

PROJECT FINAL REPORT

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Executive summary

The Energy Performance of the Buildings Directive recast (EBPD recast) states that, alongside its target to construct zero-energy new buildings, renovation targets should aim to transform existing buildings into nearly zero-energy buildings by 2021. The iNSPiRe project has set its sights on finding solutions to help meet the EU's energy-consumption reduction goals in existing building stock across Europe.

The objective of iNSPiRe was to tackle the problem of high-energy consumption by producing systemic renovation solutions applicable to residential and office buildings with the aim to reduce the primary energy consumption of a building to lower than 50 kWh/m²/year. The solutions had to be suitable for a variety of climates and maintain or even improve comfort for the building users.

Initially the project covered the assessment of building loads and architectural features and had the main objective to carry out a building stock survey for classification of the energy uses in the building sector over Europe. This profiling process led to the identification of primary types of reference buildings that could be standardised and developed into numerical models for simulation of energy performance of retrofit measures elaborated along with the project elaboration. The result of the simulation campaign is a database of Energy Renovation Solutions. This includes over 200.000 combinations of buildings types, heating and cooling generation and distribution systems for different European climates. Energy performance and Economic figures are made freely available on the project website.

As the exploitation of such measures is usually complex, expensive and results in high discomfort to the customers in the reality, a high degree of prefabrication is needed to overcome technical barriers and to trigger their acceptance by professionals and investors. Renovation technologies were developed moving the complexity involved from the construction site to the fabrication process: so called "Industrialised Kits" were elaborated including multiple functionalities and moving the installation and operation complexity outside dwellings/offices as much as possible. A number of multifunctional technologies were developed. The potential of these solutions is huge in the retrofit of residential buildings towards the n-ZEB standard.

Methods to assess the performance of the developed solutions were also elaborated, both in terms of laboratory test and on-site monitoring procedures, meant to guarantee the quality of the solutions prior delivery and reliability through their life time.

Two demo sites were renovated, one in Ludwigsburg, Germany and one in Madrid, Spain, in order to validate retrofit approaches and to assess technologies' performance. The same were also used to evaluate possible technical and non-technical barriers to the market uptake of the solutions: planners, installers and final users were deeply involved in the planning process to verify their readiness accepting, adopting and using the solutions proposed.

The industrialization and the road-to-market of the Kits developed, including key aspects such as manufacturing, logistics, installation, quality assurance and maintenance issues as well as commercialization possibilities were also explored. One-stop Shop is one possible way to market energy efficient solutions.

Description of project context and objectives

The European Union has ambitious targets for the reduction of energy consumption of buildings in Europe.

Most of the energy consumption in Europe is due to heating and cooling used for domestic, tertiary and industrial purposes. This energy is largely produced by directly burning fossil fuels with a negative environmental impact. RES directive and the SET Plan focuses its attention on the usage of RES to drive systems for heating and cooling in order to reduce greenhouse gas emissions and the dependence on energy import, and to reach the 20-20-20 target. In recognition of the potential for energy savings in existing building stock, the Energy Performance of Buildings Directive recast (EPBD recast, 2010) states that, alongside its target to construct zero-energy new buildings, renovation targets should aim to transform existing buildings into nearly zero-energy buildings by 2021.

The project iNSPiRe aimed to conceive, develop and demonstrate systemic renovation solutions made of

- envelope technologies,
- energy generation systems integrating a large amount of Renewable Energy Sources (RES) and
- energy distribution, lighting and comfort management systems.

For the deep retrofit of both residential and tertiary buildings.

The optimal integration of the mentioned sub-systems will lead to major cumulative energy savings with respect to consumption prior to renovation (therefore to extreme reductions of the CO₂ emissions), ensuring at the same time enhanced users comfort conditions. The final target of the systemic renovation approach was to reach an overall Primary Energy consumption of the building lower than 50 kWh/m²/year after retrofit.

The project committed to this overall strategic objective by:

1. Developing standardized systemic renovation packages. The renovation approaches elaborated will be based on the integration of enabling technologies available on the market. The systemic renovation packages assessed will make highly reliable solutions available, which effectiveness in terms of energy performance can be easily predicted already at the first stages of auditing and design phases, for a large amount of building types. Attention was paid both to the final energy consumption, which is related to the users' annually incurred cost, and to the primary energy that is related to the minimization of the overall environmental impact.

2. Developing multifunctional Industrialised Renovation Kits that are pre-engineered, modular compounds, manufactured off-site in a factory through an industrial process and then transferred on-site for installation. This will reduce planning and installation costs and ensure a clear footprint assessment. iNSPiRe developed, prototyped and demonstrated 5 industrialised renovation kits. The novelty introduced into the building market by the industrialized renovation kits is related to:

- fast and easy installation, minimizing discomfort to the occupants, energy consumption and costs related to this phase, and minimising the installation errors.
- easy and affordable maintenance through their life time.

3. Promoting a large and active participation of the industry into the project, through an effective exchange of competences and outcomes between research and industry sectors,

both of which will benefit from the development of innovative products and solutions.

The exploitation of the project results will make available reliable, effective and transferable solutions (both in terms of approach and technologies) for the systemic energy renovation of the European building stock. This will promote customers trust, financial viability and bankability of the renovation actions.

To do this, a number of activities were set up.

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The result of the simulation campaign is a database of Energy Renovation Solutions. This includes over 200.000 combinations of buildings types, heating and cooling generation and distribution systems for different European climates. Energy performance and Economic figures are made freely available on the project website.

The outcomes of the detailed simulation work was also used to derive simplified rules describing the operation of heating and cooling systems in retrofitted buildings. These were the basis to upgrade the commercial auditing and pre-design tool PHPP.

For renovation of the building services, it is usually necessary to demolish great amounts of lining inside the building, producing large amounts of work, and thus costs, disturbance and waste. A number of multifunctional technologies were developed as part of the project, to ease the implementation of the retrofit measures.

More precisely the project developed

- a façade-integrated micro heat pump and mechanical ventilation unit integrated into wooden-frame envelope modules for residential buildings providing contemporarily insulation to the existing façade and a cost-effective ventilation and heating device. The advantages of decentralized and façade-integrated systems are on the one hand the reduced space required to the equipment inside the building, and on the other the potential to reduce energy consumption by means of local control.
- a prefabricated wooden-frame vertical distribution shaft for residential buildings, integrating pipes and ducts into envelope modules. This Kit connects centralised HVAC systems to the single dwellings of the building with no impact on the indoor of the dwelling
- a wooden envelope module with solar thermal collectors and/or PV panels optimising architectural integration and energy performance of the active elements.
- The Energy Hub (Energy Generation Kit) allows to integrate complex hybrid systems, once active components and control have been included in a box prior delivery to the construction site. It not only allows for hydraulic connection but also for optimal control, metering and fault detection capabilities.
- The Energy Distribution Kit including low exergy thermal energy distribution (heating and cooling) and lighting functionalities in a ceiling panel, is very close to the market and so far in an early phase of commercialisation.

Laboratory test procedures were developed for both multifunctional façade elements and for heating and cooling systems:

- The wooden frame façade with integrated micro heat pump and mechanical ventilation was tested and optimized in a PASSYS test cell. Tests included building physics aspects

as well as the energy performance of the active elements.

- The wooden frame façade with integrated solar thermal collectors was tested outdoor in a facility allowing to characterise the performance of the solar collector and its interaction with the façade module in terms of thermal fluxes exchanged.
- Moreover, a dynamic test procedure developed shows the full potential of well-designed and operated heating and cooling systems when working under real-like working conditions reproduced in the laboratory.

The iNSPiRe solutions were successfully installed at two demo buildings in Madrid and in Ludwigsburg. The Energy Generation Kit and the Energy Distribution Kit were tested in Madrid where 10 dwellings on a 5 floors multifamily home were completely rehabilitated from the structural, envelope and heating and cooling perspectives.

In Ludwigsburg, 4 apartments of a 4 floors building, the façade solutions mentioned above were installed and assessed.

In both cases, a centralised air-to-water heat pump system, coupled with solar thermal collectors on the roof, was selected to cover the thermal loads of the buildings.

The monitoring data gathered at the demonstration sites was widely complemented by simulation results obtained through calibrated models of buildings and heating and cooling systems. This allows clearly extrapolating the performance of the renovation, independently of the user behaviour and of the actual weather conditions during the monitoring period. Consequently, different effects can be evaluated.

One-stop Shop is one possible way to market energy efficient solutions. The Value Chain for renovation technologies is very complex due to decision maker, payer, customer, end user and main beneficiary being possibly different. Therefore, one possible way to be able to connect all stakeholders with the customers, is to build an overall platform in the form of a One-stop Shop. On one side of this platform, there are the stakeholders such as manufacturers, installers, research institutes, policy makers, financial institutions, decision makers and energy service companies (ESCOs). The technology providers add energy efficient solutions and continuously update the platform. On the other side of the platform there are the potential customers who will define their requirements and after consultation get a customized solution that matches their need. This could help to focus on product management, develop future marketing strategies, Business Model innovation service design, allocate resources to the innovative kits and promote their technology through different channels.

Description of the main S&T results/foregrounds

The iNSPiRe project generated initially an overview of the building stock over Europe, both residential and with respect to office buildings. The work was focused into three areas:

- Survey of the characteristics and regulations governing the existing building stock;
- Survey of the energy needs and comfort requirements of the existing building stock;
- Assessment of climatic conditions and RES availability;

The building stock analysis and data gathering exercise focused on published literature and other sources, with the aim of obtaining information about the current residential and office building stock. The types of information gathered included: number and floor area of residential buildings/dwellings and office buildings / typology / age distribution / construction by type and age / façade and glazing types / average floor area / geometry / number of floors / U-value, thermal characteristic and performance of the buildings, by age / ownership and tenure i.e. number of social housing, owner occupied, private renting etc. / energy consumption and demand in terms of both, total and individual end-use including space heating, domestic hot water, cooling, lighting; fuel and heating system types and comfort requirements.

The results from the building stock analysis included an EU-27 overview and country-by-country summary of building typologies, age distribution, ownership profiles and energy use within the residential and office buildings. It also described the reference and target buildings. The supporting report covers policies that affect the retrofit of building and incentives that apply specifically to retrofit.

The dataset is part of an extensive survey covering databases (including Entranze, Tabula, BPIE, ODYSSEE, etc.) and single sources available in the open literature. The report presents information about the building stock in each country separately. All gathered data in terms of heating, cooling, domestic hot water (DHW), electricity demands and consumptions have been included into a database.

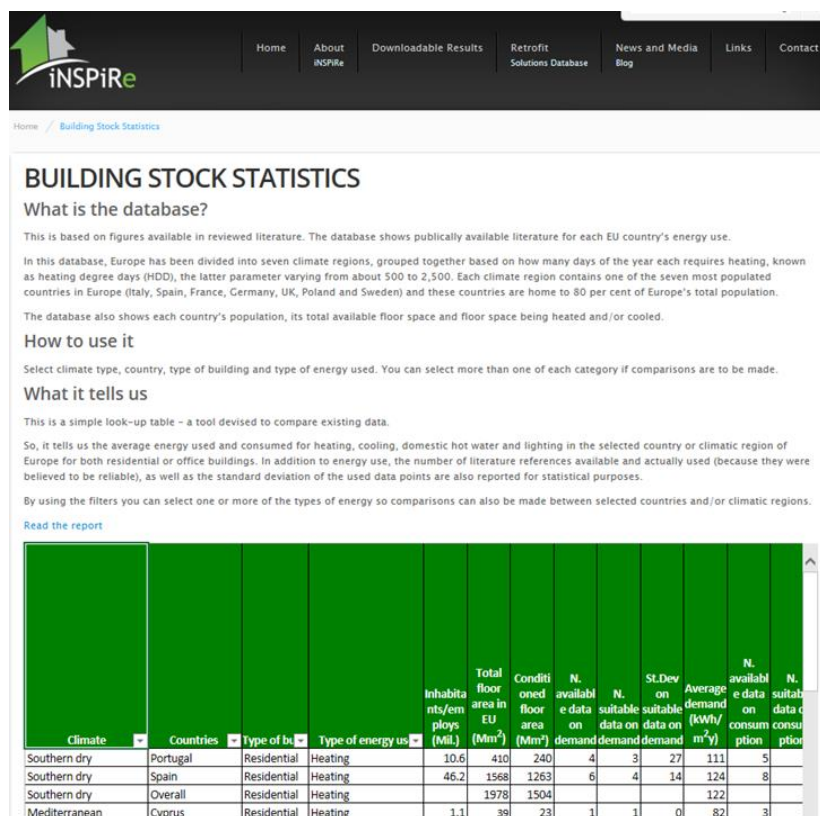


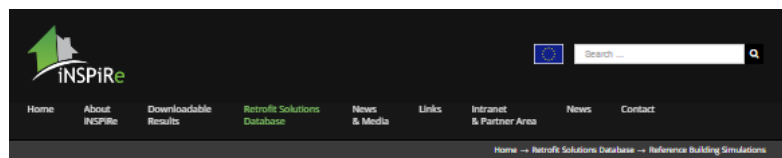
Figure 1 – Building stock database

<http://inspirep7.eu/retrofit-solutions-database/building-stock-statistics/>

Simulations were used so that the many gaps in the energy statistics could be filled and the statistics could be critically evaluated. The data for the residential building stock was split into single family houses, small and large multifamily houses, while for offices the results were given for low and high rise offices with 6 or 12 office units per floor. The simulation models of such reference buildings were calibrated against the energy statistics and thus the simulation results are consistent with them. The energy consumption, per country and climatic region, was compared with the energy consumption and demand results generated from simulation using the reference buildings and appropriate input data.

The methodology resulted in a complete and consistent overview of the heating and cooling demand and consumption in residential and office buildings for seven different climate regions covering the whole of the EU and six different periods of construction, covering pre-1945 to post 2000.

RES availability survey and boundary conditions for simulations, which analyses the availability of renewable energy sources in Europe, includes a geographical mapping of ambient air temperatures, ground temperatures and humidity ranges together with a detailed analysis of the availability of solar energy on building envelope surfaces with different orientations and in addition to this, the analysis of the availability of biomass in EU-27. Based on the analysis, seven reference locations with significantly different heating degree days were defined. The seven locations are representative of as many climate regions to be considered “homogeneous” in terms of climate properties, and are used throughout the project.



REFERENCE BUILDING SIMULATIONS

What is this database?

This is based on figures available in reviewed literature. The database shows publicly available literature for each EU country's energy use.

In this database, Europe has been divided into seven climate regions, grouped together based on how many days of the year each requires heating, known as heating degree days (HDD), the latter parameter varying from about 500 to 2,500. Each climate region contains one of the seven most populated countries in Europe (Italy, Spain, France, Germany, UK, Poland and Sweden) and these countries are home to 80 per cent of Europe's total population.

The database also shows each country's population, its total available floor space and floor space being heated and/or cooled.

How to use it

Select climate type, country, type of building and type of energy used. You can select more than one of each category if comparisons are to be made.

What it tells us

This is a simple look-up table - a tool devised to compare existing data.

So, it tells us the average energy used and consumed for heating, cooling, domestic hot water and lighting in the selected country or climatic region of Europe for both residential or office buildings. In addition to energy use, the number of literature references available and actually used (because they were believed to be reliable), as well as the standard deviation of the used data points are also reported for statistical purposes.

By using the filters you can select one or more of the types of energy so comparisons can also be made between selected countries and/or climatic regions.

Read the report

	B	C	D	E	F	G	H	I	J	K	L	M	N
			Age of construction	Indoor air temperature	Type of floor	S/V - External surface over Volume ratio	Share per Type	Share per age of construction	Demand (kWh/m ² y)	Consumption (kWh/m ² y)	Primary energy consumption (kWh/m ² y)	CO ₂ prod. (kg/m ² y)	
1	Climate	Type of building											
2	Southern dry	SFM - detached	pre 1945	18 heating	0.87	47%	6%	258	623	830	71		
3	Southern dry	SFM - semi-detached	pre 1945	18 heating	0.71	36%	5%	221	277	291	63		
4	Southern dry	SFM - row	pre 1945	18 heating	0.58	17%	1%	181	228	233	58		
5	Southern dry	SFM - detached	pre 1945	20 heating	0.87	47%	1%	338	432	441	102		
6	Southern dry	SFM - semi-detached	pre 1945	20 heating	0.71	36%	5%	290	363	381	88		
7	Southern dry	SFM - row	pre 1945	20 heating	0.58	17%	5%	241	301	317	86		
8	Southern dry	SFM - detached	pre 1945	22 heating	0.87	47%	1%	424	548	568	136		
9	Southern dry	SFM - semi-detached	pre 1945	22 heating	0.71	36%	1%	361	451	461	103		

Figure 2– Reference buildings simulations results database
<http://inspirefp7.eu/retrofit-solutions-database/building-stock-statistics/>

The above information was input to the analysis of the retrofit solutions that fit best to different building types and climates. The focus of this work was on how given retrofit packages impact on the specific reference building. An extensive simulation work was carried out, following the methodology shown in Figure 3.

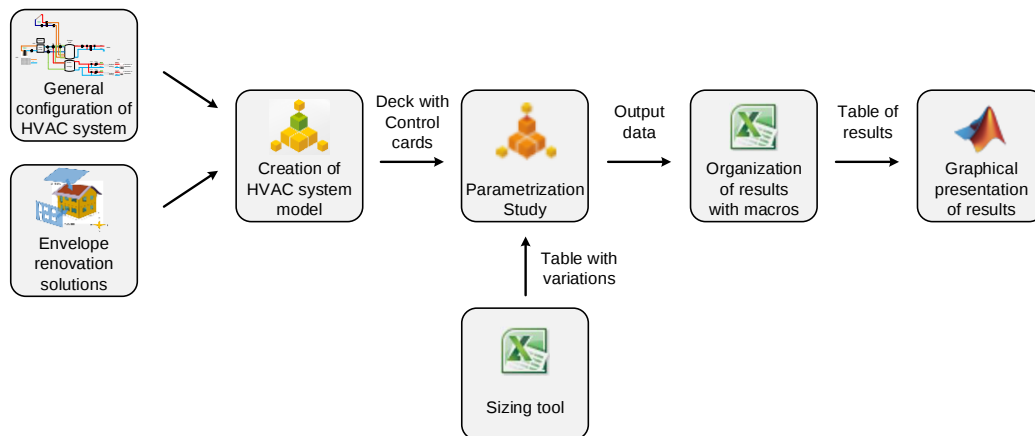


Figure 3 - Methodology used for the simulation and analysis of the systemic energy renovation variants

The first step consisted in defining the envelope renovation solutions in terms of new windows and insulation thickness added on top of the existing one in order to reach a specific energy efficiency of the building in terms of heating demand.

Although the mechanical ventilation system is not properly to be considered as an envelope renovation solution, its occurrence in the renovation packages has been defined together with the measures in terms of windows and insulation solutions, since they strongly affect each other with respect to the effect on the heating demand.

Once these solutions are defined, the cooling demand derives consequently: the envelope renovation packages entail for all climates considered external shading systems that limit the cooling demand during the cooling season (from late spring to autumn).

Secondly, a reference H&C configuration was defined, from which other H&C configuration variants can easily be derived. A sizing tool was developed in excel with the purpose of setting the system features (components sizes and set points) depending on the different loads and variants.

Simulation output files were automatically processed and relevant information data was imported into a third database. Here, in addition to climate, building type and age of construction, one can select a number of retrofit parameters, such as:

- Wished heating demand after retrofit, which determines the insulation and new windows quality
- Type of heating & cooling generation system
- Set temperatures imposed to the indoor air
- Type and temperatures of the heating & cooling distribution systems
- Size and position of the solar thermal collectors and PV panels.

Comparing the energy use in reference houses and offices before and after retrofit provides valuable information on the most suitable retrofit solutions during the early design phases, depending on climate and RES availability. The main results and lessons learned are also gathered together in a Position Paper on Energy retrofit (deliverable D6.5).

The results of the extensive simulation campaign were used also to train an auditing and pre-design tool. PHPP from Passive House Institute (PHI) is a commercial tool that allows for fast, simplified though reliable calculations of the energy performance of a building when set up with specific envelope technologies. The simulation team validated the tool against simulations (TRNSYS, Matlab/Simulink) and upgraded it in order to include simplified rules to

predict the final energy consumption related to a number of heating and cooling systems.

The availability of this data within a tool recognised by architects and engineers will allow the industry to take up the retrofitting solutions into market and to target the right solution to the building type and region correctly.

The deep retrofit measures elaborated are hardly implemented in reality, as their exploitation is usually complex and thus expensive and results in high discomfort to the customers due to the demolishing of great amounts of lining inside the building, producing large amounts of work, disturbance and waste.

For this reason, iNSPiRe worked on developing a number of standardised technological solutions that simplify the design and installation phase.

Three multifunctional active façade elements were developed for utilisation in residential buildings.

Façade-integrated micro heat pump and mechanical ventilation unit with heat recovery integrated into wooden-frame envelope modules

This technology consists of a façade-integrated cost-effective ventilation and heating device for very energy efficient buildings.

The prefabricated unit is designed as a compact system for minimal space use. With the micro heat pump (μ HP) – a small scale exhaust air heat pump in combination with mechanical ventilation with heat recovery (MVHR) – renovations with minimum intervention are enabled (minimum invasive renovation).

The heat pump uses the exhaust air of the MVHR unit as source and provides heat to the supply air of the ventilation system. Thus, one compact unit can be used for combined ventilation and heating. Fresh outdoor air flows into the MVHR unit, where it is heated with an energy recovery coefficient of up to 95 %. It is then further heated by the micro-heat pump up to 52 °C in order to supply space heating. When the micro-heat pump cannot deliver the required heat power, an additional auxiliary heater heats the supply air. An additional radiator in the bathroom is recommended for comfort reasons, which might be used as auxiliary heater. Further an auxiliary heater in the ambient air (pre-heater) is required to avoid freezing of the MVHR unit.

By means of this system, cold ducts inside the thermal envelope can be avoided. The whole solution is façade integrated and prefabricated; thus construction and installation times can be kept as short as possible. Solutions for easy maintenance were also developed and evaluated.

As the unit was fully integrated into the façade, building physical aspects were carefully investigated (avoiding/reduction of thermal bridges, avoidance of moisture related damage, sound protection). The performance of the heat recovery unit and the micro heat pump were tested in two PASSYS test cells and in an acoustic test rig.





Prefabricated vertical distribution shaft and integration of pipes and ducts into wooden-frame envelope modules for residential buildings

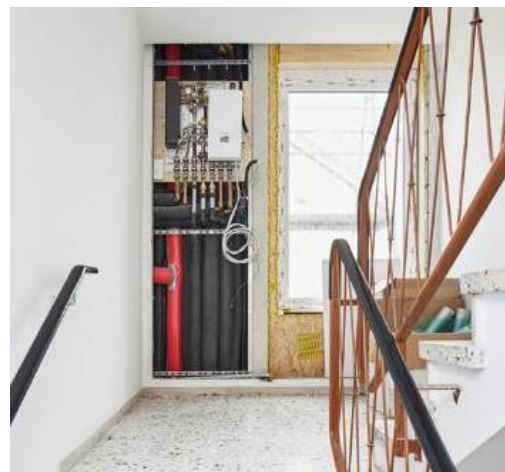
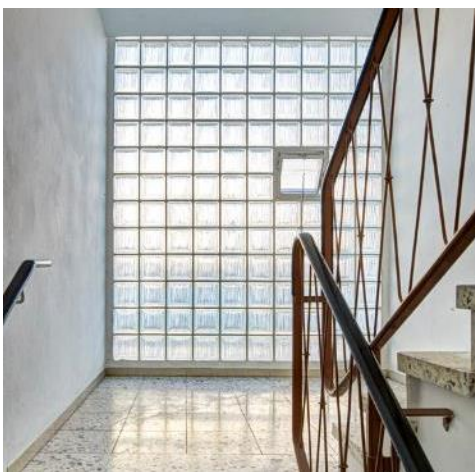
The goal of this technology is to be able to renovate the sewage, water and heating piping of a building while maintaining the services in operation, preventing from temporal relocation of the tenants. The level of prefabrication is maximized in order to reduce the impact and disturbance during the works and to reduce working time on site.

The vertical distribution of the building services is done with a prefabricated installation shaft designed as encapsulated timber construction. The pipes and ducts have to connect with the building services in each floor and with solar collectors on the roof.

The connection to the dwellings on each floor is made with hydraulic boxes which have Domestic Hot Water heat exchanger set up to guarantee the healthiness of the water distributed, and all the valves needed to distribute both, space heating and DHW, depending on the needs.

Air ducts have been also integrated allowing to connect a centralized air handling unit to the single dwellings.

A large number of pipes and fittings are concentrated in a rather enclosed box, with a series of connection points on the borders. The large amount of work concentrated in this space can be more efficiently carried out off-site in the prefabrication. Moreover, fire safety and acoustic



noise prevention measures can be solved effectively.

Envelope-integrated thermal solar collectors and PV panels into wooden-frame envelope modules for residential buildings

This consists of a best-practice solution for the integration of solar collectors and PV panels into a prefabricated timber envelope for renovation. This solution modifies and integrates existing products and technologies from partner companies in the project in order to offer both a systemic approach and a ready solution to planners and clients on the market. The optimized integration technology offers economical and aesthetical advantages in relation to current practice alternatives. The first envelope integration of solar thermal collectors was designed and tested directly at the demo case in Ludwigsburg. A second integration solution was experimentally tested and then built in a mock-up box. The goal of the second integration was to develop a common frame system for solar thermal and photovoltaic panels, with a common fixing and construction method, which can be produced on a large scale and at the most competitive costs in the market. The solar thermal collector is integrated in the timber envelope in a way that the insulation can be eliminated and the thickness can be reduced to a minimum, in order to assure best aesthetical results in all possible construction settings.



The complexity of heating and cooling systems harvesting a large share of RES, requires a high degree of prefabrication. Two paths can be followed: i) prefabricated compact plug and play systems or ii) prefabricated modules allowing plug and play installation of single market available components.

The energy Hub was developed as a thermal energy generation technology following the second strategy. It actually does not provide energy itself, rather it allows to integrate different heating and cooling components in a wide variety of hybrid system solutions, more or less complex.

The kit is adaptable to different buildings, facilitating the renovation of centralized systems for heating, cooling and domestic hot water preparation. Hydronic modules have been designed, manufactured and tested allowing flexible integration, monitoring and control of a number of components connected from a control-logic point of view, which distinguish them from other hydronic stations existing on the market.

They allow to select the correct hydraulic setup and to implement the control strategies required to achieve the best energy efficiency targets through optimal management of the use of different energy sources, and minimisation of auxiliary electricity consumptions and heat losses.



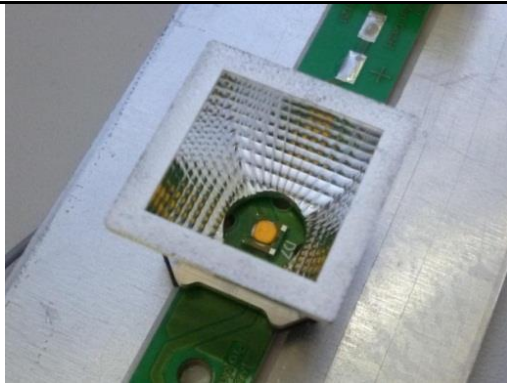
One distribution technology for distributing thermal energy into dwellings and offices was developed, manufactured and tested. The radiant ceiling panel integrates low exergy cooling and heating distribution, lighting and acoustic functions. The development consisted in a significant optimization process with respect to its original thermal efficiency, cost competitiveness, and adaptation to refurbishment actions. As part of the development, different luminaire solutions were integrated in the panel for both, residential and office building target applications.



Among these, the integration of orientable LED spheres developed within the project seem to be the most promising. The spheres are designed for home-appliances but turned out to be office-ready too. The sphere takes an existing, reflector highly glare-free reflector technology. The reflector is integrated in a rotary sphere of aluminium.

The integration of the sphere in the radiant ceiling panel is simple, by means of a simple drill hole and a cover plate. The thermal connection of the sphere is minimal, but not necessary as the thermal management of the sphere itself is working properly.

Other Luminaire solutions were studied for integration in the ceiling panel specifically for office applications. The ceiling washer is not a complete new development. It's optical component was developed in the 3encult (FP7 project) and was re-investigated within iNSPiRe. Within iNSPiRe the reflectors were integrated in a luminaire to be attached to the façade or suspended in the ceiling panel.



As part of the development of the technologies mentioned above, the Life Cycle Assessment (LCA) method was employed in order to check and assess the sustainability of the products, in particular their benefits on primary energy and CO₂ emissions savings. Specific stress was put on the cradle to gate step of the life cycle; which goes from the primary materials extraction up to the end of the manufacturing process; since the manufacturer can actually take action through purchase policies and environmental management systems.

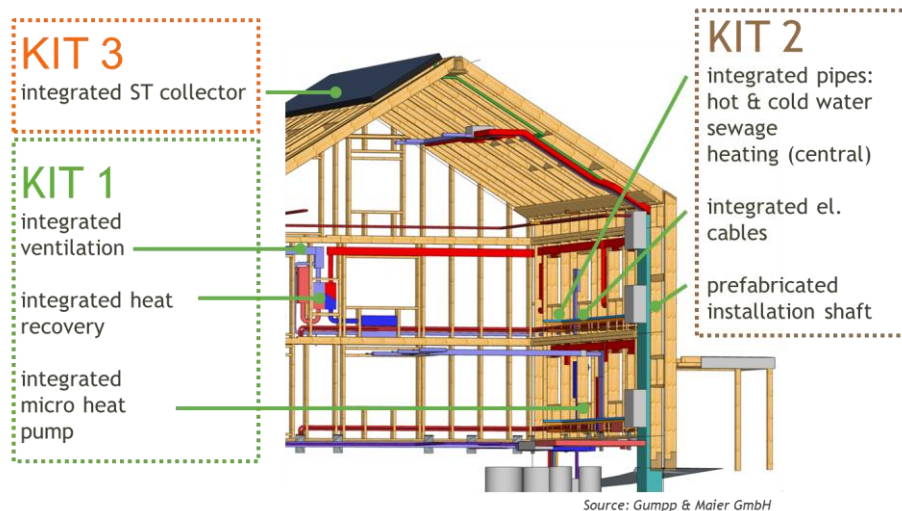
All the technologies developed needed to be tested before demonstration in real buildings as part of the project elaboration. Laboratory test procedures were elaborated specifically, since the actual performance rating standards and guidelines do not tackle these innovative multifunctional solutions:

- The wooden frame façade with integrated micro heat pump and mechanical ventilation, was tested and optimized in a PASSYS test cell. Tests included building physics aspects as well as the energy performance of the active elements. The method was developed and validated as to be further used in the future to help industry developing and characterising façade integrated active components.
- The wooden frame façade with integrated solar thermal collectors, was tested outdoor in a facility allowing to characterise the performance of the solar collector and its interaction with the façade module in terms of thermal fluxes exchanged. The method developed for iNSPiRe can be used for many similar installations and could therefore provide an important contribution to the commercial success of the building integrated solar thermal sector in general.
- Moreover, a dynamic test procedure developed, shows the full potential of well-designed and operated heating and cooling systems when working under real-like working conditions reproduced in the laboratory. The procedure and the results obtained on a few reference systems are actually shared among the scientific and industrial heating and cooling community, as a basis to generate common understanding and consensus on systems performance characterisation strategies.

The assessed renovation measures and technologies were all tested in two residential demonstration buildings.

Ludwigsburg (Germany): the building in Ludwigsburg was chosen because it represents a widely used building typology during the middle of the 20th century, which now is reaching the end of its lifetime and needs to be renovated. It is a multi-family house of 4 units –one flat per story- inserted in an urban configuration of row houses, sharing one separating wall with a neighbour. The construction was completed in 1971, with a widely used building system based on uninsulated hollow concrete blocks and pre-cast reinforced concrete slabs, which are completed with in-situ concrete. It was built without any external insulation, even though a thin layer (insufficient to the comfort of the tenants) was added in the '80s. The building is property of the Wohnungsbau Ludwigsburg GmbH, a social housing association owned by the city of Ludwigsburg.

The main strategy for the retrofit of this building was to erect a new high performance prefabricated timber envelope around the building, integrating in the process the renewal of the building services and adding equipment for harvesting energy. By means of maximizing prefabrication, this process was planned to be as short, non-invasive and intensive as possible, aiming at implementing deep renovation measures during occupation, with a minimum level of disruption for the residents. Timber elements were prefabricated in the factory and transported to the building site on semitrailers. Each one of these cassette elements was built to cover a complete side of each apartment, with total dimensions of maximum 2.95 m height, and 12.20 m length and with a weight of up to 2.5 tons. They were designed to maximise the level of prefabrication in order to reduce work on site, and to achieve a weather safe envelope as fast as possible. The off-site manufacture included closed insulated cassettes, painted timber cladding, windows, external chills and reveals, venetian blinds and steel weather profiles. On site the old tiles, chimney, windows and service ducts were removed, leaving the old ceiling structure of the attic floor without changes.



F11 - The three kits installed in the demo case of Ludwigsburg (Germany)

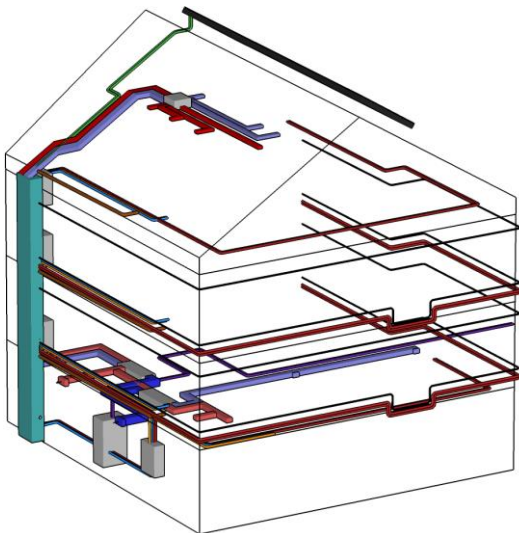
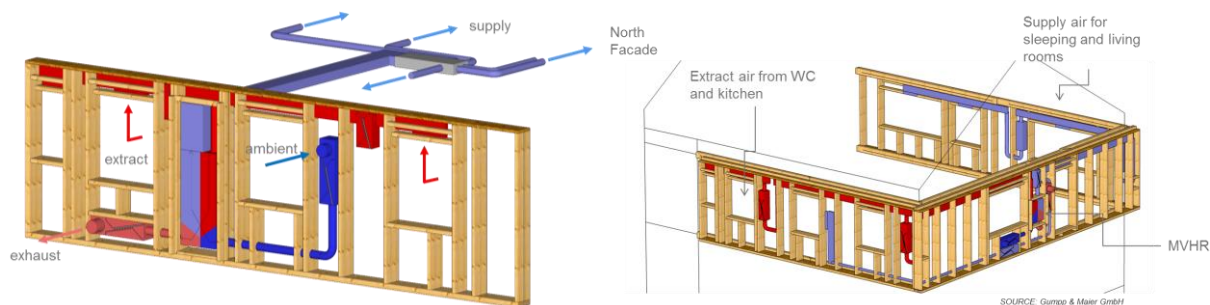
The three façade solutions were tested at this demonstration site. In order to test different solutions developed in the project, different strategies were adopted for the flats. An interesting opportunity to test the implementation of different approaches, not feasible in a standard commercial project:

- The envelope solution with micro-HP and mechanical ventilation was tested on the ground floor
- The envelope solution with mechanical ventilation (but without micro-HP) was tested on the first floor

- The wooden frame shaft with integrated pipes and ducts connects technical room in the basement to the dwellings from the ground to the attic floor. The ventilation system in the attic dwelling is performed by means of a centralized air handling unit set up in the basement.
- A version of the integration of solar thermal panels was tested as part of the roof.

The air distribution in the dwellings is performed on the ceiling with respect to the ground floor: this guarantees that warm air does not undergo thermal losses before being delivered to the different rooms. The distribution of supply air at relatively high temperatures, produces a significant heat loss through the envelope, affecting the expected efficiency of the system when being used as heating. Therefore, such a system may be recommended only in the configuration mechanical ventilation with heat recovery without integration of an active heating function. In the first floor apartment it was possible to set up the air distribution through the façade (see figures below), resulting in a very minor discomfort for the inhabitants during installation.

The prefabrication of the ventilation parts showed several advantages compared to the installation of ducts on site. Working in a horizontal position and in the protected environment of a factory, improves the quality and reduces time, producing time/cost savings in the process.



As can be understood, only ground floor space heating demand is covered through the micro heat pump, while a centralized air-to-water heat pump system, with a total 1600 litre thermal storage capacity, drives space heating in the other apartments and provides DHW. The system is also connected to a large solar field (11 m²) installed on the roof.

The prefabricated in-roof system was implemented, where the timber construction was reduced in thickness, in order to level it down to the rest of the roof. The even surface

produced by the lower height of the collector in relation to the roof, produces a good aesthetical result, and was mounted in a minimal amount of time.

The horizontal water and sewage pipes, as well as the electricity cabling were not prefabricated, but set up on site, since they require many connections between the existing building and the façade elements. Thus the positive aspects of prefabrication and the possibility of mounting the new pipes from outside the building with a considerable freedom, were combined in the renovation process.

The most important lesson learned is the importance of the planning coordination between specialists and manufacturers. The main coordination role was kept by the architect, which is common practice in Germany. The design of the timber façade was coordinated by the manufacturer along with its corresponding structural design and fire safety. The coordination of all connections and intersections with the M&E planners was the most difficult interphase, since it was carried out in a non-contractual relation. The conceptual planning was carried out by the research partners of iNSPiRe, whereas the detailed plans were carried out by local specialists contracted by the owner. Furthermore, certain planning specifications were developed and provided by the installers and component manufacturers of the building services. The multiplicity of actors and decision makers created a planning group which was difficult to keep informed and up to date.

In future projects, it remains the most relevant challenge to set up a planning team with clear tasks and responsibilities. Ideally, all manufacturers and installers should be incorporated in the planning process as early as possible, in order to allow a coordinated review of the plans and specifications by the contracted companies. This task should be clearly stated in all construction contracts.



Madrid (Spain): The building selected as demonstration building for the iNSPiRe project is located at 47, Canción del Olvido street, Ciudad De Los Angeles in Madrid. This building was commissioned in 1960 and its foundations were partially renovated back in 2003.

The property showed a number of defects prior to renovation, in particular foundation problems due to the structure's differential settlement, which caused significant cracks of the building's facade. Besides this, the building envelope lacked any kind of insulation and the roof's insulation and waterproofing consisted of what is known as 'Catalonian roofing', traditional Spanish construction technique consisting of an aired/ventilated chamber providing both insulation and waterproofing. Given the level of deterioration of the building, the property owners were left with no option but to either renovate or demolish and rebuild.

Fortunately the owner's association decided not to demolish the building but to carry out a complete renovation including new features. The existing "catalan" cover was dismantled and the remaining structure was reinforced with an added concrete structure, to avoid any future structural failures. A lift shaft was attached to the external building envelope and the two stairways were merged into one. All of these works were carried out with the occupants remaining in premises throughout the duration of the project and were planned and setup in parallel to the iNSPiRe project measures.

The envelope solutions adopted were fully commercial. The iNSPiRe renovation mainly

regarded the installation of the new centralised heating and cooling system. With this respect, the Energy Hubs (EHs) are acting as hydraulic connections between heating and cooling units, the technical room and the single dwellings' DHW and space heating distribution system.

The heat generation system is a reversible 20 kW air to water double circuit heat pump with one circuit kept in heating mode, and connected to a 500 litres hot water storage for domestic hot water preparation, and the other kept in heating mode in winter and in cooling mode in summer, with its heat being recycled into the production of DHW if needed. Heat pump and storage tank are connected via EH.

An 800 litres storage was connected in series to the 500 litres one due to the Spanish regulations, which do not allow to directly connect a heater to a solar circuit storage tank, and the lack of height of the technical room, were no bigger tank could be installed. The distribution system is a four pipes one, two for heating/cooling and two for DHW production.

All the EHs are supplied with 24V, except the ones with a pump which are powered with 230V, and are connected to each other and to an Energy Manager through a ModBus network.

The vertical lines connect and supply heating/cooling water and DHW from the tanks located in the technical room directly to the EHs located on each floor. Two EHs were installed for each dwelling, one for heating/cooling distribution and the other one for the domestic hot water preparation.



The heating and cooling system in the dwellings is provided by radiant ceilings with recessed luminaires integrated. A thermostat in the corridor acts on the pump of the distribution station when heating or cooling is needed. In addition, an indoor thermo-hygrostat was installed allowing to control in-house conditions and thus to avoid moisture condensation on the radiant ceilings in summer, by proper control of the supply temperature from the EH.

Each dwelling was designed independently in terms of the radiant panels positioning, and

follows needs and aesthetical preferences by each owner. The position of the furniture was key for the decision of the panels location in the single dwellings. Aesthetics came out to be very important for the social acceptance of the system.

The main lesson learned is that design coordination, together with the owners approval, are far more challenging than the development of the technical solutions. This could be improved in future by clarifying scope of the investment, cost and design, at the beginning of the planning phase.

Another lesson learned is that professionals are not aware of how to best install and use new systems. Therefore the setup took much more time than expected and technical issues were solved on site during installation with unforeseen additional effort. In future demonstration projects, time should be given to hire professionals in an early stage of the planning phase, and to train them before the installation phase begins. During commercialisation, significant effort has to be placed by manufacturers on the creation of a network of trained professionals able to install and maintain their systems.

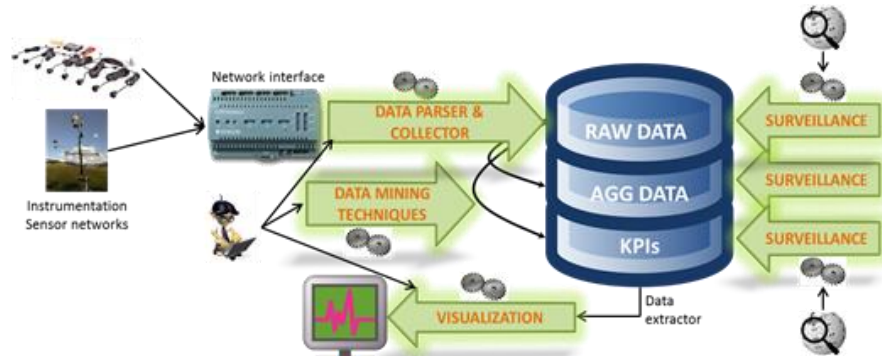


Finally, a deep rehabilitation process does not only involve the implementation of energy efficiency measures but usually a series of other works, such as structure reinforcement, elimination of architectural barriers, updating of electric wiring and water pipelines etc. are also implemented. The incentives for the energy efficiency measures often facilitate these updates. In this way, after renovation, the property not only is more energy efficient but the refurbishment also heightens its economic value and prolongs its lifetime. Unfortunately, this is hardly accounted for when evaluating the payback time of the energy efficiency measures. Specific property value estimation should be carried out, showing the overall financial picture to owners and public/private investors.

A monitoring network was defined and installed in a few apartments (three at each site) in order to assess the performance of buildings before and after refurbishment. For the selection of the monitoring network, a detailed review of the most common

architectures was done. Besides this, cost-effectiveness of sensors and the communication protocol were checked. The monitoring network installed was composed of temperature, humidity and CO₂ sensors, heat meters and electricity counters. In each demo case there was also installed a weather station to measure relative humidity, outside temperature, global and diffuse radiation.

Another milestone of the monitoring activity was the design and implementation of the monitoring and surveillance platform. This platform is the heart for the storage, the management and the display of the data gathered in the demo cases. The main features of the platform are data storage for multiple protocols, management of data, web access, cloud services, automatic computation of key performance indicators, graphical user interface and automatic reporting.



Monitoring data were assessed and analysed at the two demonstration sites for one year before retrofit and for some months after retrofit.

Unluckily, the information gathered on the winter operation after retrofit was not sufficient for the direct definition of the buildings consumption. Therefore a simulation based data reduction procedure was developed and used to extrapolated reliable data on the buildings behaviour before and after rehabilitation.

The method starts with the definition of the building model with information coming from an energy audit. Afterwards, based on the partial monitoring data series available for only a few apartments a calibration process was started on the building envelope before and after the retrofit and on the newly installed heating and cooling plants after retrofit.

The calibrated models permit to calculate heating and cooling demands and final energy consumptions for the entire building, based on standard or real weather conditions, and on real or optimal user behaviour.

This procedure allows separating the performance of the renovated building from specific occurrences encountered and from changes (e.g. rebound effect, changes of the building total volume, etc.) to the input conditions independent of the energy retrofit.

The primary energy consumption in the two buildings renovated, as assessed with this procedure, is in the range of 50 kWh/m²y as requested, but a little higher (10 to 15 kWh/m²y) than foreseen during the planning phase.

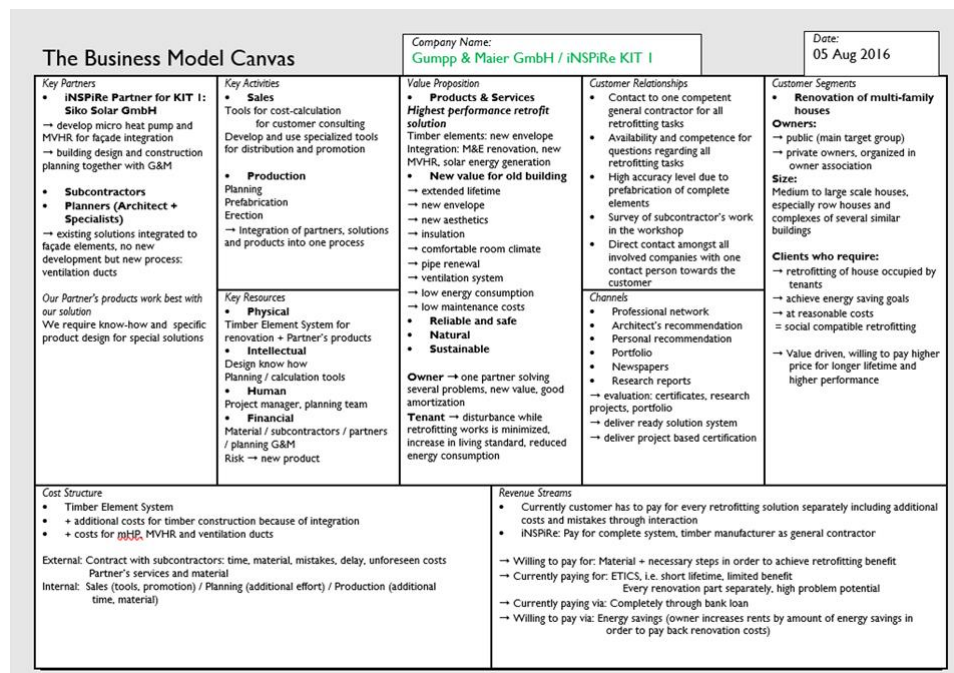
To reach the full potential of the research and development activities carried out, iNSPiRe also focused on the analysis of the industrialization and the road-to-market of the technologies. This included logistics and installation issues, indications suitable for the certification for engineers and installers willing to utilize the assessed renovation packages - quality assurance issues, long term maintenance, industrialization of the solutions and off-site production, non-technical barriers to the market placement and definition of business models for the kits placement on the market

Packaging of systemic solutions into Industrialized products is key to enable market

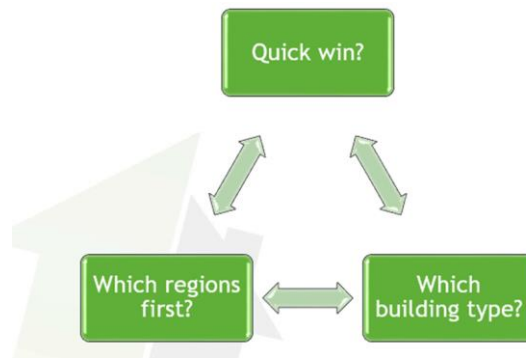
introduction, and to achieve expected installed quality, through the fragmented installation supply chain of energy efficiency products, especially in renovation applications. Focus was to establish how the elaborated solutions can be converted into industrialized products. It was defined the “Easy to...” principle, including that the technologies shall be Easy to:

- scale for different demands without the need of exhaustive engineering efforts and costs;
- get materials, superior sustainability and energy utilization optimization;
- sell; with a need for easy-to-use packaged sales tools;
- make them cost competitive and more than this, valuable, for the end-customer by addressing payback times;
- manufacture and install by existing companies, operate and maintain;
- apply to different climates;
- apply to key customer segments.

With attention mainly on the customer acceptance, business models were defined for the exploitation of the products, having in mind customer preferences, customer segments, applications, market players, supply chain structures and available financial procurement schemes. The business model ‘Canvas’ was chosen for this. Based on a research work of Alexander Osterwalder and Yves Pigneur and nine fundamental building blocks, covering the four main areas of business, infrastructure, customer, offer and financial viability, it is a widely used, practical business tool for design, test, implement and manage business models over their lifecycle.



Considering the market deployment strategies and the lessons learned from demo buildings, it was asserted that the technologies are in different technology and commercialization stages. So for market launch, they were categorized based on the “Quick win(s)” depending on their applications in different building types and geographical market. These aspects are correlated to each other as shown in the following graph.



The Value Chain for renovation technologies is very complex due to the fact, that the decision maker, the payer, the customer, the user and the main beneficiary can be different. Additionally, there are both, technical and non-technical barriers to overcome, to be able to cross the “chasm” and bring the kits to the market. One way to connect all stakeholders with the customers is to build an overall platform in the form of a One-stop shop with the stakeholders such as manufacturers, installers, policy makers, ESCOs etc. on one side and potential customers on the other side of the platform.



In order to minimize the market entry barriers, it is important to involve some actors of the supply-chain right from the start. For instance, installers play a significant role in retaining different technologies on the market. Therefore, it is crucial to involve them from the beginning. Also, entrepreneurs and SMEs are powerful enablers that can contribute to market penetration and growth as providers of renovation solutions. So, it's very important to establish relevant partnerships and involve influential stakeholders in parallel.

Besides this, political consensus on the need for essential actions on building energy efficiency cannot be underestimated. The energy system in Europe is in process of profound transformation and its quality is strongly linked to its supply. The need for diverse, reliable and cost-effective energy supply technologies is crucial and the enforcement of regulations may be the most effective way for overcoming non-technical barriers. Policies and policy instruments are necessary in the future to shape and direct the energy efficiency priorities in society (SET plan 2014). This requires efforts from several directions to get a workable plan. A strong collaboration between several decision makers, jointly developing a base for the future of energy efficiency, is needed. Carefully considered, strong energy efficiency investments can actively contribute to sustainable development in Europe, while subsidies that target specific technologies only, are not the best way to finance renovation.

Description of the potential impacts, dissemination and exploitation

Communication and dissemination activity elaborated

Several communication tools were developed to be used throughout the project. These activities included newsletters, films, press releases, leaflets, posters, presentations and web content. iNSPiRe was active on Twitter <https://twitter.com/inspirefp7> and LinkedIn www.linkedin.com/groups/4734663, where its profile is still available and still actively engaged with the topic.

The three video films provide a good overview of the project and can be viewed on the project website and on YouTube. The first video is an animation to introduce the project, the second to explain the technology and progress being made and the third to explain what is possible with the iNSPiRe technology and to look to the future:

- The iNSPiRe Project www.youtube.com/watch?v=rRZtBj9EcpY
- Systemic energy renovation of buildings www.youtube.com/watch?v=wrQ2bOopPys
- Holistic Renovation with the iNSPiRe project www.youtube.com/watch?v=ML6vOOY16go

A dedicated edition of Projects Magazine was issued, with exclusive focus on energy efficient buildings and featuring several articles about iNSPiRe alongside material from industry, related projects, and other key stakeholders like building owners and architects.

As well as promoting the achievements of the project, all this activity was designed to raise the visibility of the project at a regional, national and European scale as well as of the need for energy renovation in Europe's older buildings.

When it comes to dissemination, a key publication was the Guide Book for the Implementation of the Systemic Packages. Aimed specifically at architects as well as others directly involved in the renovation process, particularly the construction industry, the book provides detailed descriptions of all the kits and how they can be implemented and the benefits they bring. This is a valuable asset for all those considering retrofitting their building, and clearly demonstrates the energy savings that can be available using technology through an assessment of iNSPiRe's demonstration cases. The book is available for download on the projects website.

Throughout the project, 28 presentations of iNSPiRe were made at scientific conferences. The following peer reviewed papers were published:

- [10.1016/j.enbuild.2014.07.059](https://doi.org/10.1016/j.enbuild.2014.07.059) Energy performance comparison of three innovative HVAC systems for renovation through dynamic simulation Marcus Gustafsson , Georgios Dermentzis , Jonn Are Myhren , Chris Bales , Fabian Ochs , Sture Holmberg , Wolfgang Feist;
- [10.1016/j.egypro.2015.02.146](https://doi.org/10.1016/j.egypro.2015.02.146) Integration of Sorption Modules in Sydney Type Vacuum Tube Collector with Air as Heat Transfer Fluid Olof Hallstrom , Gerrit Földner;
- [10.1016/j.enbuild.2015.02.038](https://doi.org/10.1016/j.enbuild.2015.02.038) A Radiance-based modelling approach to assess the thermal and daylighting performance of complex fenestration systems in office spaces Bruno Bueno , Jan Wienold , Angelina Katsifaraki , Tilmann E. Kuhn;
- [10.1016/j.apenergy.2016.05.015](https://doi.org/10.1016/j.apenergy.2016.05.015) A Pareto-based multi-objective optimization algorithm to design energy-efficient shading devices Marina Khoroshiltseva , Debora Slanzi , Irene Poli;
- [10.1016/j.egypro.2016.06.165](https://doi.org/10.1016/j.egypro.2016.06.165) Model-based Design of a Solar Driven Hybrid System for Space Heating and DHW Preparation of a Multifamily House Chiara Dipasquale , Alessandro Bellini , Roberto Fedrizzi.

One webinar and three workshops were organised to meet and get feedback from expert stakeholders of the construction sector, which helped influence the development of the

business strategies for the projects products:

- BSRIA organised the webinar on the renovation of the existing building stock across Europe www.youtube.com/watch?v=9A2BvCV9ntw
- A workshop was organised in Berlin by ACE during their annual meeting, where representatives of national architects associations participated
- UIPI organised a workshop in collaboration with EMVS to address property owners and managers.
- A final public workshop took place in Brussels on September 15, 2016 in the form of a roundtable presentation session, followed by interactive questions and answers amongst the knowledgeable audience. Headlined 'a new understanding of energy efficient renovation' the workshop was designed to provide a clear understanding of the current state of energy-efficient renovation in Europe, based on the experiences of those taking part, who covered all the key areas of involvement – research, policy, construction, architecture and, of course, building owners and those commissioning renovation work.

An Online Interest Group was developed for Public Authorities and set up on www.procurement-forum.eu by project partner ICLEI. The group is active since 2013

Exploitation of the project results

As highlighted in the previous section, a number of relevant results were achieved throughout the project elaboration. Following, we report about the most relevant exploitation with respect to those results.

Retrofit solutions database, including statistics on the actual building stock

One of the primary objectives of the iNSPiRe project was to develop a tool that predicts the energy and cost saving impacts of various systemic retrofit interventions. This tool is now available as a database, for all those involved in the renovation of older buildings (from consulting offices, moving through construction companies and to decision makers) to use it by means of selecting which retrofit package will deliver the greatest cost saving and most improved energy efficiency.

The database is publicly available, in order to be adopted as a reference for planners in the initial phases of their projects.

The database is also currently being used:

- within the EC Buildings Observatory
- for further analysis of the heating and cooling sector, e.g. ECOFYS, 2016, "EU pathways to a decarbonised building sector – How to replace inefficient heating systems can help reach the EU climate ambitions".

EURAC foresees to populate further the database with more retrofit cases in the future, and to share the work within the Build-Up circuit.

Simulation models for buildings and renovation measures

Numerical models were developed for the simulation of the reference buildings and renovation measures, and included into TRNSYS code. The modelling work was an iterative process with various partners involved in many parts of the process. The single persons in the simulation team have rights to use and further develop all reference building as well as HVAC models and the combinations of these. They will be used in new research projects and for consultancy to planners.

PHPP Auditing and pre-designTool

The purpose of PHPP is to give building designers a tool that allows to easily plan different renovation measures with respect to the energy performance and economics. The Passivhaus Institute and the iNSPiRe simulation team agreed to embed the iNSPiRe results in the tool, to publish them and to then leave the ownership of the data with the Passivhaus which will exploit it.

Prefabricated timber façade with integrated air-to-air heat and mechanical ventilation unit

An air-to-air heat pump was developed to provide heating and ventilation in one device. The heat pump was designed to fit into a prefabricated wooden façade panel allowing fast and easy renovation of multi-family houses. Further research will be performed by SIKO Solar to optimise sizes, eventually add DHW preparation capabilities and to ease installation and service. SIKO Solar estimates the product to be ready for series production by the end of 2017.

The impact on the market and the business cannot be quantified so far as there is still development to undergo, but the potential market for the new product is huge due to the zero-energy-building trends throughout Europe.

Gumpp & Maier developed expertise about mounting and operating mechanical ventilation units within its timber frame façade modules. This foreground will be exploited by Gumpp & Maier as general contractor in collaboration with M&E companies, which get the possibility to offer a complete new product.

During prototype testing, construction details for sound insulation of the components were developed. There are however questions unanswered in relation to maintenance and eventual repair of the ducts. The method will be made public through projects dissemination, in order to enable architects or specialist planners to adopt the technology. The market potential is very high as it offers fast and high quality renovation through prefabrication in the factory. After further optimization and within an estimated spin off phase of about 5 years, about 30% of retrofitting projects done with timber elements are expected to incorporate this technology.

Prefabricated vertical timber distribution shaft

Gumpp & Maier developed expertise about mounting pipes, ducts and cables to the outside of an old building, thus retrofit the building services from the outside with minimum disruption to the residents. Exact placements of the transitions to the interior are determined by 3D timber planning and by marking positions on the timber elements during prefabrication. This foreground will be exploited by Gumpp & Maier as general contractor in collaboration with M&E companies.

Prefabricated timber envelope embedding solar elements (ST and/or PV panels)

Gumpp & Maier developed expertise about building behaviour, aesthetics and functional performance of prefabricated timber façade or roof integrated solar elements, with the aim to reach an operation time of at least 20 years and the granting of a 5 years guarantee. The knowledge is expected to result in marketing advantages towards competitors due to the ability of planning such integrations. Precondition positive long term tests, the potential impact of integrated solar energy generation to timber façade and roof elements during prefabrication, is expected to be very positive in relation to the use especially of the high-class private residential sector.

Design of a demand-controlled mechanical ventilation distribution box, reactive to apartments occupation

VAILLANT developed a demand driven control distribution box for mechanical ventilation systems. VAILLANT is currently planning the innovation roadmap of the product.

Plug and Play hydronic unit with integrated control, metering and fault detection capabilities

EURAC in collaboration with MANENS-Tifs developed a new technological solution consisting in a plug-and-play hydronic unit including the needed pumps and valves, designed to connect hydraulically to the components of a heating and cooling system, and electronically to a central controller. Compared to most of the modules available on the market that enable hydronic integration of the system components and metering of the energy uses, the modules developed are smart elements allowing also for continuous monitoring and management of the plant.

The unit needs further development towards the industrialisation and certification. For this purpose, a partnership with an Italian company was established within the H2020 project 4RinEU. By the end of the project, an updated version of the product will be commercialised. The potential market is huge, not only in the residential sector, but for all those applications where a punctual control and monitoring of the fluxes is needed. Sales numbers are under review within the project 4RinEU.

Thin, light and sound absorbing ceiling panel with integrated cooling, heating and lighting distribution

TRIPAN developed the multifunctional, thin and very light, sound absorbing ceiling panel with integrated cooling and heating distribution and luminaires. TRIPAN will start the full commercial phase in early 2017 after the finalization of further performance tests. Target groups for the panel are architects, installers and energy managers.

In the meantime, TRIPAN has already begun to sell its “Flymotion”. For example, the installation of the radiant ceiling in an Austrian car shop helped to solve problems of high temperatures in summer and low temperatures in winter.

“Flymotion” was also accepted for exhibition at the “architect@work” www.architectatwork.at, a very prestigious touring exhibition for new market entries with stops all over Europe, and a team of architects examining and selecting the products to be shown.



LED luminaire ‘Sphere’ and new faceted complex surface reflector

A sphere luminaire for ceiling integration was developed by BARTENBACH until final prototype phase. It is actually licensed for production.

A faceted complex surface reflector (type RDB) was also developed by BARTENBACH until final prototype phase. The reflector is patent-protected and also licensed for production.

Laboratory dynamic test procedure for heating and cooling systems

A laboratory dynamic test procedure was elaborated by EURAC to assess systems performance under real-like conditions. As this result has limited impact if not accepted by the

majority of the manufacturers placing this kind of units on the market, the approach will be presented and discussed with relevant stakeholders, as starting point for a labelling and performance rating standard development.

OFREE test rig: operation, observation, analysis

The exploitable foreground of the method for the performance characterization of solar collectors, is based on the experimental facility OFREE (Outdoor test Facility for Real-size building Envelope Elements) at Fraunhofer-ISE. Companies and research organizations can now measure building-integrated solar thermal BIST collectors with OFREE when they want to characterize a possible BIST product. The method developed for iNSPiRe could be used for many similar installations and could therefore provide an important contribution to the commercial success of BIST in general.

Testing procedures for integrated ventilation units

The timber frame façade with the integrated heat pump and mechanical ventilation unit was tested and optimized in PASSYS Test Cells at University Innsbruck. Tests included building physics aspects as well as the energy performance of the active elements. The method can be used for future products development: it represents an interesting service to SMEs, which want to develop façade integrated active components and want to test their performance before installation in real buildings.

Monitoring and surveillance platform

Purpose of the monitoring and surveillance platform developed within the iNSPiRe project is the measurement and evaluation of the energy consumption before and after refurbishment, surveillance of the correct operation of installations and the monitoring of the internal conditions of dwellings. CARTIF, who developed the tool, will further exploit the platform in future EC funded projects and offer the related service to private companies and/or public authorities. Future improvements of the system may include adaptation for big data, in order to integrate monitoring of city quarters.

Energy performance extrapolation procedure through numerical simulation calibrated by means of short term monitoring data series

A simulation based data reduction procedure was developed by EURAC and used to extrapolated reliable data on the buildings behaviour before and after rehabilitation.

This procedure allows separating the performance of the renovated building from specific occurrences encountered and from changes (e.g. rebound effect, changes of the building total volume, etc.) to the input conditions unconnected with the energy retrofit.

The procedure will be further refined within EC funded innovation projects, and afterwards used as a service to ESCOs and energy consultants needing to extract buildings and HVAC systems performance from short monitoring campaigns.

Potential impact

The demo buildings showed high potential for replication. The building rehabilitated in Ludwigsburg represent one of the most common construction typologies over Germany.

In Madrid the project produced the first low energy consumption retrofitted building of the city. The replicability potential of such project is over 400'000 to 500'000 of similar buildings in Spain. The same holds also for Italy and other southern Member States with similar residential building stock dominated by multifamily houses.

If the iNSPiRe technologies and measures can intercept only 1% of a residential building stock made of standard multifamily homes -ranging around 1 million units- over the next 10 years -0.1% a year = 1'000 buildings a year, around 3% of the overall retrofits market over Europe to date-, **the result is a reduction of primary energy consumption in the range of 1 TWh/y after 10 years.**

In an advanced scenario, where the technologies elaborated and proven trigger the construction industry to develop and market other similar solutions, it can be assumed that 5% of such residential stock is deeply renovated after 10 years, increasing the **primary energy savings to around 5 TWh/y**.

The turnover generated around these rehabilitation works ranges between 200 and 1000 million euros a year, depending on the scenario encountered. This also corresponds to owners/tenants utility energy costs reduced by 80 to 400 million euros per year (over the 10'000 buildings renovated in 10 years).

A deep rehabilitation process does not only involve the implementation of energy efficiency measures. It usually accounts also for structural reinforcement of the building and update to the latest regulations, for instance eliminating architectural barriers, updating electric wiring and water pipelines, etc.. Therefore, after renovation, the building has renewed life cycle, high level of design and living standards, and new services integrated.

Consequently, after the renovation, the property has not only higher energy efficiency but also higher economic value and longer lifetime. This is hardly accounted for when evaluating the payback time of the energy efficiency measures adopted. Specific property value estimation should however be carried out, as a value proposition of the retrofit action undertaken, showing the overall financial picture to owners and public/private investors.

Actions are needed to develop regulations aimed to promote -at real estate market level- the estimation of the property based on a number of quantitative verifiable parameters: primary energy consumption, structural integrity, pipelines integrity, etc.

With planning as key to success of the retrofit work, the main challenge is the coordination of planners and M&E companies within the project team. Moreover, despite the use of prefabricated solutions, the design and installation is still complex to traditional professionals.

Training is needed at national and local level to enhance professionals' skills and to promote the market uptake of tools (e.g. BIM software) facilitating their efforts during design, installation and operation of the building.

These initiatives have the potential to revitalise the construction sector through innovation and a more structured, industrial approach. Several thousands of highly skilled workers (5'000 - 10'000) could be trained and employed in the sector, only with respect to the retrofit market share assumed at the beginning of this section. The potential overall impact on the construction sector is much larger, if the solutions will demonstrate their full effectiveness and reliability.