PROJECT FINAL REPORT

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Project acronym: **MEEFS RETROFITTING**

Project title: **Multifunctional Energy Efficient Façade System for Building Retrofitting**

Funding Scheme: Collaborative project [EeB.NMP.2011-3]

Energy saving technologies for buildings envelope retrofitting, Energy saving technologies for buildings envelope retrofitting Nanosciences, Nanotechnologies, Materials and new Production

Period covered: **from** 01/01/2012 **to** 31/12/2016*

**includes extended period from 01/01/2016 to 31/12/2016 by Amendment no. 1*

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

4.1 Final publishable summary report

Executive summary

The key to greater energy efficiency lies in residential buildings which represent about 80% of the total building stock and 63% of the final energy consumption. MeeFS (Multifunctional Energy Efficient Façade System for Building Retrofitting www.meefs-retrofitting.eu) was conceived in order to address the development, evaluation, and demonstration of an innovative multifunctional façade system geared towards the residential building sector, with the potential to significantly contribute to energy efficiency in buildings across Europe. The project started on 1st January 2012 coordinated by Acciona Infrastructures (Spain) and supported by partners from 9 different countries: Tecnalia, AST, Govern of Extremadura (Spain); E&L Architects, SkaPolska (Poland); Greenovate! Europe (Belgium); CQFD, TBC (France); AntWorks, Vipiemme (Italy); Rizakos, NTUA (Greece); FHG (Germany); VTT (Finland) and Technion (Israel). The workflow was very challenging, linking: design, testing, redesigning, manufacturing and assembling. The biggest challenges in the last period were actually administrative in nature, especially as it took the project over a year to obtain the licences for the planned installation. In total it was five years of hard work and many lessons learnt.

The MeeFS multifunctional façade system can be used as a retrofitting technique across Europe, with different buildings and climates. The panels have been designed to fit social housing buildings. After analysing hundreds and hundreds of housing typologies across Europe, it has been concluded that the building standards do of course differ depending on the year of construction, aesthetics and function, but overall they are quite similar. The panels have been developed accordingly using a modular system to fit any climate and housing situation. The anchorage system has been developed with special trays that can easily be adjusted to allow for different building sizes.

The site and building chosen for the demo site was in Mérida, and owned by only one institution - the local government - which always makes the execution a lot simpler. Further into the project, it was discovered that the building residents were in a very critical social predicament and this led to a number of technical issues that had to be solved on site, such as the redistribution of the panels on the façade due to limits in access to apartments. The preliminary results from the demonstration buildings in Merida are very promising. The technical development and fine-tuning of the construction process was successful. However, the process of analysing simulations and gathering energy data is still ongoing. Final results, summing up the impact of the panels is expected in mid-2017.

MeeFS has claimed a breakthrough in developing two technologies: the advanced passive solar protector & energy absorption unit and the advanced passive solar collector & ventilation unit. Both panels aim to increase energy efficiency, reducing the total energy demand and enhancing the indoor comfort of the building. To achieve this, the panels combine several technologies that are automatically adapted to the position of the panel and the climate. Depending on the season and time of day they are able to adjust to the specific energy demand of the building.

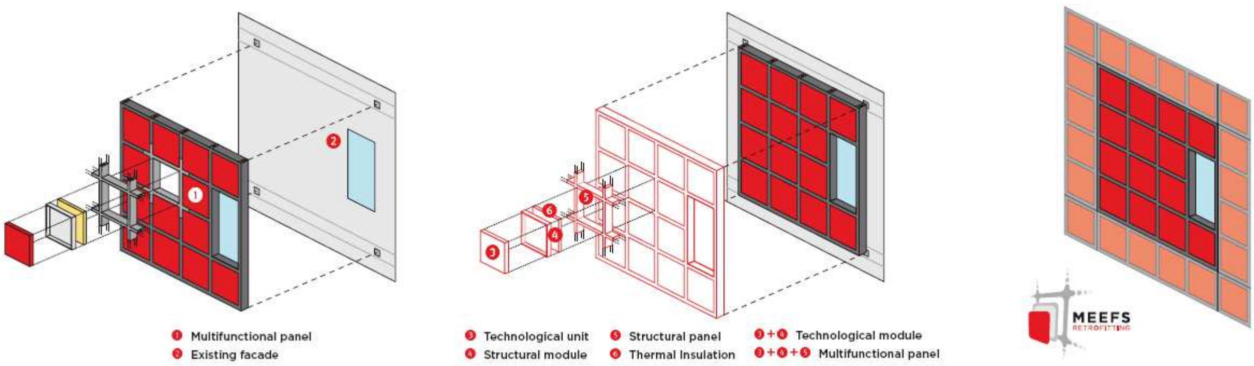
Since the MeeFS system is an innovative technology, the feasibility of the system in terms of costs is still unsure: it costs more than the state-of-the-art technologies. On the other hand this technology has been proven to be easier to adapt to buildings and its effectiveness is higher than that of standard technologies. The MeeFS façade system payback time is limited to seven years, so the panels are more energy efficient and offer greater savings in the long run. The panels have been designed to be adaptable to future technology as well, having a good chance of being competitive in maybe five to ten years.

Figure01. MeeFS Retrofitting Façade System with different Technological Units, Demo Building Mérida (Spain), final project meeting 2016

Summary of project context and objectives

The overall objective of the MeeFS project was the development, evaluation and demonstration of an innovative energy efficient multifunctional façade system for residential building sector retrofitting. This new façade system was to be easily adapted to any climate condition and any typology of residential building façade.

The concept was based on an energy efficient integrated system composed of an innovative non-intrusive façade concept, from composite materials, and advanced multifunctional panels with technological modules that will allow the integration of both active and passive technologies in the façade. The system was designed for building envelope retrofitting, to drastically improve the energy efficiency of residential buildings in Europe.



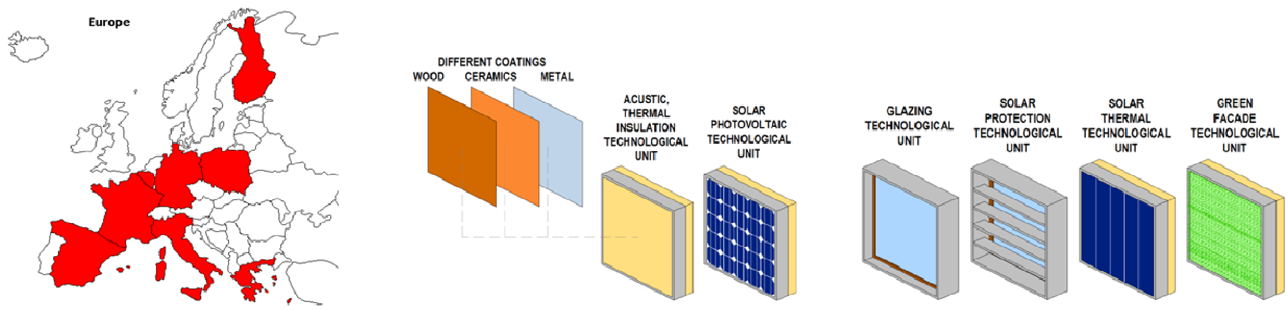


Figure02.Initial idea for the MeeFS Retrofitting Façade System, concept for structure and technological units, 2012

The innovative concepts addressed the general ideas listed below:

Innovative façade concept for retrofitting:

- its system of construction does not exist for retrofitting nowadays
- allows the integration of advanced multifunctional panels and technological modules
- standardised dimensions for panels and modules according to the different façade surface typologies
- allows for industrialised production
- allows personalised configurations for each façade typology, orientation and local climate conditions, always using standardised panels and technological modules
- low intrusive, connected with the building through a reduced number of anchorage elements
- aesthetic and compatible with the existing building functions
- the volume of the scaffolding will be reduced during the retrofitting process
- low maintenance, easy assembly and disassembly
- cost effective in service life, it will avoid future retrofitting using the same structural modules that can be upgraded with technological innovation along building life
- integration of the installations (building visible existing installation) in the façade structure system, integration among them of the different façade module installation and with the building internal installation system
- it will improve the Indoor Environmental Quality
- it will increase durability

Energy Efficient panels and modules:

- all the modules integrated in the façade include a particular technology (Active or Passive technologies) that will allow the reduction of the primary energy either reducing energy demand of the building or for supplying energy by means of RES (Renewable Energy Sources)
- most of the modules will be state of the art already proven (to be cost effective and energy efficient)
- there will be two new energy efficient breakthrough modules developed in the project based on passive strategies under bioclimatic architecture principles
    - Advanced Passive Solar Protector and Energy Absorption auto mobile (sensors and actuators) unit for building façades with thermal insulation, heat storage, heat reflection and ventilation properties according to the climate and temperature (outdoor and indoor) situation as well as sun radiation level at each moment
    - Advanced Passive Solar Collector and Ventilation Module for Building Façades. Although the concept is known for new buildings, the application in retrofitting is new.

The existing wall of the façade can act as part of the system as an element for energy storage.

- flexible combination of the different technologies in the modules will contribute to the global energy efficiency and to a higher indoor comfort

Innovative façade structure materials:

- New safe and cost effective composite materials based on improved thermoplastic polymers with better fire performance and environmental behaviour, with the following properties:
    - High thermal properties avoiding thermal bridges
    - Lower embodied energy than aluminium and even recycled steel in the whole life cycle
    - Lower cost for the same performance
    - Lighter-weight than aluminium for the same structural performance
    - Improved mechanical properties
    - Low corrosive
    - Long durability and less maintenance
    - Recyclable

Energy efficient retrofitted building:

- It will obtain at least the energy efficiency of new buildings according to current national regulations. Each country transposes the directive 2010/31/EU demanding certain requirements. As an example, in Spain, where a demonstration building will be retrofitted, the transposition of the directive is realised through three royal decrees[3]. The type and level of performance requirements for new buildings depend on the climatic zone where the building is located. The demonstrator located in Badajoz (Spain) will reach at least all the requirements[4] demanded for new buildings in this location.
    - Maximum U-value for external wall: 0.73 W/m2 ºC
    - Maximum U-value for windows oscillate between 2.2 and 4.4 W/m2ºC depending on the façade orientation
    - Maximum solar factors for windows oscillate between 0.29 and 0.57 depending on the façade orientation
- Minimum 70% solar contribution for the Domestic Hot Water (DHW)
- No obligations for PV electric contribution for residential buildings
- No obligations for Energy certification for existing buildings to be retrofitted. Minimum demanded certification in scale (A-G) is E in case of the new buildings. The objective is to obtain in our case A certification in the demonstrator. Values[5] for the energetic certification in Badajoz (Spain) count in KgCO2/m2 emissions are:

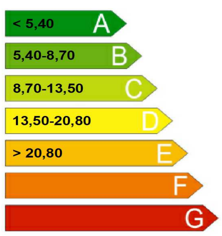


Figure03.Exampl e on energy certyfication chart

[3] According to the above decrees the buildings retrofitted have to comply with the same minimum requirements as new ones when for building retrofitted the floor area exceeds of 1000 m2, or more than 25% of the building envelope to be renovated.

[4] http://www.codigotecnico.org/cte/export/sites/default/web/galerias/archivos/DB_HE_abril_2009.pdf

[5] Values obtained by means of the procedure of calculation described in the official document "Scale of Qualification Energetics for Buildings of new construction" http://www.mityc.es/energia/desarrollo/EficienciaEnergetica/CertificacionEnergetica/DocumentosReconocidos/OtrosDocumentos/Escala_%20calif_energetica.pdf

The LIDER[6] is a software tool that permits to test the degree of compliance with the requirements of the Spanish technical code CTE mentioned above. The CALENER[7] is software tool for energetic certification (A-G).

- At least min. Indoor Environment Quality requirements as per CTE
- Building Energy Management System incorporated
- Pay-back less than 7 years

Innovative methodology for retrofitting

- The Integrated Project Delivery (IPD) Methodology will be used for the design, retrofitting, and commissioning of the building. It will be supported by BIM (Building Information Modelling)

The system will incorporate tools for system design composed by a Guide for design, retrofitting and commissioning for building to be retrofitted

- Methodology for façade design that will be implemented
    a. Architectural Design, Structural Design and Construction Process
    b. Energy Design (building on the existing passive and active design knowledge)
- A decision-support software tool for the design of the facade (optimum modules combination), depending on the energy efficiency requirements while achieving and/or maintaining the aesthetical values.
- Guide for using and maintaining the facade system.

The design guide with the decision-support software tool and maintenance guide will be also used after the project by designers for retrofitting buildings.

To achieve the objectives, the work plan was structured in 11 WPs. WP1 to WP8 are devoted to research activities and corresponding technical & scientific management/coordination, WP9 deals with the demonstration activities and WP10 deals with innovative exploitation & dissemination related activities, WP11 is devoted to project financial, legal and administrative management.

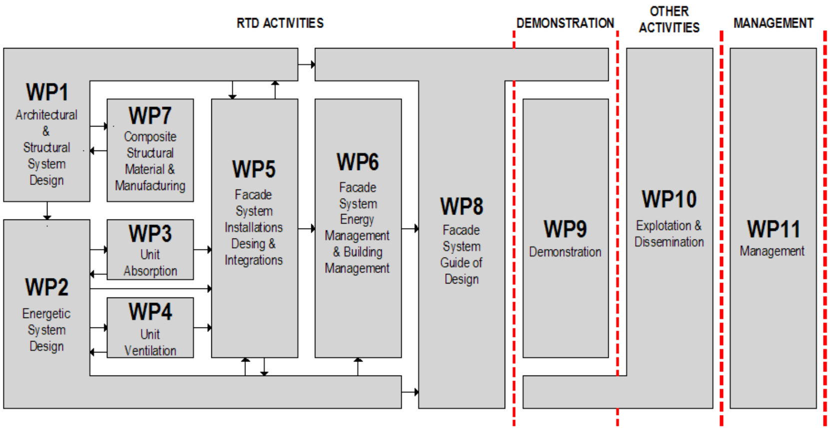


Figure04. Project management structure, 2012

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6 http://www.codigotecnico.org/web/recursos/aplicaciones/contenido/texto_0002.html
7 http://www.mityc.es/energia/desarrollo/EficienciaEnergetica/CertificacionEnergetica/ProgramaCalener/Paginas/DocumentosReconocidos.aspx

A description of the main S&T results/foregrounds

60 months into the Multifunctional Energy Efficiency Façade (MeeFS) project the consortium has completed all project phases (WPs), related to the architecture and energy façade shaping, and concluded with the demonstration and exploitation in residential building in Mérida, Spain.

Architectural & Structural System Design [WP1]

The primary goal of this work package was to develop the architectural system of the modular façade, taking into account technical and aesthetic criteria, taking into account the existing multi-family building stock in the EU, introducing innovative approaches to retrofitting philosophy: the façade is not only the external "face" of the building, but also integrates itself with the building's technical installations, adding new value and functionality helping to reduce energy expenditure and improving the living conditions of dwellers. The work planned was successfully completed, creating the revolutionary façade system from the ground up, developing all-new structural elements, dealing with innovative materials and solutions, using original, state-of-the-art building technologies. Careful analysis of the residential building typologies and legal aspects in respective EU countries inspired the standard façade system module dimensions and the definition of the standard façade structural system elements (panel, module, assembling system) for building retrofitting across Europe. In addition the analysis of climatic conditions in respective EU countries, taken in different work packages related to this, leads to economically efficient integration of existing and new building's technical installations into the multifunctional structurally uniformed façade system. Finally, the introduction of BIM parametric objects with embedded parametric data has been considered, for the creation of custom BIM libraries with MeeFS objects. At the end of the project the basic façade project guidelines were prepared, to summarise the architectural and structural developments.

The work has been organised in different steps, starting with outlining the design for the main façade system elements, its sizes and position on the façade, and concluding with the proposed design for an anchorage system. As a result of studying the various types of facade data from EU countries, the most important set of façade parameters was defined, thus creating the typology scheme for the MeeFS system. One of the crucial dimensions to be defined was the distance between the different slabs for the considered residential buildings, and the position of the main fixing points for the innovative façade system. The results of this study showed that most of the dimensions are not so different between countries, although not the same of course. The distances between slabs are different according to the country. In fact, buildings in the North Zone have distances longer than 3 metres (Germany and UK for example), and in the South and Central, shorter than 3 metres (like Poland and Spain). The average of all these distances is very different by country too, and at this moment it was clear that it was not possible to make only one module dimension. It is feasible to group some countries with similar dimensions together, like Finland with no standard dimensions, Germany and UK (and possibly Italy and Greece) where the dimensions are between 3,1 and 3 metres, Poland and Spain: under 3 metres (in one case 2.7 metres and the other one 2.4 metres). In conclusion it was decided that for the MeeFS facade it would be useful to create two different dimensions: a standard for North countries (3.05 metres) and a second one for the South ones (less than 3 metres). The deeper studies were done with help of the "Virtual Mesh" (VM), a tool designed for this analysis, to help extract generic dimensions from the catalogue of building typologies. VM was applied over the pictures/drawings and it allowed us to create axes and to generate automatic dimension between axes. These axes can be drawn to the building's outline, windows distances, slab distances and all the necessary geometry to describe the façade.
The outcomes from the initial studies and first drawings propositions on the panel, module and unit dimensions helped to inform the anchorage system to be designed for façade. On one side it should be used to fix all the different elements, with the main objective to integrate them and fix them to the

retrofitted building. Instead of using single anchoring elements as initially planned, the proposal for this project consists of using an anchoring tray, fixed in several points to the floor slab, where the multifunctional panels can be mounted and adjusted individually. The design of the tray considers the mechanical components, allowing the panels to be placed at slightly different vertical positions, absorbing the differences between the slabs dimensions. An additional feature of this tray is that it provides an area for the installation components and the passage of piping and wiring, necessary for the appropriate operation of this energy- efficient façade system.

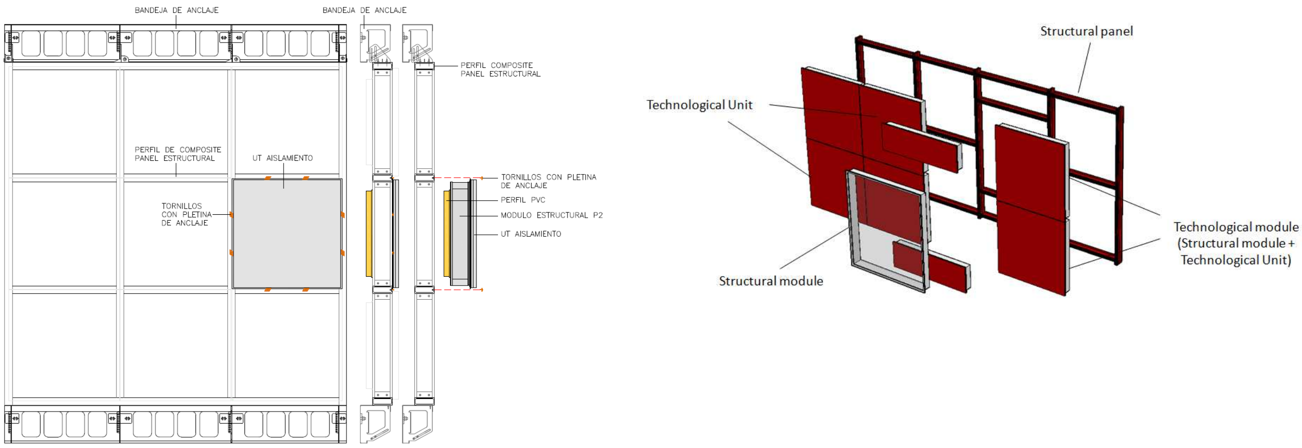


Figure05. MeeFS façade system standardised facade concept based on panel, module and technological unit, on left the 3x3 module configuration, with example integration of the technological unit (insulation unit).

Continuing with the detailed design of panels, modules and mechanical joints, technological units, its particular elements and architectural details, finally the architectural and structural design for the system was expanded in time. It was crucial to allow the façade design to adapt to the proprietary needs of the manufacturing process and material pre-selected for its execution. In close collaboration with the activities related to the material and manufacturing of the structural profile [WP7], the pre-testing campaign has been planned to decide definitely on the structural material between aluminum and composite for profile (fire requirements and manufacturing trials), in continuation for the module for technological unit. As an initial constraint the aluminium was chosen for the module structure due to its better fire behaviour and design flexibility. To avoid thermal bridges through the metallic structural module several options were analysed based on the common idea of dividing the profile in two elements: the introduction of an intermediate rubber element to break the bridge; the combination of an aluminium element with a plastic element with good LCA. The design of the structural module has been modified to create the facilities channels and to isolate each technological units’ effect to avoid unwanted interactions through the common air gap. Finally, having finalised the fire testing for the composite material, and due to the initial positive results, the selection of the composite for the façade main structural element has been decided for main panel support, alongside the aluminium for technological units also agreed.

To achieve the final goal of work package - the complete definition of the multidisciplinary MeeFS façade’s system - first the valuable building data analysis parts (several branches) were performed and all relevant information has been crossed with the data on different disciplines like installations, energy system, technological units constrains coming from the different task and work package related to them. Basing on the initial summary, the BIM (ArchiCAD) parametric objects were created for major system elements. Energetic, structural, material properties and cost data was added to parametric objects. Those objects were subsequently put in BIM libraries – created exclusively for the MeeFS Façade System. Concluding the summary of all data, the demo Façade Project has been prepared – in the basic form of Building Permit design drawings.

In continuation, all outputs from the architectural and structural design have been presented, from the generic design to the specific demo design in the residential building in Mérida, province of Badajoz, Extremadura region, Spain. [WP9] (The design file was further developed and adjusted in order to comply with the Spanish Local Law Requirements and its Mandatory Tests for the whole system. The overall MeeFS System guidelines were adapted to the demo building. The documentation was first prepared at the Basic Project level and after consortium approval, the preparation of the Execution Project begun – it was then finally concluded with testing, and deeply designed below the work package related to demo [WP9].

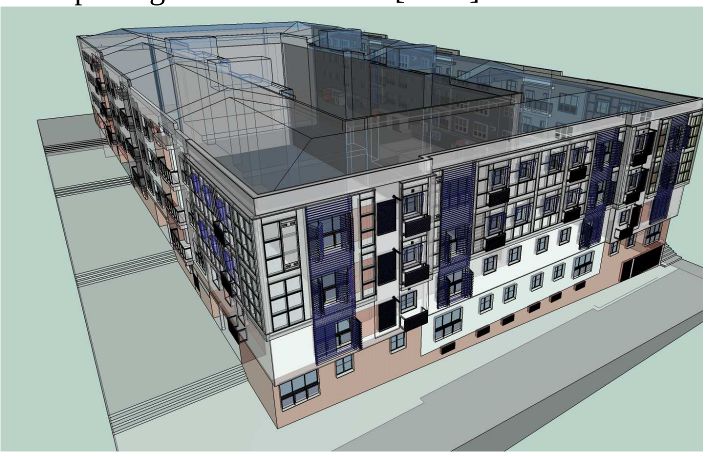


Figure06 MeeFS façade system applied on demo building façade in Mérida, Spain, 2015

Figure07 Final Execution design on demo building in Mérida, Spain, 2015

Once the Mandatory Testing for the whole system was successful, and the façade design was finally closed, the MeeFS Consortium requested the Building Permit to be issued by the National Spanish Government Entity from Extremadura. After being granted a Building Permit, the construction works commenced, according to the Execution Design, and were constantly upgraded and revised in collaboration with façade designers and demo Teams [WP1 and WP9], local Merida architects and the Main Contractor (execution) team.

Energetic System Design [WP2]

The MeeFS project energy concept is built on the technological units integrated into the architectural and structural façade system, capable of reducing the energy consumption and improving the indoor comfort of poorly insulated residential buildings across Europe. In the context of defining the appropriate energy system technology configurations for different climatic conditions and residential building types, a multi-step approach has been followed, aimed at determining representative building energy requirements for energy efficiency and indoor comfort. Building energy consumption generally depends on the external weather conditions, building characteristics and heating, cooling and ventilation (HVAC) systems. Therefore, a thorough analysis of past and ongoing European and national research projects has been carried out in order to obtain information regarding climatic characteristics, HVAC installations typologies and typical building typologies across Europe.
Initially, major European climatic zones have been identified by analysing the climatic conditions in all European Union countries; 3 different climatic zones have been defined, namely “North” (Dfb and Dfc climate categories in the Koeppen-Geiger climate classification system), “Central” (Cfb and Dfc) and “South” (Csa and Cfb), which reflect significant climatic differences. Analysis of the European climate diversity has led to the selection of 13 representative cities, for which façade wall characteristics of existing buildings have been thoroughly studied. A detailed classification of the most common façade and external wall typologies, in terms of materials used and U-values, has been

also performed, to determine the most representative external wall compositions for the MeeFS target buildings. Finally, a thorough classification study of the most common HVAC installations across Europe has been performed, aiming to determine the most typical installations used in residential buildings across Europe.

The façade, being a part of the building envelope, separates the outdoor and indoor environments, functioning as a thermal insulation and air tight barrier; visual contact to outdoors is also allowed through windows. The MeeFS Technological Units (TU) were designed to cover these main functions and also add new functionalities, while reducing the overall building energy consumption. Aiming to determine the main characteristics of the MeeFS TU to be developed, results of the aforementioned classification studies have been used, in conjunction with EPDB requirements, in order to perform a series of building energy simulations; simulation results yielded a range of average energy demand and consumption values for typical building configurations across Europe. Once areas of energy performance improvements have been identified for the simulated buildings, located in 13 characteristic European cities, a broad range of alternative technologies and solutions that can be integrated into the MeeFS system have been analysed and comparatively assessed.

The obtained results served as a starting point for the definition of the basic design requirements for the TU to be developed in the MeeFS project. 7 types of state of the art technologies have been considered initially for the MeeFS TU design, namely Building Integration Photovoltaic (BIPV), Insulation Panel, Ventilated Façade, Green Façade, Glazing, Solar Protection and Façade Integrated Solar Thermal Collectors. Aiming to comparatively assess these 7 technologies and determine their applicability for the MeeFS system, a series of building energy simulations has been performed, in conjunction with a thorough cost analysis, based on energy savings and payback calculations. The energy savings for each TU were determined using building energy simulation software tools, for 5 representative cities (Athens, Madrid, Paris, Berlin and Helsinki), covering all 3 European climatic zones. In each of the 5 investigated cities, representative wall and HVAC equipment configurations were used; all 4 possible main façade wall orientations (N, E, S, W) have been taken into account. Overall, almost 400 simulations have been performed. Simulation results were employed to quantify the energy consumption for HVAC purposes before ("current" configuration) and after ("retrofitted" configuration) the implementation of each TU. The obtained simulation results were used to evaluate and compare the potential energy savings of each TU. Significant savings in energy demand were calculated, especially for the "South" and "Central" zones, where buildings are usually not very well insulated, thus resulting in high projected gains in heating energy consumption. The estimated maximum energy savings are presented in the following table; significant potential energy savings, up to 60% are reported. However, since in the simulated "base case" apartment, all walls were assumed to be adiabatic, except from the façade, the obtained results corresponded essentially to a theoretical "best case scenario"; application of the MeeFS TU in real buildings is expected to yield lower actual energy saving values.

Additional information regarding the costs associated with the construction of each TU allowed the estimation of the respective payback period. In addition, a methodology to estimate non-monetary benefits has been developed, aiming to evaluate the sustainability of the TU by taking into account a broad range of economic, environmental and social factors like energy savings, low maintenance, recyclability, aesthetics, thermal insulation and reduction of cooling and heating energy demand, reduction of CO2, fire protection, comfort, healthy living, energy independence between the most important of them.

Technological Unit	Maximum savings in annual energy consumption
Insulation	46%
Green façade	45%
Ventilated façade	47%
Glazing	45%
Passive Solar Protection	47%
APSPEA	36%
APSCVU	60%

Figure08 Estimation on the maximum savings in annual energy consumption by TU

Results of the aforementioned assessment methodology, allowed to determine the 7 TU types to be developed in the frame of the MeeFS system: Building Integration Photovoltaic, Insulation Panel, Ventilated Façade, Green Façade, Solar Protection, Advanced Passive Solar Protector and Energy Absorption Unit [WP3], Advanced Passive Solar Collector and Ventilation Unit [WP4]. After the basic characteristics of the 7 TU have been defined, research activities focused on the determination of the final detailed design for each TU, taking into account the structural design, the façade system installation design and the energy saving strategy across Europe. The final detailed design comprised the overall description of the TU, where information on a broad range of matters, such as functional description of the TU, layout of each required component and auxiliary system, architectural design, anchoring system, auxiliary systems and installations requirements, location layout, range of validity across Europe, possible location of the TU on a façade, location of connections for its integration in the façade structure, location of ducts and wiring, possible installation restrictions, were given. Once the final detailed design stage had been reached, the following step was the determination of the manufacturing process of the 7 TU, including all relevant components, e.g. materials, systems and facilities, necessary to produce each final technological module, ready to be assembled to the MeeFS multifunctional panel. Detailed building energy simulations were once more performed for the final TU configurations, for 5 typical European cities; these simulations were accompanied by cost-effectiveness and non-monetary benefits evaluation.

A “general rules of design” handbook was subsequently created, aiming to provide guidelines and general rules for TU selection in the context of a façade refurbishment process across Europe. The first part of the handbook provides some guidelines to the user in order to select the appropriate climatic zone, initial external wall level of performance and initial windows level of performance. Guidelines are given in a checklist style mode and in tables. Towards this end, a variety of building classification rules were defined. For instance, two alternative methodologies were employed for climatic classification, the first one using “heating degree days” (HDD) and “cooling degree days” (CDD), while in the second one a list of European countries is used. Also, regarding the initial state of the external wall, various methodologies were employed, such as consideration of the U-values of the external wall (when available), consideration of the thickness of insulation (when available) or consideration of the age of the building and (when available) the date of any previous retrofitting. Finally, in terms of the initial state of the glazed areas, two classification methodologies were developed, by either considering the U-values of the windows (when available) or estimating them by considering the age of the building and (when available) the date of any previous retrofitting. The second part of the handbook allows the pre-selection of TU for the investigated building. By taking into account the energy strategy defined in the previous step, as well as special requirements given by the user, a set of suitable TU is proposed to be implemented on the building. The user is allowed to remove some of the TU for aesthetic, technological or any other reasons. Finally, the last part of the handbook allows calculation of estimated energy savings. The final TU selection is based on building energy simulation results stored in a dedicated database, which has been developed for a set of typical buildings across 13 representative European cities, by employing results obtained from approximately 1400 building energy simulations. The projected energy savings for the investigated building are determined considering the closest initial state and climatic condition compared to the one considered in the database. Different TU combination alternatives are proposed for each façade and corresponding energy gains and payback periods are reported.

In addition, detailed simulations have been performed in an effort to assess the impact of the proposed MeeFS system on the thermal and energy consumption behaviour of the demonstration building. In this context, a series of "thermal bridge" simulations has been performed initially, aiming to assess the "thermal interaction" between the MeeFS system and the existing building façade. A detailed building energy simulation model of the demonstration building has been developed, covering both the "pre-installation" and "post-installation" configurations. Since 8 different apartments of the demonstration building, located on the 2nd and 3rd floor, were considered for the MeeFS energy retrofitting process, 8 individual models have been developed, taking into account all available information pertinent to each apartment (e.g. external and internal dimensions, construction materials, internal layout, occupant characteristics, installed heating and cooling appliances etc.). A detailed monitoring system, using an extended sensor network, was installed in 3 of these apartments, aiming to provide a detailed account of the temporal evolution of a range of important parameters (e.g. outdoor and indoor temperature and humidity, wall surface temperature and heat flux, indoor velocity). The obtained monitoring data, covering a period of 18 months before the MeeFS system installation ("pre-installation" period) and 2 months after the energy retrofitting ("post-installation" period) have been used to validate the developed models.

A series of building energy simulations has been performed, using the EnergyPlus software tool. All simulations covered a period of one year, using a 1 hr time step, the sole exception being the "post-installation" validation study, where only a 2 month period, corresponding to the period for which monitoring results were available, was addressed. Initially, all 8 apartments were simulated in their "pre-installation" state, aiming to assess their thermal performance. In this context, comparison of the obtained predictions with available monitoring data provided a means of validation for the developed simulation models; good levels of agreement have been observed, given the complex nature of the simulations, especially regarding the stochastic nature of real life occupant behaviour. Energy simulations allowed an estimation of the annual energy demand for heating and cooling purposes for each apartment considered. It should be noted that due to the construction characteristics of the demonstration building (relatively new building, adequately insulated) its thermal and energetic performance before the retrofitting process were found to be quite good, thus suggesting that rather modest energy savings were expected after the retrofitting process. In order to determine the "post-retrofitting" building energy behaviour, a specific simulation model for each TU has been developed; the respective models have then been introduced in the EnergyPlus simulation tool. Once more, the obtained numerical results have been validated by means of comparison with available "post-retrofitting" monitoring data; in this case, slightly worse levels of agreement have been achieved, owed mainly to the complex thermal interactions between the various TU installed in each monitored apartment. A series of further "post-retrofitting" energy simulations yielded estimations of the potential energy savings that can be achieved either by each individual TU or by the specific TU combination used in each of the 8 apartments of the demonstration building. On average, savings in energy demand were found to be of the order of 15% (c.f. figure below).

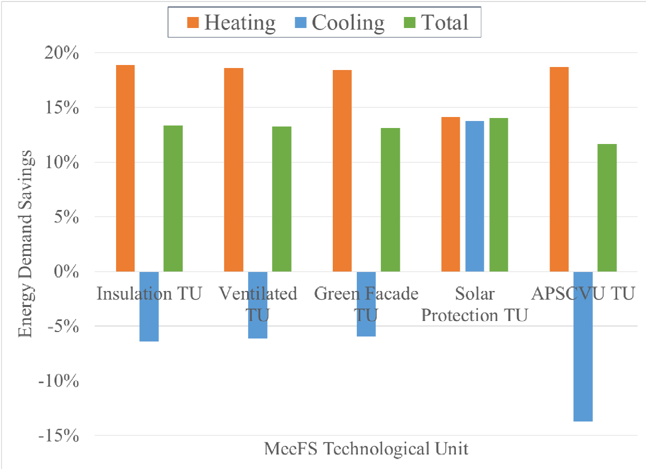


Figure09 Estimation of the energy demand savings in total (heating and cooling) by TU

As expected, due to the good thermal performance of the demonstration building even before the MeeFS system retrofitting, the achieved levels of energy savings (15%) were lower than that previously calculated for older and badly insulated buildings that constitute the main "target group" of the MeeFS retrofitting project. The best "overall" performing TU type was found to be the "Solar Protection TU", whereas in terms of reducing energy demands for "heating" purposes only, both the "Insulation Panel TU" and the "Advanced Passive Solar Collector & Ventilation Unit TU" were found to yield energy savings higher than 18%. Finally, a further series of simulations has been performed, assuming that the demonstration building, in both its "pre-installation" and "post-installation" configurations, is located in two alternative European cities (Berlin, Helsinki), corresponding to significantly different climatic conditions ("Central", "North"). In this case, maximum energy demand savings were found to be somewhat lower (up to 11%), a fact that clearly illustrates the need for optimising the TU type selection and distribution for each specific climatic region.

Advanced Passive Solar Protector and Energy Absorption Unit [WP3]

The development of the breakthrough façade units [WP3, WP4], in this case Advanced Passive Solar Protector and Energy Absorption Unit, has been proposed to complete the selection on state of the art technological unit developed under previous work package [WP2] with the innovative one. The aim was to improve the annual energy performance of the buildings to be retrofitted, balancing heating and cooling requirements. For that purpose the conceptual design of the Technological Unit was developed, defining its constructive design and operating system for its integrations to the MeeFS system. Based on the previous conceptual design, an advanced design for the unit was developed with specific metallic and plastic profiles that guaranteed the correct integration of PCM, insulation material and coating, the water tightness and thermal bridge break. New energy and CFD simulations were performed to evaluate its energy performance in different European climates.
Several approaches have been studied to identify and integrate all the required components and to achieve an optimal design. The most suitable unit configurations have been established with the best annual energy performance balance of heating and cooling loads for different climate locations and orientations in the target geographic locations defined for the MeeFS system. It has been evaluated energetically using energy simulation software tools to improve its potential to reduce building energy loads by optimising its components and operating system.

Figure10. Design concept and the first prototype on Advanced Passive Solar Protector and Energy Absorption Technological Unit

To ensure the Technical Unit thermal performance a prototype is being developed to test and evaluate its results. Two prototypes with different PCM materials were built to evaluate the performance under real climatic conditions. These prototypes were installed and evaluated in Acciona's test-cell facilities in Seville (south Spain). A special software tool was developed to gather and evaluate the prototypes performance. The evaluation of the prototypes concluded that no physical modifications were needed. The modifications detected were focused on its mechanical and control systems. The components description has been organised depending on their location and use, and detail definition made for slats, frame, mechanical and control system components.

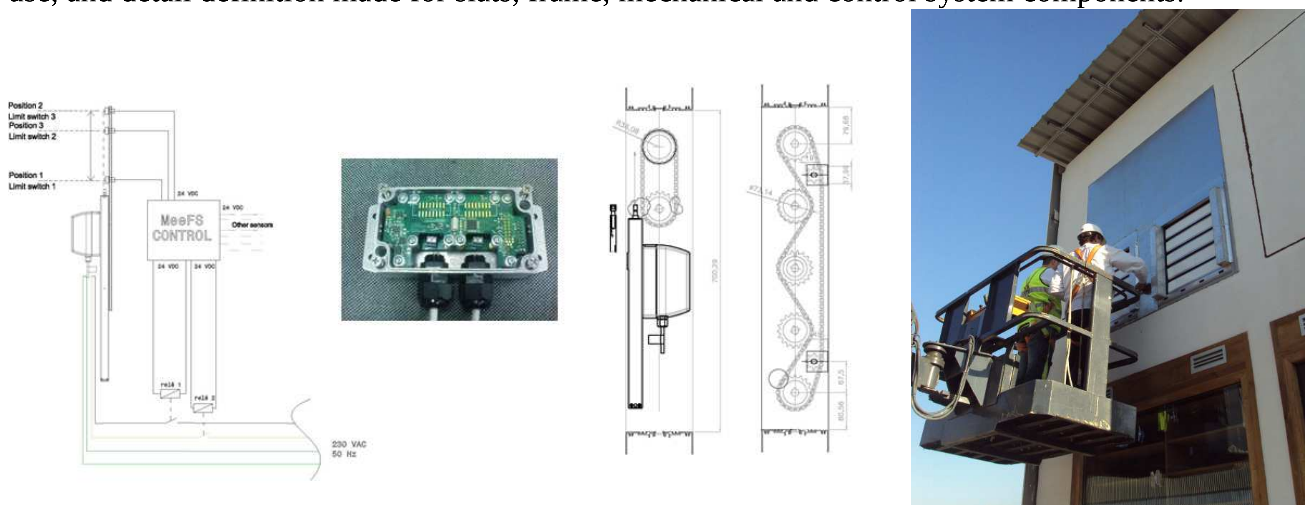


Figure11. LAB test on one of the innovative Technological Units and the unit slat system re-designed.

The manufacturing steps have been defined, and detailed drawings on manufacturing components prepared, estimating for every step the time needed and cost estimation. From material gathering, components assembly, structure fixing, to facilities connectors, including labour works. The ASP&EA units was manufactured and tested in April 2015, and has passed all mandatory tests necessary for a demonstration building. At this research phase the cost is high, compared with the state of the art components, but the industrialised cost in case of a large scale production is expected to be lower. Using the experience obtained during the prototypes manufacturing process a final design for the unit has also been defined. Due to the time limits on demonstration, and some contractual problems with the current manufacturer of the unit, the decision had to be taken not to consider it for the final demonstration design and not to put in risk the full demonstration façade process considered. [WP9]

The system is able to balance heating and cooling needs by maintaining air chamber temperatures between 15º and 30 º (outdoor 5º- 40º). The final total energy demand saving have been estimated between 25% in total consumption, divided 27% for heating and 40% for cooling.

Figure 12. Real scale unit prototype manufacturing for testing, its implementation and assessment.

Advanced Passive Solar Collector and Ventilation Unit [WP4]

The main objective of this work package has been the Development of the Advanced Passive Solar Collector and Ventilation Unit to best improve the annual energy performance of the buildings to be retrofitted, balancing heating and cooling requirements. This will provide a multifunctional bioclimatic technological unit to improve thermal performance in building façade refurbishment. The different steps have been considered to achieve the main goal, the conceptual design, thermal simulation, early prototype constructions and testing, the unit installation and energy refinement, and finally the manufacturing process and costs definition.

The first part of the work, as defined in the tasks, has been related to the detailed definition of the technological unit conceptual design. This work can mainly be summarised in the next 3 pictures.

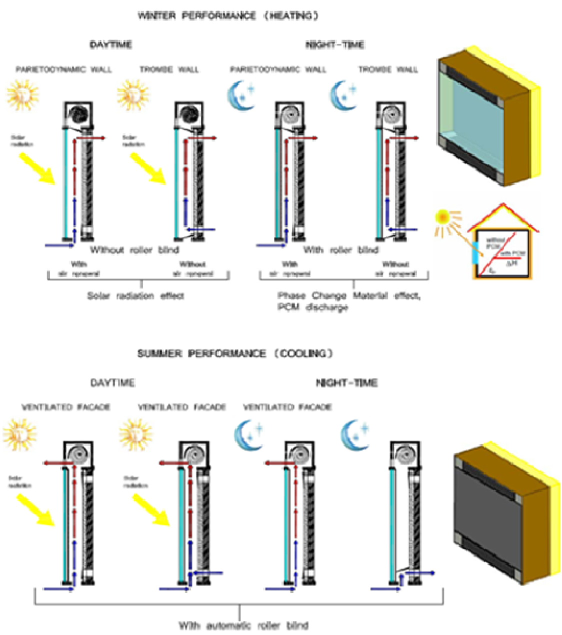


Figure13. Winter configuration of the system and Summer configuration of the system

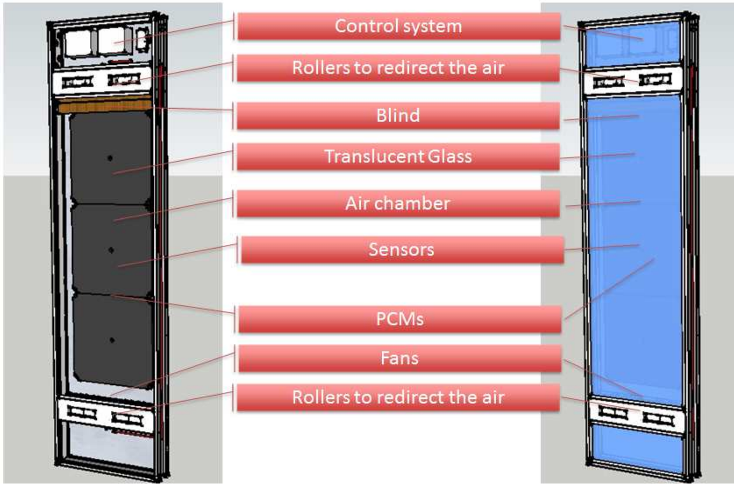


Figure14. Components of the APSC&VU

In the above Figures it can be seen the different configurations that the system can use depending on the external conditions (Winter or Summer). These configurations can be obtained using the different positions that the roller of the system could reach. With the movement of the rollers the system could work as a ventilated façade (mainly in summer conditions), as a parietodynamic wall

(heating the interior space with external air) or as a trombe wall (heating the interior space air that flows across the unit chamber). All these possibilities contribute to the final behaviour of the unit. One of the improvements that this unit has is that all the elements are controlled by an algorithm developed in the project. This algorithm is in charge of opening and closing the different active elements that the unit has depending on the internal conditions (the unit is connected with a sensor to the interior of the building), the external conditions (there is another connection with a weather station) and the internal conditions of the unit chamber (the one inside the unit itself which is in direct contact with the PCM to heat the air and the fans to allow a better flow). The algorithm and the different components are controlled by a computer installed in the unit which also has connection with the general control of the façade. These two computers manage the entire system of the unit.
To verify this information and the incidence that the system can have in the heating and cooling conditions of a specific space, they several simulations (passive and dynamic) have been done and additionally the system has been prototyped and installed in the KUBIK building of Tecnalia to measure the real behaviour (view **¡Error! No se encuentra el origen de la referencia.** and **¡Error! No se encuentra el origen de la referencia.**) of an initial prototype.

Figure15. Installation of the first prototype of the APSC&VU in KUBIK building

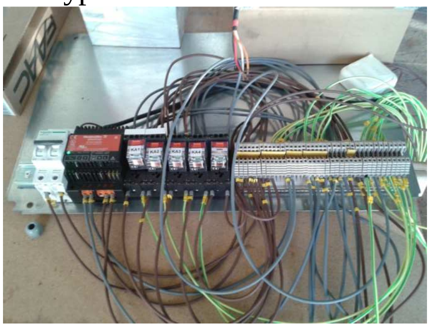


Figure16. Special control system to operate the unit in the KUBIK installation

The unit has been measured for 6 months. With the data obtained during this real test they have been provided results for different climates (South Europe as Sevilla and Madrid and North Europe as Paris and Berlin). Analysing these results it can be seen (view an example of the results for Madrid in Figure 17 and **¡Error! No se encuentra el origen de la referencia.**) that the unit has a good result related to the heating energy output (around 25%-30% in all the climates analysed) but the behaviour related to the cooling energy output is not representative (in all the climates analysed). Some changes can be done in the characteristics of the PCMs of the chamber but the results do not look very promising. The good result is related to the heating possibilities of the system in all the climates.

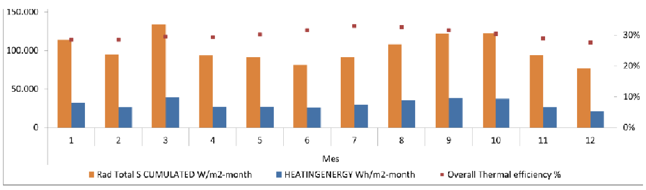


Figure17. Monthly heating energy output per sqm of collector surface for Madrid

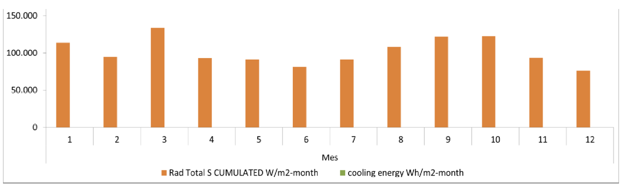


Figure18. Monthly cooling energy output per sqm of collector surface for Madrid

One of the next steps after the early prototype construction and validation in real conditions is to verify the system previous to the final design. A structural verification was conducted under simulations of the different components of the technological unit, to have more data before producing the final prototypes.
The final objective of the work-package tasks has been to install the unit in a demo building located in Mérida (Spain) to validate the performance in real conditions with real users. To make this

installation it was necessary to verify that the characteristics of the unit comply with the different European standards and also with the legal construction requirements of the demo country. In WP7 of this project the entire analysis of the system has been conducted and in the next table are the results obtained by this specific technological unit. These results are higher than the minimum as defined by the Spanish Construction Code. Due to this and taking into account both results and requirements, it was established that the unit didn’t have legal problems to be installed in the demo building in Mérida (Spain).

	Reaction to fire (EN 13823; EN 13501-1 ETAG 034 Annex E1)	Wind load (ETAG 034)	Impact: Hard body(ISO 7892:1988) ; Soft body (ISO 7892:1988); Impact categories according to ETAG 034	Watertightness (EN 12865 and ETAG 034)	Airborne insulation (EN ISO 10140, EN ISO 717-1)	Air permeability (EN 1026, EN 12207)
APSC&VTU	B-S1-D0	3.000Pa (P) 2.000Pa (S)	Category I (Hard Body) Category I (Soft body)	≥ 300 Pa	Modo A: 37,7 dBA ; Modo B: 38,1dBA ; Modo C: 42,6dBA	Class 1

Figure 19. Test results under European standards for APSC&VU

Once the testing validation was finished, with minor changes in the design (it was necessary to repeat some of the tests to confirm the new designs), the manufacturing of the samples that were going to be installed in the demo building began. The different components were collected during this process, some of them provided by the partners of the project (the profiles in aluminum and pvc, the insulation, some of the electronic components) and other ones were commercial products that were bought by Tecnalia.

Figure 20. General view of the demo building with the APSC&VU

Figure 21. Detail view of one of the units

After receiving all the components, the process of manufacturing started in order to have the two units for the demo project built and checked. After the installation of the different components that form the sample, the mechanical components were tested connecting the unit to a computer with the control software. The rollers, the blind and the fans were tested in order to verify that everything works as expected. Once this verification was finished the units were sent to Merida to collect them in the final workshop and to make additional tests once the controller of the unit was installed.

In this last verification all the modes were tested that the sample can use to open and close the internal and external air ventilation elements, depending on the configuration of the rollers: connection between inside and outside of the unit, connection of the chamber with the outside and connection of the chamber with the inside. Apart from this it was tested again (after the transport), checking the operation of the algorithm simulating different conditions to see if the fans, rollers and blind reached their different positions without problems.

After all these tests the units were installed in the demo building as it can be seen in the above pictures.

Façade System Installations Design and Integration [WP5]

Designing the façade system installations and integrating them with the existing façade was a successfully overcome challenge. The main achievements on this part are described below.

At the beginning of the project a design methodology was elaborated, which allowed the identification of the essential information required to attain an optimised integrated solution related to the specific needs of the Technological Units to be designed and manufactured within the project.

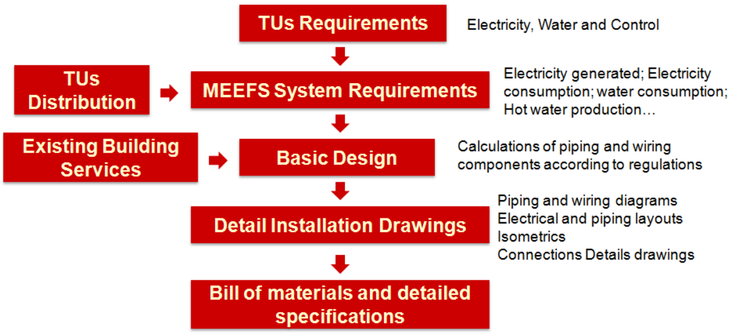


Figure 22 Installations design methodology

Based on the steps indicated by the previous methodology, different important tasks were successfully completed: (1) Identification and analysis of relevant functional and legal requirements for the installations needed by the Technological Units; (2) Development of different solutions for the integration of the service installations into the structural panel; (3) Analysis and selection of solutions for connection and connectors. Assessment of innovative solutions for future implementation and, (4) Elaboration of a design guideline to aid the creation of optimised wiring and piping layouts on each particular façade.

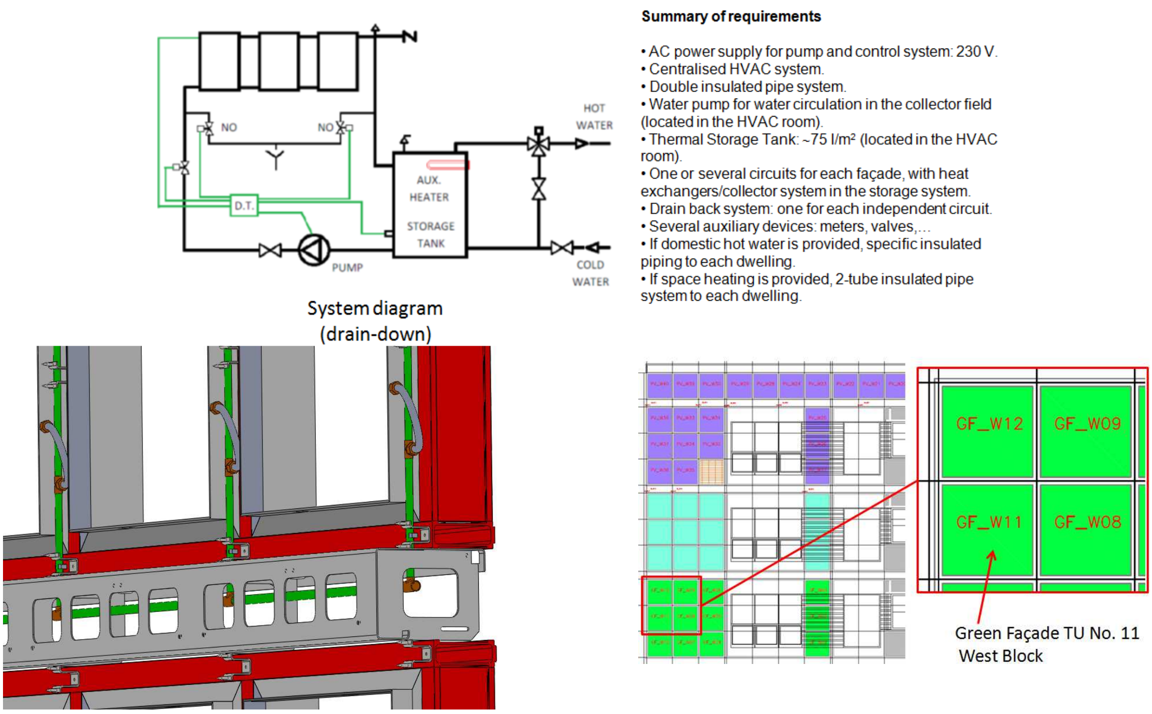


Figure 23 Different aspects of the installations design considered in the proposed design methodology

Once all these activities were completed, a software application called IMET (Installation Material Estimation Tool) was developed to make initial estimates of the required installation components for buildings to be retrofitted with the MeeFS façade system. It consists of an Excel VBA Tool that runs under a Graphical User Interface (GUI) created using the .NET framework. It has been designed as a standalone software, however, it is intended to be used in conjunction with the ERES software. Once the architect/designer of the retrofitting project of the building has determined the TU layout of the façade using ERES, he/she will be able to roughly estimate all installation components that will be required for that configuration. The user can also save a summary of the results obtained in .PDF and .DOC.

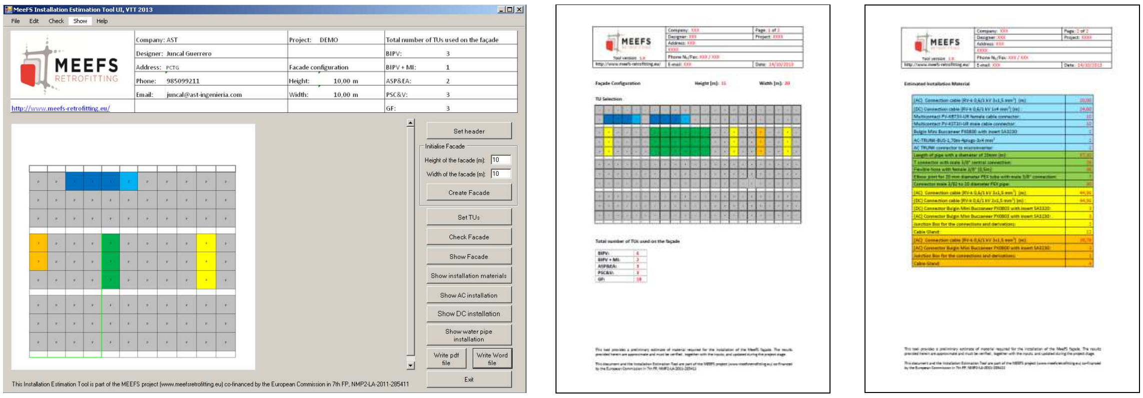


Figure 24 IMET Tool. User Interface and PDF Summary Document

Finally, the last achievement consisted of the design and proposal of viable technical solutions for the integration of the different façade distribution systems (electricity and water) with the existing building installations. The latter can be configured in many different ways and does not follow any identifiable pattern. Consequently, a general classification of these installations was performed and different solutions for connection with the existing building services were proposed, considering all specific technical and legal aspects of each particular problem. Finally, solutions for the demo building were also provided, together with the complete set of installation drawings, bills of materials and descriptions, necessary for the preparation of the demo project.

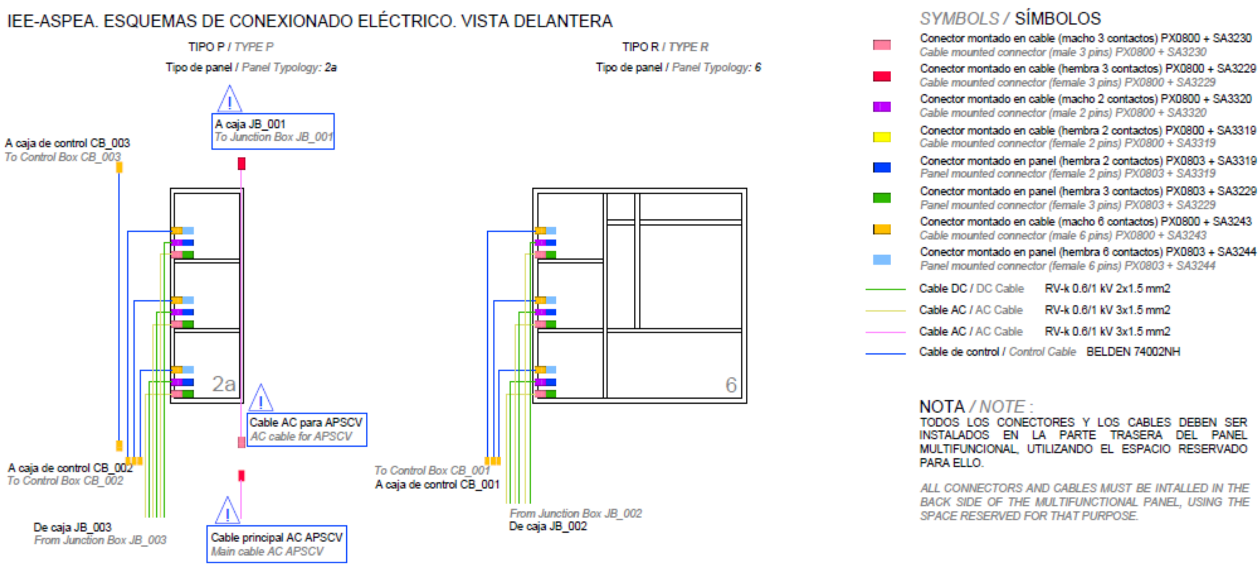


Figure 25 Detail of electrical installation drawings for demo

Façade System Energy Management & Building Management [WP6]

The façade Energy Management System (EMS) is a vital achievement of MeeFS project. This system may be compared to the nervous system of a human body, performing similar functions in MeeFS intelligent façade structure, i.e.:

- <u>sensing/measuring</u> the signals from the nearest surrounding of the façade, and from the inside of façade's structure itself,
- <u>analysing</u> the current state of the façade, by taking into account the façade's current operating conditions, and computing the best set of actions for the façade to make, in order to bring the façade to the next, most desirable state,
- <u>issuing the control signals</u> to active TUs.

This system is easily adaptable to highly different configurations of possible application scenarios (different buildings, different climates and different operating conditions), because of its highly flexible design in terms of hardware and software structures. The flexibility of these structures has been attained by using simple and easily scalable solutions in both the hardware and software design cases, i.e.:

- the hardware – consisting of façade's CPU, an interconnected group of integrated drivers (called nodes) and sensors. Different roles of CPU and nodes may be implemented by using software modifications, and/or by using hardware extension boards,
- software – CPU has a linux based system running on it, allowing for writing custom façade management programs, for example implementing services, like: façade's algorithm evaluation, communication service for nodes, monitoring system management, external communication (useful for e.g. ESCO, surveillance, failure detection applications).

The range of possible configurations of EMS is very large. This feature is intentional, as it allows for the system to adapt to many different building retrofitting scenarios. In order to present one of the possible configurations of the system, and also to test its performance in the real case conditions, the particular version of the EMS has been designed and made for the case of the Demonstrator (Demo) building (located in Merida, Spain), and integrated with the MeeFS intelligent façade structure. Following will be the short description of the Demo EMS.

The Demo EMS consists of the following components:

Central Processing Unit (CPU)

Nodes (integrated at each active TU)

Control boxes (communication between CPU and TUs)

Weather Station (WS)

Figure 26. Components used in the Demo EMS structure

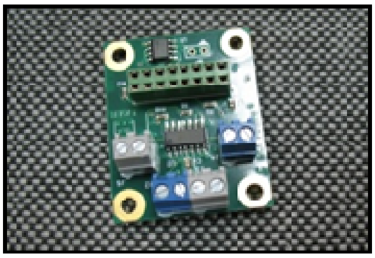
The following picture presents the layout of the EMS structure integrated in the Demo intelligent façade.

Figure 27. Overall layout of the Demo EMS structure

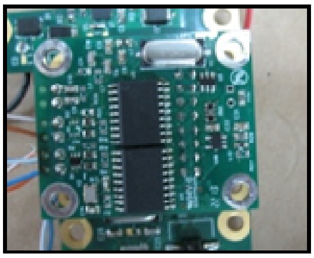
The EMS of the Demo implements the control algorithm that controls the operation of the PSC&V TUs, taking into account factors like: external ambient temperature and wind speed from the WS, internal temperature of the TU, temperature inside the corresponding dwelling, specific day of the year and time of the day, dwellers input. The EMS of the Demo is also responsible for performing monitoring data acquisition from the weather station.

The EMS is designed to operate fully autonomously, although it is possible to access it with internet via dedicated VPN connection.

For the node components special extension boards have also been developed, which were intended to be used with other types of TUs, however due to changes in the project, they have been not used in the final Demo EMS configuration. The following photographs indicate particular extension boards:

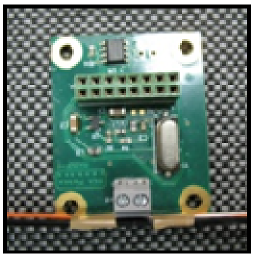


PSC&V TU
(used in EMS DEMO)



ASP&EA TU

(not used in EMS DEMO)



GREEN TU

(not used in EMS DEMO)

Figure 28. The EMS components considered for different façade units.

Composite Structural Material and Manufacturing [WP7]

The research related to the innovative material and its manufacturing process has fulfilled major achievements in terms of innovative composite materials, production process and product standardisation. Among the main achievements, the 6 followings are outstanding:

1. The Production of a thermoplastic pultruded profile with multi-orientation reinforcement fibre has been proven, at the same time the possibility to use the anionic pultrusion process to produce hollow section profiles reinforced by transversal fibres either from winding technique or from the use of fabrics. This opens a wide range of possible profile designs with outstanding mechanical properties.

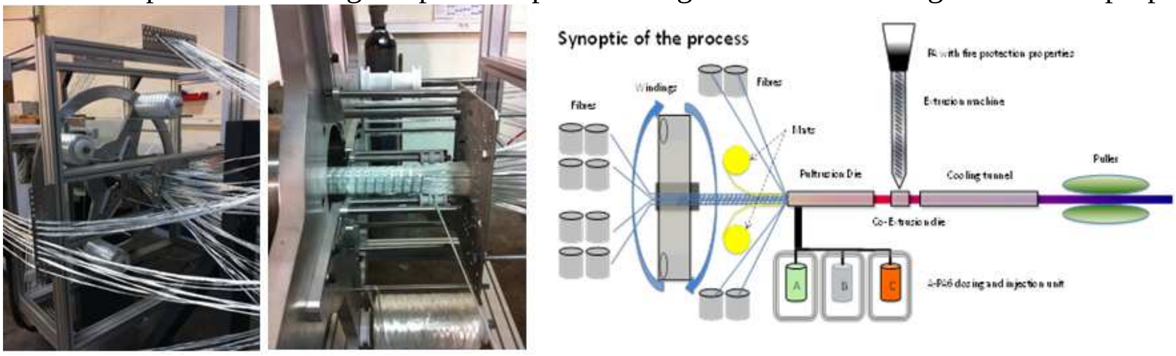


Figure 29. The production process considered for thermoplastic pultruded profile..

2. The Production of a large thermoplastic complex composite hollow cavities profiles has been carried out. During the course of the MeeFS project extensive trials have been carried out to identify the process parameters for the production of the main structural frame profile with multi-cavities. An impressive number of more than 800 bobbins have been used to form the pultruded shape.

Figure 30. The large thermoplastic complex composite hollow cavities profile manufactured.

3. The novel prototype reactive thermoplastic pultrusion line has been studied and achieved. The production of the structural panel required the design and construction of a novel thermoplastic pultrusion prototype line including specific dosing unit adapted to the anionic pultrusion process. Design, assembling, testing and production were successfully carried out at CQFD.

Figure 31. The novel prototype reactive thermoplastic pultrusion line.

The new reactive thermoplastic pultrusion process is powered by a powerful caterpillar machine specially designed for the production of such hollow cavity profile of about 5kg/m. The pulling capacity is around 7Tons with force sensors and profile slipping detection. The multi-component resin system is injected under pressure via the dosing unit developed for pultrusion into a pultrusion die of the required profile

shape.

Figure 32. The novel prototype reactive thermoplastic pultrusion line.

4. The special non-burning inorganic paint for thermoplastic composite profiles has been manufactured. This non-burning paint is based on geo-polymers which do not burn until 1000°C. With such a coating, the burning ability of the composite profile is reduced and the smoke emission is limited. CQFD has carried out trials to identify a formulation compatible with PA6 surface.

Figure 33. Special non-burning inorganic paint for thermoplastic composite profiles

5. Fast and easy assembling and mounting on site has been proven [WP9]. The complete façade was assembling on site to minimise transport cost. The full operation took about one month, plus 2 weeks of façade installation onto the building. Assembling and Mounting the MeeFS system turned out to be easy and without any majors troubles.

6. Finally, successful complete standardisation of the novel MeeFS facade, one of the most crucial project milestone points, has been successfully performed. The main objective of this task is to define the legal requirements that apply to the new façade developed by MeeFS project and to make the corresponding tests to be carried out on the façade units to address the Spanish Requirements. To be able to make this characterisation it has been necessary to build specific prototypes. The final results have been used to define which technological units can be installed in the demo building in Merida.

The steps carried out in the document to define the requirements that need to be fulfilled by the system are the next ones:

1. Product definition: The MeeFS project is going to define a new type of façade with some differences compared to the façades that are at this moment in the market. In this point it is going to be described how we define the MeeFS façades trying to find similarities to those defined in the façades standards.
2. Test according to product definition-ETAG 034: Once found one standard that could be used as a start point to define the characteristics of the MeeFS façades, define which are the requirements that must be evaluated and the verification method.

3. Spanish requirements and mandatory tests: to define those product characteristics that shall be determined according to national, regional or local regulation, taking into account the requirements established for Spain
4. Test vs. technological modules: To define the units that must be tested and the tests per unit.

To define the product, the MeeFS system has been analysed taking into account its different components, the characteristics of these components and the definitions in the different standards. After this analysis it was obtained that there is a standard that almost covers the entire system. This standard is the ETAG 034 “Kits for external wall cladding”. The conclusion after the analysis is that ETAG 034 should be used as a base for verification of the performance of MeeFS System because there is no other standards that cover better the system.

The tests according to product definition (ETAG 034) have been defined. The objective of this point is to check the contribution made by MeeFS System to the fulfilment of the seven Essential Requirements, as stated in the CPR for the construction works in which the product is installed.

- Basic Requirements for Construction Works (BWR):
    - BWR1: Mechanical resistance and stability
    - BWR2: Safety in case of fire
    - BWR3: Hygiene, health and the environment
    - BWR4: Safety and accessibility in use
    - BWR5: Protection against noise
    - BWR6: Energy economy and heat retention
    - BWR7: Sustainable use of natural resources
    - ETAG also considers “Aspects of durability and serviceability”
- INITIAL ASSUMPTION: MeeFS System is a ventilated cladding
- ETAG 034 defines the test procedures to be applied. These tests are defined in deliverable D7.7

The Spanish requirement and mandatory tests have been defined, the Objective of this point of the document is to define those product characteristics that shall be determined according to national, regional or local regulation. In Spain the reference document is called **Código Técnico de la Edificación, CTE.** The Spanish Technical Building Code (CTE) is the normative framework that establishes the safety and habitability requirements of buildings set out in the Building Act (Ley Orgánica de la Edificación, LOE). CTE is based on the concept of performance or objectives, in which objectives and the means of achieving them are clearly stated, without implying an obligation to use particular procedures or solutions.

According to all above, the test for the Technological modules have been performed and the final results presented. In the next table shows the different tests performed to the MeeFS system per technological unit and the final results obtained by the system.

TECHNOLOGICAL UNITS	REACTION TO FIRE (EN 13823; EN 13501-1 ETAG 034 Annex E1)	WIND LOAD (ETAG 034)		IMPACT: Hard body impact (ISO 7892:1988); Soft body impact (ISO 7892:1988); Impact categories according to ETAG 034		WATERTIGHTNESS (EN 12865 and ETAG 034)	SOUND INSULATION (EN ISO 10140, EN ISO 717-1)	AIR PERMEABILITY (EN 1026, EN 12207)
	TEST	PRESSURE	SUCTION	HARD BODY	SOFT BODY	TEST	TEST	TEST
BIPV	No Classification	2400Pa	3000Pa	Category I	Category I	450 Pa		
INSULATION	B-S1-D0	2400 Pa	3000 Pa	Category I	Category I	450 Pa		
VENTILATED FACADE	B-S1-D0	3000 Pa	2000 Pa	Category I	Category I	600 Pa		
GREEN FACADE	B-S1-D0	2500 Pa	3000 Pa	Category I	Category I	600 Pa		
SOLAR PROTECTION	B-S1-D0	3000 Pa	2000Pa					
ASP&EA	B-S2-D0	2400 Pa	3000 Pa	Category I	Category I	600 Pa		
APSC&VU	B-S1-D0	3000 Pa	2000 Pa	Category I	Category I	≥300 Pa	Mode A: 37,7 dBA ; Mode B: 38,1dBA ; Mode C: 42,6dBA	Class I

Figure34: Tests results of the MeeFS system

As can be seen in the table all the samples obtained a valid classification (green rows). The only unit that had problems during testing was the BIPV (photovoltaic unit). This technological unit didn't obtain the minimum classification under the fire reaction test (for Spain is a B-S3-D2). Due to this, the unit couldn't be installed in the demo building. In the table there are also grey rows. These rows were defined as not necessary for some of the tests (example: the solar protection didn't require the water tightness test because it is an open unit which always has a window on its back space (the window is the element that provides the water tightness).

All this information is explained in detail in D7.7 "Report with the verification of performance of the system designed under European Standards". The main conclusion of the task T7.11 is that the system demonstrates the minimum characteristics to be installed in the demo building without legal problems. Some of the units demonstrated very high values in the different tests. These values can be used in the future as commercial arguments to sell the system with better possibilities.

Façade System Guide of Design [WP8]

The Façade system guide of design has been developed, in the framework of work package [WP8] in order to provide guidance and reference to retrofitting designers, and users of buildings; it is composed by three different entities: A Guide of Design, which establish the most adequate bioclimatic approaches for each climatic zone and considered building; the ERES software tool, which is a decision support Tool for designers that delivers the most adequate refurbishment configuration based on technical and economic considerations and; a Guide of Maintenance, to ensure the performance of the refurbished buildings during the service life of the refurbishment system, as well as its required maintenance.
The Guide of Design introduces the building designer to the proposed refurbishment modular system as well as its energetic performance. This guide covers constructive capabilities, thermal and energetic considerations, regulatory restrictions and the most suitable façade configuration of a set of standard cases. The guide of design is a supporting tool for the MeeFS Facade designers: architects, structural & MEP engineers. It allows for optimal organising of construction process and the selection of the most appropriate Technological Units. The guide document is a multi-disciplinary

explanation of the MeeFS Design process: the most important theoretical basis of MeeFS Façade System.

The ERES software tool comes right after the design guide: it can recognise characteristic façade elements thanks to its interoperability with third-party BIM software, and analyse the building surroundings. According to the climatic zone and to the intentions of the user, it provides optimal combinations of the MeeFS Technological Units, giving as a result the expected energy and economic savings, the estimated payback period, and a forecast of the investment needed for the whole retrofitting.

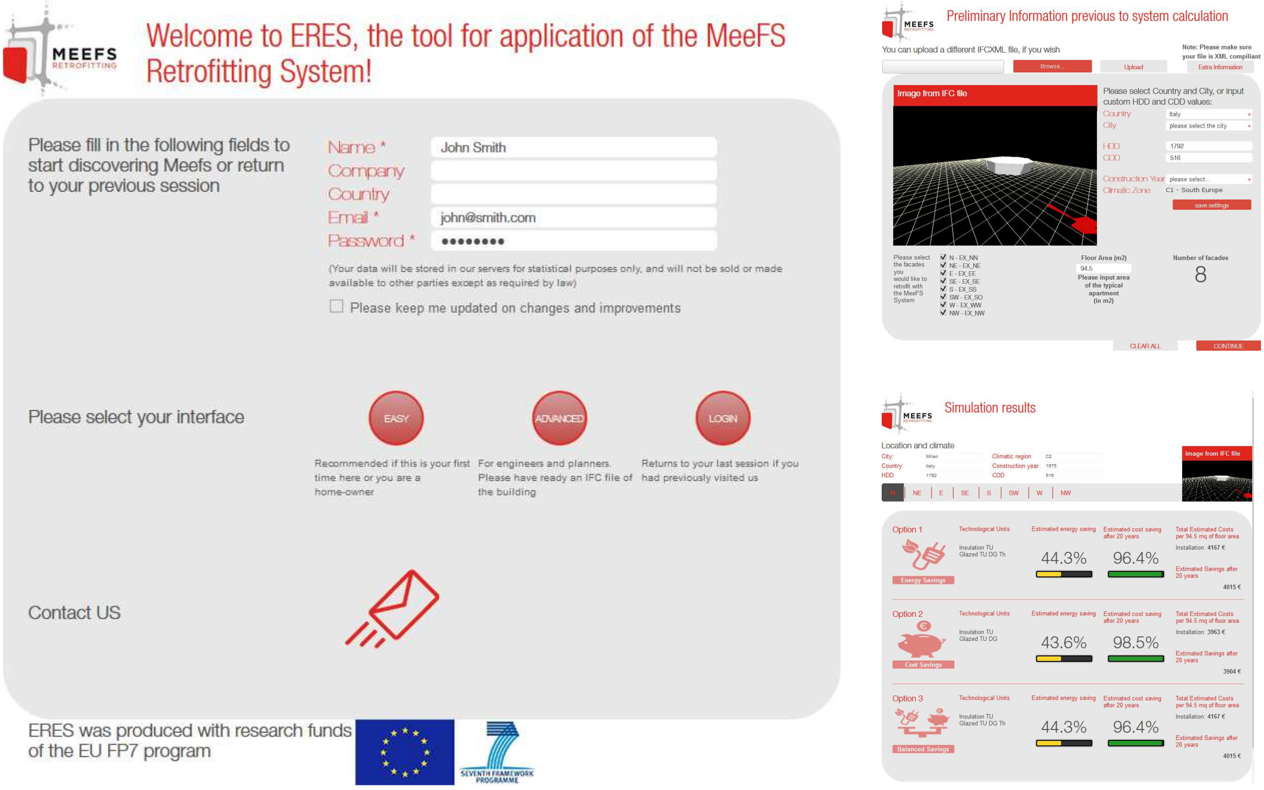


Figure 35. ERES is free to use and public available at the URL http://simulator.meefs-retrofitting.eu/

Additionally, the Guide of Maintenance for the façade system takes advantage of two main databases: the knowledge of the construction process and the correct maintenance practices regime. The document is a summary of experience gathered during the construction of the Demonstration Façade, and an overall set of rules for good maintenance practices in building management. It was also enriched with some proprietary information about advanced maintenance techniques required during handling of breakthrough technology prototypes. There is also a detailed section of the document covering legal actions and public hiring process that precede actual site works.
The guide provides a support to future MeeFS System users & customers: designers, building managers and owners. It is also the most comprehensive source of MeeFS data for execution teams.

Demonstration of MeeFS Façade System [WP9]

The main goal achieved during the whole project in the frame of the demonstration activities [WP9] was the full scale MeeFS prototype installation in the Pilot Building in Mérida (Spain). The final demonstration is a result of the process composed by different phases of the installation process, the most crucial ones being the technical design documentation preparation process, assembly activities in the workshop, and the real demonstration on-site.

The first steps were to carry out of a set of initial studies, in order to provide the best possible starting conditions in the demo site. Thus, a demo preparation management plan was developed, focused on the successful performance of the demo “Pilot Building”, both in a technical but also social context.
The insight to the social environment of the Pilot Building provided the first tips on how to address the demonstration in a real scenario. Having collected information from the social workers staff from Junta de Extremadura, the decision to change from the initially selected demo building was taken, due to the possible social problems indicated which would be difficult to solve in the limited project execution time. The communication strategies were defined and the first contacts with the residents were established. Informative printed documentation was provided disseminating the retrofitting plans in the form of documentation (posters, flyer and mailing campaign), phone campaigns, meetings and door-to-door visits. Additionally, regular contact with the residents was necessary, to keep them informed about the Project. Studies of the consumption habits of the residents (billing information, surveys) were also conducted. In the context of the basic design and particular technical conditions to be considered, the information was compiled about the Pilot Building construction, installations and constructive details. Initial “As built” documentation was obtained and analysed. Accurate drawings of the three façades affected were elaborated from a topographic survey and readjusted with the on-site Laser Scan 3D (points cloud). Finally, the technical inspection was carried out, and the corresponding report of the current state described the construction pathologies detected outside and inside the apartments. The slabs identified for the installation of the new façade elements were also initially tested, to define the maximum loads allowed.

Figure 36. Pilot Building considered for retrofitting with MeeFS facade

Figure 37. MeeFS Partners visiting the Pilot Building, Mérida 2012 (Spain

Using the initial information gathered the modelling of the Pilot Building with Energy Software Tool was performed under the conditions extracted from all the information collected and results were presented. The energetic simulations were made with Design Builder (energy software tool). The modelling and the simulations of the Pilot Building were elaborated for both cases, the base case (Pilot Building at the initial state) and the MeeFS case (first draft of the Pilot Building retrofitting with MeeFS Façade System). This way, a comparison of the results before and after the retrofitting was obtained.
These results showed the great energy saving potential of MeeFS retrofitting solution in the building stock constructed before 2000.

On the basis of the ongoing progress of the Architectural and Structural Design and the Energetic concept of the system, the draft of the Façade System Construction Project for the Pilot Building retrofitting and its economic analysis was elaborated.
The demo design was issued in the form of the Building Permit and Execution Project Design. The complete set of the drawings and descriptions were delivered, following the established strategy for

their performance in the Spanish legal framework. The process on adaptation of the technical documentation to the Spanish regulations required the involvement of the local team of architects (GREENSTD) that worked in close collaboration with the partners directly involved in demonstration. The technical design documents (Execution Projects) were produced for the installation of the MeeFS System in the external East, South and West Façades, but also the installation of the traditional ETICS System on the courtyard façade to avoid the envelope thermal bridge effect and to allow the correct monitoring of the MeeFS façade system in the dwellings affected.
Based on the Spanish technical documents (Executio Projects), and in collaboration with the City Council, the Building Permit was obtained and the on-site activities started.
The assembly activities and storing of the construction materials have been taken at the workshop of the local company (EXTREPERSIANAS S.L). The MeeFS façade structural panels, and integrated technological modules, were successfully assembled following the "Assembly Guides" prepared. Two training sessions were arranged on-site in Mérida, in a manner that the partners involved taught the local operators the procedures and details of each step of assembling the components of the system. The control of the materials was ensured by the corresponding register of delivery notes and shipping sheet, as well as the registration of all materials before exiting the workshop. In order to ensure the quality control of all activities of assembly, a control inspection sheet was filled for each multifunctional panel assembled.

Figure 38. Sequence of the assembly of a Structural Panel and Technological Units

The on-site activities started with the installation of the ETICS **System on the Patio Façade**. This task was developed under the Construction Contract signed with the specialised company IMBATÍVEL E NOTÁVEL, and it was finished in February 2016.
Having obtained the building licence, the public tendering was launched in order to the hiring process of the construction company (COEDYPRO). Following Spanish regulations, and after the certificate of commencement of work was signed, the on-site work started in September promoted by the owner of the building Consejería de Salud y Políticas Sociales (Junta de Extremadura) and parties involved COEDYPRO, Empresa Constructora S.L. as builder, GREENSTD as architects and engineers team in charge on Project and Site Management and ELABOREX in charge of the Quality Control inspection. All these companies have acted in the Project subcontracted by Consejería de

Salud y Políticas Sociales (Junta de Extremadura). Following the calendar approved, the construction duration was 12 weeks, and completed in December 2016.

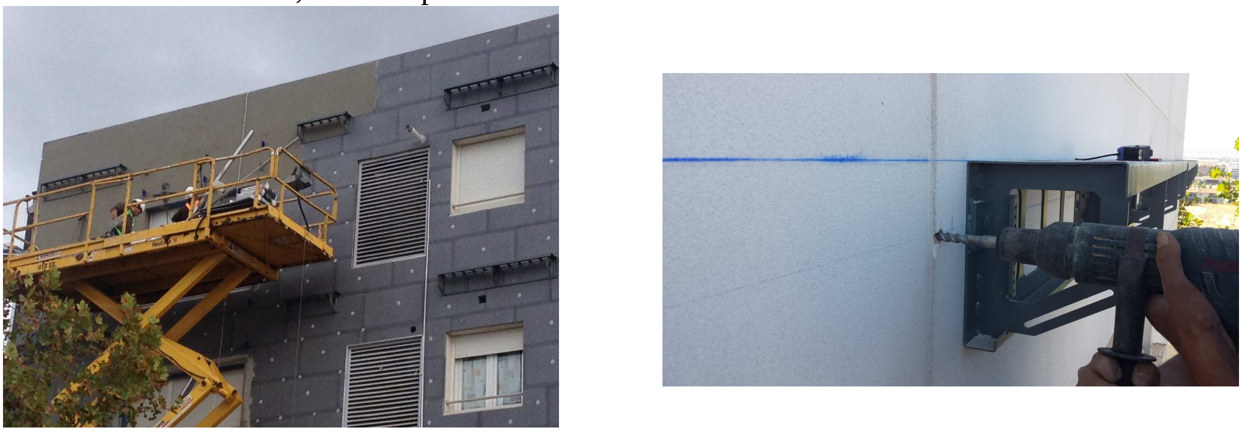


Figure 39. Installation of ETICS layer and fixing of Structural Trays

Figure 40. Transport and Lifting the Multifunctional Panels

Figure 41. Fastening the Multifunctional Panels to the Structural Trays

Figure 42. Traction tests performed and concret strength tests.

The preparation of an appropriate plan for the monitoring system, allowing monitoring of the building's energetic and comfort living related conditions for a certain period before and after installation of the MeeFS intelligent façade, was a challenging, lengthy and absorbing process. There were several reasons for this fact, like: the overall complexity of the system (e.g. a vast amount of various types of signals/sensors), the battery operated data acquisition system (greatly limiting the acquisition hardware capabilities), many changes of initial TU's distribution pattern in the monitoring system plan development phase (implicating many changes of the monitoring system design). However, eventually a well-suited design of the monitoring system has been developed, strictly addressing the specific Demo building monitoring needs. To see the system complexity, the following diagram may be presented, demonstrating the topology of the interconnections, sensors and acquisition nodes used in the system.

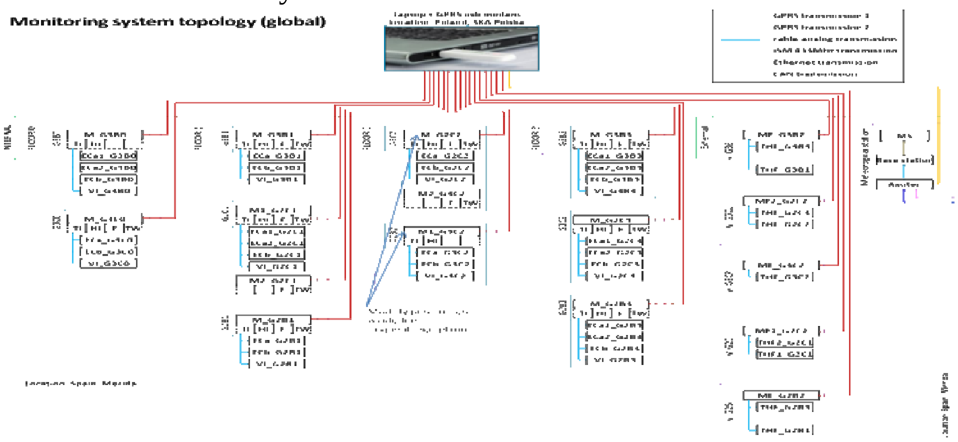


Figure 44. Topology of the MEEFS intelligent façade monitoring system

The physical implementation of the system has been mostly based on commercially available hardware equipment, like sensors and acquisition modules. However, some of this equipment had to be adapted in order to comply with the electronic and mechanical standards used within the monitoring system structure. Adaptation has been achieved by making additional pieces of customised PCBs and by providing the modified mechanical enclosures. The monitoring system, up to the moment of writing this document, has provided nearly 3 years of observation data.

The initial comparisons between the data before and after the retrofitting, even from such a short available period, show the sensible improvements in thermal resistivity of façade and internal comfort level. The energy certification of the dwellings was made with the Spanish well recognised software tool CE^{3}X. The modelling and simulation obtained between building cases before and after the renovation led to an increase in the building energy certification notes. The energy certification obtained must be considered as an approximation, due to the tool design limits, at least until the final monitoring results relocation and treatment. Under these initial simulation conditions, and in order to have an idea of the impact of the whole performance, the average data from each block was calculated. For the Energy Demand (saving around 15%) and Primary Energy Consumptions (saving around 36%), the improvements were so significant, since the MeeFS case was tuned to a better mark. For the CO2 Emissions, even that the mark did not change, the savings obtained were relevant, around 35%.

ENERGY QUALIFICATIONS PRIMARY ENERGY CONSUMPTION
kWh/m2 año

GATE	APARTMENT	HEATING DEMO	HEATING MEEFS	COOLING DEMO	COOLING MEEFS	GLOBAL DEMO	GLOBAL MEEFS	SAVING
P03	P01_VIV_J	203,48 F	125,83 E	26,46 D	23,47 D	248,60 F	168,00 E	-32%
	P01_VIV_E	184,16 F	104,33 E	24,58 D	21,37 D	228,00 E	145,00 E	-36%
	P02_VIV_J	191,82 F	101,57 E	26,87 D	22,68 D	237,40 F	142,90 E	-40%
	P02_VIV_E	184,16 F	100,59 E	24,58 D	20,86 D	228,00 E	140,70 E	-38%
	P02_VIV_J	223,28 G	150,00 E	25,79 D	21,45 D	277,80 G	190,20 E	-32%
	P02_VIV_E	224,24 G	148,46 E	23,55 D	19,80 D	267,10 F	187,60 E	-30%
					GATE 03	247,81 F	162,40 E	-34%
P02	P01_VIV_J	189,03 F	110,19 E	24,86 D	21,56 D	232,60 E	150,50 E	-35%
	P01_VIV_E	184,16 F	104,33 E	24,58 D	21,37 D	228,00 E	145,00 E	-36%
	P02_VIV_J	182,57 F	84,86 E	25,15 D	20,71 D	226,40 E	124,30 E	-45%
	P02_VIV_E	184,16 F	100,59 E	24,58 D	20,86 D	228,00 E	140,70 E	-38%
	P03_VIV_J	222,11 G	131,64 E	24,16 D	19,63 C	265,00 F	170,00 E	-36%
	P03_VIV_E	224,24 G	148,46 E	23,55 D	19,80 D	267,10 F	187,60 E	-30%
					GATE 02	241,18 F	153,01 E	-37%
					PILOT BUILDING	244,49 F	157,70 E	-36%

< 26.2	A
26.2-45.2	B
45.2-73.7	C
73.7-115.8	D
115.8-237.0	E
237.0-267.8	F
≥ 267.8	G

Figure 44. Pilot Building before and after the retrofitting with MeeFS System, on the left corner the final certification performed in comparison to the

In the context of a social housing neighbourhood, the communication with the residents has been permanent since the beginning of the Project. The success of the demonstration was only possible in the context of good connection with the dwellers. Awareness raising activities were carried out, informing the residents about the Project, and involving them actively into the approach of energy efficiency renovation. The project faced different problems, related to the social issues and the public nature of the demonstration, being still on-going the part on recollecting of the monitoring data under the agreement made between the partners involved.

Exploitation & Dissemination [WP10]

The MeeFS project partners were actively involved in a number of Dissemination & Exploitation activities throughout the project, that are deeply described in continuation of the document. Communication material (flyer, posters, roll-up banner) has been regularly used by all partners and was distributed to stakeholders whenever possible. Dissemination material can be easily downloaded from the Project Website www.meefsretrofitting.eu. The website has been regularly updated and promoted by all partners. In addition, six scientific articles and ten journalistic articles were published. Consortium members have also been involved in networking activities, jointly attending over 100 events/dissemination activities.
Beyond the global façade system, the MeeFS consortium has generated a whole set of results, some of them with a high potential for exploitation The exploitation strategy of each result was built with the consortium during five yearly exploitation workshops, and through bilateral exchanges. In the case of results with multiple ownership, “exploitation leaders” were designated. An Exploitation Plan for each key result was prepared and delivered. Two events, targeting different stakeholder communities, were also organised.

The potential impact and the main dissemination activities and exploitation of results

Only 1 to 2% of the building stock is replaced annually in the EU (less than 1% in some countries)[8]. Hence most of the energy savings required to meet the 2050 goals must come from existing buildings. According to IMPRO-building study, about 70% of the total building stock was constructed after 1945 and a majority of these buildings were constructed without consideration for energy efficiency criteria.

The targets to reach greater energy efficiency are residential buildings, which represent about 75% of the total building stock and 63% of final energy consumption in the building sector. The current retrofitting practices for residential buildings pose a variety of challenges to the construction sector, leaving considerable room for future performance improvement. Furthermore, today's measured rate of refurbishment (1.2%) is much lower than what is necessary to remain in line with Europe's 2050 ambitions. There is a need to accelerate the market uptake and large-scale implementation of energy efficient refurbishment solutions and increase the renovation level to 2-3% per year until 2030. This ambition is reflected in several European regulations and roadmaps, such as the Energy Performance of Building Directive, the Energy Efficiency Directive, the SET-Plan (Action 5) and the recent Energy Union Winter Package.

The building envelope (roof, façade and basements) must be addressed as a priority in order to achieve proper levels of energy efficiency coming from the retrofitting of buildings. The façade represents the largest part of the heat transmission surface and includes a number of critical components (like windows, balconies, ventilation units, etc.), while facing thermal bridge phenomena. However, most solutions available in the market only offer thermal insulation, have poor aesthetics and are rather uniform in terms of applicability to different typologies of buildings and to different façade orientations. Climate and energy needs are also not properly considered.

This calls for the development of an energy efficient integrated and modular system that can be easily and quickly fitted to the façade of any residential building in Europe: this is the challenge addressed by MeeFS retrofitting, which has developed, evaluated and demonstrated an innovative and integrated energy efficient multifunctional façade system (decreasing the energy demand by more than 30%), modular and adaptable, geared towards the residential building sector.

The potential socio-economic impact includes the following points:

- The market uptake and roll-out of solutions such as the MeeFS system will contribute to reaching the 2020 and 2050 EU targets (i.e. by decreasing CO2 emissions and energy consumption of the residential building stock)
- The future commercialisation of MeeFS would also create specialised jobs, in particular for the pre-fabrication of the components and their pre-assembly.
- Additionally, the wide-scale deployment of pre-fabricated solutions such as MeeFS will contribute to reaching the expected performance when refurbishing buildings. The European building sector is indeed highly fragmented (with over 95% of SMEs) and not yet able to offer holistic solutions for deep renovation at acceptable cost and quality. Renovation processes are seen as costly, time-expensive, disruptive and risky by the consumers, and the measured performance is often below the expected one. Integrated pre-fabricated refurbishment solutions, which reduce the risk of poor installation and construction (and

[8] according to the EPBD recast directive

associated cumulative commissioning gaps) address this challenge and also pave the way to the deployment of energy performance based contracts, which are seen as one of the potential future business models which will allow consumers and the market to invest with confidence.

Main dissemination activities

To raise awareness on the innovative solutions developed within the MeeFS project and facilitate their introduction onto the market, project partners have participated in a wide number of dissemination activities. Early on in the project, graphical material has been produced for the MeeFS project to ensure consistency and efficiency in communication activities. As part of this material, a visual and written identity has been developed for the project together with key messages on technology, energy and economic impact. In addition, a project leaflet has been created and updated to include the main project achievements. A poster and a roll-up banner have also been produced and used to promote the project at events, fairs and conferences.

This graphical material has been presented in a detailed Awareness and Dissemination Plan aiming to define the key messages, target audiences and main dissemination channels for the project. This Awareness and Dissemination Plan was used as guideline for all communication activities related to the MeeFS project and has been updated on a yearly basis. Each of the subsequent versions summarised the dissemination activities already carried out by project partners and presented an updated list of stakeholders that should be targeted within the project and the concrete plans and dissemination opportunities of the year ahead.

The first list of target audiences established at proposal stage has thus been enriched by partners throughout the whole project. The stakeholders mentioned in the following list have been identified as target audiences. This list gives examples of the specific stakeholders that have been targeted with dissemination activities, but it is nevertheless not exhaustive as project partners have been in contact with a wide range of audiences.

- European Technology Platforms such as European Construction Technology Platform (ECTP) and other related platforms such as the PV platform, RHC (RES for Heating and Cooling), SUSCHEM.
- Local Authorities & National/Regional Public Bodies (like Municipalities) are key players as policy makers, favourable legislative framework creation, public procurements, owners and promoters of their own buildings.
- Architects' Associations like ACE (Architects Council of Europe) need to be provided with appropriate tools for retrofitting.
- Building industry providers and installers through national, European and international associations related with the technologies developed in the project like EPIA (European Photovoltaic Industrial Association), ESTIF (European Solar Technology Industrial Federation).
- Construction companies' associations should be aware of the new technologies that will be developed like ENCORD, FIEC and more.
- National and regional Energy Agencies.
- Public Promoters like CECODHAS (European Federation of Social Housing) and Private Promoters (European Real State Association) can offer to their clients the advantage of the developed systems.
- Clients and users are key actors providing their perspectives in the formulation and assessment of the project results.
- Related research community and citizens.

- Standardisation and Certification bodies
- The European Commission, European Network of National Contact Points (NCPs) for NMP theme.
- Innovation Relay Centres (IRCs) network and other European market places, by offering technology transfer possibilities regarding MeeFS results for industries but specifically for SMEs.
- ICT based stakeholders: Analysis and Design tool providers.
- Designers, Engineers and consultants

These target audiences were addressed through different communication channels, defined at the beginning of the project. The dissemination channels were selected to reach out to a wide variety of audiences and comprised:

- **A dedicated website presenting the objectives, partners and the activities of the project.**

The website has been online since M3 and has been updated with 49 stories on activities and developments within the project. A series of ten articles and interviews written by professional journalists has also been published on the project website and hosted on the www.youris.com website, the youris.com media centre as well as on LinkedIn and on partners' websites.
Since its launch, the MeeFS website had 23,823 visits, representing over 5,000 unique visitors. Web traffic particularly picked up in the final year of the project, thanks to communications efforts as results became available. As shown in the map below, the project website attracted visitors from around the globe. The darker the shade of blue, the more unique visitors from each country:

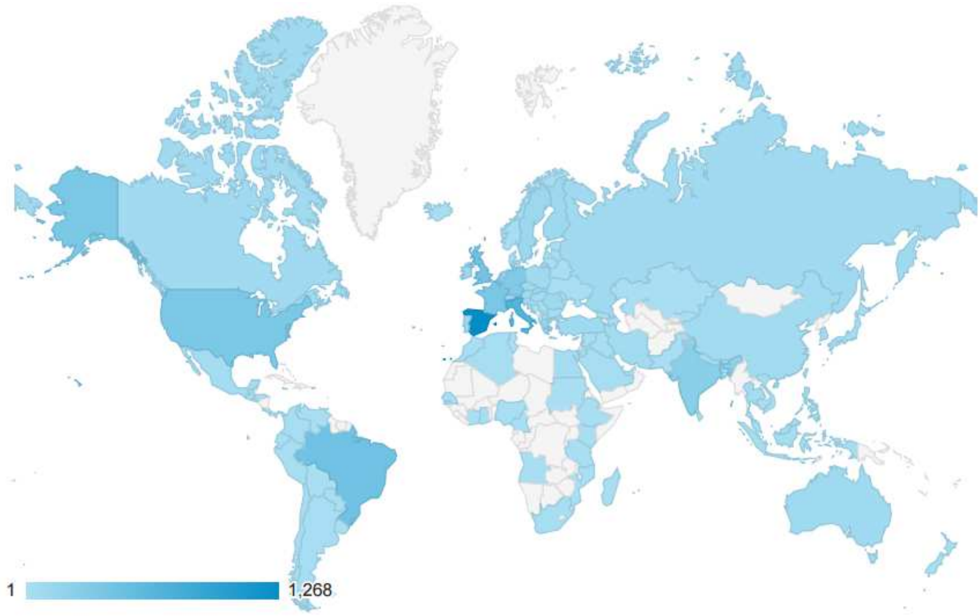


Figure 45: Geographical spread of website

- **Social media presence.**

The MeeFs project had a social media presence throughout the entire duration of the project. Twitter and LinkedIn have been selected as main social media channels to communicate about MeeFS innovative solutions. To reach a wider audience, consortium partners used their Twitter accounts to disseminate the information, jointly tweeting about MeeFs over 60 times.

- **Publications in scientific literature and dedicated journals and reviews.**

Publications in at least 4 ‘high impact’ peer-reviewed international journals were planned in the first version of the Awareness and Dissemination plan to make the obtained results available to the scientific community. This target has been successfully achieved with 6 papers published in international academic journals. MeeFS partners published peer-reviewed articles in international journals such as the Journal of Sustainable Cities and Society, Journal of Energy Journal of Renewable Energy, Journal of Facade Design and Engineering or Fire Safety Journal.

Articles were also submitted to conferences for presentation, including large, international industry conferences such as Congress on Architectural Envelopes, CISBAT Conference and the Conference on Advanced Building Skins, among others.

In addition, partners have produced a number of non-scientific articles about the project. Together, project partners have published a total of 44 papers/articles.

- **Presentations and participation at congresses, workshops, symposia conferences, exhibition fairs.**

Throughout the project, partners have presented the MeeFS project in over 10 international conferences or congresses such as the CISBAT conference, REHABEND or GENERA as well as during the EU Sustainable Energy Week and the World Sustainable Energy Days. Additionally, the project was represented in five trade fairs, including BATIMAT and SOLAREXPO.

At the end of the project, the MeeFS retrofitting system was showcased as an example of cutting-edge innovation during the 7th European Construction Technology Platform (ECTP) conference on 17-18 November 2017, attended by over 100 people in Brussels, Belgium. The MeeFS envelope system was presented by Magdalena Rozanska from Acciona during the conference session on 'New technical solutions to accelerate the renovation of Europe's building stock'. In addition, MeeFS had its own exhibition stand, manned by Greenovate! Europe, enabling face-to-face interaction with conference attendees from across the construction industry. The conference was an ideal opportunity to explain the advantages and future potential of the MeeFS facade and discuss the possibilities for commercialisation or further development with a wide group of stakeholders.

In total, project partners took part in over 100 events to disseminate information about the MeeFS project. Through these events, a wide range of audiences covering building industry representatives, researchers, entrepreneurs, students, investors and policy-makers were reached.

- **Project events**

To reach the dissemination objectives of MeeFs, two stakeholder workshops were organised with the aim to involve professional stakeholders to enhance their awareness about the project and the novel technologies which are being developed as a part of it, spread best practices, and foster networking opportunities.

The first MeeFS stakeholder workshop, entitled “Pre-fabricated facades – niche forever or mass market soon?” took place 2 November 2015 in Vienna, Austria. The workshop, hosted by the University of Natural Resources and Life Sciences (BOKU) of Vienna, and organised in partnership with the EU-GUGLE project, brought together professional stakeholders from the construction and energy sectors to discuss the actual deployment pre-fabricated facades based on the experiences of the two projects. The event allowed for exchange of views on the proposed innovative technologies, and facilitated networking opportunities and synergies with potential early adopters and users throughout Europe.

The second stakeholder workshop was combined with the project's final mini-conference and networking reception on 16 November 2016 in Brussels, Belgium. Nearly 30 stakeholders from the construction and energy sectors as well as regulators, researchers and policy-makers attended the event to learn about the technology developed, lessons learned from the MeeFS project and discuss how to bring multifunctional pre-fabricated facades closer to the market. The interactive format of event allowed for an exchange of views on the proposed innovative technologies, and facilitated networking between the attendees.

- **Networking activities**

Different types of networking activities were conducted, mainly focusing on establishing networks with existing networks or projects. Active links were established with construction and energy related European platforms such as ECTP, SmartGrid, PVTP, ESTP, E2BA and more.

Also, the EC supported FP7 project NEWBEE was approached to create active links with them and find areas of collaboration. Both NEWBEE and MeeFS have in common the development of business models which will support the expansion of high performance construction processes resulting in sustainable buildings, both new and renovated. In addition, cooperation was established with the EU-GUGLE project in the framework of the first stakeholder workshop.

- **Audiovisual material.**

G!E/iCons developed and released a project video, which introduced the project, its main objectives and achievements, as well as energetic, environmental and industrial features of the MeeFS technology.
The video production was coupled with a tailored distribution methodology. It has been published on the project website, promoted on the partners’ website, Greenovate! Europe Twitter accounts and Greenovate! Europe YouTube Channel.

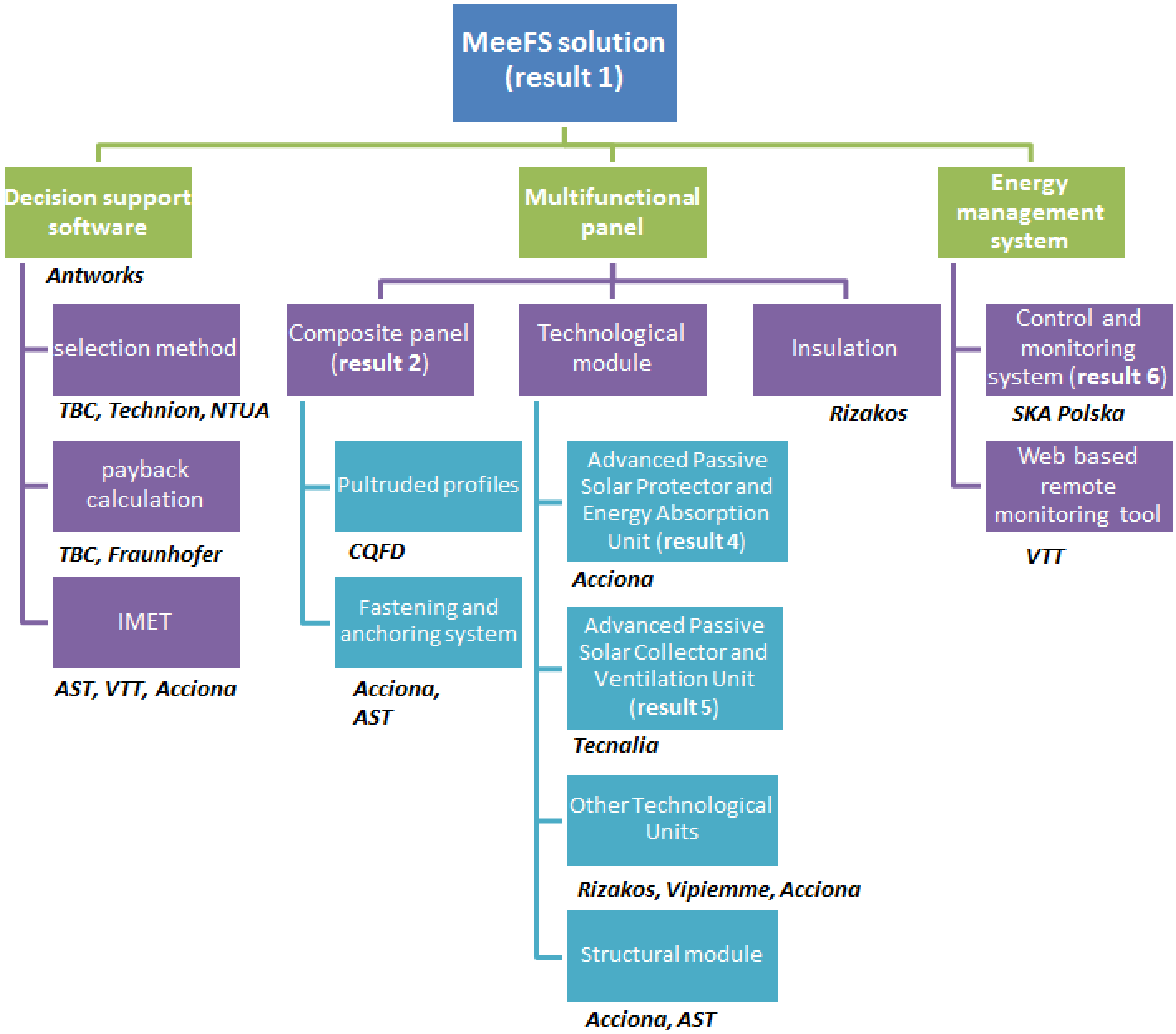
The joint efforts of WP10 Leader Greenovate! Europe and project partners helped the MeeFS project reach a worldwide audience through the whole duration of the project. Selected target audiences have thus been informed about the MeeFS system through different communication channels, opening the way for further exploitation of the project results.

Exploitation results

MeeFS Retrofitting has developed, evaluated and demonstrated an innovative energy efficient multifunctional façade system, modular and adaptable, geared towards the retrofitting of residential building, but also applicable to the non-residential sector and for new constructions.
Beyond the global façade system, MeeFS consortium has generated a whole set of results outlined below. Some of them have a high potential for exploitation:

Results	Co-owners	Exploitation potential
The whole retrofitting process using MeeFS technologies	All partners cited below	KEY RESULT 1
A structural frame made of a thermoplastic composite material	CQFD, AST, Acciona	KEY RESULT 2
A new industrialised pultrusion process for cost-effective manufacturing of the structural components	CQFD	KEY RESULT 3
An Advanced Passive Solar Protector and Energy Absorption Unit	Acciona	KEY RESULT 4
An Advanced Passive Solar Collector and Ventilation Unit	Tecnalia	KEY RESULT 5
A structural module, compatible with the structural frame	Acciona, AST	included in RESULT 1
ERES (software for design strategies), including: - The selection method to choose the optimal layout of Technological Units depending on the building location and orientation - Payback calculation	Antworks, TBC, Technion, NTUA, Fraunhofer	Included in RESULT 1
IMET (Installation Material Estimation Tool)	AST, VTT and Acciona	Included in RESULT 1
Building Energy Management System, including Control and monitoring system for the active technologies	SKA Polska	Included in RESULT 1
Web based remote monitoring tool, displaying the data from the BEMS	VTT	Included in RESULT 1

The interdependencies between these results are presented below.



At the beginning of MeeFS, most of these results were at TRL[9] 2 (technology concept formulated), except for result 5 (TRL 3 – experimental proof of concept) and result 3 (MRL[10] 3 – proof of concept validation). Thanks to the project and its full scale demonstration, most of the results reached a TRL 7 / MRL 8, as illustrated below.

[9] Technology Readiness Level
[10] Manufacturing Readiness Level

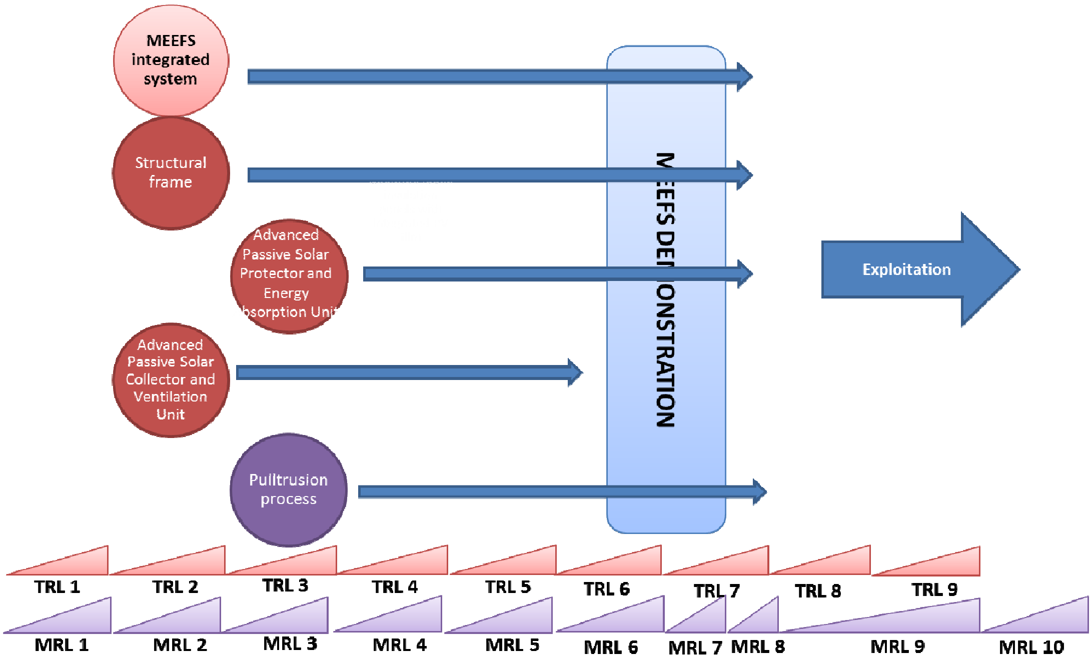


Figure 46 : TRL and MRL at the beginning and at the end of the project

Lessons learnt from the project and the demonstration

The demonstration on a residential building in Merida, Spain, has been very ambitious from the early beginning. It was a unique opportunity to test the construction processes developed in MeeFS, to measure the real-life performance of the various components of the multifunctional façade, and to capture important lessons learnt. It was also a strong constraint for the R&D phase, since the prototypes development had to quickly reach a TRL 7, with little time for iterations: this meant that risks related to R&D had to be carefully addressed and minimised, but which limited the potential for design optimisation.

The main lessons learnt are summarised in the following table:

MeeFS objectives	-	+	Potential for improvement
A multifunctional façade system with a multi-module technology and standard modules dimensions	Because of the pre-defined dimensions of the modules and panel, the system is in practice difficult to replicate in all EU buildings, as each building has its specific dimensions.	Flexible design, adaptability to various climate condition and facade orientation thanks to the different available modules	Make the system more flexible in terms of dimensions
Integration of innovative solutions, including lightweight materials (composites)	The costs required to test the system and obtain a Technical Agreement (compulsory for the demo) are very high. New tests may have to be carried out to demonstrate or commercialise in other EU countries	The composite panel and innovative technologies successfully passed the tests	Optimise the design of the structural profiles and module boxes to make the most of the lightweight and insulating properties of the composites.
Manufacturing with easy industrialisation	The sourcing of some of the innovative materials (i.e. PCM) is challenging.	Successful manufacturing of composites via pre-	Industrialise the manufacturing process for the composites panels.

	Prototype costs are very high since involving a lot of manual operations (e.g. drilling, painting, coating)	industrial production line.	Develop key partnerships to secure the manufacturing of the other units.
Off-site assembly	The assembly requires for the time being additional manual operations (e.g. screwing) The site for the assembly and storage of the different components had to be carefully selected (e.g. to reduce transportation costs).	Easy assembly of the panels thanks to the clear guidelines. Secured transportation with the dedicated lifting beam.	Optimise the design of the structural profiles and module boxes to facilitate the assembly
Fast installation with reduced on-site works	Difficulties to find a contractor willing to take the risk to install an innovative solution.	Very easy to install on site	Develop key partnership with interested construction companies and provide training to reach the required skills

Synthesis of exploitation plans for project results

The exploitation strategy for each result was built with the consortium during five yearly exploitation workshops and through bilateral exchanges. In the case of results with multiple ownership, “exploitation leaders” were designated.

A major challenge has to be overcome by the partners to exploit the MeeFS system: manufacturing. Apart from the manufacturing by CQFD of the pultruded profiles for the composite panel, no partner has the in-house capacity to manufacture the other technologies. Key partnerships with manufacturers therefore have to be developed. This also means that the industrialisation process (investment required, planning, time to reach first sales, break even, etc.) is not under the sole responsibility of the consortium. Preliminary Business Plans were nevertheless proposed. Although confidential, the main conclusions are presented below:

Result	Exploitation leader	Co-owners	Exploitation route	Further research or investment required
The whole retrofitting process using MeeFS technologies	ACCIONA	AST CQFD TECNALIA Antworks Technion NTUA Fraunhofer VTT SKA Polska	Trademark licensing	• Optimisation of design to maximise the benefits of composites Industrialisation to reduce costs • Certification / standardisation
A structural frame made of a thermoplastic composite material	AST	CQFD ACCIONA	Commercialisation by CQFD with Acciona and AST	• Optimisation of design to maximise the benefits of composites • Development of new coating • Certification
A new industrialised pultrusion process for cost-effective manufacturing of	CQFD	/	Direct use by CQFD	• Development of an industrial production line to reduce production

the structural components				cost
An Advanced Passive Solar Protector and Energy Absorption Unit	ACCIONA	/	To be determined when the manufacturing potential is secured	• Optimisation of design and sourcing of PCM to reduce cost
An Advanced Passive Solar Collector and Ventilation Unit	TECNALIA	/	Licensing by Tecnalia (under patent EP2520870 A1)	

The bigger picture: innovative business models for deep energy efficient retrofitting

Being technologically innovative is not enough, innovative business models need to be developed. New business models and financial mechanisms have to be put in place to make building retrofitting processes more and more affordable. This applies in particular to the retrofitting of facades for which the upfront investment is high.

Business models that cover the whole value chain (to achieve the targeted refurbishment performances) were reviewed. In particular, the adaptation of the ESCO approach to the residential sector was investigated as a potential route to commercialise the MeeFS system.

These business models and the potential for the future exploitation of the MeeFS system were presented and discussed during two stakeholder workshops organised in Vienna, 2015, and Brussels, 2016. These events allowed an exchange of views on the proposed innovative technologies, and provided networking opportunities and synergies with potential early adopters and users throughout Europe.

The address of the project public website and contact details

www.meefs-retrofitting.eu

All project contacts, its logo, diagrams, reports and photographs on progress, as well as the official project video may be found directly at the web page indicated above.

4.2 Use and dissemination of foreground

All the contents related to the Section A and Section B may be found at the Participant Portal in sections related Dissemination and Exploitation, in division on:

A. Dissemination measures, including scientific publications relating to the foreground.
B. Exploitable foreground and plans for exploitation.

In addition to part B1, No patents, trademarks or registered designs were applied for. Tecnalia holds a patent for the Advanced Passive Solar Collector and Ventilation Unit (European patent EP2520870 A1).

In addition to part B2, the table related to the exploitable foregrounds has been attached, see below.

Part B2

Type of Exploitable Foreground[11]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[12]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	Ex: New superconductive Nb-Ti alloy			*MRI equipment*	*1. Medical* *2. Industrial inspection*	*2008* *2010*	*A materials patent is planned for 2006*	*Beneficiary X (owner) Beneficiary Y, Beneficiary Z, Poss. licensing to equipment manuf. ABC*
Commercial exploitation of R&D results	An energy efficient integrated system (and associated constructive processes)	no		MeeFS multifunctionnal facade	1. building retrofitting (residential and non residential), 2. new constructions	To be defined still, the common agreement is needed, the business plans definition on-going	none today	Acciona, CQFD, AST, Tecnalia, Antworks, Technion, NTUA, Fraunhofer, SKA Polska, VTT
Commercial exploitation of R&D results	Structural panel made of thermoplastic composites	no		Structural panel made of thermoplastic composites	1. building retrofitting (residential and non residential), 2. new constructions	2019 2021	A patent must be applied once the design is optimised and the material aging tested and certified	CQFD, AST, Acciona
Commercial exploitation of R&D results	A new pultrusion process for cost-effective manufacturing of the structural components	no		new pultrusion process	1. Construction sector, 2. automotive industry, 3. infrastructures	To be defined still, the business plans definition on-going	secrecy	CQFD

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.
[12] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[11]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[12]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Advanced Solar Protection & Energy Absorption Technological Unit	no		Advanced Solar Protection & Energy Absorption Technological Unit	1. building retrofitting (residential and non residential), 2. new constructions	To be defined still, the business plans definition on-going	none today	Acciona
Commercial exploitation of R&D results	Advanced Passive Solar Collector and Ventilation Unit	no		Advanced Passive Solar Collector and Ventilation Unit	1. building retrofitting (residential and non residential), 2. new constructions	To be defined still, the business plans definition on-going	European patent EP2520870 A1	Tecnalia

The following table (to be treated as confidential) provides more details about the exploitable foreground, in particular:

- Its purpose
- How the foreground might be exploited, when and by whom
- IPR exploitable measures taken or intended
- Further research necessary, if any
- Potential/ expected impact (quantify where possible)

Result	Purpose	Expected impact	IPR measures	Further research or investment necessary	Exploitation of foreground (who, how)	Exploitation plan 2017-2018
The whole retrofitting process using MeeFS technologies	An energy efficient integrated system (and associated constructive processes) composed of a multifunctional panel with technological modules that allow integrating both active and passive technologies on façades for retrofitting purposes Includes Technological Units developed in MeeFS, ERES online tool (to optimise modules combination) and dedicated Building Energy Management	Reduction of building energy demand by 30%	A trademark could be applied for	• Optimisation of design to maximise the benefits of composites Industrialisation to reduce costs • Certification / standardisation	*Exploitation leader: Acciona* Trademark licensing, depending on demonstration success	• Identify a manufacturer to adapt the demonstrated system to mass-production constraints. • Search for technology providers interested in integrating MeeFS to

	System.					their product portfolio, to reach European markets • If manufacturing secured: new demonstrator with industrialised solution.
A structural frame made of a thermoplastic composite material	Structural panel made of thermoplastic composites. The panel has been designed to enable the use of pultruded profiles, i.e.: - dimensioning to ensure mechanical resistance (to wind or to phenomena such as creep) taking into account the physical characteristics of composites –"lean" design to make sure the profiles can be manufactured with a pultrusion process	Contribution to decreasing building energy demand (insulating properties)	A design patent could be applied for	• Optimisation of design to maximise the benefits of composites • Development of new coating • Certification	*Exploitation leader: AST* Commercialisation by CQFD (commercial conditions to be defined with Acciona and AST, according to Consortium Agreement)	• Commercialisation as part of CQFD portfolio of products
A new industrialised pultrusion process for cost-effective manufacturing of the structural components	A new industrialised pultrusion process for cost-effective manufacturing of the structural components. The main innovation with regard to the process lies in the adaptation of the pultrusion process from thermoset matrices to thermoplastic matrices, and from thermoplastics prepregs to a process that starts from the monomer (reactive pultrusion).		Secrecy	• develop an industrial production line to reduce production cost	Direct use by CQFD	• Investment to develop an industrial production line • Reinforce the current activities and expand client portfolio
An Advanced Passive Solar Protector and Energy Absorption Unit	The Advanced Solar Protection & Energy Absorption Technological Unit is a breakthrough technology whose main goal is to improve the annual energy performance of the buildings, balancing heating and cooling requirements. The Advanced Solar Protection & Energy Absorption Technological uses horizontal rotating multifunctional slats that capture several passive technologies to perform different energetic strategies depending on the changing climatic conditions.	Contribution to decreasing building energy demand	A patent could be applied for	• Optimisation of design and sourcing of PCM to reduce cost	To be determined when the manufacturing potential is secured by Acciona	• To be determined when the manufacturing potential is secured
An Advanced	The Advanced Passive Solar Collector &	Contribution	European	• Will depend on the	Licensing by Tecnalia	• Ongoing search of

Passive Solar Collector and Ventilation Unit	Ventilation Technological Unit (APSC&V TU) uses a dual layer system, whose external layer is semi-transparent. A thermal storage wall is used as internal layer for thermal storage both heating and cooling. Ventilation of the cavity is allowed by a series of lower and upper opening gaps, equipped with adjustable louvers. These louvers are operated according to external climate conditions.	to decreasing building energy demand	patent EP2520870 A1	results of the demo		commercial partners (façade manufacturers)

4.3 Report on societal implications

All the contents related to the report on societal implications may be found at the Participant Portal in sections related to financial contribution.

5. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

All the contents related to the report on the distribution of the European Union financial contribution may be found at the Participant Portal in sections related to financial contribution.