ENSNARE

ENSNARE - ENvelope meSh aNd digitAl framework for building Renovation

Author:
[RIVENTI]

WP Leader:
[RIVENTI]

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Main authors	Nuria Jorge, Guillermo Rilova, Hugo Bergado (RIVENTI)
Contributors	Izaskun Álvarez, Julen Astudillo, Peru Elguezabal, José María Vega de Seoane (TECNALIA), Kepa Iturralde (TUM), Jesús Cerezo, Miguel Ángel Nuñez, Ricardo Arauz (ENAR), Alejandro Prieto Hoces, Tatiana Armijos, Thaleia Konstantinou (TUDE), José María Jiménez (ONYX), Ilija Nasov, Stole Filipov, Anka Trajkovska (KAMEL), Juan Carlos Casado Hernando (TRESPA), Angelo Zarrella, Jacopo Vivian (UNIPD), Reith András, Francisca Tapia, Evangelos Kyrou (ABUD), Sara Tikka (BIONOVA), Martina di Gallo (CIVIESCO), Giselle Morabito (IES), Kaspar Alev (TARTU), Quirino Crosta (COAF)
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The opinion stated in this report reflects the opinion of the authors and not the opinion of the European Commission nor that of the Innovation and Networks Executive Agency.

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3. Contents

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EXECUTIVE SUMMARY

The main goal of the ENSNARE project is to boost the implementation of NZEB renovation packages in Europe, with a focus on residential buildings. To accomplish this objective, the project develops two key structures: an envelope mesh and a digital platform that interconnect all building components.

The envelope mesh is fully modular and facilitates the mechanical assembly and interconnection of all components and energy/data networks.

As specified in the proposal, the main objective of this work package 5 "Industrialised and modular envelope system" is to develop the multifunctional façade system that will be the component where all technologies will be implemented and the active window.

In this deliverable "D5.1. Products design requirements" the main objective is to compile a series of studies and investigations to define the main characteristics of the façade system and the energy systems integrated in it. It takes into account three main aspects; dimensions, costs and energy, operational and technical parameters. It has to be set the following points: design concept, system cost, system dimension, system energy, operational and technical parameters.

The deliverable includes an extensive review of European projects related to the integration of renewable energies in the facade. The most outstanding projects have been collected in files in Appendix C. The selection criteria has been based on the integration of renewables in the façade following a modular approach, the use of active windows and the use of aluminium as a bearing load material. The objective of the state of the art was to establish a series of references that would collaborate in the establishment of a system design concept that would respond to the needs detected during the process. The integration of renewable energies on the façade is a highly developed process in recent years, however it is necessary to deepen the high industrialization of the system that integrates them.

The deliverable includes a list of the main elements to be used within the system, from the industrialized mesh to the finishing materials through active technologies, insulation and possible active window solutions.

As a starting point for establishing the system requirements are the different pilot buildings. The main geometric, material and energy characteristics have been compiled to determine the behaviour of existing buildings.

Establishing a methodology that allows knowing the cost of the system has been considered one of the points to be addressed within the deliverable. Based on the information collected from the pilot buildings, a preliminary analysis of the energy that can potentially be generated in each of their facades has been carried out. No losses are being considered both from the BOS (balance of the system) and from cast shadows. These analyses are collected in Appendix A.

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The Section 5.1 outlines the methodology used to determine the cost of the façade so that it is competitive in the climatic and techno-economic conditions in which it will be installed. In particular, the parameters of four case-study buildings in different locations have been used together with economic and financial parameters related to the energy markets of the corresponding countries.

One of the factors that influence the establishment of the cost of the system is the time of manufacture, assembly in the workshop and on-site installation. As a benchmark to consider, the manufacturing and installation of curtain wall modules (CWM) was analyzed. The data is gathered in Table 6. In total, it would make 3,27 h/m², which makes it very similar to manual processes for a rain-screen

Within the project, it is considered essential to approach the cost study from a holistic perspective. For this reason, the deliverable includes the focus on the usefulness of the LCC methodology as a tool. LCC methodology can improve the transparency of cost composition, making it easier and more effective to choose between different alternatives and achieve the objectives. The LCC approach makes it feasible to determine the global cost of a project by considering its whole life cycle and thus include the costs of design, construction/purchase, use, operation, maintenance, and decommissioning.

The Section 6 analyses the requirements and specifications to be considered in order to achieve the established objectives for the ENSNARE façade system. These requirements can be structured in two main groups:

Regulatory requirements: considering the current conceptual design, three façade system standards have been taken as a reference. The configuration of all of them have a certain similarity with the ENSNARE system. Based on these standards, the aim of this task is to identify the essential characteristics to be considered in order to comply with the requirements defined in the Construction Products Regulation (CPR, No. 305/2011). The most relevant ones have also been identified in order to comply with the main targets of the ENSNARE façade.

Functional and technological requirements: this point will consider aspects related to the modularity, weight, aesthetics, etc. of the system that need to be considered in order to achieve the ENSNARE façade objectives.

In conclusion, the last section defines the target values for those parameters that have the greatest influence on the objectives of the system based on the requirements analysed and established in the previous sections.

In addition, this last section shows a definition of the system, what concepts it is based on and what its main characteristics are.

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1. INTRODUCTION

The main goal of the ENSNARE project is to boost the implementation of NZEB renovation packages in Europe, with a focus on residential buildings. To accomplish this objective, the project develops two key structures: an envelope mesh and a digital platform that interconnect all building components.

The envelope mesh is fully modular and facilitates the mechanical assembly and interconnection of all components and energy/data networks.

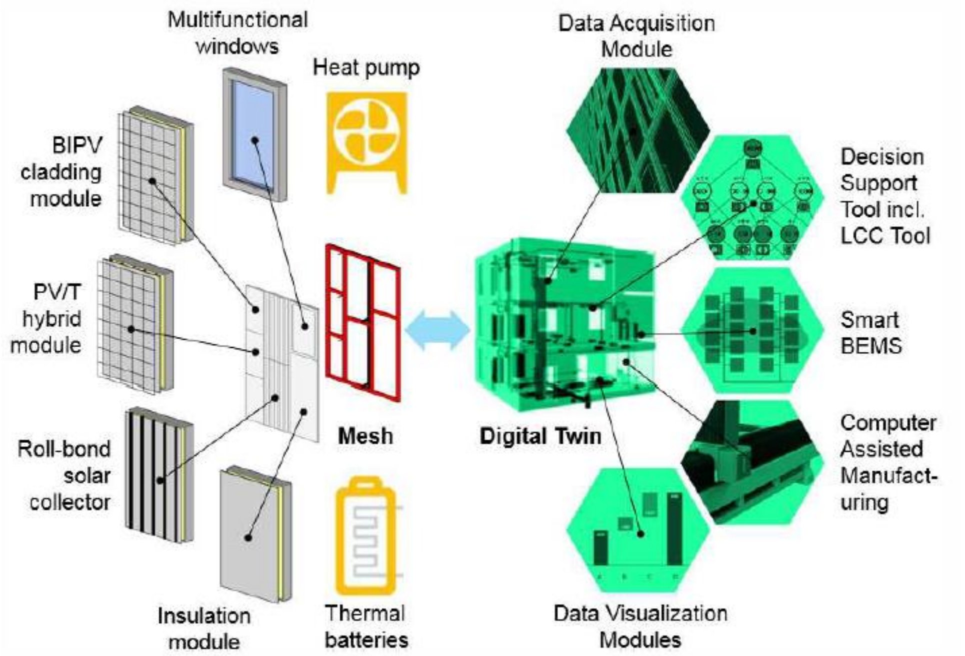

Figure 1. General scheme of the Ensnare project. Source. ENSNARE proposal

1.1. Work Package 5 and its role within the ENSNARE project.

As specified in the proposal, the main objective of this work package 5 "Industrialised and modular envelope system" is to develop the multifunctional façade system that will be the component where all technologies will be implemented and the active window. The partial objectives are:

- To develop an industrialized, modular and flexible façade system that can be used in residential buildings in terms of speed of installation, adaptability to balconies, corners and other elements typical from these buildings.

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- To reduce the cost of the entire system based in the concepts of modularity and industrialization

- To provide enough flexibility to the energetic components to be installed using plug-and-play technologies

- To define new characteristics for the windows using active and digital technologies improving comfort and air quality conditions

The work package 5 includes five tasks to address the above objectives:

- Task 5.1 Product design requirements
- Task 5.2 Design of the new multifunctional façade system
- Task 5.3 Design of component combinations.
- Task 5.4 Active window
- Task 5.5 Prototyping of the systems for laboratory testing and demo buildings

1.2. Introduction to Task 5.1 Design products requirements

Riventi is leading work package 5 and specifically tasks 5.1, 5.2 and 5.4. This D5.1 report is being carried out with the support of 15 more participants from the Ensnare project consortium.

"D5.1. Products design requirements" is framed within task 5.1, whose main objective is to compile a series of studies and investigations to define the main characteristics of the façade system and the energy systems integrated in it. It takes into account three main aspects; dimensions, costs and energy, operational and technical parameters. It has to be set the following points:

- Design concept.
- System cost.
- System dimension.
- System energy, operational and technical parameters.

1.2.1. Approach to define the design products requirements

The present document establishes the design products requirements as follows:

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- The first step is to set the **design concept of the façade system** based on the ENSNARE target requirements, collected in the proposal and specified through a study of the state of the art and some workshops held during the last months.
- To establish the **cost of the system**, an economic feasibility study is carried out that takes into account the characteristics of the demonstration buildings and the information on the energy that can be generated in each of their facades.
- Through a previous analysis of the demonstration buildings, together with the information on the technology to be integrated and the previously established design concept, **preliminary dimensional parameters** are established.
- To establish the **energy, operational and technical parameters,** three standards are taken in consideration; EN 13830: curtain walling product standard, EAD 090062-00-0404: kits for external wall claddings mechanically fixed and EN 50583: Photovoltaics in buildings. For each basic requirement (according to the Construction Products Regulation, CPR), the essential characteristic to validate is assigned by referring to one of the three first standards. The target reference values for some essential characteristic will be those indicated by the national regulations of each demonstration building. Then it will be evaluated if a higher demand is adequate and a recommended value will be established for those that are considered relevant to the project.

1.2.2. Structure of the document

The document includes the next information:

- An analysis of the previous studies carried out in the field of modular facades with integration of renewables in rehabilitation, with the aim, together with the workshop carried out, to extract the definition of the main characteristics of a modular and flexible system.
- An analysis of the main technologies to be integrated into the façade system.
- A preliminary economic feasibility study that indicates the range of costs in which the system should be developed. To consider how to evaluate costs throughout the life cycle of the product, from its manufacture to its dismantling.
- An analysis of the main characteristics and needs of the pilot buildings that have an impact on the integration of the façade system.
- An analysis the different requirements established in the European regulation for facades of these characteristics and relate them to the requirements of the

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national regulations in order to establish recommended values for each one of the requirements considered relevant to the project.

1.3. Relation to other task and deliverables

The information provided by the studies carried out in this task is the starting point for tasks:

- Task 5.2 Design of the new multifunctional façade system
- Task 5.3 Design of component combinations.
- Task 5.4 Active window

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2. STATE OF ART

The state of art about the concept of the modular industrialized façade that includes power generation, and with aluminium as bearing load system, has been developed.

56 European projects and 4 commercial solutions have been analysed. These European projects have been extracted from two studies [1] [2] and completed with the collaboration of the consortium partners. In a first stage of analysis, the aim has been to identify those projects that met a series of requirements.

These requirements are mainly:

- Projects that include a modular solution,
- Projects that integrate RES (renewable energy system) on the facade,
- Projects that integrate active window solutions with heat exchange,
- Projects that integrate HVAC equipment on the facade and
- Projects that use aluminium as a load bearing material.

After the first analysis, the most interesting projects have been selected, of which a more in-depth analysis has been carried out, extracting the most relevant issues for development of ENSNARE façade system

As reflected in the study [1], there are a series of technical challenges that have to be faced in new developments on modular facades with integration of renewables for the rehabilitation of residential buildings: modular design and fixing methods, embeddable renewable technologies, and parts/technologies that are capable of coping with on-site tolerance.

This state of the art is focused on finding the best experiences carried out so far in the integration of renewable energies in the façade for the rehabilitation of existing buildings and, most importantly, with a modular and industrialized approach. There are many previous experiences in the use of renewable energies on the facade, however there are not so many that pursue this high industrialization of the solution. The industrialized modular approach and the union of different technologies make it possible to optimize the behavior of the solution based on:

- multiple variables like different energy demand and orientation of the façade,
- improve the ratios on site with an optimal fixing method and with flexible, factory-assembled solutions to anticipate on-site tolerance problems
- and guarantee a higher quality of the solution thanks to the control in the manufacturing workshop.

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3. LIST OF COMPONENTS.

In this section, an explanation of the different elements to be incorporated in the façade is provided. For each technology, a description is given with photos and main characteristics of the elements currently on the market.

3.1. Industrialized mesh

The curtain wall as a system, also called a light façade, is defined by the European standard EN 13119: 2017 (Light facades. Terminology) as "an external facade of the building made with framing made mainly of metal, wood or PVC-U, which normally consist of vertical and horizontal structural elements, connected to each other and anchored to the supporting structure of the building, which provides, by itself or subsequently with the construction of the building, all the normal functions of an exterior wall but does not contribute to supporting the characteristic loads of the building structure". On the other hand, the European standard EN 13830 (Light facades. Product standard) defines the light façade as "a grid made with profiles, which generally consists of vertical and horizontal profiles, connected to each other and anchored to the supporting structure of building, and containing fixed and / or practicable fillings, which provide all the functions required of an internal or external wall or part of it, but which do not contribute to the load bearing or stability of the main structure of the building. The lightweight façade is designed as a self-supporting load transferred to the structure."

Light facades are generally designed in the form of a grid, so that their structural elements can be divided into vertical and horizontal, commonly called mullions and transoms, respectively. Normally, the mullions are fixed by means of fixing brackets to the structure of the building, they are intended to support their own weight, the actions that the transoms and the rest of the elements that are fixed to them transmit to them and the loads that affect the facade: mainly wind, impacts, etc.….

The choice of the mullion, therefore, depends mainly on the type of load to be supported as well as on the design and assembly criteria when executing the façade.

Systems for light façades can be made of different materials, but in this study, we focus on those made of aluminium, and we will highlight three groups that differ according to their constructive configuration:

- **Stick systems**. These systems are the most traditional and are made up of the juxtaposition of profiles, mullions and transoms, generally forming a grid. Its design allows the incorporation of opaque, semi-transparent or transparent panels. Transportation and assembly on site are carried out individually for each component. In turn, there are variants that differ from each other by the way the panels are attached to the grid:

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- Fixing with a cover, by means of pressure plate or cover cups, which presses the filler panel to an interior element. There are different morphological possibilities for this piece, which can be converted into different elements, both in the mullions and in the transoms, for example Brise soleil and slats.

- Structural fixing, by gluing with structural silicone in order to avoid external elements and provide an aspect of total flatness, displaying only the filling elements.

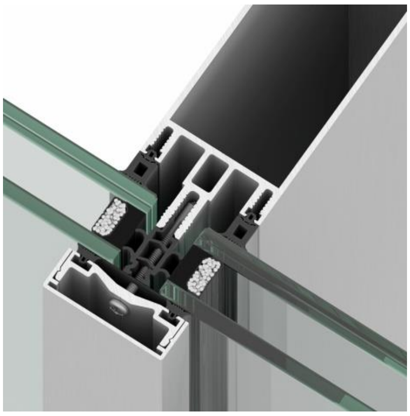

Figure 2. R50T System. Source Riventi

- **Structural systems**.
  - Structural system with independent frame glued to the panel. Panels, glass, double glazing or infill panels are fixed by means of the adherence that the structural silicone guarantees to a frame element fixed in turn to the main profiles. This system allows the glass to offer a continuous surface always without offset. It is the most suitable for integrating facade elements such as walkways and double glass skins. The support pieces of these accessories are led through the open space between the glass, ensuring watertightness. The finish, therefore, is totally uniform with an open sore between 20 mm glass.

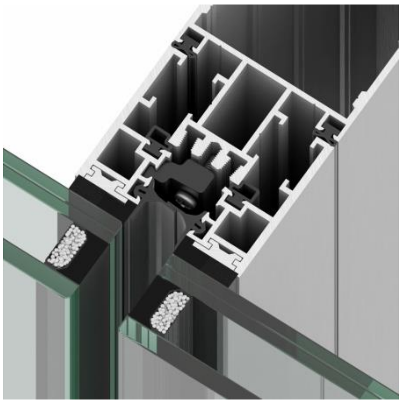

Figure 3. R70ST System. Source Riventi

  - **Modular System or cassette construction** is considered an evolution of the stick system. The modules are made up of mullions, transoms and the required filling and openable elements. The modules are preassembled in the workshop to later, when finished, be placed directly on site. Modular systems can have different assembly criteria, neutral or tongue-and-groove, and another aspect that differentiates them is the use or not of an intermediate frame to fasten the panel to the profiles. These systems are designed with

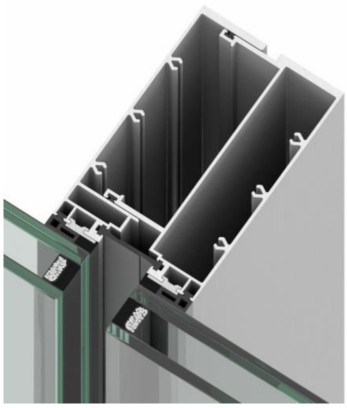

Figure 4. Modular System. Source Riventi

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perimeter joints that ensure watertightness and air permeability. The greatest advantage of modular systems is the great control that exists over their construction in the workshop, simplifying work on site.

- **Ventilated façade**, is one system that generates an internal air chamber between two layers or skins, which are fully integrated within the thickness allowed by the system. The air that is housed in the internal chamber can respond to the air conditioning needs of the building, conditioning the rooms in a controlled way at different times of the year, thus reducing the mechanical energy inputs to the building, which can lead to savings important energy.

The modular industrialized mesh that is one of the objectives of this project is a type of superimposed façade on an existing one to improve its performance. This modular industrialized mesh will act as an additional outer skin. To achieve the maximum degree of industrialization, insulation must also be incorporated into the façade, which requires careful study of the requirements related to air permeability, water tightness and the thermal resistance of the whole.

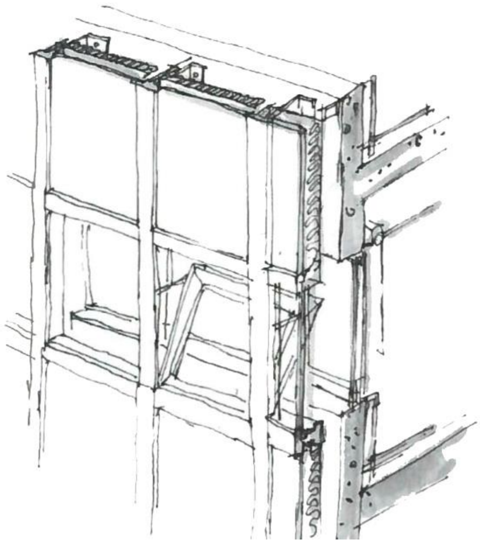

Figure 5. Superimposed façade scheme. ASEFAVE. Source Light Facades. Product Manual. 2015.[1]

The components of a lightweight facade are the following:

- Structural elements
- Practical elements
- Infill elements.

Structural elements:

Horizontal and vertical aluminium profiles that make up the module. The module is anchored to the structure of the building by means of fixing brackets, therefore the module must support its own weight, the actions of the elements that are attached to it and the loads that may affect the façade.

The European standards EN 12020-1, EN 10020-2 and EN 14024 contain the specifications that the extruded aluminium profiles used in the manufacture of façade elements, specifically light façades, must meet. These specifications refer to the technical inspection and supply conditions, to the shape and dimensional tolerances, as well as to their mechanical behaviour and their evaluation.

In addition, the alloys used in the profiles are of the types EN AW 6060 and EN AW 6063, according to the EN 573-3 standard, and the tensile behaviour is carried out according to the EN 10002-1 standard.

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To avoid corrosion, the aluminium profiles must be protected, either through a lacquering process or an anodizing process, each one directed by the requirements set forth by the Qualicoat or Qualanod brand regulations respectively.

Practical elements.

Within a light façade, practicable elements can be integrated that allow the opening of a filling element to be able to ventilate, facilitate maintenance or even allow the passage of people, also in emergency situations.

These vertical elements can be integrated following two procedures, either by placing a standard opening with the characteristics of a product that meets the specifications contained in the European Standard EN 14351-1, or by installing an opening specifically designed for placement in light facades.

At this point it is important to reflect on the different specifications that exist between the light façade standards and the window standards for the requirements of air permeability, watertightness and wind resistance, both in the level of performance and the type of test done.

Infill elements or panels

As infill elements or panels, we understand those elements that are supported by the structural elements or horizontal and vertical profiles. Their characteristics and composition depend on the utility for which they are intended. We can differentiate them into two large groups, transparent or vision, in which case glass is used mainly, and opaque, which can be executed with different types of panels.

The opaque panels integrated within curtain wall systems are usually used in the slab or spandrel areas, as well as for aesthetic reasons at any other point of the façade. The possible combinations have no limit and can be executed with different materials and solutions. The panel must always be understood as a finished element, prepared to be incorporated into a system made up of horizontal and vertical profiles, to become part of the building's skin.

Opaque panels are mainly made up of three layers that can be studied independently:

- The outer or finishing layer, whose performance must respond to aesthetic considerations as well as resistance to weathering. Different materials can be used for this layer, from glass to phenolic resin plates to metal plates or sheets.
- The insulation layer that is usually confined between sheet metal elements that are part of the outer or inner layers, or be independent of them.
- And finally, the interior or finish face that can be attached to the insulation layer.

The ENSNARE project investigates the integration of renewable, photovoltaic, solar thermal energy panels and a hybrid of both, the specific development of which is carried out within the WP6 Energy harvesting and storage modules work package. These panels would become part of the outer layer of the opaque panel. And its main characteristics for the study of its integration are:

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Table 1. Requirements table with influence on the façade system.

Requirements table with influence on the façade system						
	Technology 01 Photovoltaic panel		Technology 02 Solar thermal collectors		Technology 03 PVT Hybrid collector	
	Max	Min	Max	Min	Max	Min
Dimensional parameters	GA					
Length (mm)	4000	900	1685	1685	1580	1580
Width (mm)	2000	450	1025	1025	2880	480
Height (mm)	17,8	7,8	85	85(1)	85	85(2)
Layers	Name	usual thickness (mm)	Name	usual thickness (mm)	Name	usual thickness
1	Glass	from 4 to 8	Glass	3,2	Glass	Onyx should provide
2	EVA	1,8	Absorber	22,5	Absorber	22,5
3	Glass(3)	from 4 to 8	Roll bond	12(4)	Roll bond	12(4)
4			Isolation	50	Isolation	20
5			Backside Al sheet	0,4	Backside Al sheet	0,4
Weight (kg/m^2)	(5)3+3= 15,18 kg/m^2 4+4= 20,24 Kg/m^2 6+6= 30,36 Kg/m^2 8+8= 40,48 Kg/m^2		17 kg/m^2		17 kg/m^2	
Cost of supply for its assembly (€/m^2) <1000m^2 1000m^2>x <5000m^2 >5000m2	Will depend on the design		80		60(6)	

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Assemby characteristics. Need for tolerances. Default anchors	As glass cladding		Max.dimension 2005x1005x85 mm		Max. dimenions depends from Onyx PV module	
Thermal characterisitics of the material W/mK	Name	conductivity	Name	conductivity	Name	conductivity
layer 01	Glass	1.0 W/mK	Glass	1.0W/mk	Glass	Onyx should provide
layer 02	EVA	0.34 W/mK	Absorber (7)		Special thermo conductive adhesive	0,484W/mK
layer 03	Aluminium	190 W/mK	Roll bond	200	Roll bond	200
layer 04	Stone	1 W/mK	Isolation	0,035	Isolation	0,033
layer 05	Ceramic	1.7 W/mK	Backside Al sheet	160	Backside Al sheet	160
...	TRESPA	0.3 W/mK				
Generated energy (kWh/m2year)	Orientation and latitude dependence		Orientation and latitude dependence		Orientation and latitude dependence	
Need for ventilation (Yes/Not)	No special needs, but the heat dissipation of the rear side of the PV system will be positive to the performance		Yes		No	
Need for access for maintenance work. Technology elements/areas to be accessible	Access to the rear side of the PV system to check the connections if it is needed, or for replacing a damage or malfunctioning unit.		Yes		Yes	
Connections types	MC4 connectors or compatible. Electrical wiring, halogen free cable for PV equipment.		For Solar thermal collectors the main pipe line can be with copper pipe that are connected with the roll bond Al . pipes throw Locking connection elements according list of comonents sent by Kamel		For PVT panels the main pipe line can be with alupex pipes according list of components	
Need for air tightness (Yes/Not)	Not		Not		Not	

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Need for water tightness (Yes/Not)	Not	Yes	Yes

(1) Height of Kamel Solar thermal collectors is 85mm. To reduce this thickness it is necessary to change tools for extruding Al frames. We suggest thickness to stay 85mm.

(2) Height of PVT collector depends from ONYX PV module .We use PV modules with 35mm thickness of the Al frame. For us it is not problem to use suggested thickness from ONYX.

(3) other substrates are under study: aluminium, polymeric, stone and ceramic.

(4) Total thickness of roll bond absorber including outlet pipes from roll bond is 12mm.Thickness of Al plate from roll bond is 4mm.

(5) At this moment is not possible establish a weight. We can provide an estimation based on a glass/glass composition. In this sense you can see the weight for the following glass configurations: 3+3, 4+4, 6+6 and 8+8.

(6)60* means Eur/m2 only PVT roll bond absorber.

Fixing brackets and joints.

The fixing brackets are a set of industrialized elements whose main function is to connect the light façade with the building's structure, and transmit the façade's own loads, such as weight and wind loads.

These fixing brackets must be designed to meet the durability and resistance requirements of the facade To establish the design requirements of the anchors in each type of facade, the following considerations must be taken into account:

- The layout of the building's supporting structure should be considered as a starting point. In building rehabilitation, the anchor point or zone in the building's bearing structure is the slab edge. For this reason, the set of pieces that make up the anchoring system must be designed for this purpose. The design of these pieces and the starting characteristics of each building will determine the distance between the existing façade and the new façade.
- In the same way, as it is a modular solution and with outside assembling from the outside, the specific characteristics of each façade must be assessed in order to establish the necessary tolerances that the different pieces that make up the anchor must absorb. There are open investigations (University of Munich) in this field that can provide new solutions to the necessary three-dimensional regulation that generally foresees tolerances of 30mm in all three directions. Research on the new types of fixing brackets could reduce the distances between the existing facade and the new facade.
- Once the fixing brackets have been adjusted, which allows the facade to be positioned in its theoretical position, they must be blocked so that this position lasts throughout facade's useful life. This blocking process could be avoided with a more advanced design of the anchoring system.

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- The different pieces must be dimensioned according to the magnitude of the loads that are transmitted from the façade to the building structure.
- In addition to the mounting tolerances, the anchoring system must allow the differential movements that occur due to the changing actions that the façade supports or those that occur in the building structure itself. The fixing brackets are designed with sufficient clearances to absorb certain movements in a certain direction, generally parallel to the facade while limiting movements in the direction perpendicular to it.
- The usual material for the manufacture of the pieces is extruded aluminium. Plates with direct plugs are used for fixing to concrete structures, which can be mechanical, chemical, high resistance or countersunk. It is necessary to avoid incompatibility of materials. If materials with different electrical potential are used there may be a risk of corrosion under certain conditions. The use of insulating materials or stainless-steel screws.

Similarly, to establish the design requirements for the joints between the different façade modules and between the different elements that make up the module, the following aspects must be taken into consideration:

- In the first place, the drainage must be taken into consideration due to the possible appearance of water due to infiltration or condensation. Equalised pressure systems do not pretend to be totally watertight but rather to allow the aeration of the system itself by controlling the evacuation through channels designed for this purpose.
- In the case in question, the need for water y and air tightness must be considered in each case, since we have a pre-existing skin that already acts as a watertight protection barrier. However, the thermal insulation needs to achieve almost zero energy buildings requires the analysis of the hermetic barriers at each point.
- The joints must also avoid deformations between modules due to loads or expansion and avoid noise continuity.

Joints and Sealings

Sealings in situ or profiles made of elastomer material are used to produce watertight joints between the different elements of the façade. In any case, it is necessary to check the compatibility between the different materials that come into contact to guarantee their correct behavior throughout the useful life of the facade, without adhesion problems.

Joints and sealings fulfil various functions: sealing, waterproofing, separation, absorption of movements, improving the values of thermal transmission and acoustic insulation.

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3.2. Active components.

3.2.1. Standard existing technology

3.2.1.1. Components for standard solar thermal collector's

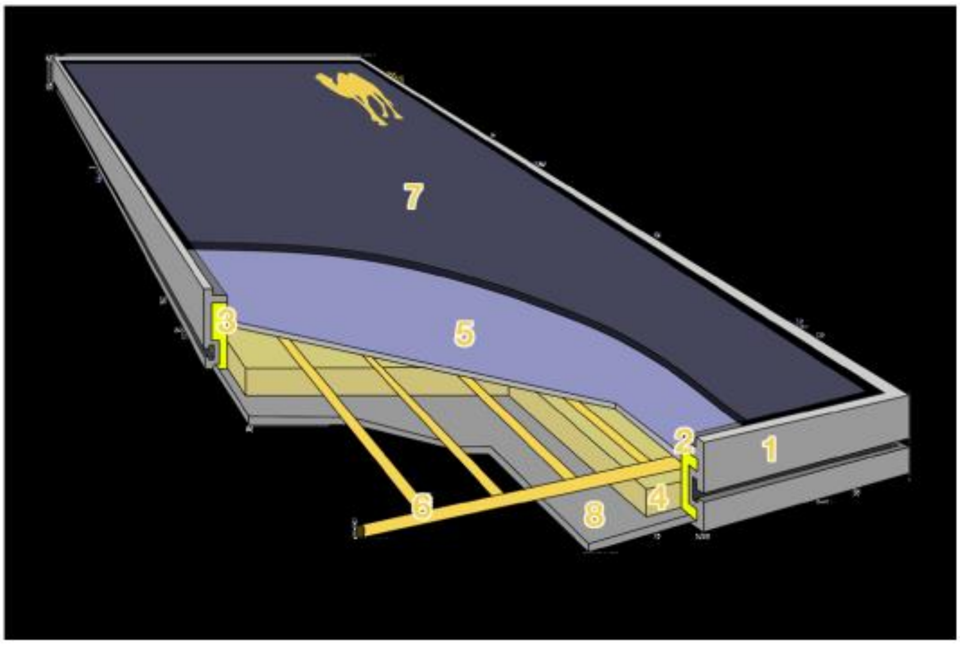

Figure 5. Components of solar thermal collector: 1 - Aluminium Frame | 2 - Silicone Seal | 3 - Thermal Sidewall Insulation | 4 - Thermal Insulation | 5 & 6 - Absorber | 7 - Glass | 8 - Aluminium Back side sheet |Source Kamel Solar

1. **Aluminium frame**
   – Special Kamel Solar design made from aluminium alloy 6063
2. **Silicone seal**
   – Elastotet S100
3. **Thermal Sidewall insulation**
   - Knauf TSP Solar Board D5
4. **Thermal insulation**
   - Knauf TSP Solar Board D5
5. **Absorber**
6. **Absorber**

Kamel Solar Full Plate Absorbers

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Using the latest technology, Kamel Solar produces the newest absorbers without outside visible welding lines and deformation of the absorber which is commonly seen in most solar thermal collectors.

The Kamel Solar absorber uses ultrasonic welding technology. This is done on the backside of the absorber. For the first time the heat transfer from the absorber plate to the copper register is a combination of conductivity and convection. This means the heat transfer is much better than the existing laser or ultrasonically welded absorbers.

Absorbers can be manufactured with different types of registers. (U shape, serpentine and harp style). The register and size of the absorber can be changed depending on the client's requirements.

Figure 6. Kamel Solar Absorber for solar thermal collector. Source Kamel Solar

7. **Tempered antireflective glass**
8. -SUN ARC antireflective glass **Aluminium back side sheet**

- Aluminium sheet from alloy 3105

In next drawings are shown dimensions of solar thermal collector.

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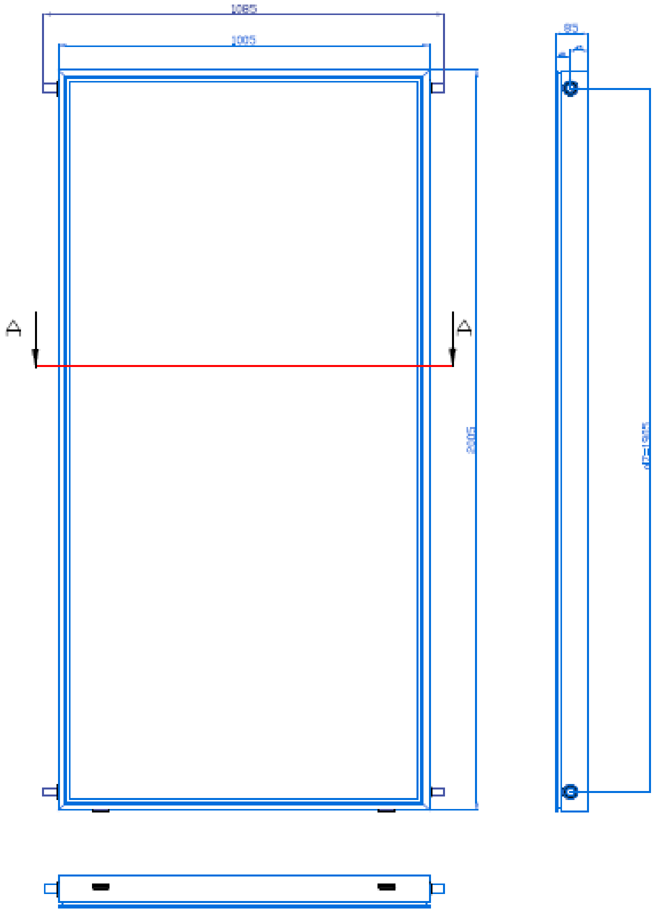

Figure 7 Kamel Solar. Solar thermal collector dimensions. Source Kamel Solar

3.2.1.2. Characteristics of PV panels

Crystalline silicon glass (Mono and Poly)

From the PV technologies available on the market, the Crystalline silicon technology features more power installed per Sqm in comparison to thin film technologies (such as amorphous silicon or CIGS). In terms of efficiency the crystalline technology offers a ratio between 16% to 21% in comparison with thin film technologies with a ratio between 6% to 13%. Translating the efficiency to power installed values the results obtained are the next:

- **Crystalline silicon technology** (eff. from 16% to 20%) = 160Wp to 210Wp per m^2
- **Thin film technologies** (eff. from 6% to 13%) = 60Wp to 130Wp per m^2

This means that under the same conditions the BIPV units based on crystalline technology will produce more energy due to the fact that the power installed will be twice than in the same installation if was based on thin film PV technology.

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This technology is suitable to be used on BIPV units to be integrated on buildings and facilities. The BIPV system will integrate on the buildings envelope a constructive solution with active (due to electrical energy generation) and passive properties (as a part of the ventilated façade system). It is important to remark that the main concept of the BIPV technology is the possibility of replacing a conventional glass in buildings by an equivalent PV glass. This means that besides of the envelope of the building (like the façades and skylights); it is also possible to install PV units based on crystalline technology on other constructive elements like canopies, balustrades, spandrels and walkable floors. For all these cases the solution adopted by the BIPV design will comply with the same functional and mechanical properties as a conventional architectural glass used in construction for architectural purposes.

In the following picture the main parts of a BIPV module are represented:

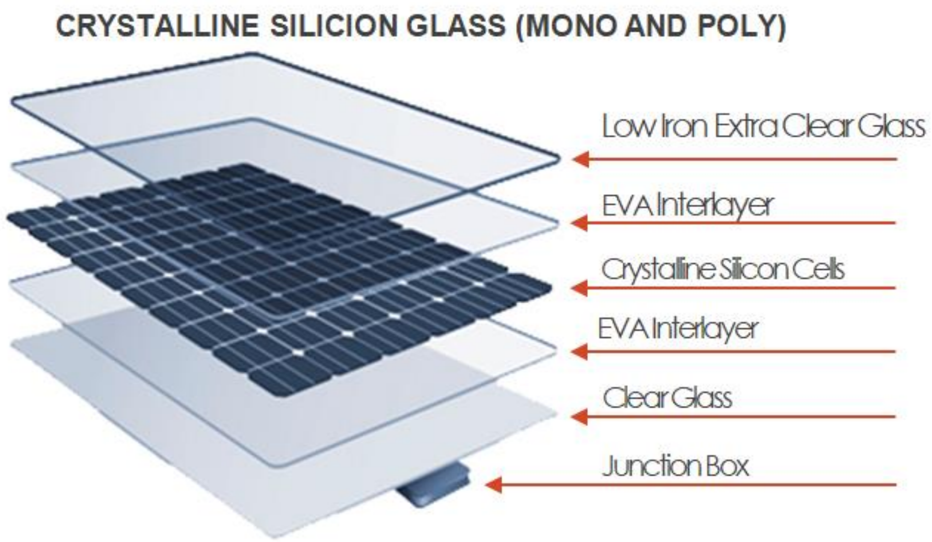

Figure 8. PV module components. Source: https://artisanelectricinc.com/what-type-of-solar-panel-is-best/. Adapted by ONYX

The success of the BIPV integration is based on the adaptability of the PV technology to the buildings needs and requirements. In order to meet these requirements, the BIPV module could be fully customized in terms of:

- Size: Onyx has developed standardized dimensions based on the cells density optimization within the BIPV unit (% of glass surface covered by PV cells). There is a limit on the dimension, the PV glass could not be bigger than 2000mm x 4000mm. Stock Dimensions (most cost-effective options)
    - 1700 x 1000 mm (60 cells)
    - 1641 x 989 mm (60 cells)
    - 1650 x 850 mm (36 cells)
    - 1475 x 480 mm (16 cells)

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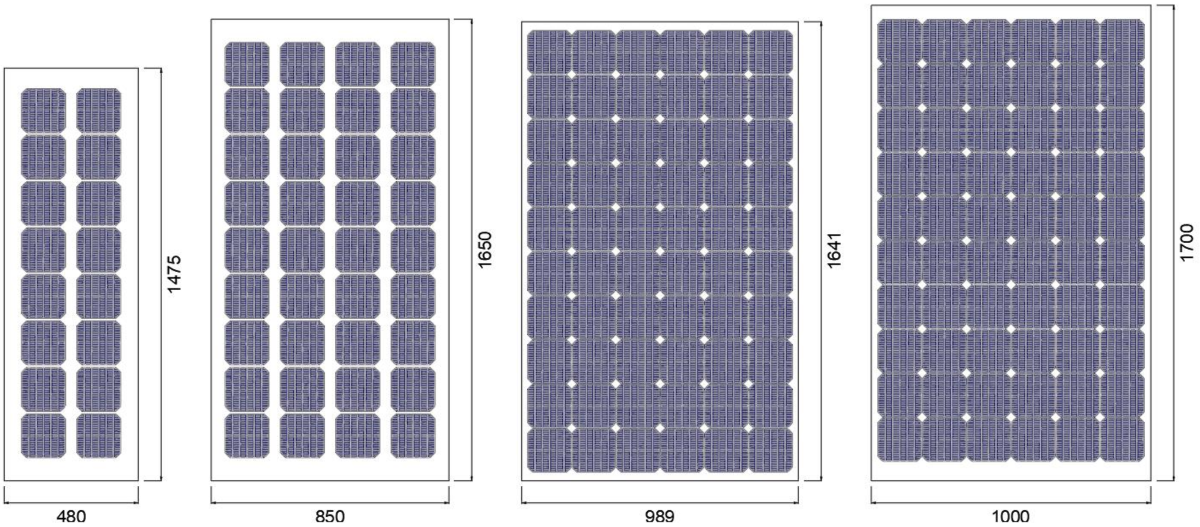

Figure 9. PV cost-effective options design. Source: ONYX

As it is showed in the previous picture, the dimensions of the glass will largely determine the density of cells in the design, as well as the power of each unit and efficiency (in terms of Wp/m^2).

- PV Cells technology, quantity and distribution on the BIPV unit.

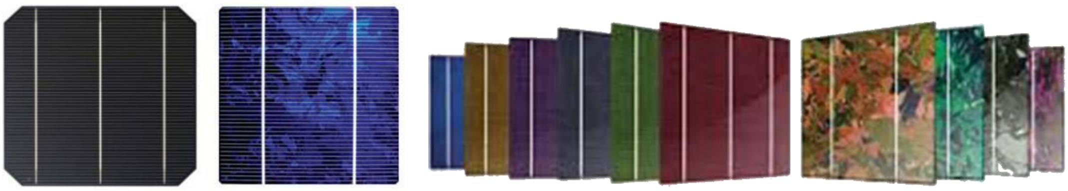

Figure 10. PV solar cells. Source mono and polycrystalline cells: https://www.researchgate.net/figure/Left-Mono-crystalline-and-right-multi-crystalline-silicon-solar-cells-It-is-possible_fig13_268487729 / source colour cells: https://www.taiwanexcellence.org/en/award/product/30268

- Glass type and thickness. The thickness of the glass will determine the optical and physical characteristics of the PV units. The thickness to be used could go from 4mm to 12mm, depending on the design of the PV units. In addition, it is possible to customize the PV glass units using the following glass types:
  - Fully tempered glass
  - Heat strengthened glass
  - Heat soak tested glass

  As well it is possible use glass with different treatments like:
  - Low-e coatings (low emissive coatings)
  - Anti-reflective glass
  - Hydrophobic coat

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Linked to the glass properties, the aesthetics of the PV units could be customized by using coloured glass (glass with ceramic frit or mass coloured glass) in combination with PV coloured cells:

Figure 11. Example of coloured PV units. Source: ONYX

- Following the list of components of a PV unit the encapsulants are one of the parts that could be customized using different solutions as:
  - PVB (polyvinyl butyl)
  - EVA (ethylene vinyl acetate)
  - High resistance polymers (like sentry glass)
- Finally, the junction box is an important part of the PV units. The junction box is an enclosure on the module where the PV strings are electrically connected. As well as the rest of the components listened, it is possible to use different types, mainly the following:
  - Rear junction box, located on the back side of the PV unit.
  - Lateral junction box, on the edge of the glass lamination.

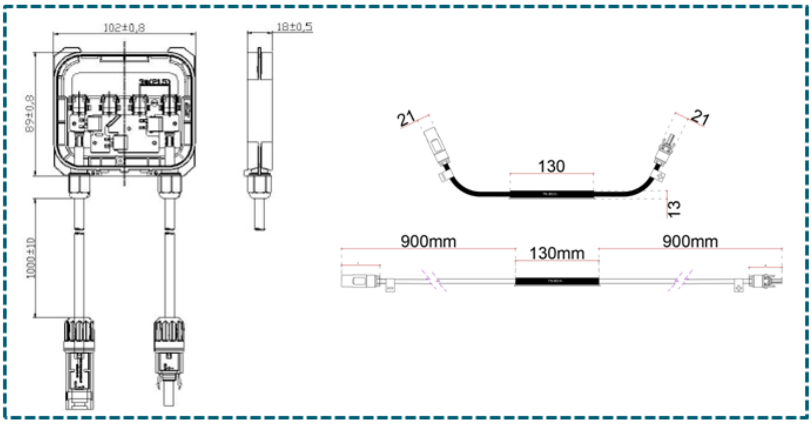

Figure 12. Example of rear junction box (left) and lateral junction box (right). Source: ONYX

The selection of the junction box will depend (as well as the rest of the components of the PV units) on the needs that the PV design should meet.

3.2.1.3. Components for standard solar PVT collector's

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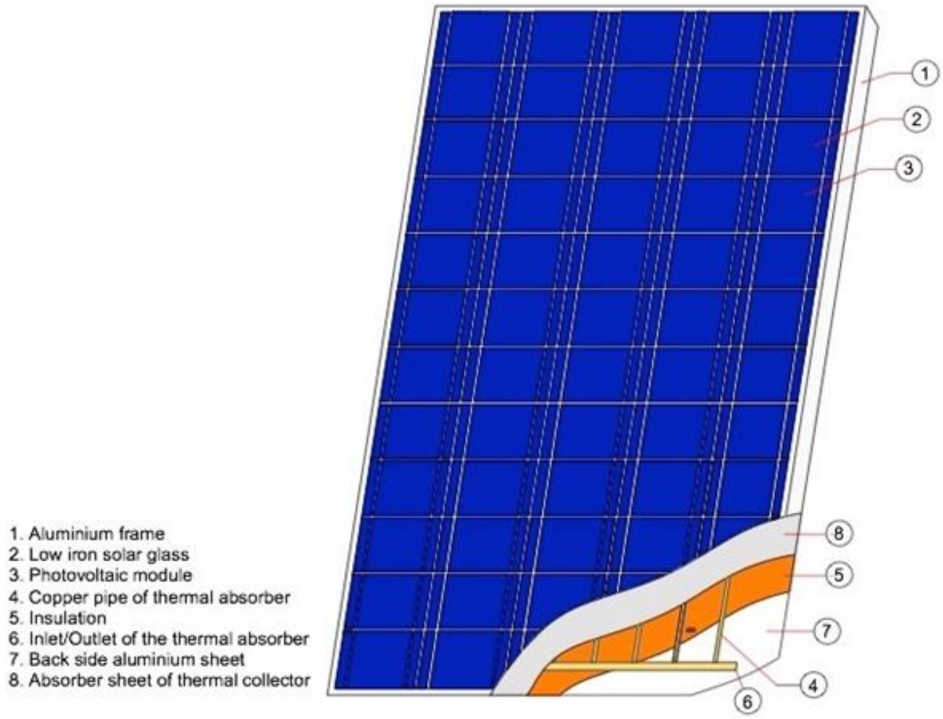

Figure13. Components of PVT collector. Source Kamel Solar

1. **Aluminium frame**
    a. Unglazed PVT: original design from PV module producer
    b. Glazed PVT: Kamel Solar design made from aluminium alloy 6063
2. **Tempered antireflective glass**
    a. Original glass from PV producer
    b. Sun Arc antireflective glass
3. **Polycrystalline or monocrystalline PV module.**

4. **Copper pipes of thermal absorber**

Camel Solar produce two types of PVT absorbers: with and without Al sheet.

a) In the first case cooper pipes are welded to Al omega shape and sealed directly to EVA protective back sheet of PV while

b) In the second case cooper pipes welded to Al omega shape, ultrasonically welded to Al absorber sheet through two welding lines and then sealed to EVA protective sheet of PV

- In both cases, the number of cooper pipes F6 mm are 18 PCS,

a) Cu pipe welded with Al omega shape sealed with EVA back sheet

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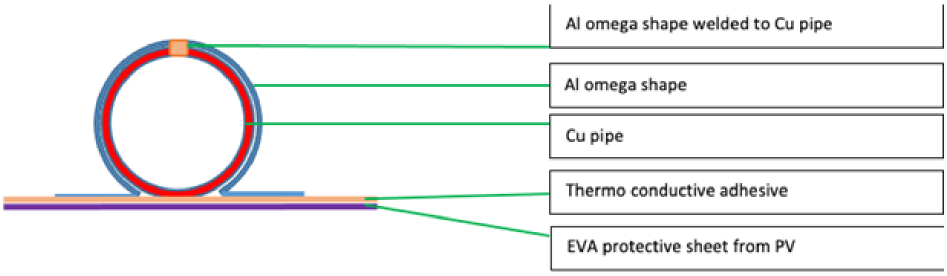

Figure 14. Kamel Solar Absorber Type 1 for PVT collector. Source Kamel Solar

b) Cu pipe welded with Al omega shape ultrasonically welded to Al absorber sheet and then sealed to EVA protective sheet from PV

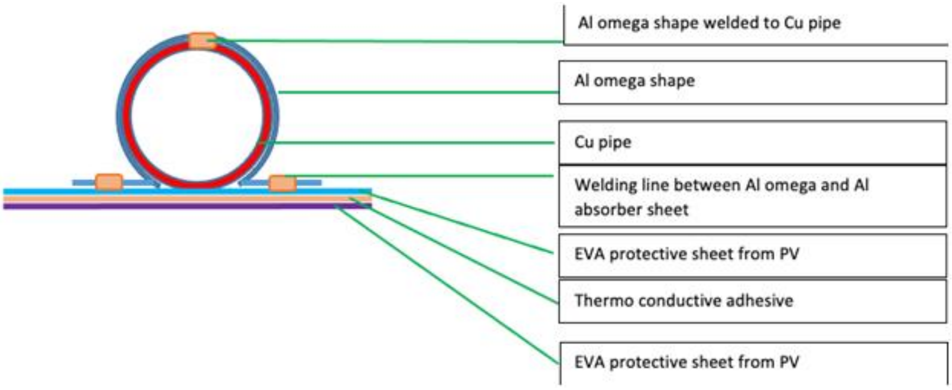

Figure 15. Kamel Solar Absorber Type 2 for PVT collector. Source Kamel Solar

- Copper pipes are soldered with two connecting copper pipes F22mm.

This Omega shape absorber is produced on shaping machine. All aluminium omega shape foils are with 0,125mm or 0.25 mm thickness. The heat transfers from PV module to Al shape and then to cooper pipes, is a combination of conductivity and convection. This means that heat transfer is much better than the existing laser or ultrasonic welding technology.

5. **Insulation**
   - Rock wool - Fibran Geo B-001
6. **Inlet/outlet connecting pipes**
   - Copper pipes F22mm.
7. **Aluminium back side sheet**
   - Aluminium sheet from alloy 3105
8. **Absorber** (explained in 4)

Dimensions of the standard existing PVT unglazed collector use by Kamel are:

a. 1.6 m2: Length 1640 x Width 990 x Thickness 35 mm.
b. 2.0 m2: Length 1950 x Width 990 x Thickness 35 mm.

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3.2.2. New technology for ENSNARE project

3.2.2.1. Components for new solar thermal collector's technology:

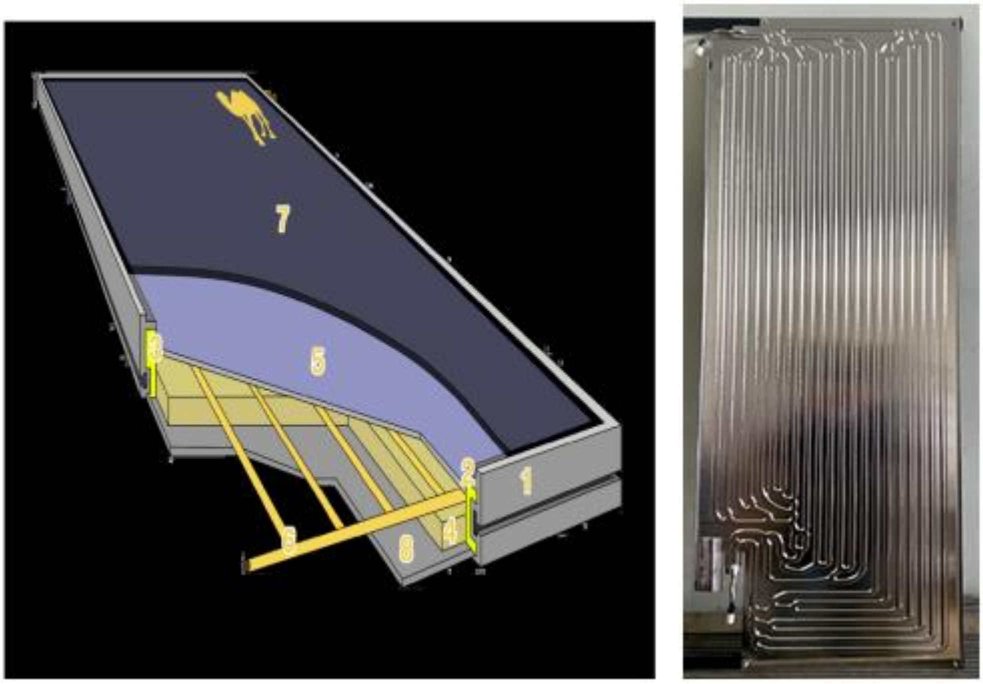

Figure 16. Components of solar thermal collector: 1 - Aluminium Frame | 2 - Silicone Seal | 3 - Thermal Sidewall Insulation | 4 - Thermal Insulation | 5 & 6 standard Absorber | 7 - Glass | 8 - Aluminium Back side sheet |Source Kamel Solar

Standard Absorber (5 & 6) will be replaced with roll bond absorber (right side) coated with Kamel Solar optical selective coating.

In this new technology for solar thermal collectors, everything is the same, except absorber with copper pipes and aluminium selective sheet is replaced with aluminium Roll Bond absorber coated with special selective coating on the flat side of Roll Bond absorber.

Aluminium frame

- Special Kamel Solar design made from aluminium alloy 6063

1. Silicone seal

- Elastotet S100

2. Thermal Side wall insulation

- Knauf TSP Solar Board D5

3. Thermal insulation

- Knauf TSP Solar Board D5

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5 - 6. Al roll bond absorber

7. Tempered antireflective glass

- SUN ARC antireflective glass

8. Aluminium back side sheet

- Aluminium sheet from alloy 3105

In next drawings are shown dimensions of solar thermal Roll Bond collector.

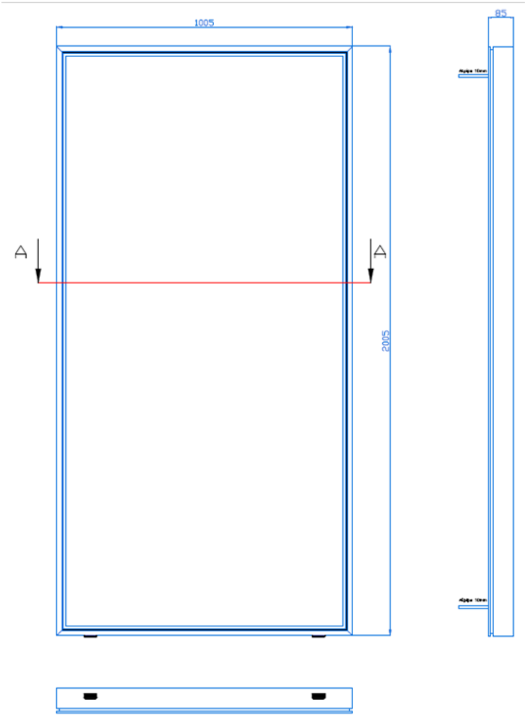

Figure17. Kamel Solar thermal collector dimensions Source Kamel Solar

Outlet and inlet connection pipes can be connected to the pipelines with LOKRING technology. This technology is a mechanical method for producing permanent bond between two pipes using proper fitting and proper anaerobic sealant LOKPREP. The four aluminium pipes f8 mm from the back side of the roll bond collector can be connected with copper pipes and all pipe line with copper material.

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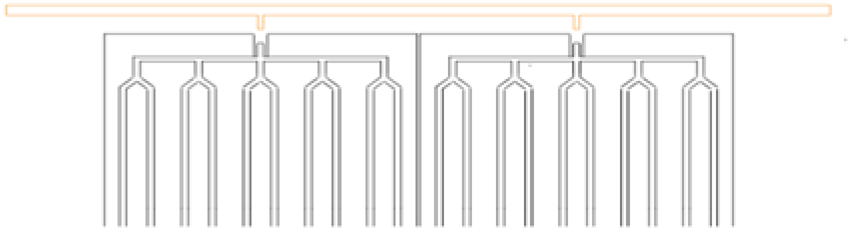

Figure 18. Connection of new solar thermal collector with roll bond absorber. Source https://www.vulkan.com/en-us/lokring/Documents/Kataloge/Kaelte-Klima-Kataloge/LOKRING-REFRIGERATION-AND-AIR-CONDITIONING-EN.pdf

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3.2.2.2. New substrates under study for PV panels

Within WP6, in T6.1 different alternative substrates to replace the inner glass on the PV laminate will be studied. At a first stage five different alternatives will be studied in order to select two of them for the subsequent prototyping phase.

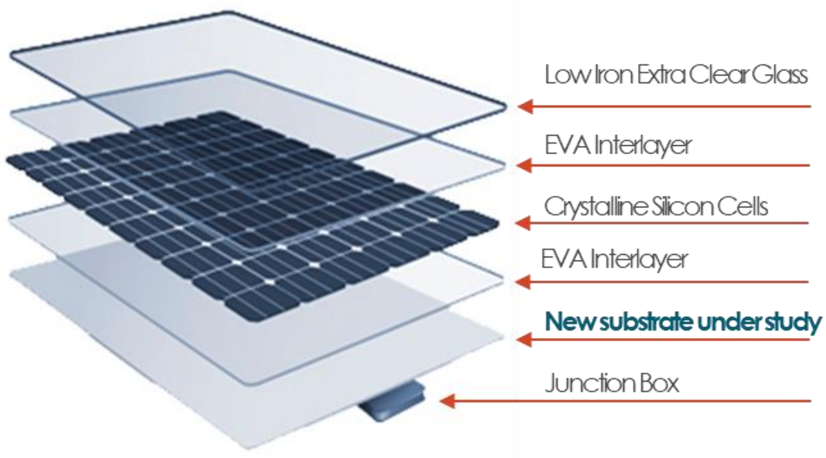

Figure 19. Location of the glass layer to be replaced by an alternative substrate. Source: ONYX

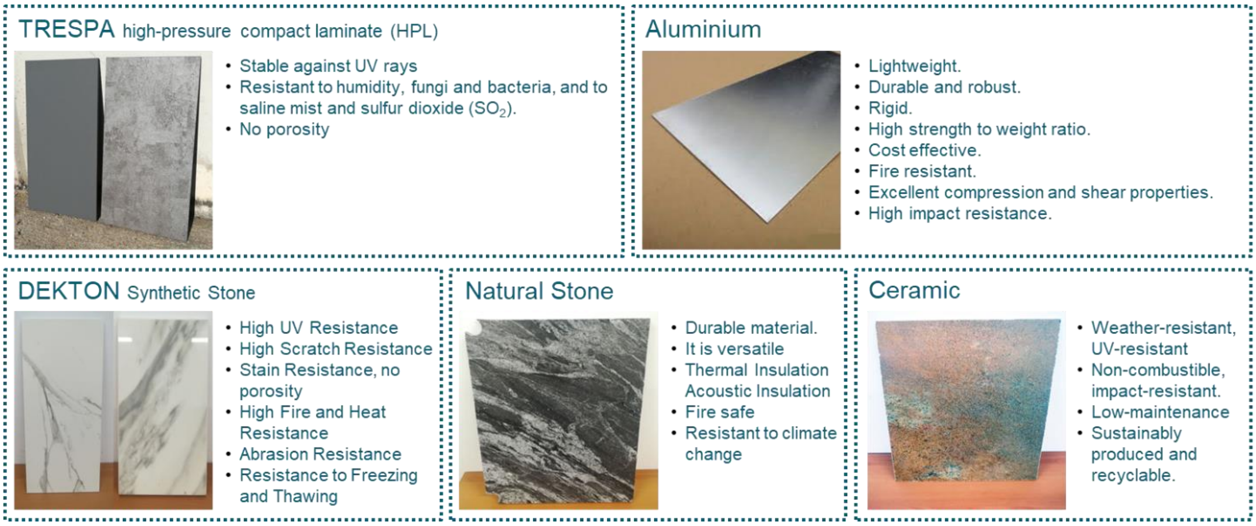

Figure 20. Substrates under study. Source: ONYX

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3.2.2.3. Components for new PVT collector's technology

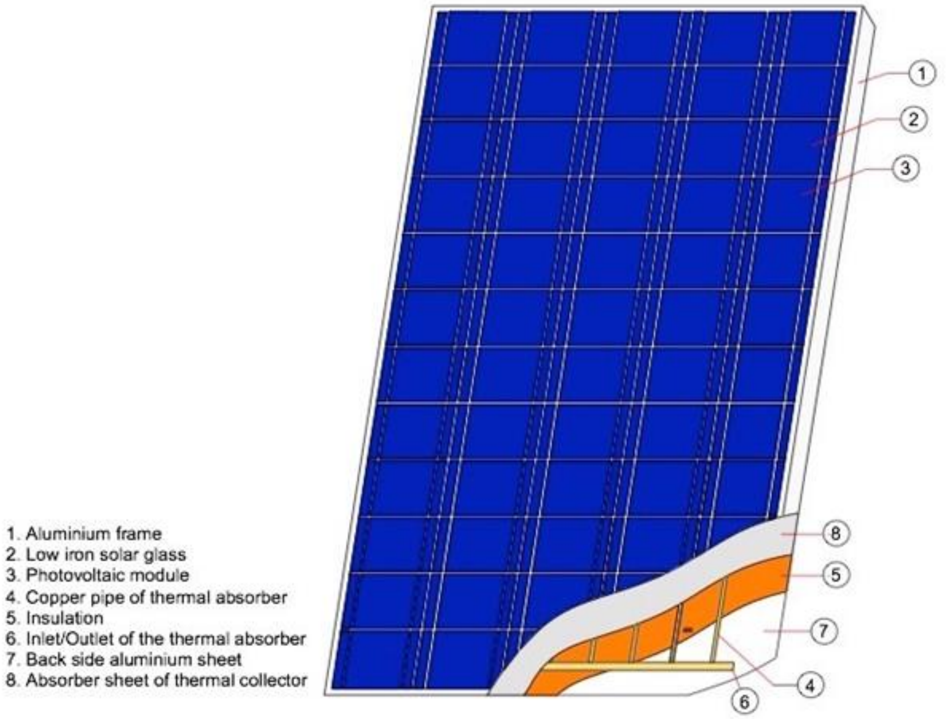

Figure 21. Components of PVT collector Source Kamel Solar

In this new technology for solar PVT collectors, everything is the same, except classical absorber with copper pipes and aluminium foil, will be replaced with aluminium Roll Bond.

Aluminium frame

- **Depends from Onyx type of aluminium frame**

1. **Low iron solar glass**
   - Depends from Onyx type of solar glass
2. **Polycrystalline or monocrystalline PV module**
   - Depends from Onyx module type

-

Figure 22. Connection fitting for roll bond PVT collector. Source: https://www.presblock.com/ENG/pdf/termoidraulica/cataloghi/english-plumbing-catalog.pdf

4 & 8. Copper pipes (4) and Al sheet (8) of thermal absorber will be replaced with aluminium roll bond absorber

- In Ensnare project will be used Roll Bond aluminium absorber. This Roll Bond will be glued to the back side of PV module with special thermo-conductive adhesive.

5. Insulation

- Rock wool - Fibran Geo B-001

6. Inlet/outlet or connecting pipes will be replaced with Al pipes from roll bond absorber

- Aluminium pipes F8 mm.

7. Aluminium back side sheet

- Aluminium sheet from alloy 3105

Dimensions of new roll bond PVT collectors depends from Onyx PV panel where will be assembled our thermal PVT absorber with max. dimensions of 2000 x1000 mm or standard dimension 1600 x 1000 mm.

Connecting of outlet and inlet aluminium pipes of PVT roll bond collectors will be done with plastic connector fitting like drawings below on the back side of the PVT collector.

From the plastic fitting the main pipe can be alupex pipes.

For more information about the energy panels see requirements table with influence on the façade system, section 3.1.

3.3. Smart window

Among the elements to be integrated into the Ensnare façade is the active window with highly efficient heat recovery ventilation system

The development of this window is the goal of task 5.4 of work package 5.

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This task 5.4 deals with the initial conceptual designs of the window components which will transform it into a multifunctional building component. These new functions include:

Heat recovery ventilation system; This system will allow the outside fresh air to take thermal energy from the air conditioned indoor air by means of crossing both air flows in a heat exchanger which is fully integrated into window profiles.

Auxiliary systems design and development; the new functionalities allocated into the window requires of an auxiliary system which will provide air circulation, pressure drop control or variable air pressure into window gaskets. These auxiliary systems require of a technical characterization and specification that has to take into account also its allocation into the window.

In addition to this, the connection of this active window with the Digital Twin of the building will be resolved as well as the different sensors needed (temperature, humidity, CO_2 concentration, etc.) to improve the behaviour of the façade and the air quality of the spaces served by the window.

The following paragraphs are a brief explanation about what characterizes a window within a light façade system.

The active window is considered a practicable element within the ENSNARE façade system. This system is developed under the principle of curtain wall systems, so the active window is considered a filling element which is allowed to open. A new element is introduced with ventilation as main function.

The integration of a practicable element within a light façade system has two possible ways:

Placing a standard window with the characteristics of the product included in the European Standard EN 14351-1, or installing an opening specifically designed for placement on a light façade.

It is important to differentiate between these two possible options because it influences the technical performance that they may have.

In the first option, there are two possibilities for integrating the standard window into the light façade profile system, either by means of an adapted frame or by means of a connector between the window frame and the façade system.

In this first option, the existence of these elements is important to guarantee the performance of the whole and of each of the elements separately. In other words, the light façade would be guided by the product standard EN 13830 and the window by its corresponding product standard EN 14351-1. The performances in terms of air permeability, watertightness and wind resistance differ.

On the contrary, if it is decided to follow the path of a development of specific profiles for a light façade based on performance and aesthetic criteria, the performance tests of the

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window and its technical characterization would be carried out on the structure of the light façade and therefore would follow the UNE-EN 13830 standard.

Currently there are **several products on the market** that have developed this type of functionalities for windows. These solutions can be classified into two different types:

Solutions that also integrate all the necessary devices in the window profiles to guarantee ventilation and heat exchange. This is the case of Climawin, a window developed within the framework of a European project included in chapter 2 of this document.

CLIMAWINDA is developing an intelligent ventilation window that can preheat and cool itself to minimise energy loss and optimise ventilation. The CLIMAWIN unit works as a natural heat recovery ventilation system in cooler climates and as a daylighting (self-cooling) device in hotter climates. It is targeted at the retrofitting market but could also suit new build situations.

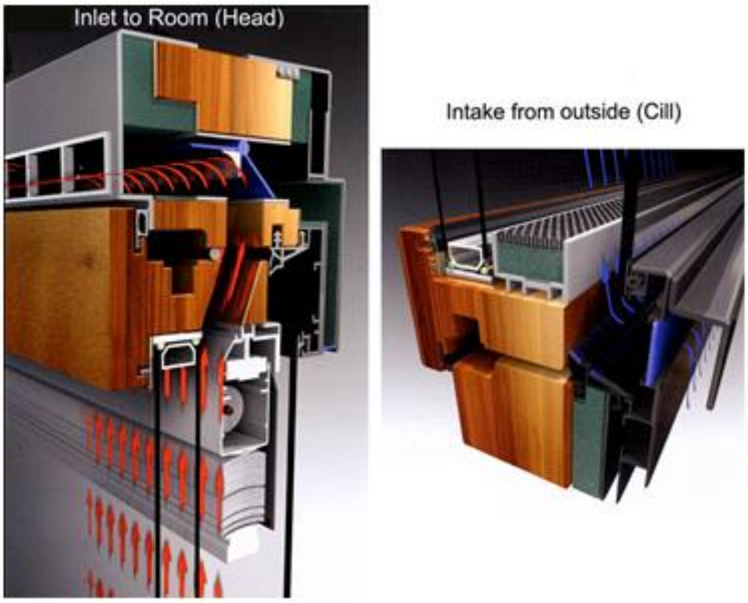

Figure 23. Climawin system. Source: www.construible.es
https://www.construible.es/2014/02/04/ventanas-inteligentes-con-ventilacion-y-recuperacion-de-calor-pasiva

On the other hand, there are solutions that solve the ventilation and heat exchange system by means of an independent device placed next to the window. This is the case of the commercial solutions presented by the companies Schüco and Renson with their Vento-Therm Twist system, and the company Siegenia and its Euromat VT system.

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Figure 24. Vento-Therm Twist system. Source Schüco.
https://www.schueco.com/web2/ventilation-systems

Figure 25. Euromat VT system. Source Siegenia.
https://www.siegenia.com/es/products/comfort-systems/window-ventilators/aeromat-vt-wrg

Both cases are decentralized systems integrated into the window for ventilation and heat exchange. The main benefits are the improvement of air quality as well as an efficient use of energy with the heat recovery unit. All this is complemented by air filtering systems and automatic humidity, temperature and CO2 and VOC concentration controls. Their compact size makes them easily embeddable within a facade system with a good aesthetic adaptation.

These devices already have effective acoustic insulation of more than 50dB and can be connected with applications in their intelligent variants for a more personalized control of energy and air quality based on occupancy or demand patterns.

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One of the main advantages of these independent and decentralized devices is its easy installation and maintenance. If the device had a functional problem, its repair and replacement could be carried out easily without great inconvenience to the users, while the systems or devices integrated in the window profiles have greater difficulty when it comes to being repaired or revised.

For its integration within the façade systems, the study and development of profiles or connection elements that can be attached to the façade system as in the case of windows is necessary.

3.4. Complementary elements:

3.4.1. Insulation

There are several types of insulation to respond to the regulatory requirements of the ventilated façade.

The quantity and type of insulation is very large:

Table 2. Thermal conductivity of insulations

Product	Thermal conductivity, λ[W/(m·K)]
Polyurethane (PUR)	0.022-0.028
Polyisocyanurate (PIR)	0.021-0.028
Extruded Polyestyrene (XPS)	0.033-0.036
Glass Wool	0.032-0.040
Rock Wool	0.034-0.039
Light Reflective Products (PLR)	0.012-0.025
Wood Fibers	0.037-0.040

Depending on the thermal transmittance to be met and the thermal conductivity of the insulating material, its thickness will be dimensioned. Plastic insulation such as PIR and PUR, have lower thermal conductivities than other insulators, on the other hand, they are classified in the area of less safe materials in terms of fire resistance. If the fire requirements are high, safer insulating materials with fire classification A1 and A2 (such as rock wool and glass wool) should be used.

Knowing the thermal resistance for the system layer, we can obtain the necessary thickness:

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$R = e/\lambda$

R: thermal resistance

λ: thermal conductivity

Several parameters have to be considered when choosing the insulating material to use.

- Thermal conductivity: W / m · K, is a coefficient of proportionality between the heat flow, the temperature difference and the thickness.
- Compressive strength: kPa, allows it to resist the action of external forces, it represents the ability of a material to resist a force that compresses it and takes it to the ultimate deformation.
- CO2 production: kgCO2 / kg, quantity that emits one m2 of material to the nearby outdoor environment and causing contamination of the environment.
- Recyclability: refers to the ability of a material to be used again, with some materials it is possible to obtain a raw material, while others allow the creation of a new product.
- Combustibility: basically defines the spread of fire in a fire. Understood as the reaction behavior of a material to fire, these will be classified according to the European standard EN 13501-1-202 EUROCLASES.
- Porosity: parameter that directly affects mechanical resistance, which decreases as porosity increases. Porosity can allow gas or liquid permeability.

MINERAL WOOL

Insulating mineral wool is a material composed of an interlacing of filaments of stone materials that form a fabric that keeps the air between them in an immobile state.

Figure 26. Mineral Wool. Source: Ursa website

This structure makes it possible to obtain very light insulating products that, due to their peculiar configuration, offer high levels of protection against heat, noise and fire.

Mineral wools are recognized as thermal insulators - due to the interlacing that keeps the air immobile-, acoustic insulators - due to their flexible structure-, being, in addition, non-combustible materials due to their inorganic origin.

Two main types of mineral wool are distinguished: glass wool and rock wool. Both come from natural raw materials (siliceous sand makes up glass wool and basalt rock makes

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up rock wool) that go through a production process to result in these lightweight and versatile insulating materials.

As materials with open porosity (thanks to which they have good thermal and acoustic performance) they can retain liquid water inside, so mineral wool should be used in applications that are protected from direct contact with water.

HEAT-REFLECTIVE INSULATION

Heat-reflective insulation are materials composed of a combination of layers of various materials such as foams, wadding or aluminium.

Figure 27. Reflective Insulation Source: Danosa insulation,

An air chamber is added between the two to increase their thermal resistance. They are thin insulators with high thermal resistance. These insulations are effective against the transmission of heat through radiation.

EXTRUDED POLYESTYRENE (XPS)

Extruded Polystyrene is a rigid foam that is obtained through an extrusion process. Extrusion is a continuous process, in which XPS extruded polystyrene sheets are obtained by melting polystyrene and additives. In the polystyrene extrusion process, a foaming gas is added in the extruder, obtaining a rigid foam, with a closed cell structure, which provides the excellent mechanical and thermal properties to the extruded polystyrene XPS.

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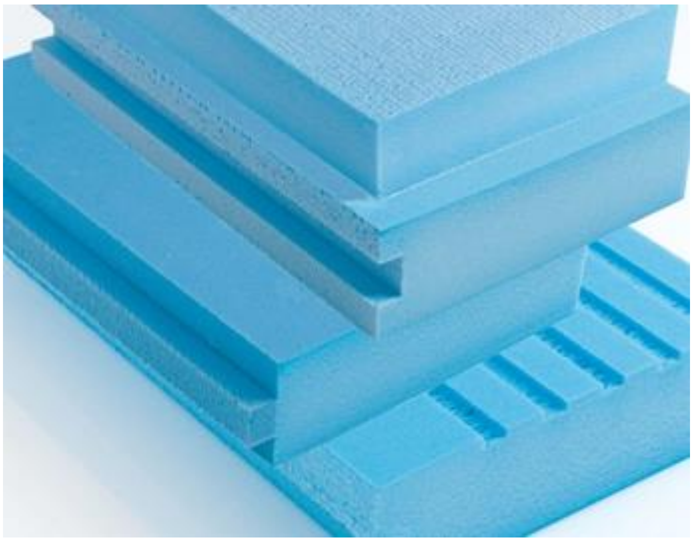

Figure 28. Polyestyrene Extruded. Source: Internet

Extruded polystyrene is made up of approximately 95% polystyrene and 5% gas. Its characteristics include its ability to get wet and not lose its properties.

The main characteristics of this material are its lightness, its mechanical resistance, durability, high thermal resistance, zero water absorption and easy installation.

3.4.2. Cladding

For the cladding in areas where technologies are not going to be used, a facade cladding will be installed that allows integration with the rest of the facade

There are many types of cladding materials and installation systems. The use of the ventilated façade with Trespa® Meteon® phenolic panel was chosen because it is an architectural solution that offers both technical and aesthetic benefits. First, ventilated façade draws air through the cavity, aiding in the removal of heat and moisture from rain or condensation. Second, the rainscreen blocks some solar gain and accommodates continuous insulation, considerably reducing air-conditioning and heating expenses. Third, these results are shown to improve comfort within occupied zones. Residents and users not only find themselves in a low-maintenance-environment, but the dry and comfortable conditions of the building may also make a positive contribution to indoor environmental air quality.

Trespa® Meteon® is a decorative high-pressure compact laminates according to EN 438-6:2005 with thicknesses of 6 mm (± ¼ in) or greater for outdoor applications. Sheets consisting of layers of wood-based fibres (paper and/or wood) impregnated with thermosetting resins and surface layer(s) on one or both sides, having decorative colours or designs. A transparent topcoat is added to the surface layer(s) and cured by Trespa's unique in-house technology Electron Beam Curing (EBC), to enhance weather and light

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protecting properties. These components are bonded together with simultaneous application of heat (≥ 150° C / ≥ 302° F) and high specific pressure (> 7 MPa) to obtain a homogeneous non-porous material with increased density and integral decorative surface.

Trespa® Meteon® can be applied in a number of ways, using a variety of joinery details and fixing methods. Choice of fixings and availability per country is dependent on relevant building codes and national certifications.

Due to the nature of the product Trespa® Meteon® and its application as drained and back-ventilated rain screen cladding and unrelated to any fixing method, there are 3 topics that need special attention:

1. **Ventilation.** The facade cladding needs to be ventilated at the rear of the panel to release migrated water vapour from the ambient rooms and to dry condensation at the inner parts of the wall construction. This requires a certain ventilation cavity depth and a certain dimension of the ventilation inlets and outlets.
2. **Tension-free fastening.** The facade cladding needs to be able to expand and shrink independently from its load-bearing sub-frame due to heat and moisture influences. This requires a certain free space in the fastening for movements. Also limitations in the maximum panel size as well as minimum dimensions of the joints in between panels and between panels and other construction parts are a result of this requirement.
3. **Sub-frame.** Trespa® Meteon® panels must be installed on a sub-frame of sufficient strength and permanent durability. Quality and/or treatment of the sub-frame must be in accordance with certificate holders' recommendations as well as applicable building standards and regulations.

Following fixing methods are recognized by Trespa:

- Invisible fixing
- Visible fixing
- Deep cavity fixing
- Special fixing

Invisible Fixing

Trespa can be invisibly (i.e. concealed) fixed by using mechanically fastened metal brackets at the rear of the panels in combination with horizontal metal rails, or by machining profiled edges in the panels in combination with metal rails or clamps.

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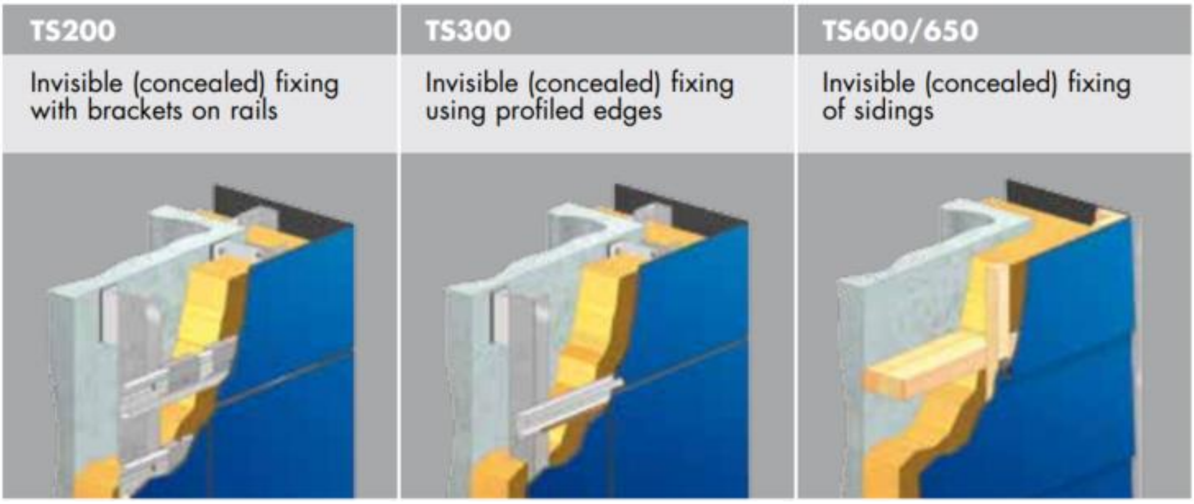

Figure29. Invisible fixing. Source: Trespa Guidelines

Visible Fixing

Trespa® Meteon® can be visibly (i.e. exposed) fixed by using screws and a timber sub-frame or using rivets or screws on a metal sub-frame.

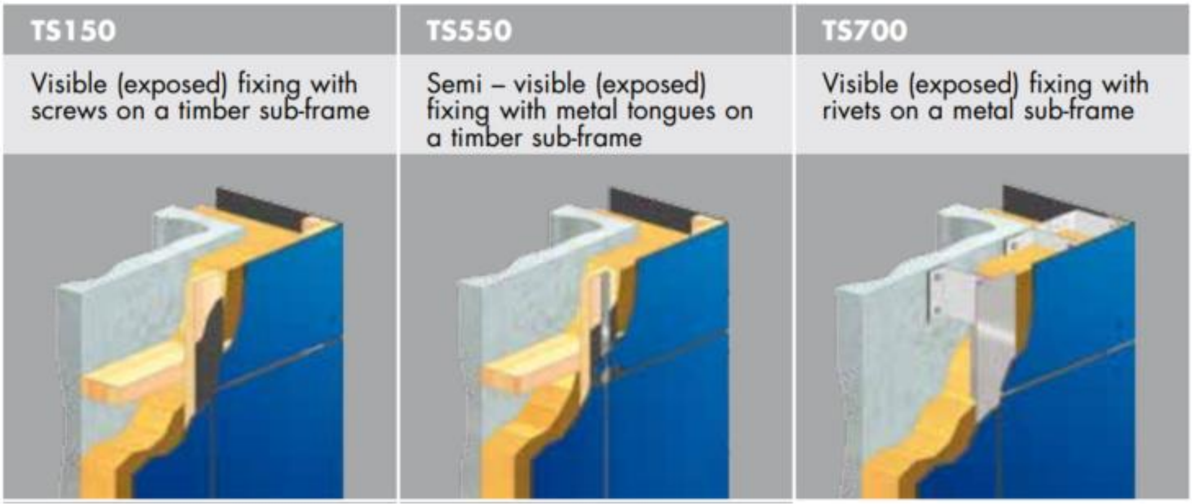

Figure 30. Visible fixing. Source: Trespa Guidelines

Special fixing

For high rise buildings a metal sub-frame is developed to span from floor to floor including fire barriers at each floor. This fixing method is predominantly used for visible fixing with rivets.

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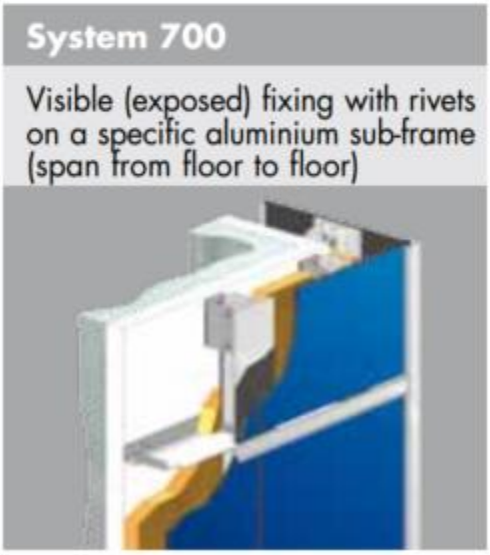

Figure 31. Special fixing. Source: Trespa Guidelines

Adhesive fixing

Finally, there are also fixing methods that have a limited geographical acceptance. These fixing methods are based on elastic adhesives that fasten the cladding panels to a timber or metal load-bearing sub-frame. Country specific certificates are issued to the manufacturer or agent of the adhesive system.

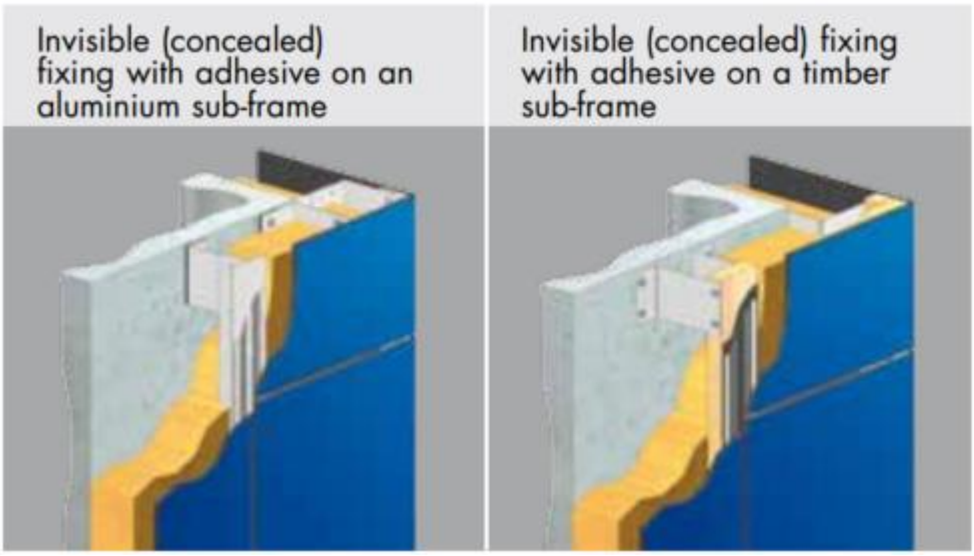

Figure 32. Chemical fixing. Source: Trespa Guidelines

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4. PILOT BUILDING CHARACTERISTICS

The characteristics of the buildings which will be retrofitted in Europe can be seen in the images below. Once the architectural project has been technically and economically validated, the system project's definitive implementation will be carried out in the demo buildings.

4.1. Summary of the physical properties of each pilot

a. **Description:**

Demo Building 1: Tartu
The demo building 1, labelled Annemõisa 12, has the following characteristics:

- Location: Tartu, Estonia
- Latitude: N/A
- Year of construction: 1947
- Storeys number: 2
- Typology: Residential
- Number of dwellings: Up to 15 (after renovation)
- Current occupancy: 30

Figure 33. Tartu Annemõisa Building

Demo Building 2: L'Aquila

The demo building 2 in L'Aquila has the following characteristics:

- Location: L'Aquila, Italy
- Latitude: 42°21'40.6"N 13°17'40.1"E
- Year of construction: 1978
- Storeys number: 3
- Typology: Residential

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- Number of dwellings: 2
- Current occupancy: max 20

Figure 34. Aerial view of the demo building in L'Aquila

Virtual Building 1: Glasgow

The virtual building 1 in Glasgow has the following characteristics:

- Location: Glasgow, Scotland
- Latitude: 55.92074
- Year of construction: N/A
- Storeys number: 2
- Typology: Non-residential/office
- Number of dwellings: N/A
- Current occupancy: N/A

Virtual Building 2: Amsterdam

The virtual building 2 in Amsterdam has the following characteristics:

- Location: Reigersbos (Block 584), Amsterdam, the Netherlands
- Latitude: 52° 17' 47.4'' N
- Longitude: 4° 58' 34.32'' E
- Year of construction: 1985
- Storeys number: 4
- Typology: Residential (1,2,3 floors); commercial (ground floor)
- Number of dwellings: 30
- Current occupancy: N/A

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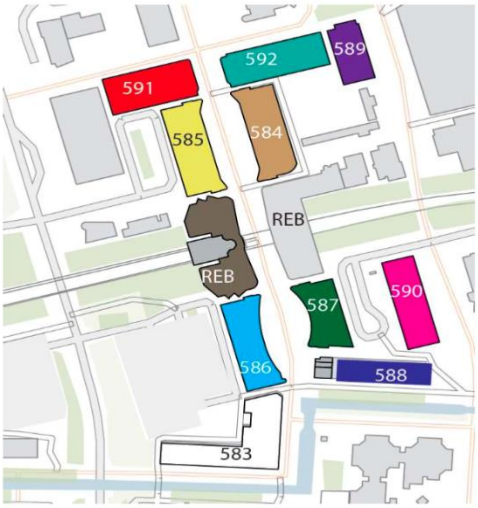

Figure 35: Location information of virtual building in Amsterdam

Virtual Building 3: Milano

The virtual building 3 in Milano has the following characteristics:

- Location: Via Valsesia, 66, Milano, Italy
- Latitude: 45°27'15.9" N
- Year of construction: 1972
- Storeys number: 13
- Typology: Residential
- Number of dwellings: 36

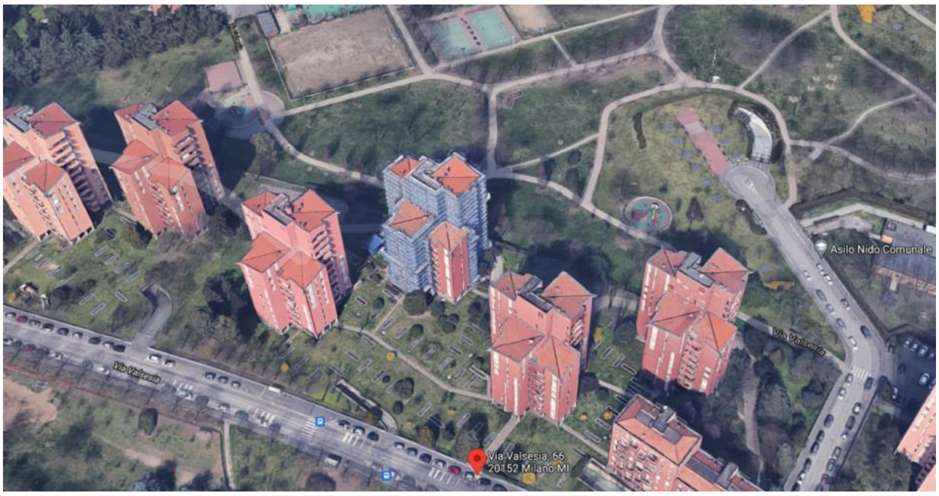

Figure 36. Milano virtual building, Via Valsesia, 66

b. Thermal Characteristics:

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ENVELOPE CHARACTERISTICS										
BUILDING	FACADE 01		FACADE 02		FACADE 03		FACADE 04		ROOF	
DEMO										
TARTU	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.848
COAF										
BAL										
VIRTUAL										
AMSTERDAM	U value W/(m² K)	2.8	U value W/(m² K)	2.8	U value W/(m² K)	2.8	U value W/(m² K)	2.8	U value W/(m² K)	No applicable
MILANO	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.054	U value W/(m² K)	1.848
GLASGOW	U value W/(m² K)	0.2599	U value W/(m² K)	0.2599	U value W/(m² K)	0.2599	U value W/(m² K)	0.2599	U value W/(m² K)	0.18

Table 3. U-value Cases studies summary

More details on the thermal characteristics of the façade and roof materials are provided in the Appendix A, Section 1.

4.2. Elevation diagrams of façades.

Considering the envelope characteristics of each case study and an energy consumption analysis, a preliminary study predicts the typology of the module.

The PV modules considered for the pilot buildings aim to be adaptable to each scenario and configuration. The designed dimension and technology should be flexible to the structure and the corresponding layout.

Demo Building 1: Tartu

The envelope composition of the building in Tartu is categorised as a medium-height structure adaptable for PV modules. In the Annemõisa 12 building, most windows are in the west (14 windows) and east side (7 windows), while on the north and south façade two windows are located on each one of them. (See Appendix A, Section 1).

A preliminary analysis indicated the outputs and the estimation of PV energy production, to clarify the scenarios in Annemõisa 12 building (See Appendix A, Section 1, Estimation of PV energy production, Tartu). The elevations are described as follows:

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Figure 37. Facade 1, Tartu

Figure 38. Facade 2, Tartu

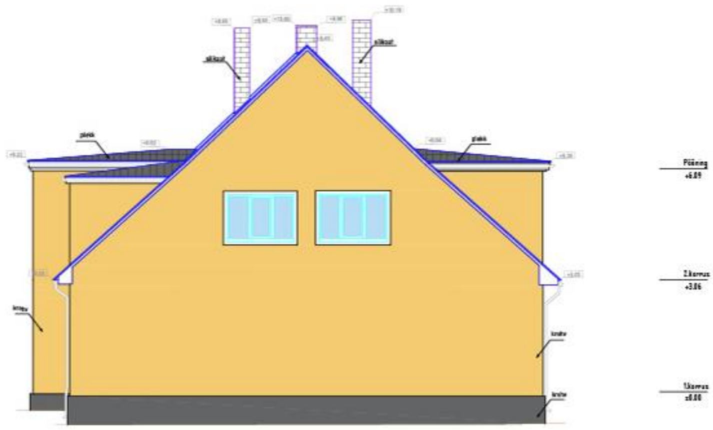

Figure 39. Facade 3 Tartu

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Figure 40. Facade 4 Tartu

Demo Building 2: L'Aquila

The envelope composition of the building in L'Aquila is categorised as a medium-height structure adaptable for PV modules. Most windows are in the north (26 windows), while there are 6 windows on the south façade, 7 on the west façade, 6 on the east façade and 4 at the roof. (See Appendix A, Section 2, Envelope characteristics).

A preliminary analysis indicated the outputs and the estimation of PV energy production, to clarify the scenarios in L'Aquila building (See Appendix A, Section 2, Estimation of PV energy production, L'Aquila). The elevations are described as follows:

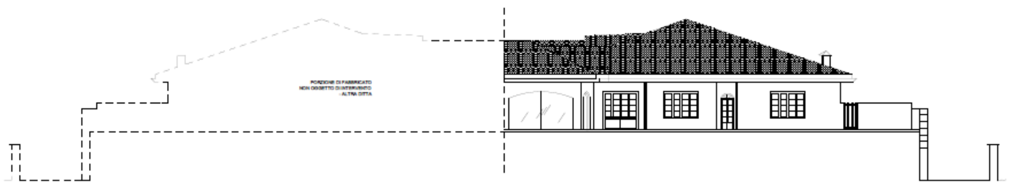

Figure 41. Facade 1 Villa Irti, Italy

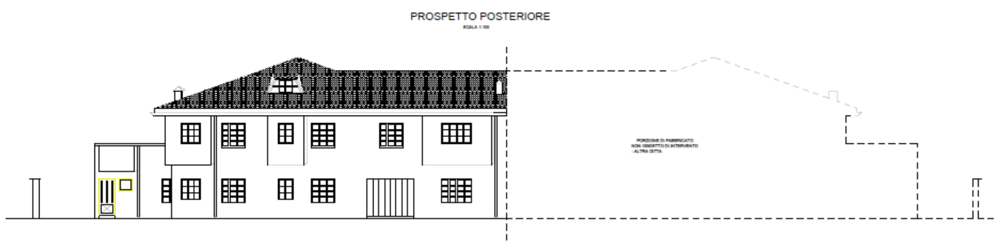

Figure 42. Facade 2 Villa Irti, Italy

Figure 43. Facade 3 Villa Irti, Italy

Virtual Building 1: Glasgow

The envelope composition of the building in Glasgow is categorised as a medium-height structure adaptable for PV modules. Most windows are in the west (20 windows) and east side (15 windows), while on the north façade there are 8 (+ 1 bigger) windows and on the south façade 8 windows. (See Appendix A, section 3, Envelope characteristics).

A preliminary analysis indicated the outputs and the estimation of PV energy production, to clarify the scenarios in Glasgow building (See Appendix A, section 3, Estimation of PV energy production, Glasgow).

Virtual Building 2: Amsterdam

The envelope composition of the building in Amsterdam is categorised as a medium-height structure adaptable for PV modules. Most windows are in the west (213 windows) and east side (216 windows), while on north façade there are 3 windows and on the south façade 10 windows. (See Appendix A, section 3, Envelope characteristics).

A preliminary analysis indicated the outputs and the estimation of PV energy production, to clarify the scenarios in Amsterdam building (See Appendix A, section 4, Estimation of PV energy production, Amsterdam).

Virtual Building 3: Milano

The envelope composition of the building in Milano is categorised as a medium height-structure adaptable for PV modules. Most windows are in the south-east (73 windows) and in the north-west side (61 windows), while on the south-west and north-east façades, they are distributed (54 and 42 windows, respectively). (See Appendix A, section 5, Envelope characteristics).

A preliminary analysis indicated the outputs and the estimation of PV energy production to clarify the scenarios in Milano building (See Appendix A, section 5, Estimation of PV energy production, Milano).

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Regarding the energy consumption and irradiation analysis on each façade, it will be possible to propose a modularity in the building according to the PV panels specifications and technologies adapted in each case study

4.3. HVAC and Domestic Hot Water (DHW) system

Demo Building 1: Tartu

The Annemõisa building is currently equipped with the following building system services (BSS):

- *Heating system installed:* Wood-burning stove in every room. The heat from the fire warms the stove and the air in the room. The smoke from the fire is drawn out of the house through the stove's chimney. The damper allows the user to control the airflow to the stove, which affects how large the fire grows and how much heat it emits.
- *Domestic hot water (DHW) system:* Communal hygiene room with water from electric boiler.
- *Air-conditioning system:* Not available.
- *Mechanical ventilation system:* Not available.

Available low carbon Technologies. Description, in any already present, of low carbon technologies:

- *Renewable heat generation source:* Not available.
- *Renewable electricity generation source:* Not available.

Demo Building 2: L'Aquila

The building in L'Aquila is currently equipped with the following building system services (BSS):

- *Heating system installed:* Hydraulic central heating system: gas-fired condensing boiler and radiators consisting of assembled cast-iron heating elements: there is one boiler for each of the two building units.
- *Domestic hot water (DHW) system:* The DHW system is fed by the same condensing boiler that provides hot water distribution to the radiant heating system.
- *Air-conditioning system:* Not available.
- *Mechanical ventilation system:* Not available.

Available low carbon Technologies. Description, in any already present, of low carbon technologies:

- *Renewable heat generation source:* Not available.
- *Renewable electricity generation source:* Not available.

Virtual Building 1: Glasgow

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The Glasgow building is currently equipped with the following building system services:

- *Heating system installed:* Natural gas LTHW boiler with seasonal efficiency of 0.95. Heat distributed through radiators. Heating setpoint of 21 °C in office spaces and 18 °C elsewhere.
- *Domestic hot water (DHW) system:* Yes.
- *Air-conditioning system:* Not available.
- *Mechanical ventilation system:* Two spaces have mechanical supply at 1.8 W/(l/s) supply specific fan power each. Three spaces have mechanical exhaust at 0.6 W/(l/s) exhaust specific fan power and 10 ac/hr extract flow rate. All office spaces and some other spaces have natural ventilation only.

Available low carbon Technologies. Description, in any already present, of low carbon technologies:

- *Renewable heat generation source:* Not available.
- *Renewable electricity generation source:* Not available.

Virtual Building 2: Amsterdam

The Amsterdam building is currently equipped with the following building system services:

- *Heating system installed:* The heating consists of an individual central heating system per house (CH boiler), with flue gas discharge per house on the façade. Depending on the layout of the house, the central heating boiler is located at the front of the house, with flue gas outlet above the gallery, just outside the rising façade, or at the rear, with flue gas outlet above the balconies.
- *Domestic hot water (DHW) system:* CH boiler.
- *Air-conditioning system:* Not available.
- *Mechanical ventilation system:* The apartments are ventilated by exhaust air via joint ducts with roof ventilator per shaft. The air supply is via window grilles in the front and rear (it is expected that these are often closed). As a result, there are many damp complaints in the homes.

Available low carbon Technologies. Description, in any already present, of low carbon technologies:

- *Renewable heat generation source:* Not available.
- *Renewable electricity generation source:* Not available.

Virtual Building 3: Milano

The Milano building is currently equipped with the following building system services:

- *Heating system installed:* There is a central heating system with three generators, with an average power of 1126 kW. The three boilers serve the whole condominium consisting of 6 buildings. The energy carrier used is methane gas.

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- *Domestic hot water (DHW) system:* The production of domestic hot water is autonomous for each apartment.
- *Air-conditioning system:* Some apartments have an air conditioning system. The system consists of an outdoor unit and split.
- *Mechanical ventilation system:* Not available.

Low carbon Technologies. Description, in any already present, of low carbon technologies:

- *Renewable heat generation source:* Not available.
- *Renewable electricity generation source:* Not available.

4.4. Description of existing control and management systems

Virtual Building 1: Glasgow

The Glasgow building BMS consists of the following:

- *Building management system (BMS) or control system:* Sensors to record energy data.

The rest of the demo building does not have a building management system (BMS) or control system

4.5. Desription of the structural system.

Demo Building 1: Tartu

The Annemõisa building has the following structural system details:

- Structure typology: Timber framing
- Distance between slabs (floors): 2,42m to 2,82m
- Slab structure thickness: 0,37m to 0,49m
- Slab material properties: Timber beams
- Height: 0,609m; 1,00 m to top of chimney
- Floor dimensions (length x width): 3,06mx10,56m?

Demo Building 2: L'Aquila

The building in L'Aquila has the following structural system details:

- Structure typology: Structure of concrete floors and pillars
- Distance between slabs (floors): 3,00 m
- Slab structure thickness: 0,30 m
- Slab material properties: Reinforced concrete
- Height: 9,00 m
- Floor dimensions (length x width): 20,00 x 15,00m

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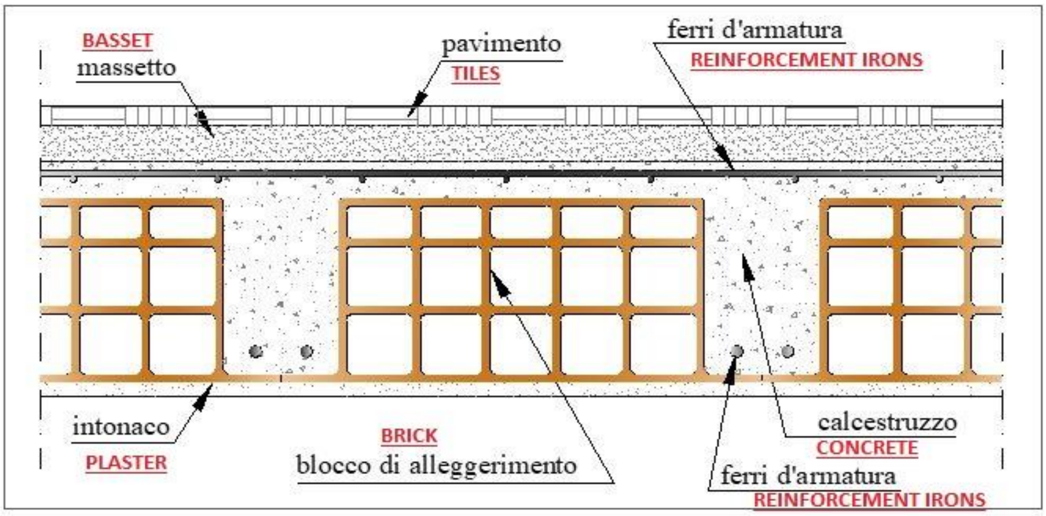

Figure 44. Italian pilot Structural scheme

Virtual Building 1: Glasgow

The Glasgow building has the following structural system details:

- Structure typology: N/A
- Distance between slabs (floors): N/A
- Slab structure thickness: N/A
- Slab material properties: N/A
- Height: N/A
- Floor dimensions (length x width): N/A

Virtual Building 2: Amsterdam

The Amsterdam building has the following structural system details:

- Structure typology: Bearing walls
- Distance between slabs (floors): 2,52m
- Slab structure thickness: 0,27m
- Slab material properties: Concrete
- Height: 2,52m
- Floor dimensions (length x width): 65,44m x 11,38m

Virtual Building 3: Milano

The Milano building has the following structural system details:

- Structure typology: Structure of concrete floors and pillars
- Distance between slabs (floors): 3,0 m
- Slab structure thickness: 0,30 cm
- Slab material properties: Not available
- Height: 42,9 m

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- Floor dimensions (length x width): 10,00 m x 10,00 m

4.6. Fire resistance and fire reaction of external walls of each pilot

The fire resistance and the fire reaction characteristics of the façade for each pilot case are fundamental data in the knowledge of its behaviour to fire. This information is pending to be received by the different managers of the pilot buildings.

4.7. National regulations summary

For the national building regulations, several inputs are required to clarify the characteristics and technologies of the module for each country.

For each demo building, the following information is provided regarding the national building regulations, in summary for five different categories: energy save, indoor air quality, security in case of fire, structure and acoustics. (some information not yet received)

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Table 4. Energy save. National Building Regulation

		Tartu (Estonia)		L'Aquila (Italy)		Glasgow (Scotland)		Amsterdam (Netherlands)		Milan (Italy)	
NATIONAL BUILDING REGULATION	Requirement	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value
ENERGY SAVING (e.g. Building regulation Part L in the UK, EnEV in Germany)	**U-value** of the external wall (W/(m^2 K))	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	0,12...0,14 W/(m²K)				0.3 W/(m2·K) when improving existing building stock	BRISbouwbesluit	R-value ≥ 4.5 m2K/W (new buildings) R-value ≥ 1.3 m2K/W (renovations)	DDUO 18/12/19	0,28
	Limit value for **air permeability of holes** in the thermal envelope. (m^3/h·m^2)	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	less than 1				10 m^3/(h·m^2)	BRISbouwbesluit, NEN-EN 12207	Maximum pressure (Pa): 150; 50 m3/h•m2 Maximum pressure (Pa): 300; 27 m3/h•m2 Maximum pressure (Pa): 600; 9 m3/h•m2	DDUO 18/12/19	1.50
	Non-renewable primary energy consumption [kW·h/m2year]	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	100	https://www.reteambiente.it/normativa/energia/indici/vigente/?p=all				BENG	25 kWh/m2.year	DDUO 18/12/19	Epgl,nren<Epgl,nren,lim
	Total primary energy consumption [kW·h/m2year]	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	100					BENG	25 kWh/m2.year	DDUO 18/12/19	Epgl,tot<Epgl,tot,lim
	Minimum contribution of renewable energy to cover the domestic hot water demand	Not set in regulation	No applicable					BENG	0,5	DDUO 18/12/19	
	Minimum generation of electrical energy	Not set in regulation	No applicable						Not applicable	DDUO 18/12/19	
	Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	Not set in regulation	No applicable						Not applicable	DDUO 18/12/19	

Table 5. Indoor air quality. National Building Regulation

		Tartu (Estonia)		L'Aquila (Italy)		Glasgow (Scotland)		Amsterdam (Netherlands)		Milan (Italy)	
NATIONAL BUILDING REGULATION	Requirement	Source	Value	Source	Value	Source	Value	Source	Value	Source	Value
INDOOR AIR QUALITY	Ventilation rates	https://www.evs.ee/et/evs-en-16798-7-2017	0,5 L/s/m2				Not available	BRISbouwbesluitonline - NEN1087	Residential: at least 0.9 dm³/s per m² floor area with a minimum of 7 dm³/s § Cooking appliance: at least 21 dm³/s A bathing area: at least 14 dm³/s	DDUO 18/12/19	0.5-0.7 L/s/m2

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Table 6. Security in case of fire. National Building Regulation

		Tartu (Estonia)		L'Aquila (Italy)		Glasgow (Scotland)		Amsterdam (Netherlands)		Milan (Italy)	
NATIONAL BUILDING REGULATION	**Requirement**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**
SECURITY IN CASE OF FIRE	Minimum fire resistance of the wall (minutes)	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	R30				Medium for office	BRISbouwbesluit	<7m high: 60 minutes >7m and <13m high: 90 minutes >13m high: 120 minutes	D.M. 16.2.2007	R 15
	Spread of fire	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	D-s2,d2	https://www.vigilfuoco.it/aspx/Page.aspx?IdPage=5136			insulation exposed in a cavity should be constructed from products which achieve European Classification A1, A2 or B	BRISbouwbesluit- NEN 6090	The time is shortened by 30 minutes if the permanent fire load of the fire compartment does not exceed 500 MJ/m².	UNI EN 13501-1	Classes 0 to 5
	Reaction to fire.	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	D-s2,d2					BRISbouwbesluit - NEN-EN 13501-1	NEN-EN 13501-1	NTC 2018	25

Table 7. Structure. National Building Regulation

		Tartu (Estonia)		L'Aquila (Italy)		Glasgow (Scotland)		Amsterdam (Netherlands)		Milan (Italy)	
NATIONAL BUILDING REGULATION	**Requirement**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**
STRUCTURE	wind load (without increasing)		0,37 kN/m²	https://www.gazzettaufficiale.it/eli/gu/2018/02/20/42/so/8/sg/pdf https://www.ingenio-web.it/18847-ntc-2018-le-novita-capitolo-per-capitolo			a. for wind loadings, BS EN 1991-1-4:2005 (Eurocode 1)	BRISbouwbesluit - NEN-EN 1991-1-4	0.88 kN/m^2	NTC 2018	Basic wind speed (m/s): 25, Basic wind speed pressure (kN/m2): 0.39, Coefficient of wind exposure: 0.17
	seismic load (without increasing)		No applicable							NTC 2018	Basic seismic acceleration [ab/g] (m/s²): 0.15, Contribution coefficient k: 0.4

Table 8. Acoustics. National Building regulation.

		Tartu (Estonia)		L'Aquila (Italy)		Glasgow (Scotland)		Amsterdam (Netherlands)		Milan (Italy)	
NATIONAL BUILDING REGULATION	**Requirement**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**	**Source**	**Value**
ACOUSTICS. (noise)	Minimum airbone sound insulation (dB)		30 (appartment) 45 in common room	https://www.ingenio-web.it/25954-norme-tecniche-di-acustica-edilizia-stato-dellarte-e-prospettive-future			56 DnT,w for new buildings and conversions no including traditional buildings 53 DnTw for conversions of traditional buildings.	BRISbouwbesluit - NEN 5077	Minimum of 20 dB	D.P.C.M. 5-12-1997	40

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4.8. Local requirements about the aesthetic aspects

Demo Building 1: Tartu
For the building in Tartu, the following information is provided:

- Local requirements about aesthetic aspects: some information not yet received):
- Code for cultural heritage: N/A

Demo Building 2: L'Aquila

For the building in L'Aquila, the following information is provided:

- Local requirements about aesthetic aspects: The existing building is one of the most beautiful garden villas in the area and will become a residence for the elderly. For this reason, it will be essential to combine aesthetic choices, the wishes of the owners and technological requirements.
- Code for cultural heritage: N/A

Virtual Building 2: Amsterdam

For the Amsterdam building, the following information is provided:

- Local requirements about aesthetic aspects: Under the windows, the façade is closed with a non-insulated Trespa plate. Some façade parts are fitted with asbestos cladding.
- Code for cultural heritage: To renew the façades, permission is required from the architect Cees van Dam.

Virtual Building 3: Milano

For the Milano building, the following information is provided:

- Local requirements about aesthetic aspects: Building submitted to the opinion of the landscape commission.
- Code for cultural heritage: D. Lgs. 22 gennaio 2004 n.42 Parte III Titolo I. <u>The Code constraints are to</u>:
  - Preserve and respect the typological, morphological and chromatic characters inside the original residential settlement.
  - Safeguard and enhance the vegetation characteristics of the public park inside the neighbourhood.

Safeguard and enhance the overall system of public and private green areas preserving its continuity and perceptual permeability from the inside and outside of the neighbourhood.

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5. COSTS

5.1. Feasibility Study.

Methodology
This section outlines the methodology used to determine the cost of the active façade so that it is competitive in the climatic and techno-economic conditions in which it will be installed. In particular, the parameters of the six case-study buildings have been used together with economic and financial parameters related to the energy markets of the corresponding countries. The latter are resumed in Table 9. These values were obtained using the EUROSTAT database [EUROSTAT, 2021] and information by the partners of the project. For the specific energy consumption, if the data was available for the specific case study it was used instead of the mean value for the selected Country. This choice led to considering a significantly lower electricity consumption compared to the national average for both UK (-33%) and NL (-50%) case study buildings.

Table 9 – Input data for the analysis in each case studies.

Demo case	**DB1**	**DB2**	**DB3, VD3**	**VD1**	**VD2**
Country	EE	BG	IT	UK	NL
Price of natural gas for households, p_{gas} (€/kWh)	0.043	0.041	0.083	0.049	0.093
Price of electricity for households, $p_{el,b}$ (€/kWh)	0.130	0.100	0.220	0.190	0.180
Stock market price for electricity, $p_{el,s}$ (€/kWh)	0.041	0.041	0.051	0.044	0.038
Annual energy consumption for space heating, Q_{SH} (kWh/m^2)	180.8	78.2	128.4	112.4	100.4
Annual energy consumption for DHW, Q_{DHW} (kWh/m^2)	29.3	26.6	23.9	29.0	26.5
Annual electricity consumption per dwelling, W_{EL} (kWh)	2759	3667	2623	2418	1537
Primary energy conversion factor for	2.00	2.00	2.42	2.50	2.56

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electricity (-)					
Reference climate for NZEB evaluation (SFH: Single Family House) [EU, 2016]	Nordic-SFH	Continental -SFH	Continental -SFH	Continental -SFH	Continental -SFH
Annual primary energy consumption range for NZEB, $f_{el,P}$ (kWh/m²) [EU, 2016]	40-65	20-40	20-40	20-40	20-40

The analysis assumes electricity as the only energy vector for the retrofitted buildings. Both space heating (SH) and domestic hot water (DHW) are supplied by air source heat pumps with seasonal energy efficiency COP equal to COP_{SH} = 3.5 and COP_{DHW} = 3.0 for all the cases considered. ENSNARE includes three possible plants to be integrated in the active facades: either PV systems, solar thermal collectors (STC) or hybrid PV-thermal (PVT) systems. Since ST and PVT systems would only affect the primary energy consumption for DHW production, the present preliminary analysis considers building-integrated PV systems as standard solution.

The methodology consists of four consecutive steps:

(i) Calculate a baseline cost for space heating, DHW production and electricity assuming there is no local renewable and both space heating and DHW production are supplied by means of a traditional gas boiler.

$$C_{base} = p_{gas}\left(Q_{SH,base} + Q_{DHW}\right) + p_{el,b}\, W_{EL} \qquad (1)$$

As an example, the following Figure 1 shows the baseline costs for the energy supply of the case-study building in Tartu.

End use	*Reference consumption (kWh)*	*Reference operating costs (€)*
EL	16'554	2'152
SH	79'190	3'405
DHW	12'833	552
Tot		6'109

Figure 45. Baseline costs for the case-study building in Tartu.

(ii) Calculate the final cost for the same energy uses after the refurbishment under different scenarios of active surface area and thermal insulation of the envelope. Here sixteen solutions arise from the combination of four surface areas covered by the active façade (30% (S-A), 45% (S-B), 60% (S-C) and 75% (S-D) out of the total opaque surface) and four levels of thermal insulation measured in terms of reduced consumption for space heating (-40% (S-1), -60% (S-2), -80% (S-3) and

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-90% (S-4) compared to the initial situation). The combinations of the scenarios are reported in Figure 46.

Scenario	*Active part out of opaque surface area*	S-1 (low insulation)	S-2 (medium insulation)	S-3 (high insulation)	S-4 (very high insulation)
S-A	30%	-40%	-60%	-80%	-90%
S-B	45%	-40%	-60%	-80%	-90%
S-C	60%	-40%	-60%	-80%	-90%
S-D	75%	-40%	-60%	-80%	-90%

Figure 46. Combinations of the considered scenarios.

The new cost is evaluated as:

$$W_{EL,new} = \frac{Q_{SH,new}}{COP_{SH}} + \frac{Q_{DHW}}{COP_{DHW}} + W_{EL} \tag{2}$$

The envelope is assumed to be partly covered by the active façade and partly by a ventilated façade. Depending on the surface area covered by the active façade, different amounts of electricity are produced over the year:

$$W_{PV} = \sum\nolimits_{j=1}^{4} w_{PV,j} A_{act,j} \tag{3}$$

where $w_{PV,j}$ is the producibility of the active façade on the j-th orientation of the building envelope. Part of this energy is self-consumed by electrical devices or by the air-source heat pump ($W_{EL,self}$), and the remaining part is sold to the grid ($W_{EL,sold}$) at the average stock market price.

$$W_{EL,self} = k_{SH,self} \frac{Q_{SH}}{COP_{SH}} + k_{DHW,self} \frac{Q_{DHW}}{COP_{DHW}} + k_{EL,self} W_{EL} \tag{4}$$

$$W_{EL,sold} = W_{PV} - W_{EL,self} \tag{5}$$

$$C_{new} = p_{el,b} \left(\frac{Q_{SH}}{COP_{SH}} + \frac{Q_{DHW}}{COP_{DHW}} + W_{EL} - W_{EL,self} \right) - p_{el,s} W_{EL,sold} \tag{6}$$

The level of self-consumption is assumed to depend completely on the energy demand of the considered buildings; the corresponding percentages are reported in the following Table 10.

Table 10 Self-consumption values considered in the analysis.

Parameter	$k_{EL,self}$	$k_{SH,self}$	$k_{DHW,self}$
Energy end use	EL	SH	DHW
PV self-consumption with respect to the electricity demand	35%	20%	45%

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The annual cost saving is then calculated as follows:

$$S = C_{base} - C_{new} \tag{7}$$

As an example, Figure 47 shows the operating costs and the corresponding annual cost savings for all 16 scenarios for the case-study building in Tartu.

Net operating costs (€)	S-1	S-2	S-3	S-4
S-A	3'117	2'646	2'138	1'884
S-B	2'958	2'451	1'943	1'689
S-C	2'763	2'255	1'747	1'494
S-D	2'567	2'060	1'552	1'298
Cost savings (€)	S-1	S-2	S-3	S-4
S-A	2'993	3'463	3'971	4'225
S-B	3'151	3'659	4'166	4'420
S-C	3'346	3'854	4'362	4'615
S-D	3'542	4'049	4'557	4'811

Figure 47. New cost and savings for the case-study building in Tartu.

(iii) Set a payback time and calculate the investment cost required for each of the scenarios considered. The inverse procedure proposed here adopts the Discounted Cash Flow method to calculate the target investment cost for a given payback time PBT based on the annual cost savings S calculated in the previous step. The resulting investment cost for the overall solution is given by:

$$I^* = \sum_{i=1}^{N=PBT} \frac{S_{(i)}}{(1+r)^i} = S \sum_{i=1}^{N=PBT} \frac{1}{(1+r)^i} \tag{8}$$

The specific investment cost for the overall solution i_{tot}^* (€/m²) can be obtained by dividing the required investment cost by the total opaque area A_{op}:

$$i_{tot}^* = \frac{I^*}{A_{op}} \tag{9}$$

Based on the experience of the partners, realistic values for the annual discount rate is r = 3%, respectively. For example, Figure 48 shows the target investment cost calculated with the inverse procedure assuming PBT = 12 years for the case study in Tartu.

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Investment cost for overall solution (€/m2)	S-1 (low insulation)	S-2 (medium insulation)	S-3 (high insulation)	S-4 (very high insulation)
S-A	87	101	116	123
S-B	92	107	121	129
S-C	98	112	127	135
S-D	103	118	133	140

Figure 48. Specific investment cost for the overall retrofit solution in Tartu.

(iv) Calculate the primary energy consumption for all the considered scenarios and select the cost of those scenarios that achieve NZEB standards. Since electricity is the only energy vector considered after the refurbishment, the primary energy consumption is calculated as follows:

$$E_P = f_{el,P}\, W_{EL,new} \tag{10}$$

where $f_{el,P}$ is the primary energy conversion factor for electricity based on the supply mix of the considered country (see Table 9). In the following Figure, the red (green) solutions lead to a higher (lower) primary energy consumption compared to NZEB standards according to the guidelines of the European Commission [EU, 2016] (see Table 9). Therefore, the investment cost required to achieve NZEB building in Tartu assuming PBT = years corresponds to white cells in Figure 49. The corresponding costs range from 112 to 121 €/m^2 for the overall surface (Figure 48).

Distance from NZEB target (kWh/m2)	S-1 (low insulation)	S-2 (medium insulation)	S-3 (high insulation)	S-4 (very high insulation)
S-A	-49	-28	-7	0
S-B	-27	-6	0	0
S-C	-5	0	11	22
S-D	0	12	33	43

Figure 49. Selection of NZEB solutions.

The analysis has been carried out in each case study considering the methodology reported above. The next Section outlines the main results.

Results

Figure 49 shows the effect of the PBT on the investment cost for the ENSNARE façade system reaching the NZEB target for demo buildings. In order for the façade system to be paid back after 12 years, the overall system should cost 112-121 €/m^2 in Tartu, 215-220 €/m^2 in Milan, 64-66 €/m^2 in Glasgow, 241-245 €/m^2 in Amsterdam. The resulting investment cost can therefore be interpreted as an available budget for the ENSNARE façade system, given the boundary conditions for the specific building and the target payback time, that should be fixed according to alternative technologies. A low investment cost for the overall solution represents a low budget and therefore indicates a low economic sustainability. The lowest values occur for Glasgow and Tartu and are

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linked to the reduced cost saving brought by the thermal insulation of the envelope. In particular, Glasgow's building envelope is already well insulated and in Tartu the cost saving is hindered by the low price of natural gas.

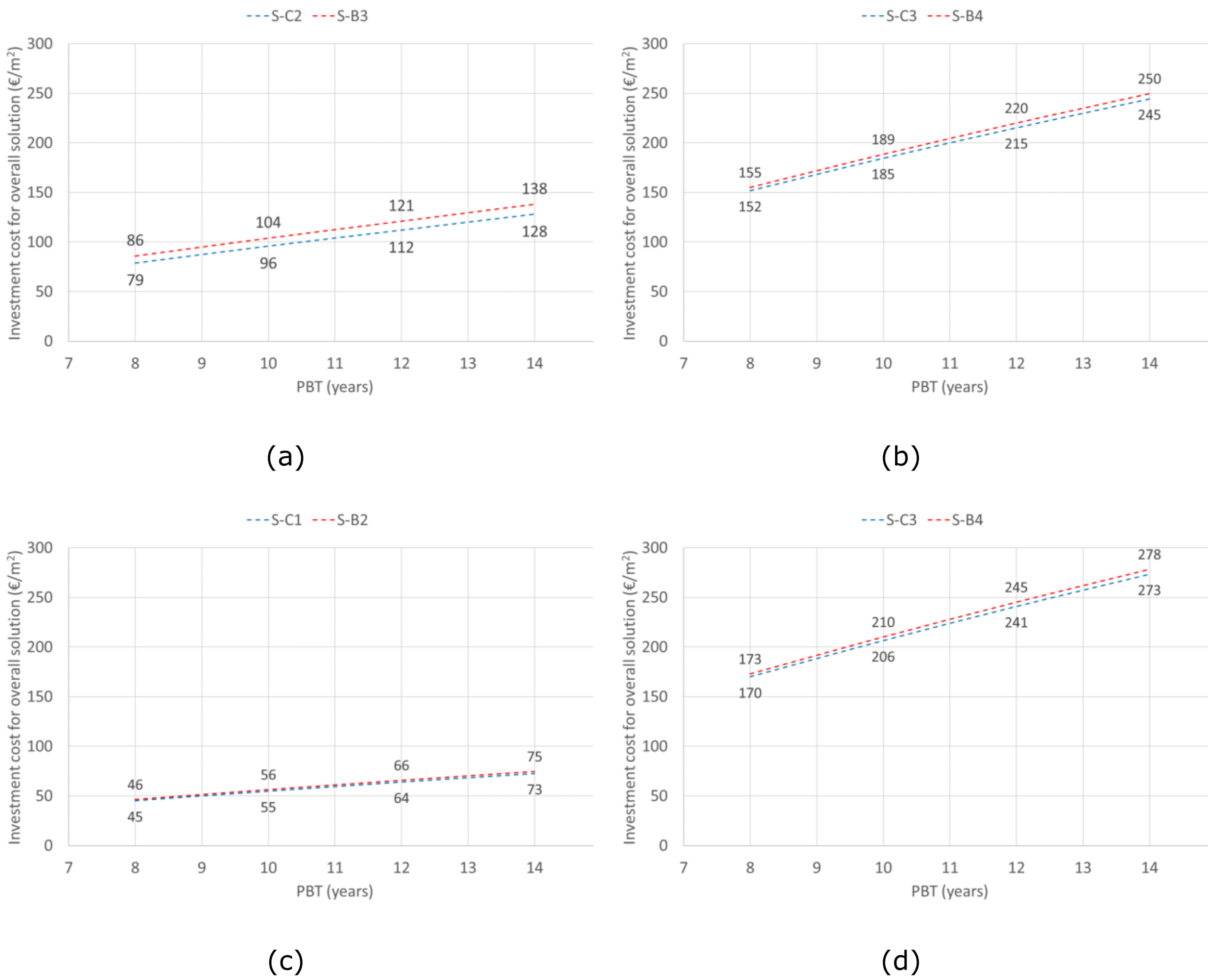

Figure 50. Effect of PBT on the specific investment cost for NZEB retrofit solutions in demo buildings: (a) Tartu, (b) Milan, (c) Glasgow, (d) Amsterdam.

Figure 50 shows the effect of the area covered by the active façade out of the total opaque envelope surface on the target investment cost in the considered demo buildings. The Figures show that increasing the active surface has a beneficial effect in each climate, as a higher investment cost leads to the same payback time that is set here to 12 years.

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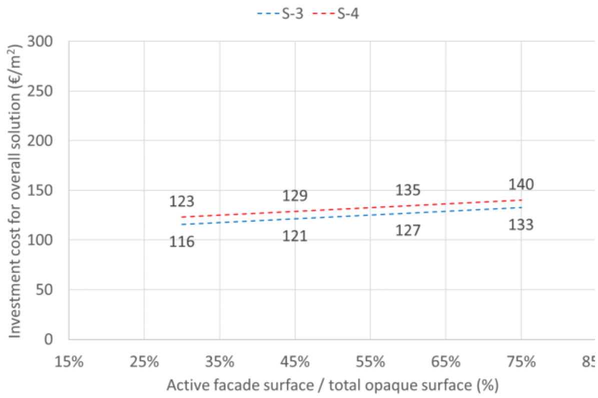
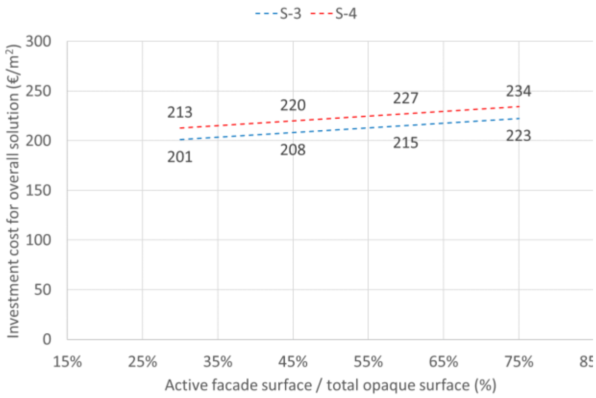


(a)



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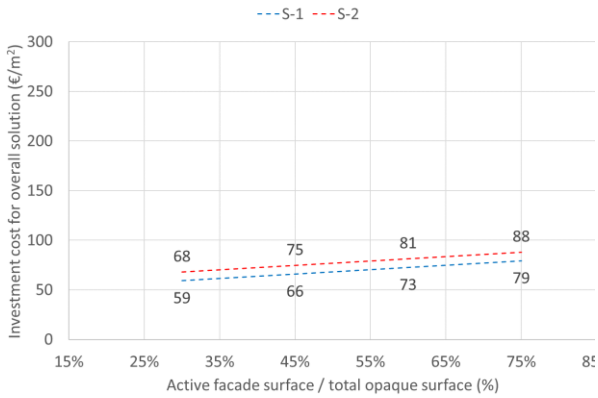

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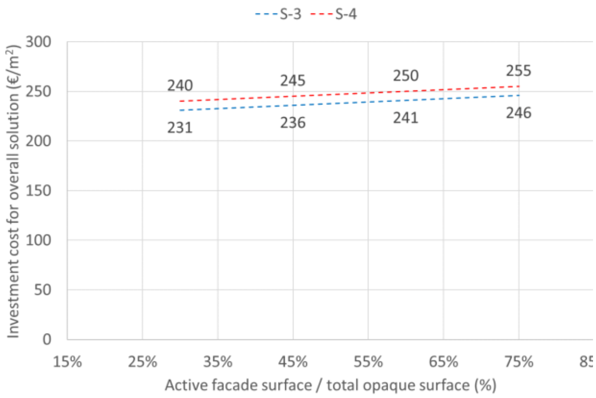

(d)

Figure 51. Specific investment cost for demo buildings with PBT = 12 years: (a) Tartu, (b) Milan, (c) Glasgow, (d) Amsterdam.

Finally, Figure 51 shows the effect of thermal insulation (in terms of energy demand reduction for space heating) on the target investment cost in demo buildings. As it can be seen, a higher thermal insulation leads to a higher cost saving, which turns into a higher investment cost for a given PBT. It is still an open question whether such a high energy demand reduction can actually be achieved by only insulating the opaque vertical walls. Figure 51 shows that the two lines corresponding to two different values of area of PV modules (S-A versus S-D) present the same slope; as it was expected, the cost is lower when a lower area is covered by PV modules (S-A).

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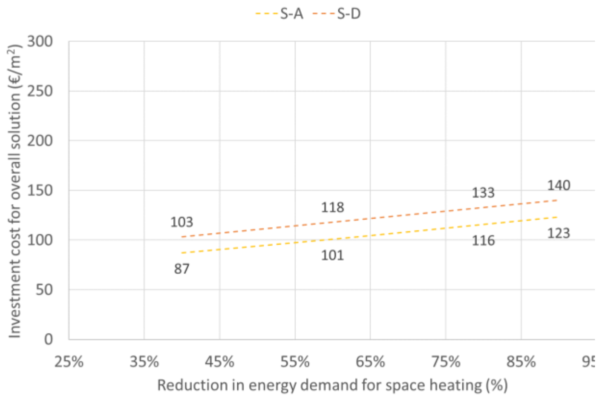
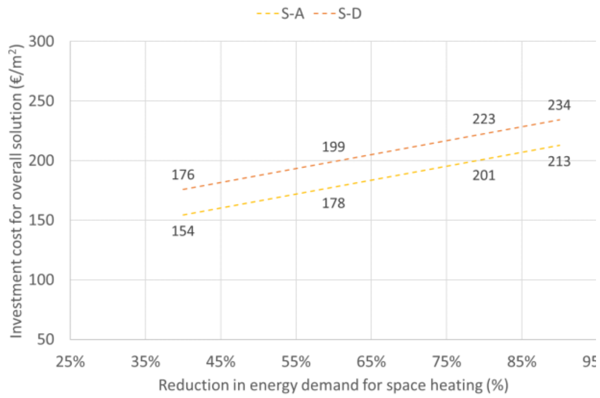
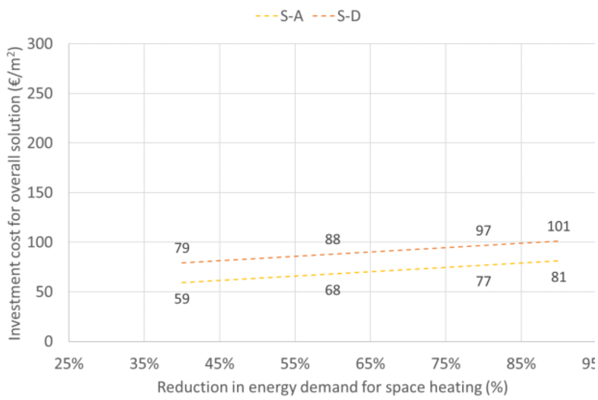


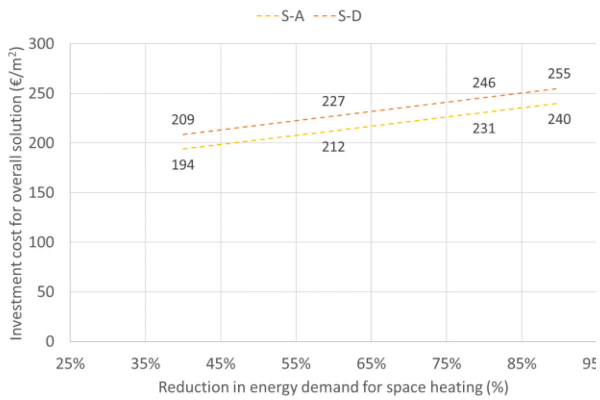
(a)



(b)



(c)



(d)

Figure 52. Specific investment cost for demo buildings with PBT = 12 years: (a) Tartu, (b) Milan, (c) Glasgow, (d) Amsterdam.

Nomenclature
A: surface (m^2)
C: cost (€)
COP: energy efficiency of the heat pump (kWh/kWh);
p: specific cost (€/kWh)
Q: thermal energy (kWh)
W: electrical energy (kWh)
w: specific electrical PV productivity (kWh/m^2)
I: investment cost (€)
Acronyms
DHW: Domestic Hot Water
EL: electricity

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5.2. Estimation for the reduction on manufacturing and installation time costs.

As a benchmark to consider, the manufacturing and installation of curtain wall modules (CWM) was analyzed. The data is gathered in Table 11. In total, it would make 3,27 h/m², which makes it very similar to manual processes for a rain-screen.

Table 11: Necessary time for the aluminium curtain wall manufacturing (SC2) procedures. [4]

MANUFACTURING	
Cutting and CNC machining	0,21 h/m²
Assembly of profiles and rest of elements	1,74 h/m²
Quality inspection and finishing	0,17 h/m²
Logistic	0,69 h/m²
DATA FLOW	
Determine the cast in channel location during form working process	0,02 h/m²
Survey for determining location of brackets-connector	0,02 h/m²
ON-SITE INSTALLATION	
Cast in channel fixation to the rebar during form working process	0,02 h/m²
Brackets-connector installation and setting out	0,03 h/m²
Panel Preparation	0,03 h/m²
Panel Transportation to launching Bed position	0,06 h/m²
Panel on Launching Bed and Lubrication	0,10 h/m²
Panel Connected to Crane, Lifted and Rotated	0,08 h/m²
Panel Alignment on side (mullions engagement)	0,04 h/m²
Panel Alignment to Brackets	0,02 h/m²
Panel Levelling	0,03 h/m²
Gasket Placement per 5 units	0,01 h/m²

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Panel Protection Installation per 10 units	0,01 h/m²
TOTAL	**3,27 h/m²**

The data on Table 11 doesn't consider the necessary time to:

- Design and adjust the CWM to an existing façade. Depending on the techniques, it might take from 0,49 h/m² *[4]*
- Time for data acquisition of an existing building. This is a data that ENSNARE manufacturing partners might provide.

According to current data, the current time for refurbishing building with fully prefabricated modules that include energy harvesting devices is around 4,00 h/m².

5.3. LCC Approach.

In recent years, several methodological approaches for assessing the environmental performance have been developed. These approaches have brought some of the most significant changes in design activity. The compatibility assessment requires the Life Cycle Thinking (LCT) approach, which takes into account all aspects of the life cycle (from cradle to grave). To assist business practitioners in using an LCT approach, a wide range of tools and methods have been proposed around the world. The most commonly used tools are Life Cycle Assessment (LCA) and Life Cycle Cost (LCC). The LCA, defined by ISO 14040/44, is "a method to assess and quantify the energy and environmental loads and potential impacts associated with a product, process or activity over its life cycle, i.e. from production to disposal". The LCC Life Cycle Costing is "a technique for the economic evaluation of a new construction or an existing asset, taking into account both immediate and long-term costs and benefits". It is therefore a tool to support design choices in a variety of contexts, from individual products or components to refurbishments and new construction projects.

In particular, the purpose of LCC is to measure and analyze new and existing buildings. In the European context, models are often based on EN 16627 Sustainability of construction works - Assessment of economic performance of buildings, that complements the EN 15643-4 Sustainability of construction works – Assessment of buildings – Part 4: Framework for the assessment of economic performance -standard. The standard provides the calculation rules for the assessment of economic performance as a part of an assessment of sustainability of the building. The assessments should be carried out based on a chosen reference study period, that is equal to the required service life of the building. It is often most fruitful, if the basic outcome is a comparison between "Business as usual" and "Improvement", where two options are compared against each other to see how improvements affect each life cycle stage. The system boundary used in the assessment determines all the processes that are considered. For an existing building (or a part of it), the system boundary should include the possible acquisition costs, as well as all the remaining stages of the manufacturing and use stages, and the end-of-life stage of the building.

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The life-cycle stages are as follows:

- A0 Pre-construction stage – Costs that relate to activity carried out before a development site is selected, including for example purchase, rental costs and taxes. Based on actual project related data.
- A1-A3 Product stage – Generic data or manufacturer given costs on the product
- A4 Transport – Transport to construction site
- A5 Construction and installation – For example wastage at the site, work (professional fees)

The use stage covers the period from the practical completion and handover of the construction work to the point of time when the building is deconstructed/demolished.

- B1 Use – The costs arising from the normal anticipated conditions of use of the building and building related incomes. This includes any taxes, regulatory, insurance and, security costs or other costs normally incurred during the operation of the building that do not fall within modules B2 – B7.
- B2 Maintenance
- B3 Repair
- B4 Replacement
- B5 Refurbishment
- B6 Operational energy use
- B7 Operational water use
- C1-C4 End of life

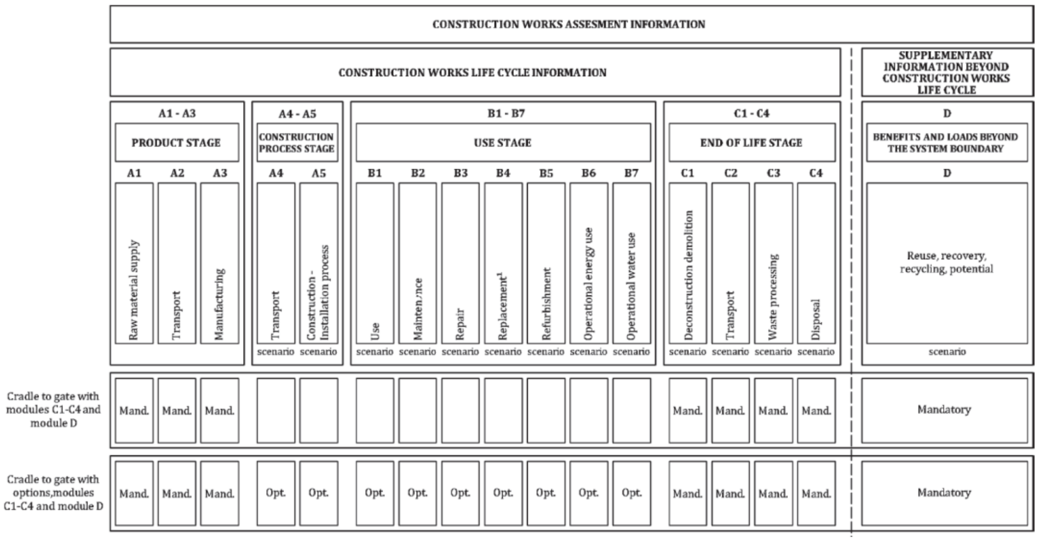

Figure 53 Source: EN 16627 Sustainability of construction works. Assessment of economic performance of buildings

From an operational point of view, LCC can be implemented in 15 steps as reported in the following table.

Tabla 12.LCC Steps

Step	Definition	To do

1	Identifying the LCC analysis general purpose, goals, and expected results.	It is required to define if the analysis is about choices on already existing assets (working on planning processes, budget programming) or also choices on the purchase of an asset with the related technological/design variants
2	Identifying the specific purpose of the LCC methodology	It is required to specify in which phases of the asset life cycle the tool is applied and the context of the analysis (single asset, component, material or individual system, a portfolio comprising a number of assets).
3	Identifying relationships between sustainability analysis and LCCs	Although the LCC and LCA approaches are distinct processes, it is needed to choose whether to use them in distinct or combined mode (LCC combines all relevant costs associated with the asset in financial terms and thus as a basis for investment decisions; LCA, on the other hand, makes decisions possible on the basis of potential environmental impacts).
4	Identifying of the analysis period and economic evaluation methods	The analysis period of step 2 is now defined in more detail. The LCC analysis period is defined and is chosen on the basis of the people directly involved in the project or the financial and regulatory sphere (e.g. it can be chosen according to the project time, the lease period, the loan period or the restructuring period)
5	Identifying the need for additional analyses	It is checked whether it is needed a risk analysis or an uncertainty analysis (e.g. uncertainty about costs or paybacks).
6	Identifying asset and project requirements	The main characteristics of the asset are identified in relation to the context and the project objectives, distinguishing between new construction, renovation and adaptation, and disposal.
7	The alternatives to be included in the LCC analysis and the cost items to be considered are identified.	Here it is checked that the selected alternatives are sufficiently detailed for the cost and time data to be identified. Only alternatives are evaluated according to the most relevant costs and future performance of the assets (relevant costs).
8	Collecting cost and time data for use in LCC analysis	Costs and time scales for different alternatives to which the LCC analysis should be applied are identified. Usually an LCC analysis is based on cost items categorised in ISO 15686 part 5.
9	Checking the financial parameter values and the analysis period	The financial and time parameters set in step 3 are reconsidered before applying the LCC methodology. The analysis method is selected according to the objectives of the LCC analysis and the stakeholders involved in the evaluation
10	Reviewing the risk strategy and producing a preliminary risk and uncertainty analysis	This is an optional step, useful for reviewing the risk strategies identified in step 5 and then being able to proceed to steps 12 and 13, making a detailed risk analysis
11	Economic evaluation	Economic indicators are used to evaluate alternatives. When considering sustainability analysis based on environmental criteria, two approaches are recognised for comparing alternatives on the basis of cost: cost-effectiveness analysis and cost-benefit analysis.
12	Application of risk analysis (if needed)	This is an optional step. An extensive risk analysis is carried out. The results of this step are presented as a probability percentage of the total life-cycle costs exceeding a given value, highlighting the most probable value.
13	Application of sensitivity	This is an optional step. The sensitivity analysis is carried out with

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	analysis (if needed)	the aim of determining the "sensitivity of the output of an LCC analysis to changes in the input data". It is done by changing the values of pre-selected critical variables. Although very simple, it allows risk management to achieve "risk-adjusted" LCC values and to assess the probability of a scenario occurring
14	Interpreting the preliminary results	The results of the LCCs are integrated with the analysis judgements, identifying the most suitable way of presenting them to the target audience.
15	Results presentation and final reporting.	The final report is drafted with a level of detail that meets the requirements of ISO 15686.

Regarding step 7, in order to be used as a method to promote economic choice between sustainable alternatives, the basic LCC model takes into account cost items according to the following clusters: 1) Acquisition, pre-construction and construction costs; 2) Operating, maintenance and replacement costs; 3) Residual value, disposal costs. Each relevant cost item must be addressed on a time-to-money basis. According to ISO 15686-Part 5, the period of analysis is defined as "the time period over which an LCC analysis is carried out". This can be defined over the entire life cycle (also only a specific period can be analysed -from a start date to an end date), or over the period of an ownership of an asset. For this reason, in the valuation, acquisition, construction and pre-construction costs do not need to be discounted as they are incurred at the beginning of the period of analysis; while operating costs, maintenance costs, replacement costs and end-of-life/disposal costs need to be discounted.

Regarding step 11, the following indicators are generally used: 1) Net Present Value-NPV to check the eligibility of an alternative from an economic point of view; 2) payback period-PBP checking that it is shorter than the time period considered; 3) net savings - NS which is a measure of the benefits to be achieved; and is used to evaluate a single option or to rank the preference of alternative options (the higher the net savings the lower the life cycle cost); 4) Saving Investment Ratio - SIR which is the ratio between the present value of the income generated by the investment and the initial investment cost; according to it, alternatives can be accepted and rejected or managed according to preference; 5) Adjusted Internal Rate of Return - AIRR which represents the measure of the annual return of a project compared to a reference period. It should be higher than the discount rate and is used to rank projects.

LCC methodology can improve the transparency of cost composition, making it easier and more effective to choose between different alternatives and achieve the objectives. It allows a balance between initial capital costs, future capital costs and revenues, recognizing opportunities and promoting economic efficiency. The LCC approach makes it feasible to determine the global cost of a project by considering its whole life cycle and thus include the costs of design, construction/purchase, use, operation, maintenance, and decommissioning.

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6. REQUIREMENTS

This section analyses the requirements and specifications to be considered in order to achieve the established objectives for the ENSNARE façade system. These requirements can be structured in two main groups:

- Regulatory requirements: considering the current conceptual design, three façade system standards have been taken as a reference. The configuration of all of them have a certain similarity with the ENSNARE system. Based on these standards, the aim of this task is to identify the essential characteristics to be considered in order to comply with the requirements defined in the Construction Products Regulation (CPR, No. 305/2011). The most relevant ones have also been identified in order to comply with the main targets of the ENSNARE façade.
- Functional and technological requirements: this point will consider aspects related to the modularity, weight, aesthetics, etc. of the system that need to be considered in order to achieve the ENSNARE façade objectives.

6.1. Regulatory requirements

The ENSNARE façade system shall comply with the Basic Requirements required by the Construction Products Regulation (CPR - No. 305/2011). This Regulation aims to establish harmonised conditions for the marketing of construction products in the EU. These Basic Requirements are:

BR1: Mechanical resistance and stability

BR2: Safety in case of fire

BR3: Hygiene, health and the environment

BR4: Safety and accessibility in use

BR5: Protection against noise

BR6: Energy economy and heat retention

BR7: Sustainable use of natural resources

Durability

All commercial envelope systems must be validated by a Product Standard, a European Assessment Document (EAD) or a European Technical Approval Guide (ETAG). These documents define the essential characteristics to be assessed in order to comply with the Basic Requirements required by the CPR. In the case of envelope systems BR1 does not apply.

To identify the essential characteristics to be assessed in the ENSNARE façade system, the following evaluation documents have been reviewed:

EAD 090119-00-0404: Kits for external wall cladding of mineral boards with renderings applied in situ

EN 13830: Curtain walling. Product standard

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EN 50583: Photovoltaics in buildings

The EAD has been selected because the ENSNARE system has a cladding (where the different technologies are integrated). This cladding is mechanically fixed to the inner module of the ENSNARE façade. In addition, a ventilated air chamber can be provided. On the other hand, ENSNARE is mainly conceived as a façade refurbishment system and therefore there is an existing façade where ENSNARE is connected.

The design development of the ENSNARE system is essentially based on curtain wall technology and for this reason EN 13830 has been analysed.

One of the technologies to be implemented in the ENSNARE façade is photovoltaic modules. EN 50583 about BIPV (Building Integrated Photovoltaics) is currently in draft version, however it has also been considered in this study.

Related to this, there is no standard setting out the requirements to validate the solar thermal and hybrid panel integration in the buildings envelope. During the course of the project, the need to determine alternative tests to ensure the correct implementation of these technologies in the ENSNARE façade system will be assessed.

In the case of active windows, when they are included as standard openings within the modular façade system, their essential characteristics are included in the EN 14351-1 standard.

The following tables show the comparative analysis made of these three standards for the fulfilment of the CPR Basic Requirements. The last column indicates which essential characteristics need to be assessed in the ENSNARE system and which standard will be the reference.

Table 13. Basic Requirement 2: Safety in case of fire.

BR2: Safety in case of fire				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORIA C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM. Reference standard
Fire resistance	-	EN 13501-2: EN 1364-3/ EN 1364-4	EN 13501-2	NOT NECESSARY (existing wall performance)
Fire reaction	EN 13501-1	EN 13501-1	EN 13501-1	EN 13501-1
Propagation	Large scale test depending on the country	EN 13501-2: EN 1364-4	-	Large scale test depending on the country. Applied on ventilated chamber and watertight chamber. To be considered in the design phase
Smouldering	EN 16733 (mineral wood cork and wood fibers)	-	-	Not applicable (other materials will be used)

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Table 14. Basic Requirement 3: Hygiene, Health and the environment

BR3: Hygiene, health and the environment				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORY C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM Reference standard
Watertightness (protection against driving rain)	Design check or EN 12865 procedure A	EN 12155 watertightness Results according to EN12154	-	Design check or EN 12865 procedure A
Water absorption	Depending on the material (cladding)	-	-	Only when TRESPA cladding is implemented (valid with product certificate)
Water vapour permeability (for non ventilated facades)	Depending on the material	Depending on the material	-	Design check. Applied on the internal module
Drainability	Design check	-	-	Design check. Applied on the exterior frame (cladding)
Content emission and/or release of dangerous substances	EOTA TR 34, Superseded by EOTA GD14	-	-	EOTA TR 34

Table 15. Basic Requirement 4: Safety and accessibility in use

BR4: Safety and accessibility in use				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORY C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM Reference standard
Modules with adhesive unions	-	-	EN 13022-1/2	When PV or PVT is implemented. Kamel technology. to be reviewed
Construction glass, pendulum test	-	-	EN12600	When PV or PVT is implemented. Kamel technology to be reviewed
Glass with structural sealant	-	-	ETAG 002	When PV or PVT is implemented. Kamel technology to be reviewed
Weight resistance	-	Calculation according EN 1991-1-1	-	1) Revision of the existing slabs mechanical capability is needed. 2) EN 13830 + EN 1991-1-1 3) IEC 61215-2: 4.16: static mechanical load if BIPV
Hail test	-	-	-	Only when PV, PVT or ST is implemented (valid with product certificate if it exits) IEC 61215-2: 4.17: hail test if

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				BIPV
Snow load	-	Calculation according EN 1991-1-3	-	Applied only when RES on the roof Calculation according EN 1991-1-3
Wind load resistance	Annex F	EN 12179	EN 12179 IEC 61215 IEC 61730	EN 12179
Impact resistance	Annex G	EN 14019	IEC 61215 IEC 61730	1) EN 14019 for ENSNARE mechanical structure (Only external classification is needed) 2) Depending on the cladding (valid with product certificate)
Mechanical resistance: resistance of profiles	General description	Calculation according EN 1991-1-1	-	EN 1991-1-1
Resistance to horizontal point loads (boards)	Annex H	-	-	Not applicable
Mechanical resistance: bond strength	Annex I or EN 1015-12	-	-	Not applicable
Mechanical resistance: bending strength of the board	Relevant hEN or EAD, or 7.3.2 EN 12467, 5.6 EN 15283-1/2, 5.7 EN 520	-	-	Only when TRESPA cladding is implemented (valid with product certificate)
Mechanical resistance: Connexions: embedding/shear strength	Relevant hEN or EAD or Annex J.1	prEN 16758: This document specifies test methods for the determination of bearing capacity (ultimate limit state and serviceability limit state), of connections between curtain walling framing members which cannot be calculated in accordance with current codes or conventional calculations based upon the strength of the materials.	-	prEN 16758 if necessary

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Mechanical resistance: Connexions: pull-though/ pull-out resistance	Relevant hEN or EAD or Annex J.2	-	-	Not applicable
Mechanical resistance: subframe-fixings: tension/pull-out resistance	Relevant hEN or EAD or Annex K.1	-	-	Not applicable
Mechanical resistance: subframe-fixings: shear load resistance	Relevant hEN or EAD or Annex K.2	prEN 16758: This document specifies test methods for the determination of bearing capacity (ultimate limit state and serviceability limit state), of connections between curtain walling framing members which cannot be calculated in accordance with current codes or conventional calculations based upon the strength of the materials.	-	prEN 16758 if necessary
Mechanical resistance: bracket resistance	Annex L	-	-	Validated by calculation
Seismic resistance	-	D.4 (similar to (AAMA 501.4/6))	-	Depending on the demo sites regulations. EN 1998-1 + AAMA 501.4/6 if necessary

Table 16. Basic Requirement 5: Protection against noise

BR5: Protection against noise				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORY C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM Reference standard
Acoustic attenuation	EN ISO 10140-1 Annex G EN ISO717-1 (Classification)	(Rw) EN ISO 10140-2 EN ISO717-1 (Classification)	-	EN ISO 10140 if necessary
Flanking sound transmission	-	EN ISO 10848-1 EN ISO 10848-2. EN ISO 717-1	-	EN ISO 10848 if necessary

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Airflow resistivity of the thermal insulation	EAD applicable or EN 29053	-	-	Not applicable

Table 17. Basic Requirement 6: Energy economy and heat retention

BR6: Energy economy and heat retention				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORY C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM Reference standard
Thermal transmittance (U) Thermal resistance (R)	For non-ventilated façade: R calculation according to EN ISO 6946. Tested according to EN 12667, EN 12939 or EN 12664, EN ISO 8990 For ventilated façade: EAD applicable or EN 12667, EN 12939 or EN 12664	U calculation according EN 12631. Test according EN ISO 12567-1		Applied on the internal modular system
Air permeability*	-	Test according EN 12153. Results according EN 12152		Applied on the internal modular system

*: It is not really an essential characteristic associated with BR6. However, given the configuration of the ENSNARE system (including airtight chamber), the air permeability of the inner modular system may negatively affect the thermal transmittance of the façade.

Table 18. Durability

Durability				
ESSENTIAL CHARACTERISTIC	EAD 090119-00-0404 (ventilated facade)	EN 13830 (curtain wall)	EN 50583 (GENERAL + CATEGORY C Y D)	REQUIRED FOR ENSNARE FAÇADE SYSTEM Reference standard
Accelerated aging behaviour	Annex M1-2-3	-	IEC 61215: UV preconditioning - Thermal cycling - Humidity-freeze - Damp-heat	Valid with product certificate of the technology
Cracking strength due to board deformation	Annex M4	-	-	EAD Annex M4. Only for Trespa panel. Valid with product certificate
Dimensional stability by humidity	Relevant EAD/hEN or EN 818 or EN 1170-7	-		Applied when cladding is Trespa panel (EAD/hEN or EN 818 or EN 1170-7) or PV (IEC 61215-2: 4.13). Valid with product certificate

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Dimensional stability by temperature	Relevant EAD/hEN or 3.2.6 EN 1993-1-1, 3.2.5 EN 1999-1-1 or EN 14617-11	-	-	Design check considering all the technologies implemented on the structural frame
Moisture content	Relevant EAD/hEN or EN 322	-		Depending on cladding material. Valid with product certificate
Corrosion	Follow material standards	-		Follow material standards
UV preconditioning test			IEC 61215-2: 4.10: (UV tests before thermal/humidity and freezing tests.)	Valid with product certificate of the technology
UV radiation resistance	Relevant EAD/hEN or EN ISO 877-1, EN ISO 877-3, EN ISO 4892-1, EN ISO 4892-2, EN ISO 4892-3, EN 927-2, EN 13245-2 or EN 10169	-	-	Valid with product certificate of the technology
Outdoor exposure test	-	-	IEC 61215-2: 4.8 Outdoor exposure test (MQT (module quality test) 08): no visual damage and electric validation	valid with product certificate of the technology
Watertightness	-	Joints: EN 12365-4. Sealants: EN 15651-1/2		Applied between technologies and structural exterior frame
Thermal transmittance	-	Low emissivity glass: EN 1096-4 Insulating glass: EN 1279-5 Sandwich boards: EN 14509 Insulation products: from EN 1316 to EN 13171		Applied on the internal module. Linked to the long-term performance of the insulation and also to the air permeability (airtight chamber)

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air permeability	-	Joints: EN 12365-4. Sealants: EN 15651-1/2	-	Applied on the internal module. Linked to thermal transmittance durability

6.2. Operational and technical requirements.

6.2.1. Dimension and modulation

The factors that influence the determination of the façade module dimension are multiple. In the next section we will analyse what these factors are and how they should be addressed in the next steps of the solution development.

First, the pilot buildings should be taken as a starting point. It is necessary to carry out a dimensional study of its facades to establish which the predominant parameters are:

- distance between floors,
- distances between windows,
- sill height
- window dimensions

In this regard, it is important to carry out a dimensional study of the formal limit characteristics that a façade may have so that the implementation of the solution can be viable. For example, complex curved shapes or facades with a large number of cantilevered or recessed elements would not be advisable for the implementation of a standardised modular solution
A preliminary analysis of the energy that can be generated in the different facades of the pilot buildings has been carried out (Appendix A). In this first exercise, only the orientation of the facades and the possible shadows cast by the surrounding elements have been taken into account. However, it is necessary to deepen the adequacy of the blind cloths available for the reception of technology and, depending on their size, which technologies can achieve higher yields.

It is necessary to evaluate the bearing capacity of the existing structure to know the admissible loads that can support its floors. The objective is to know the limit weight that the solution can reach and at what points and how it distributes the load to the existing building. The maximum distance between supports is one of the determining factors of the overall dimension of the module. When dealing with interventions in existing buildings, it is important to highlight at this point the need to work from the outside, and the implication of this installation procedure in determining the anchor points. For example, modules that span more than two floors require intermediate anchoring points that are difficult to adjust and therefore their design must respond to these premises.

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The limitation imposed by the means of transport is another of the factors to be analysed for the establishment of maximum module dimensions:

Maximum height

The general rule states that the maximum height should be 4 meters. However, there are some exceptions. These are: Vehicle carriers (rigid trucks, road trains and articulated vehicles), crane vehicles, and vehicles that transport closed containers approved for combined or intermodal transport. This set of vehicles can have a maximum height of 4.50 meters.

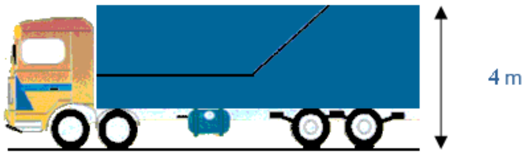

Figure 54. Maximum height. Source: www.mitma.gob.es. Ministry of transport. Spain government

Maximum width

The general standard establishes that the maximum width should be 2.55 meters

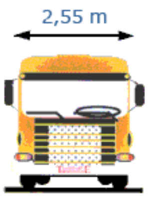

Figure 55. Maximum width. Source: www.mitma.gob.es. Ministry of transport. Spain government

Maximum length

Maximum distance between hitch pivot axis and rear of trailer. 12.6m

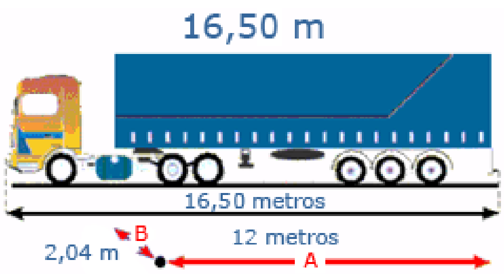

Figure 56. Maximum lenght. Source: www.mitma.gob.es. Ministry of transport. Spain government

After establishing the minimum requirements to be met, it must be studied which module dimensions are the most appropriate. In small modules, the number of

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installation joints is greater, thus increasing the weak points in relation to thermal bridges.

The objective of the industrialized mesh is the integration of three different types of technology, photovoltaic panels, thermo-solar panels and hybrid PVT panels of the two technologies. Within each façade module it is possible to integrate different sub-modules, in such a way that a single module can house different types of panels and even the active window. It is important to know the minimum and maximum dimensions of each type of panel, but also the dimensions that lead to higher yields and use of each technology. The maximum and minimum dimensions of the technologies are as follows:

Table 19. Dimensional parameters of technology

Dimensional parameters	Photovoltaic panel		Solar thermal collectors		PVT Hybrid collector	
	Max	Min	Max	Min	Max	Min
Length (mm)	4000	900	1685	1685	1580	1580
Width (mm)	2000	450	1025	1025	2880	480

In a first assessment, there are two possibilities: to use small-format modules, height equal to the distance between floors and width related to each of the façade openings or blind panels, or to use modules that span more than one façade opening, and wide blind panels. Each of these options has its advantages and disadvantages.

Small module.

<u>Advantages</u>

- ease of transport
- greater manageability in the installation
- maximum adaptation to different façade arrangements or facades with more complex geometries

<u>Disadvantages</u>

- Greater number of joints that increase losses and points of uncertainty.

Large module.

<u>Advantages</u>

- Quick assembly
- More area covered in less time.
- Greater dimension covered by greater control of the execution in the workshop.
- Reduce the number of connections on site.
- Less number of anchors.

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<u>Disadvantages,</u>

- transportation constraints and limitations
- Higher loads on the anchor points, therefore greater demand on the structural capacity of the existing building

The main sections of two of the pilot buildings are exposed below, where the main measurements of the structure between floors are shown.

Demo Building 1: Tartu

For the Annemõisa building in Tartu, the sections can be seen below:

Figure 57. Section 1-1'Annemoisa Building, Tartu

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Figure 58.Section 2-2'Annemoisa Building, Tartu

Demo Building 2: L'Aquila

For the demo building in L'Aquila, a section can be seen below:

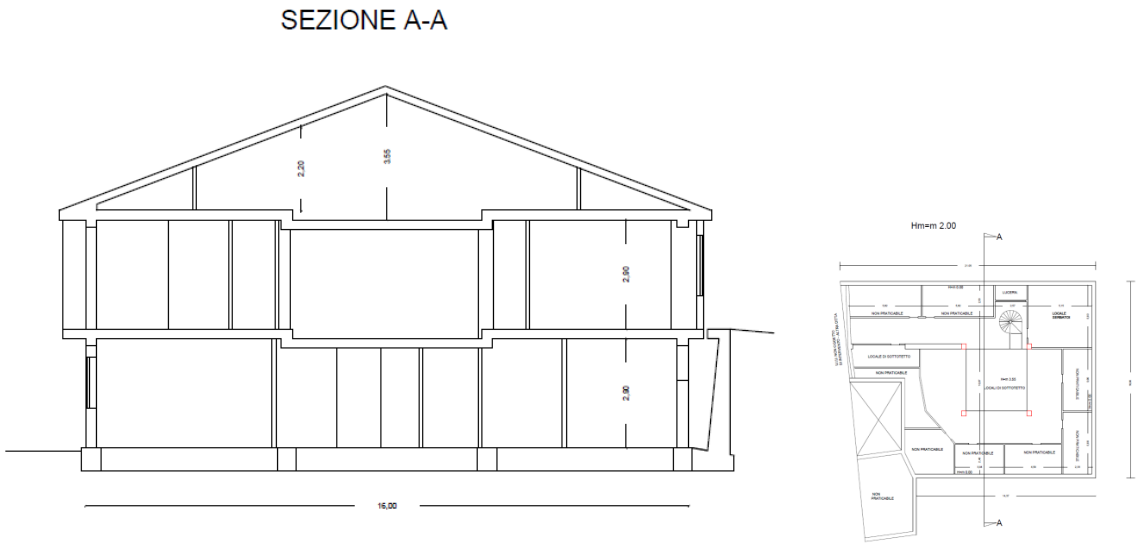

Figure 59. Section 1-1' Villa Irti, L'Aquila, Italy

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Table 20. Distance between slabs (floors) - Demo and Virtual buildings

STRUCTURE	
BUILDING	**Distance between slabs (floors)**
DEMO	
TARTU	2,42 m - 2, 82 m
COAF	3,00 m
BAL	N/A
VIRTUAL	
GLASGOW	N/A
AMSTERDAM	2,52 m
MILANO	3,00 m

Finally, after evaluating the main advantages and disadvantages and studying the main sectional measurements provided by the pilot buildings, it is determined that the maximum height measurement of the module is 3,40 meters.

To avoid that the module reaches great weights that make its installation infeasible, the width is preliminarily limited to a measure of 2,2m. A 2,2x3,40m module as a maximum measure would adequately respond to the main requirements of flexibility, lightness, easy transport and installation.

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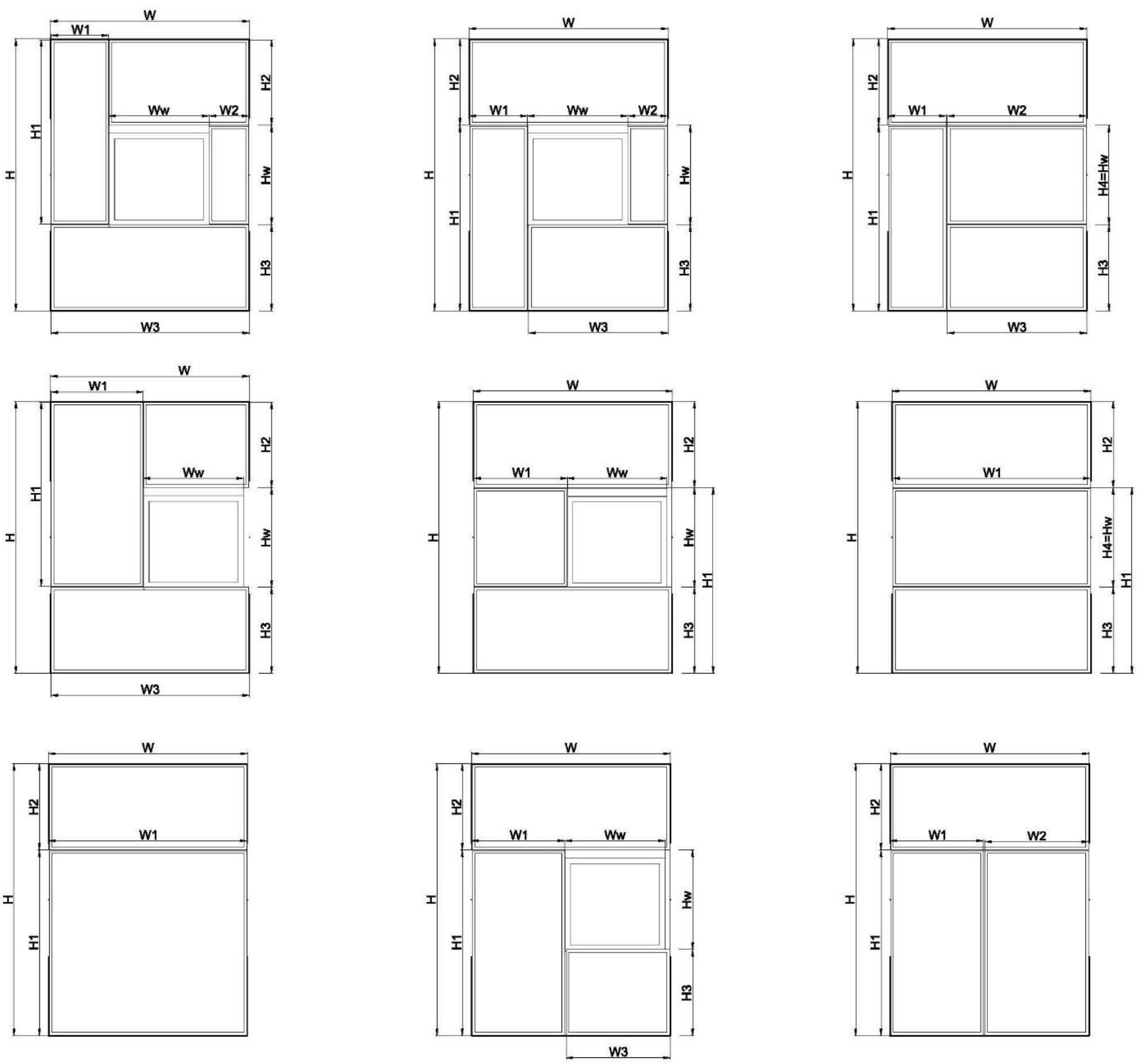

Figure 60. Modulation study based on the position of the different façade elements.

Starting from the conceptualization of the façade as a modular element that has to integrate different façade elements, both active and passive, a series of modulation possibilities is proposed through a preliminary study. The modulation will depend on the position adopted by the technologies, the passive elements and the active window within the module. The position of the technologies will depend on multiple factors:

- The efficiency of the system due to the external conditions of the building, for example orientation and sunlight.
- The efficiency of the technology that depends for example on the number of cells that can be distributed within the active panel.
- The ease of making connections between active panels.
- The position of the windows that will require the installation of embouchures

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- The existence of unique façade elements that will require the adaptation of the system.

6.2.2. Weight

Weight is another functional requirement to consider. As has already been stated, the module can integrate different types of technology, which will determine its weight. In the event that the module does not integrate any type of technology and only includes insulation and phenolic plate as cladding, the weight would be around 60 kg/ m2. On the other hand, if the module integrates technology, the weight of the module can reach 100kg/m2. We would therefore be talking about a weight range of 60 to 100kg/m2. In any case, the means to install this type of element is the crane.

6.2.3. Aesthetics. Appereance

Aesthetic conditioning factors are a subjective variable in many cases and in some cases must be submitted to the approval of the local authorities. As a general rule, the system will seek to give the greatest possible flexibility in the combinations of elements, so that the architects in charge of the final design have maximum freedom. Among the elements that must be developed according to aesthetic conditions are:

The joints between the panels that make up the module. These should be as imperceptible as possible to avoid excessive visual partitioning of the facade if it is not desired.

The joints between the different modules, as in the previous case, will be treated in such a way that they do not generate large divisions between modules and that these go unnoticed compared to the previous ones.

The flatness between the different panels that make up the module is a fundamental aspect that can be easily solved by developing in each case the necessary profile to hold the different technological and finishing panels.

6.2.4. Sustainable use of natural resources.

Life-cycle assessment (LCA) is an effective methodology to measure any project's whole life carbon and reach the carbon reduction goals. LCA is a standardized and science-based method that quantifies the environmental impacts of, for example, products and buildings over a given lifetime. Product and building LCAs are based on standards, that dictate the rules for any assessment. In European context, the standards used are the EN 15804 and the EN 15978, that both belong to the "Sustainability of Construction works" standard family.

The standards divide the life cycle of a building into different life-cycle stages and modules, from product and construction process stages to use stage, and end-of-life. The different life-cycle stages and modules are presented below.

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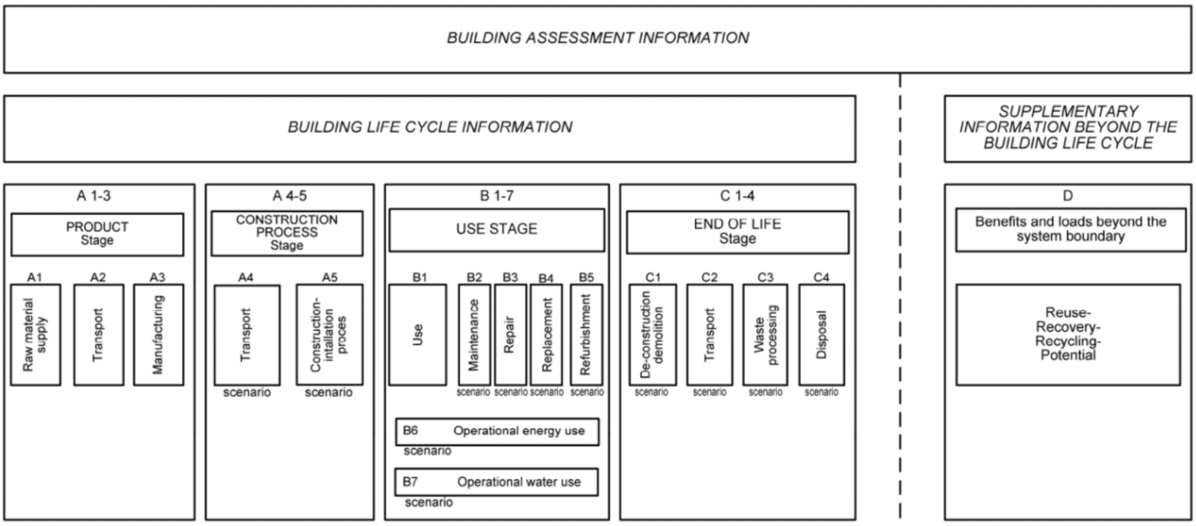

Figure 61. Life-cycle assessment modules (EN 15978:2011 Sustainability of Construction works - Assessment of environmental performance of buildings – Calculation method)

The calculation methodology is similar with both, the existing building stock, and its refurbishments, as well as new construction. However, with the refurbishment of an existing building, all retained materials (left in place) are accounted as zero impacts for their residual life cycle.

Whenever considering a building LCA, it is crucial to take into account the whole life cycle of the building as presented above. However, some life-cycle stages can be left out, depending on the type and usage of the building and the expected goals of the assessment. Below presented all the life cycle stages and the inputs for each life-cycle stage, as considered in this project, along with suggested technical requirements for any project.

Table 21. Life-cycle stage. Expected inputs and suggested requirements.

Life-cycle stage	Expected input	Suggested requirements
A1-A3 Product stage	Manufacturer data (EPD or LCA) for specified materials, generic LCA data on materials for others.	Global warming potential and the amount of recycled raw materials in product.
A4 Transportation	Standard values assumed for transportation modes and distances.	Prioritizing locally manufactured products and less carbon intensive modes of transportation.
A5 Construction	Wastage and construction site energy usage.	Zero carbon construction site and reducing the amount of wastage on construction site.
B1 Use	Only relevant for refrigerant use.	
B2-B3 Maintenance and repair	Not included as no useful prediction power.	
B4-B5 Replacement and refurbishment	Manufacturer estimated lifetime.	Prioritizing durable products.

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B6 Operational energy	Yearly operational energy used.	Energy efficiency.
B7 Operational water	Suggested to be left out, often a low impact.	
C1-C4 End-of-life	Standard end-of-life scenarios for different material categories.	Design for disassembly and recycling.
D Benefits and loads beyond the system boundary	Energy export and material specific inputs.	

Considering the sustainability, life cycle carbon and embodied carbon of any product or building, the sustainable usage of materials plays a big role, from the acquiring of the raw materials to their end-of-life. Material efficiency by minimizing the usage of materials, as well as the effective management of waste and recycled materials, is one key part of sustainability and a good starting point for decarbonization. The goal is often to design alternatives that can minimize the quantities of materials altogether over the lifetime of a building. In this, it is also crucial to consider material lifespan in the whole building concept. Durable materials may also be more desirable to reuse at the end of the life of the building itself. Durability should always be assessed in the context of the specific requirements of the building, for example the weather conditions and other relevant parameters.

The end of life of a product or assembly can also have a considerable effect on the life cycle emissions of a building. Products that are easy to disassemble and reuse often have a lower carbon footprint at the end of life. Materials that are directly reusable without further processes have the lowest impact, in terms of end-of-life emissions, followed by materials that can be recycled or used for energy recovery. In terms of wastage specifically, it is also important to minimize the amount of hazardous waste. Assemblies and products, that are easier to dismantle and do not contain any hazardous substances are where waste can be separated, often have a bigger probability of being completely recycled, reused or used for energy recovery, thus creating lower emissions at their end of life.

Structural materials are often the most significant sources of embodied carbon emissions due to the large quantities and masses of materials used. Materials efficiency and waste reduction are both effective in minimizing embodied carbon emissions and reducing the strain on raw materials. They often also hold no great drawbacks, even when looked at across the whole life cycle, if the durability and adaptability of different materials and structures is not compromised. Methodologies and tools, such as design option comparisons can help to identify where to improve materials efficiency the most. A focus on materials efficiency can help unlock significant embodied carbon and cost savings.

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7. CONCLUSIONS AND OBJECTIVES

7.1. Priority requirements for the ENSNARE façade system.

Based on the requirements analysed and established in the previous sections, this section has defined the target values for those parameters that have the greatest influence on the objectives of the system. These requirements and their target values will guide the constructive development of the ENSNARE façade. In some of them a target value, range or classification has been assigned and in other parameters this value will be given by the conditions or regulations of the demo buildings.

Table 22. Recommended value of priority requirements

BR*	Priority requirements	Recommended value		
2	Fire reaction	B-s3, d0		
	Fire propagation	EI60		
3	Watertightness	R7 (600Pa)		
	Water vapour permeability	Design check. Relevant in the inner module with airtight chamber		
	Drainability	Design check		
4	Weight resistance	$\delta < L/500$ mm (horizontal profiles)		
	Wind load resistance	[2-3] kN/m^2		
	Impact resistance	E3		
	Seismic resistance	If required in local regulations (demosites)		
5	Acoustic attenuation	not to worsen classification of the existing façade. Special care in the design of elements that connect the interior of the building with the exterior, e.g, window reveal		
	Flanking sound transmission			
6	Thermal transmittance	0,2 $W/m^2 \cdot K$	Overall value of the facade	
	Air permeability*	A4 (without plates on the joints)		
	Weight	60-100kg/m²		
	Dimension	Height	Minimum 2,40m	Maximum 3,40m
		Width	Minimum 1,50m	Maximum 2,20m
	Installation time	3.27h/m²		

The system seeks to respond to renovations to reach **nearly zero energy buildings or positive buildings**. This type of reform is normally achieved by using passive

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thermal insulation solutions (usually SATE or ventilated façade) on the one hand and more efficient installations on the other. **The system to be developed in Ensnare would respond to this type of rehabilitation with a unique solution**. Therefore, when studying the necessary investment in relation to a normal renovation, it must be taken into account that the Ensnare system replaces a passive façade plus the active elements that generate the energy that make the building one of zero consumption. In short, in the comparative cost with a traditional reform, all the generating elements would have to be added even if they were not on the facade. Therefore we can assimilate the return on investment to that of a NZEB refurbishment.

7.2. Qualitative requirements. Concept design

The starting point is the façade concept pursued by the ENSNARE project. It is a facade that seeks to integrate **three types of technology, photovoltaic, solar thermal and a hybrid PV/T**, **and also an active window that contains a highly efficient heat recovery ventilation system**. It is also proposed that during the project, developments will be made in the use of new substrates that are yet to be determined and among which different options are considered (phenolic panels (trespa), aluminium and ceramic panels) for photovoltaic technology, and Roll-bond technology in the solar thermal will be use.

The main objective of the project is to carry out rehabilitation of residential buildings with almost zero or positive energy in approximately half the time, and this reduction in terms implies a reduction of the cost of the execution process in its different stages. The way in which the WP5 contributes to this is by developing a highly industrialized and modular system that can be quickly assembled and installed, thus speeding up the activities carried out on site.

In addition, it seeks to develop a **flexible system** that can be used not only in rehabilitation but can also be installed in **new construction**. Therefore, it must be self-supporting and seek support in floors, avoiding problems by not using the existing enclosure as a support point. The starting point is to solve **the demonstration buildings** but also to have a product that has a market.
The system will allow that each technology can be distributed by zones within the façade where its performance is most suitable.
One factor to solve is **the maintenance of the systems to be integrated**. This requires that the system allow the register of items that are likely to break down or that may need replacement.
The insulation layer is another issue considered. To achieve a fully industrialized system that integrates the insulation and that does not require a previous layer adhered to the base substrate, it is necessary to carefully study the hygrothermal characteristics of the set. The layer of air that would remain between the module and the base substrate cannot be ventilated because the insulation would lose its thermal capacity. It is necessary that between the module and the facing there are at least 100mm to be able to anchor the system, as there is no possibility of access from the rear face. The chamber is variable due to the possible inclination of the facade.

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Another issue to consider when designing the system is its **tightness**, watertight and / or airtight. The position of the tightness barrier is important to determine, on the one hand, the insulating layer and, on the other, the technological layer, which may need ventilation and maintenance

With these premises, the different possibilities offered by curtain wall systems have been evaluated. It has been considered to combine two concepts to solve the proposed system, on the one hand a warm superimposed façade, which would solve the insulation needs by incorporating it into the solution itself, and on the other a breathable façade that would allow the ventilation of the panels that need it. This approach requires a high airtightness of the resulting chamber between the existing building and the ENSNARE system to meet the high demands for insulation.

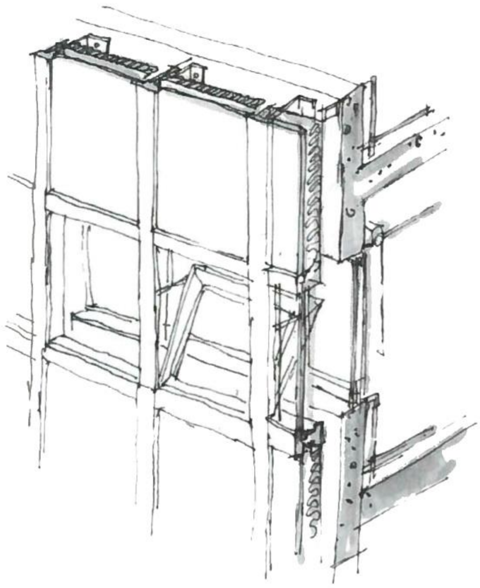

Figure 62. Superimposed façade scheme. Source: ASEFAVE. Light Facades. Product Manual. 2015.

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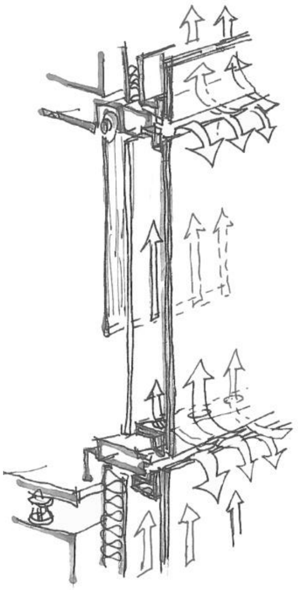

Figure 63. Breathing facade. ASEFAVE. Source: Light Facades. Product Manual. 2015.

As a system concept, the possibility of using a modular system with a independence frame and / or with a cover is considered. The cover would create the space to bed pipes or filaments and their connections, while the frame would allow the technology to be integrated into the module in a registrable and replaceable way.

The possibility was also considered, as an alternative to the cover, that each "module" would have, in addition to the active elements such as PV, thermal and hybrid, a "crowning" phenolic panel that is located at the top of each module and that it is also accessible to access the connections for maintenance and repair.

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7.3. Schematic sketch of the system and its components.

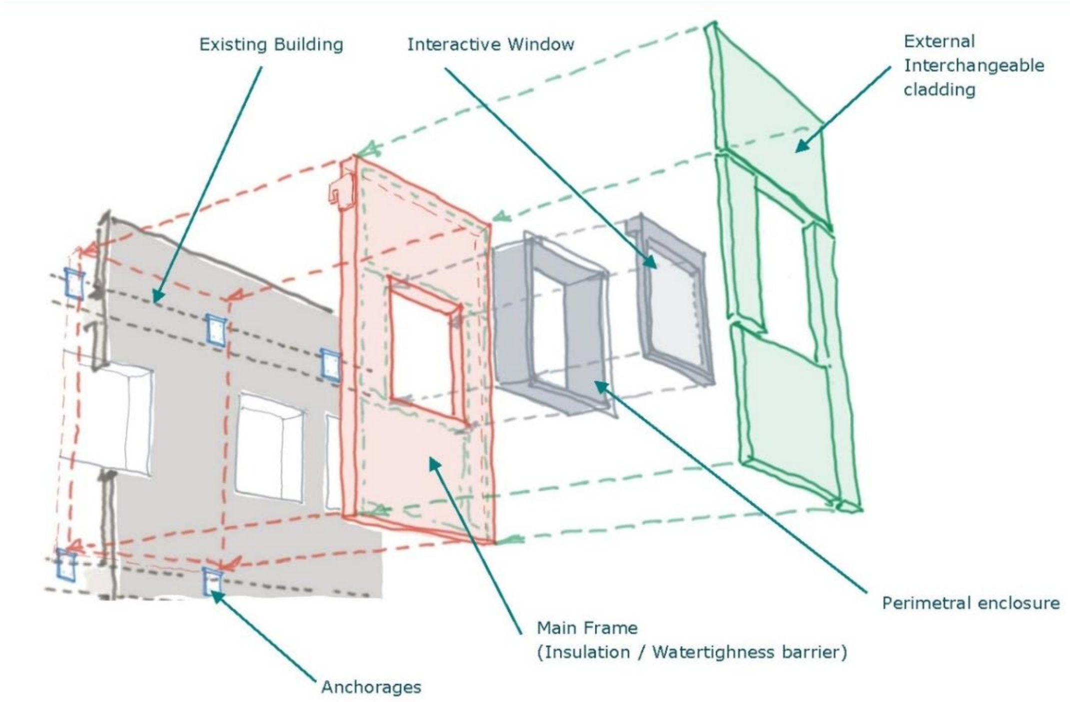

Figure 64. ENSNARE system. Source Schematic sketch. ENAR

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[15] EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

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[17] EN 16627 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods

[18] EN 15643-4 Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance

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Appendix A. Characteristics of pilots

1. Demo Building 1, Tartu

- **Thermal characteristics**

Estonian architecture generally consists of households of homes and dependencies, located around a central place. Old buildings are mostly composed of wood, using beams and sloping roofs.

The façade layout of the Annemõisa building is composed of (1) external plaster, (2) wood lining, (3) gypsum board, and (4) internal plaster.

The roof layout consists of (1) corrugated steel, (2) vapor block, (3) insulation layer, and (4) inner cladding.

Table 1. Thermal characteristics of the envelope. Tartu

FAÇADE 01 Thermal characteristics of the material			
Layer	Material name	Thickness (m)	Conductivity (W/mK)
layer 01	external Plaster	na	na
layer 02	wood lining	na	na
layer 03	gypsum board	na	na
layer 04	internal plaster	na	na
FAÇADE 02 Thermal characteristics of the material			
Layer	Material name	Thickness (m)	Conductivity (W/mK)
layer 01	external Plaster	na	na
layer 02	wood lining	na	na
layer 03	gypsum board	na	na
layer 04	internal plaster	na	na
FAÇADE 03 Thermal characteristics of the material			
Layer	Material name	Thickness (m)	Conductivity (W/mK)
layer 01	external Plaster	na	na
layer 02	wood lining	na	na
layer 03	gypsum board	na	na
layer 04	internal plaster	na	na
FAÇADE 04 Thermal characteristics of the material			
Layer	Material name	Thickness (m)	Conductivity (W/mK)

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layer 01	external Plaster	na	na
layer 02	wood lining	na	na
layer 03	gypsum board	na	na
layer 04	internal plaster	na	na
layer 05	double layer bricks		
ROOF Thermal characteristics of the			
Layer	Material name	Thickness (m)	Conductivity (W/mK)
layer 01	Corrugated steel	na	na
layer 02	vapour block	na	na
layer 03	insulation	na	na
layer 04	inner cladding	na	na

- **Energy parameters**

Table 2. Energy Parameters

ENERGY PAREMETERS	
Energy consumption for heating (kWh/m2 year)	n/a
Energy consumption for cooling (kWh/m2 year)	0
Total energy consumption for electrical appliances (kWh/year)	8000
Air Conditioned Floor Surface (m^2)	438
Air Conditioned Volume (m^3)	0
Façade Total surface (m^2)	340.43
Windows no.	25
Window-To-Wall ratio (%)	1 / 0,139
Energy Cost (Gas & Electricity) (€/year)	Gas: N/A
	Electricity: 2064
clearance height overhead (m)	6
Climatic zone	Estonia
Compactness: Volume/External Surface V/A [m^3/m2]	2,241666667

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- **Envelope characteristics**

Table 3. Envelope characteristics and estimation of the energy generated.

FAÇADE 01	
Orientation	North
Degrees*	20
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	90.94
windows no.	2
Window-To-Wall ratio	1 : 0,054
U value W/(m^2 K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	YES
Average size of windows. Width by Height (m)	

Energy generated (kWh/year) PV (100m²)	4532
Energy generated per m². (kWh/year) Solar Thermal	152.5

FAÇADE 02	
Orientation	South
Degrees	110
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	90.94
windows no.	2
Window-To-Wall ratio	1 : 0,054
U value W/(m^2 K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	NO
Average size of windows. Width by Height (m)	
Energy generated (kWh/year) PV (100m²)	10637
Energy generated per m². (kWh/year) Solar	313

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Thermal	
Unreal situation due to the high influence of the surrounding cast shadow by the trees	

FAÇADE 03	
Orientation	East
Degrees	160
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	72.6
windows no.	7
Window-To-Wall ratio	1 : 0,287
U value W/(m^2 K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	YES
Average size of windows. Width by Height (m)	

Energy generated (kWh/year) PV (100m²)	12482
Energy generated per m². (kWh/year) Solar Thermal	386.58

FAÇADE 04	
Orientation	West
Degrees	70
Structure (Light-Medium-Heavy)	Medium/heavy
External or Internal	External
Surface (m^2)	85.95
windows no.	14
Window-To-Wall ratio	1 : 0,193
U value W/(m^2 K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	NO
Average size of windows. Width by Height (m)	

Energy generated (kWh/year) PV (100m²)	7872
Energy generated per m². (kWh/year) Solar Thermal	260.36

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ROOF	
Orientation	East
Degrees	110º
Structure (Light-Medium-Heavy)	
External or Internal	external
Surface (m²)	
windows no.	
Window-To-Wall ratio	
U value W/(m² K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	
Average size of windows. Width by Height (m)	
Inclination	44º

Energy generated (kWh/year) PV (100m²)	14050
Energy generated per m². (kWh/year) Solar Thermal	429.38
Unreal situation due to the high influence of the surrounding cast shadow by the trees	

ROOF	
Orientation	West
Degrees	70º
Structure (Light-Medium-Heavy)	
External or Internal	external
Surface (m²)	
windows no.	
Window-To-Wall ratio	
U value W/(m² K)	n/a
g factor (-)	n/a
Shaded by other buildings? (YES or NOT)	
Average size of windows. Width by Height (m)	
Inclination	44º

Energy generated (kWh/year) PV (100m²)	11068
Energy generated per m². (kWh/year) Solar Thermal	352.65

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- **Estimation of PV energy production – Preliminary results**

Façade assumptions:

- North, South, and West orientations
- PV surface covered 100 m^2 (each orientation)
- Mono-crystalline technology
- Power installed 16 kWp (each orientation)
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

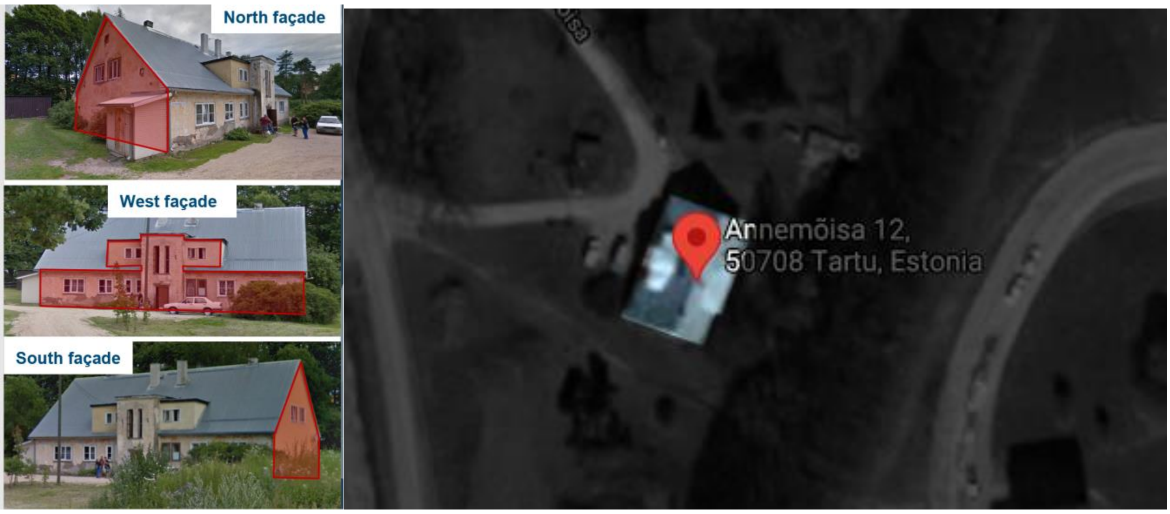

Figure 1. General assumptions demo building 1, Tartu

– North façade:

Figure 2. North façade, Tartu

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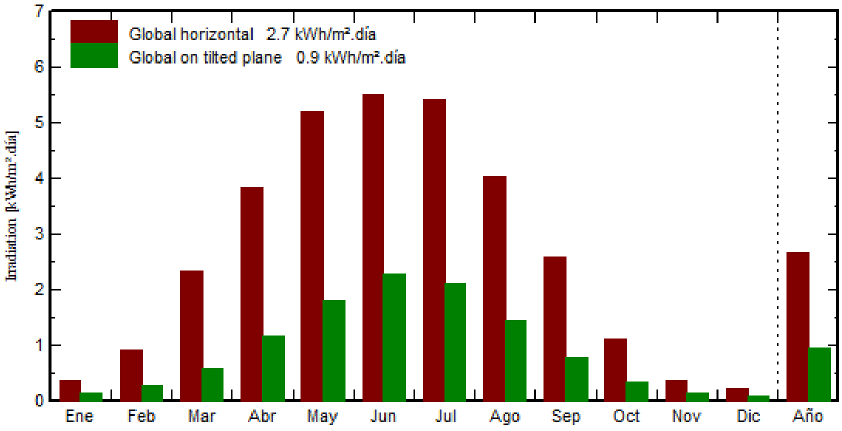

Figure 3. Irradiation analysis north façade, Tartu

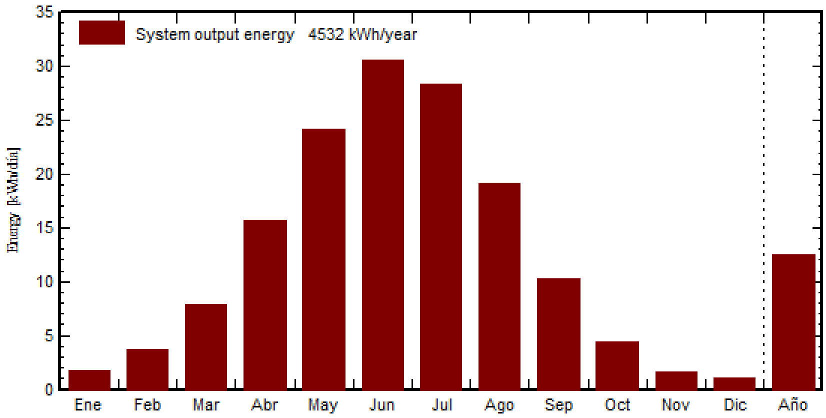

Figure 4. Energy kWh/year north façade, Tartu

North façade analysis:

Table 4. North façade estimated energy production, Tartu

NORTH façade 100 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.34	0.13	1.71	**53**
February	0.91	0.28	3.71	**104**
March	2.32	0.59	7.88	**244**
April	3.82	1.16	15.64	**469**
May	5.19	1.80	24.18	**750**
Jun	5.51	2.27	30.50	**915**
July	5.40	2.11	28.37	**879**
August	4.04	1.42	19.13	**593**
September	2.58	0.76	10.24	**307**
October	1.11	0.32	4.36	**135**
November	0.34	0.12	1.63	**49**
December	0.20	0.08	1.07	**33**
Annual	**2.66**	**0.92**	**12.42**	**4.532**

– West façade:

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Figure 5. West façade, Tartu

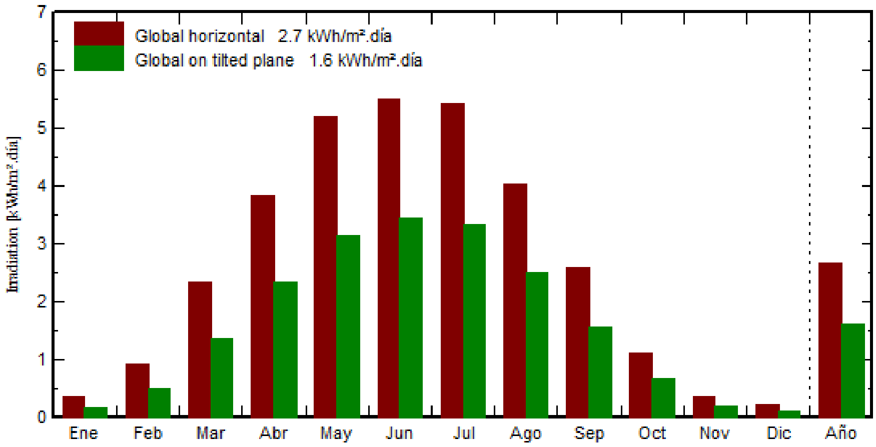

Figure 6. Irradiation analysis west façade, Tartu

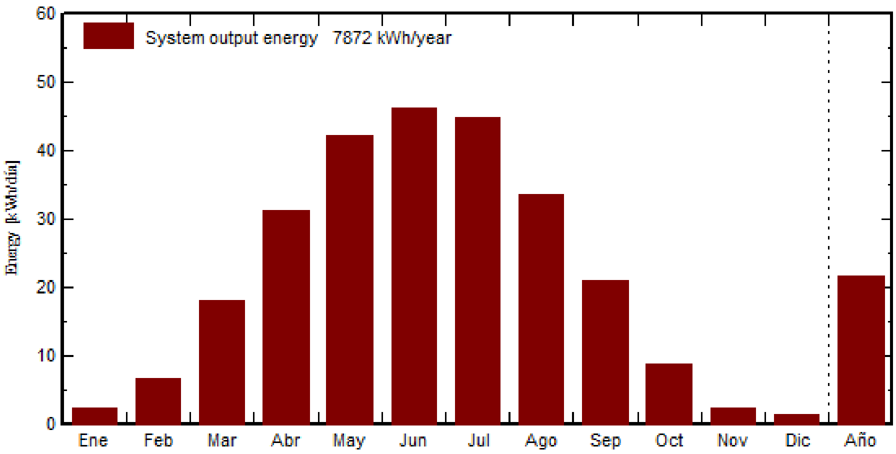

Figure 7. Energy kWh/year west façade, Tartu

West façade analysis:

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Table 5. West façade estimated energy production, Tartu

WEST façade 100 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.34	0.17	2.22	**69**
February	0.91	0.50	6.67	**187**
March	2.32	1.34	18.08	**560**
April	3.82	2.32	31.26	**938**
May	5.19	3.14	42.16	**1.307**
Jun	5.51	3.43	46.09	**1.383**
July	5.40	3.33	44.81	**1.389**
August	4.04	2.49	33.43	**1.036**
September	2.58	1.55	20.84	**625**
October	1.11	0.64	8.65	**268**
November	0.34	0.17	2.30	**69**
December	0.20	0.10	1.32	**41**
Annual	**2.66**	**1.60**	**21.57**	**7.872**

– South façade:

Figure 8. South façade, Tartu

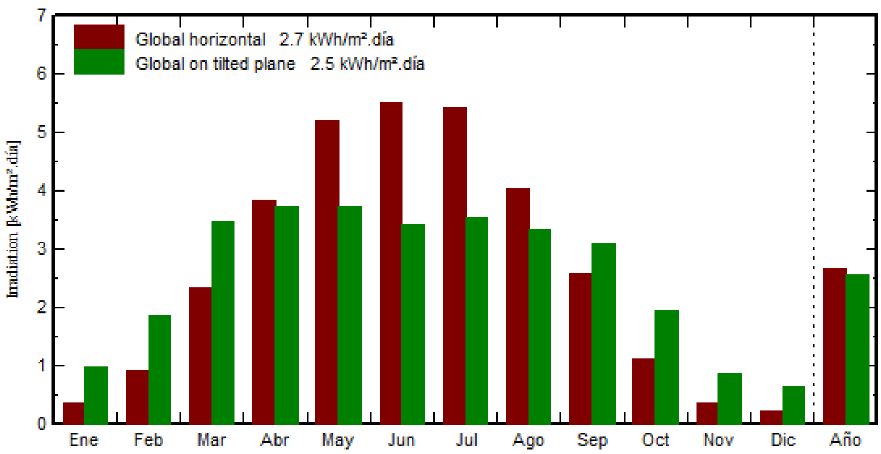

Figure 9. Irradiation analysis south façade, Tartu

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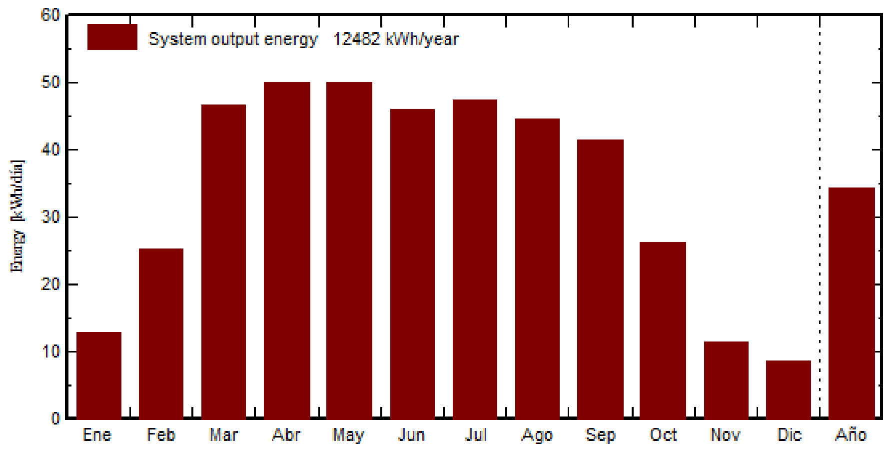

Figure 10. Energy kWh/year south façade, Tartu

South façade analysis:

Table 6. South façade estimated energy production, Tartu

SOUTH façade 100 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.34	0.95	12.81	**397**
February	0.91	1.86	25.07	**702**
March	2.32	3.47	46.67	**1.447**
April	3.82	3.71	49.95	**1.498**
May	5.19	3.72	49.98	**1.549**
Jun	5.51	3.42	46.04	**1.381**
July	5.40	3.53	47.45	**1.471**
August	4.04	3.32	44.59	**1.382**
September	2.58	3.08	41.36	**1.241**
October	1.11	1.94	26.04	**807**
November	0.34	0.85	11.39	**342**
December	0.20	0.64	8.54	**265**
Annual	**2.66**	**2.54**	**34.20**	**12.482**

Roof assumptions:

- West Roof
- East orientations Roof and façade
- PV surface covered 100 m^2
- Mono-crystalline technology
- Power installed 16 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

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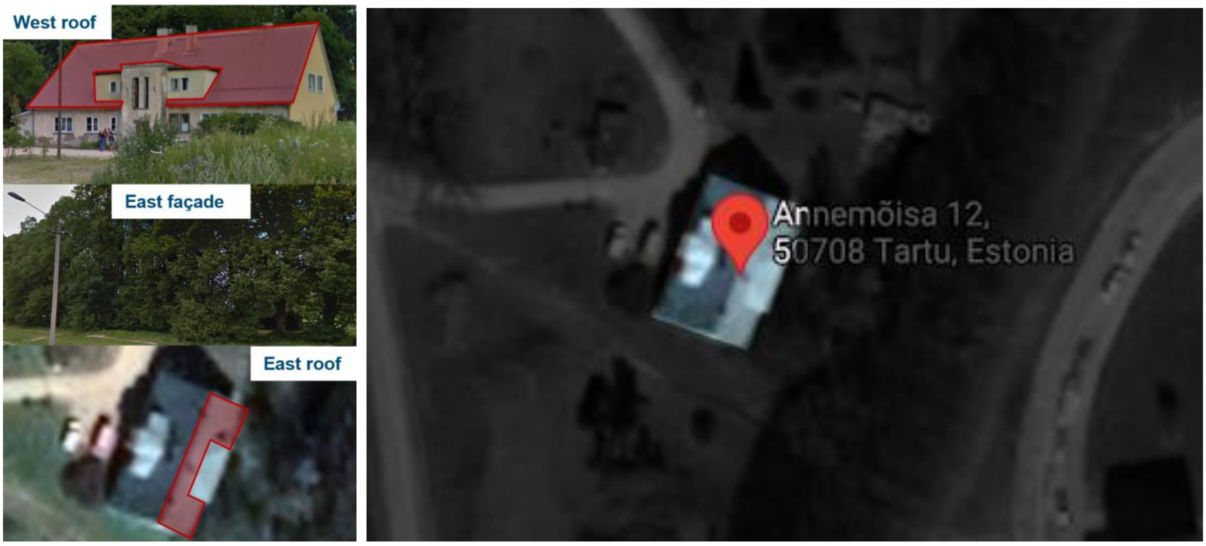

Figure 11. General roof assumptions, Tartu

– West roof:

Figure 12. West roof, Tartu

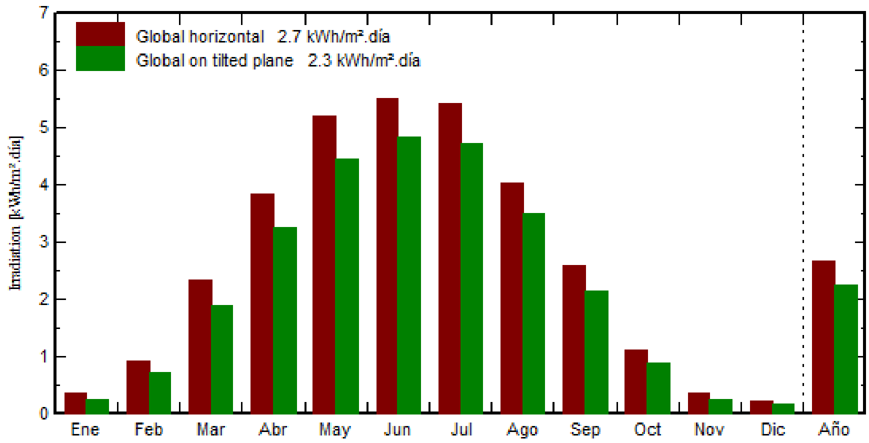

Figure 13. Irradiation analysis west roof, Tartu

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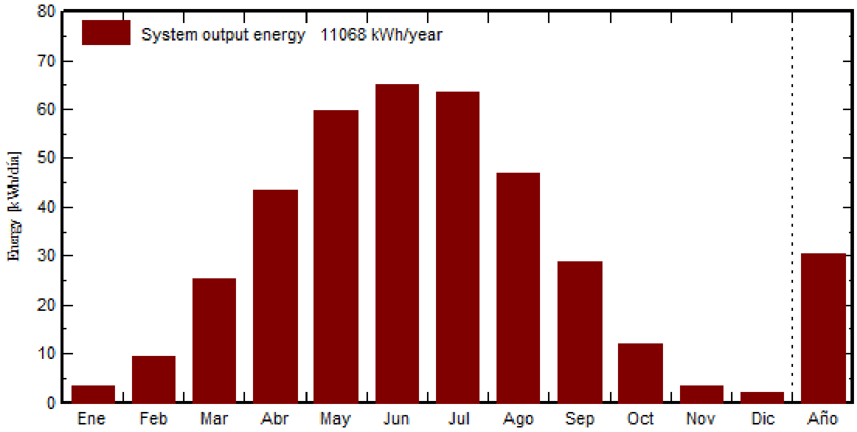

Figure 14. Energy kWh/year west roof, Tartu

West roof analysis:

Table 7. West roof estimated energy production, Tartu

WEST roof 100 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.34	0.25	3.31	**103**
February	0.91	0.70	9.41	**263**
March	2.32	1.87	25.17	**780**
April	3.82	3.24	43.52	**1.306**
May	5.19	4.44	59.76	**1.853**
Jun	5.51	4.83	64.97	**1.949**
July	5.40	4.71	63.35	**1.964**
August	4.04	3.48	46.84	**1.452**
September	2.58	2.14	28.84	**865**
October	1.11	0.89	11.98	**371**
November	0.34	0.25	3.38	**101**
December	0.20	0.15	1.97	**61**
Annual	**2.66**	**2.26**	**30.32**	**11.068**

– East façade:

Figure 15. East façade, Tartu

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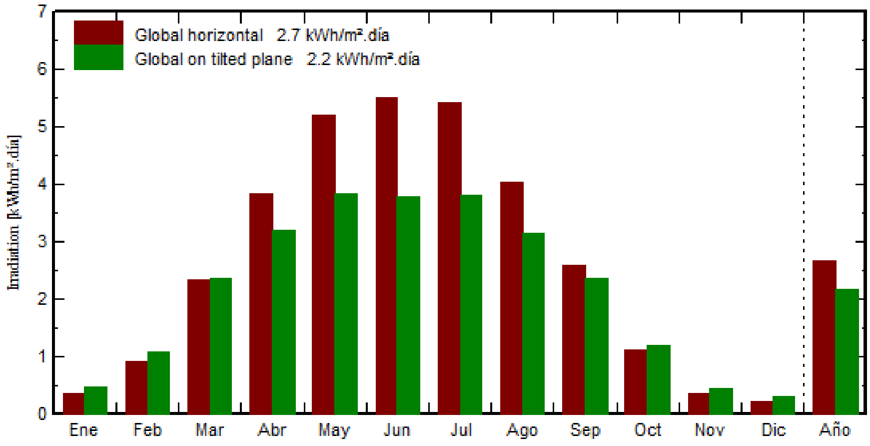

Figure 16. Irradiation analysis east façade, Tartu

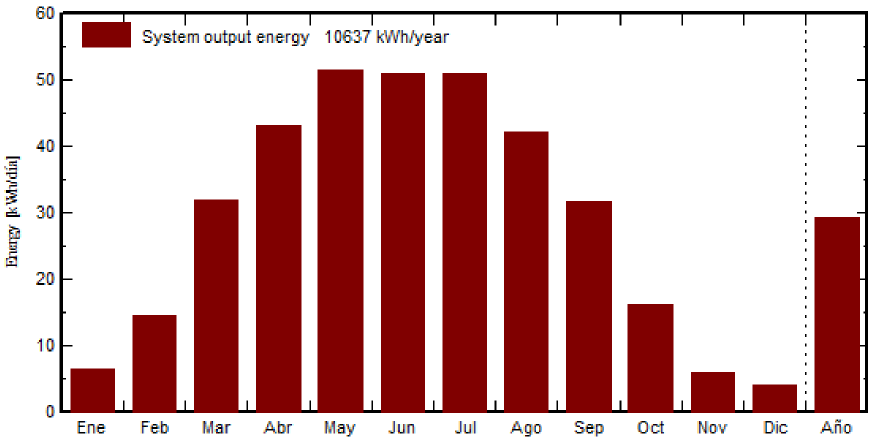

Figure 17. Energy kWh/year east façade, Tartu

East façade analysis:

Table 8. East façade estimated energy production, Tartu

EAST façade 100 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.34	0.47	6.34	**197**
February	0.91	1.08	14.53	**407**
March	2.32	2.36	31.77	**985**
April	3.82	3.20	42.97	**1.289**
May	5.19	3.83	51.52	**1.597**
Jun	5.51	3.78	50.89	**1.527**
July	5.40	3.80	51.05	**1.582**
August	4.04	3.13	42.13	**1.306**
September	2.58	2.35	31.54	**946**
October	1.11	1.20	16.11	**499**
November	0.34	0.44	5.89	**177**
December	0.20	0.30	4.03	**125**
Annual	**2.66**	**2.17**	**29.14**	**10.637**

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– East roof:

Figure 18. East roof, Tartu

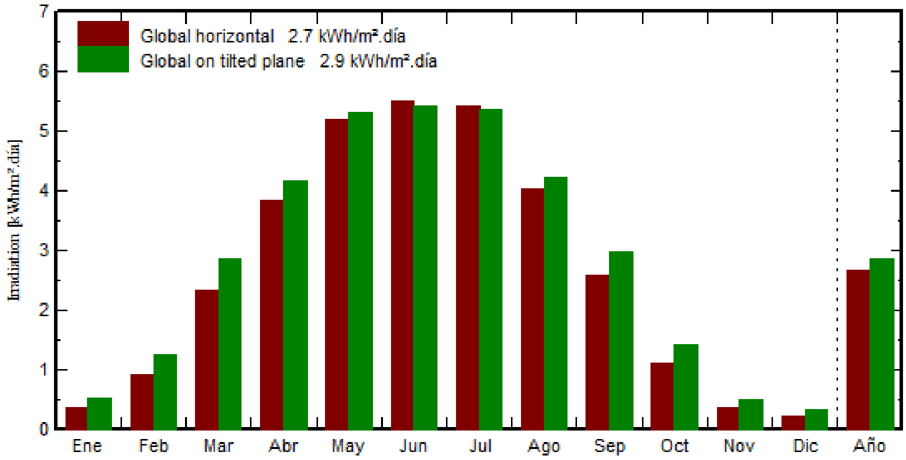

Figure 19. Irradiation analysis east roof, Tartu

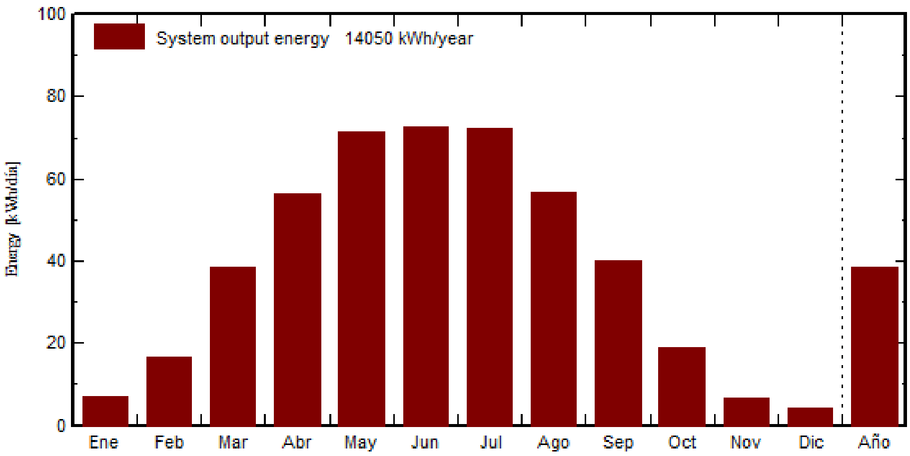

Figure 20. Energy kWh/year east roof, Tartu

East roof analysis:

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Table 9. East roof estimated energy production, Tartu

EAST roof 100 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.34	0.51	6.81	**211**
February	0.91	1.23	16.52	**463**
March	2.32	2.85	38.36	**1.189**
April	3.82	4.18	56.17	**1.685**
May	5.19	5.31	71.36	**2.212**
Jun	5.51	5.41	72.76	**2.183**
July	5.40	5.36	72.09	**2.235**
August	4.04	4.23	56.84	**1.762**
September	2.58	2.97	39.92	**1.198**
October	1.11	1.41	18.95	**587**
November	0.34	0.48	6.50	**195**
December	0.20	0.31	4.22	**131**
Annual	**2.66**	**2.86**	**38.49**	**14.050**

- **Building services system (BSS)**

Table 10. Building services system, Tartu

BUILDING SERVICES SYSTEM	
Is there any **heating system**? If yes, please provide the brief introduction of heating system (energy source, power and capacity.), Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied heating system installed?	Every room has a wood-burning stove to heat the room
Is there a **domestic hot water (DHW) system**? If yes, please provide the DHW system (energy source, power and capacity)	There is one communal hygiene room with water from electric boiler
Is there an **air-conditioning system**? If yes, please provide the brief introduction of air-conditioning system (energy source, power and capacity) Is there an individually controlled (e.g. one thermostat per	no

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office/apartment) but centrally supplied cooling system installed?	
Is there a **ventilation system**? If yes, please provide the brief introduction of ventilation system (energy source, power and ventilation rate, Is the ventilation	no
Is there a renewable heat generation source? If yes, please provide the brief introduction of renewable heat generation source (power and generation-storage capacity)	no
Is there a renewable electricity generation source? If yes, please provide the brief introduction of renewable electricity generation source (power and generation-storage capacity)	no

- **Control and management systems**

Table 11. Control and management systems, Tartu

Is there a **building management system (BMS) or control system** already installed? If yes, please provide a brief introduction of the building management system.	no

- **Structural performance**

Table 12: Structural performance, Tartu

STRUCTURE	
Structure type (bearing wall, timber framing, structure of concrete floors and pillars, …)	timber framing
Distance between slabs (floors)	242cm to 282cm

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Slab structure thickness	37cm to 49cm
Slab material properties.(e.g. Compressive strength, reinforcement, bulk density)	timber beams
Height (m)	609cm; 1000 cm to top of chimney
Floor dimension (length x width) (m)	306,1056

- **Local and aesthetic requirements**

Table 13. Local and aesthetic requirements, Tartu

AESTHETICS	
Is there any local requirement about aesthetic aspects of the building? If yes, provide a brief introduction about how affect the building.	no

HERITAGE AND LANSCAPE CODES	
Is there any Code for the cultural heritage of the building? If yes, provide information, about how affect the building.	no

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2. *Demo Building 2, L'Aquila*

- **Thermal characteristics**

  The façade layout of the demo building in L'Aquila is composed of (1) plaster, (2) brick element, (3) cavity, (4) brick element, and (5) plaster (from external to internal layer).

  In addition, the roof layout consists of (1) tile, (2) basset, (3) concrete, (4) brick, and (5) plaster.

Table 14. Thermal characteristics of the envelope. L'Aquila

FACADE 01 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.03	1.4
layer 02	brick element	0.25	0.36
layer 03	cavity	0.1	0.026
layer 04	brick element	0.1	0.36
layer 05	plaster	0.03	1.4
FACADE 02 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.03	1.4
layer 02	brick element	0.25	0.36
layer 03	cavity	0.1	0.026
layer 04	brick element	0.1	0.36
layer 05	plaster	0.03	1.4
FACADE 03 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.03	1.4
layer 02	brick element	0.25	0.36
layer 03	cavity	0.1	0.026
layer 04	brick element	0.1	0.36
layer 05	plaster	0.03	1.4
FACADE 04 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.03	1.4

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layer 02	brick element	0.25	0.36
layer 03	cavity	0.1	0.026
layer 04	brick element	0.1	0.36
layer 05	plaster	0.03	1.4
ROOF Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	TILE	0.013	1.05
layer 02	BASSET	0.05	1.3
layer 03	CONCRETE	0.2	1.3
layer 04	BRICK	0,2-0,24	0.36
layer 05	PLASTER	0.02	1.4

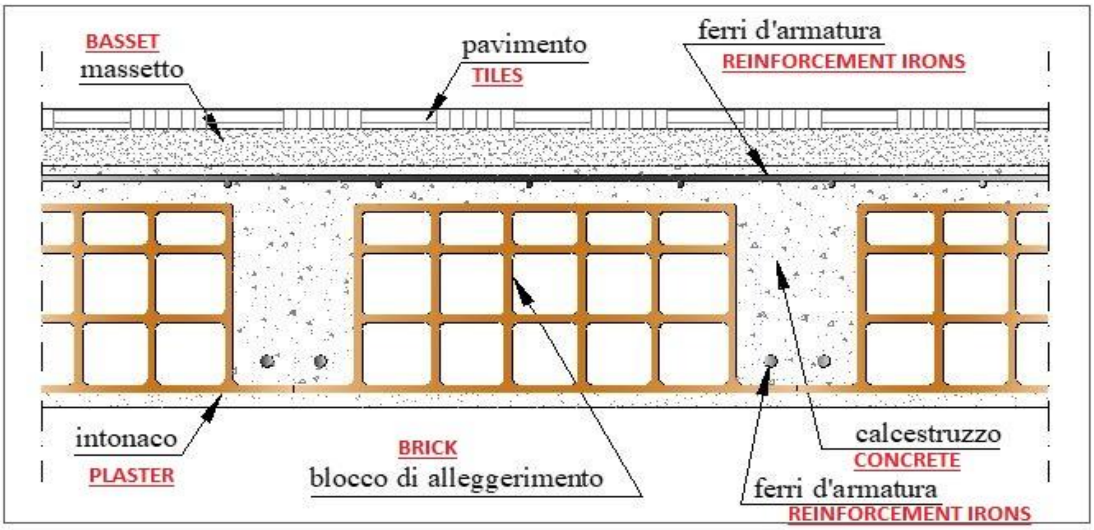

Figure 21. Details of façade materials, L'Aquila

- **Energy parameters**

Table 15. Energy parameters, L'Aquila

ENERGY	
Energy consumption for heating (kWh/m2 year)	0
Energy consumption for cooling (kWh/m2 year)	0
Total energy consumption for electrical appliances (kWh/year)	140 kWh/m^{2}year

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Air Conditioned Floor Surface (m^2)	820
Air Conditioned Volume (m^3)	5233
Façade Total surface (m^2)	772.75
Windows no.	46
Window-To-Wall ratio (%)	14
Energy Cost (Gas & Electricity) (€/year)	gas
	electricity
clearance height overhead (m)	9.75
Climatic zone	E
Compactness: Volume/External Surface V/A [m^3/m2]	6.771918473

- **Envelope characteristics**

Table16. Envelope characteristics, L'Aquila

FAÇADE 01	
Orientation	south
Degrees*	160
Structure (Light-Medium-Heavy)	h
External or Internal	i
Surface (m^2)	160
windows no.	6
Window-To-Wall ratio	6
Surface_without windows (m^2)	140,8
Power installed kWp	22,5
U value W/(m^2 K)	
g factor (-)	
Shaded by other buildings? (YES or NOT)	n
Average size of windows. Width by Height (m)	2 x 1,6
Energy generated (kWh/year) PV (total surface without windows)	22940
Energy generated per m2. (kWh/year) Solar Thermal	501,08

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FAÇADE 02	
Orientation	west
Degrees	258
Structure (Light-Medium-Heavy)	h
External or Internal	i
Surface (m^2)	130
windows no.	7
Window-To-Wall ratio	3
Surface_without windows (m^2)	118,8
Power installed kWp	19
U value W/(m^2 K)	
g factor (-)	
Shaded by other buildings? (YES or NOT)	n
Average size of windows. Width by Height (m)	1 x 1,6
Energy generated (kWh/year) PV (total surface without windows)	22940
Energy generated per m2. (kWh/year) Solar Thermal	463,91

FAÇADE 03	
Orientation	north
Degrees	-20
Structure (Light-Medium-Heavy)	h
External or Internal	i
Surface (m^2)	360
windows no.	26
Window-To-Wall ratio	4
Surface_without windows (m^2)	301,5
Power installed kWp	48,2
U value W/(m^2 K)	
g factor (-)	
Shaded by other buildings? (YES or NOT)	n

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Average size of windows. Width by Height (m)	1,5 x 1,5
Energy generated (kWh/year) PV (total surface without windows)	48307
Energy generated per m2. (kWh/year) Solar Thermal	224,03
FAÇADE 04	
Orientation	east
Degrees	78
Structure (Light-Medium-Heavy)	h
External or Internal	i
Surface (m^2)	160
windows no.	6
Window-To-Wall ratio	6
Surface_without windows (m^2)	140,8
Power installed kWp	22,5
U value W/(m^2 K)	
g factor (-)	
Shaded by other buildings? (YES or NOT)	n
Average size of windows. Width by Height (m)	2 x 1,6
Energy generated (kWh/year) PV (total surface without windows)	18994
Energy generated per m2. (kWh/year) Solar Thermal	357.58
ROOF	
Orientation	n - s - e -w
Degrees	all
Structure (Light-Medium-Heavy)	h
External or Internal	i
Surface (m^2)	980
windows no.	4
Window-To-Wall ratio	
Surface_without windows (m^2)	980

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Power installed kWp	16
U value W/(m² K)	
g factor (-)	
Shaded by other buildings? (YES or NOT)	n
Average size of windows. Width by Height (m)	1,6 x 0,86
Energy generated (kWh/year) PV (total surface without windows)	73903
Energy generated per m2. (kWh/year) Solar Thermal	2590,05

*Degrees. Not only indicate north, south, east and west, but also consider the degrees. According to this scale; 0º for north, 90 east, 180º south, 270º west

- **Estimation of PV energy production – Preliminary results**

Assumptions:

- North, South, West and East façade orientations + Roof
- Mono-crystalline technology

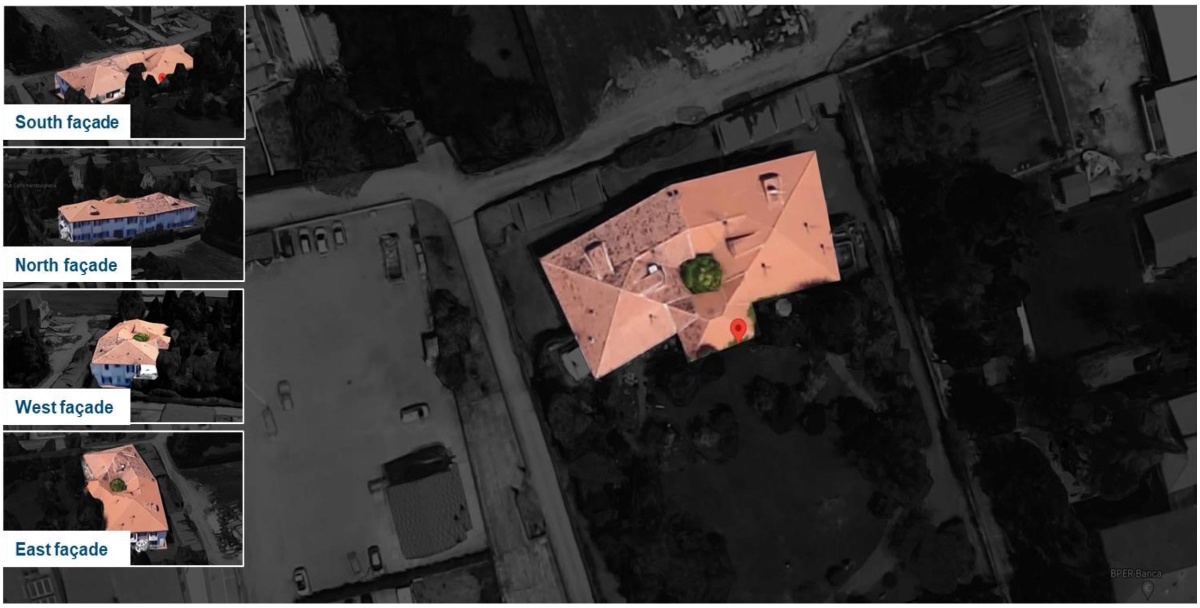

Figure 22. General assumptions demo building 2, L'Aquila

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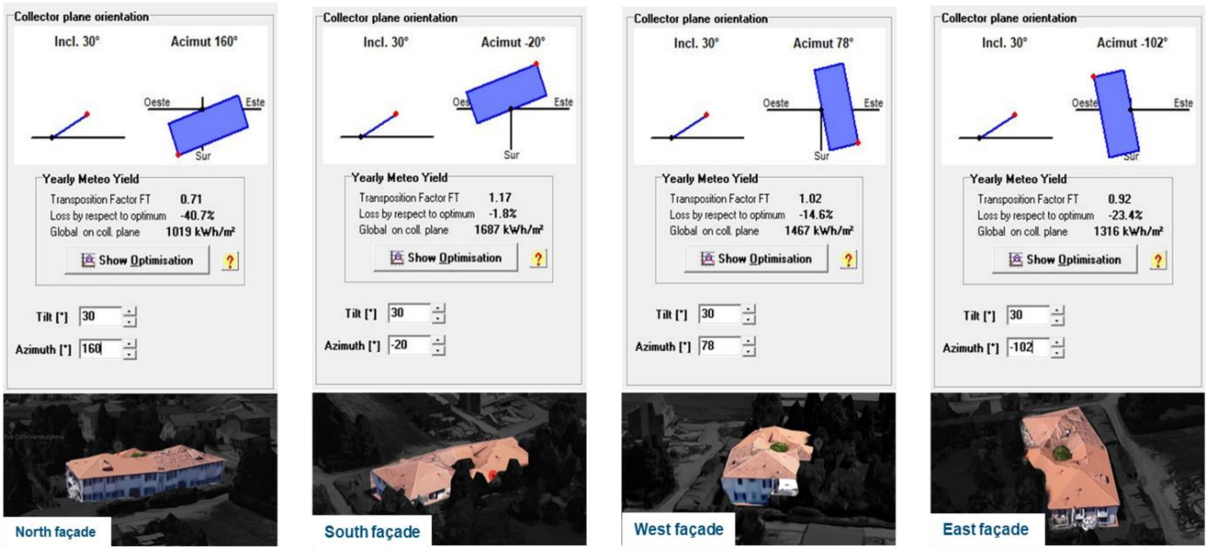

Figure 23. Clarifications demo building 2, L'Aquila+

- North façade:

Assumptions:

- Surface: 160,00 m^2
- Window-to-wall ratio: 6%
- PV surface covered: 140,80 m^2
- Mono-crystalline technology
- Power installed: 22,50 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 24. North façade, L'Aquila

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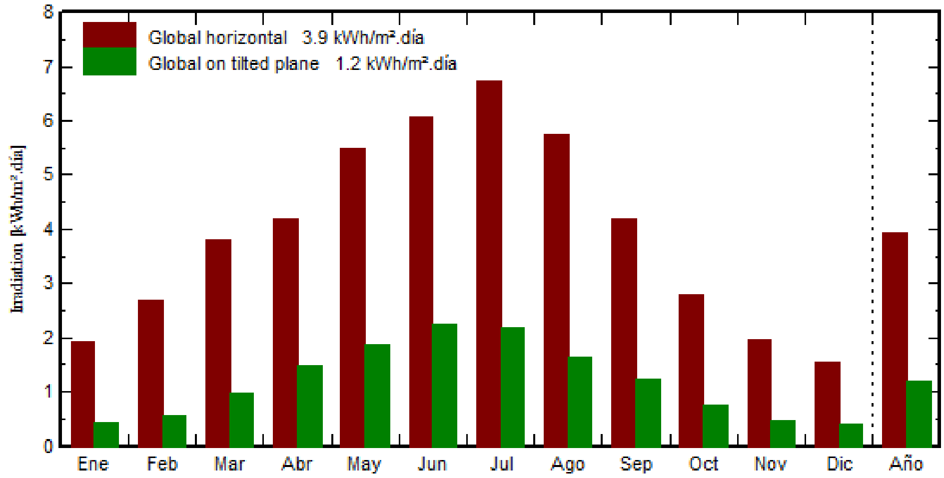

Figure 25. Irradiation analysis north façade, L'Aquila

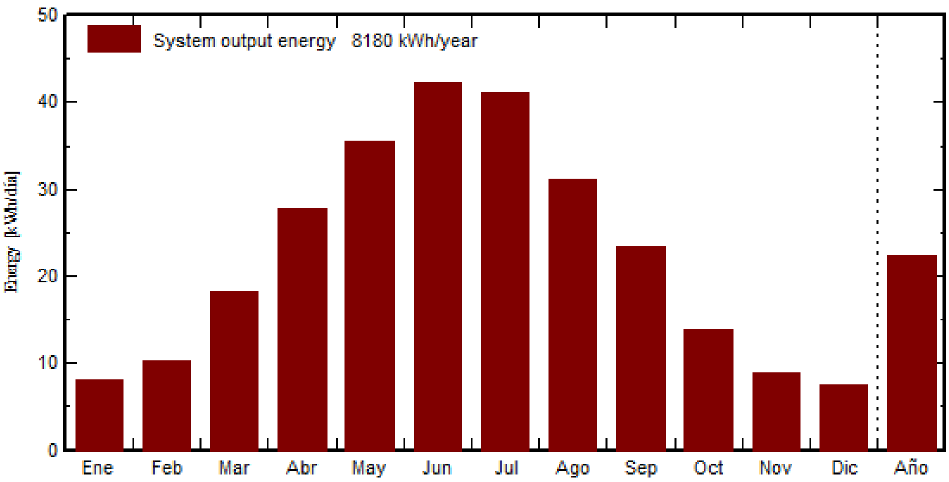

Figure 26. Energy kWh/year north façade, L'Aquila

North façade analysis:

Table 17. North façade estimated energy production, L'Aquila

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NORTH façade 140,80 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.94	1.94	31.01	**961**
February	2.69	2.69	42.93	**1.202**
March	3.80	3.80	60.75	**1.883**
April	4.19	4.19	66.99	**2.010**
May	5.49	5.49	87.63	**2.716**
Jun	6.07	6.07	96.96	**2.909**
July	6.74	6.74	107.7	**3.339**
August	5.74	5.74	91.67	**2.842**
September	4.18	4.18	66.83	**2.005**
October	2.77	2.77	44.32	**1.374**
November	1.95	1.95	31.09	**933**
December	1.55	1.55	24.72	**766**
Annual	**3.93**	**3.93**	**62.85**	**22.940**

– South façade:

Assumptions:

– Surface: 360,00 m^2
– Window-to-wall ratio: 4%
– PV surface covered: 301,50 m^2
– Mono-crystalline technology
– Power installed: 48,20 kWp
– No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 27. South façade, L'Aquila

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

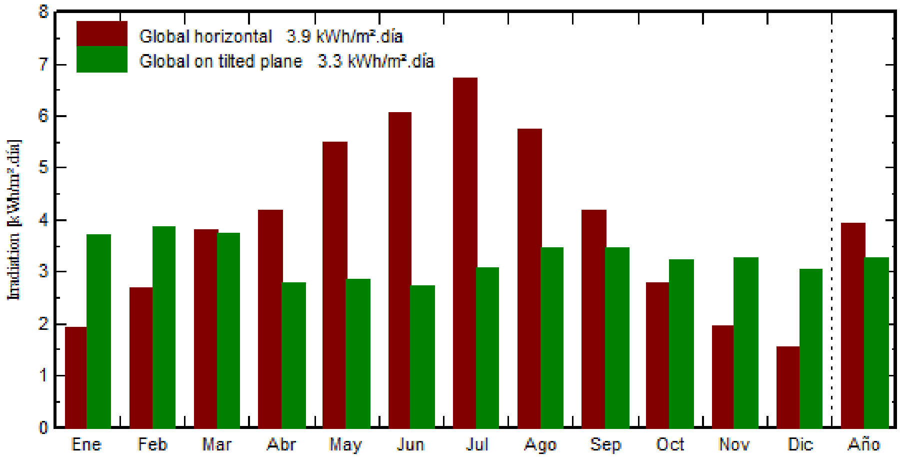

Figure 28. Irradiation analysis south façade, L'Aquila

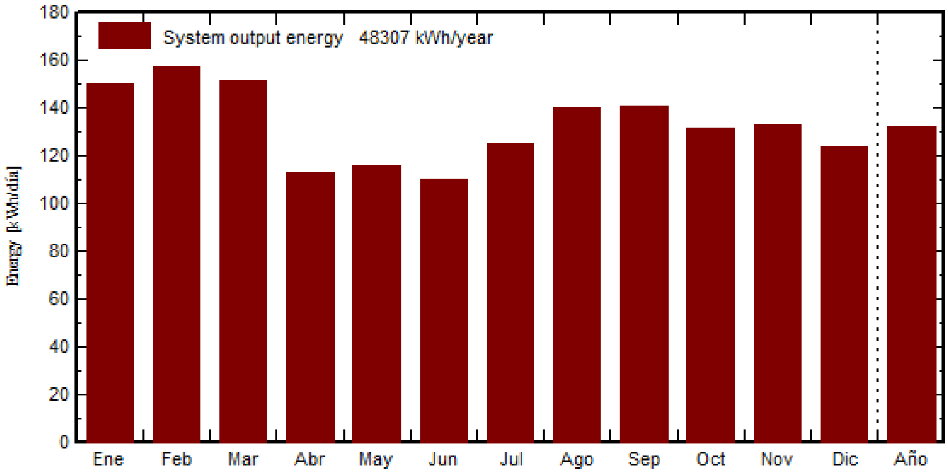

Figure 29. Energy kWh/year south façade, L'Aquila

South façade analysis:

Table 18. South façade estimated energy production, L'Aquila

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SOUTH façade 301,50 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.94	3.69	149.7	**4.641**
February	2.69	3.88	157.2	**4.401**
March	3.80	3.73	151.3	**4.690**
April	4.19	2.79	113.1	**3.394**
May	5.49	2.85	115.5	**3.581**
Jun	6.07	2.71	110.0	**3.299**
July	6.74	3.08	124.8	**3.868**
August	5.74	3.45	139.9	**4.336**
September	4.18	3.47	140.6	**4.219**
October	2.77	3.24	131.5	**4.076**
November	1.95	3.27	132.6	**3.977**
December	1.55	3.04	123.4	**3.825**
Annual	**3.93**	**3.26**	**132.3**	**48.307**

– West façade:

Assumptions:

– Surface: 160,00 m²
– Window-to-wall ratio: 6%
– PV surface covered: 140,80 m²
– Mono-crystalline technology
– Power installed: 22,50 kWp
– No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 30. West façade, L'Aquila

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

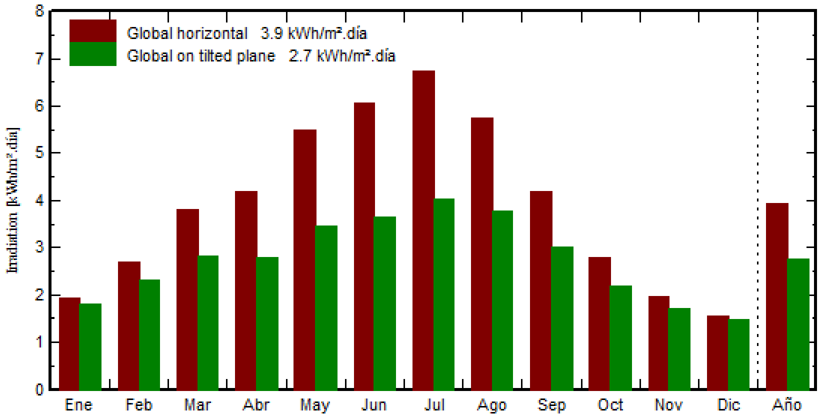

Figure 31. Irradiation analysis west façade, L'Aquila

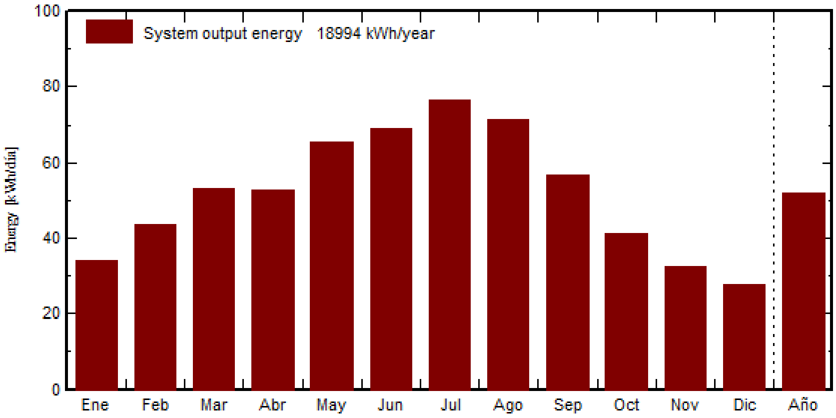

Figure 32. Energy kWh/year west façade, L'Aquila

West façade analysis:

Table 19. West façade estimated energy production, L'Aquila

WEST façade 140,80 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	1.94	1.81	34.19	**1.060**
February	2.69	2.30	43.50	**1.218**
March	3.80	2.81	53.23	**1.650**
April	4.19	2.77	52.52	**1.576**
May	5.49	3.45	65.38	**2.027**
Jun	6.07	3.64	68.97	**2.069**
July	6.74	4.04	76.47	**2.370**
August	5.74	3.77	71.30	**2.210**
September	4.18	3.00	56.75	**1.702**
October	2.77	2.17	41.07	**1.273**
November	1.95	1.72	32.51	**975**
December	1.55	1.47	27.85	**863**
Annual	**3.93**	**2.75**	**52.04**	**18.994**

– East façade:

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Assumptions:

- Surface: 130,00 m^2
- Window-to-wall ratio: 3%
- PV surface covered: 118,80 m^2
- Mono-crystalline technology
- Power installed: 19,00 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 33. East façade, L'Aquila

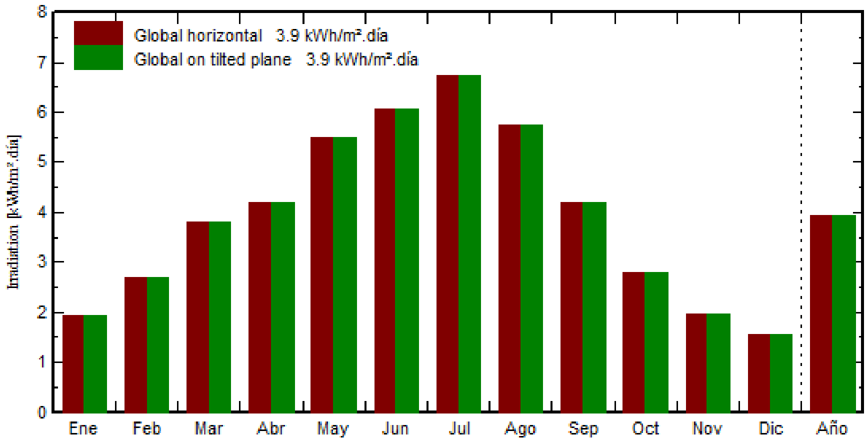

Figure 34. Irradiation analysis east façade, L'Aquila

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

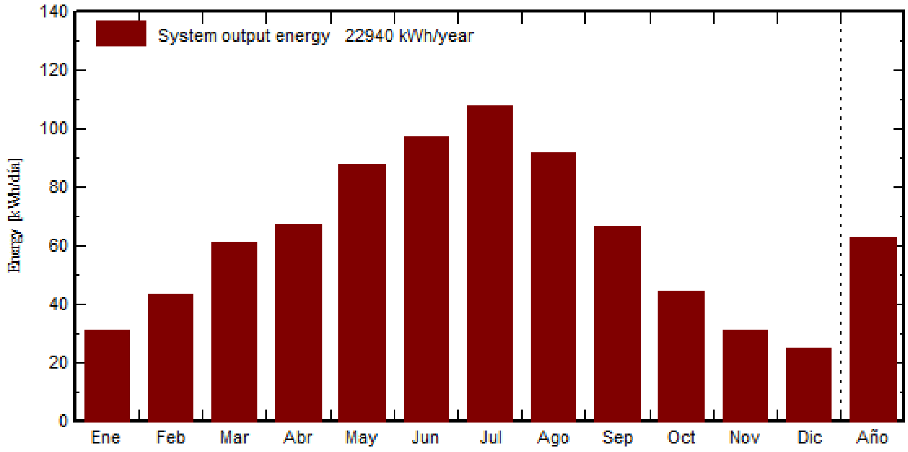

Figure 35. Energy kWh/year east façade, L'Aquila

East façade analysis:

Table 20. East façade estimated energy production, L'Aquila

EAST façade 118,80 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	1.94	1.94	31.01	**961**
February	2.69	2.69	42.93	**1.202**
March	3.80	3.80	60.75	**1.883**
April	4.19	4.19	66.99	**2.010**
May	5.49	5.49	87.63	**2.716**
Jun	6.07	6.07	96.96	**2.909**
July	6.74	6.74	107.7	**3.339**
August	5.74	5.74	91.67	**2.842**
September	4.18	4.18	66.83	**2.005**
October	2.77	2.77	44.32	**1.374**
November	1.95	1.95	31.09	**933**
December	1.55	1.55	24.72	**766**
Annual	**3.93**	**3.93**	**62.85**	**22.940**

- North roof:

Assumptions:

- PV surface covered: 100,00 m^2
- Mono-crystalline technology
- Power installed: 16,00 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

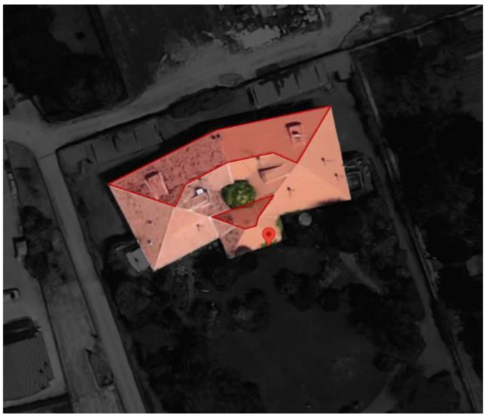

Figure 36. North roof, L'Aquila

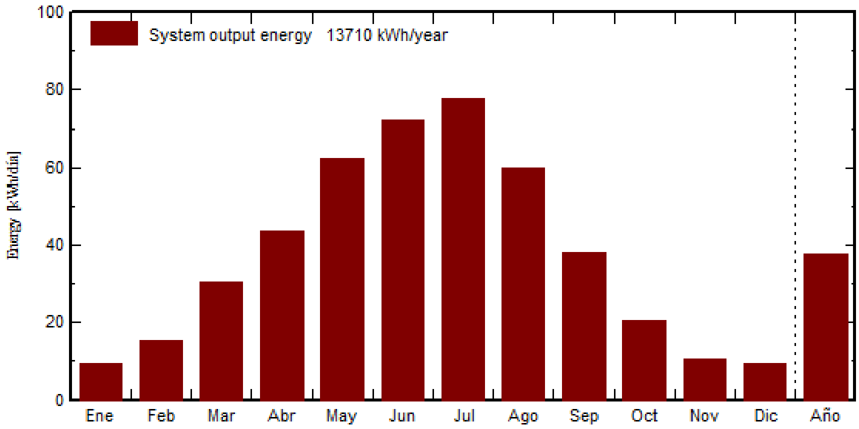

Figure 37. Energy kWh/year north roof, L'Aquila

North roof analysis:

Table 21. North roof estimated energy production, L'Aquila

NORTH roof 100,00 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	1.94	0.70	9.46	**293**
February	2.69	1.14	15.38	**431**
March	3.80	2.28	30.62	**949**
April	4.19	3.23	43.47	**1.304**
May	5.49	4.62	62.07	**1.924**
Jun	6.07	5.38	72.29	**2.169**
July	6.74	5.78	77.73	**2.409**
August	5.74	4.45	59.86	**1.856**
September	4.18	2.84	38.20	**1.146**
October	2.77	1.51	20.33	**630**
November	1.95	0.78	10.51	**315**
December	1.55	0.68	9.17	**284**
Annual	**3.93**	**2.79**	**37.56**	**13.710**

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

- South roof:

Assumptions:

- PV surface covered: 100,00 m^2
- Mono-crystalline technology
- Power installed: 16,00 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

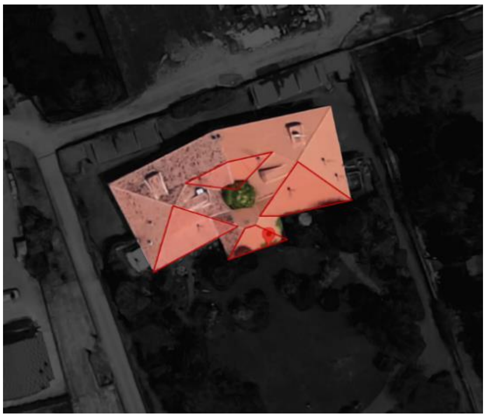

Figure 38. South roof, L'Aquila

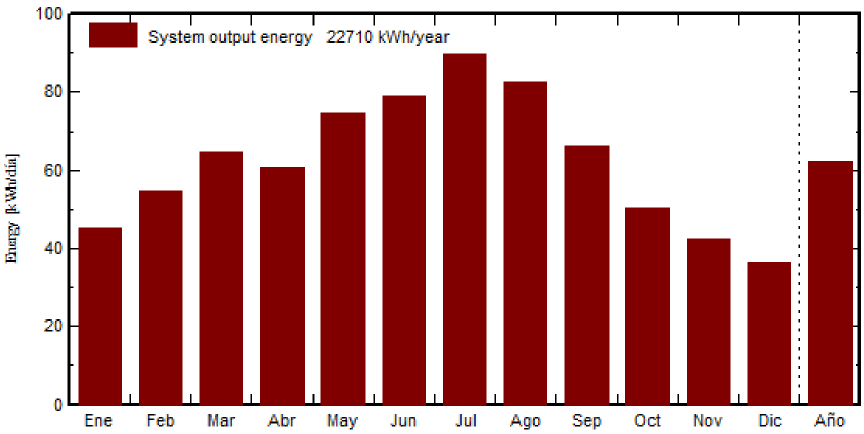

Figure 39. Energy kWh/year south roof, L'Aquila

South roof analysis:

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Table 22. South roof estimated energy production, L'Aquila

SOUTH roof 100,00 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	1.94	3.36	45.14	**1.399**
February	2.69	4.05	54.52	**1.526**
March	3.80	4.81	64.63	**2.004**
April	4.19	4.50	60.53	**1.816**
May	5.49	5.55	74.61	**2.313**
Jun	6.07	5.87	78.96	**2.369**
July	6.74	6.66	89.53	**2.776**
August	5.74	6.15	82.67	**2.563**
September	4.18	4.92	66.20	**1.986**
October	2.77	3.75	50.45	**1.564**
November	1.95	3.14	42.21	**1.266**
December	1.55	2.71	36.41	**1.129**
Annual	**3.93**	**4.63**	**62.22**	**22.710**

– East roof:

Assumptions:

– PV surface covered: 100,00 m^2
– Mono-crystalline technology
– Power installed: 16,00 kWp
– No losses are being considered both from the BOS (balance of the system) and from cast shadows

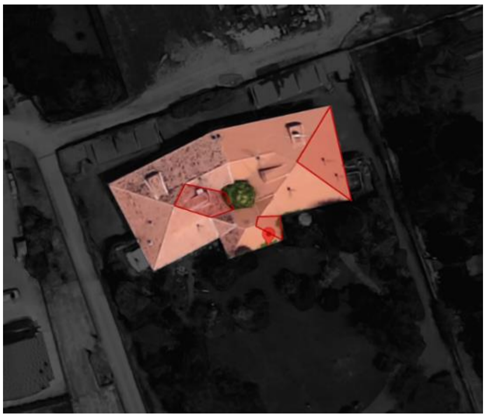

Figure 40. East roof, L'Aquila

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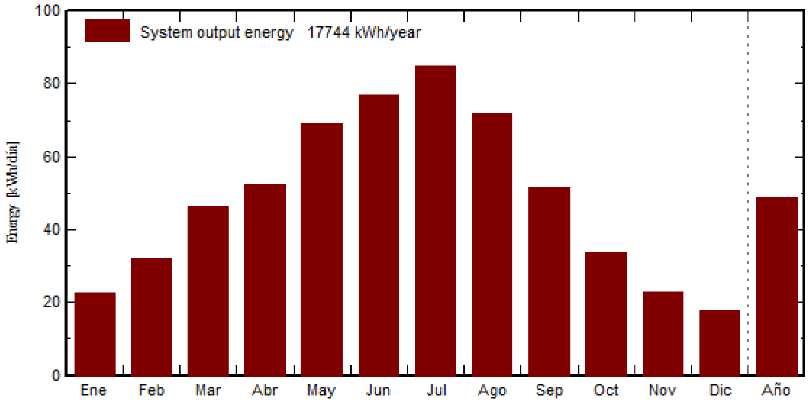

Figure 41. Energy kWh/year east roof, L'Aquila

East roof analysis:

Table 23. East roof estimated energy production, L'Aquila

EAST roof 100,00 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.94	1.67	22.51	**698**
February	2.69	2.37	31.89	**893**
March	3.80	3.46	46.53	**1.442**
April	4.19	3.90	52.39	**1.572**
May	5.49	5.14	69.05	**2.141**
Jun	6.07	5.72	76.95	**2.309**
July	6.74	6.31	84.91	**2.632**
August	5.74	5.33	71.66	**2.222**
September	4.18	3.84	51.64	**1.549**
October	2.77	2.51	33.76	**1.046**
November	1.95	1.70	22.91	**687**
December	1.55	1.33	17.87	**554**
Annual	**3.93**	**3.62**	**48.61**	**17.744**

- West roof:

Assumptions:

- PV surface covered: 100,00 m^2
- Mono-crystalline technology
- Power installed: 16,00 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

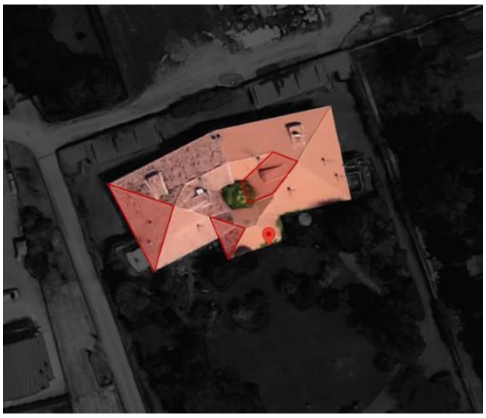

Figure 42. West roof, L'Aquila

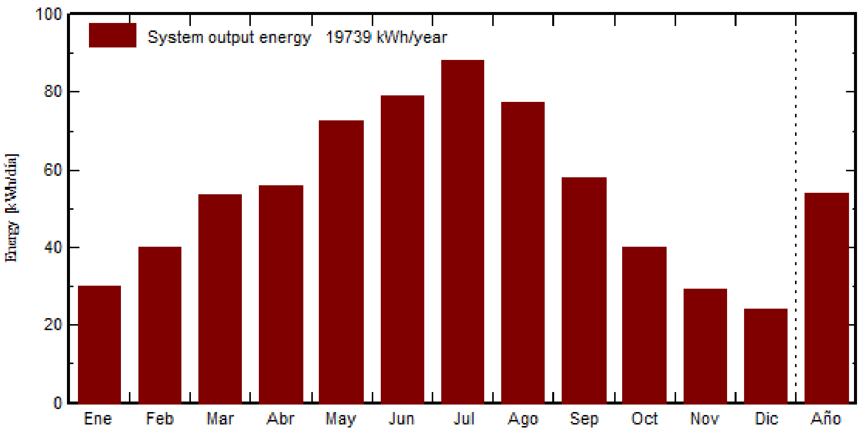

Figure 43. Energy kWh/year west roof, L'Aquila

West roof analysis:

Table 24. West roof estimated energy production, L'Aquila

WEST roof 100,00 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.94	2.24	30.10	**933**
February	2.69	2.99	40.16	**1.125**
March	3.80	3.97	53.36	**1.654**
April	4.19	4.17	56.03	**1.681**
May	5.49	5.39	72.51	**2.248**
Jun	6.07	5.87	78.94	**2.368**
July	6.74	6.55	88.02	**2.729**
August	5.74	5.75	77.29	**2.396**
September	4.18	4.31	57.92	**1.737**
October	2.77	2.96	39.80	**1.234**
November	1.95	2.19	29.45	**883**
December	1.55	1.80	24.20	**750**
Annual	**3.93**	**4.02**	**54.08**	**19.739**

- **Building services system (BSS)**

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Table 25. Building services system, L'Aquila

BUILDING SERVICES SYSTEM	
Is there any **heating system**? If yes, please provide the brief introduction of heating system (energy source, power and capacity.), Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied heating system installed?	hydraulic central heating system: gas-fired condensing boiler and radiators consisting of assembled cast-iron heating elements: there is one boiler for each of the two building units
Is there a **domestic hot water (DHW) system**? If yes, please provide the DHW system (energy source, power and capacity)	the domestic hot water system is fed by the same condensing boiler that provides hot water distribution to the radiant heating system
Is there an **air-conditioning system**? If yes, please provide the brief introduction of air-conditioning system (energy source, power and capacity) Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied cooling system installed?	no
Is there a **ventilation system**? If yes, please provide the brief introduction of ventilation system (energy source, power and ventilation rate, Is the ventilation	no
Is there a **renewable heat generation source**? If yes, please provide the brief introduction of renewable heat generation source (power and generation-storage capacity)	no
Is there a **renewable electricity generation source**? If yes, please provide the brief introduction of renewable electricity generation source (power and generation-storage capacity)	no

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- **Control and management systems**

Is there a **building management system (BMS) or control system** already installed? If yes, please provide a brief introduction of the building management system.	no

Table 26. Control and management systems, L'Aquila

- **Structural performance**

Table 27. Structural performance, L'Aquila

STRUCTURE	
Structure type (bearing wall, timber framing, structure of concrete floors and pillars, …)	structure of concrete floors and pillars
Distance between slabs (floors)	3,00 m
Slab structure thickness	0,3 m
Slab material properties.(e.g. Compressive strength, reinforcement, bulk density)	reinforced concrete
Height (m)	9 m
Floor dimension (length x width) (m)	20 x 15

- **Local and aesthetic requirements**

Table 28. Local and aesthetic requirements, L'Aquila

AESTHETICS	
Is there any local requirement about aesthetic aspects of the building? If yes, provide a brief introduction about how affect the building.	The existing building is one of the most beautiful garden villas in the area and will become a residence for the elderly. For this reason it will be essential to combine aesthetic choices, the wishes of the owners and technological requirements.

HERITAGE AND LANSCAPE CODES

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Is there any Code for the cultural heritage of the building? If yes, provide information, about how affect the building.	no

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3. Virtual Building 1, Glasgow

- **Thermal characteristics**

Virtual Building 1: Glasgow

The façade layout of the virtual building in Glasgow is composed of (1) rainscreen - metal, (2) air cavity, (3) insulation layer, (4) cement-bonded particle board, (5) air cavity, and (6) plasterboard.

In addition, the roof layout consists of (1) insulation layer, (2) membrane, (3) concrete deck, (4) air cavity, and (5) plasterboard.

Table 29. Thermal characteristics of the envelope, Glasgow

FACADE 01 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Rainscreen - metal	0.003	50
layer 02	Cavity	0.05	
layer 03	Insulation	0.0814	0.025
layer 04	Cement-bonded particle board	0.012	0.23
layer 05	Cavity	0.05	
layer 06	Plasterboard	0.0125	0.21
FACADE 02 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Rainscreen - metal	0.003	50
layer 02	Cavity	0.05	
layer 03	Insulation	0.0814	0.025
layer 04	Cement-bonded particle board	0.012	0.23
layer 05	Cavity	0.05	
layer 06	Plasterboard	0.0125	0.21
FACADE 03 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Rainscreen - metal	0.003	50
layer 02	Cavity	0.05	
layer 03	Insulation	0.0814	0.025
layer 04	Cement-bonded	0.012	0.23

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	particle board		
layer 05	Cavity	0.05	
layer 06	Plasterboard	0.0125	0.21
FACADE 04 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Rainscreen - metal	0.003	50
layer 02	Cavity	0.05	
layer 03	Insulation	0.0814	0.025
layer 04	Cement-bonded particle board	0.012	0.23
layer 05	Cavity	0.05	
layer 06	Plasterboard	0.0125	0.21
ROOF Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Insulation	0.1544	0.03
layer 02	Membrane	0.0001	1
layer 03	Concrete deck	0.1	2
layer 04	Cavity	0.05	
layer 05	Plasterboard	0.0125	0.21

- **Energy parameters**

Table 30. Energy parameters, Glasgow

ENERGY	
Energy consumption for heating (kWh/m2 year)	40.4
Energy consumption for cooling (kWh/m2 year)	0
Total energy consumption for electrical appliances (kWh/year)	24181.2
Air Conditioned Floor Surface (m^2)	1445.116
Air Conditioned Volume (m^3)	4665
Façade Total surface (m^2)	External wall area 1446.3 m^2. External opening area 235.4795 m^2. Roof area 767 m^2.

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Windows no.	52
Window-To-Wall ratio (%)	16
Energy Cost (Gas & Electricity) (€/year)	gas
	electricity
clearance height overhead (m)	12.208 to top of roof pitch
Climatic zone	
Compactness: Volume/External Surface V/A [m³/m2]	

- **Envelope characteristics**

Table 31: Envelope characteristics and estimation of the energy generated, Glasgow

FACADE 01	
Orientation	North
Degrees*	30º
Structure (Light-Medium-Heavy)	
External or Internal	External wall
Surface (m^2)	306.3
windows no.	8 average and 1 bigger
Window-To-Wall ratio	16.80%
Surface_without windows (m^2)	254,84
Power installed kWp	40,80
U value W/(m^2 K)	0.2599
g factor (-)	
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	2.5*1.55 average (one larger of 4*6.4)

Results: (**Technologies Energy. Energy generated per m²**)

Energy generated (kWh/year) PV (total surface without windows)	30653,00
Energy generated per m2. (kWh/year) ST	145,36

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NOTE: This north-east side has a lot of trees that will make shadow on the panels that are mounted on the vertical façade. We think that this façade will not be suitable for installing solar panels.

FACADE 02	
Orientation	East
Degrees	120º
Structure (Light-Medium-Heavy)	
External or Internal	External wall
Surface (m^2)	417
windows no.	15
Window-To-Wall ratio	13.90%
Surface_without windows (m2)	359,04
Power installed kWp	57,40
U value W/(m^2 K)	0.2599
g factor (-)	
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	2.5*1.55

Results: (**Technologies Energy. Energy generated per m²**)

Energy generated (kWh/year) PV (total surface without windows)	25656,00
Energy generated per m2. (kWh/year) ST	300,34

NOTE: This east-south side has a lot of trees that will make shadow on the panels that are mounted on the vertical façade. We think that this façade will not be suitable for installing solar panels

FACADE 03	
Orientation	South
Degrees	210º
Structure (Light-Medium-Heavy)	
External or Internal	External wall
Surface (m^2)	306.1
windows no.	8

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Window-To-Wall ratio	11.50%
Surface_without windows (m^2)	270,90
Power installed kWp	43,30
U value W/(m^2 K)	0.2599
g factor (-)	
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	2.5*1.55

Results: (**Technologies Energy. Energy generated per m²**)

Energy generated (kWh/year) PV (total surface without windows)	14266,00
Energy generated per m2. (kWh/year) ST	357,63

NOTE: According google maps this south-west side has some shadow during the day. If it is possible to receive more information or picture during the day to see this shadow.

FACADE 04	
Orientation	West
Degrees	300º
Structure (Light-Medium-Heavy)	
External or Internal	External wall
Surface (m^2)	416.9
windows no.	20
Window-To-Wall ratio	20.40%
Surface_without windows (m^2)	270,90
Power installed kWp	43,30
U value W/(m^2 K)	0.2599
g factor (-)	
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	2.5*1.55

Results: (**Technologies Energy. Energy generated per m²**)

Energy generated (kWh/year) PV (total surface without windows)	36386,00
Energy generated per m2. (kWh/year) ST	202,41

ROOF

Orientation	3 sections: Roof 1 orientation 270 deg and tilt 17 deg. Roof 2 orientation 90 deg and tilt 17 deg. Roof 3 horizontal
Degrees	
Structure (Light-Medium-Heavy)	
External or Internal	External
Surface (m^2)	Roof 1 is 303 m2. Roof 2 is 303 m2. Roof 3 is 160.9704 m2
windows no.	
Window-To-Wall ratio	
Power installed kWp	122,80
U value W/(m^2 K)	0.18
g factor (-)	
Shaded by other buildings? (YES or NOT)	
Average size of windows. Width by Height (m)	

Results: (**Technologies Energy. Energy generated per m²**)

Energy generated (kWh/year) PV (total surface without windows)	104633,00
Energy generated per m2. (kWh/year) ST	492,73

On the roof the panels are south oriented on 45 degrees angle

Note: All data from Camel Solar are based from software T*SOL 2018, regarding the weather condition from Meteo Syn for Glasgow, Scotland with yearly solar radiation of 935.90 kWh/m2.

- **Estimation of PV energy production – Preliminary results**

Façade Assumptions:

- North, South, West and East façade orientations + Roof
- Mono-crystalline technology

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- Power installed 317,40 kWp

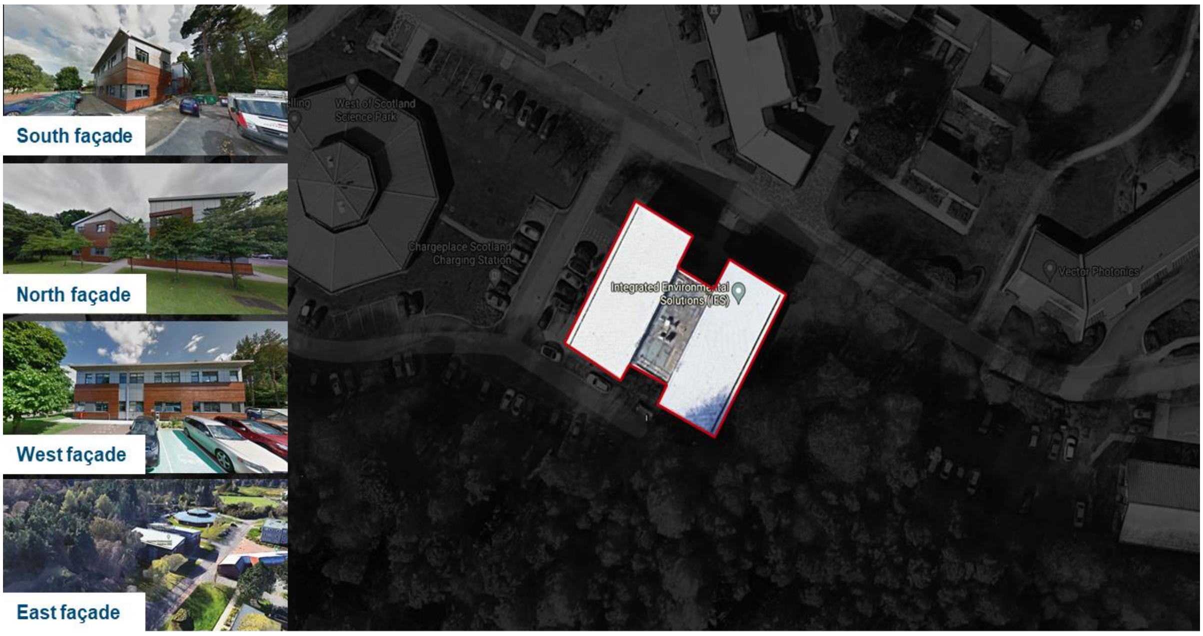

Figure 44. General assumptions Virtual building 1, Glasgow

– South façade:

Assumptions:

- Surface: 306,10 m^2
- Window-to-wall ratio: 11,50%
- PV surface covered: 270,90 m^2
- Mono-crystalline technology
- Power installed: 43,30 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 45. South façade, Glasgow

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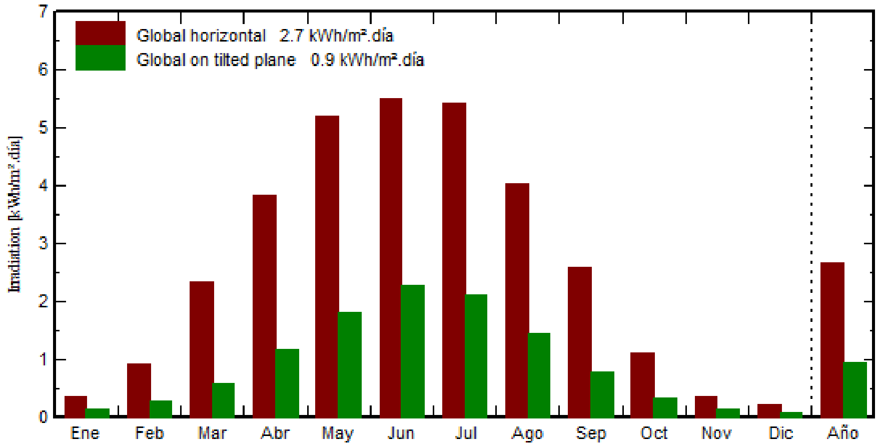

Figure 46. Irradiation analysis south façade, Glasgow

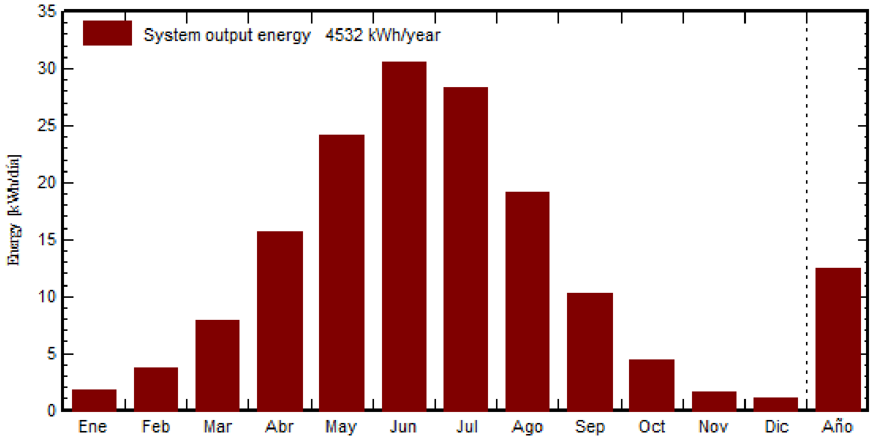

Figure 47. Energy kWh/year south façade, Glasgow

South façade analysis:

Table 32. South façade estimated energy production, Glasgow

SOUTH façade 270,89 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.69	0.22	7.87	**244**
February	1.25	0.42	15.44	**432**
March	2.50	0.81	29.49	**914**
April	4.21	1.44	52.57	**1.577**
May	5.09	2.10	76.45	**2.370**
Jun	5.44	2.32	84.63	**2.539**
July	4.69	1.98	71.95	**2.230**
August	3.52	1.55	56.48	**1.751**
September	2.90	0.99	36.04	**1.081**
October	1.63	0.55	20.14	**624**
November	0.81	0.26	9.38	**281**
December	0.55	0.20	7.12	**221**
Annual	**2.78**	**1.07**	**39.08**	**14.266**

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– North façade:

Assumptions:

- Surface: 306,30 m^2
- Window-to-wall ratio: 16,80%
- PV surface covered: 254,84 m^2
- Mono-crystalline technology
- Power installed: 40,80 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 48. North façade, Glasgow

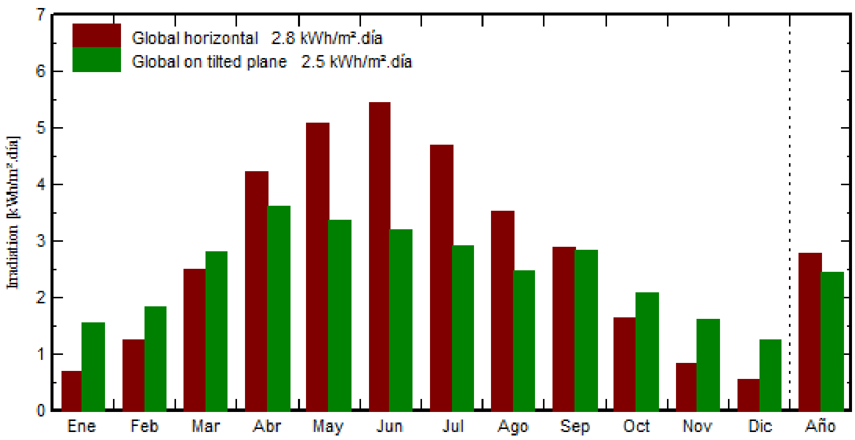

Figure 49. Irradiation analysis north façade, Glasgow

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

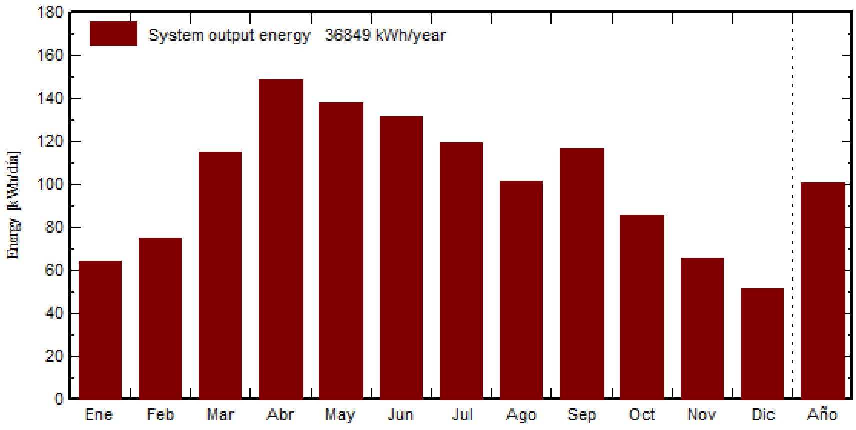

Figure 50. Energy kWh/year north façade, Glasgow

North façade analysis:

Table 33. North façade estimated energy production, Glasgow

NORTH façade 254,84 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.69	1.56	53.41	**1.656**
February	1.25	1.82	62.25	**1.743**
March	2.50	2.80	95.89	**2.972**
April	4.21	3.60	123.4	**3.703**
May	5.09	3.34	114.5	**3.550**
Jun	5.44	3.20	109.5	**3.286**
July	4.69	2.90	99.28	**3.078**
August	3.52	2.46	84.27	**2.612**
September	2.90	2.82	96.58	**2.898**
October	1.63	2.07	71.04	**2.202**
November	0.81	1.60	54.69	**1.641**
December	0.55	1.24	42.35	**1.313**
Annual	**2.78**	**2.45**	**83.98**	**30.653**

– West façade:

Assumptions:

- Surface: 416,90 m²
- Window-to-wall ratio: 20,40%
- PV surface covered: 331,85,28 m²
- Mono-crystalline technology
- Power installed: 53,10 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

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Figure 51. West façade, Glasgow

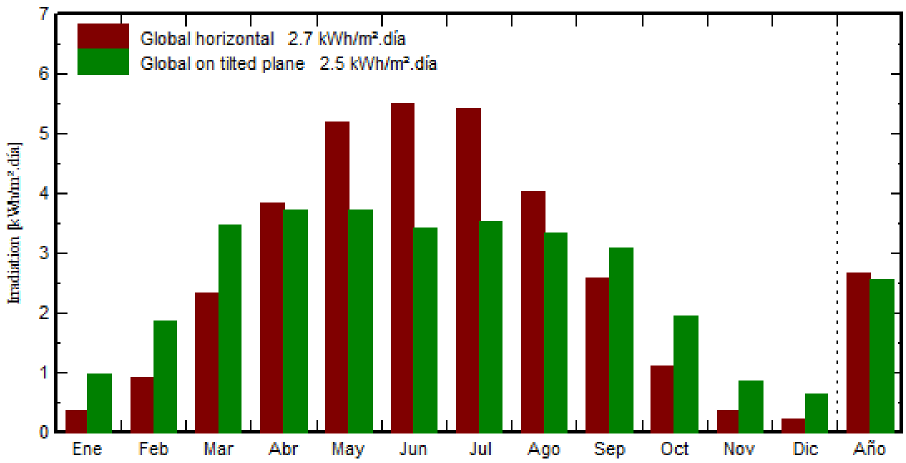

Figure 52. Irradiation analysis west façade, Glasgow

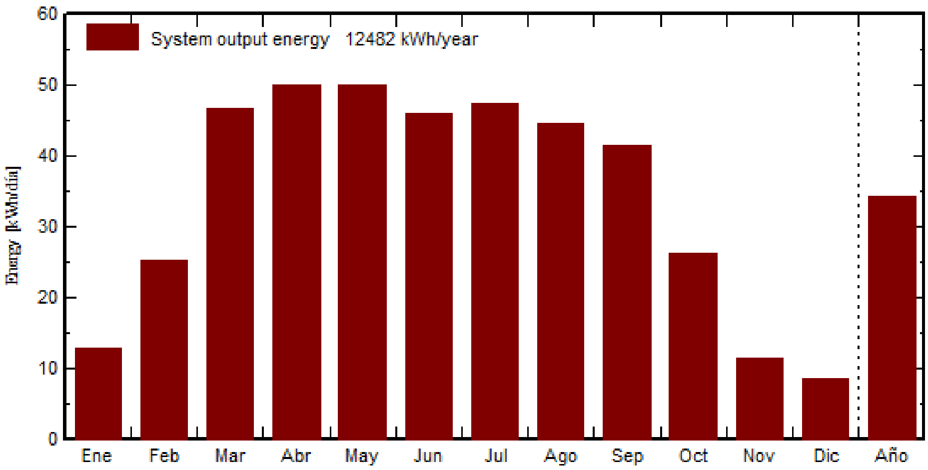

Figure 53. Energy kWh/year west façade, Glasgow

West façade analysis:

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Table 34. West façade estimated energy production, Glasgow

WEST façade 331,85 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.69	1.05	47.02	**1.458**
February	1.25	1.37	60.99	**1.708**
March	2.50	2.36	105.5	**3.269**
April	4.21	3.37	150.6	**4.517**
May	5.09	3.48	155.3	**4.815**
Jun	5.44	3.52	156.9	**4.707**
July	4.69	3.11	138.8	**4.302**
August	3.52	2.46	109.7	**3.400**
September	2.90	2.48	110.6	**3.317**
October	1.63	1.64	73.21	**2.270**
November	0.81	1.10	49.21	**1.476**
December	0.55	0.83	37.01	**1.147**
Annual	**2.78**	**2.23**	**99.69**	**36.386**

– East façade:

Assumptions:

- Surface: 417,00 m^2
- Window-to-wall ratio: 13,90%
- PV surface covered: 359,04 m^2
- Mono-crystalline technology
- Power installed: 57,40 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 54. East façade, Glasgow

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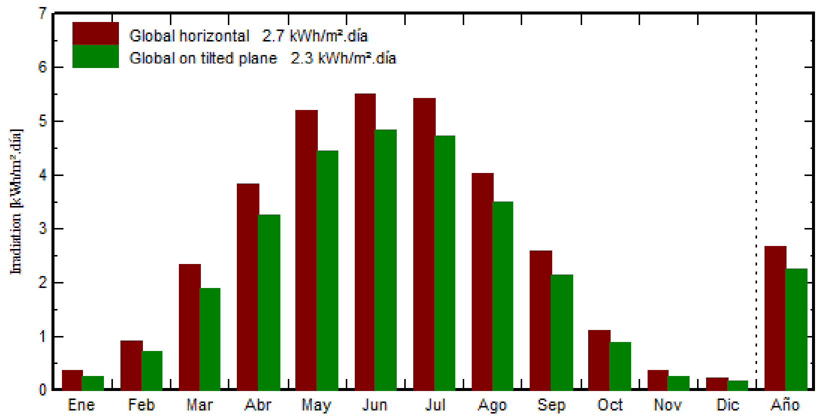

Figure 55. Irradiation analysis east façade, Glasgow

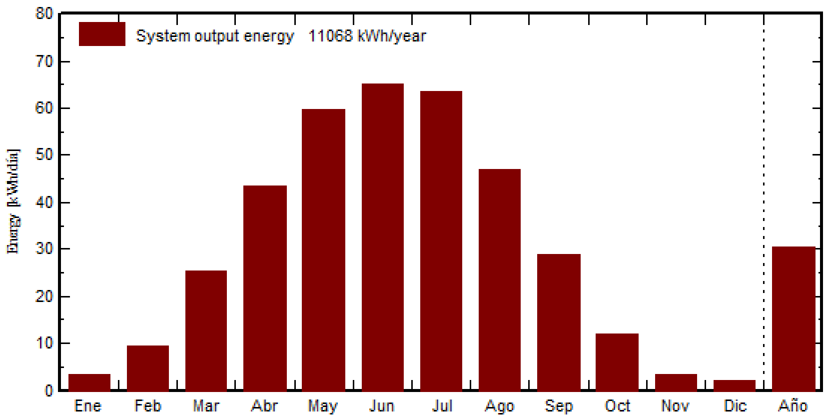

Figure 56. Energy kWh/year east façade, Glasgow

East façade analysis:

Table 35. East façade estimated energy production, Glasgow

EAST façade 359,03 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.69	0.27	13.14	**407**
February	1.25	0.58	27.93	**782**
March	2.50	1.22	58.66	**1.819**
April	4.21	2.14	103.5	**3.105**
May	5.09	2.82	136.0	**4.215**
Jun	5.44	3.02	145.9	**4.377**
July	4.69	2.63	126.7	**3.929**
August	3.52	1.94	93.62	**2.902**
September	2.90	1.48	71.65	**2.150**
October	1.63	0.77	37.09	**1.150**
November	0.81	0.34	16.34	**490**
December	0.55	0.22	10.66	**330**
Annual	**2.78**	**1.46**	**70.29**	**25.656**

– Roofs 1&2:

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Assumptions:

- PV surface covered: 606,00 m^2 (303,00m^2 each roof)
- Mono-crystalline technology
- Power installed: 97 kWp (48,5 kWp each roof)
- No losses are considered both from the BOS (balance of the system) and from cast shadows

Figure 57. Roofs 1&2, Glasgow

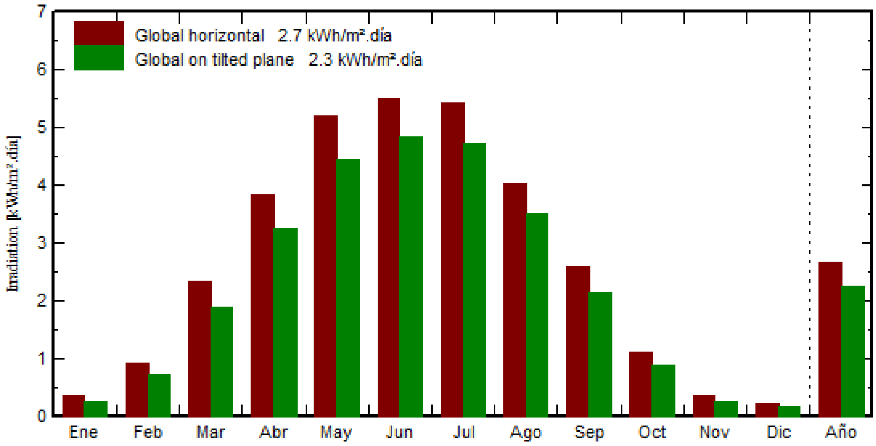

Figure 58. Irradiation analysis roofs 1&2, Glasgow

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

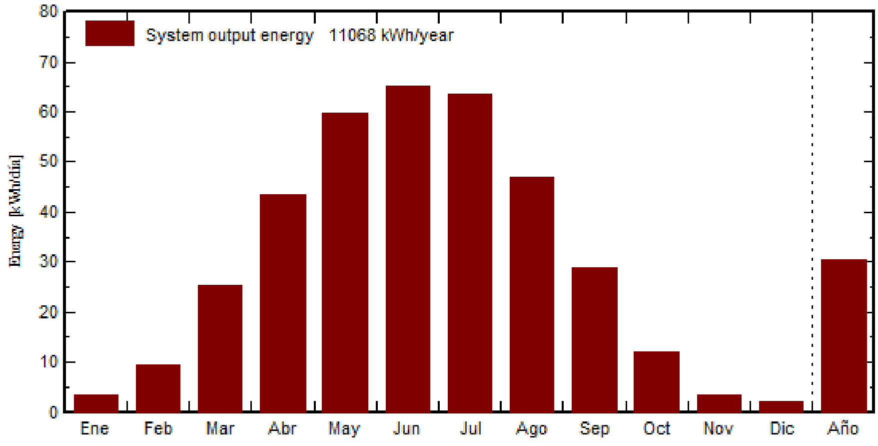

Figure 59. Energy kWh/year roofs 1&2, Glasgow

Roofs 1&2 analysis:

Total estimated production: **82,670 kWh/year**

Table 36. Roofs 1&2 estimated energy production, Glasgow

ROOF 1&2 * 303,00 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.69	0.69	28.26	**876**
February	1.25	1.25	51.07	**1.430**
March	2.50	2.50	101.7	**3.154**
April	4.21	4.21	171.5	**5.146**
May	5.09	5.09	207.3	**6.425**
Jun	5.44	5.44	221.7	**6.650**
July	4.69	4.69	191.2	**5.928**
August	3.52	3.52	143.3	**4.441**
September	2.90	2.90	118.0	**3.541**
October	1.63	1.63	66.50	**2.062**
November	0.81	0.81	33.14	**994**
December	0.55	0.55	22.21	**689**
Annual	**2.78**	**2.78**	**113.2**	**41.335**

** each one of the roofs*

– Roof 3:

Assumptions:

- PV surface covered: 160,97 m^2
- Mono-crystalline technology
- Power installed: 25.8 kWp
- No losses are considered both from the BOS (balance of the system) and from cast shadows

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Figure 60. Roof 3, Glasgow

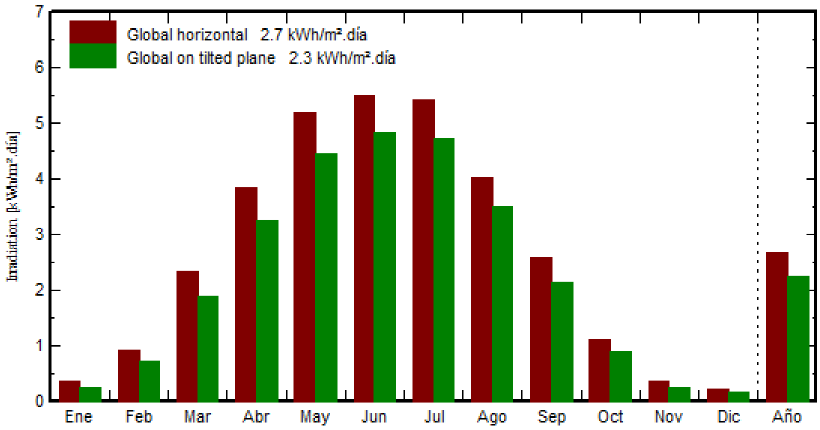

Figure 61. Irradiation analysis roof 3, Glasgow

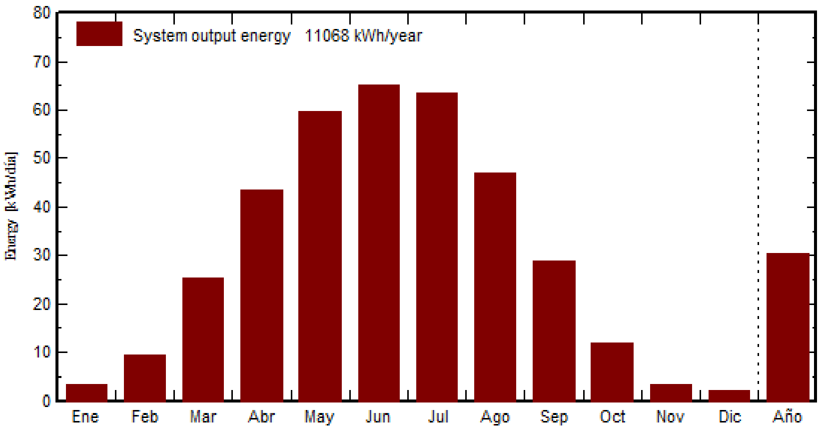

Figure 62. Energy kWh/year roof 3, Glasgow

Roof 3 analysis:

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Table 37. Roof 3 estimated energy production, Glasgow

ROOF 3 160,97 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.69	0.69	15.01	**465**
February	1.25	1.25	27.14	**760**
March	2.50	2.50	54.05	**1.676**
April	4.21	4.21	91.14	**2.734**
May	5.09	5.09	110.1	**3.414**
Jun	5.44	5.44	117.8	**3.533**
July	4.69	4.69	101.6	**3.150**
August	3.52	3.52	76.12	**2.360**
September	2.90	2.90	62.71	**1.881**
October	1.63	1.63	35.34	**1.095**
November	0.81	0.81	17.61	**528**
December	0.55	0.55	11.80	**366**
Annual	**2.78**	**2.78**	**60.17**	**21.963**

- **Building services system (BSS)**

Table 38. Building services system, Glasgow

Is there any **heating system**? If yes, please provide the brief introduction of heating system (energy source, power and capacity.), Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied heating system installed?	Heating system is natural gas LTHW boiler with seasonal efficiency of 0.95. Heat distributed through radiators. Heating set point of 21°C in office spaces and 18°C elsewhere.
Is there a **domestic hot water (DHW) system**? If yes, please provide the DHW system (energy source, power and capacity)	Yes
Is there an **air-conditioning system**? If yes, please provide the brief introduction of air-conditioning system (energy source, power and capacity) Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied cooling system installed?	No
Is there a **ventilation system**? If yes, please provide the brief introduction of ventilation system (energy source, power and ventilation rate, Is the ventilation	Two spaces have mechanical supply at 1.8 W/(l/s) supply specific fan power each. Three spaces have mechanical exhaust the 0.6 W/(l/s) exhaust specific fan power and 10 ac/hr extract flow rate. All office space and

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	some other spaces have natural ventilation only.
Is there a **renewable heat generation source**? If yes, please provide the brief introduction of renewable heat generation source (power and generation-storage capacity)	No
Is there a **renewable electricity generation source**? If yes, please provide the brief introduction of renewable electricity generation source (power and generation-storage capacity)	No

- **Control and management systems**

Table 39Control and management systems, Glasgow

Is there a **building management system (BMS) or control system** already installed? If yes, please provide a brief introduction of the building management system.	Sensors to record energy data

- **Structural performance**

Table 40. Structural performance, Glasgow

STRUCTURE	
Structure type (bearing wall, timber framing, structure of concrete floors and pillars, …)	
Distance between slabs (floors)	
Slab structure thickness	
Slab material properties.(e.g. Compressive strength, reinforcement, bulk density)	
Height (m)	
Floor dimension (length x width) (m)	

- **Local and aesthetic requirements**

Table 41. Local and aesthetic requirements, Glasgow

AESTHETICS

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Is there any local requirement about aesthetic aspects of the building? If yes, provide a brief introduction about how affect the building.	No

HERITAGE AND LANSCAPE CODES	
Is there any Code for the cultural heritage of the building? If yes, provide information, about how affect the building.	No

4. Virtual Building 2, Amsterdam

- **Thermal characteristics**

Virtual Building 2: Amsterdam

For the west and east façades of the virtual building in Amsterdam, the façade layout is composed of (1) double glass with aluminium frames (including ventilation grilles on top), (2) non-insulated Trespa (HLP) plate (under the windows), and (3) asbestos cladding.

For the north and south façades of the virtual building in Amsterdam, the façade layout consists of (1) concrete wall, and (2) brick wall.

Table 42. Thermal characteristics of the envelope, Amsterdam

FAÇADE 01 Thermal characteristics of the material				West Façade
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**	
layer 01	Double glass with aluminium frames, including ventilation grilles on top	0.1	Aluminium: 121; Glass: 0.96	
layer 02	Non-insulated Trespa (HLP) plate (under the windows)	0.01	0.2	
layer 03	Asbestos cladding	0.01	0.15	
FAÇADE 02 Thermal characteristics of the material				North Façade
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**	
layer 01	Concrete wall	0.2	0.4 - 0.7	
layer 02	Brick wall	0.12	0.6 -1.0	
FAÇADE 03 Thermal characteristics of the material				East Façade

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Layer	Material name	Thickness (m)	Conductivity (W/mK)
layer 01	Double glass with aluminium frames, including ventilation grilles on top	0.1	Aluminium: 121; Glass: 0.96
layer 02	Non-insulated Trespa (HLP) plate (under the windows)	0.01	0.2
layer 03	Asbestos cladding	0.01	0.15
FAÇADE 04 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Concrete wall	0.2	0.4 - 0.7
layer 02	Brick wall	0.12	0.6 -1.0

South Façade

ROOF Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	Concrete flat roof	0.275	0.4 - 0.7
layer 02	Asphalt roofing	0.16	0.75

- **Energy parameters**

Table 33. Energy parameters, Amsterdam

ENERGY			
Energy consumption for heating (kWh/m2 year)	27.95		
Energy consumption for cooling (kWh/m2 year)			
Total energy consumption for electrical appliances (kWh/year)	-		
Air Conditioned Floor Surface (m^2)	No applicable		
Air Conditioned Volume (m^3)	No applicable		
Façade Total surface (m^2)	1949.9		
Windows no.	442		
Window-To-Wall ratio (%)	38%		
Energy Cost (Gas & Electricity) (€/year)	gas	490m3 per household (55m2) annually = 390	Approx.

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		€/year (per household)	
	electricity	1537kWh per household (55m2) annually = 340 €/year (per household)	Approx.
clearance height overhead (m)	No applicable		
Climatic zone	Oceanic climate (Köppen Cfb)		
Compactness: Volume/External Surface V/A [m³/m2]	5.7		

- **Envelope characteristics**

Table 44. Envelope characteristics and estimation of the energy generated, Amsterdam

FAÇADE 01	
Orientation	West
Degrees*	255SW
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	777.4
windows no.	Residential: 180; Commercial: 33
Window-To-Wall ratio	54%
Surface_without windows (m^2)	357,60
Power installed kWp	57,20
U value W/(m^2 K)	2.8
g factor (-)	0.43
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	Residential: 0.875m x 1.70m (including 0.40m ventilation grid); Commercial: 1.70m x 2.80m

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Energy generated (kWh/year) PV (total surface without windows)	28038,00
Energy generated per m2. (kWh/year) ST	312,38
FAÇADE 02	
Orientation	North
Degrees	345NW
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	190
windows no.	3
Window-To-Wall ratio	7%
Surface_without windows (m2)	176,70
Power installed kWp	28,30
U value W/(m^2 K)	2.8
g factor (-)	0.43
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	Commercial: 1.70m x 2.80m
Energy generated (kWh/year) PV (total surface without windows)	20182,00
Energy generated per m2. (kWh/year) ST	153,4
FAÇADE 03	
Orientation	East
Degrees	75NE
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	792.5
windows no.	216
Window-To-Wall ratio	41%
Surface_without windows (m^2)	467,58
Power installed kWp	74,80

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U value W/(m² K)	2.8
g factor (-)	0.43
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	Residential: 0.875m x 1.70m (including 0.40m ventilation grid); Commercial: 1.70m x 2.80m
Energy generated (kWh/year) PV (total surface without windows)	45332,00
Energy generated per m2. (kWh/year) ST	238,28

FAÇADE 04	
Orientation	South
Degrees	165SE
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m²)	190
windows no.	10
W+H24:K24indow-To-Wall ratio	24%
Surface_without windows (m²)	144,40
Power installed kWp	23,10
U value W/(m² K)	2.8
g factor (-)	0.43
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	Commercial: 1.70m x 2.80m
Energy generated (kWh/year) PV (total surface without windows)	6622,00
Energy generated per m2. (kWh/year) ST	346,47

ROOF	
Orientation	Flat roof
Degrees	Flat roof
Structure (Light-Medium-Heavy)	Medium
External or Internal	External

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Surface (m^2)	744.7
windows no.	No applicable
Window-To-Wall ratio	No applicable
Power installed kWp	119,00
U value W/(m^2 K)	No applicable
g factor (-)	No applicable
Shaded by other buildings? (YES or NOT)	No
Average size of windows. Width by Height (m)	No applicable
Energy generated (kWh/year) PV (total surface without windows)	98299,00
Energy generated per m2. (kWh/year) ST	98299

*Degrees. Not only indicate north, south, east and west, but also consider the degrees. According to this scale; 0º for north, 90 east, 180º south, 270º west.

- **Estimation of PV energy production – Preliminary results**

Façade Assumptions:

- North, South, West and East façade orientations + Roof
- Mono-crystalline technology
- Power installed 317,40 kWp

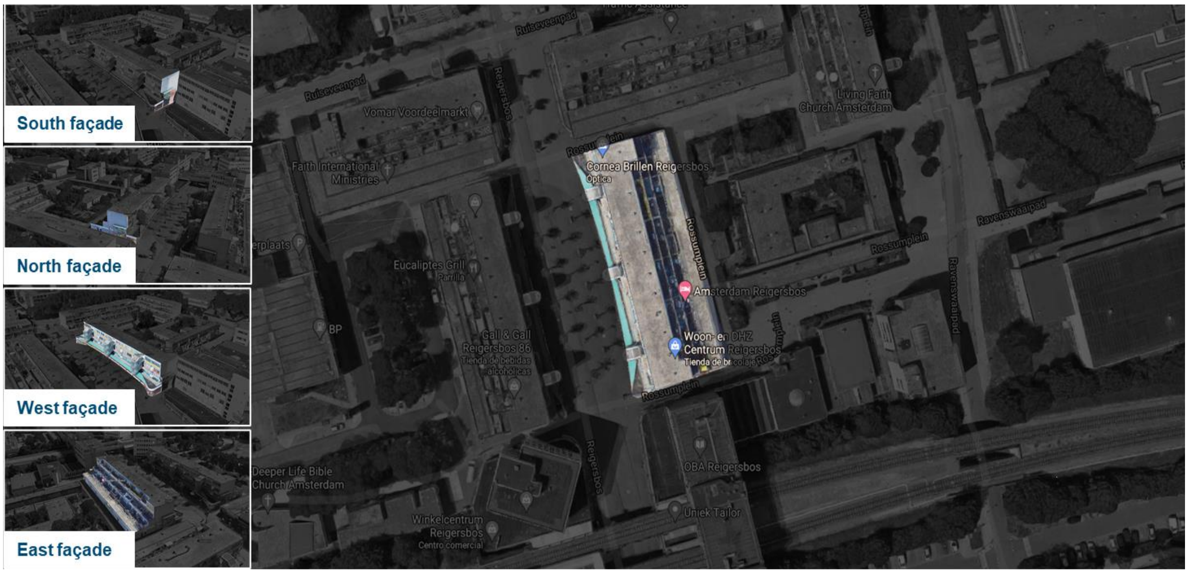

Figure 63. General assumptions Virtual building 2, Amsterdam

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- North façade:

Assumptions:

- Surface: 190,00 m^2
- Window-to-wall ratio: 7%
- PV surface covered: 176,70 m^2
- Mono-crystalline technology
- Power installed: 28,30 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 64. North façade, Amsterdam

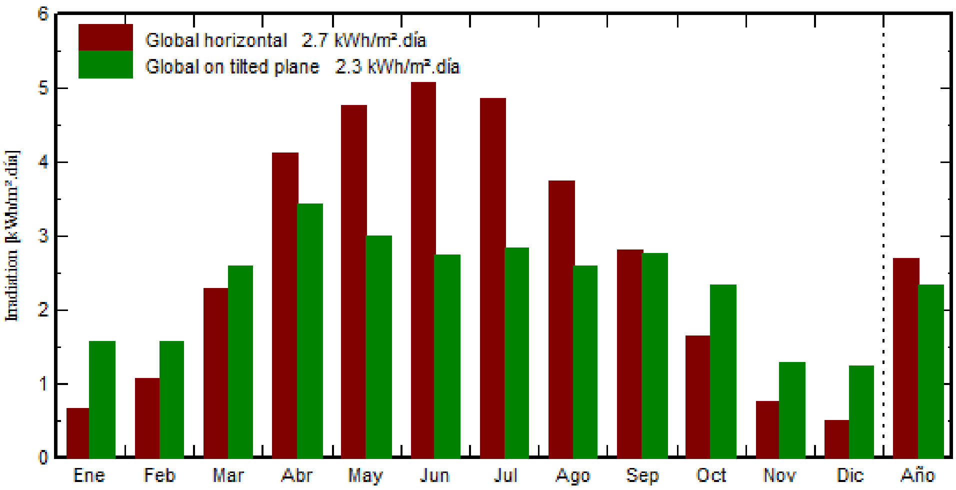

Figure 65. Irradiation analysis north façade, Amsterdam

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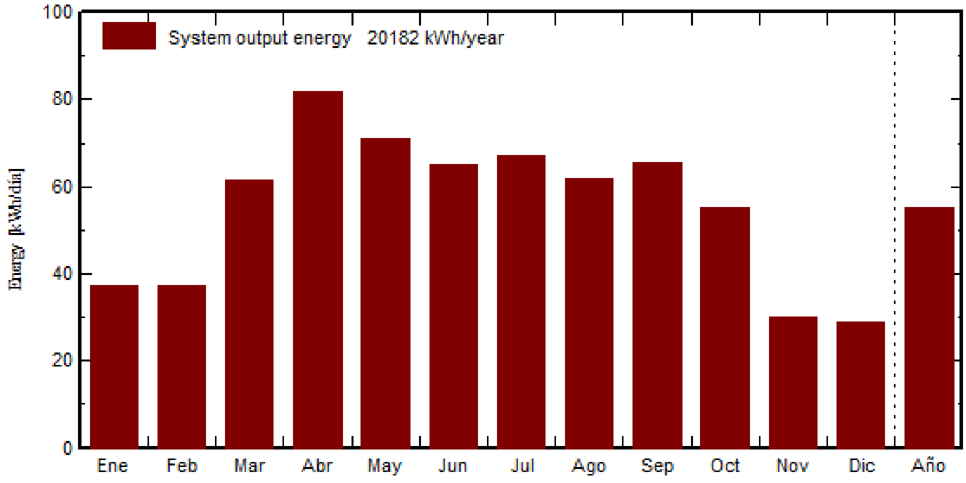

Figure 66. Energy kWh/year north façade, Amsterdam

North façade analysis:

Table 45. North façade estimated energy production, Amsterdam

NORTH façade 176,70 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.65	1.57	37.31	**1.157**
February	1.07	1.57	37.33	**1.045**
March	2.27	2.59	61.59	**1.909**
April	4.12	3.44	81.67	**2.450**
May	4.76	2.99	71.01	**2.201**
Jun	5.07	2.75	65.22	**1.957**
July	4.86	2.82	67.00	**2.077**
August	3.73	2.60	61.80	**1.916**
September	2.80	2.75	65.29	**1.959**
October	1.63	2.32	55.14	**1.709**
November	0.75	1.27	30.09	**903**
December	0.48	1.22	29.02	**900**
Annual	**2.69**	**2.33**	**55.29**	**20.182**

South façade:

Assumptions:

- Surface: 190,00 m^2
- Window-to-wall ratio: 24%
- PV surface covered: 144,40 m^2
- Mono-crystalline technology
- Power installed: 23,10 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 67. South façade, Amsterdam

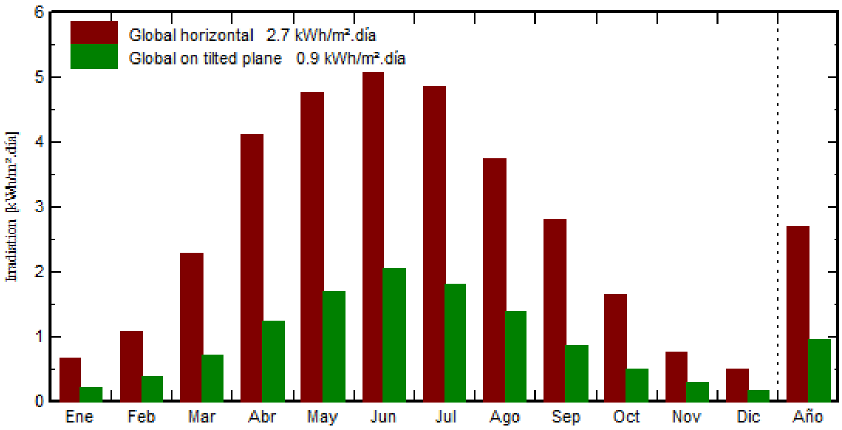

Figure 68. Irradiation analysis south façade, Amsterdam

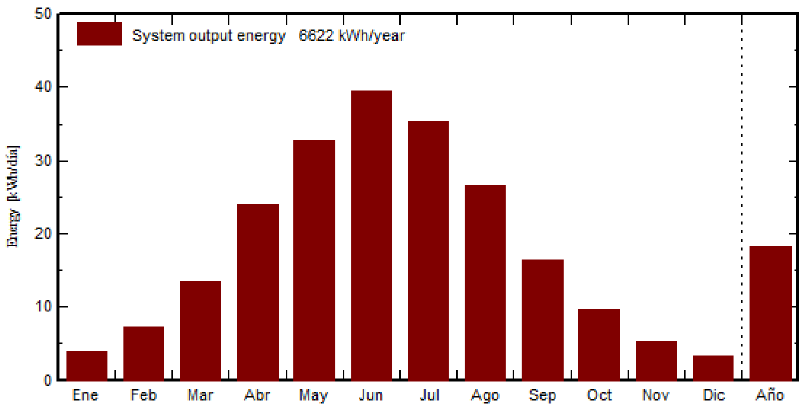

Figure 69. Energy kWh/year south façade, Amsterdam

South façade analysis:

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Table 46. South façade estimated energy production, Amsterdam

SOUTH façade 144,00 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.65	0.20	3.94	**122**
February	1.07	0.37	7.21	**202**
March	2.27	0.69	13.48	**418**
April	4.12	1.24	24.00	**720**
May	4.76	1.68	32.67	**1.013**
Jun	5.07	2.03	39.48	**1.184**
July	4.86	1.81	35.22	**1.092**
August	3.73	1.37	26.53	**823**
September	2.80	0.85	16.44	**493**
October	1.63	0.49	9.56	**296**
November	0.75	0.27	5.31	**159**
December	0.48	0.17	3.23	**100**
Annual	2.69	0.93	18.14	6.622

- West façade:

Assumptions:

- Surface: 744,40 m^2
- Window-to-wall ratio: 54%
- PV surface covered: 357,60 m^2
- Mono-crystalline technology
- Power installed: 57,20 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

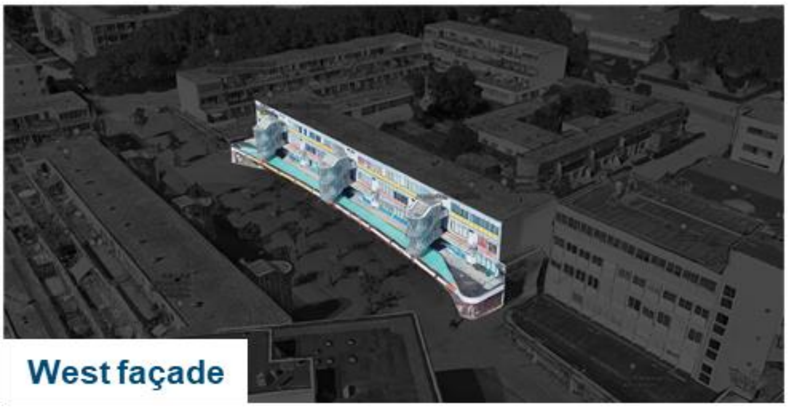

Figure 70. West façade, Amsterdam

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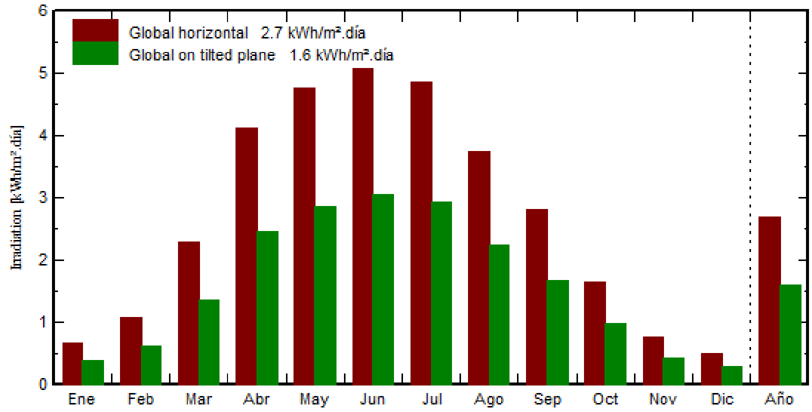

Figure 71. Irradiation analysis west façade, Amsterdam

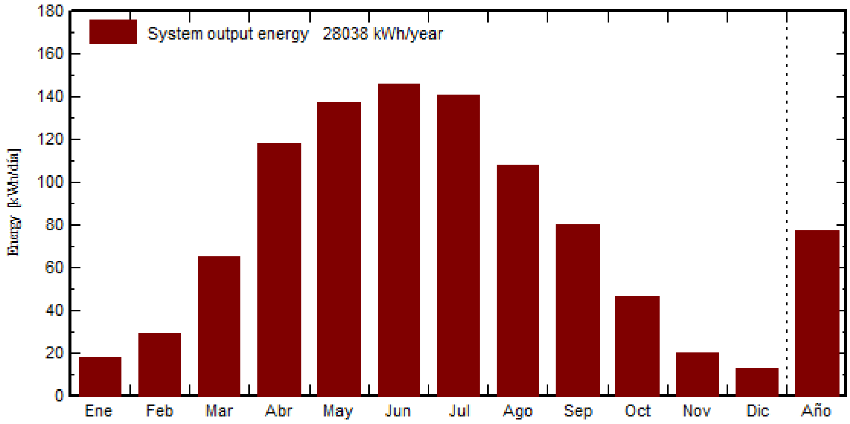

Figure 72. Energy kWh/year west façade, Amsterdam

West façade analysis:

Table 47. West façade estimated energy production, Amsterdam

WEST façade 357,60 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.65	0.36	17.53	**544**
February	1.07	0.61	29.30	**820**
March	2.27	1.34	64.49	**1.999**
April	4.12	2.45	117.6	**3.528**
May	4.76	2.85	136.8	**4.242**
Jun	5.07	3.04	146.0	**4.380**
July	4.86	2.93	140.9	**4.369**
August	3.73	2.24	107.7	**3.339**
September	2.80	1.66	79.60	**2.388**
October	1.63	0.96	46.23	**1.433**
November	0.75	0.42	19.96	**599**
December	0.48	0.27	12.76	**396**
Annual	**2.69**	**1.60**	**76.82**	**28.038**

– East façade:

Assumptions:

- Surface: 792,50 m^2
- Window-to-wall ratio: 41%
- PV surface covered: 467,58 m^2
- Mono-crystalline technology
- Power installed: 74,80 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

Figure 73. East façade, Amsterdam

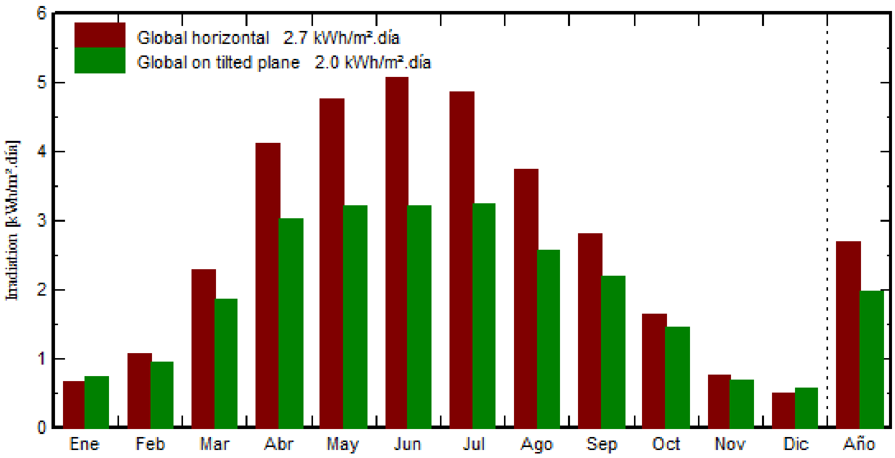

Figure 74. Irradiation analysis east façade, Amsterdam

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

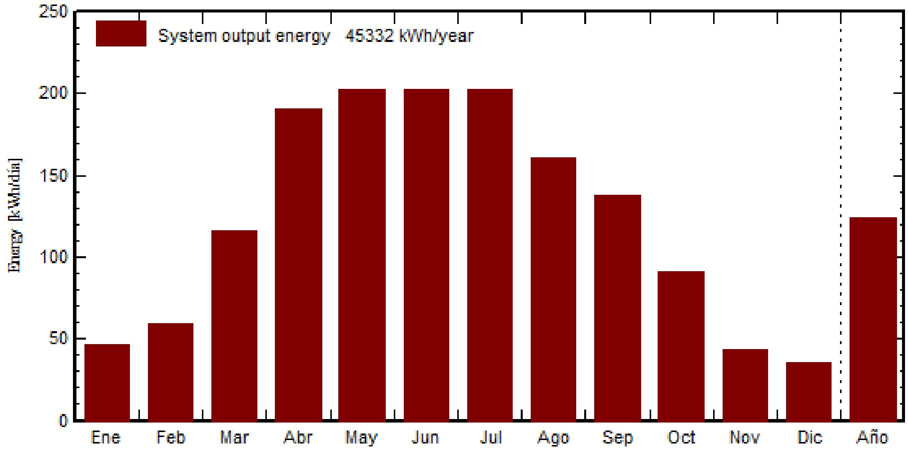

Figure 75. Energy kWh/year east façade, Amsterdam

East façade analysis:

Table 48. East façade estimated energy production, Amsterdam

EAST façade 357,60 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	0.65	0.73	46.17	**1.431**
February	1.07	0.95	59.56	**1.668**
March	2.27	1.84	115.8	**3.591**
April	4.12	3.03	190.6	**5.717**
May	4.76	3.21	202.1	**6.264**
Jun	5.07	3.22	202.4	**6.071**
July	4.86	3.22	202.7	**6.283**
August	3.73	2.56	160.7	**4.982**
September	2.80	2.19	137.4	**4.122**
October	1.63	1.45	90.86	**2.817**
November	0.75	0.69	43.55	**1.306**
December	0.48	0.55	34.86	**1.081**
Annual	**2.69**	**1.98**	**124.2**	**45.332**

- Roof:

Assumptions:

- PV surface covered: 744,70 m^2
- Mono-crystalline technology
- Power installed: 119,00 kWp
- No losses are being considered both from the BOS (balance of the system) and from cast shadows

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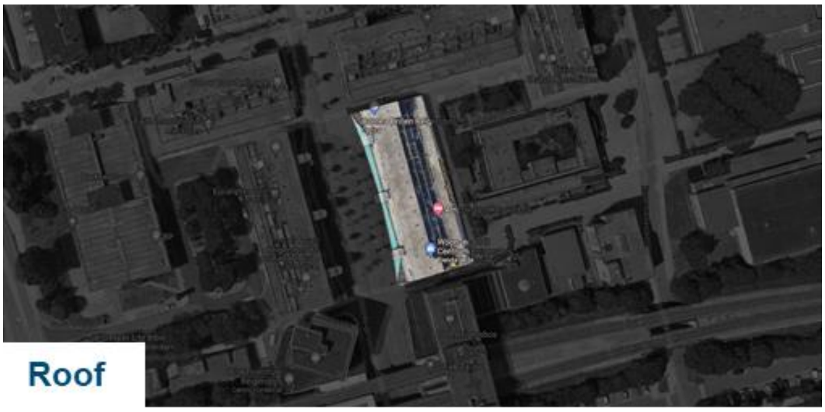

Figure 76. Roof, Amsterdam

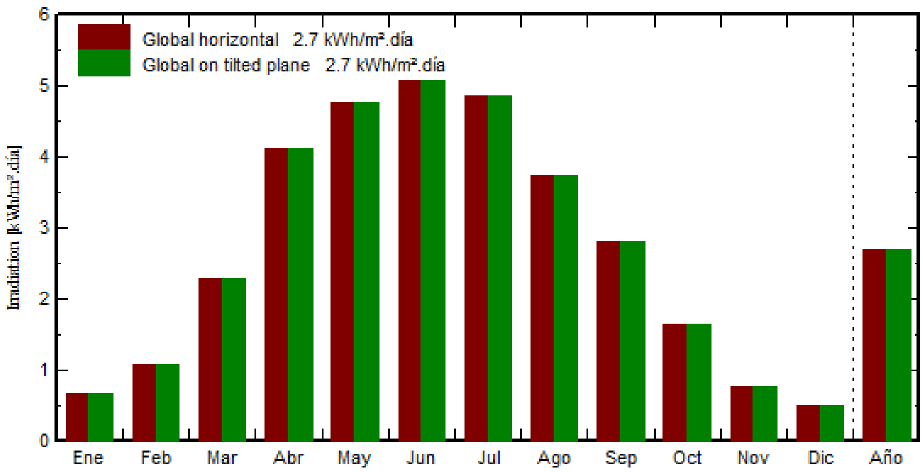

Figure 77. Irradiation analysis roof, Amsterdam

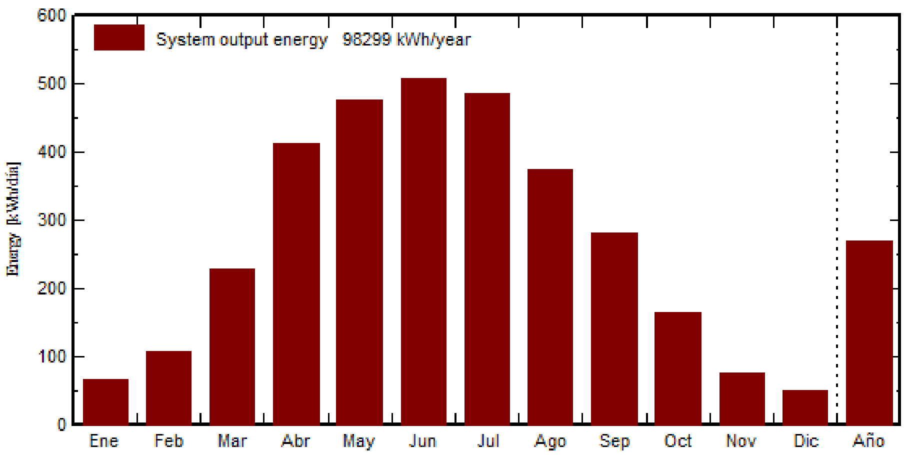

Figure 78. Energy kWh/year roof, Amsterdam

Roof analysis:

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ROOF 744,70 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	0.65	0.65	65.25	**2.023**
February	1.07	1.07	106.9	**2.994**
March	2.27	2.27	227.7	**7.060**
April	4.12	4.12	412.3	**12.368**
May	4.76	4.76	476.2	**14.762**
Jun	5.07	5.07	507.4	**15.222**
July	4.86	4.86	486.5	**15.081**
August	3.73	3.73	373.7	**11.586**
September	2.80	2.80	280.7	**8.422**
October	1.63	1.63	162.8	**5.047**
November	0.75	0.75	74.79	**2.244**
December	0.48	0.48	48.14	**1.492**
Annual	**2.69**	**2.69**	**269.3**	**98.299**

Table 49. Roof estimated energy production, Amsterdam

- **Building services system (BSS)**

Table 50. Building services system, Amsterdam

BUILDING SERVICES SYSTEM	
Is there any **heating system**? If yes, please provide the brief introduction of heating system (energy source, power and capacity.), Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied heating system installed?	The heating consists of an individual central heating system per house (CH boiler), with flue gas discharge per house on the facade. Depending on the layout of the house, the central heating boiler is located at the front of the house, with flue gas outlet above the gallery, just outside the rising facade, or at the rear, with flue gas outlet above the balconies.
Is there a **domestic hot water (DHW) system**? If yes, please provide the DHW system (energy source, power and capacity)	CH boiler
Is there an **air-conditioning system**? If yes, please provide the brief introduction of air-conditioning system (energy source, power and capacity) Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied cooling system installed?	no

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Is there a **ventilation system**? If yes, please provide the brief introduction of ventilation system (energy source, power and ventilation rate, Is the ventilation	The apartments are ventilated by exhaust air via joint ducts with roof ventilator per shaft. The air supply via window grilles in the front and rear (it is expected that these are often closed). As a result, there are many damp complaints in the homes.
Is there a **renewable heat generation source**? If yes, please provide the brief introduction of renewable heat generation source (power and generation-storage capacity)	no
Is there a **renewable electricity generation source**? If yes, please provide the brief introduction of renewable electricity generation source (power and generation-storage capacity)	no

- **Control and management systems**

Table 51. Control and management systems, Amsterdam

Is there a **building management system (BMS) or control system** already installed? If yes, please provide a brief introduction of the building management system.	no

- **Structural performance**

Table 52. Structural performance, Amsterdam

STRUCTURE	
Structure type (bearing wall, timber framing, structure of concrete floors and pillars, …)	Bearing walls
Distance between slabs (floors)	2.52m
Slab structure thickness	0.27m
Slab material properties.(e.g. Compressive strength, reinforcement, bulk density)	Concrete
Height (m) (Average)	2.52m
Floor dimension (length x width) (m) (Average)	65.44m x 11.38m

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- **Local and aesthetic requirements**

Table 53. Local and aesthetic requirements, Amsterdam

AESTHETICS	
Is there any local requirement about aesthetic aspects of the building? If yes, provide a brief introduction about how affect the building.	Under the windows, the facade is closed with a non-insulated trespa plate. Some facade parts are fitted with asbestos cladding.

HERITAGE AND LANSCAPE CODES	
Is there any Code for the cultural heritage of the building? If yes, provide information, about how affect the building.	To renew the facades, permission is required from the architect Cees van Dam.

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5. Virtual Building 3, Milano

Thermal characteristics

Virtual Building 3: Milano

The façade layout of the Milano building is composed of (1) plaster, (2) brick masonry, (3) cavity, (4) brick masonry, and (5) plaster.

Furthermore, the roof layout consists of (1) plaster, (2) brick slab, and (3) mat.

Table 54. Thermal characteristics of the envelope, Milano

FAÇADE 01 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.015	0.700
layer 02	brick masonry	0.080	0.360
layer 03	cavity	0.150	0.833
layer 04	brick masonry	0.120	0.360
layer 05	plaster	0.015	0.700
FAÇADE 02 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.015	0.700
layer 02	brick masonry	0.080	0.360
layer 03	cavity	0.150	0.833
layer 04	brick masonry	0.120	0.360
layer 05	plaster	0.015	0.700
FAÇADE 03 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.015	0.700
layer 02	brick masonry	0.080	0.360
layer 03	cavity	0.150	0.833
layer 04	brick masonry	0.120	0.360
layer 05	plaster	0.015	0.700
FAÇADE 04 Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.015	0.700
layer 02	brick masonry	0.080	0.360

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layer 03	cavity	0.150	0.833
layer 04	brick masonry	0.120	0.360
layer 05	plaster	0.015	0.700
ROOF Thermal characteristics of the material			
Layer	**Material name**	**Thickness (m)**	**Conductivity (W/mK)**
layer 01	plaster	0.015	0.700
layer 02	brick slab	0.180	0.660
layer 03	mat	0.070	1.490
layer 04			
layer 05			

- **Energy parameters**

Table 55. Energy parameters, Milano

ENERGY PARAMETERS	
Energy consumption (kWh/m^2 year)	183.97
Air Conditioned Floor Surface (m^2)	3706
Air Conditioned Volume (m^3)	11118
Façade Total surface (m^2)	3380
Windows no.	245
Window-To-Wall ratio (%)	16%
Energy Cost (Gas & Electricity) (€/year)	gas
	electricity
clearance height overhead (m)	42.9
Climatic zone	E
Compactness. V/A [m^3/m2]	2.49

- **Envelope characteristics**

Table 46. Envelope characteristics and estimation of the energy generated, Milano

FAÇADE 01	
Orientation	North-East
Degrees*	45
Structure (Light-Medium-Heavy)	Medium

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External or Internal	External
Surface (m^2)	939
PV Surface (m2)	798.15
Power installed kWp	108
windows no.	42
Window-To-Wall ratio	15%
U value W/(m^2 K)	1.054
g factor (-)	
Shaded by other buildings? (YES or NOT)	no
Average size of windows. Width by Height (m)	1,3 x 2,05
Energy generated (kWh/year) PV (total surface without windows)	45239
Energy generated per m2. (kWh/year) ST	244,04
FAÇADE 02	
Orientation	Nord-West
Degrees	315
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	1056
PV Surface (m2)	929,28
Power installed kWp	110
windows no.	61
Window-To-Wall ratio	12%
U value W/(m^2 K)	1.054
g factor (-)	
Shaded by other buildings? (YES or NOT)	yes
Average size of windows. Width by Height (m)	1,3 x 2,05
Energy generated (kWh/year) PV (total surface without windows)	45999
Energy generated per m2. (kWh/year) ST	246,66
FAÇADE 03	
Orientation	South-East

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Degrees	135
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	815
PV Surface (m2)	684,6
Power installed kWp	149
windows no.	73
Window-To-Wall ratio	16%
U value W/(m^2 K)	1.054
g factor (-)	
Shaded by other buildings? (YES or NOT)	yes
Average size of windows. Width by Height (m)	1,3 x 2,05
Energy generated (kWh/year) PV (total surface without windows)	105837
Energy generated per m2. (kWh/year) ST	389,21
FAÇADE 04	
Orientation	South-West
Degrees	225
Structure (Light-Medium-Heavy)	Medium
External or Internal	External
Surface (m^2)	826
PV Surface (m2)	677,32
Power installed kWp	128
windows no.	54
Window-To-Wall ratio	18%
U value W/(m^2 K)	1.054
g factor (-)	
Shaded by other buildings? (YES or NOT)	no
Average size of windows. Width by Height (m)	1,3 x 2,05
Energy generated (kWh/year) PV (total surface without windows)	91307

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Energy generated per m2. (kWh/year) ST	402,81
ROOF	
Orientation	
Degrees	
Structure (Light-Medium-Heavy)	Medium
External or Internal	internal
Surface (m^2)	410
PV Surface (m2)	410
Power installed kWp	65,6
windows no.	
Window-To-Wall ratio	0%
U value W/(m^2 K)	1.848
g factor (-)	
Shaded by other buildings? (YES or NOT)	
Average size of windows. Width by Height (m)	

On the roof the panels are south oriented on 35 degrees angle

Energy generated (kWh/year) PV (total surface without windows)	62052
Energy generated per m2. (kWh/year) ST	613,92

*Degrees. Not only indicate north, south, east and west, but also consider the degrees. According to this scale; 0º for north, 90 east, 180º south, 270º west.

Note: All data from Camel Solar are based on software T*SOL 2018, regarding the weather conditions from Meteo Syn for Milano, Italy with yearly solar radiation of 1125.699 kWh/m^2.

- **Estimation of PV energy production – Preliminary results**

Façade assumptions:

- North, South, West, and East orientations
- PV surface covered 3100 m^2
- Mono-crystalline technology
- Power installed xxx kWp

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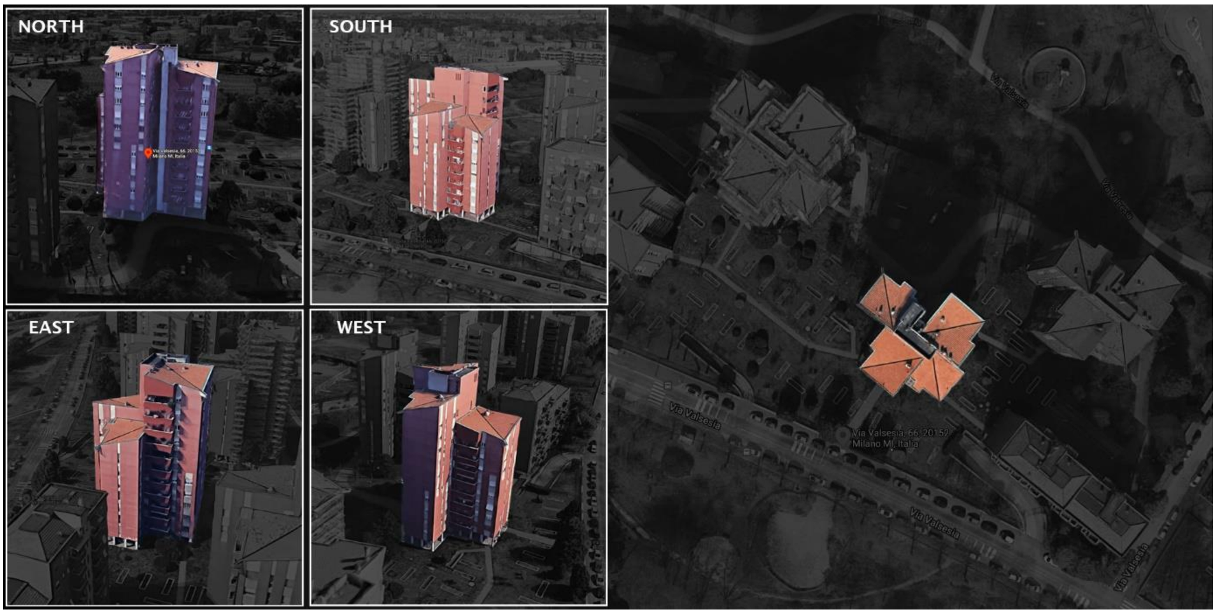
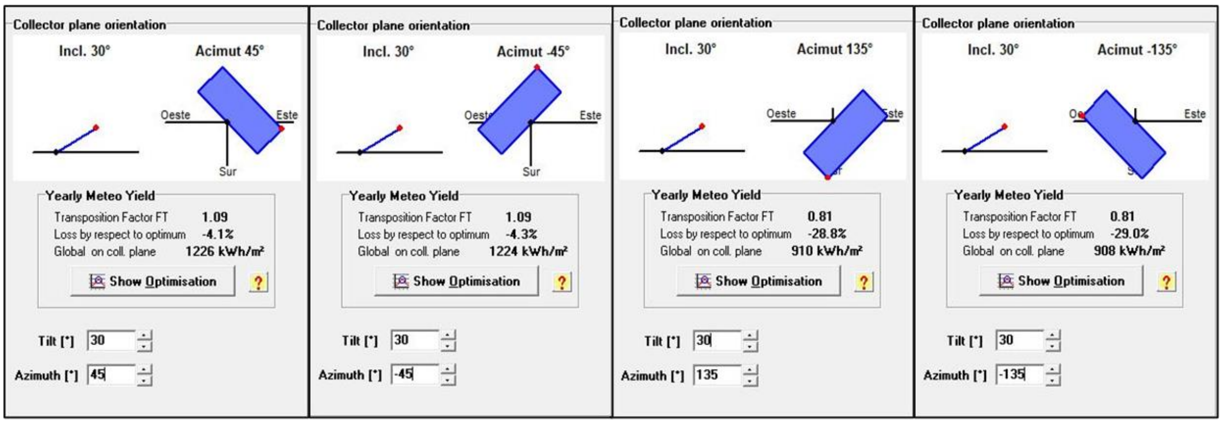


Figure 79. General assumptions virtual building 3, Milano



FACADE 01		FACADE 02		FACADE 03		FACADE 04	
Orientation	Nord-Est	Orientation	Nord-Ovest	Orientation	Sud-Est	Orientation	Sud-Ovest
Degrees*	45	Degrees	315 (-45)	Degrees	135	Degrees	225 (-135)
	South-West		South-East		North-West		North-East

Figure 80. Clarifications virtual building 3, Milano

– North-east façade:

Assumptions:

- Surface: 939,00 m^2
- Window to wall ratio: 15%
- PV surface covered: 799,15 m^2
- Mono-crystalline technology

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- Power installed: 128 kWp

No losses are considered both from the BOS (balance of the system) and from cast shadows

Figure 81. North-east façade, Milano

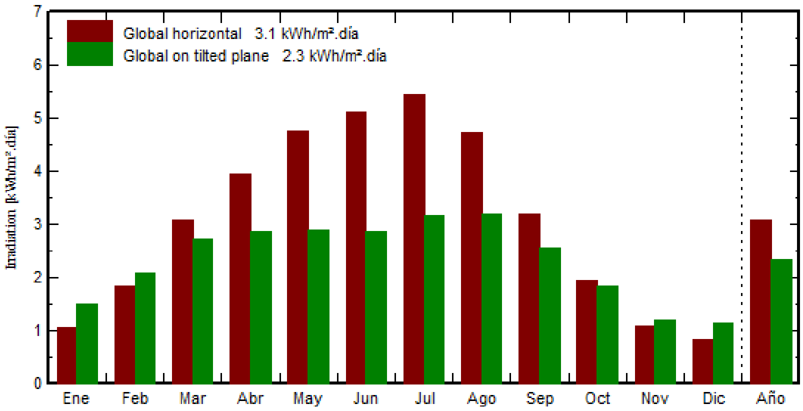

Figure 82. Irradiation analysis north-east façade, Milano

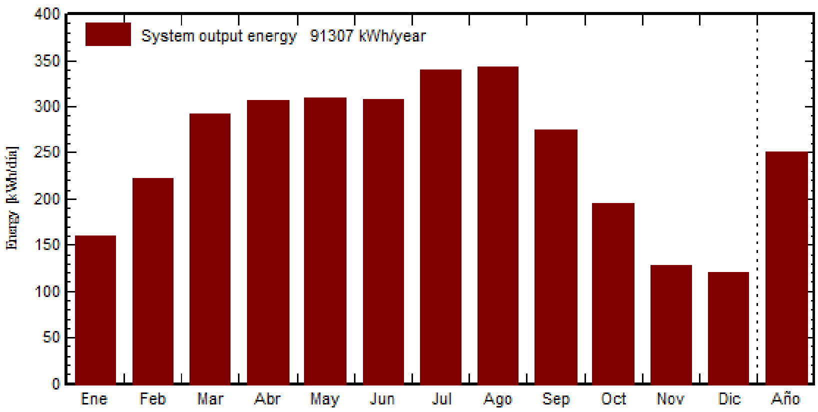

Figure 83. Energy kWh/year north-east façade, Milano

North-east façade analysis:

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Table 57: North-east façade estimated energy production, Milano

NORTH-EAST façade 788,15 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.04	1.50	160.5	**4.975**
February	1.82	2.06	221.5	**6.202**
March	3.08	2.72	292.3	**9.060**
April	3.95	2.86	306.7	**9.202**
May	4.76	2.89	310.1	**9.612**
Jun	5.10	2.86	307.4	**9.223**
July	5.45	3.17	339.8	**10.534**
August	4.72	3.20	343.0	**10.632**
September	3.18	2.56	274.7	**8.240**
October	1.93	1.82	194.8	**6.038**
November	1.06	1.20	128.6	**3.857**
December	0.83	1.12	120.4	**3.732**
Annual	**3.08**	**2.33**	**250.2**	**91.307**

– North-west façade:

Assumptions:

- Surface: 1056,00 m^2
- Window to wall ratio: 12%
- PV surface covered: 929,28 m^2
- Mono-crystalline technology
- Power installed: 149 kWp

No losses are considered both from the BOS (balance of the system) and from cast shadows

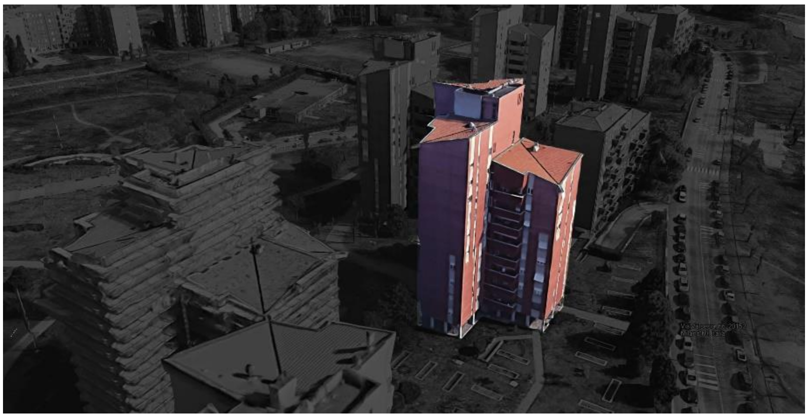

Figure 84: North-west façade, Milano

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

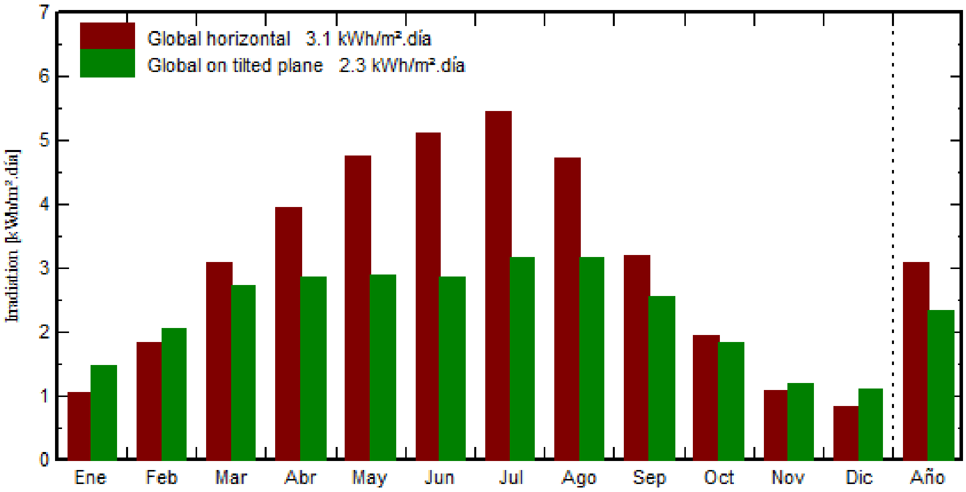

Figure 85. Irradiation analysis north-west façade, Milano

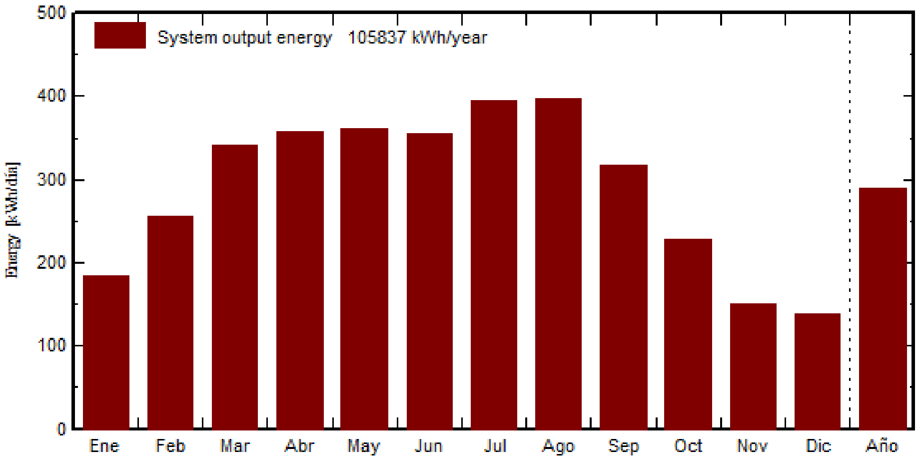

Figure 86. Energy kWh/year north-west façade, Milano

North-west façade analysis:

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement nº 958445

Table 58. North-west façade estimated energy production, Milano

NORTH-WEST façade 929,28 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.04	1.48	184.5	**5.721**
February	1.82	2.04	255.1	**7.143**
March	3.08	2.72	340.3	**10.549**
April	3.95	2.86	357.2	**10.715**
May	4.76	2.89	361.1	**11.193**
Jun	5.10	2.85	355.5	**10.666**
July	5.45	3.17	395.7	**12.265**
August	4.72	3.17	396.4	**12.290**
September	3.18	2.54	316.9	**9.507**
October	1.93	1.82	226.8	**7.031**
November	1.06	1.20	149.7	**4.491**
December	0.83	1.10	137.7	**4.267**
Annual	**3.08**	**2.32**	**290.0**	**105.837**

– South-east façade:

Assumptions:

- Surface: 815,00 m^2
- Window to wall ratio: 16%
- PV surface covered: 686,60 m^2
- Mono-crystalline technology
- Power installed: 110 kWp

No losses are considered both from the BOS (balance of the system) and from cast shadows

Figure 87: South-east façade, Milano

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

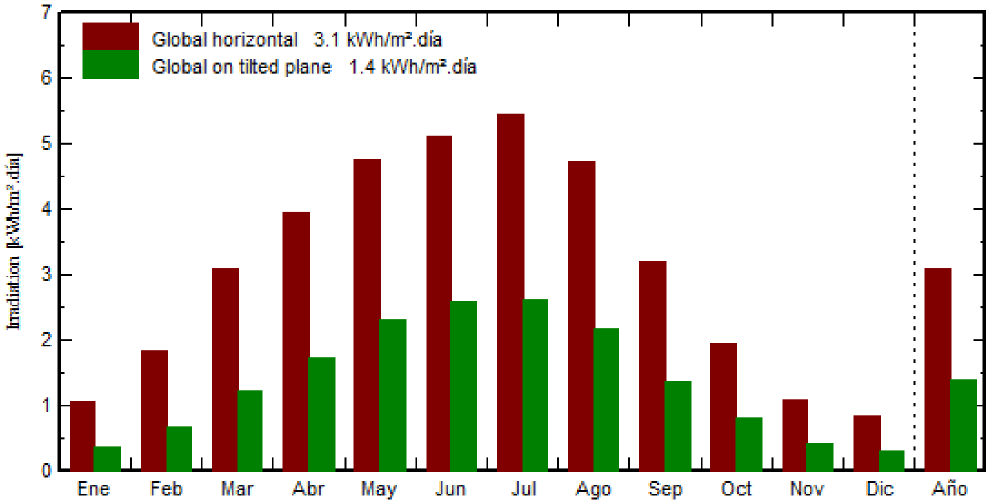

Figure 88. Irradiation analysis south-east façade, Milano

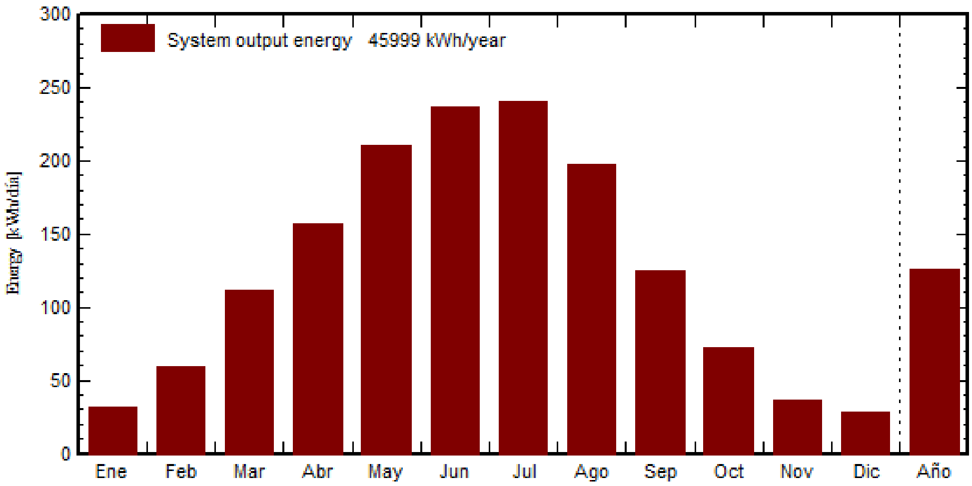

Figure 89. Energy kWh/year south-east façade, Milano

South-east façade analysis:

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Table 59. South-east façade estimated energy production, Milano

SOUTH-EAST façade 684,6 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.04	0.34	31.29	**970**
February	1.82	0.65	59.62	**1.669**
March	3.08	1.22	112.1	**3.474**
April	3.95	1.71	157.4	**4.721**
May	4.76	2.29	210.8	**6.535**
Jun	5.10	2.57	236.8	**7.105**
July	5.45	2.61	240.0	**7.438**
August	4.72	2.15	197.8	**6.133**
September	3.18	1.36	124.9	**3.747**
October	1.93	0.78	71.87	**2.228**
November	1.06	0.40	36.99	**1.110**
December	0.83	0.30	28.03	**869**
Annual	**3.08**	**1.37**	**126.0**	**45.999**

– South-west façade:

Assumptions:

- Surface: 826,00 m²
- Window to wall ratio: 18%
- PV surface covered: 677,32 m²
- Mono-crystalline technology
- Power installed: 108 kWp

No losses are considered both from the BOS (balance of the system) and from cast shadows

Figure 90: South-west façade, Milano

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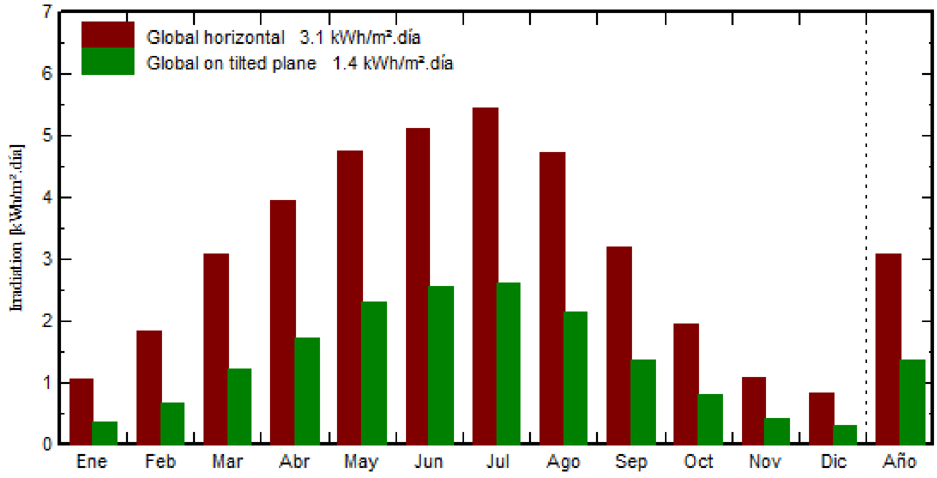

Figure 91. Irradiation analysis south-west façade, Milano

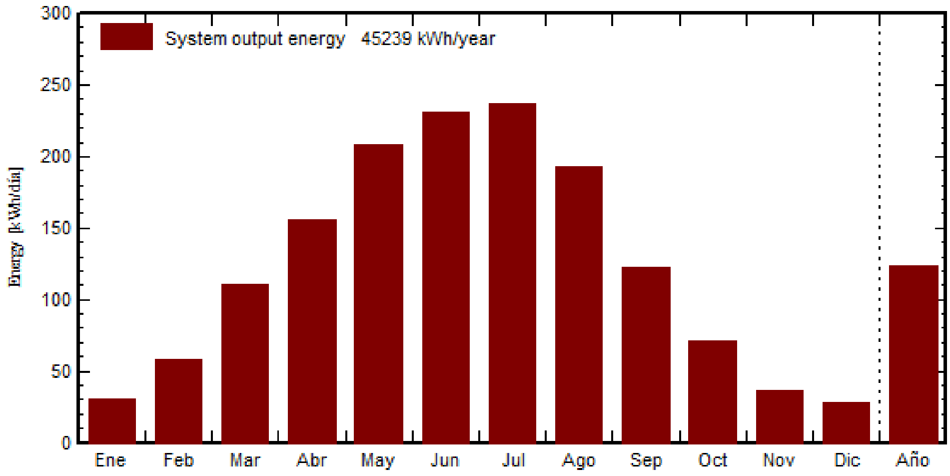

Figure 92. Energy kWh/year south-west façade, Milano

South-west façade analysis:

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Table 60: South-west façade estimated energy production, Milano

SOUTH-WEST façade 677,32 sqm	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh/year
January	1.04	0.34	30.59	**948**
February	1.82	0.64	58.47	**1.637**
March	3.08	1.22	110.9	**3.437**
April	3.95	1.71	155.7	**4.671**
May	4.76	2.29	208.6	**6.466**
Jun	5.10	2.54	230.9	**6.926**
July	5.45	2.61	237.4	**7.359**
August	4.72	2.12	192.9	**5.981**
September	3.18	1.34	121.9	**3.656**
October	1.93	0.78	71.11	**2.204**
November	1.06	0.40	36.59	**1.098**
December	0.83	0.30	27.57	**855**
Annual	**3.08**	**1.36**	**123.9**	**45.239**

– Roof:

Assumptions:

- PV surface covered: 410,00 m^2
- Mono-crystalline technology
- No tilt
- Power installed: 65,60 kWp

Figure 93: Roof, Milano

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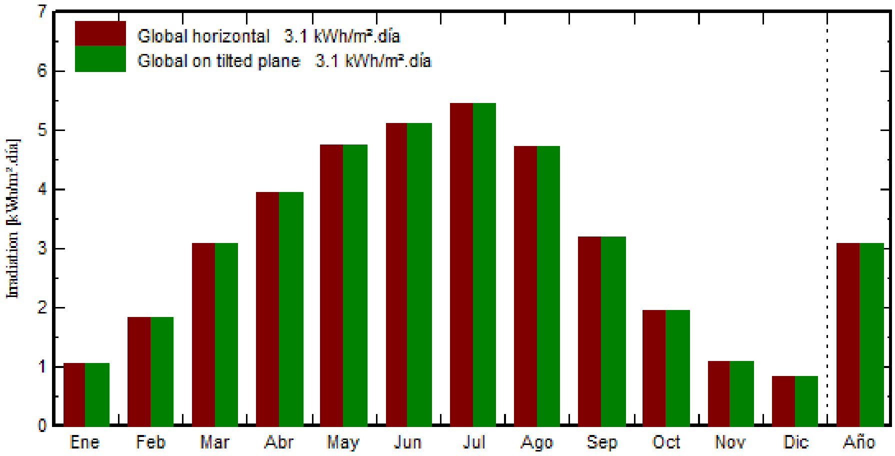

Figure 94. Irradiation analysis Roof, Milano

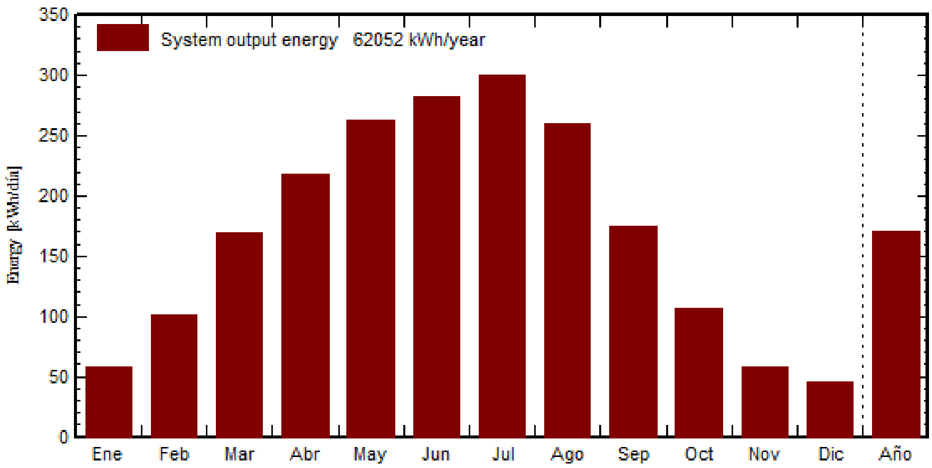

Figure 95. Energy kWh/year Roof, Milano

Table 61: Roof estimated energy production, Milano

Roof façade 410,00 sqm	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh/year
January	1.04	1.04	57.44	**1.781**
February	1.82	1.82	100.6	**2.817**
March	3.08	3.08	169.7	**5.259**
April	3.95	3.95	217.6	**6.528**
May	4.76	4.76	262.3	**8.132**
Jun	5.10	5.10	281.4	**8.441**
July	5.45	5.45	300.2	**9.306**
August	4.72	4.72	260.2	**8.066**
September	3.18	3.18	175.1	**5.254**
October	1.93	1.93	106.3	**3.297**
November	1.06	1.06	58.44	**1.753**
December	0.83	0.83	45.71	**1.417**
Annual	**3.08**	**3.08**	**170.0**	**62.052**

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- **Building services system (BSS)**

Table 62. Building services system, Milano

BUILDING SERVICES SYSTEM	
Is there any **heating system**? If yes, please provide the brief introduction of heating system (energy source, power and capacity.), Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied heating system installed?	There is a central heating system with 3 generators, average power 1126 kw. The 3 boilers serve the whole super condominium consisting of 6 buildings. The energy carrier used is methane gas.
Is there a **domestic hot water (DHW) system**? If yes, please provide the DHW system (energy source, power and capacity)	The production of domestic hot water is autonomous for each apartment
Is there an **air-conditioning system**? If yes, please provide the brief introduction of air-conditioning system (energy source, power and capacity) Is there an individually controlled (e.g. one thermostat per office/apartment) but centrally supplied cooling system installed?	Some apartments have an air conditioning system. The system consists of an outdoor unit and split
Is there a **ventilation system**? If yes, please provide the brief introduction of ventilation system (energy source, power and ventilation rate, Is the ventilation	NO
Is there a **renewable heat generation source**? If yes, please provide the brief introduction of renewable heat generation source (power and generation-storage capacity)	NO

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Is there a **renewable electricity generation source**? If yes, please provide the brief introduction of renewable electricity generation source (power and generation-storage capacity)	NO

- **Control and management systems**

Table 63. Control and management systems, Milano

Is there a **building management system (BMS) or control system** already installed? If yes, please provide a brief introduction of the building management system.	NO

- **Structural performance**

Table 64. Structural performance, Milano

STRUCTURE	
Structure type (bearing wall, timber framing, structure of concrete floors and pillars, …)	structure of concrete floors and pillars
Distance between slabs (floors)	3 m
Slab structure thickness	30 cm
Slab material properties.(e.g. Compressive strength, reinforcement, bulk density)	
Height (m)	42.9
Floor dimension (length x width) (m)	10 x 10

- **Local and aesthetic requirements**

Table 65. Local and aesthetic requirements, Milano

AESTHETICS	
Is there any local requirement about aesthetic aspects of the building? If yes, provide a brief introduction about how affect the building.	Building submitted to the opinion of the landscape commission

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HERITAGE AND LANSCAPE CODES	
Is there any Code for the cultural heritage of the building? If yes, provide information, about how it affects the building.	D. Lgs. 22 gennaio 2004 n.42 Parte III Titolo I. The Code constraints are: - to preserve and respect the typological, morphological and chromatic characters inside the original residential settlement -Safeguard and enhance the vegetation characteristics of the public park inside the neighbourhood - Safeguard and enhance the overall system of public and private green areas preserving its continuity and perceptual permeability from the inside and outside of the neighbourhood

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Appendix B. National building regulations

1. Safety in case of fire

For the Annemõisa building in Tartu, the following information is provided:

Table 66. National building regulations (Tartu, Estonia): Security in case of fire

SECURITY IN CASE OF FIRE	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	Minimum fire resistance of the wall (minutes)	R30
	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	Spread of fire	D-s2,d2
	https://www.riigiteataja.ee/akt/104042017014?leiaKehtiv	Reaction to fire.	D-s2,d2

For the building in L'Aquila, the following information is provided:

Table 67. National building regulations (L'Aquila, Italy): Security in case of fire

SECURITY IN CASE OF FIRE	https://www.vigilfuoco.it/aspx/Page.aspx?IdPage=5136	Minimum fire resistance of the wall (minutes)	
		Spread of fire	
		Reaction to fire.	

For the virtual building in Glasgow, the following information is provided:

Table 68. National building regulations (Glasgow, Scotland): Security in case of fire

SECURITY IN CASE OF FIRE	Fire resistance for Scotland	Minimum fire resistance of the wall (minutes)	Minimum fire resistance duration for compartimentation and elements of structure: Medium for office
	Link 1 Link 2 Link 3	Spread of fire	Ventilation ductwork passing through a compartment wall or compartment floor or other fire resisting construction protecting escape routes should be provided with either: • fire dampers, or • fire resisting enclosures, or • fire resisting ductwork.

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			To reduce the risk of a fire starting within a combustible separating wall or a fire spreading rapidly on or within the wall construction: insulation exposed in a cavity should be constructed from products which achieve European Classification A1, A2 or B (see annex 2.E), and • the internal wall lining should be constructed from products which achieve European Classification A1, A2, or B, and • the wall should contain no pipes, wires or other services.
	Link	Reaction to fire.	

For the virtual building in Amsterdam, the following information is provided:

Table 69. National building regulations (Amsterdam, Netherlands): Security in case of fire

SECURITY IN CASE OF FIRE	BRISbouwbesluit	Minimum fire resistance of the wall (minutes)	<7m high: 60 minutes; >7m and <13m high: 90 minutes; >13m high: 120 minutes;
	BRISbouwbesluit - NEN 6090	Spread of fire	The time is shortened by 30 minutes if the permanent fire load of the fire compartment does not exceed 500 MJ/m².
	BRISbouwbesluit - NEN-EN 13501-1	Reaction to fire.	'Material behaviour during a fire' (reactions to fire), these regulations are specified in accordance with NEN-EN 13501-1. New buildings strictly have to adjust to these standards but for existing buildings it is still possible to choose between the old and the new systematics.

For the virtual building in Milano, the following information is provided:

Table 70. National building regulations (Milano, Italy): Security in case of fire

SECURITY IN CASE OF FIRE	D.M. 16.2.2007	Minimum fire resistance of the wall (minutes)	R 15
	UNI EN 13501-1	Reaction to fire.	Classes 0 to 5

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2. *Safety and accessibility in use*

For the Annemõisa building in Tartu, the following information is provided:

Table 71. National building regulations (Tartu, Estonia): Structural requirements

STRUCTURE		wind load (without increasing)	0,37 kN/m^2
		seismic load (without increasing)	Not applicable

For the building in L'Aquila, the following information is provided:

Table 72. National building regulations (L'Aquila, Italy): Structural requirements

STRUCTURE	https://www.gazzettaufficiale.it/eli/gu/2018/02/20/42/so/8/sg/pdf https://www.ingenio-web.it/18847-ntc-2018-le-novita-capitolo-per-capitolo	wind load (without increasing)	
		seismic load (without increasing)	

For the virtual building in Glasgow, the following information is provided:

Table 73. National building regulations (Glasgow, Scotland): Structural requirements

STRUCTURE	Link 1	wind load (without increasing)	a. for wind loadings, BS EN 1991-1-4:2005 (Eurocode 1)
	Table 1.10	seismic load (without increasing)	

For the virtual building in Amsterdam, the following information is provided:

Table 74. National building regulations (Amsterdam, Netherlands): Structural requirements

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STRUCTURE	BRISbouwbesluit - NEN-EN 1991-1-4	wind load (without increasing)	0.88 kN/m^2

For the virtual building in Milano, the following information is provided:

Table 75. National building regulations (Milano, Italy): Structural requirements

STRUCTURE	NTC 2018	Basic wind speed (m/s)	25
	NTC 2018	Basic wind speed pressure (kN/m^2)	0.39
	NTC 2018	Coefficient of wind exposure	0.17
	NTC 2018	Basic seismic acceleration [a_b/g] (m/s^2)	0.15
	NTC 2018	Contribution coefficient k	0.4

3. Protection against noise

For the Annemõisa building in Tartu, the following information is provided:

Table 76. National building regulations (Tartu, Estonia): Acoustics requirements

ACOUSTICS. (noise)		Minimum airborne sound insulation (dB)	30 (apartment), 45 (common room)

For the building in L'Aquila, the following information is provided:

Table 77. National building regulations (L'Aquila, Italy): Acoustics requirements

ACOUSTICS. (noise)	https://www.ingenio-web.it/25954-norme-tecniche-di-acustica-edilizia-stato-dellarte-e-prospettive-future	Minimum airborne sound insulation (dB)	

For the virtual building in Glasgow, the following information is provided:

Table 78. National building regulations (Glasgow, Scotland): Acoustics requirements

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<table>
<tr>
<td>ACOUSTICS. (noise)</td>
<td>Noise separation</td>
<td>Minimum airborne sound insulation (dB)</td>
<td>Table 5.1. Design performance levels in dB [1]
<table>
<tr><th>Design Performance</th><th>New build and conversions not including traditional buildings</th><th>Conversions of traditional buildings [2]</th></tr>
<tr><td>Minimum airborne sound insulation [3]</td><td>56 $D_{nT,w}$</td><td>53 $D_{nT,w}$</td></tr>
</table>
</td>
</tr>
</table>

For the virtual building in Amsterdam, the following information is provided:

Table 79. National building regulations (Amsterdam, Netherlands): Acoustics requirements

ACOUSTICS. (noise)	BRISbouwbesluit - NEN 5077	Minimum airborne sound insulation (dB)	Minimum of 20 dB

For the virtual building in Milano, the following information is provided:

Table 80. National building regulations (Milano, Italy): Acoustics requirements

ACOUSTICS. (noise)	D.P.C.M. 5-12-1997	Minimum airborne sound insulation (dB)	40

4. Energy, economy and heat retention

For the Annemõisa building in Tartu, the following information is provided:

- Energy saving:

Table 81. National building regulations (Tartu, Estonia): Energy saving requirements

ENERGY SAVING (e.g. Building regulation	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	**U-value** of the external wall (W/(m²K))	0,12...0,14W/(m²K)*
	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	Limit value for **air permeability of holes**	less than 1

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Part L in the UK, EnEV in Germany)		in the thermal envelope. ($m^3/h·m^2$)	
	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	Non-renewable primary energy consumption [kW·h/m2year]	100
	https://www.riigiteataja.ee/akt/113122018014?leiaKehtiv	Total primary energy consumption [kW·h/m2year]	100
	Not set in regulation	Minimum contribution of renewable energy to cover the domestic hot water demand	Not applicable
	Not set in regulation	Minimum generation of electrical energy	Not applicable
	Not set in regulation	Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	Not applicable

* Recommended U-value for NZEB small houses. In the end, it depends on engineering and the value is not set in any regulation.

- Indoor air quality:

Table 82. National building regulations (Tartu, Estonia): Indoor air quality requirements

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INDOOR AIR QUALITY	https://www.evs.ee/et/evs-en-16798-7-2017	Ventilation rates	0,5 L/s/m²

For the building in L'Aquila, the following information is provided:

- Energy saving:

Table 83. National building regulations (L'Aquila, Italy): Energy saving requirements

ENERGY SAVING (e.g. Building regulation Part L in the UK, EnEV in Germany)	https://www.reteambiente.it/normativa/energia/indici/vigente/?p=all	**U-value** of the external wall ($W/(m^2 K)$)	
		Limit value for **air permeability of holes** in the thermal envelope. ($m^3/h·m^2$) Non-renewable primary energy consumption [kW·h/m2year]	
		Total primary energy consumption [kW·h/m2year]	
		Minimum contribution of renewable energy to cover the domestic hot water demand	
		Minimum generation of electrical energy	
		Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	

- Indoor air quality:

Table 84. National building regulations (L'Aquila, Italy): Indoor air quality requirements

INDOOR AIR QUALITY		Ventilation rates	

For the virtual building in Glasgow, the following information is provided:

- Energy saving:

Table 85. National building regulations (Glasgow, Scotland): Energy saving requirements

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ENERGY SAVING (e.g. Building regulation Part L in the UK, EnEV in Germany)	6. Energy	**U-value** of the external wall (W/(m² K))	0.3 when improving existing building stock
		Limit value for **air permeability of holes** in the thermal envelope. (m³/h·m²)	10
		Non-renewable primary energy consumption [kW·h/m2year]	?
		Total primary energy consumption [kW·h/m2year]	?
		Minimum contribution of renewable energy to cover the domestic hot water demand	?
		Minimum generation of electrical energy	?
		Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	?

- Indoor air quality:

Table 86. National building regulations (Glasgow, Scotland): Indoor air quality requirements

INDOOR AIR QUALITY	3.14 Ventilation	Ventilation rates	-

For the virtual building in Amsterdam, the following information is provided:

- Energy saving:

Table 87. National building regulations (Amsterdam, Netherlands): Energy saving requirements

ENERGY SAVING (e.g. Building regulation Part L in the UK, EnEV in Germany)	BRISbouwbesluit	**U-value** of the external wall (W/(m² K))	≥ 4.5 m2.K/W (new buildings); ≥ 1.3 m2K/W (renovations)
	BRISbouwbesluit, NEN-EN 12207	Limit value for **air permeability of holes** in the thermal envelope. (m³/h·m²)	Maximum pressure (Pa): 150; 50 m3/h·m2. Maximum pressure (Pa): 300; 27 m3/h·m2. Maximum pressure (Pa): 600; 9 m3/h·m2
	BENG	Non-renewable primary energy consumption [kW·h/m2year]	25 kWh/m2.year

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	BENG	Total primary energy consumption [kW·h/m2year]	25 kWh/m2.year
	BENG	Minimum contribution of renewable energy to cover the domestic hot water demand	50%
		Minimum generation of electrical energy	No applicable
		Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	No applicable

- Indoor air quality:

Table 88. National building regulations (Amsterdam, Netherlands): Indoor air quality requirements

INDOOR AIR QUALITY	BRISbouwbesluitonline - NEN1087	Ventilation rates	Residential: at least 0.9 dm³/s per m² floor area with a minimum of 7 dm³/s; Cooking appliance: at least 21 dm³/s; A bathing area: at least 14 dm³/s.

For the virtual building in Milano, the following information is provided:

- Energy saving:

Table 89. National building regulations (Milano, Italy): Energy saving requirements

ENERGY SAVING (e.g. Building regulation Part L in the UK, EnEV in Germany)	DDUO 18/12/19	**U-value** of the external wall (W/(m² K))	0.28
	DDUO 18/12/19	Limit value for **air permeability of holes** in the thermal envelope. (m³/h·m²)	1.50
	DDUO 18/12/19	Non-renewable primary energy consumption [kW·h/m2year]	Epgl,nren<Epgl,nren,lim
	DDUO 18/12/19	Total primary energy consumption [kW·h/m2year]	Epgl,tot<Epgl,tot,lim
	DDUO 18/12/19	Minimum contribution of renewable energy to cover the domestic hot water demand	50%
	DDUO 18/12/19	Minimum generation of electrical energy	-
	DDUO 18/12/19	Limit value of the solar control parameter. qsol;jul,lim [kWh/m²·month]	-

- Indoor air quality:

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Table 90. National building regulations (Milano, Italy): Indoor air quality requirements

INDOOR AIR QUALITY	DDUO 18/12/19	Ventilation rates	0,5-0,7

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Appendix C. State of art

The sheets with the selected projects are shown below.

All pictures below have been collected from the reference indicated in the sheet.

Project	RETROKIT:Toolboxes for systemic retrofitting
Year	2012-2016
Reference	https://www.retrokit.eu https://cordis.europa.eu/project/id/314229
Objectives of the project	RetroKit is a software platform that helps housing professionals to make evidence-based investment decisions for their energy upgrade projects, integrating efficient energy use systems and RES for systemic retrofitting of residential buildings. It helps to reduce the carbon footprint of the housing stock, alleviate fuel poverty and improve the health and well-being of the tenants
Relevant issues for development of ENSNARE façade system	RetroKit is a software based decision-support tool. The first step is to create a customised database, with the baseline energy performance of the residential building, including energy use and expenditure, carbon savings and BER rating. This database is then used to model and compare a wide range of energy renovation scenarios, helping to decide on the best route to meeting the desired objectives, whether these are based on budget, CO2 emissions, health or fuel poverty targets. This data allows to define an energy retrofit action plan, defining bespoke packages of energy conservation measures with budget estimates, funding opportunities and a work plan.

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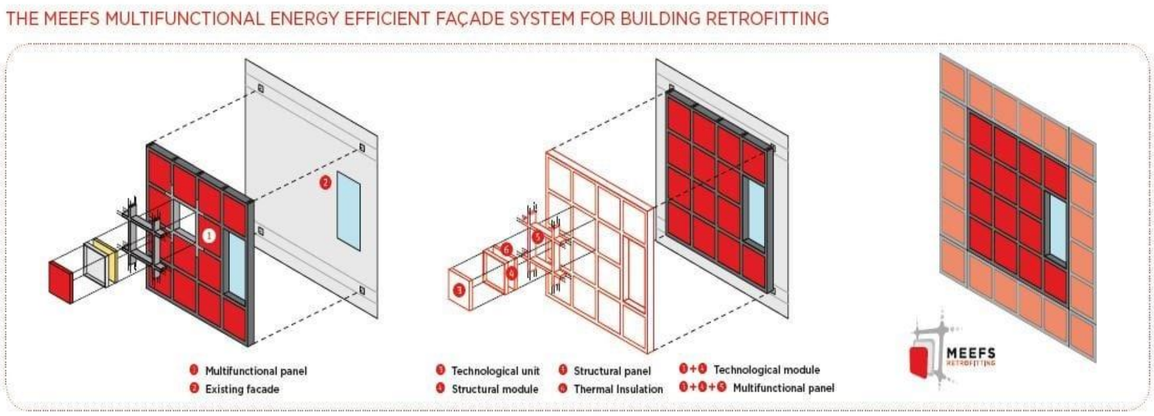
Project	MEEFS - Multifunctional Energy Efficient Façade System for Building
Year	2012-2016
Reference	https://greenovate-europe.eu/meefs-multifunctional-energy-efficient-facade-system-for-buildings-retrofitting/
	https://cordis.europa.eu/project/id/285411
Objectives of the project	The MeeFS project developed an innovative multifunctional façade system for drastically improving the energy efficiency of retrofitting, geared towards the residential building sector across Europe. The developed solution included a structural frame upon which different active and passive elements can be mounted, making it modular and very flexible.
Relevant issues for development of ENSNARE façade system	This façade system applies multifunctional energy efficiency panels and technological modules with innovative composite façade structure materials, for building envelope retrofitting. The MeeFS system will be easily adaptable to a variety of climatic conditions and any type of residential building. Its modular approach will allow for the integration of both active and passive technologies into the façade.

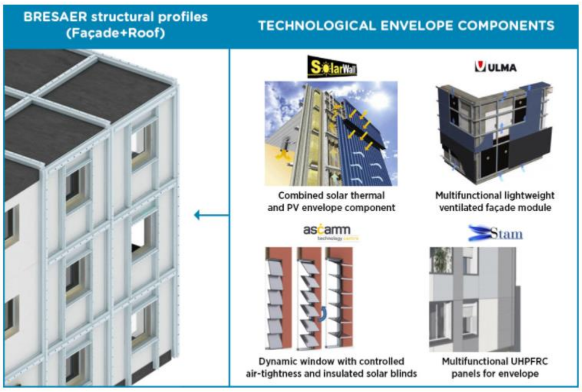


This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

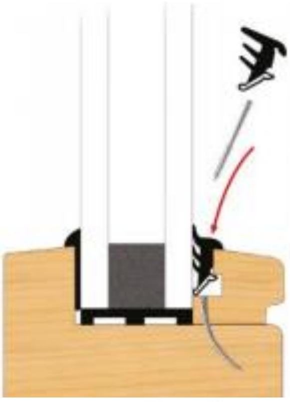
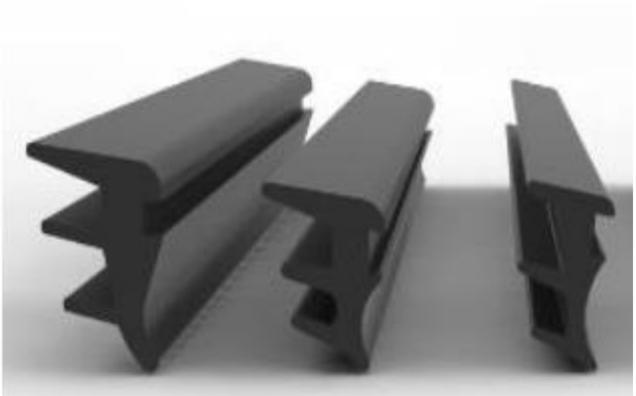
Project	BERTIM - BUILDING ENERGY RENOVATION THROUGH TIMBER PREFABRICATED MODULES
Year	2015-2019
Reference	http://www.bertim.eu/
Objectives of the project	BERTIM project wants to contribute to increased energy efficient building renovation rates in Europe by means of developing energy efficient and cost-effective products for the wood industry. BERTIM has developed a façade prefabricated solution which provides the opportunity to renovate buildings improving energy performance, air quality, aesthetics, comfort, and property value at the same time, while ensuring low intrusiveness during renovation works. These modules integrate: - windows - insulation materials - collective HVAC systems - renewable energy systems - energy supply systems The manufacturing of the solution was included in a holistic methodology for the renovation project process, from data collecting to installation. The systemic methodology has been based in a digital data flow in BIM that was implemented in a software named RenoBIM that enables reduction of renovation operation time, customized mass production, and lower financial risk for investors.
Relevant issues for development of ENSNARE façade system	- Modular façade system for building refurbishment (implemented on existing façade) - Solar thermal technology implemented - HVAC equipment implemented

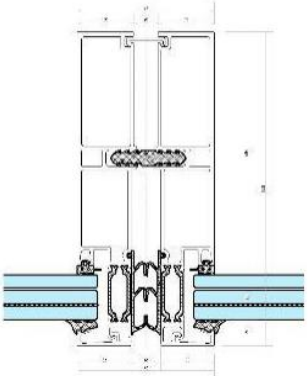
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	BRESAER - BREakthrough Solutions for Adaptable Envelopes in building
Year	2015-2019
Reference	http://www.bresaer.eu/
Objectives of the project	BRESAER has developed a cost-effective, adaptable and industrialized “envelope system” for buildings refurbishment. The BRESAER’s envelope (for façades and roofs) includes a combination of active and passive pre-fabricated solutions which are integrated in a versatile lightweight structural mesh. Objectives: - reduce building’s primary energy consumption - reduce greenhouse emisions - improve indoor environment quality Moreover an innovative Building Energy Management System governs all the different envelope functions, the energy facilities of the building and monitor the energy generated by the BRESAER system
Relevant issues for development of ENSNARE façade system	- Development of aluminium mesh to integrate several technologies of façade (actives and pasives) - PV and Solar Thermal (air) technologies implemented - RES on the roofs developed - Smart window developed



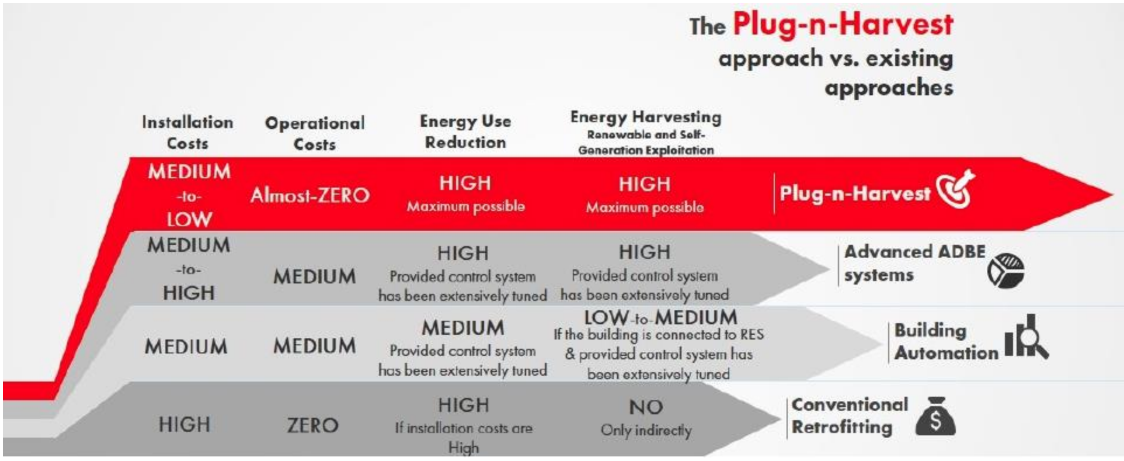
Project	EENSULATE - Development of innovative lightweight and highly insulating energy efficient components and associated enabling materials for cost-effective retrofitting and new construction of curtain wall facades
Year	2016-2021
Reference	http://www.eensulate.eu/
Objectives of the project	The goal of the project is to develop an affordable advanced architectural glass to address thermal and acoustic insulation - minimize thermal bridges between curtain walls and sub-structures, have cost-effective control of solar radiation and approach to insulate the spandrel, allow for an easy implementation on site by reducing the weight of the curtain wall. The EENSULATE objectives have been achieved through the development of three main key enabling technologies: - Highly insulating mono and bi-component environmentally friendly foams - A lightweight and thin double pane vacuum glass (VIG), - A multi-functional thermo-tunable coating, capable to control solar gains based on temperature and switchable from 20 to 70% G value
Relevant issues for development of ENSNARE façade system	This project focuses on improving thermal behaviour of curtain walls. For this purpose, not only an special glass panel and insulation foam have been developed and integrated in curtain wall but also a development of the structural frame and its components have been carried out.



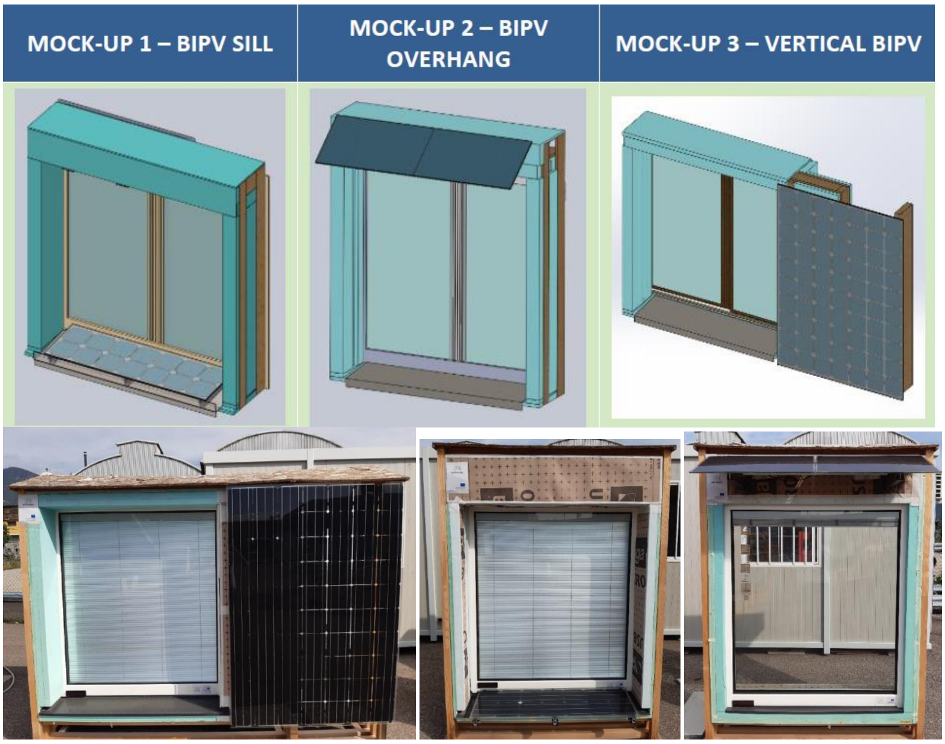
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	PLUG'N'HARVEST - Plug-n-play passive and active multi-modal energy Harvesting systems, circular economy by design, with high replicability for Self-sufficient Districts & Near-Zero Buildings
Year	2017-2021
Reference	https://www.plug-n-harvest.eu/
Objectives of the project	Main objective: To design, develop, demonstrate and exploit a new modular, plug-n-play concept/product for ADBE(Adaptable/Dynamic Building Envelopes) – deployable to both residential and non-residential buildings – which is able to provide high (maximum possible) energy use reductions and high (maximum possible) energy harvesting from RES(Renewable Energy Sources) both at the single-building and the district scale while requiring medium-tolow installation costs and almost-zero operational costs.
Relevant issues for development of ENSNARE façade system	- Flexible aluminum façade design with high insulation layer and energy-harvest enabling elements - Modular façade system - Window integrated - PV, Solar Thermal and Hybrid integrated - HVAC integrated



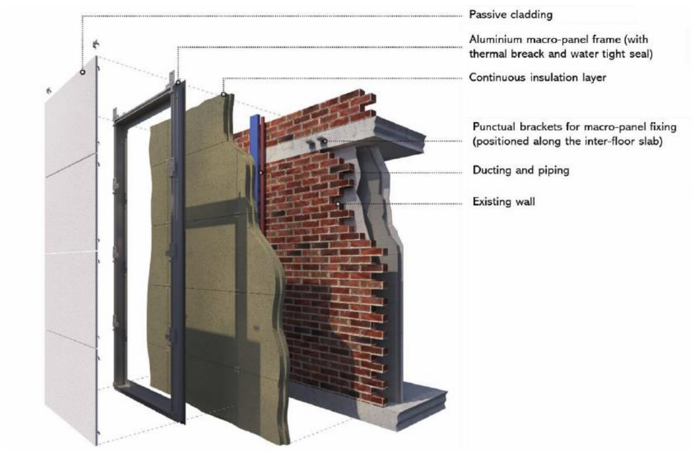
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	ENERGYMATCHING - Adaptable and adaptive RES envelope solutions to maximise energy harvesting and optimize EU building and district load matching
Year	2017-2022
Reference	https://www.energymatching.eu/
Objectives of the project	**Main objective:** The overall objective of the project is to maximize the RES harvesting in the built environment by developing and demonstrating cost-effective active building skin solutions as part of an optimised building energy system, being connected into local energy grid and managed by a district energy hub implementing optimised control strategies within a comprehensive economic rationale balancing objectives and performance targets of both private and public stakeholders
Relevant issues for development of ENSNARE façade system	- The Solar Window Block: autonomous modular and flexible solution aimed at improving building energy efficiency and increasing indoor comfort, while also generating energy from a renewable source. The window block is a physical framework surrounding the window frame made of insulating materials, composite wood, metal supports and sealing bands. Its design can easily be varied depending on the window hole and the design needs, determining a very flexible solution. In addition, it can guarantee fast and correct installation, minimalization of thermal bridges, and is completely compatible with the rest of principle elements that form the window block: mechanical ventilation system, integrated shading system and integrated BIPV. - The online EnergyMatching Platform aims to support designers and other professionals in maximizing the RES harvesting in their built environment. Through the integration of a matchmaking tool, it guides users to meet their own interests and potential exploiting resources developed within the project. An optimization tool suggests optimal configurations of BIPV systems and provides inspiring examples of



This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	BuildHEAT - Standardised approaches and products for the systemic retrofit of residential Buildings, focusing on HEATing and cooling consumptions attenuation
Year	2015-2020
Reference	http://www.buildheat.eu/
Objectives of the project	BuildHeat aims to elaborate a set of reliable, energy efficient and affordable retrofit solutions for multifamily houses, which execution is facilitated by industrialised, modular and flexible HVAC, façade and ICT systems made available on the market. Despite the affordability, innovative solutions are more expensive compared to off the shelf ones.
Relevant issues for development of ENSNARE façade system	The solution is a preassembled multifunctional façade system made out of a **preassembled metal substructure by HALFEN**, which is anchored to the existing façade, a thermal insulation layer integrated in the metal frame and between the frame and the existing façade and cladding panels. The façade system is engineered to allow hosting eventual pipelines, ducts and cables between the metal frame and the existing façade. In this way, decentral units can be connected to central systems (e.g. a central heat pump, a PV field on the roof) without new shafts being installed. In addition, the metal frame can host PV panels or solar thermal collectors in place of the cladding elements, allowing to use the new façade as a surface to generate useful energy for the building.



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Project	RC panels
Year	Commercialized solution **EXTREMELY INTERESTING**
Reference	https://rcpanels.nl/
Objectives of the project	Integrated dta flow process with point cloud. Foam based modules, with reinforcement. Includes some HVAV. In the module?, not clear Robotic assembly of certain elements: https://www.youtube.com/watch?v=Nz1fBo5GtLM Conventional installation process with cranes and scaffolding. Similar company: https://www.youtube.com/watch?v=w2oEFOySs0E
Relevant issues for development of ENSNARE	Normal installation process.





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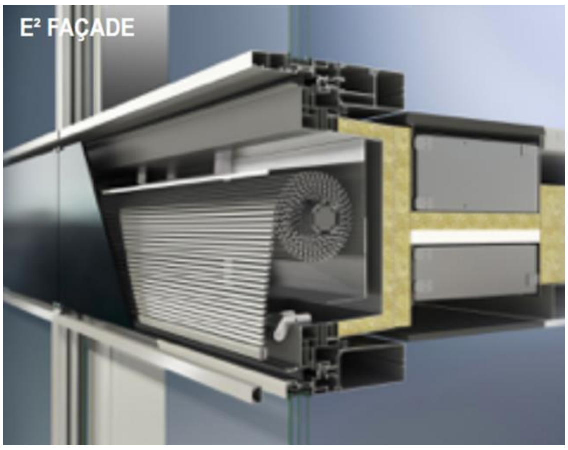
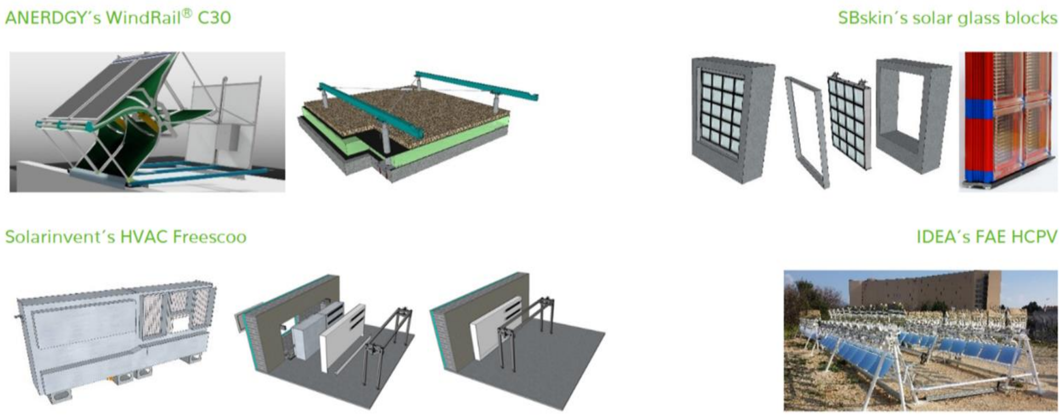
Project	Schüco E² façade
Year	Commercial product. **Schüco itself doesn't provide the information.**
Reference	http://www.geopetaluminium.com/E2.html
Objectives of the project	The Schüco E² façade is an energy efficient, complete system with a revolutionary combination of façade and system technology, which both saves and generates energy. Its four function modules allow individual solution packages to be created. The Schüco E² façade combines elegant design and intelligent façade technology. The perfect combination of transparency and energy efficiency. **Concealed decentralised ventilation technology:** The integrated Schüco IFV fan with its air outlets in the floor and/or ceiling area of interior rooms also accommodates the design requirement for a floor-to-ceiling, highly transparent, glazed façade. **Thin-film modules - the power station in the façade:** Façade-integrated photovoltaics use the large available surfaces of the building envelope to generate solar energy. Semi-transparent PV modules are particularly suitable for storey height installation, with a transparency level of up to 30%, a view to the outside is retained. **Solar shading integrated in the façade:** The externally mounted Schüco CTB solar shading is completely concealed within the façade. When fully retracted, it is not visible from the outside and therefore does not affect the appearance of the façade. **Opening units:** The comprehensive integration of all window systems - from AWS 60 to AWS 75.SI - into the Schüco FW 50+ and FW 60+ façades provides a huge scope for design and thermal insulation. The concealed, flush-fitted projected top-hung and parallel opening SFC 85 windows integrated into the façade load bearing structure create a highly transparent façade design.
Relevant issues for development of ENSNARE	- PV and Solar Thermal (air) technoloogies implemented - Smart window developed



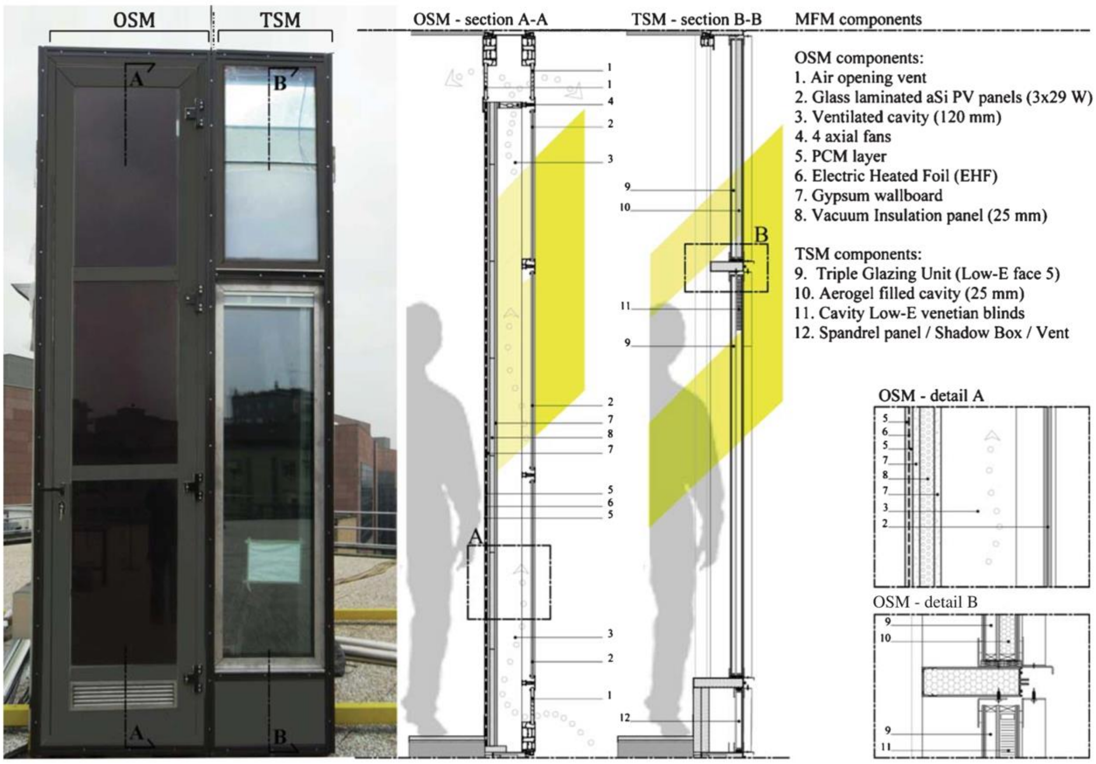
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	Zero-Plus
Year	2015-2020
Reference	http://www.zeroplus.org/
Objectives of the project	Buildings and settlements are nowadays increasingly expected to meet higher and potentially more complex levels of performance. They should be sustainable, use zero-net energy, be healthy and comfortable, grid-friendly, yet economical to build and maintain. Buildings are central to the EU's energy efficiency policy. Improving the energy performance of Europe's building stock is crucial, not only to achieve the EU's 2020 targets but also to meet the longer term objectives of the climate strategy as laid down in the low carbon economy roadmap 2050. The aim of ZERO-PLUS (Acronym of "Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology") research project is to search for buildings design for new highly energy performing buildings (H2020-EE-2015-1-PPP). In this project, a comprehensive, cost-effective modular system for Net Zero Energy (NZE) settlements will be developed and implemented in a series of case studies across the EU. In ZERO-PLUS, the challenge of significantly reducing the costs of NZE settlements will be achieved through the implementation of three parallel strategies: Increasing the efficiency of the components directly providing the energy conservation and energy generation in the NZE settlement. Reducing initial costs through efficient production and installation processes and use of less material and space for energy conservation and energy production. Reducing operational costs through better management of the loads and resources on a district scale rather than on the scale of a single building.
Relevant issues for development of ENSNARE façade system	-Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology -Integrated facade system in one of the modules



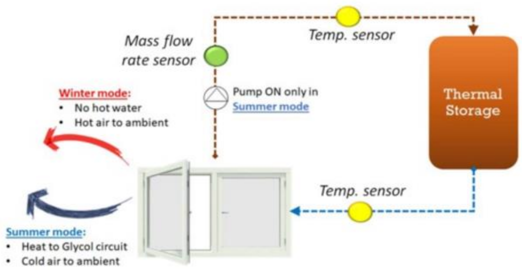
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

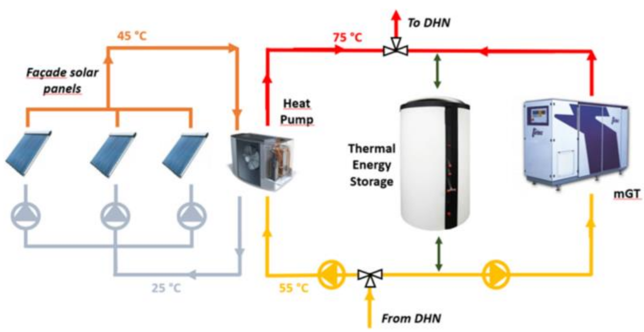
Project	ACTRESS (Active, Responsive and Solar) – facade module
Year	2015-2016
Reference	https://www.sciencedirect.com/science/article/pii/S0038092X16002310 https://journals.open.tudelft.nl/jfde/article/view/1013
Objectives of the project	The ACTive, RESponsive and Solar envelope is designed to play different roles through its ability to change its **thermo-physical behaviour** to suit the **different environmental conditions**. The ACTRESS module was designed to implement the following capabilities/functions: - **Proper balance between opaque and transparent** parts (50% each). - **Selective activation** of the thermal storage layers the whole year. - **Management of the solar gains** both in the transparent and in the opaque components, through conventional layers, as shading devices and hybrid ventilation, and novel strategies as PCMs layer coupled with a thermoelectrical carpet.
Relevant issues for development of ENSNARE façade system	The main goal of the ACTRESS facade module is to overcome the limitation given by the current AIF technologies and to assess the effects of **an adaptive Multifunctional Facade Module (MFM)** on **building energy savings** and **indoor environmental quality,** by **embedding technologies** (e.g., PV and solar panels) to **increase the exploitation of solar energy**, directly at the façade level.



This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

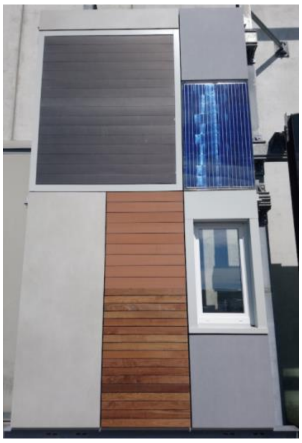
Project	ENVISION (ENergy harVesting by Invisible Solar IntegratiON in building
Year	2017-2022
Reference	https://cordis.europa.eu/project/id/767180
	https://www.energy-envision.eu
Objectives of the project	'ENVISION' will demonstrate a full renovation concept that **harvests energy from ALL building surfaces** (transparent and opaque). It focusses on energy harvesting of the façade, and works by **absorbing the invisible part of the solar radiation** allowing visible aspects to be retained. The 'ENVISION' harvesting of solar energy is achieved via: - heat collecting non-transparent aesthetically pleasing façade elements by harvesting the NIR solar radiation, - heat harvesting ventilated glass by harvesting the NIR solar radiation, - electricity harvesting photovoltaic glazing solutions
Relevant issues for development of ENSNARE façade system	- **Active harvesting** of the solar radiation from all the building surfaces - **Linking heat generation façade elements to district heat network:** The interaction with different generations of DHN at low and high temperature will be enabled. - **Large scale deployment potential:** Thanks to the **modularity and flexibility** of the **prefab solutions**. - **Easy maintenance:** Enabled by the **"click-on" façade concept** for the non-transparent parts. The **ventilated window concept** will be developed so that the glass can be cleaned easily on the outside and inside of the glazing. - **Easy Installation:** The patented click-façade solution, allows "**plug and play**" of well insulated pre- fab elements by all kinds of new 'ENVISION' façade solutions. - **Cost Effectiveness** : Payback period lower than 10 years.





This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	RENOZEB - Accelerating Energy renovation solution for Zero Energy
Year	2017-2021
Reference	https://renozeb.eu/
Objectives of the project	RenoZEB aims to unlock the nZEB renovation market leveraging the gain on property value through a new systemic approach to retrofitting that will include innovative components, processes and decision making methodologies to guide all value-chain actors in the nZEB building renovation process.
Relevant issues for development of ENSNARE façade system	- A cost-effective and non-intrusive prefabricated multifunctional modular “plug and play” system for the renovation of buildings is being developed - Curtain wall type modular structure - window integrated - RES integrated: solar thermal and PV




Project	HERB - Holistic energy-efficient retrofitting of residential buildings
Year	2012-2016
Reference	https://cordis.europa.eu/project/id/314283/es
Objectives of the project	The overall objective of the Herb project is to develop energy efficient technologies and holistic solutions for retrofitting residential buildings and to demonstrate how existing residential buildings can be refurbished up to at least the latest national standards for new residential buildings. One of the specific objectives of the project is: Develop technologies for energy efficient envelope retrofitting such as aerogel, starch microporous insulation, and vacuum insulated panels, phase change materials, multi-functional facades, integrated heat recovery panels, smart windows and surface coatings.
Relevant issues for development of ENSNARE façade system	- transparent multi-functional façade technology - smart control systems - novel photovoltaic - solar thermal (PVT) systems

This project has received funding from European Union’s Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	ReCo2st - Residential Retrofit assessment platform and demonstrations for near zero energy and CO2 emissions with optimum cost, health,
Year	2018-2021
Reference	https://cordis.europa.eu/project/id/768576
Objectives of the project	The Smart window is based on a solution developed in the EU CLIMAWIN project. This solution included triple plane glazing, integrated solar shading, preheating of ventilation air and wireless room zone control for IEQ optimization. This solution was developed for renovation projects, where comfortable controlled ventilation is required, but installation of a balanced mechanical system is difficult or very expensive. In the ReCO2ST project the idea is to further develop this smart window technology by optimising harvesting of solar energy (thermal) and heat recovery. The existing smart window will be combined with an air based solar thermal collector (installed in combination with the window), a PCM solar energy storage, an air to water heat pump on exhaust air and an intelligent control solution to optimise solar energy harvesting, energy storage and exhaust air heat recovery. The solution will also include a night cooling option to improve summer comfort.
Relevant issues for development of ENSNARE façade system	- smart window

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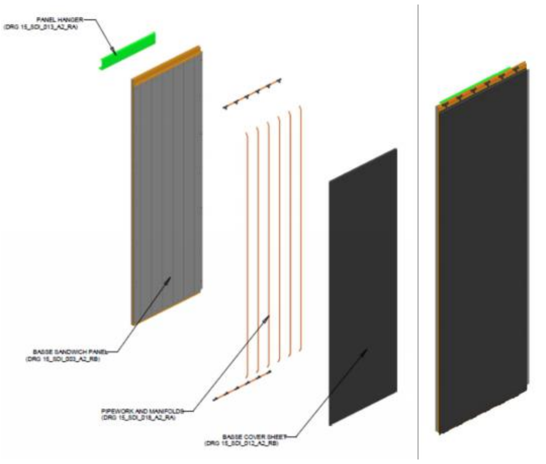
Project	BIPVBOOST - Bringing down costs of BIPV multifunctional solutions and processes along the value chain, enabling widespread nZEBs
Year	2018-2022
Reference	https://bipvboost.eu/
Objectives of the project	The main objective of this project is to bring down the cost of multifunctional building-integrated photovoltaic (BIPV) systems, limiting the overcost with respect to traditional, non-PV, construction solutions and non-integrated PV modules, through an effective implementation of short and medium-term cost reduction roadmaps addressing the whole BIPV value chain and demonstration of the contribution of the technology towards mass realization of nearly Zero Energy Buildings (nZEBs).
Relevant issues for development of ENSNARE façade system	- Development and improvement of BIPV technology

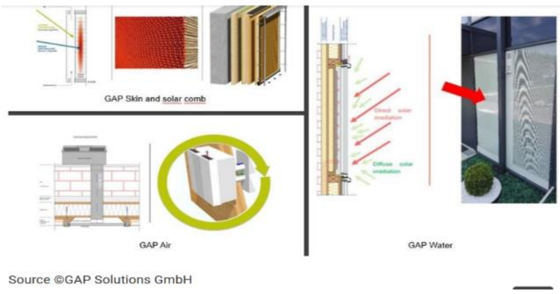
This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	BASSE - BUILDING ACTIVE STEEL SKIN
Year	2013-2016
Reference	https://op.europa.eu/en/publication-detail/-/publication/b4642076-7d05-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-213669558
Objectives of the project	The objective of the project was to develop an energy harvesting system having the dual function of being the enclosing envelope of the building and the main provider of heating, and hot water requirements for buildings. The BASSE system as defined comprises three main elements: A sandwich panel solar collector; A heat pump system including energy storage; A control and management system. A prototype of the system was developed, manufactured and installed on the Kubik test facility in Derio, Spain. The installation was used to validate the theoretical models developed to predict the system performance and refine the installation procedures for the system.
Relevant issues for development of ENSNARE façade system	- Solar Thermal panel integrated in façade - Modular façade solution - Heat pump coupled (inside the building)



This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	GAP solutions
Year	Commercialized solution
Reference	http://www.gap-solutions.at
Objectives of the project	The GAP facade forms a unique building envelope which prevents any heat loss. A simple, high-quality and ecological interaction of light, wood and air eliminates any thermal bridges and significantly increases hygrothermal and acoustic comfort. The GAP solutions is a complete solution developed around three core business, GAP Engineering, Gap systems and GAP Services. GAP1 engineering. GAP1 engineering stands for close collaboration of architects, planners and executors as well as for the careful coordination of building-physical and energetic conditions. GAP engineers are the competent interlocutors that accompanies the client through all realization phases, from conception to implementation. This combination ensures integrated processes and smooth work flows. Based on a comprehensive collection of facts, an energy-optimized construction and management concept are developed in order to be implemented precisely and efficiently. In doing so, solid craftsmanship is combined with industrial production and the special GAP system. GAP2 Systems. The intelligent GAP facade solutions practically don't allow any heat loss – the interaction of light, wood and air eliminate thermal bridges and increases the hygrothermal and acoustic comfort. The GAP system has been developed in collaboration with leading universities and research institutions and extensively tested. The optimized house envelope also allows for optimization of the house technology. Simple and decentralized systems are cost effective in investment and maintenance.
Relevant issues for development of ENSNARE façade system	-Integarted facade with Solar cells and Solar Thermal for renovation processes.



Project	CLIMAWIN (An intelligent window for optimal ventilation and minimum thermal loss) - CLIMAWINDA (Demonstrating the effectiveness and commercial potential of CLIMAWIN intelligent windows for energy efficiency in retrofit of buildings in Europe)
Year	2010-2012/2013-2016
Reference	https://cordis.europa.eu/project/id/315324
Objectives of the project	CLIMAWINDA is developing an intelligent ventilation window that can preheat and cool itself to minimise energy loss and optimise ventilation. The CLIMAWIN unit works as a natural heat recovery ventilation system in cooler climates and as a daylighting (self-cooling) device in hotter climates. It is targeted at the retrofitting market, but could also suit new build situations. Objective: -developing a novel high performance window with electronic operation of an auto-regulated natural ventilation system powered by solar power. Through in-situ smart sensors and Radio Frequency BasedTechnology (RFBT), the system will optimize, in real time, indoor climate on the basis of parameters such as indoor/outdoor temperature, CO2 and humidity etc., thereby providing both better indoor climate and reducing thermal loss.
Relevant issues for development of ENSNARE façade system	- Smart window developed

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 958445

Project	The Matching Kit
Year	2021
Reference	Iturralde, K. 2021, Study on Automated and Robotic Renovation of Building Façades with Prefabricated Modules, TUM
Objectives of the project	The Matching Kit (MK) is a technique developed previously that corrects the deviations due to lack of measurement and/or during the fixation of the connector. It consists of three main elements: • part 1, which is the first part installed in the existing building wall, • part 2, which is the element fixed in the 2D module based on the location of part1 • a customized interface between Part 1 and Part 2.
Relevant issues for development of ENSNARE façade system	- Connectors