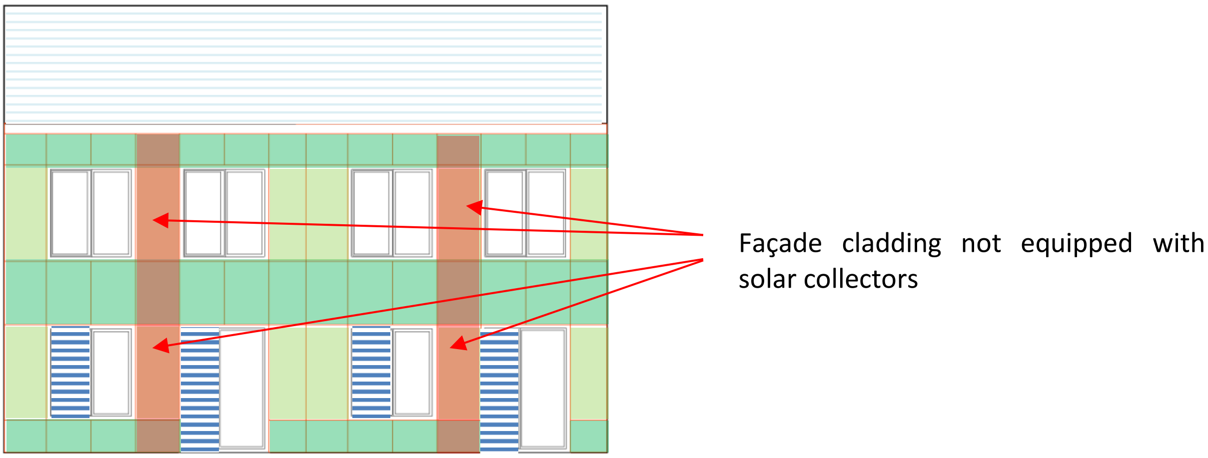


Figure 3.26 – Positioning of the easily removable panels

Maintenance and cleaning of facade elements should be done by means of a proper system allowing the operator to work comfortably at the height of the elements to be maintained. In the case of the two-storey building analysed, such maintenance can easily be carried out by means of mobile elevating work platforms.

Figure 3.27 – Mobile elevating work platforms (on the left) and anti-fall system on the roof (on the right)

In order to ensure the safe maintenance of the photovoltaic panels on the roof, a dedicated anti-fall system, integrated with the roof modules, must be installed in the context of the renovation works.

3.4 Monitoring of the system

This paragraph is dedicated to the identification of the parameters to be monitored and the relative sensors to be installed in order to:

- allow the proper operation of the systems,
- evaluating the energy benefits of the harvesting module and the single technologies
- check the possible degradation of their performances

Concerning the hydronic circuit of the solar collectors:

For the purpose of both circuit tuning and the evaluation of the benefits of the individual technology, inlet and outlet temperatures and flow rates of at least each group of solar collectors connected in series have to be measured.

.

With regard to the aeraulic and hydronic circuits of the ventilated windows:

For the purpose of both circuit tuning and the evaluation of the benefits of the individual technology, temperature inside the ventilated window chamber, inlet and outlet air and water temperature of the heat exchanger, as well as flow rate of air and water in the circuit have to be measured

It is also necessary to measure the temperatures in the water tank at both coils (Ts1 and Ts2 in Figure 3.28).

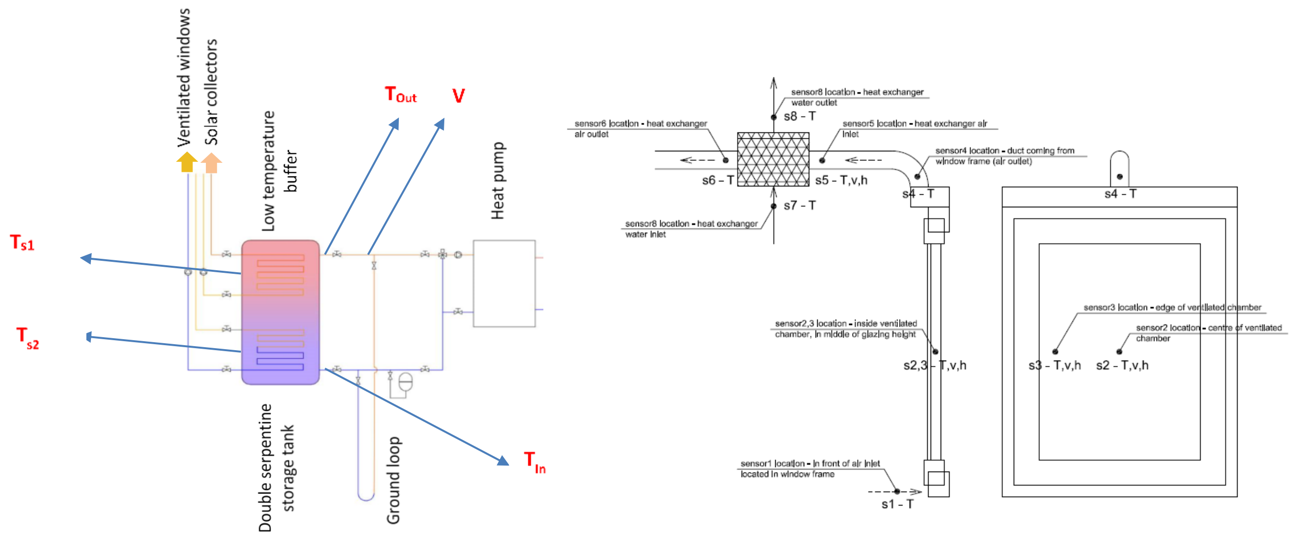


Figure 3.28 – Sensors to be installed. Low temperature storage tank (on the left) and ventilated window (From Deliverable 2.4 - on the right)

In addition, for both hydronic circuits, even if not necessary for the tuning of the systems, in order to monitor the degradation of the solar field performance it is also advisable to keep track of the in-plane solar irradiance, the in-plane longwave irradiance and wind speed (all directions).

Finally, in order to be able to effectively assess the share of energy produced by the Envision system actually absorbed by the heat pump evaporator for heating the housing unit, it is necessary to measure the flow rate and the inlet and outlet temperatures from the low temperature storage tank (V, T_{Out} and T_{In} Figure 3.28).

3.5 Adaptation to other building types

The purpose of this paragraph is to demonstrate how the Envision system can also adapt well to other building types than the one identified in this chapter (Terraced houses) and to define the process to be followed during the design with the ENVISION system.

Figure 3.29 shows the building types potentially targeted by Timber Façade Systems. The considerations raised in the previous paragraphs remain valid also for all the schemes identified, where the adoption of the ENVISION system is eventually limited only by (1) the inadequacy of the existing structures in supporting the loads resulting from the façade and (2) the lack of room for the components that the integration of solar collectors and ventilated windows requires.

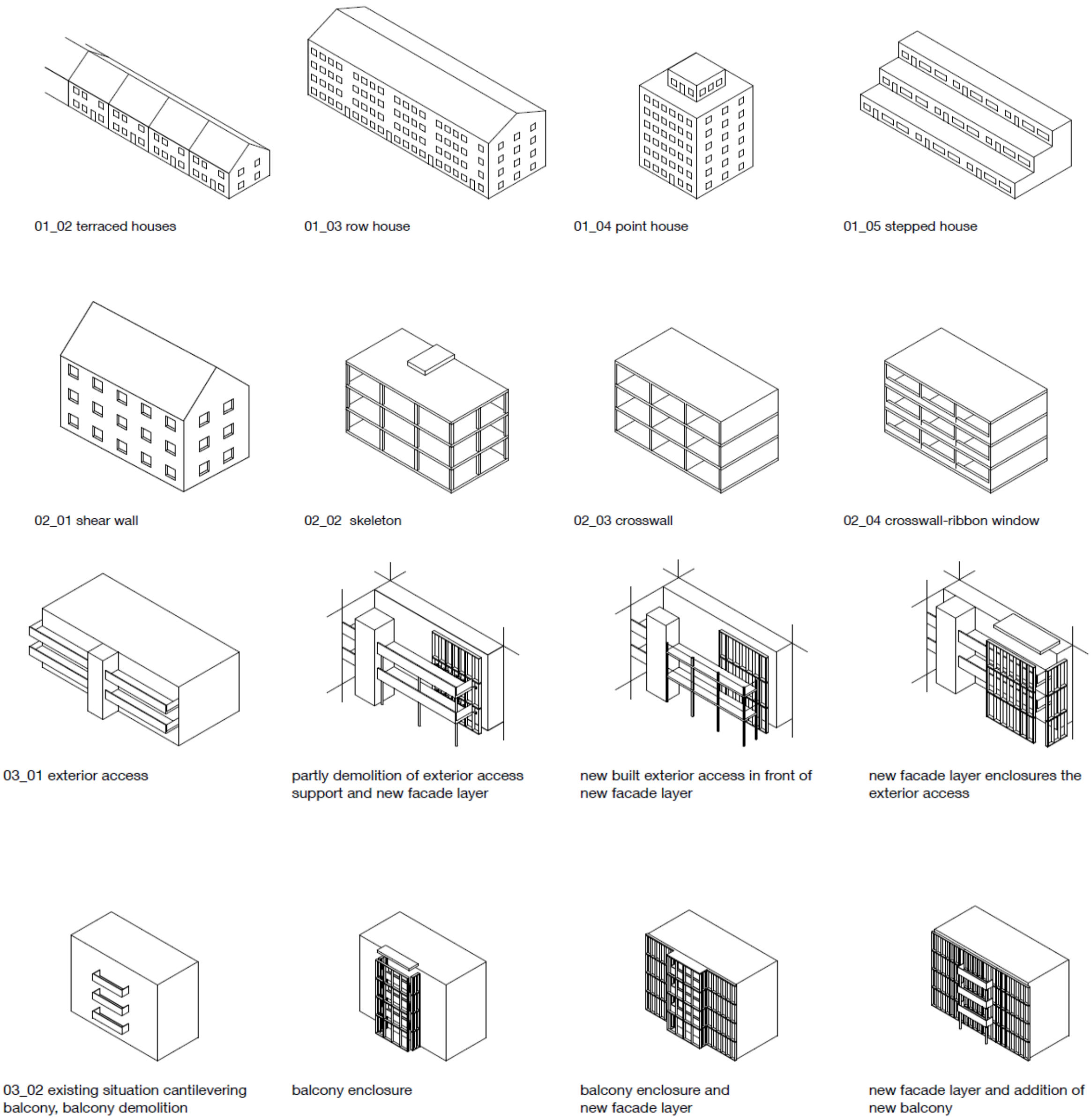


Figure 3.29 – Typology of relevant building types and strategies to adapt TES systems to irregular facades (Lattke, Larsen, Ott, & Cronhjort, 2011)

An interesting application case to demonstrate the adaptability of ENVISION is the project developed by BAM for the deep renovation of a complex of row houses with ribbon windows in the district “Bouwlust” in the Hague (the Netherlands).

Figure 3.30 –Deep renovation of row houses with ribbon windows. Photorealistic view before (on the left) and after (on the right) the intervention (BAM project)

In this case, three main problems have been identified during the preliminary survey:

- The existing structures are not adequate to withstand the vertical loads transmitted by the facades.
- The presence of ribbon windows doesn’t allow the insertion of the vertical pipes of the solar collectors inside the facade modules.
- Due to the size of the windows there is not enough space on the ceiling for the positioning of ventilation ducts and the other components (fans, heat exchanger, throttle) complementary to the ventilated windows.

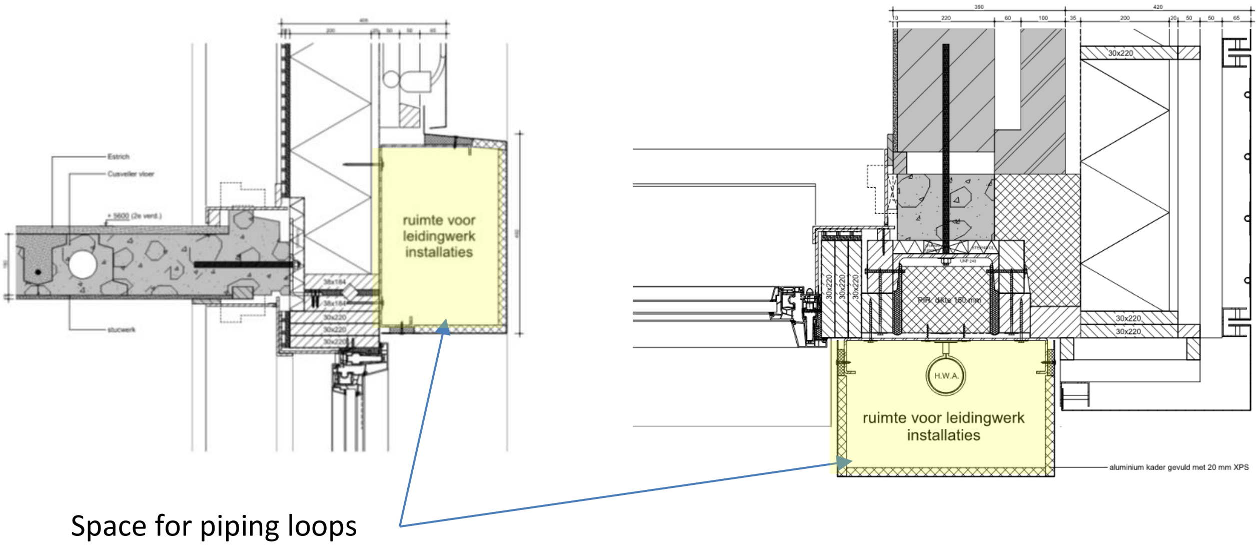


Figure 3.31 –Deep renovation of row houses with ribbon windows. Vertical detail of the anchorage to the floor slab (on the left) and horizontal detail of the facade corner (on the right) (BAM project)

The designer has overcome the first two problems by introducing external conduits along walls and slabs (Figure 3.31) and envisaging the construction of an independent foundation for the new façade, similarly to that seen in Figure 5.3.

With respect to the third point, in order to keep as much glass surface as possible, the choice has fallen on the installation of traditional glazing.

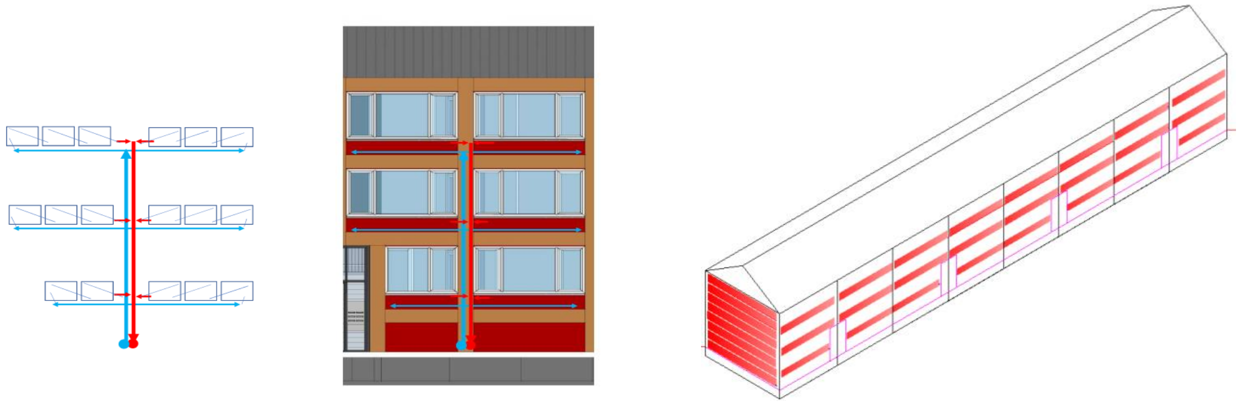


Figure 3.32 –Deep renovation of row houses with ribbon windows. Positioning of solar collectors (on the right) and piping distribution on the facade (on the left) (BAM project)

Figure 3.32 shows the positioning of the collectors on the facade and the piping distribution for the connection with the storage tank located in the basement similarly to the hypothesis made in the previous paragraphs.

4 Conclusions

The first part of the present document (chapter 2) gathers all the information on the work carried out on the individual technologies, relevant for the definition of their installation and correct use, as well as their maintenance needs.

The second part (chapter 3), being the core of the document, defines the methodology to be followed for the use of the overall system in the context of full renovation projects. The methodology is illustrated and demonstrated through the virtual application of the *Envision harvesting modules* on a building representative of the most suitable typology to fully exploit its potential. The framework is completed by (1) the description of how to proceed with the proper and safely installation of the system, (2) the identification of the measures to ensure the easy maintenance over time, in line with the needs emerged in the first part of the document and (3) the identification of the parameters, and therefore the sensors, necessary to monitor performances and their degradation over time.

Finally, it is shown how the considerations made for the representative building keep their general validity also for other building typologies, providing an example of how it is possible to adapt the system to overcome the most common obstacles that can be encountered when implementing ENVISION in existing buildings (i.e.: structures that are not adequate to support the loads of the façade, lack of space for the passage of the system distributions on the façade).

5 References

Bakker, M., Zondag, H., Elswijk, M., Strootman, K., & Jong, M. (2005). Performance and costs of a roof-sized PV/thermal array combined with a ground coupled heat pump.

Dott, R., Genkingera, A., & Afjeia, T. (2012). *System Evaluation of Combined Solar & Heat Pump Systems.* Energy Procedia.

Hesaraki, A., Holmberg, S., & Haghighat, F. (2015). Seasonal thermal energy storage with heat pumps and low temperaturesinbuildingprojects—A comparativereview.. *RenewableandSustainableEnergyReviews*.

Lattke, F., Larsen, K., Ott, S. J., & Cronhjort, Y. (2011). *TES Energy Facade – prefabricated timber based building system for improving the energy efficiency of the building envelope.*