



D9.13 GUIDEBOOK FOR THE IMPLEMENTATION OF THE SYSTEMIC PACKAGES



Development of systemic packages for deep energy renovation of residential and tertiary buildings including envelope and systems





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Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

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GLOSSARY OF KEY TECHNICAL TERMS

AHU	Air Handling Unit
AWHP	Air Water Heat Pump
COND	Condensing boiler
DHW	Domestic Hot Water
EPBD	Energy Performance of Building Directive
HDD	Heating degree-days
LCA	Life Cycle Assessment
LED	Light Emitting Diode
MVHR	Mechanical Ventilation with Heat Recovery
m-HP	Micro heat pump
MFH	Multi-family house is the term used for a dwelling in a multi-occupancy building (for example a house divided into flats or a purpose-built apartment block)
RES	Renewable Energy Sources
Retrofit	The improvement of existing buildings using energy efficiency fabric, systems or other approaches
SFH	Single family house (for example, detached, semi-detached or terrace house).
SMEs	Small and Medium-sized Enterprises
U-values	Thermal transmittance

EXECUTIVE SUMMARY

The purpose of this Guide Book is to provide an accessible insight into the results of the iNSPiRe project, a four-year collaborative research effort funded by the European Commission through its Seventh Framework Programme (FP7). The project, which came to an end in September, 2016, involved 24 partners from eight EU countries and had a budget of €11 million.

The overall aim of the project was to develop systemic renovation packages designed to reduce the energy consumption of existing buildings to lower than 50kWh/m²/year. The majority of existing buildings in Europe currently have low energy performance, consume 40 per cent of all energy used and have a significant impact on harmful emissions and climate change. Of course, these buildings can't simply be knocked down and replaced by new, greener buildings, making their renovation using energy-efficient retrofit solutions the simplest way to tackle the issue.

iNSPiRe looked to address this by developing five systemic renovation packages for residential buildings in different combinations to meet the particular needs of specific building types and their users. In seeking to explain this work, this guide will add to the understanding of what technology exists to improve energy efficiency in our buildings and how this can be applied in a variety of ways to suit a variety of conditions.

The guide also provides a full explanation of the project's analysis of Europe's existing building stock, as well as the development of the online retrofit decision support tool that enables those involved in renovation work to accurately predict the energy impact of specific retrofit solutions on specific buildings in specific climate areas of Europe. This is a hugely important tool and will help architects, building owners and the construction industry make the right decisions.

In essence, therefore, this guide can be used to ensure the practical application of the solutions developed by iNSPiRe and this is important, not only providing a lasting legacy for the research and development that took place over four years, but to add to the state of the art of building energy retrofitting.

The publication is a comprehensive guide to energy saving solutions for residential buildings and can be used to complement other work that has taken place and will continue to take place in this sector.

1. INTRODUCTION TO ENERGY EFFICIENT RETROFIT AND THE iNSPiRe PROJECT

Across the EU-27 member states (prior to 2013), there is approximately 18 billion m² of residential floor area, and 1.251 billion m² of office floor area. This is a vast amount of area requiring lots of energy to heat, cool, light and power the functions and activities that go on in these buildings. The 2030 EU climate and energy framework sets ambitious targets for the year 2030, including at least 27% improvement in energy efficiency and 27% share for renewable energy.

In order to reach the required level of ambition, significant efforts are needed in all sectors, including improvements to the existing energy inefficient building stock in Europe. The recognition of the potential for energy savings in existing building stock has been notably framed under the European Energy Performance of Buildings Directive and its Recast, which states that, alongside its target to construct nearly zero-energy new buildings by 2020, all new public buildings must be nearly zero-energy by 2018. Member States shall 'draw up national plans for increasing the number of nearly zero-energy buildings' and 'develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings'.

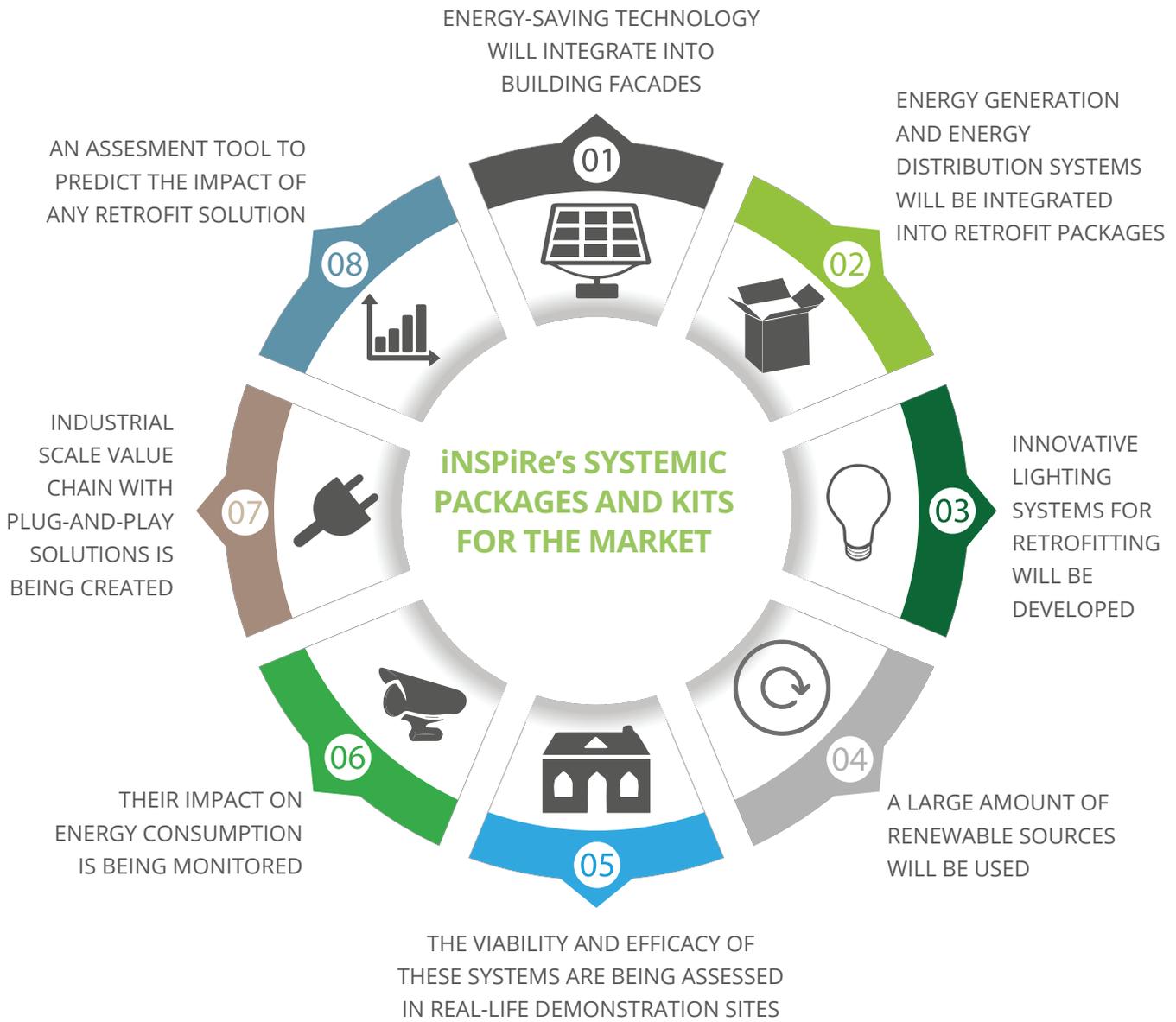
This guidebook shows how the EU and national goals of saving energy and other resources can be combined with the need for improved comfort and reduced energy bills, through an innovative approach to deep building renovation.

The European project iNSPiRe, a four-year initiative coordinated by EURAC and involving 24 partners across Europe, is addressing the problem of the high-energy consumption of the existing building stock. The project developed five systemic renovation packages that can be applied to residential and office buildings in different combinations, after being customised to the end-users needs. These multifunctional renovation packages make use of innovative envelope technologies, energy generation systems (including RES integration) and energy distribution systems. The packages aim to reduce the primary energy consumption of a building to lower than 50 kWh/m²/year in a cost-effective way compared to the existing solutions for deep retrofitting available on the market. They have been designed as plug-and-play systems, easily reproducible under various climates, whilst providing and maintaining comfort for building users.

This guidebook, aimed at private and public building owners, public procurers, architects, building managers, and other stakeholders involved in energy efficiency, describes solutions for an easy renovation process. The iNSPiRe renovation packages aim to prevent, as far as possible, disruption, avoiding the need to decant occupants during the whole renovation process.

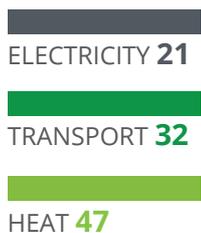
This guidebook begins with an overview of the current European building stock, which helped in the profiling of the buildings' energy usage and thus informing the different energy-saving needs. Following this, each of the six kits are explained in detail, as well as some showcase examples from implementation in demonstration case buildings. The effectiveness was accessed through the monitoring of energy usage before and after retrofitting.

iNSPiRe APPROACH IN SUMMARY

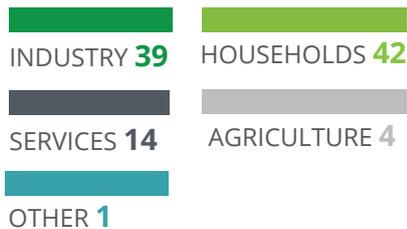


CURRENT ENERGY USE

TYPE OF ENERGY USED



WHO'S USING THE ENERGY?



40% of all this energy is used by buildings

ABOUT iNSPiRe

DURATION



4 YEAR
PROJECT
(2012-2016)

PACKAGES



9 WORK
PACKAGES

BUDGET



€11 MILLION
BUDGET

PARTNERS



24 PARTNERS
(FROM 8 EU
COUNTRIES)

iNSPiRe VISION

THE MAJORITY OF EXISTING BUILDING STOCK IN EUROPE AND WORLDWIDE IS MADE OF BUILDINGS WITH LOW ENERGY PERFORMANCE



iNSPiRe TARGETS A PRIMARY ENERGY DEMAND OF

50kWh/(m²y)

FOR EXISTING RESIDENTIAL AND OFFICE BUILDINGS.

iNSPiRe will do this through:



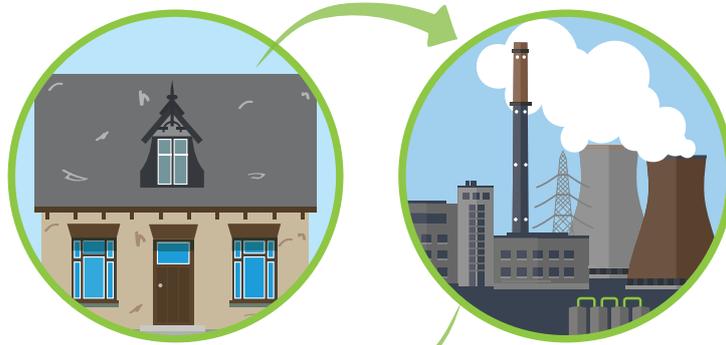
A SYSTEMIC APPROACH FOR THE DEEP RETROFIT OF THE EXISTING BUILDINGS, WHICH INCLUDES ENVELOPE AND HVAC SYSTEM TECHNOLOGIES
(ENERGY RENOVATION PACKAGES).



THE DEVELOPMENT OF MULTIFUNCTIONAL SYSTEMS, INCLUDING ENERGY PRODUCTION AND DISTRIBUTION INTEGRATED INTO THE ENVELOPE SYSTEM
(ENERGY RENOVATION KITS).

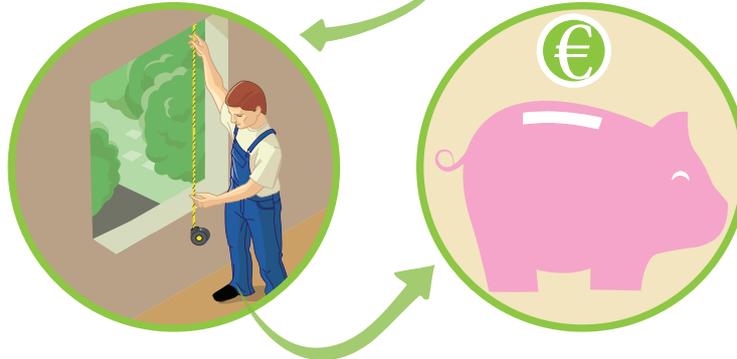
WHY RENOVATE?

THE MAJORITY OF BUILDINGS IN EUROPE ARE OLDER AND INEFFICIENT IN TERMS OF ENERGY CONSUMPTION



THEY ARE SIGNIFICANT CONTRIBUTORS TO HARMFUL CO² EMISSIONS AND USE A HIGH PROPORTION OF OUR PRECIOUS ENERGY

RETROFITTING THEM WITH ENERGY-SAVING SOLUTIONS IS THE ONLY VIABLE ANSWER, AS THEY CAN'T ALL BE KNOCKED DOWN AND REBUILT



BUT RETROFITTING IS EXPENSIVE AND DISRUPTIVE TO THE BUILDING OCCUPANTS

iNSPiRe METHODS?



PRODUCING SYSTEMATIC RENOVATION PACKAGES FOR RESIDENTIAL AND OFFICE BUILDINGS



MAKE THESE RENOVATION PACKAGES TO SUIT A VARIETY OF CLIMATES AND BUILDING TYPES



PRODUCE 6 INNOVATION KITS MADE UP OF INNOVATIVE ENERGY SAVING PRODUCTS



PRODUCE A DATABASE OF RETROFIT SOLUTIONS TO BE USED AS A TOOL TO ASSESS THEIR IMPACT



TEST THE KITS EFFICIENCY IN REAL LIFE DEMONSTRATION SITES



CREATE STANDARDISED PLUG + PLAY SOLUTIONS TO BE AVAILABLE ON THE MARKET

2. BUILDING STOCK ANALYSIS

2.1 STATUS OF EUROPEAN BUILDING STOCK

2.1.1 Background and approach

The targets and requirements set at international, EU, national and local level are forcing the real estate sector and the construction industry to address issues of high energy consumption and associated CO₂ emissions within the existing building stock. Retrofitting is a way of doing so.

Through retrofitting energy consumption and emissions associated with operating the household can be reduced, allowing the building occupants to save money on their energy bills, and make their homes and working places warmer and a more pleasant and comfortable place to live and work. It should also contribute to increase the value and limit the vacancy of a property as well as contribute to its maintenance and structural as well as aesthetic improvement.

Retrofitting existing buildings can be challenging due to financial constraints as well as the highly fragmented and diverse nature of the building stock. Across the EU-27 and even within each country, they vary in age, size, typology, construction, material and tenure type. For example, across the EU-27:

- more than 50% of residential buildings are privately owned by private single owners
- 20-30% are rented by single tenants
- approximately 10% are owned by social housing companies

In addition, there are challenges related to the supply and retrofitting chain. As we will discuss in this guide, the market is largely dominated by SMEs both on the manufacturers and the professional side. To successfully plan and perform retrofit, a good understanding of the existing building stock is required. iNSPiRe undertook an extensive literature review to capture this sort of information. The information and data collected included the number of buildings, floor area, typology, age distribution, typical construction, façade systems and glazing, average floor areas, geometry and number of floors, thermal characteristics of the building fabric (e.g. U-values), ownership/tenure profiles and energy use as a total and by end-use (space heating, domestic hot water, cooling, lighting etc.).

iNSPiRe gathered data from national housing surveys, Census outputs, Office of Statistics and Energy Agencies with each of the countries and results from other recent research projects. However, the information available was sometimes limited and fragmented, which was notably the case for the office stock. To overcome this, a bespoke questionnaire was developed for the project and semi-structured interviews with industry and academic experts were conducted.

The statistics collected from the literature review was checked, validated and stored within a database developed for the iNSPiRe project. This is available at www.inspirefp7.eu/building-stock-statistics

A categorisation approach was applied to the data, and the EU-27 countries were grouped into seven regions based on the heating degree-days, as shown in the table (page 11).

CLIMATIC ZONE	COUNTRIES WITHIN CLIMATIC ZONE
Southern Dry	Portugal, Spain
Mediterranean	Cyprus, Greece, Italy, Malta
Southern Continental	Bulgaria, France, Slovenia
Oceanic	Belgium, Ireland, Netherlands, UK
Continental	Austria, Czech Republic, Germany, Hungary, Luxembourg, Romania, Slovakia
Northern Continental	Denmark, Lithuania, Poland
Nordic	Estonia, Finland, Latvia, Sweden

Table 1: These climatic zones were used throughout the iNSPiRe project and in the database.

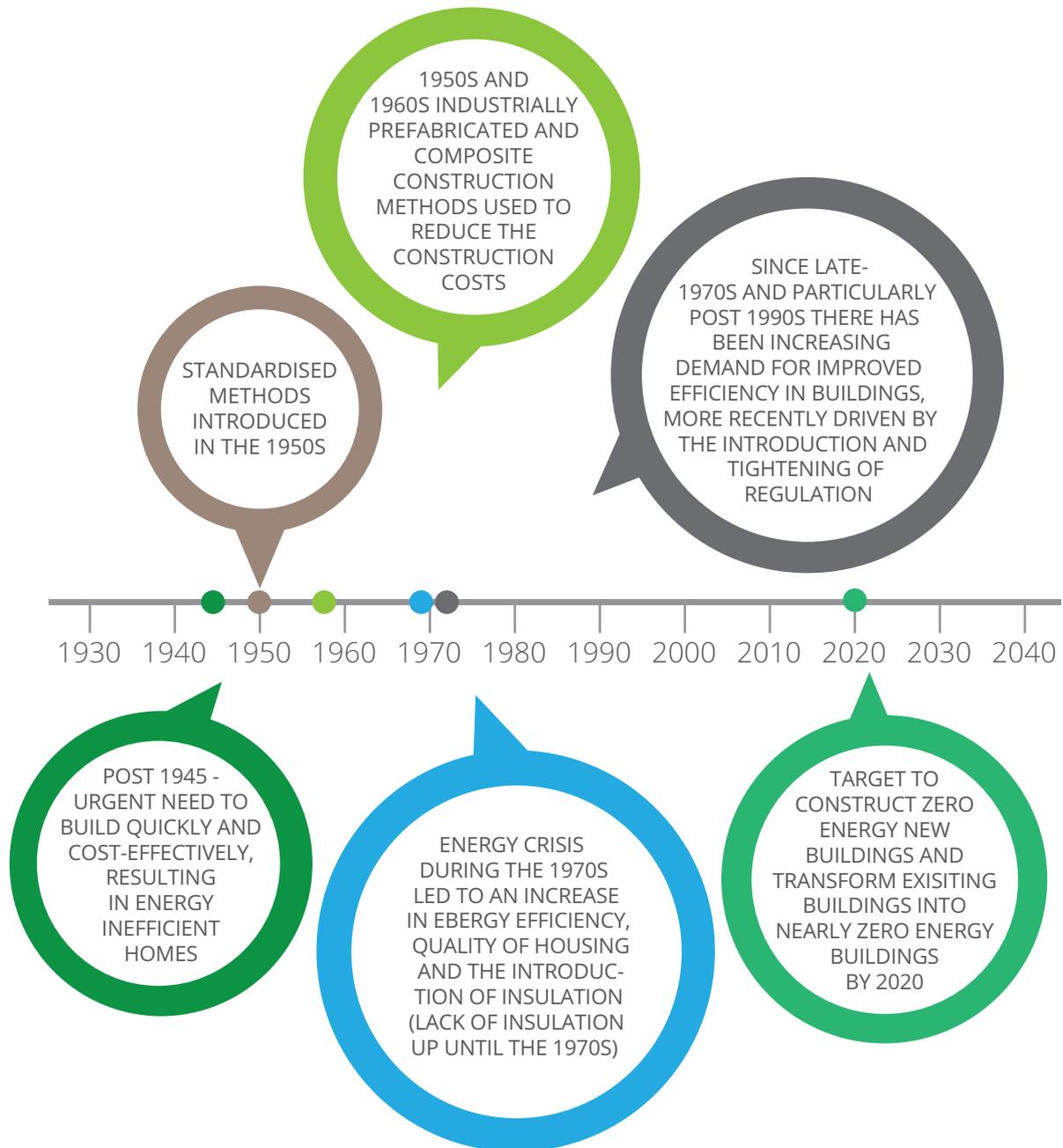
Residential buildings

The residential building stock varies across the EU-27 countries varies in a number of distinct ways:

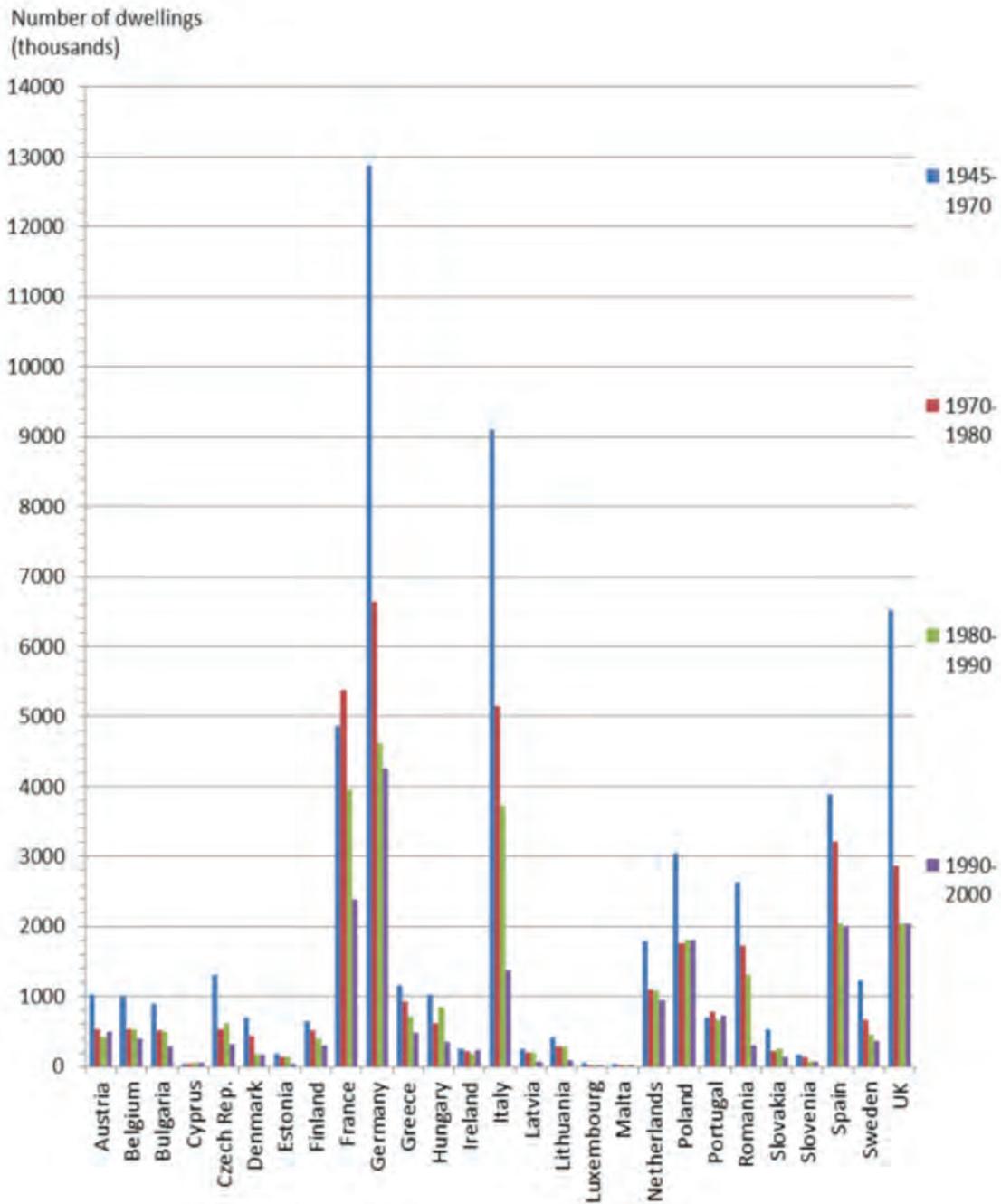
- Scale (linked to the population and household profile of each country)
- Age (linked to history and public/private support for development)
- Type (Single Family House or Multi Family House) and construction
- Energy used for space heating/cooling, hot water, appliances/cooking (linked to climate, each country's history and regulatory regime)
- Fuel used (linked to natural resources, industrialisation and geography)

RESIDENTIAL BUILDING STOCK IN EUROPE

Within each country, the residential building stock has been growing and changing since 1945. Methods and standards of construction have generally improved, as described in the timeline below.

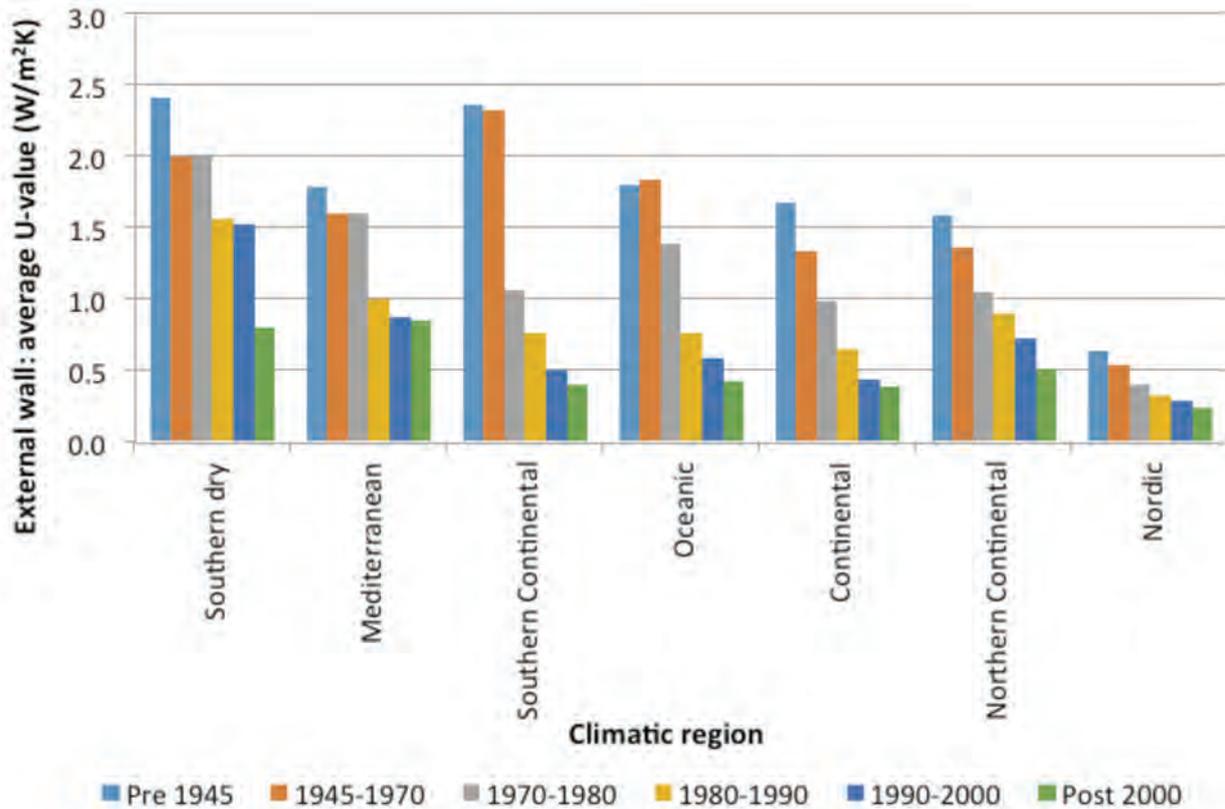


Over half of the residential building stock within the EU-27 countries (based on floor area) was constructed before 1971, as shown below.



Prior to the 1970s, there was very little in terms of standards, policy and regulation related to energy efficiency in buildings. Since these were introduced there have been improvements, with the introduction and tightening of building and energy regulation. In the chart below you can see how the U-values (thermal transmittance) of the external walls have improved over the years. The lower an element's U-value, the more slowly heat is able to transmit through it, and therefore the better it performs as an insulator.

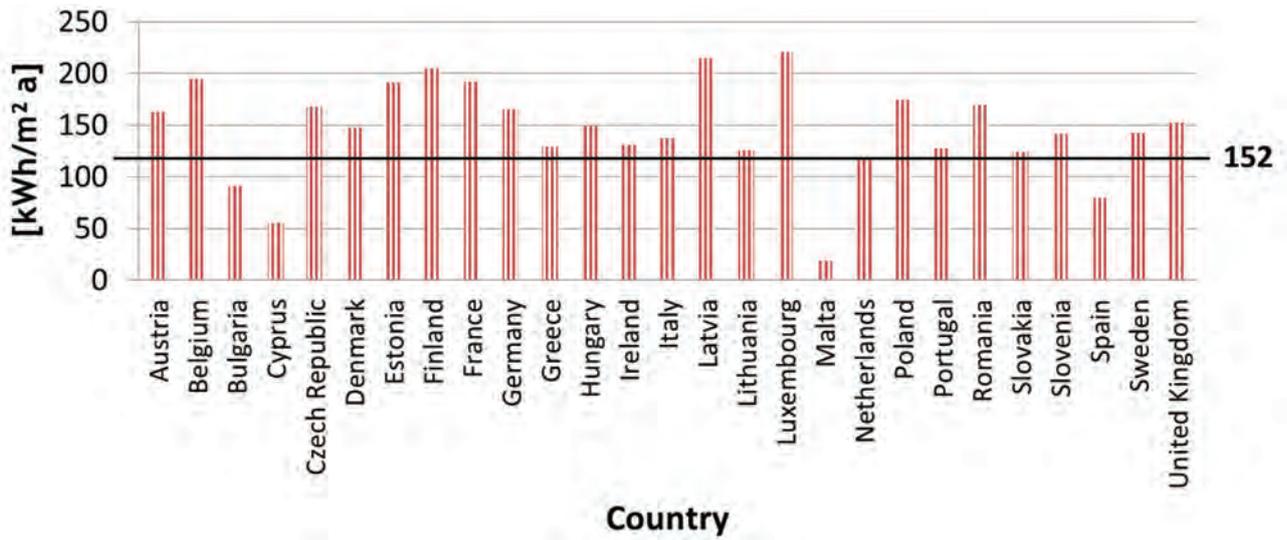
EXTERNAL WALL U-VALUES IN RESIDENTIAL BUILDINGS BY CONSTRUCTION YEAR



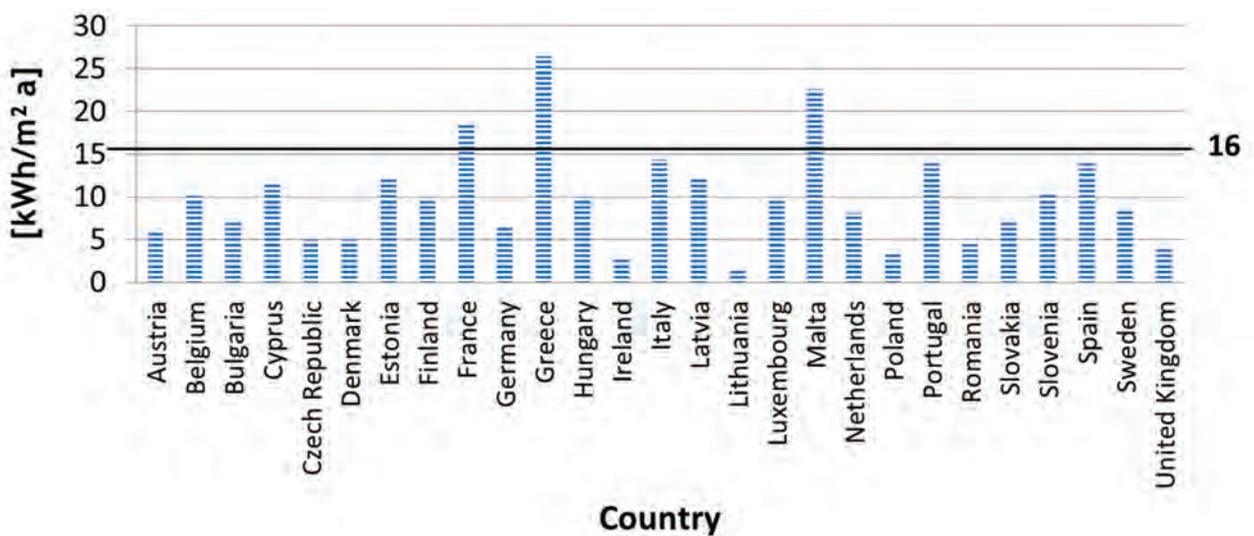
From the data collected, we estimated that the average specific heating demand of residential buildings across Europe is 140-150 kWh/m²/y, compared with average domestic hot water (DHW) demand of 20-25 kWh/m²/y. The average cooling demand is 30-50 kWh/m²/y in countries located in the south of Europe.

The charts show the specific energy consumption averages by end use for each country and the weighted average for the EU-27 (based the countries floor area).

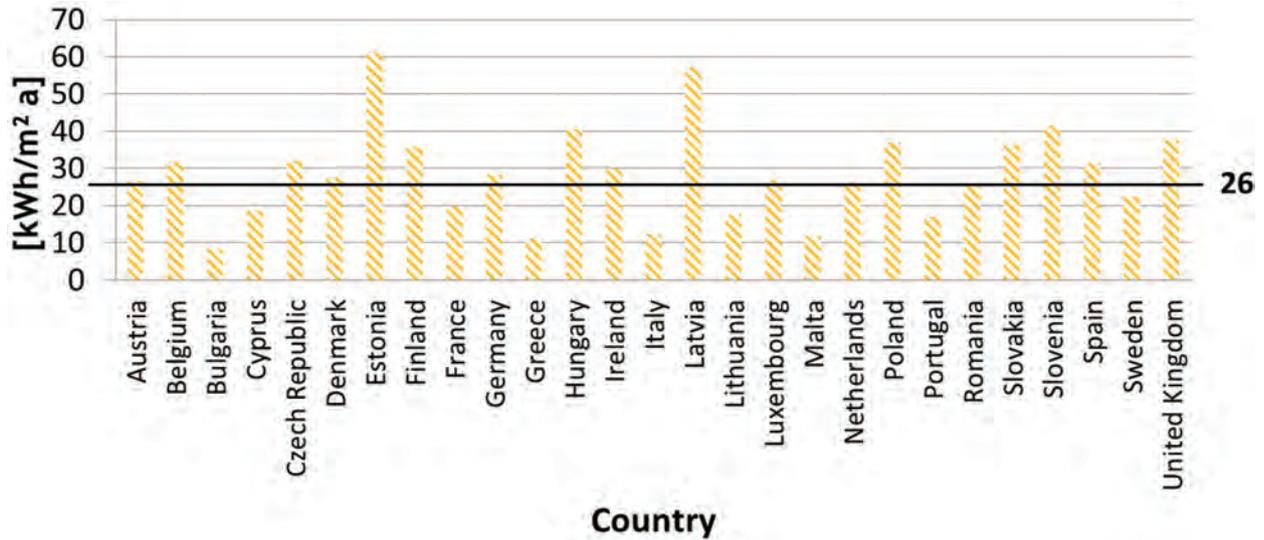
SPACE HEATING CONSUMPTION PER COUNTRY, RESIDENTIAL SECTOR (EU-27)



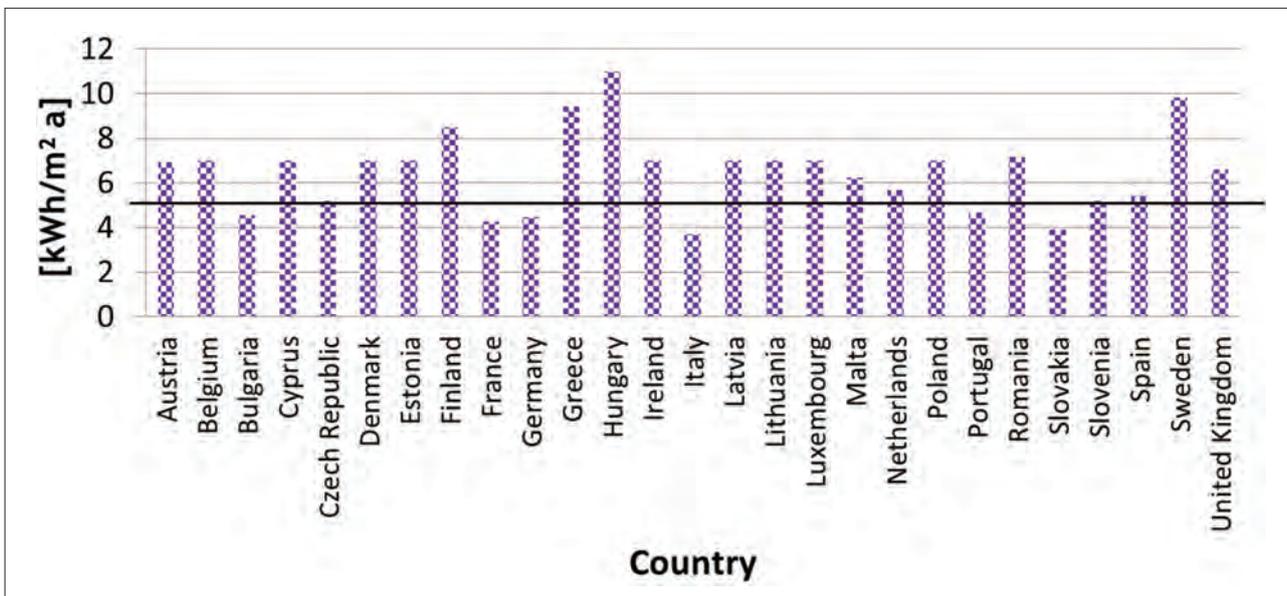
SPACE COOLING CONSUMPTION PER COUNTRY, RESIDENTIAL SECTOR (EU-27)



DHW CONSUMPTION PER COUNTRY, RESIDENTIAL SECTOR (EU-27)



LIGHTING CONSUMPTION PER COUNTRY, RESIDENTIAL SECTOR (EU-27)



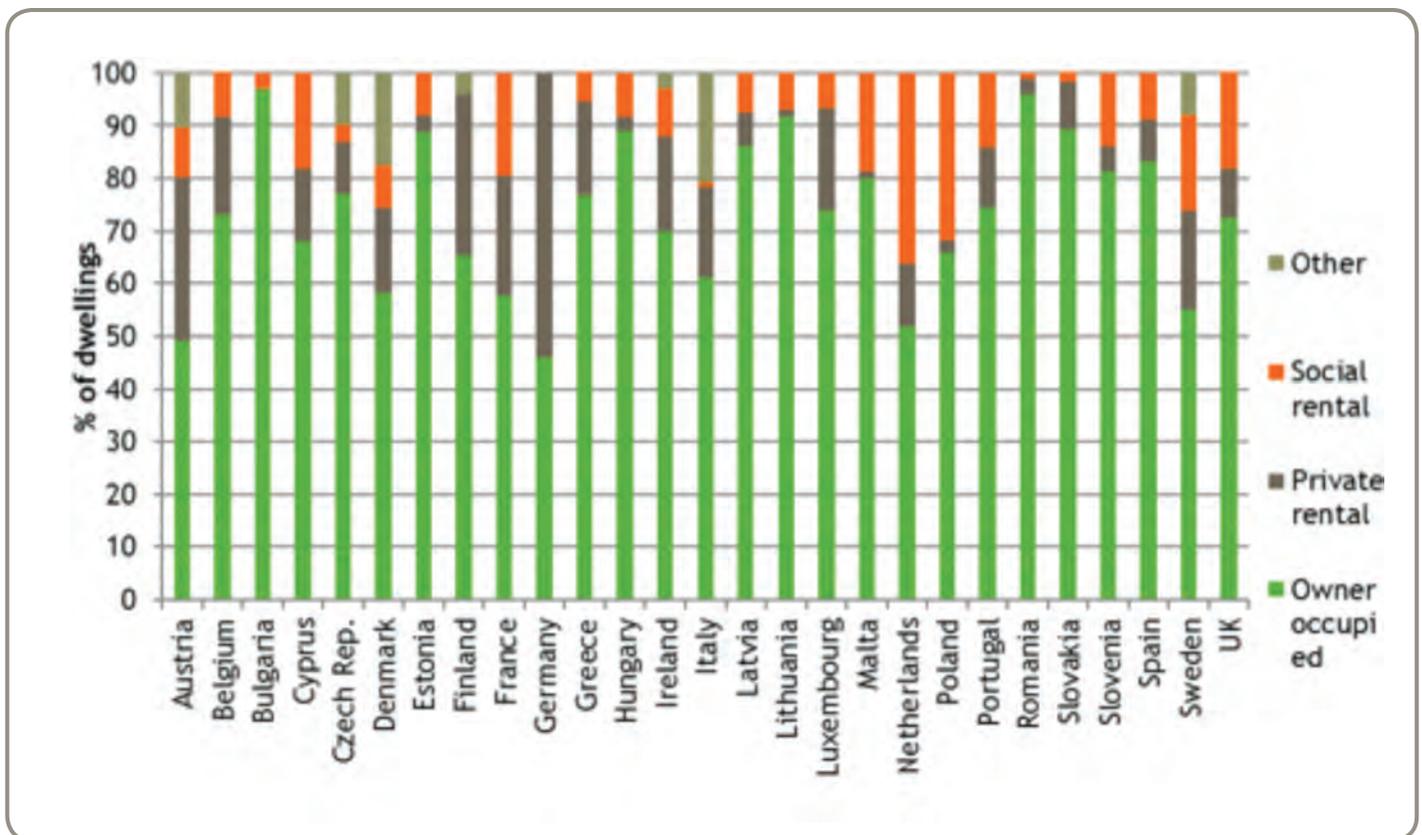
All this energy results in great amounts of consumption within the residential sector across Europe.

- Heating consumption 2300 TWh/y
- Cooling consumption 100 TWh/y
- DHW consumption 500 TWh/y

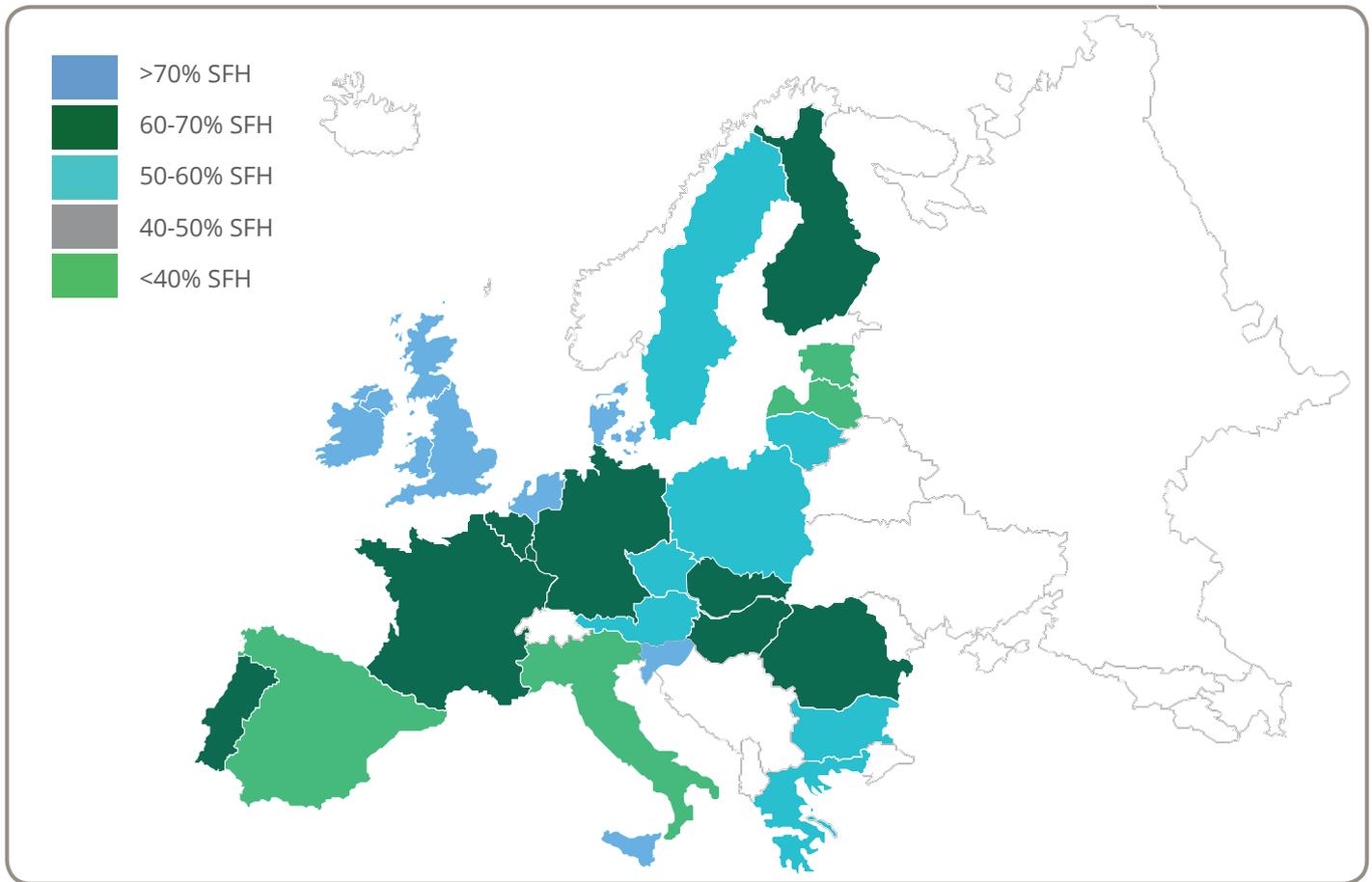
Total heating energy consumption across residential sector is approximately 14 times more than the office sector, underlining the importance of the residential sector in energy-reduction retrofit.

When planning for retrofit, a significant factor is the type of ownership and this is link to both the financing and implementation. Decanting occupants whilst retrofit measures are applied is not always possible, therefore careful managing the expectations of the occupants is a key consideration.

Generally, the level of owner-occupation across the EU-27 is high. In some countries, such as Bulgaria, Lithuania, Romania, it is greater than 90% and in most countries it is higher than 70%. High levels of owner occupation can be helpful for retrofit projects, as one of the key barriers to retrofit measures that reduce energy consumption is where the costs are borne by the landlord, but the benefits are seen by the tenant. This is a situation that occurs in rented properties. However, financing retrofit can be challenging and this is where incentives and grants can help.



Overall, single family houses represent the majority of the heated floor area across the EU-27, at 60%. Yet the residential mix between SFHs and MFHs differs widely between countries. Denmark, Ireland, Netherlands and United Kingdom have the highest proportions of SFHs whereas Estonia, Italy, Latvia and Spain have the lowest proportions of SFHs.



To be effective across the whole residential stock, retrofit solutions need to be designed to accommodate both single and multi-family houses. MFHs are often considered easier to apply retrofit measures to, partly because their exteriors are more uniform, which makes external insulation or replacement glazing easier to install, and partly because each building contains multiple dwellings so a single project can improve conditions for more families. Carrying out retrofit projects that affect an entire MFH building (such as façade/window replacement or upgrading communal heating systems) can also be easier where there is a single owner or landlord for the whole building.

Office buildings

There is approximately 1.251 billion m² of office floor area in the EU-27, and similar to the residential sector 71% is located in the six most populated countries.

Understanding the characteristics of the office building stock was more challenging than for the residential stock. The lack of detailed information collected during the literature review revealed that little is known about the age of the current office stock, particularly those built pre-1980. This appears partly due to the fact that historically there was no schematic way or need to collect information, unlike the census approach in residential buildings. The information collected indicated that the office stock is generally younger than the residential stock, with the proportion of the pre-1945 stock being much lower.

The construction of office buildings accelerated from 1960s, peaking in the 1990s. The post-2000 construction is also significantly higher than other decades, with some exceptions.

The general construction types found across the EU-27 are the same in most countries. For example office buildings with concrete structural frame and curtain wall facades often have different number of floors or shapes, yet the outside of them look very similar whether you are in Germany, Italy, Hungary or the UK, for example. The issue is that in just one country there are many different types of offices, i.e. size, geometry and number of storeys etc., making the office stock difficult to categorise.

The pre-1945 office buildings are often brick structural walls with an exposed wall façade or concrete structure with concrete façade. Offices built 1945-1964 often have concrete structures with brick or concrete façade. The first curtain walls also seem to have appeared during these years. Concrete structures continued to dominate the construction of office buildings into the 1970s and 1980s. During this time prefabricated sandwich walls were introduced.

Office buildings built in the 1980s often consist of pre-fabricated elements, either load bearing or in-fill only. Glass curtain walls and/or aluminium panels were fairly typical during the 1980s. The curtain wall façade seems to be the most typical type of construction, particularly those built after 1960.

The situation nowadays is often that many new office buildings are part of mixed-use or speculative developments.

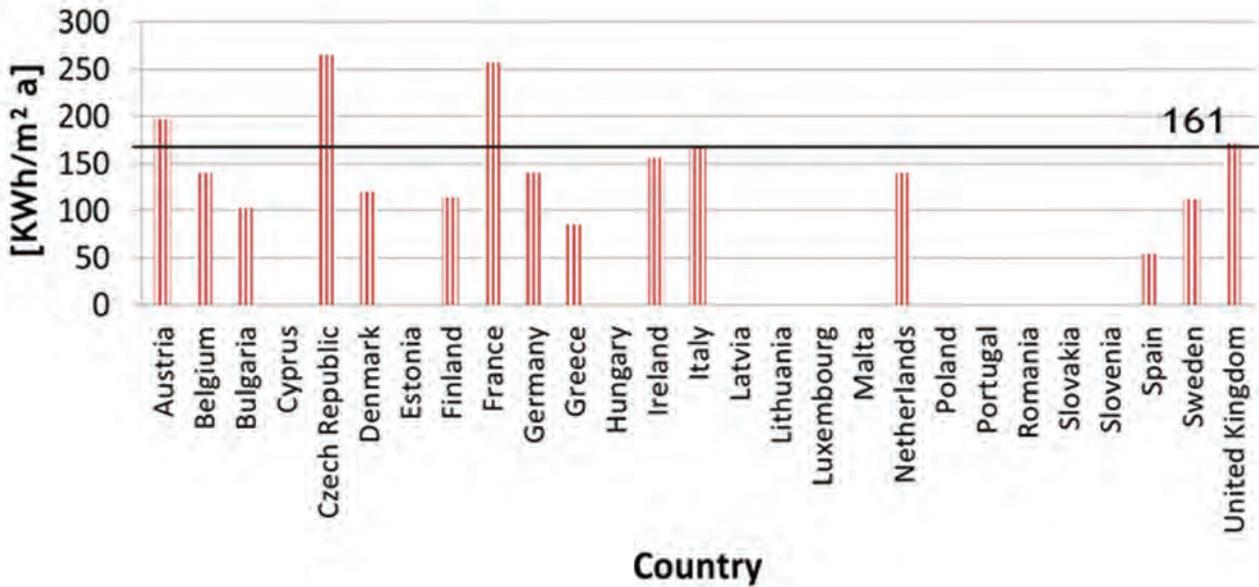
The façade is an important factor in retrofitting the office building stock. Over the years there has been an increase in the amount of glazing and the use of non-structural infill panels.

Similar to the situation in residential buildings, the main stakeholders in the office sector are the private owners.

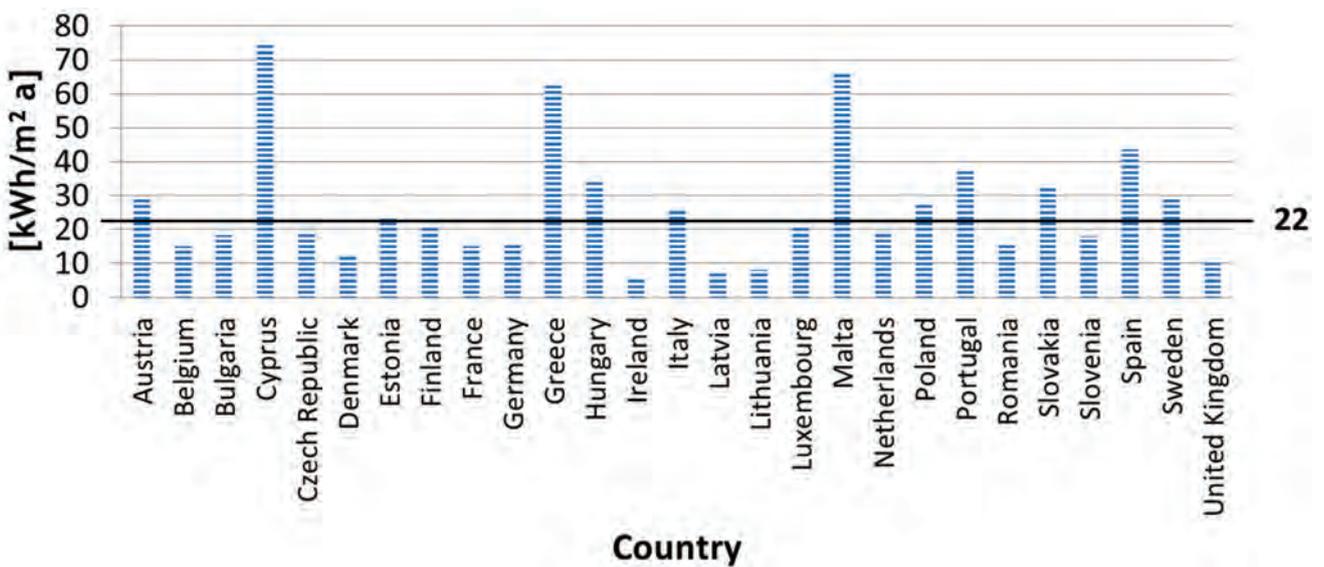
Due to the lack of information found during the literature review, there are some uncertainties over the reliability of the data reported for some of the regions and gaps exist. Specifically, the literature review revealed limited data about the Northern Continental region and for some countries within Southern Dry, Nordic and Continental regions. The availability of data related to domestic hot water energy use in office buildings was partial in most countries.

The charts below show the specific energy consumption averages for each country and a weighted average across all countries. These figures have been estimated from the data collected during the literature review.

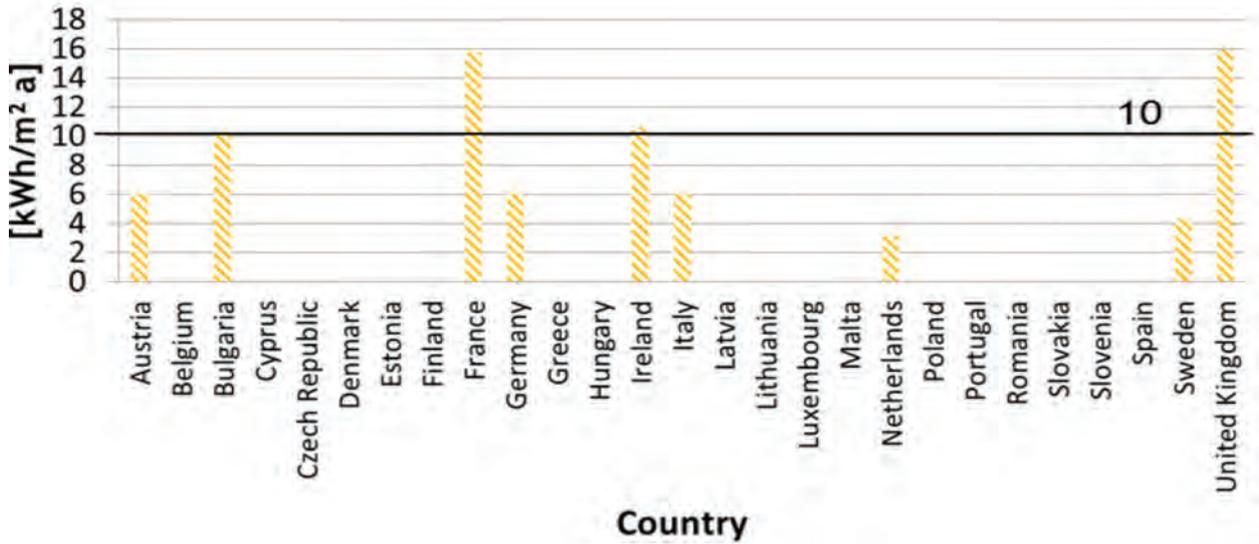
SPACE HEATING CONSUMPTION PER COUNTRY, OFFICE SECTOR (EU-27)



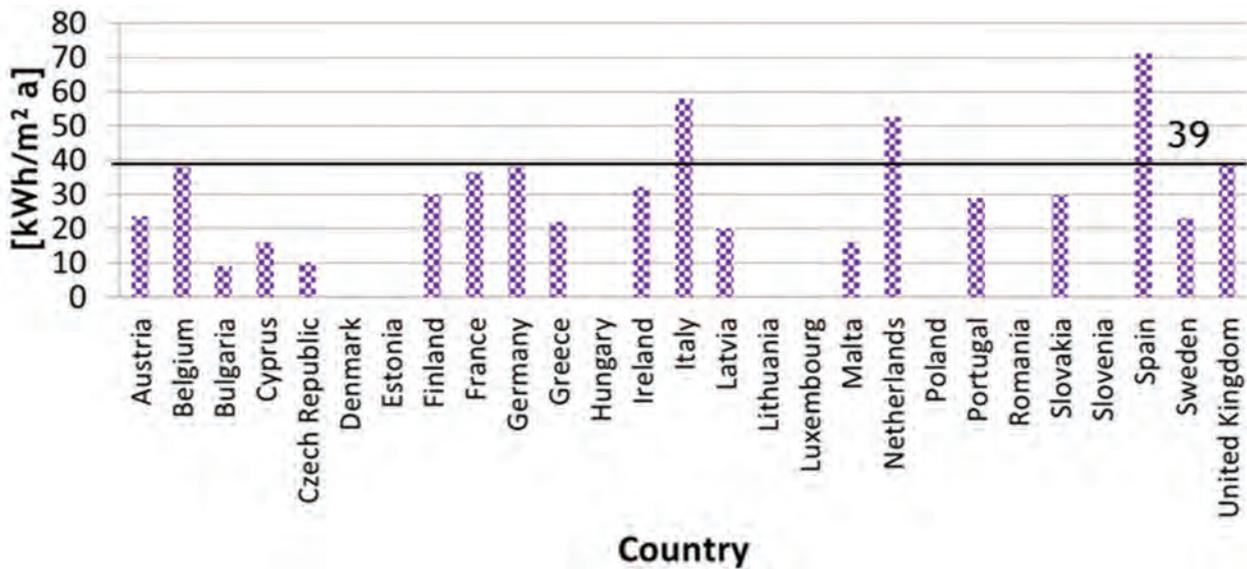
SPACE COOLING CONSUMPTION PER COUNTRY, OFFICE SECTOR (EU-27)



DHW CONSUMPTION PER COUNTRY, OFFICE SECTOR (EU-27)



LIGHTING CONSUMPTION PER COUNTRY, OFFICE SECTOR (EU-27)



All this energy results in great amounts of consumption within the office buildings across Europe.

- Heating consumption 159 TWh/y
- Cooling consumption 18 TWh/y
- DHW consumption 7 TWh/y

Database

The information collected and analysed from the building stock survey has been validated and presented in a database and is freely available for download from the iNSPiRe website. www.inspirefp7.eu/building-stock-statistics.

What are the key findings from the building stock survey?

The concentration of both residential and office space is in the six most populated countries of France, Germany, Italy, Poland, Spain and United Kingdom. These six countries account for 72% of residential and 71% of office floor area.

Across the EU-27, single-family houses represent the majority of the heated floor area at 60%. This means that although single-family houses tend to have a larger floor area than MFH dwellings, the SFHs still constitute around 50% of dwellings and therefore 50% of households. To be effective across the whole residential stock, retrofit solutions need to be designed to accommodate both single and multi-family houses.

Total heating energy consumption across residential and office sectors is 2299TWh/year and 159 TWh/year respectively, giving a ratio of 14:1. This underlines the importance of the residential sector in energy-reduction retrofit. Yet, the variability of the buildings in the residential sector means that this segment of the market is also harder to treat with standardised solutions.

One of the recent developments in the field of office building construction in the EU is that the European Commission developed green public procurement (GPP) criteria in different application areas aiming at facilitating public authorities the purchase of products, services and works with reduced environmental impacts. The use of the criteria is voluntary. The criteria are formulated in such a way that they can be integrated into its tender documents. One of the recent GPP criteria relates to office building design, construction and management. The criteria set addresses the procurement process for office buildings, including their design, site preparation, construction, servicing and ongoing management.¹

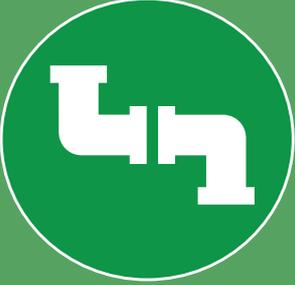
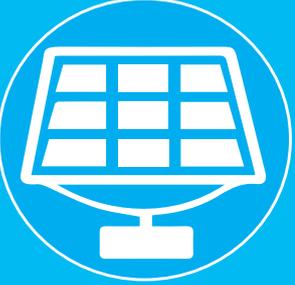
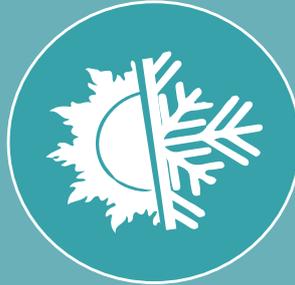
The document will be accompanied with a procurement practise guidance document for procurers, estate managers and project teams on how to procure environmentally improved office building.² Besides a technical background document will be updated onto the European Commission website in the close future.

¹ The criteria document is available via the EC DG Environment website: http://ec.europa.eu/environment/gpp/pdf/swd_2016_180.pdf

² At the time of preparation of this document only the draft final version of the guidance document is available on the EC DG Environment website: http://ec.europa.eu/environment/gpp/pdf/Guidance_Buildings%20final.pdf

3. RENOVATION TECHNOLOGIES (KITS)

3.1 RENOVATION TECHNOLOGY 1: WOODEN ENVELOPE WITH MICRO-HEAT PUMP

<p>KIT ONE</p>  <p>WOODEN FRAME ENVELOPE MODULE INCORPORATING DUCTS AND AIR-TO-AIR HEAT PUMP</p>	<p>KIT TWO</p>  <p>WOODEN FRAME ENVELOPE MODULE INCORPORATING WATER PIPES</p>	<p>KIT THREE</p>  <p>WOODEN FRAME ENVELOPE MODULE INCORPORATING SOLAR COLLECTORS</p>
<p>KIT FOUR</p>  <p>METAL-GLASS FAÇADE MODULE FOR OFFICE BUILDINGS INCORPORATING THE AIR-HANDLING UNIT</p>	<p>KIT FIVE</p>  <p>STANDARDISED HYDRONIC MODULE FOR COMPLEX HYBRID HEATING AND COOLING SYSTEMS</p>	<p>KIT SIX</p>  <p>MULTIFUNCTIONAL CEILING PANEL FOR HEATING AND COOLING, VENTILATION AND LIGHTING</p>

3.1.1 Main features and design

A ventilation system, providing the required air supply and good levels of air quality is essential in state of the art retrofit, especially given the high levels of airtightness required by current building regulations. In order to achieve the required energy demand, incorporating a heat recovery feature is also necessary. Ventilation systems are a rare feature in existing dwellings and therefore when undertaking retrofit, large set of ducts and parts have to be introduced.

In previous projects, where a prefabricated timber envelope retrofit solution have been applied, it did not incorporate heat recovery ventilation systems, due to the impacts its installation has in occupied flats. A goal of this project was to overcome this by developing a system, which delivers a MVHR (mechanical ventilation with heat recovery), minimising where possible the installation of ducts inside the occupied dwelling.

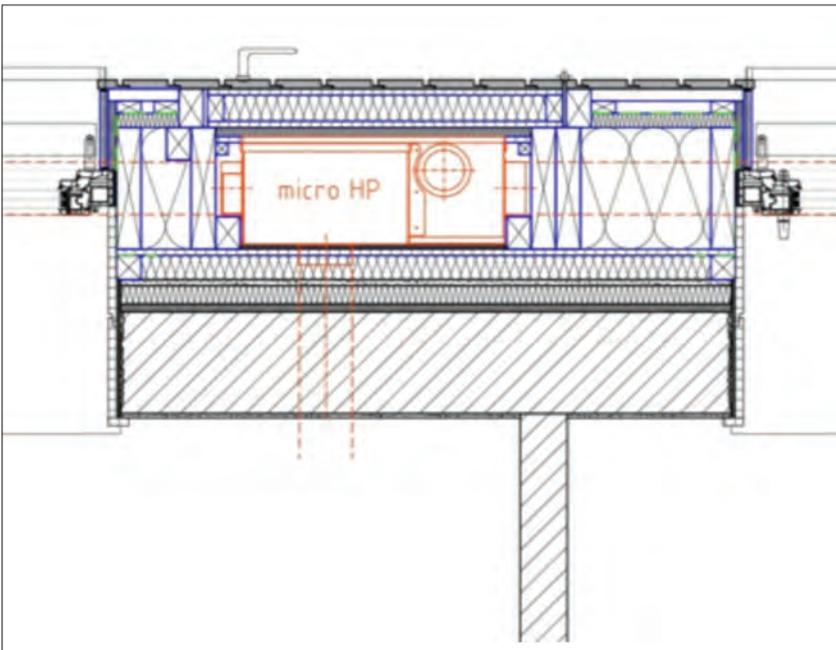


Figure 1: Detail section of the integration of the micro heat pump with MVHR unit (Source: Gumpp & Maier GmbH)



Figure 2: Picture of the installed unit (Source: Gumpp & Maier GmbH)

3.1.2 Installation, operation and maintenance

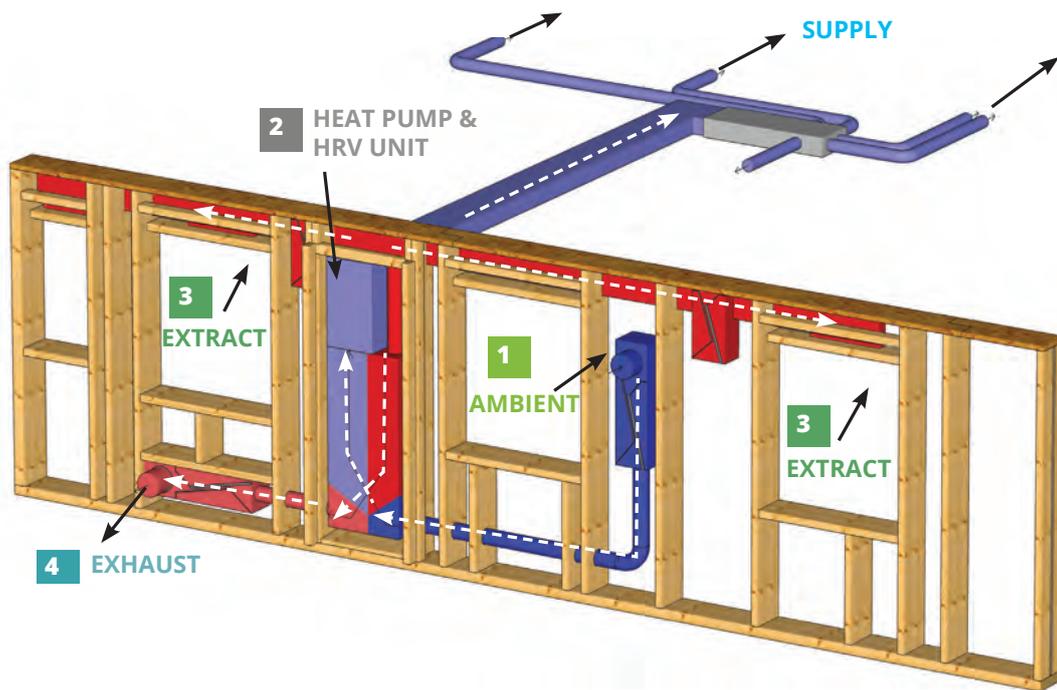
The micro heat pump, based on a MVHR unit available on the market, has been delivered by the company Siko GmbH. The evaporator is added on the exhaust of the MVHR unit, and the condenser to the supply air of the system, using the remaining heat of the system to deliver the active heating. The unit is accessible from the outside through a door in the cladding for periodic maintenance and filter exchange. The mHP and the MVHR units should be accessible from a balcony or at ground floor level for maintenance. Ventilation ducts should not require any service during the lifetime of the ventilation system.

In the Ludwigsburg demonstration building, the unit has been placed in the north façade, where all the rooms requiring air extract are located. It is a common floor layout that kitchens and bathrooms are placed to the north, enabling to integrate their ducts in one element. Therefore, the MVHR+mHP unit has been assembled off-site in the north façade. The supply air is taken out of the external envelope, and brought in directly into the flat through air ducts installed on the ceiling.

The acoustic silencers, to reduce noise transmission between rooms and to the ambient and exhaust intakes have also been integrated in the timber frame and delivered to site in a way that no further work is required apart from commissioning.

The extract air inlets from the bathroom, toilet and kitchen are integrated in the window upper chill, requiring on site only the installation of the grill, which is carried out along with the dry lining.

MHVR SYSTEM



1 OUTSIDE AIR IS DRIVEN THROUGH THE DUCTS INTEGRATED INTO THE FAÇADE. A SILENCER AND A FILTER ARE FITTED TO THE MVHR AND MHP UNIT

2 THE OUTSIDE AIR IS PREHEATED IN THE HEAT EXCHANGER AND FURTHER HEATED, IF REQUIRED, THROUGH THE HEAT PUMP. IT IS DISTRIBUTED THROUGHOUT THE FLAT THROUGH THE DUCTS

3 EXTRACTED AIR OR WARM EXTRACTED AIR IS DRIVEN THROUGH THE HEAT EXCHANGER, WHERE IT PREHEATS THE INCOMING COOL AIR

4 THE REMAINING ENERGY OF THE EXHAUST AIR IS USED AS A SOURCE FOR THE MICRO-HP AND IS THEN DRIVEN THROUGH THE SILENCER TO THE OUTSIDE



Figure 4: Parts of the ventilation system installed in the wall during prefabrication (Source: Gumpp & Maier GmbH)



Figure 5: Installation of the wall element on the left figure. (Source: Gumpp & Maier GmbH)

The prefabrication of the ventilation parts has shown 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 times, producing time/cost savings in the process.

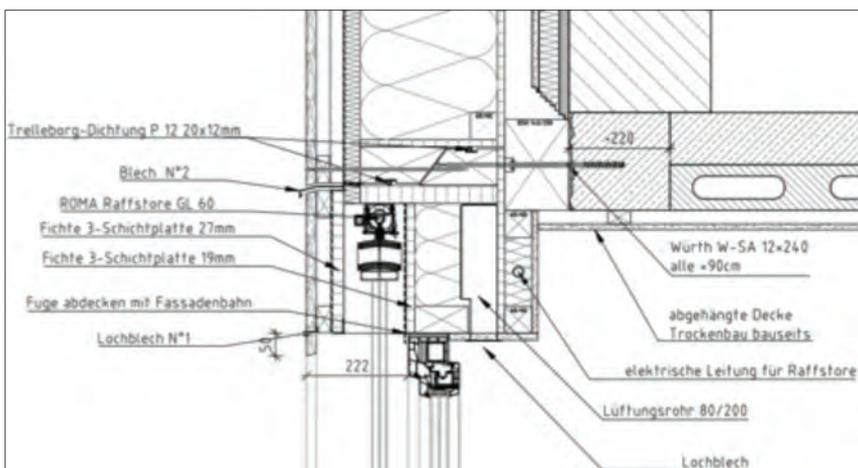


Figure 6: Detail of the upper window detail, integrating ventilation ducts, sun shading and the structural connection to the existing (Source: Gumpp & Maier GmbH)

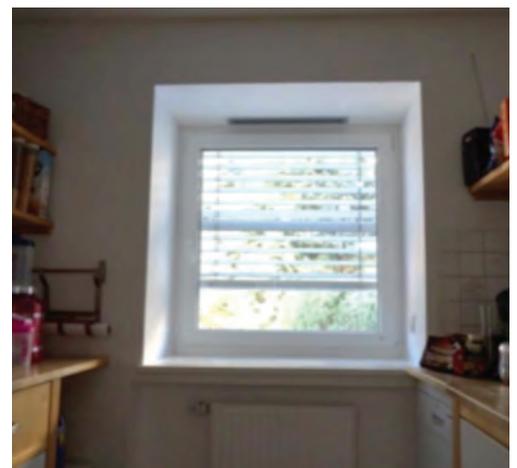


Figure 7: Picture of the finished reveal with an integrated ventilation outlet (Source: Gumpp & Maier GmbH)

The ventilation extract duct and solar shading had to be integrated to the timber element at the junction with the slab, which is simultaneously the structural fixation point. Figure 6 shows the integration of all components at this junction, which has been engineered to integrate all aforementioned functions and a reasonable amount of insulation to avoid thermal bridging.. Once the reveals are installed, the final solution is aesthetically pleasing from inside and outside of the property

3.1.3 Deconstruction – disposal – lifespan

The walls comprise timber, cellulose insulation, OSB, timber soft fibre board and different sorts of cladding. Windows, shading or other elements can also be prefabricated. These materials do not cause any health and safety issues, and are sourced responsibly/in an environmentally friendly manner, as PEFC or FSC certified products. Every timber facade has to be calculated by a static specialist, also in terms of earthquake resistance.

3.1.4 Life cycle analysis

The envelope kit 1 (EK^{n°1}) is not standard but tailor made to the existing building. The life cycle analysis (LCA) conducted within iNSPiRe dealt with the specific case of Ludwigsburg. In this building, two versions of the kit have been implemented, one for the ground floor, the EK n°1.1, and the first floor, the EK n°1.2.

The unit of analysis is the following: “1 m² of facade renovation kit ensuring thermal insulation reinforcement, heating and MVHR to the existing building”. The assessment is cradle to gate. (cf. D3.5 “Assessment of embodied impacts of Envelope products and kits” for more details on the LCA study).

The charts presented in Figure 8 and Figure 9 show how much each component contributes to the EK n°1.1 on non-renewable energy and climate change impacts respectively. The area of each circle matches with the impact of the component named next to it.

The charts presented in Figure 10 and Figure 11 show how much each component contributes to the EK n°1.2 on non-renewable energy and climate change impacts respectively.

The bio-sourced products generate negative impacts (i.e. a positive effect) on climate change. This is due to the fact that biogenic carbon is absorbed by wood while it grows. Notice that this result can be balanced with the inclusion of the end of life treatment impact in the assessment: if the bio-sourced product is incinerated the balance is null.

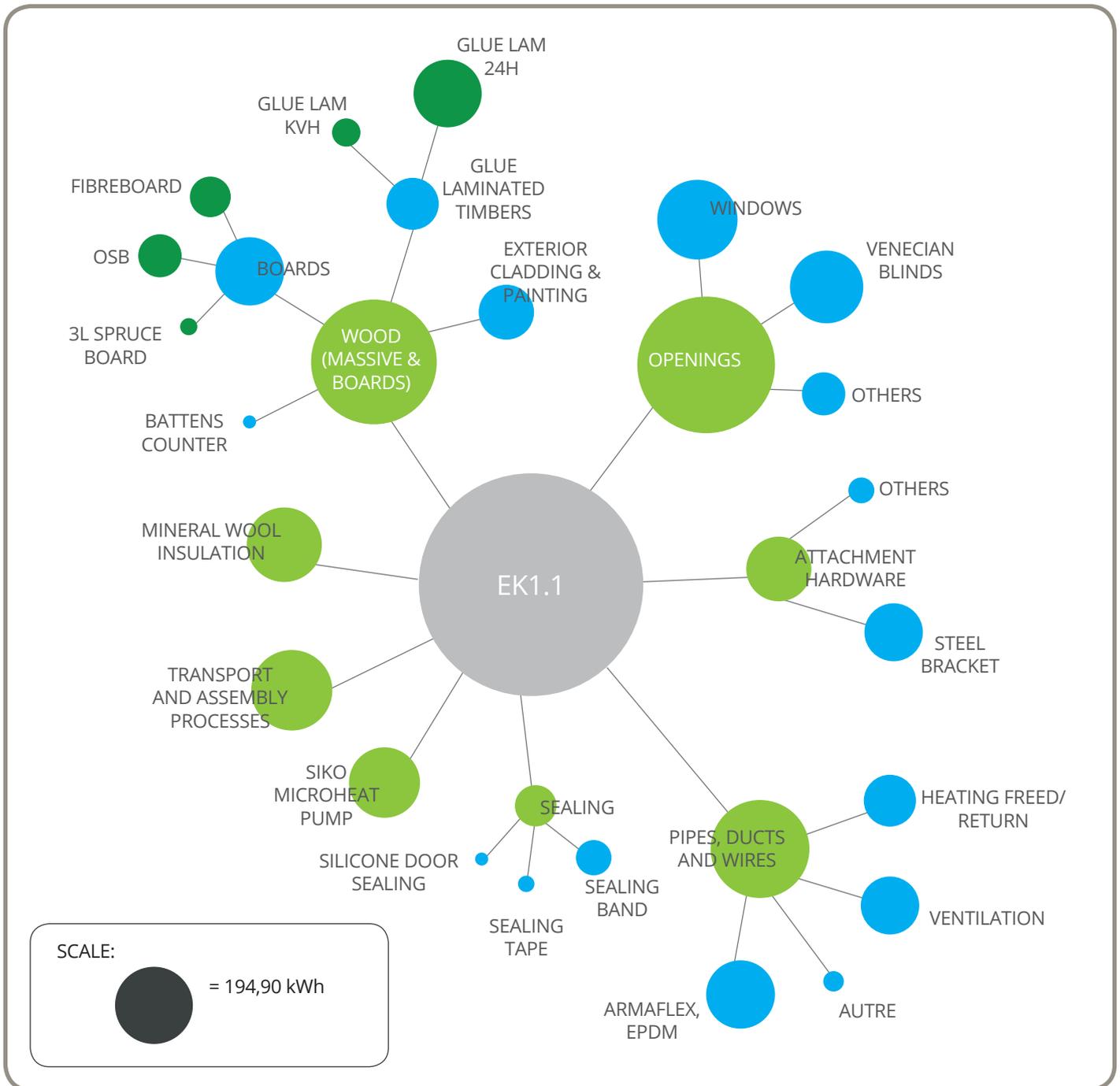


Figure 8 : Contribution of the components of the kit n°1.1 to the non-renewable energy impact.

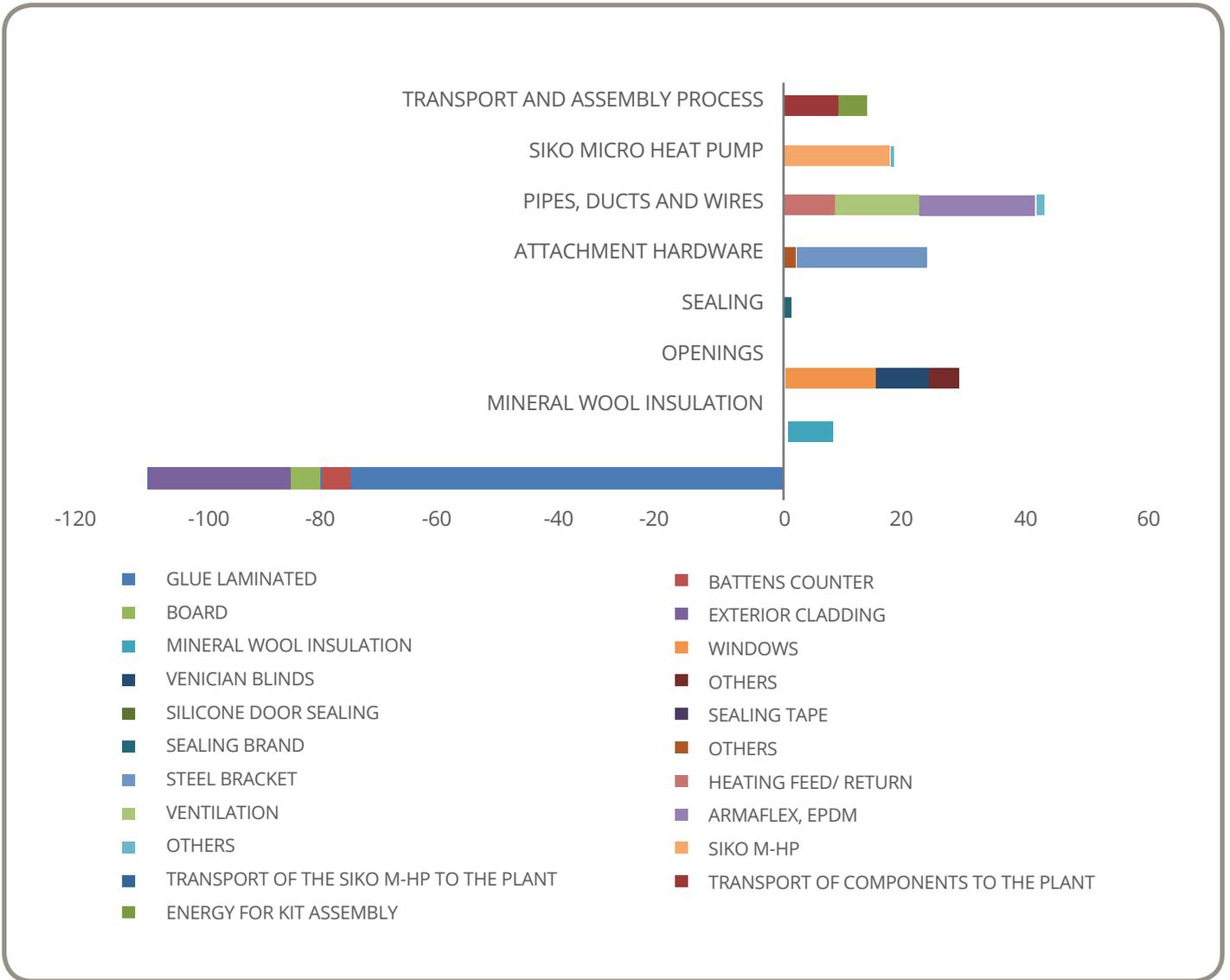


Figure 9: Contribution of the components of the kit n°1.1 to the climate change impact.

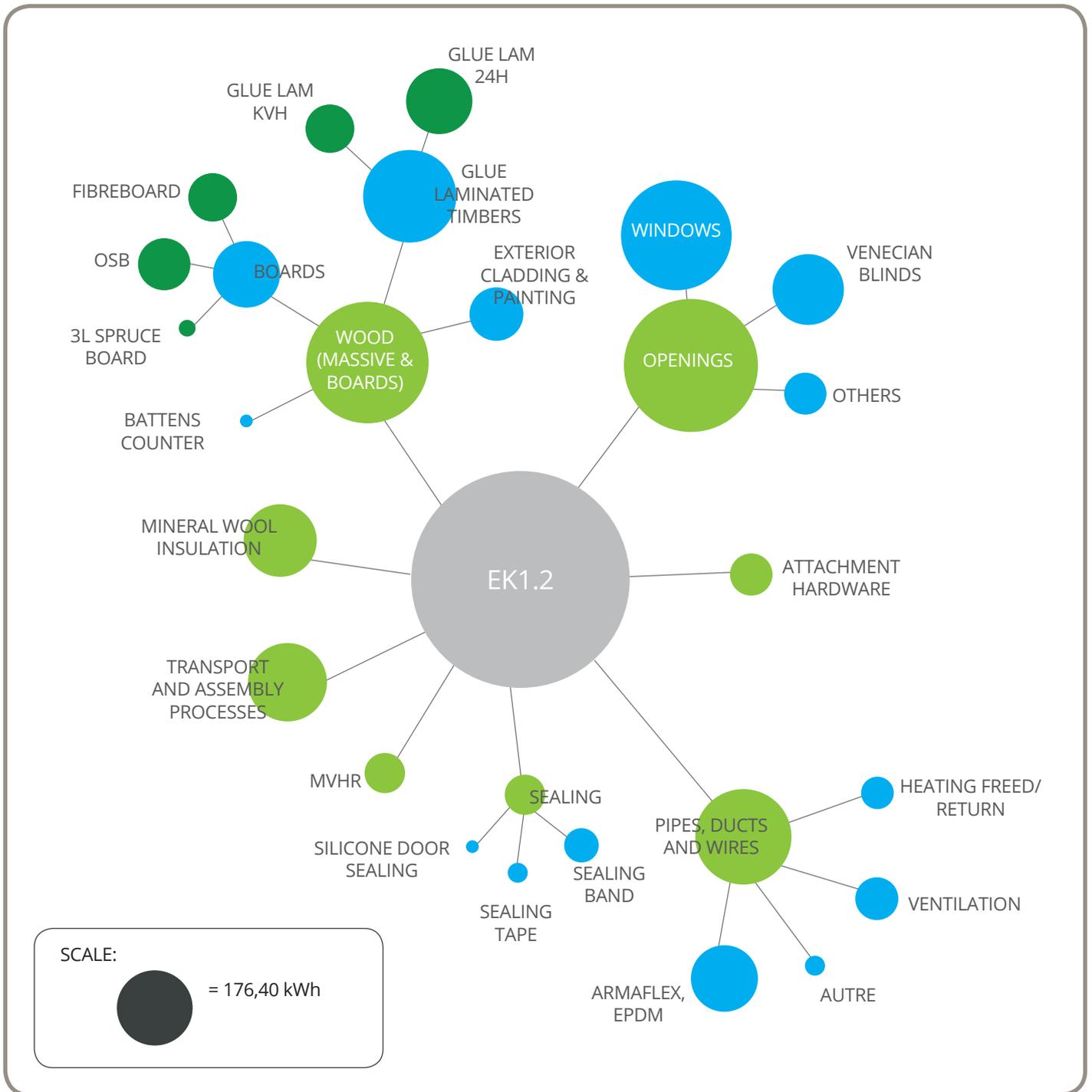


Figure 10: Contribution of the components of the kit n°1.2 to the non-renewable energy impact.

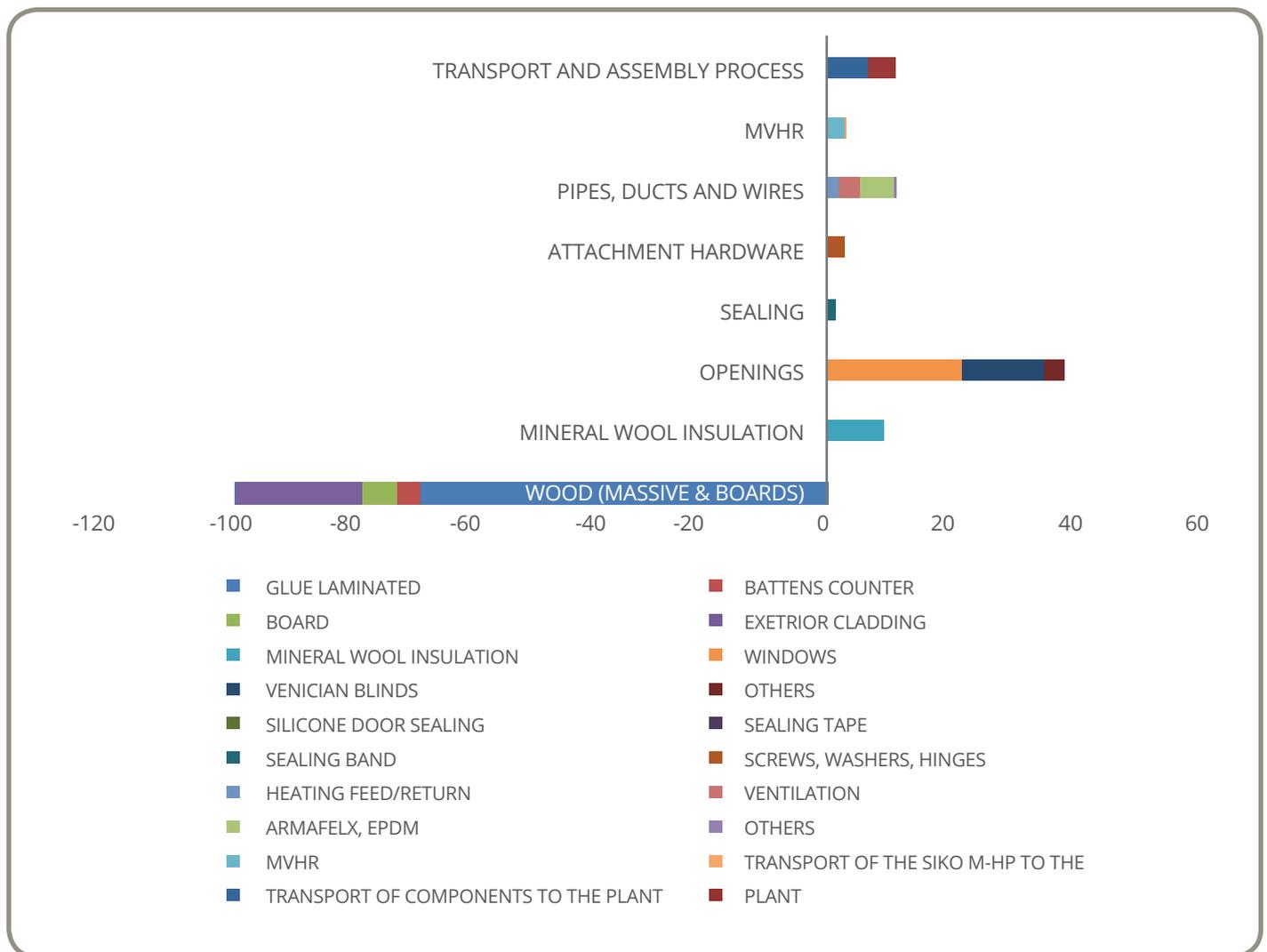


Figure 11: Contribution of the components of the kit n°1.2 to the climate change impact.

	Kit 1.1	Kit 1.2	Kit 1 (avg.)	Unit
Climate change	39.98	-20.88	9.55	kg CO2 eq
Acidification	7,34E-05	3,60E-05	5,47E-05	molc H+ eq
Human toxicity, cancer effects	3,06E-04	1,23E-04	2,14E-04	CTUh
Human toxicity, cancer effects	0,36	0,25	0,31	CTUh
Particular matter	2,77	1,57	2,17	Kg PM2.5 eq
Freshwater eutrophication	0,28	0,12	0,20	kg P eq
Freshwater ecotoxicity	6315,86	2635,90	4475,88	CTUe
Land use	1508,52	1422,12	1465,32	kg C deficit
Non-renewable energy	973,88	754,90	864,39	kwh

Table 2: Embodied environmental impacts of 1m2 of envelope kit n°1.

3.2 RENOVATION TECHNOLOGY 2: WOODEN ENVELOPE WITH PIPES AND DUCTS

3.2.1 Main features and design

This technology addresses the technical problems and save significant costs by integrating all the ductwork and components of the HRV systems into the timber envelope off-site while the HRV unit is integrated with the heat pump, for the most efficient heating and ventilation performance and energy efficiency. Outlets and inlets can be integrated through the prefabricated window reveals, minimizing the work needed inside the house, thus reducing the disturbance for the residents.

By installing this decentralized system thermal losses are reduced to nearly zero, and fire safety requirements are reduced.

For energy retrofitting, a heat recovery ventilation (HRV) system and efficient heating are a must. They significantly improve energy efficiency, assure a healthy indoor environment and keep the building fabric in good condition. Installing these systems inside inhabited dwellings cause a lot of disturbance for the residents and increases costs dramatically. Distributing ventilation, heating and cooling in the house through a centralized aeraulic system also poses a number of technical problems such as thermal losses, fire safety issues and high installation and maintenance costs. That is particularly true in case of renovations, when major construction works are needed to prepare the installation of the system.

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.

This technology has been designed as a variation of the above, without the integration of a micro heat pump. Heating is therefore delivered by the central water based system through new radiators.

An example can be seen in Figure 12 (page 33). Here the MVHR unit has been located in the gable wall, and the air ducts have been integrated to all three facades of the flat.

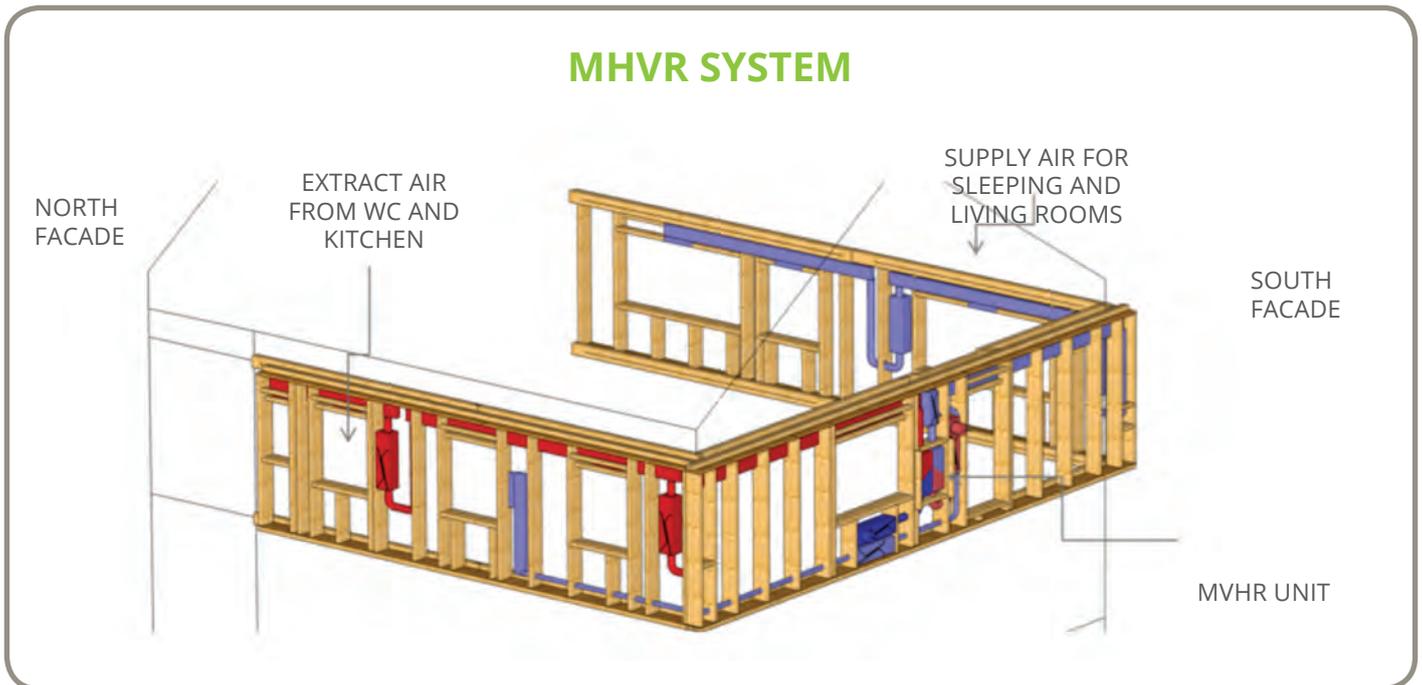


Figure 12: Diagram explaining the MVHR system of the upper flat (Source: Gump & Maier GmbH)

The ducts shown in red colour in the figure above represent the extract air, following the same principle as in the ground floor flat. The supply air ducts shown in blue are lying inside the facades to and supply the rooms in the south wall.

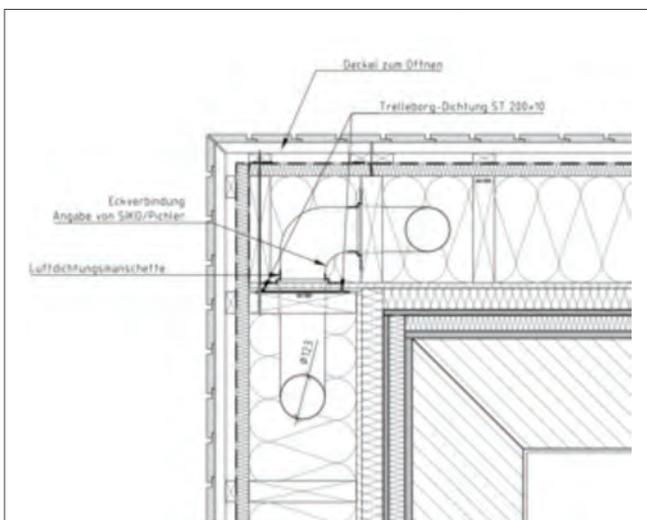


Figure 13: Detail of the corner: Connection of the ventilation ducts on site (Source: Gump & Maier GmbH)



Figure 14: Connection of the ventilation ducts on site (Source: Gump & Maier GmbH)

3.2.2 Installation, operation and maintenance

All ducts are fitted by carpenters in a factory, whereas the connections on the corners at the element junctions are fitted on site. Standard plastic pipes meet CEN standards and should be available locally, where the kit will be installed. It is possible that some parts of the existing walls have to be perforated or removed locally. All internal ducts have to be redirected to the external wall for the connections of the network on the building. The technology has to be installed by the local M&E installer and should fulfil all national/ local requirements. Strong design collaboration is vital between the local planners and the manufacturers. The pipes and ducts on the facade have to be installed on the existing facade according to the collaborative design with the timber manufacturer. This should avoid any risks of duct damage. No specific training is required for the hand-over, as it works as any standard shaft/ sewage/ water system. Furthermore it does not require any change in user behaviour or maintenance. This technology does not need any replacement parts.

3.2.3 Deconstruction – disposal – lifespan

As the technology before, the walls include timber, cellulose insulation, OSB, timber soft fibre board and different sorts of cladding. Windows, shading or other elements can also be prefabricated.

Similar to any duct, it is hidden in the construction. The pipes on the facade can be reached through disassembly of the timber wall elements. Pipes and ducts in the shaft should be accessible from the inside or have removable panels from the outside. This should be determined case by case.

The timber materials do not cause any health and safety issues and are sourced responsibly/ environmentally friendly, as PEFC or FSC certified products regarding. As these are standard materials, they can be recycled according to national/local criteria. Every timber facade has to be calculated by a static specialist, also in terms of earthquake resistance.

3.2.4 Renovation Technology 2: Wooden Envelope with Pipes and Ducts

The technology n°2 is a wooden façade which can integrate all networks of the building. As this technology is not standard but tailor made to the existing building, the LCA conducted within iNSPiRe dealt with the specific case of Ludwigsburg. In this building the EK n°2 includes domestic hot and cold water pipes – encompassing solar collector pipes, heating water pipes, electric wires and ducts for distribution of air in basement and attic. The unit of analysis is the following: “the area of kit necessary to provide air, water and energy networks distribution for 1m² living area to an existing building”. Notice that the unit of reference is in this case 1m² of living area and not 1m² of façade. The assessment is cradle to gate. (cf. D3.5 “Assessment of embodied impacts of envelope products and kits” for more details on the LCA study).

The charts presented in Figure 15 and Figure 16 show how much each component contributes to the EK n°2 on non-renewable energy and climate change impacts respectively. The area of each circle matches with the impact of the component named next to it.

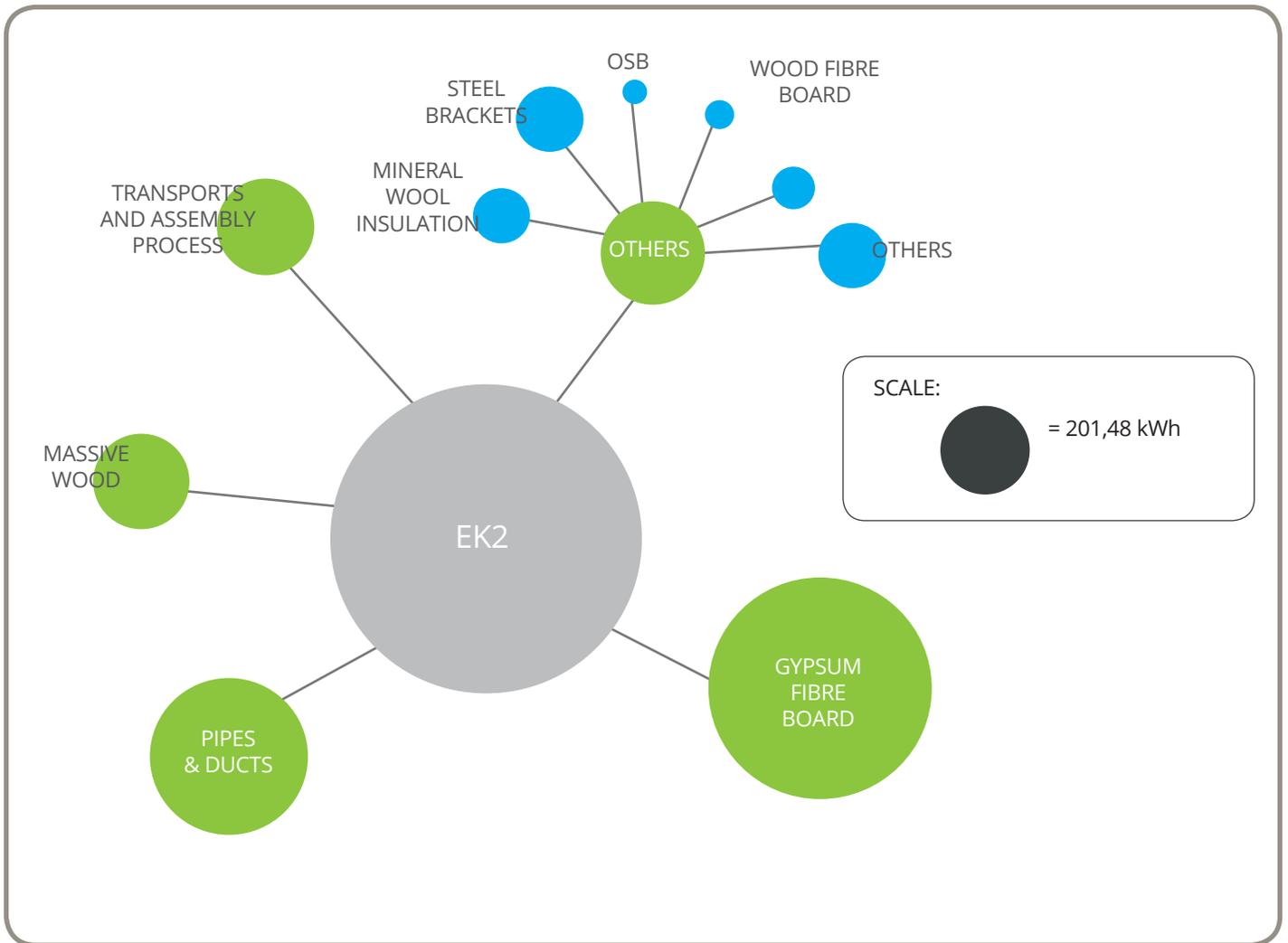


Figure 15: Contribution of the components of the kit n°2 to the non-renewable energy impact.

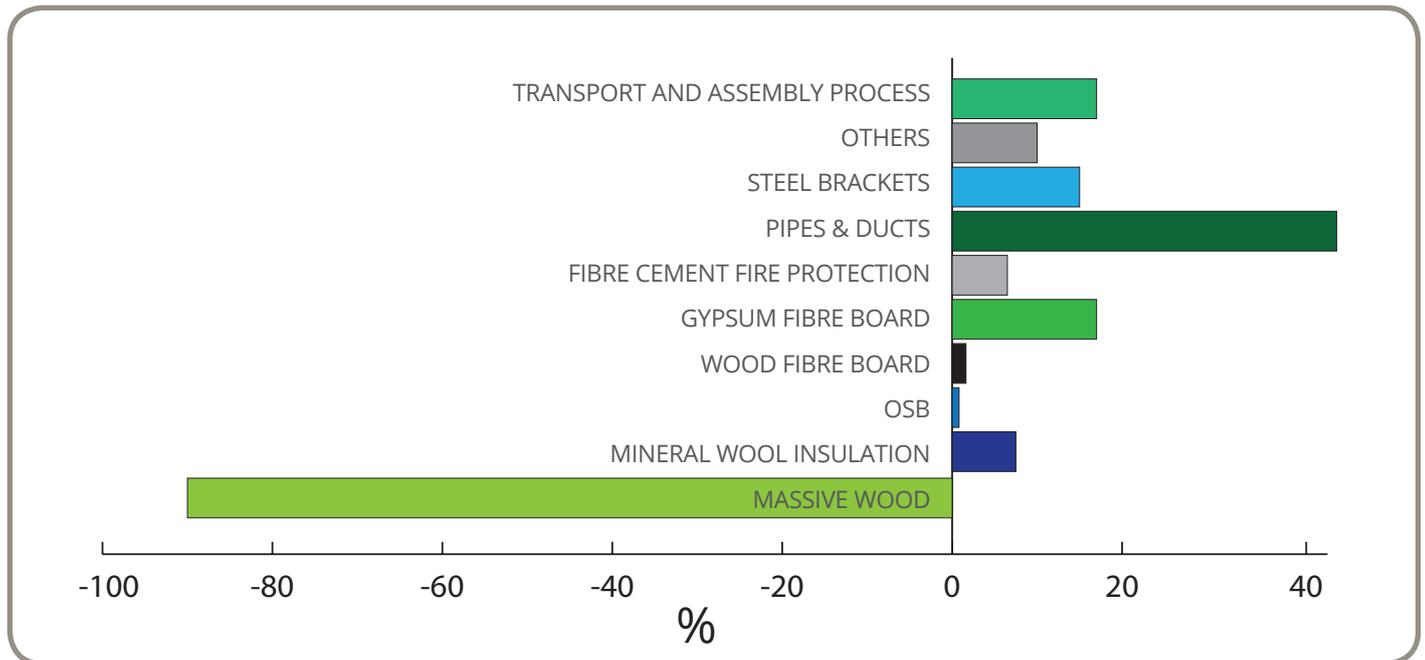


Figure16: Contribution of the components of the kit n°2 to the climate change impact.

	Impacts	Unit
Climate change	5,88	kg CO2 eq
Human toxicity, cancer effects	1,53E-06	CTUh
Human toxicity, non-cancer effects	6,59E-06	CTUh
Particulate matter	1,16E-02	kg PM2.5 eq
Acidification	7,40E-02	molc H+ eq
Freshwater eutrophication	3,35E-03	kg P eq
Freshwater ecotoxicity	106,42	CTUe
Land use	56,63	kg C deficit
Non-renewable energy	60,38	kwh

Table 3: Embodied environmental impacts of the envelope kit n°2 for 1m² floor area.

3.3 RENOVATION TECHNOLOGY 3: WOODEN ENVELOPE WITH ST/PV

3.3.1 Main features and design

This technology solution is again a pre-fabricated wooden façade, that this time optimises the integration of solar collectors.

The work on the solar collectors has five clear objectives:

- To improve the architectural aesthetic of the integration by creating flat surfaces, which are also water tight
- To optimize cost savings by including insulation in the collector installation, reducing its frame size and simplifying the way it connects to the façade
- To reduce costs further by using a common solution for integrating both PV and ST roof and façade applications, by making them simpler to manufacture off-site.
- To improve the thermal performance of the timber envelope by reducing losses in winter.
- To simplify the maintenance and replacement of the units

There are, of course, PV and ST systems already on the market, some that integrate the units on to the façade – roof and wall. With the most common on-roof applications, most are not aesthetically pleasing are generally uneconomical, require separate insulation panels and it is not possible to pre-fabricate the roof with them in place as they cannot be fully integrated.

In-envelope systems are available but again, the aesthetics are generally poor as the units are raised from the wall or roof and they are expensive and require separate insulation. They can, however, be pre-fabricated into the façade, while replacement is relatively cheap as well.

In the demonstration building in Ludwigsburg, Germany a large solar thermal collector, with a size of 11.3 m², was installed on the roof. It was designed to maximise the degree of prefabrication and to develop a solution, which is aesthetically integrated to the roof surface.

For that purpose, an in-roof solution was implemented, where the timber construction was reduced in thickness, in order to level it down with the rest of the roof.

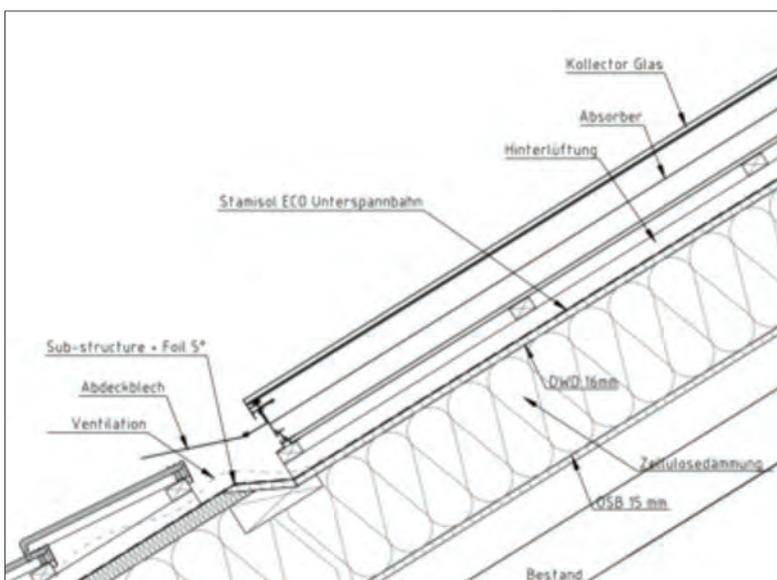


Figure 17: Section of the integration of the solar collector, detail below (Source: Gumpp & Maier GmbH)

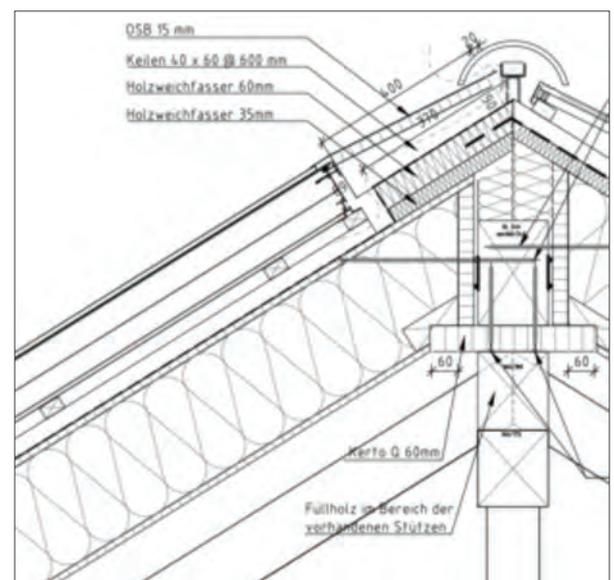


Figure 18: Detail above (Source: Gumpp & Maier GmbH)

3.3.2 Installation, operation and maintenance

Two large modules of 2.2x5.6 m were transported to the building site, and craned lifted into its final position on the roof. The producer of the collector connected the two parts on-site. 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 modules can be installed on the facade or roofs. They can be accessed by a cherry picker or scaffold, if required for maintenance.



Figure 19: Installation of the solar collector
(Source: Gump & Maier GmbH)



Figure 20: Final view of the surface-integrated solar collector
(Source: Gump & Maier GmbH)

3.3.3 Deconstruction – disposal – lifespan

Similar to the two technologies before, the walls include timber, cellulose insulation, OSB, timber soft fibre board and different sorts of cladding. Windows, shading or other elements can also be prefabricated.

The timber materials do not cause any health and safety issues and are responsibly/ environmentally friendly sourced, as PEFC or FSC certified products regarding. As these are standard materials, they can be recycled according to national/local criteria. Every timber facade has to be calculated by a static specialist, also in terms of earthquake resistance.

3.3.4 Renovation Technology 3: Wooden Envelope with ST/PV

The technology n°3 is a prefabricated timber envelope for renovation, for both roofs and facades, which integrates solar collectors (solar thermal and photovoltaic). As the EK n°3 is not standard but tailor made to the existing building, the LCA conducted within iNSPiRe dealt with the specific case of Ludwigsburg. In this building the EK n°3 has been implemented on the roof and includes solar thermal collectors.

The unit of analysis is the following: “1 m² of roof renovation kit ensuring thermal insulation reinforcement and DHW supply to the existing building”. The assessment is cradle to gate. (cf. D3.5 “Assessment of embodied impacts of Envelope products and kits” for more details on the LCA study).

The charts presented in Figure 21 and Figure 22 show how much each component contributes to the EK n°3 on non-renewable energy and climate change impacts respectively. The area of each circle matches with the impact of the component named next to it.

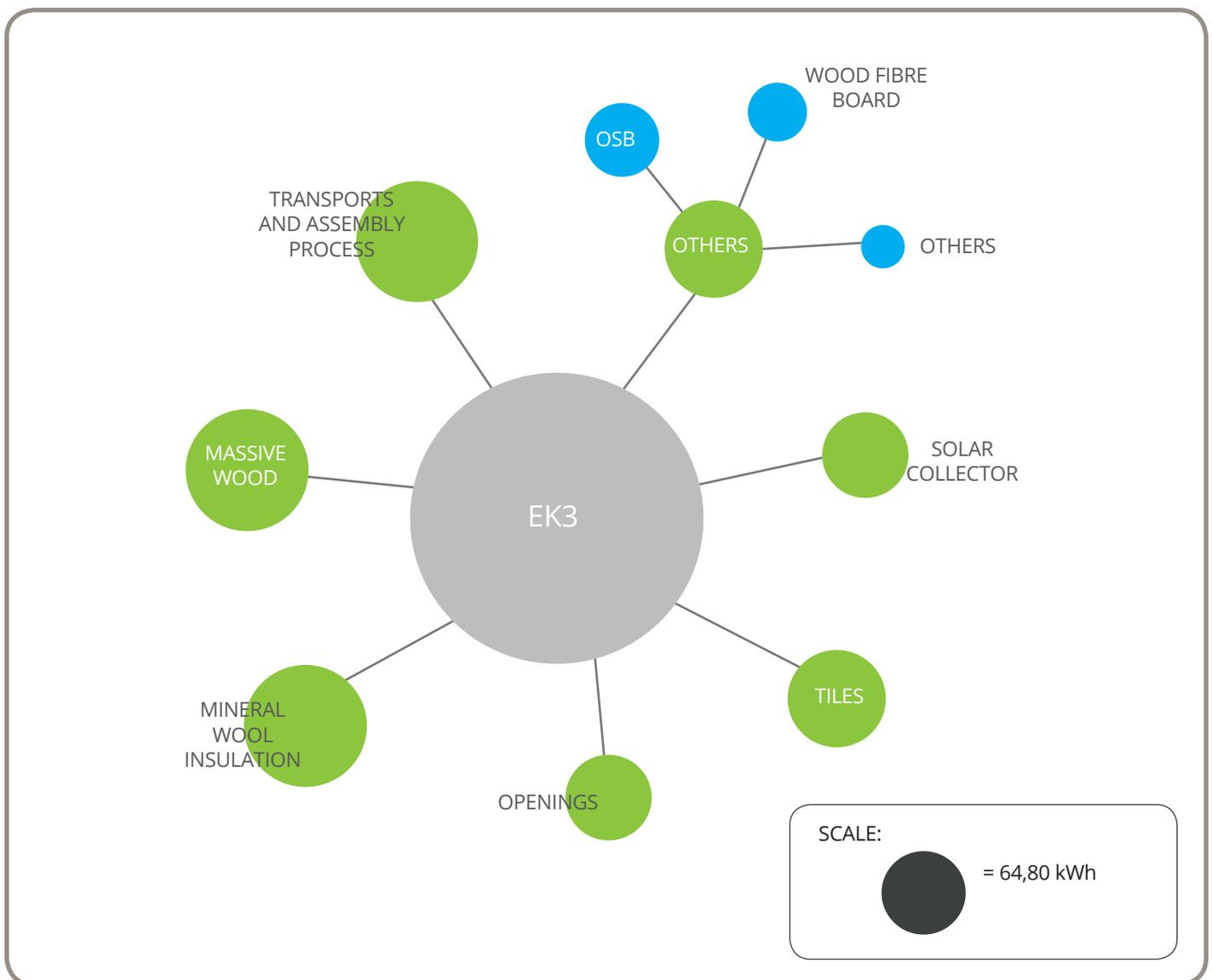


Figure 21: Contribution of the components of the kit n°3 to the non-renewable energy impact.

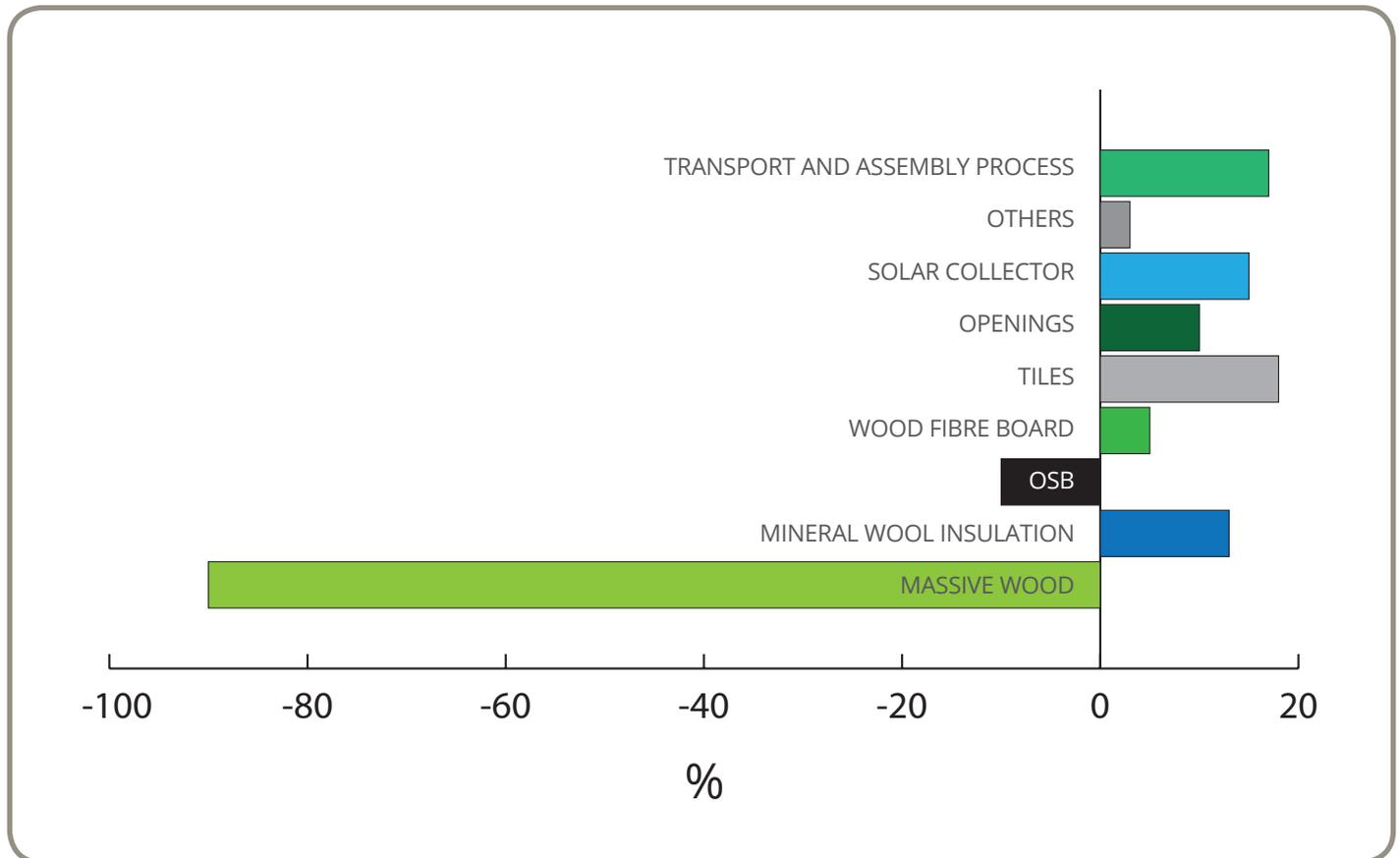


Figure 22: Contribution of the components of the kit n°3 to the climate change impact

	IMPACTS	UNIT
Climate change	-48,97	kg CO2 eq
Human toxicity, cancer effects	1,97E-05	CTUh
Human toxicity, non-cancer effects	1,12E-04	CTUh
Particulate matter	0,21	kg PM2.5 eq
Acidification	1,23	molc H+ eq
Freshwater eutrophication	0,07	kg P eq
Freshwater ecotoxicity	2801,93	CTUe
Land use	1379,91	kg C deficit
Non-renewable energy	603,74	kwh

Table 4: Embodied environmental impacts of 1m2 of envelope kit n°3.

3.4 RENOVATION TECHNOLOGY 4: THE ENERGY HUB

3.4.1 Main features

The Energy Hub (EH) is a multi-functional hydronic modular unit, which:

- connects different components of a building's heating and cooling system (heat pump, solar collectors, geothermal probes, oil/gas/pellet boiler radiant ceilings/floor/wall, radiators, fan-coils);
- can be used for the production of domestic hot water;
- performs low cost measurement of the thermal and electrical energy flows in the heating and cooling system;
- remotely optimizes and manages the heating and cooling system;
- incorporates "continuous commissioning" procedures to increase the reliability of the heating and cooling system.

The Energy Hub offers flexibility, with various models and the use of modules, for example to provide domestic hot water (DHW), control the flow at the solar collectors (Solar), regulate the supply temperature of the water, provide recirculation of the water in the distribution lines (pumping), provide space heating and cooling (SHC) and to implement parallel or series connection of components. The Energy Hub modules are coordinated by a central unit called Energy Manager. The Energy Manager is the central processing unit responsible for data acquisition, real-time control, system supervision and human-machine interaction.

Figure 15 shows a conceptual diagram of how the Energy Hub and Energy Manager (EM) are connected. The Energy Hub modules, together with the Energy Manager unit, connected to the active and passive components of the energy system (boilers, heat pumps, storage tanks, distribution system), implement the so called Energy Management Network (EMN).

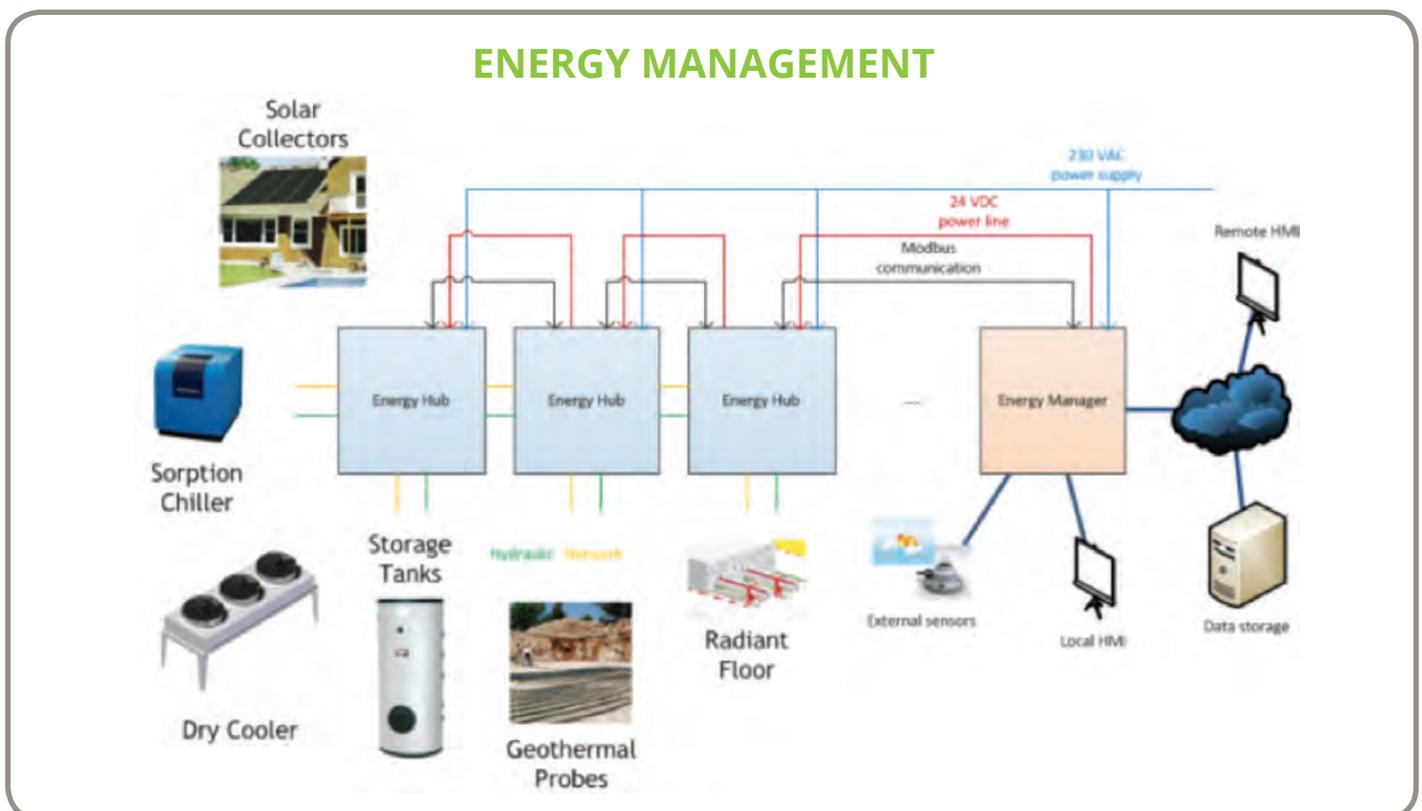


Figure 23: Energy Hub, Energy Management and Energy Management Network

3.4.2 Design

All the Energy Hub modules in the family integrate a variable number of hydraulic components. They also include surface temperature sensors. Every EH model is equipped with an electronic board and an electric meter, if circulators are installed (the electronic equipment is protected by a IP65 enclosure). Apart of these components, the modules consist of a number of copper tubes, an aluminium support structure and enclosure.

The overall design of the heating and cooling system is not conventional. To make the best use of the Energy Hub concept, the designer of the building energy system should be aware of the technology potential. The system designer should be aware of the possibilities/combination offered by the EH models and design the system's hydraulics according to control and monitoring capabilities. An example of the process is the following: to provide solar thermal energy, solar collectors and water storage are needed. An EH providing these functions can be manufactured including the heat exchanger (hydraulic separation), two circulators (vector fluid movement), four temperature sensors and one or two flow meters (heat flows and temperature monitoring and metering).

All the components in this network are generally "off the shelf" components, therefore familiar to trained installers. All the EH are essentially hydronic components that should be managed on-site by plumbers and electricians with some experience of automation system or by a trained installer with the two expertise. However, recent experience with Madrid installation is that installers can experience problems with components such as medium-sized heat pumps, solar collectors, etc. As a consequence, much attention is still to be paid during the commissioning phase, despite the high level of prefabrication of the units connecting the main system's components.

A good example of application of the EH concept is given by the Madrid demo case (shown in Figure 24) where 20 EHs have been installed, driving, monitoring and metering a centralised system that provide space heating, space cooling and domestic hot water to 8 apartments in a Multifamily house.

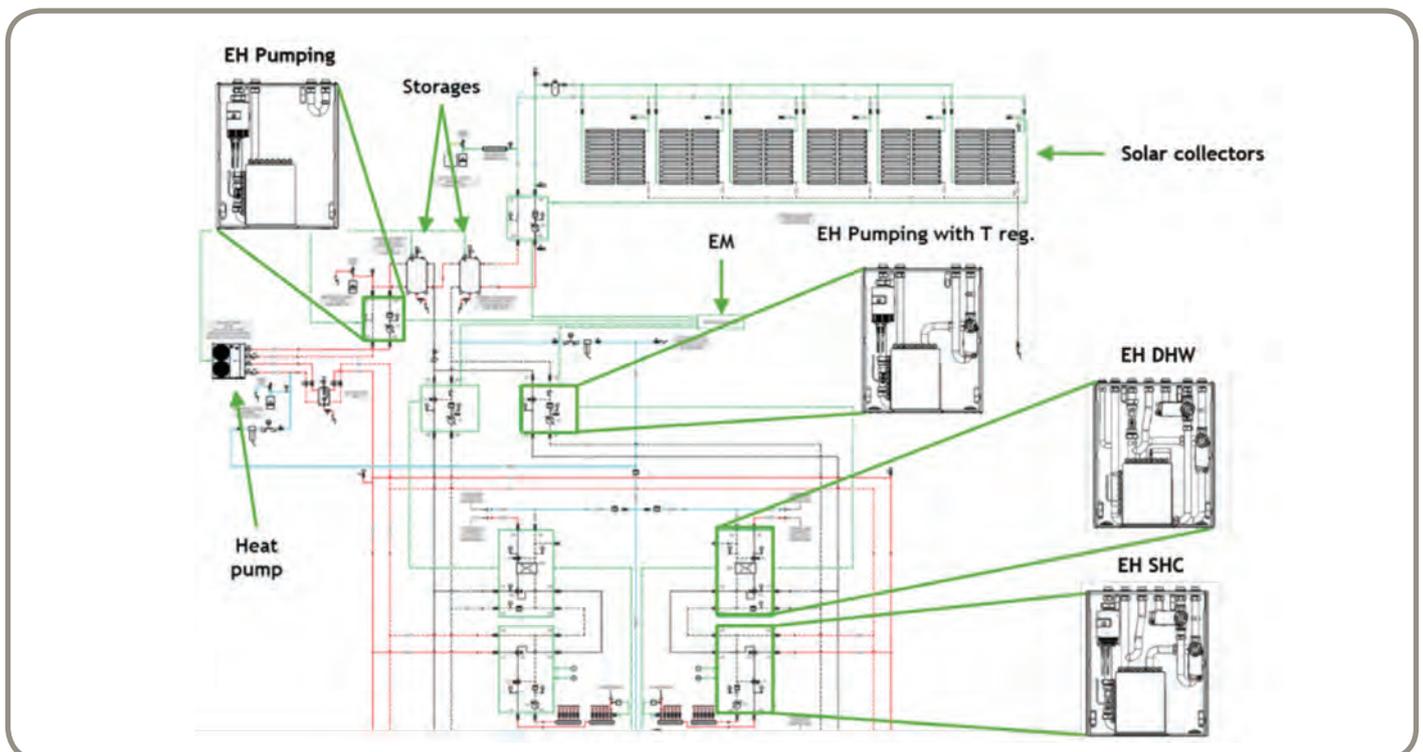


Figure 24: 4 types of EH installed in the Madrid demo building



Figure 25: Picture of the 4 EH installed in the technical room.

There are currently no known standards or European directives regarding the construction of hydronic modules like the EH. However, many EU directives and standards affect the EH or part of it (see the table below). The components installed in the EHs are compliant with the EU regulations.

EH COMPONENT	COMPLIANCY
Circulators	Eco-design directive (ErP), energy labelling directive, PED (Pressure Equipment Directive), LVD (Low Voltage Directive), EMC (Electromagnetic Compatibility Directive)
Heat exchanger	PED (Pressure Equipment Directive)
Control valves	PED (Pressure Equipment Directive)
Temperature sensors	MID (Measuring Instrument Directive)
Flow meters	MID (Measuring Instrument Directive), PED (Pressure Equipment Directive)
Piping	PED (Pressure Equipment Directive)
Non return valve	PED (Pressure Equipment Directive)
IOC board	EMC directive, MID, RoHS

Having said that, it may be possible to use them in the renovation of these types of buildings, provided the renewable energy integration is permitted and suitable technical rooms or alternative spaces are available. Yet, no specific design choice has been made to ease their installation in historic buildings.

3.4.3 Installation, commissioning and handover

The EH and EM units are more alike industrial parts than household electronic devices. Their installation is an easy-to-do plumbing and electric work. The installation of the Energy Hub and Energy Manager can be performed by plumbers (for the Hydraulic part of the EH) and electricians (with expertise of field-buses, for the electric part of the EH and connection to the EM).

The Energy Hub and Energy Manager, collectively represent the connective and control part of the energy generation package. This means that the installation of the Energy Hub, without the components of the energy generation and distribution system (Heat pump, solar collectors, geothermal probes, radiant surfaces, fans, storage tanks), is not possible. Typically, the EHs modules are installed in the central technical room of dwellings or in wall recess just outside (e.g. in corridors or staircases in the case of multi-family homes). The Energy Hubs of the system need to be connected to the EM via a serial line (ModBus protocol over a RS485 serial line). The electrician performing the connection should pay attention to follow the most common good practices when implementing such buses (right termination of the line, right cable, correct connection to the protective earth). The plant must be commissioned by the manufacturer and in accordance with the specification.

A full specification, prepared by the manufacturer of the Energy Hub, is available and covers the construction and maintenance operations. The designer of the heating and cooling system must also provide an operating manual for the plant. It is essential that these manuals are read by the operators and those responsible for maintaining the system.

3.4.4 Operation and maintenance

The EH itself has been designed as a hydraulic component, therefore does not require additional maintenance when compared with other hydraulic modules. After installation and commissioning, the plant is intended to operate until the end of the lifetime of the heating and cooling system of which it is part of.

For periodical maintenance once per year, the EH can be opened to inspect the presence of leakages or see the position of valves in case of a malfunction is detected. Pumps can be operated manually even without opening the EH. The Energy Hubs and Energy Modules can be fully opened by removing the cover (Energy Hubs) or opening the front panel (EM). Extraordinary maintenance (for example, substituting a valve or pump in the EH) can be performed on-site. Electrical extra-ordinary maintenance (like substituting the IOC board) needs to be performed by a trained electrician used to work with field buses.

The Energy Hub status is checked by the Energy Manager. It is recommended to check the readings of the measured quantities (temperatures and flows) on the EM frequently the first weeks after the commissioning. Later the frequency of these inspections can be reduced to one every two months.

The EMN design supports the introduction of "remote maintenance" contracts with the manufacturer or distributor. If granted with external access to the EMN data the contractor can foresee problems and perform the minimal maintenance actions before problems arise.

The EH and EM are designed to run constantly 24hrs and do not need anybody to oversee their functioning. EH and EM, as part of the heating and cooling system however, are expected somehow to interact with the inhabitants of the building where they are installed. The user is not required to change its habits in order to use the EH, however the EM can provide the users with information about the energy consumption of the building or flat. This is expected to have an impact on the user's behaviour in terms of energy consumption: it must be understood however, that if energy saving is the aim, using high set-points in winter and low set-points in summer can degrade the performance of the heating and cooling systems as a whole.

3.4.5 Deconstruction – disposal – lifespan

The EHs are expected to be dismantled when the entire building or the heating and cooling system is renovated again. Although the EMN technology is designed to last several years and be “maintainable” in the sense that all the EH components are replaceable on site.

Most of the components are made out of metals: copper, aluminium, brass. Copper is used in particular for the piping, brass for the joints and the body of the valves. The enclosure and supporting structure is in aluminium. Also, the modules are insulated with polyethylene sheets. The used materials pose no problem for the health of the users.

3.4.6 Renovation Technology 4: The Energy Hub

The Energy Generation Kit (EGK) is a hydronic system, based on the use of water as a heat transfer medium. Its main function is to ensure and control the transfer of thermal power and information between the energy production devices (solar collectors, heat pump...), storages and the energy distribution device (Tripan Leichtbauteile Wimmer GmbH ceiling panels). EGKs are composed of several elements called energy hubs and energy managers.

The unit of analysis for the energy hub is: “One energy hub fully equipped providing connectivity for heat sources or sinks, storages and loads and ensuring transfer of information, electrical power and thermal power”.

The unit of analysis for the energy manager is: “One energy manager providing centralisation of the data monitored by the energy hubs and the acquisition of external sensors, the supervision and real-time control of the overall system, the generation and visualisation of alarms, the configuration and management of the energy hubs network via a human-machine interface, and the visualisation of a synoptic of the plant state”. The assessment is cradle to gate. (cf. D4.5 “Assessment of embodied impacts of EG-D products and kits” for more details on the LCA study).

The charts presented in Figure 26 and Figure 27 show how much each component contributes to the energy hub on climate change and non-renewable energy impacts respectively. The area of each circle matches with the impact of the component named next to it.

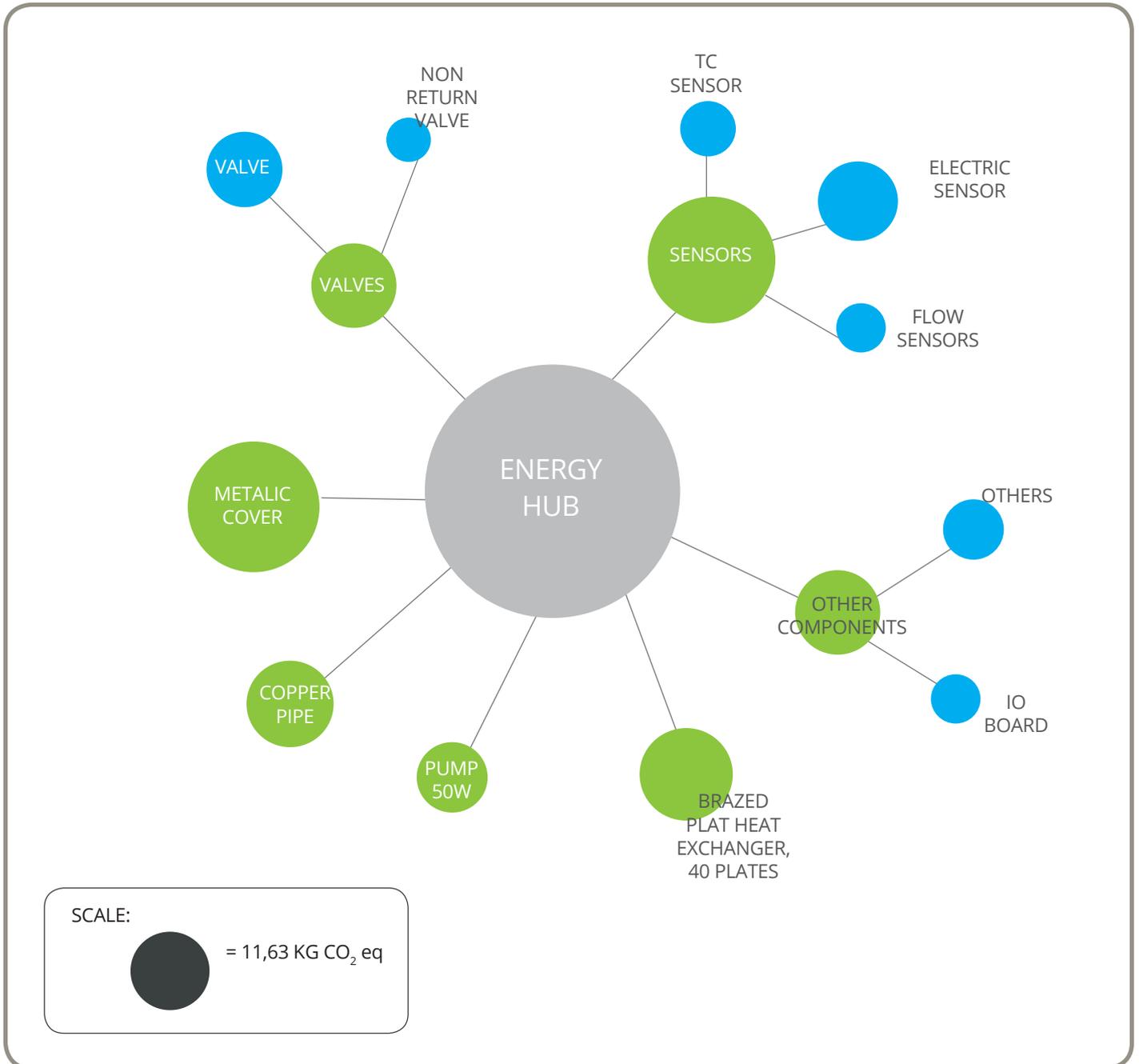


Figure 26: Contribution of the components of the energy hub to the climate change impact.

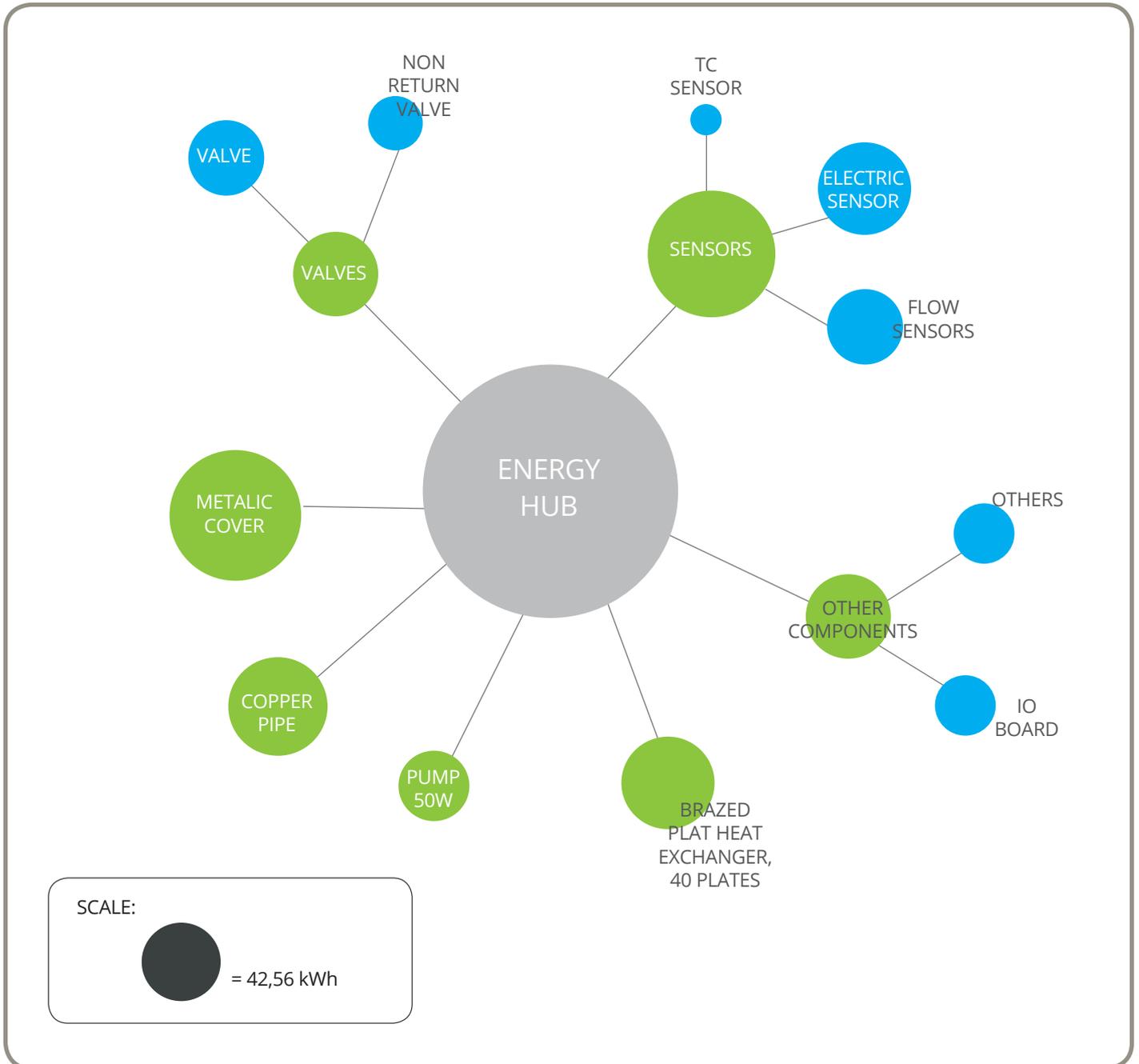


Figure 27: Contribution of the components of the energy hub to the non-renewable energy impact.

	IMPACT	UNIT
Land use	434,47	kg C deficit
Acidification	2,66	molc H+ eq
Human toxicity, cancer effects	6,93E-05	CTUh
Human toxicity, non-cancer effects	8,53E-04	CTUh
Particulate matter	0,24	kg PM2.5 eq
Freshwater eutrophication	0,45	kg P eq
Freshwater ecotoxicity	182267	CTUe
Climate change	168,53	kg CO2 eq
Non-renewable energy	566	kwh

Table 5: Embodied environmental impacts of the energy hub (fully equipped).

The chart presented in Figure 28 shows how much each component contributes to the energy manager on climate change and non-renewable energy impacts. The weight of each component to the impact is similar for both climate change and non-renewable energy impact categories. In consequence, the chart stands for both indicators.

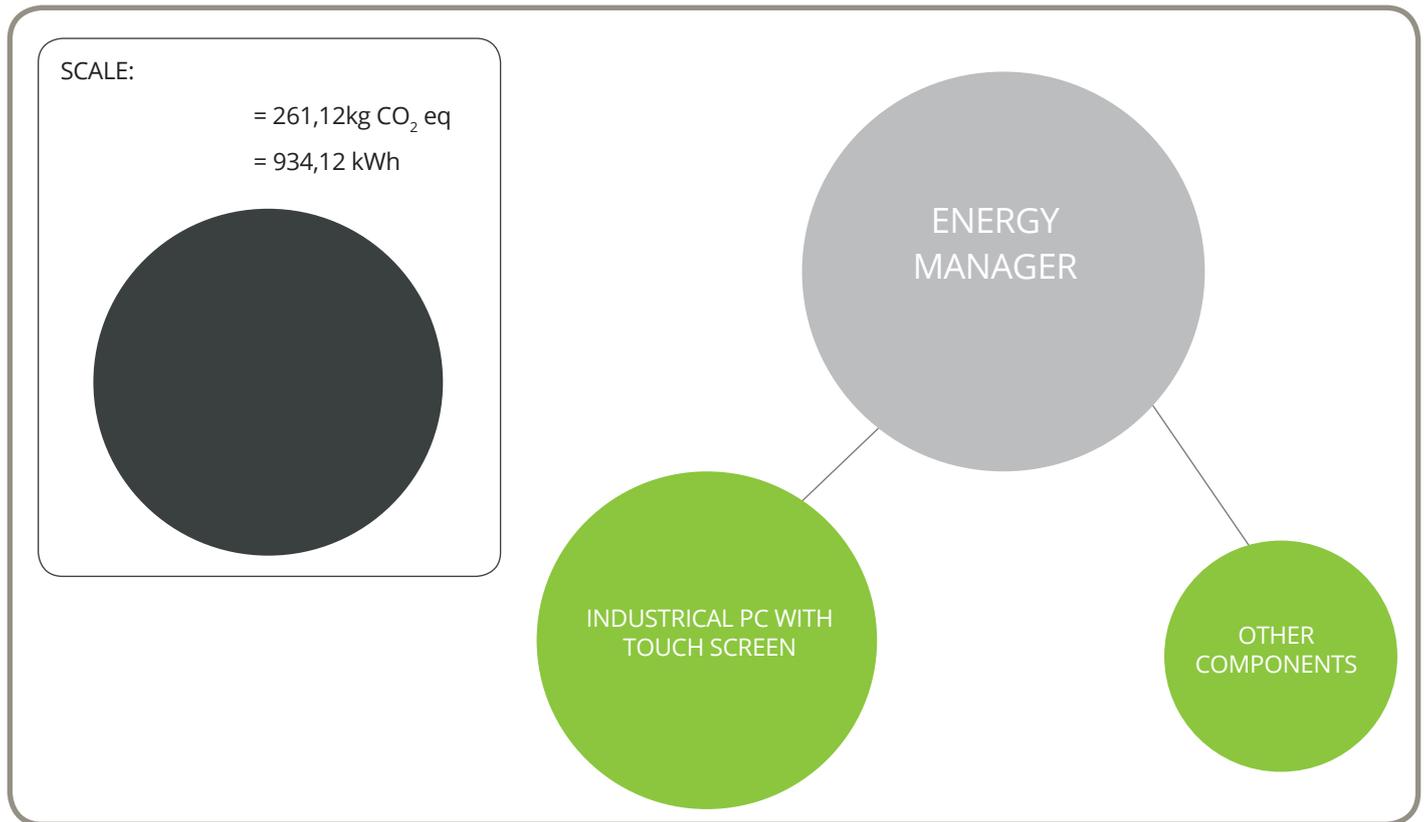


Figure 28: Contribution of the components of the energy manager to the climate change and non-renewable energy impacts.

	IMPACT	UNIT
Land use	1095	kg C deficit
Acidification	3,45	molc H+ eq
Human toxicity, cancer effects	8,80E-05	CTUh
Human toxicity, non-cancer effects	1,08E-03	CTUh
Particulate matter	0,39	kg PM2.5 eq
Freshwater eutrophication	0,69	kg P eq
Freshwater ecotoxicity	29841	CTUe
Climate change	378	kg CO2 eq
Non-renewable energy	1337	kwh

Table 6: Embodied environmental impacts of the energy manager (final assessment).

3.5 RENOVATION TECHNOLOGY 5: THE RADIANT CEILING PANEL

3.5.1 Main features and design

The prefabrication modular ceiling panel incorporates lighting, low temperature water heating/cooling and ventilation distribution. The radiant ceiling panels are a simple solution with a high-quality design, sophisticated and flexible. Moreover special shapes, dimensions, alternative materials are possible. The modular nature means it is flexible in size and permits the utilization of all distribution media (light, water and air), if needed.

Two versions were developed within the iNSPiRe project:

- The first distribution kit is specialized for residential applications: it integrates two components of artificial lighting systems into radiant ceiling panels.
- The second distribution kit is designed for office applications: It integrates a set of LED lighting solutions into a radiant cooling/heating panel.

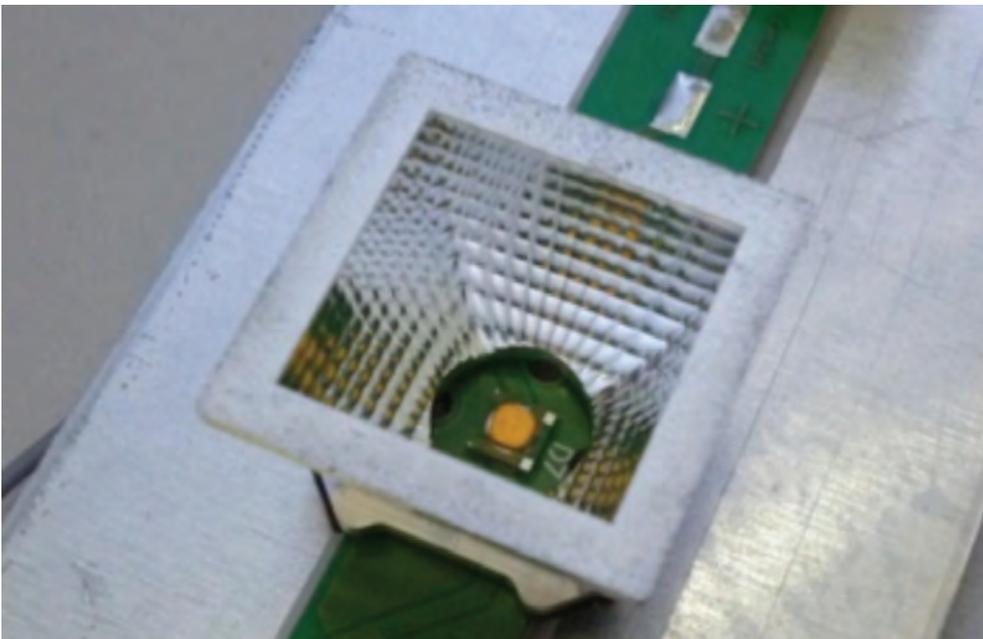


Figure 29: The spheres are designed for home-appliances but can be applied to offices as well. The sphere takes a highly glare-free, faceted reflector technology

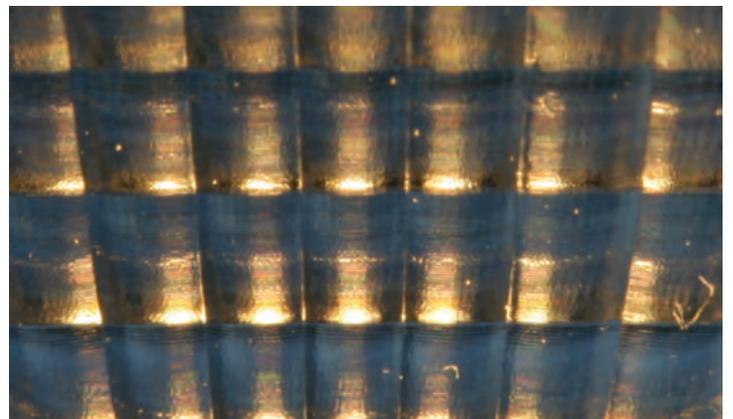
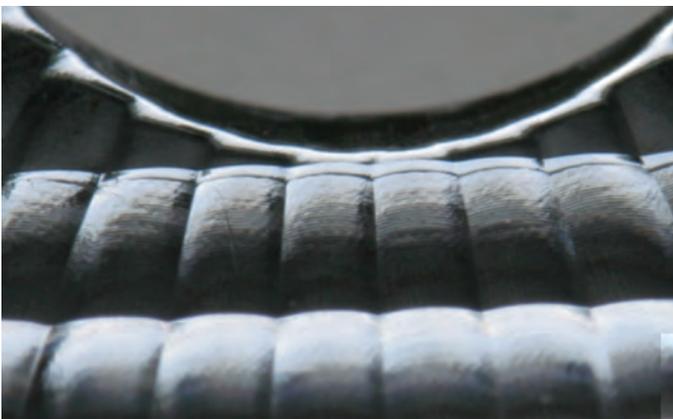


Figure 30: The apparent relief on the facets is producing high scattered luminance



Figure 31: The sphere: sphere of aluminium holding the reflector

3.5.2 Installation, commissioning and handover

A qualified plumber/ heating contractor must install the ceiling panel. The kit is easy to install, with teams requiring just a short introduction to this kit. During the handover process, the operation must be explained to the building user including maintenance requirements. This should also be covered in the building user guidance provided. Qualified plumbers/ heating contractors provide service and maintenance for heating and cooling ceilings. Existing ceiling systems on the market are similar in the tube connection details used in this technology. Hence any professional should be able to work with it. Important for a long live span is to check annually whether there is enough anti-corrosion fluid in the water system. A thermal limit at 50°C of heating water is necessary.

It is not necessary to modify the building to allow for the use of this technology. Only the water supply must be provided. The weight of the ceiling is so little, that you can install it on nearly all types of ceilings.

Island installation:

The heating/cooling demand in post-refurbishment times will be small. As the heating/cooling capacities of the TRIP-panel are high, the surface needed for conditioning (i.e. the active panels) might be reduced and might be installed as, furniture on the ceiling'.

The installation is foreseen via ,long holes', so that the panel can be moved into holding position (Figure 32). The perimeter is closed via a foam strip (Figure 32). The edges of the panels are closed (Figure 33).

The supply pipes (electricity, fluid air and water) are covered by a metal sheet, in case the island is not directly connected to the wall (Figure 34 - Figure 35).

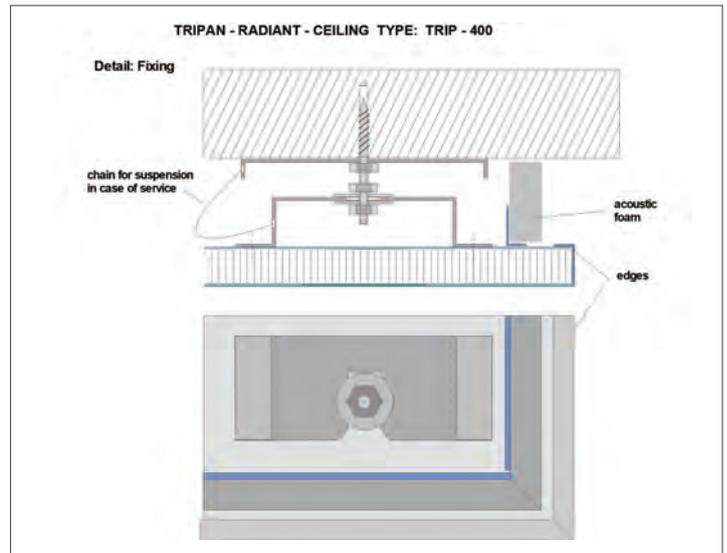


Figure 32: The island installation, using a long-hole screw and holding plate



Figure 33: The perimeter edges are closed, for ecstastic reasons



Figure 34: The supply pipes (here water) are hidden by a cover

The light engine is integrated in a plate (Figure 37). The lower temperatures increase the efficacy and lifetime by 3-7%.

2 Office application

The office application, called 'inspire-d ceiling', is available in two different shapes, curved or plane.

Curved: The curved ceiling is designed to redirect artificial light from a ceiling washer as well as daylight, which is redirected by the 'winglamella'.

Plane: In cases where structural restrictions exist, the curved panel may not be suitable. In these situations, a plane panel can be installed. The luminaire, which is needed hereby, is 'asymmetric linear'. This luminaire's main feature is the accurately designed luminous intensity distribution: if it is mounted parallel and close to façade no lighting energy will be dispersed to the external environment (losses through façade are minimized), visual comfort and energy efficiency are optimized as well.

Asymmetric linear. The reflector is simulated and designed to fit into existing PCB-Layout.

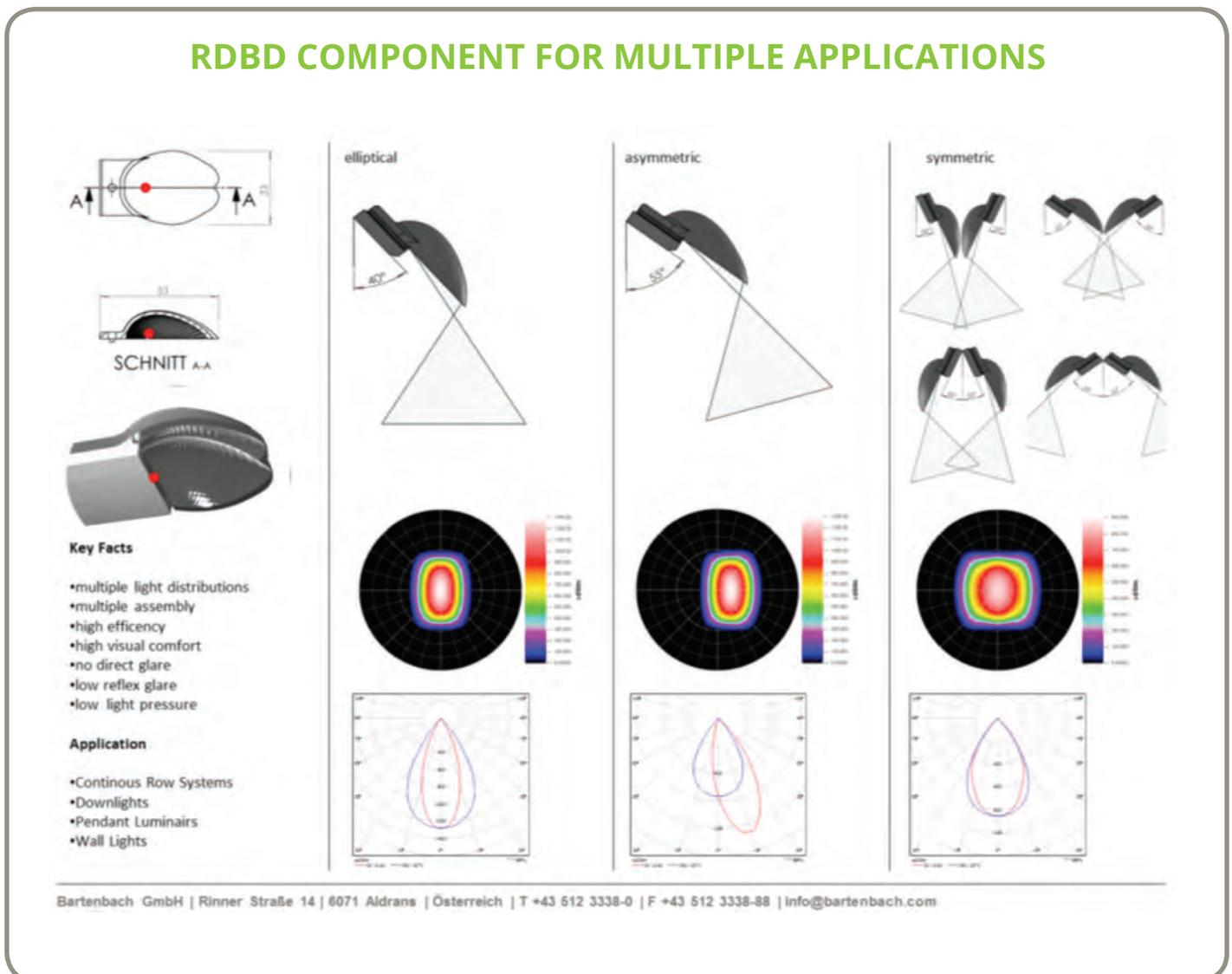


Figure 38: The new reflector will be used in many different applications

Ceiling washer: Within the iNSPiRe project the reflectors are integrated in a luminaire to be attached to the wall and illuminating the ceiling structure.

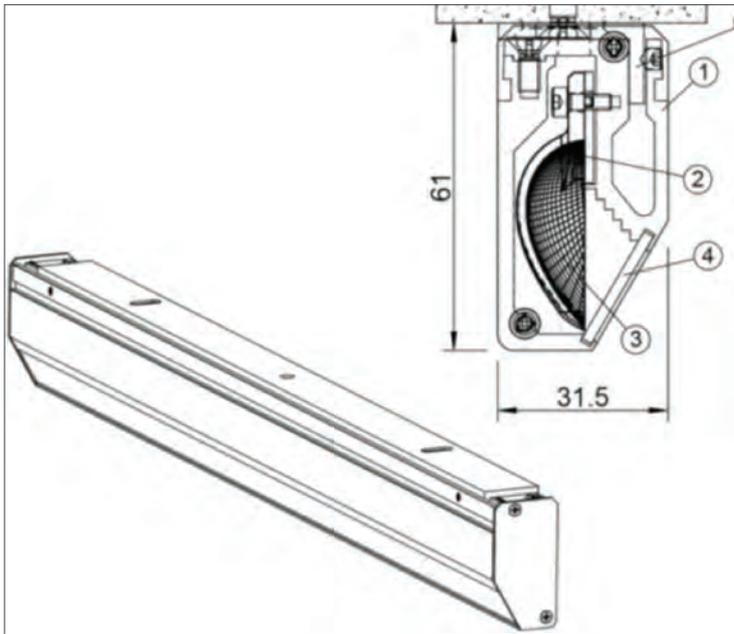


Figure 39: The luminaire to be installed at the façade, illuminating the ceiling, from where the light is redistributed

Plane panel: The curved panel is used to redistribute day and artificial light.

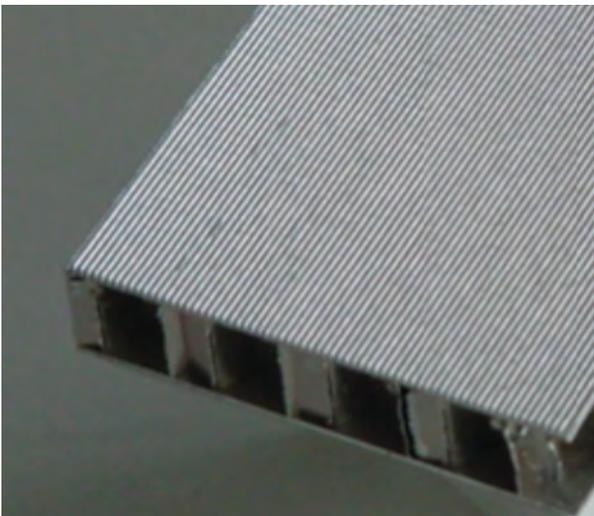


Figure 40: By the saw-toothed grooved surface, light is reflected in a predetermined direction.



Figure 41: Prototypes of skybright (sawtooth highly reflective aluminum surface) covered heating-cooling panel. The pipes are not perceivable.

Integration: The luminaire is integrated into the ceiling itself. It is used in case, that the ceiling must not be curved, e.g. if the room's height or the window's height is limiting. The new reflector is applicable in many different situations. The two most important ones are: (i) asymmetric applications parallel to the façade and (ii) symmetric luminous intensity distribution for room internal application.

3.5.3 Operation and maintenance

After the kit has been distributed and installed, a malfunction could occur due to the electric of the heating system, which is not part of the reliability of the panel producer. If the system is not used, you should make sure that the system temperature is above 5°C. If the system is deactivated for a long period of time, antifreeze should be added. Moreover it is not necessary for the function of this kit to read any user guide or change the occupier behaviour. Yet, in case of energy saving we hand over supplements and information to the customer.

Once a year the following items should be checked: control of the quality of water, visual inspection of the kit, functional inspection of the heating and cooling power. The visual inspection should include the suspension and the water-tube system. This can be undertaken by the local building manager or plumber/ heating contractor. It is advisable to have a service-contract with an installation engineer, who is doing the annual maintenance. In case of an unplanned problem (leaking water, unusual bending of the panel, or detachment from the ceiling) a specialized company should be contacted immediately.

All contemporary controlling systems are possible plus individual room control.

Servicing unit: The maintenance of the pipes, luminaires and ventilation ducts is realized by a suspending mechanism.

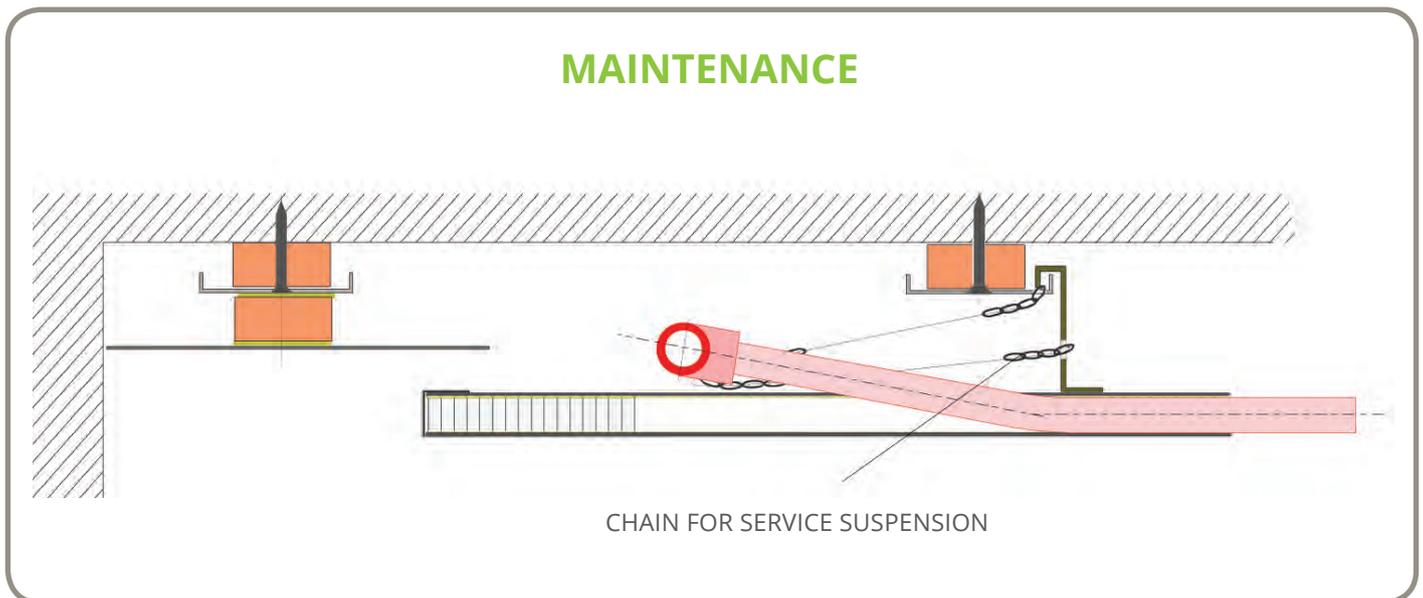


Figure 42: Maintenance – servicing mechanism



Figure 43: Maintenance mechanism to lower the panels.

3.5.4 Deconstruction – disposal – lifespan

Provided the technology is operated and maintained as intended, the life expectancy is 30 years. The technology is almost 100% recyclable. The radiant ceiling panels are high-tech products, which are sourced environmentally friendly without any health and safety issues. Over 95% of all used materials of the radiant ceiling panels are made out of aluminium (sheets, core and tubes). This material is fully recyclable, producing the same high-tech aluminium material again. The glue, so-called thermal adhesive is also using in the clothing industry and does not bear any health risks. The acoustic foil of polyester, a material, which is also used in the clothing industry and bears no risk for health and has a very long live span. The water circulation of the heating is closed and separate to the drink water circulation. Thus the tubes do not cause any health problems.

This kit can be used for the renovation of historic buildings, if the inside of the building is not protected. The kit and how it is attached to the ceiling is, as far as we know, earthquake-resistant. The maximum load per square meter will be documented in the technical data sheets of the kit. If higher loads are required, they will be calculated case by case.

3.5.5 Renovation Technology 5: The Radiant Ceiling Panel

The Energy Distribution Kit (EDK) aims at supplying residential and office buildings with space heating, possibly space cooling, and lighting, in an integrated and profitable way.

The unit of analysis for the EDK is: “an EDK providing residential and office buildings with space heating (around 150W power), possibly space cooling, and lighting (684 lumens), in an integrated and profitable way”. It is composed of 1m² of radiant Tripan Leichtbauteile Wimmer GmbH ceiling panel including 3 Bartenbach Lichtlabor GmbH spheres for lighting and a suspension system made of galvanized steel.

The assessment is cradle to gate. (cf. D4.5 “Assessment of embodied impacts of EG-D products and kits” for more details on the LCA study).

The chart presented in Figure 44 shows how much each component contributes to the EDK impact. The weight of each component to the impact is similar for both climate change and non-renewable energy impacts. The area of each circle matches with the impact of the component named next to it. The weight of each component to the impact is similar for both climate change and non-renewable energy impact categories. In consequence, the chart stands for both indicators.

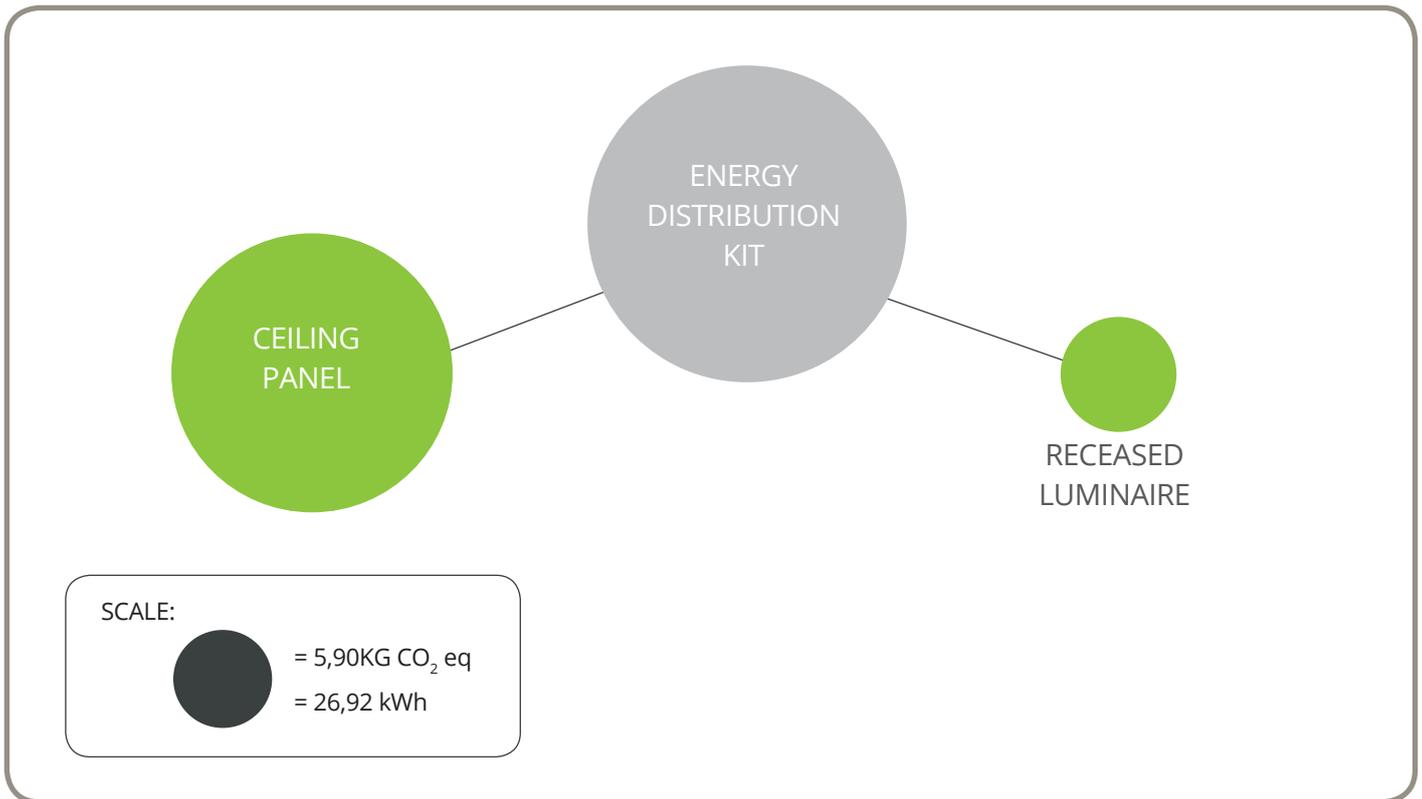


Figure 44: Contribution of the components of the EDK to the climate change and non-renewable energy impacts.

	ISLAND CONFIGURATION	UNIT
Climate change	48,16	kg CO2 eq
Human toxicity, cancer effects	2,12E-05	CTUh
Human toxicity, non-cancer effects	4,12E-05	CTUh
Particulate matter	5,52E-02	kg PM2.5 eq
Acidification	0,51	molc H+ eq
Freshwater eutrophication	2,53E-02	kg P eq
Freshwater ecotoxicity	1527	CTUe
Land use	91,18	kg C deficit
Non-renewable energy	226	kwh

Table 7: Embodied environmental impacts of a EDK.

4. DEMONSTRATION EXAMPLES

4.1 DEMONSTRATION BUILDING IN LUDWIGSBURG, GERMANY

The implementation of the renovation kits developed during iNSPiRe in an example of practical case renovation, which uncovers real life application issues. It turned out to be more than an implementation phase, but a consecutive phase in the technological development, where the kits had to be improved and adapted during the planning, construction and use phases of the project.

Three of the kits developed were implemented in the demonstration site in Ludwigsburg, Germany. The owner of the building Wohnungsbau Ludwigsburg GmbH also co-funded the renovation works. Renovation technologies 1 and 2, mechanical ventilation with heat recovery with and without active heating, were tested on two apartments. The prefabricated shaft together with the method for the renovation of the service pipes was tested in three flats of the property and a variation of renovation technology 3, integration of solar thermal panels, was tested on the roof. These are the main technologies developed for the renovation of residential buildings.

In addition to the Kits developed in iNSPiRe, which mostly regard envelope solutions and systems installed into/onto the envelope, heating and ventilation solutions market available by Vaillant were installed.

This has permitted to setup and compare four different heating and ventilation solutions in the four dwellings of the building, which provided invaluable information in terms of design, installation and operation issues to be tackled when installing advanced HVAC systems in refurbished residential buildings.

All technologies developed and market available solutions were installed after a long planning and improvement process involving many stakeholders within and outside the iNSPiRe research program. The kits and renovation concepts were first designed by the partners, and then received an input from the practitioners involved in the detailed design, approval and implementation. The coordination effort of the detailed design was without question the most challenging task.

The new state-of-the-art prefabricated timber envelope is now in place along with all mentioned technologies, working properly until the issue of this report. Several points remain to be improved in a commercialisation phase post- research project, but the major common lesson learned is that the technology developed during iNSPiRe and tested in this demonstration project is ready to pass to the next phase of commercialisation.

4.1.1 Building status before renovation

The demonstration project in Ludwigsburg was selected 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. The building is located in Ludwigsburg, Germany and belongs to the housing association owned by the city of Ludwigsburg.

It is a semi-detached multi-family house comprising 4 units, one flat per storey. It was originally constructed in 1971 using uninsulated hollow concrete blocks and pre-cast reinforced concrete slabs, completed with in-situ concrete. It was built without any external insulation.

Some renovation measures have taken place since its construction, including the installation of new windows, 60 mm EPS insulation added to the building fabric. Although the measures have introduced improvements, they were not enough to bring the building to up-to-date standards, and cannot extend its lifetime for another 40 to 50 years.

The building fabric, with U values between 0.5 and 1.8 W/m²K, had severe thermal bridges and poor airtightness, resulting in condensation issues mainly around windows. The energy demand was 168.2 kWh/(m².a), with a primary energy demand of 188.11 kWh/(m².a).

It was a requirement of the building owner to bring this building to current standards, pro-longing the lifetime of the building for another 50 years. Without this measure the building would have been subject to evaluation of demolition. The project iNSPiRe sets the target of an intensive retrofit, which assures a primary energy demand of 50 kWh/(m².a).



Figure 45: Picture of the building before renovation

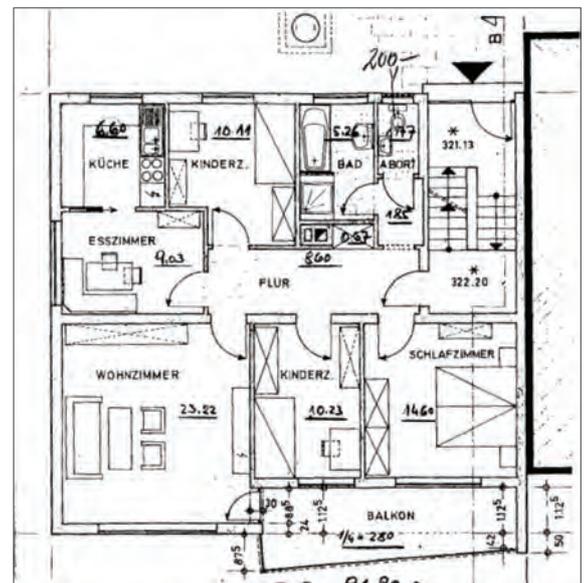


Figure 46: Plan of the ground floor apartment before renovation

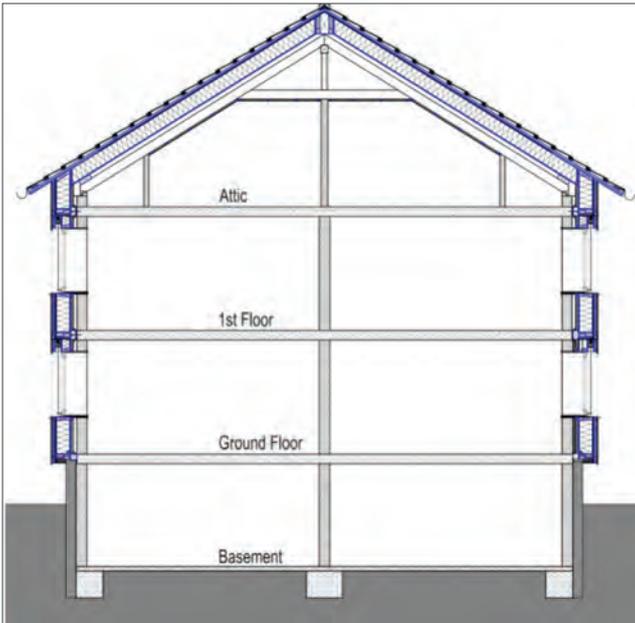


Figure 47: Section of the planned new timber envelope (Source: Gump & Maier GmbH)

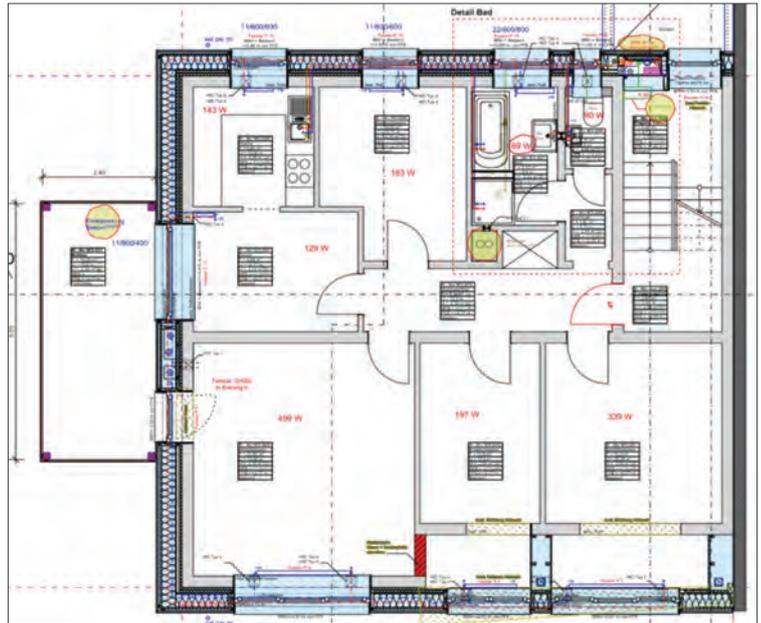


Figure 48: Plan of the new envelope (Source: kelzenberg + jahnke freie architekten)

4.1.2 Integral building renovation

The main retrofit strategy 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 is 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.

A continuous timber envelope was developed for the building on the ground floor level and around the existing walls and roof fabrics. For the cellar, since a large portion of its wall surface is below the ground level, standard EPS insulation was planned.

The timber envelope was designed with the following layers:

Inside

Existing structure: wall or roof build-up

- 80 mm mineral wool | as tolerance layer, used for pipes (only walls)
- OSB 15 mm | as vapour and airtight layer
- Timber structure | glulam studs and rafters 60 x 300 mm
- Insulation 300 mm | frames filled with mineral wool or cellulose
- External insulation 60 mm | wooden soft fibre boards also as wind barrier
- Battens and counter battens 60 mm | two layers of each 30 x 50 mm
- Cladding | 20 mm painted timber cladding or roof tiles

Outside

The U value achieved by this wall build up, including the existing wall is 0.10 W/m²K. The roof construction achieves 0.13 W/m²K.

Timber elements were prefabricated in the factory of Gump & Maier in Binswangen (DE) 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 tonnes. 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.

In order to obtain a continuous envelope around the building, the balconies, entrance roofs and chimney had to be demolished. The spaces from the old balconies left inside the thermal envelope were integrated as an extension of the sleeping rooms. New balconies are planned on the gable wall as an independent structure added on to the envelope. A new entrance roof was built out of a prefabricated timber structure. The works planned to be carried out on-site were the structural fixings to the existing building, the insulation of the tolerance gap, and the last layer of paint. The internal chills and the gypsum reveals were carried out on-site in occupied and empty apartments.

For the prefabricated roof elements, eaves, weather foil and counter battens were assembled in the factory, and the battens, roof windows and tiles were installed on site.



Figure 49: Prefabricated wall elements arriving to site (Source: Gump & Maier GmbH)



Figure 50: Wall elements being craned to their position during erection (Source: Gump & Maier GmbH)

Steel brackets were designed to be load bearing, fixed at the existing concrete slabs. These supports had to be in contact and chemically dowelled to the existing slab, therefore the existing cladding had to be removed on site for their installation. The glued anchors carry horizontal loads while vertical loads are transmitted via contact by a steel flange resting on top of the slab. The support level of these brackets was adjusted by 5 to 15 mm plywood elements, and the timber cassettes of the ground floor were mounted directly on them.

For the cellar, since a large portion of its wall surface is below the ground level, the insulation was planned with a standard EPS achieving a U value of 0.15 W/m²K. The bottom side of the timber cassettes was insulated on site with the same EPS insulation used for the walls, creating the junction.

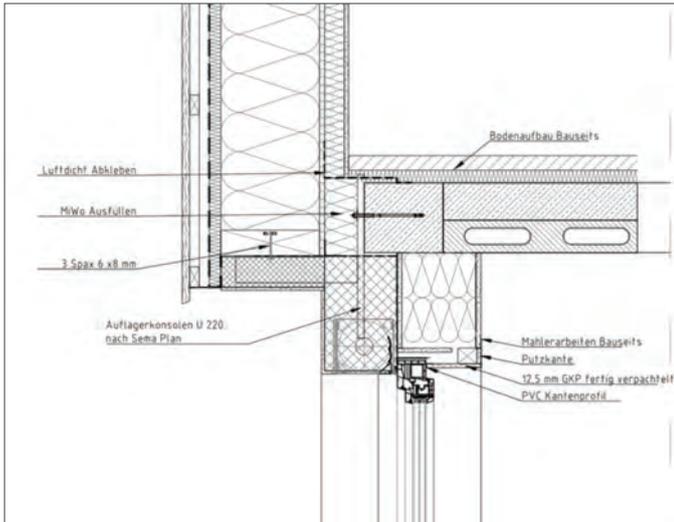


Figure 51: Detail of the support of the wall elements (Source: Gumpp & Maier GmbH)



Figure 52: Installation of the steel elements on the façade (Source: Gumpp & Maier GmbH)

The prefabricated wall elements are fixed to the existing structure through a wall plate, previously installed and connected to the face of the concrete slab by screwed dowels. These timber elements leave a gap of 60 +/- 20 mm which is used as tolerance for the unevenness of the existing wall, and filled up with mineral wool insulation. This gap has also been used in Kit N°2 for the installation of the new pipework and cables.

The airtight layer is the OSB plate, which is taped around the junctions and sealed between elements with a rubber profile.

Venetian blinds are incorporated as solar protection installed in the factory. They are operated by an electrical switch installed on the new internal reveals.

The roof elements were designed to be supported by the existing walls and roof structure. This avoided that their load is transmitted to the new walls, which would have meant they had to be treated as load bearing, overcoming higher fire safety requirements. The loads of the roof are transmitted to the brick wall through the existing rafters onto the existing wall. Timber posts supporting the roof structure had to be reinforced with additional timber beams, which were screwed onto them. This increased stability and bearing surfaces. For the existing brick walls no reinforcement was necessary.

On site the old tiles, chimney, windows and service ducts were removed, leaving the old ceiling structure of the attic floor without changes. Although the difficulty of the construction process increases by leaving the old roof in place, it allows keeping the existing internal surfaces and the attic apartment without disruptions. With the exception of some parts of the central structural elements, the old roof structure can be removed from the inside whenever the tenants leave and the flats are renovated.

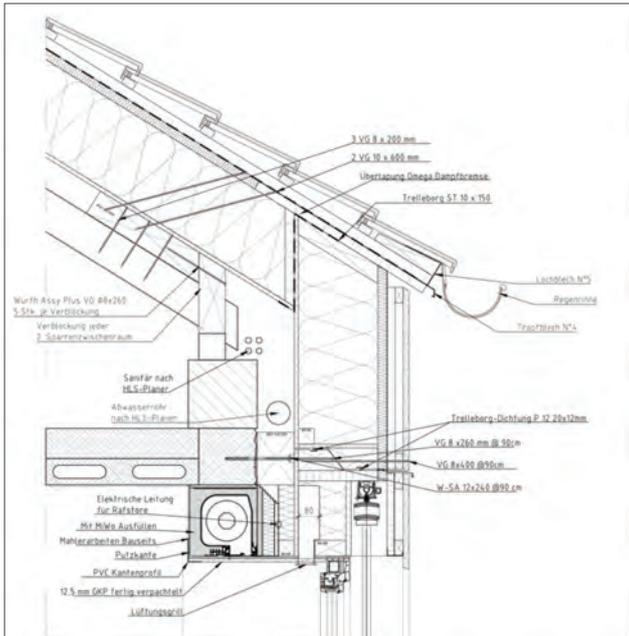


Figure 53: Detail section of the roof-wall junction (Source: Gumpp & Maier GmbH)



Figure 54: View of the roof before the erection of the prefabricated elements (Source: Gumpp & Maier GmbH)

Due to the volume of works and the characteristics of the changes proposed to the building, the fire safety concept had to be redesigned.

In general, for a building of this size and characteristics (building class 3 in Germany), the concept is defined by the architect and approved by the building authority. In this case, due to the new features, which involved a new façade and installations through a fire wall, a fire safety specialist with experience in this type of renovation was involved in the project, to propose an appropriate fire concept. The main features of this fire concept are:

- The required 60 minute resistance (REI-60) for the separation wall is provided by the existing brick and concrete construction.
- The timber envelope is therefore considered as insulation, which in this building class has the requirement of combustibility B2 (standard flammable according to DIN 4102) which is achieved by the proposed timber envelope.
- Smoldering behind the façade is avoided by the use of mineral wool in the tolerance gap.
- The shaft has a requirement of F30 A, to all its sides, which is provided by a timber construction protected with a 30 minute encapsulation to DIN EN 13501-2: 2003-12 and DIN EN 14135:2004-11.
- The secondary fire escape route is provided via the newly installed balcony on the gable wall (building law: LBO Baden-Württemberg).

The intervention was carefully planned in a way that the building remains in building class 3 (Germany: "Gebäudeklasse"), whereas a new rating to Building class 4 would have required stronger measures.

5.1.3 Building services

The renewal of the building services provides new installations for ventilation with heat recovery, heating, energy harvesting, sewage pipes and water distribution (warm and cold). The method aims at minimizing the disruptions to the residents in the inside of their flats, and keep in continuous operation during the construction works.

In order to test different solutions developed in the project, different strategies have been adopted for the flats. This has given an interesting opportunity to test the implementation of different approaches, but would not be applied in a standard commercial project. As a result, a different strategy for heating and ventilation has been adopted for every dwelling. The connection to the new service pipes is carried out only to the vacant flats, during the construction period, because the interiors of bathrooms and kitchens were also renovated. The internal renovation of the occupied flats will be carried out when the current tenants move out, and the sewage and water systems will only then be connected to the new one.

A summary table of the different approaches to heating, ventilation and services in relation to the flats can be found on page 66.

FLAT	OCCUPIED	VENTILATION	HEATING AND DHW	SERVICE RENEWAL
Cellar	No	Ventilation with heat recovery. Unit in the cellar	Central water based heating system with air-to-water heat pump and solar thermal system. Space heating by new radiators	Water, sewage and heating pipes renewed directly in the cellar
Ground Floor	Yes	Kit 1 a (MVHR with integrated air-to-air heat pump) and b (MVHR without integrated air-to-air heat pump) with heat recovery. Unit in the timber wall	Space heating by Kit 1.a: micro heat-pump integrated to the MVHR unit. Only extract air ducts prefabricated. DHW produced through centralised system	New water and sewage pipes installed on the wall, to be connected when residents move out
1st Floor	No		Central water based heating system with air-to-water heat pump and solar thermal system. Space heating by new radiators	Kit 1.b. Supply and extract air ducts prefabricated in the new envelope. New water and sewage pipes installed on the existing wall and connected to the interior
Attic	Yes	Ventilation with heat recovery. Unit in the cellar	Central water based heating system with air-to-water heat pump and solar thermal system. Space heating by new radiators	Kit 1.b. Supply and extract air ducts prefabricated in the new envelope do carry ventilation from cellar to attic. New water and sewage pipes installed on the existing wall and connected to the interior

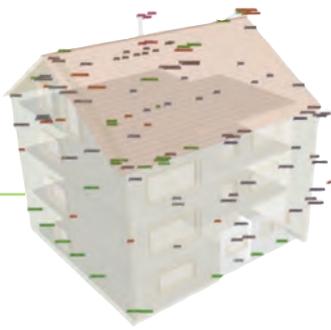
Table 8: Different approaches for renovation of heating, ventilation and services

The following timeline explains the whole retrofitting process for Ludwigsburg

3D TACHYMETRIC SURVEY

A tachymetric and constructive survey was carried out during the planning phase of the project. It generates a precise 3D model of the building, with detailed information about the location and geometry of the relevant structural and constructive elements. The unevenness of the façade was measured.

The precise location, composition and structural characteristics of the required elements were assessed with a partially destructive survey.



OFF-SITE FABRICATION OF THE SHAFT

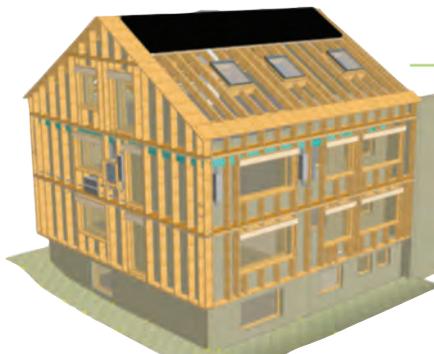
The installation shaft was built in the factory of Gump & Maier GmbH. The timber structure was assembled and fire protected with two layers of gypsum fibre board. The installers worked in the prefabrication line and were able to install all pipes and ducts in a horizontal position. The Vaillant satellite stations providing the connection between shaft and each level were also assembled and connected in the workshop.



NOVEMBER 2014

JANUARY- JUNE 2015

SEPTEMBER 2015



3D CAD-CAM MODEL OF THE TIMBER ENVELOPE

The timber envelope was designed in 3D on the previous model, designed to fit exactly on the measured points and the surface. During this design phase, the input of all designers (architecture, structure, fire planning and timber production planning) was coordinated to determine the envelope as shown. The result is a CAD-CAM model, which can be directly exported to the factory for a semi-automated production.



OFF-SITE FABRICATION OF THE WALL ELEMENTS

The wall elements were assembled in the factory, including insulated timber cassettes, internal OSB layer and external cladding. The internal layer was not installed to the parts where ventilation ducts still had to be inserted.

OFF-SITE INSTALLATION OF WINDOWS AND REVEALS

Windows were installed off-site, with the necessary air- and watertight seals. External sills, reveals and sun shading elements were installed off-site as well, in order to minimise the work required on site. The cladding was installed coated, requiring only a last site finishing layer.



MOUNTING OF THE STEEL SUPPORTS

Stripes of the existing layer of insulation were removed, in order to create space for the installation of the pipes, and to uncover the face of the concrete slabs. The structural steel supports were mounted to the concrete structure with chemical gluing anchors. They are dimensioned for carrying the vertical dead loads from the façade and horizontal loads from wind. The level of the supports was adjusted by fixed pieces of high density fibre boards



OCTOBER 2015



OFF-SITE FABRICATION OF THE ROOF ELEMENTS

The roof elements were manufactured insulated and closed from the top and bottom sides. The roof felt was installed on the factory to protect the elements from rain during construction. The roof elements were prefabricated at max. 2.50 m width, each covering the complete length of the roof. The roofing membrane is open to diffusion and was applied during the prefabrication.



EXCAVATION AND INSULATION OF THE CELLAR

The first step on site was to excavate around the house to insulate the cellar walls and to install the service ducts for the connection to the urban networks. Water sealing and insulation with a standard EPS based system were applied to the wall.

The windows of the cellar were replaced during this period.

INSTALLATION OF THE MVHR UNIT WITH MICRO-HEAT PUMP

The micro-heat-pump was delivered ready by the manufacturer, and installed in the factory in the opening planned for it. In this system, the micro ventilation heat recovery system was connected to the micro heat pump in order to use the energy contained in the warm exhaust air. The connection ducts of the unit are lead through the OSB-layer and sealed with air tight tape during the prefabrication. On site a duct will be lead through the existing exterior wall and connected to this prepared junction.



INSTALLATION OF THE INSULATION AND OSB LAYER

After the ducts had been installed, the walls were insulated with mineral wool, making sure that all spaces between ducts and the timber structure are filled in. This work can be done easily in the workshop, assuring a high quality of the thermal and acoustic insulation.



NOVEMBER 2015



INSTALLATION OF THE PARTS OF THE VENTILATION SYSTEM

The ventilation ducts were installed in the workshop by the research partner Siko Solar GmbH from Austria. They were mounted in the window station, where the element can be lowered into the ground. This improved accessibility and comfort of the installers. The complete ducting system was installed by 2 people in 2 days. The ducts are mounted on top of sheets of sound insulation in order to acoustically separate ducts and construction.



ERECTION OF A FULL SCAFFOLD

A full scaffold was installed around the building for the installation of the services and erection of the timber envelope. A gap of 600 mm was left between the scaffold and the existing building to leave space for the timber frame elements to be craned in. This gap was filled with a temporary platform extension, which was removed for the installation of the prefabricated components.



DEMOLITION OF BALCONIES, CANOPY AND ELEMENTS ON THE FACADE

The cantilevered balcony slabs were cut by a specialised sub-contractor, organised by the timber frame manufacturer. Old windows were removed from the non-occupied apartments, the parapets were removed, and the openings were temporarily protected.

The windows and parapets were not removed in the occupied apartment until after the timber envelope was erected.

DEMOLITION OF NEW OPENINGS

The new openings required for the new balconies on the western facade were carried out. The openings in the occupied flats were only done at the same day, shortly before the new envelope elements were installed to minimise inconvenience to the residents.



ERECTION AND FIXATION OF THE SHAFT

The shaft was mounted in front of the staircase, where the existing wall from glass bricks was removed. It is based on a steel foundation placed on top of a concrete basement wall, which has been casted newly underneath the shaft. The timber posts of the shaft are fixed against horizontal loads at the wall plates in the middle and at the top of the shaft via steel brackets.



NOVEMBER 2015



MOUNTING OF TIMBER WALL PLATES

The structural timber wall plates were erected and fixed to the existing slabs, determining the spaces available for the installation of the pipes and cables of the new services. They were marked by the CNC milling station with precise instructions and reference locations for the installers to coordinate the position of the penetrations for the connection between the old and the new envelope.



CRANING OF THE SHAFT

The prefabricated shaft was the first envelope-element to be installed on site, in order to complete the installation of the pipes before the timber elements were erected. It was transported to site in lying position. It could be lifted with the crane as one piece, although the crane had to go to the very front to reach the mounting position.

INSTALLATION OF PIPING ON THE FAÇADE

The position for wall perforations had been carefully measured, keeping in mind that the installation inside the apartments would not be changed and an exact connection of new and old pipes was intended. The wall plates were cut at positions which had already been marked during the computer aided manufacturing.



PERFORATION OF THE WALLS FOR NEW INSTALLATIONS

The holes in the existing wall were drilled from outside. This reduced pollution of the interior and showed the possibility of doing most work from outside. In this picture a hole for ventilation in the ground floor is shown. Thanks to exact measuring and planning the hole enters the room just next to the partition wall. The furniture remained in this room and was only protected by covering with plastic sheets against dust.



DECEMBER 2015



CONNECTION OF PIPING TO THE SHAFT

After the mounting of the shaft, new pipes leading from the shaft to the inside of each level were installed to the surface of the existing wall. They were connected to the shaft using crimp and screw connections. Due to different requirements on the properties of pipes inside and outside of the shaft, the pipe material has to be changed using appropriate adaptors. All pipes are insulated according to heat and sound insulation requirements.



INSULATING THE TOLERANCE GAP

Insulation mats of mineral wool were fixed with spray glue, keeping them in position while the façade elements were mounted. This insulation fills the gap between the new façade elements and the existing building surface. As stated before, this is the layer where the new installation was mounted.

TRANSPORT OF THE PREFABRICATED FAÇADE ELEMENTS

The façade elements were transported to the site standing on semi-trailers. The timber frame structure, cladding, insulation, ventilation ducts and windows had all been assembled during the prefabrication. The elements were protected with plastic sheets against rain and moisture until they were fixed to the façade.



MOUNTING OF THE WALL ELEMENTS

The picture shows the top of the ground floor wall element. The next element will take place on top of this one, with the help of a diagonally halved beam on its bottom, fitting to the one in the picture. The fixation against horizontal loads is done with horizontal screws, linking these two beams. Vertical loads are carried via contact between the timber elements. The pictured heating pipes and electrical wires go further on around the building.



DECEMBER 2015



CRANING AND ERECTION OF THE ENVELOPE ELEMENTS ON THE FAÇADE

In this project each element covered the length of a complete building façade and had the height of one building storey. Limiting factors for the element size are weight and requirements for transportation on the roads. Especially in this case, where a relatively small crane was used and access roads to the residential area were very narrow, it was challenging to use elements of this large size.



FINALISATION OF THE WALLS

The status after mounting all façade elements. It took 3 days to mount 8 façade elements. The work was coordinated with the residents who granted access to their apartments. The aim of a high prefabrication level is to minimise working time on the site and disruption to the residents.

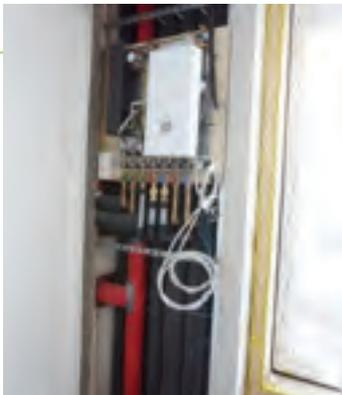
CONNECTION OF THE VENTILATION SYSTEM IN THE CORNERS

Small parts of the façade were left open in order to access the ventilation ducts at the corners. The connection was done after both elements had been mounted, using a corner piece. The connection had already been developed accordingly during the 3D manufacturing planning. Afterwards the gap was filled with insulation. The covering, which had already been prepared in one piece, was mounted with timber screws.



INSTALLATION OF THE INTERNAL WINDOW CILLS AND REVEALS

The façade elements had to be connected to the interior by unusually deep window chills. Fitting new windows and existing openings was done such that the glass area is maximised and demolition works on the existing walls are avoided. As a result the new windows are slightly smaller than the old windows but with the advantage of little pollution and short installation times in the interior.



INTERNAL CONNECTIONS IN THE SHAFT

Each floor was equipped with a Vaillant satellite station. These provide the connection between building circle and the circle of each floor via heat exchangers. They also show the water and energy consumption of each apartment. The satellite stations were covered with a drywall possessing the same fire resistance as the shaft walls, which is REI 30. Maintenance of the satellite stations will be possible via special doors in these drywalls.



INTERNAL FINISHES ON CHILLS AND REVEALS

This picture of a living room during the retrofitting works is proof for little pollution and fast renovation times during installation of the new window chills. The chills were made from painted medium-density fibreboards (MDF) and cover the transition between old building and new envelope. Since the exterior walls increased to a thickness of around 88 cm, the deep window reveals add a new architectural element to the interior appearance of the windows and the whole room.

REMOVAL OF OLD ROOF TILES AND INSULATION

The new roof elements were put on top of the old roof. Therefore the old tiles and insulation were removed. Additional loads from the new elements, caused by larger windows and the solar collector, had to be carried by strengthened beams in the roof, but reinforcement of the supporting walls was not necessary.



INSTALLATION OF SOLAR PANEL

The solar panel was delivered to site as two pieces, each measuring 5.20m x 1.60 m. It was mounted in an integrated manner, flush with the roof surface.

In this case a well-insulated collector was used, enabling ventilation between the collector and roofing membrane without a loss of productivity to the collector. Ventilation tiles above the collector allow for a free airflow behind the panels, transporting water vapour away from the construction.



DECEMBER 2015



INSTALLATION OF ROOF ELEMENTS AND TILES

The airtight connection between the roof elements is provided by rubber seals, which were pressed together when the elements were fixed. The picture shows the opening for the staircase window, which has been cut into the existing roof after the new roof elements were mounted. This window will work as smoke outlet in case of fire.



CONNECTION OF THE SHAFT WITH THE CENTRAL SYSTEM

Inside the shaft high standard pipe materials were chosen in order to be flexible enough for fitting all pipes into the small space. In the basement conventional pipe materials were used. Despite this material change, the connection can be done very easily using standard parts. All lead-throughs in the shaft have been protected to fire and the shaft was continued to the basement floor with a drywall fulfilling EI 90.

INSTALLATION OF THE CENTRAL HEATING SYSTEM

The installed extensive building services included hot water storage tanks, a large domestic heat pump and connecting facilities for electrical installation. These had to be fitted into the existing basement room, which was a challenge for the plumbing company.



INTERNAL FINISHING

Inside the apartments the last finishing works were done. The aluminium grills of the ventilation shafts were put into place. They are located on top of the gypsum board and are sealed with the ventilation shaft inside the element. The picture shows a kitchen window where the extract air is sucked out of the apartment via the ventilation opening above the window. Other extract openings are located in the bathroom and the toilet. Fresh air inlets are located in the living room and in the bedrooms.



JANUARY 2016



COMMISSIONING OF THE DEVICES DELIVERED

The integrated micro heat pump and ventilation heat recovery unit can be accessed through the façade. After last adjustments from the outside, the remaining space was filled with mineral wool as sound and heat protection. Very cold parts of the heat pump cause condensation. The dripping water is collected and led through a pipe behind the insulation to the ground for seepage.



FINISHED PROJECT

All together the renovation took 3 months of construction time on site and two apartments were inhabited throughout all this time. The project is the first of its kind adding new lifetime to a building at the end of its serviceability by renewing insulation and building services integrated to prefabricated façade elements. Besides energy saving this project also realised energy generation thus creating a high level of energy efficiency.

Lessons learnt

The main lesson learned is that an intensive retrofit with renewal of building services is possible and applicable in the current context, possibilities and limitations. Regulations in Germany make it feasible to implement the proposed measures, although some new approaches and criteria had to be applied, for example in matters related to fire safety.

The maximisation of the prefabrication level has a considerable and positive impact towards the goal of reducing disturbance on site for the residents. The level of disruption was acceptable for both residents during the construction process, and limited in time. The highest level of disruption was caused by the installation of the ducts inside the property in the ground floor flat, which required good coordination with the residents and their patience. The erection of the timber envelope caused very little disruption to the tenants, in a way that no complaints were received throughout the process. The tasks producing noise did cause complaints from the neighbours of the next building, and had to be coordinated in timeframes in which it was acceptable. This happened mainly during the demolition phase. An effort can be done in future projects to use tools and fixation mechanisms which minimise sound emissions.

Time on site was short, considering the volume of the work carried out. The main works on the façade lasted only 11 weeks, from October to the middle of December 2015, which can be considered a very short period for these massive renovation measures. Finishing works inside the non-occupied apartments did take a longer time, but did not affect the residents.

The most important lesson learned for improvement is the importance of the planning coordination between specialists and manufacturers. This was a privileged project because of the very long time available for planning, which would be dramatically reduced in future commercial projects. 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 inputs from the structural designer and fire safety specialist were also communicated with difficulties to the rest of the team, since they were contractually organised under the timber frame manufacturer.

The conceptual planning was carried out within the research partners of iNSPiRe, whereas the detailed plans and approval were carried out by local specialists contracted by the owner. Furthermore, a certain deal of 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 as the most relevant challenge to set up a planning team with clear tasks and responsibilities. Ideally, the manufacturers and installers should be incorporated to the planning process as early as possible, to allow for a coordinated review of the plans and specifications from the contracted companies. This task should be clearly stated in all construction contracts to become an obligation to all parties involved.

Due to the involvement of several manufacturers and installers for the different components of the building services, the definition of the interphases and the liabilities present a major challenge. Never the less the interphases can be solved properly provided that an adequate effort is put in the coordination. The process is expected to improve with a rising amount of experience and integrated planning. The issues of warranty and design liability should be taken into account and agreed before any design or execution contract is awarded, to avoid ex-post discussions and uncertainties.

An air tightness value of 1,0 air change rate (n50 value) was set as target for the new envelope, according to the principles of the certification enerPHit. The measures taken to comply with it included rubber seals between the prefabricated elements and glued foils to connect to the existing render in the separation gable wall. This value was proven very difficult, and a n50 value of 1.5 ac/h was achieved with a corresponding increase on the energy demand of 6%.

As the planning process refers to an existing object, the level of information and constraints tend to increase along with the project's progress. This reaches a maximum during the construction phase, where inevitably new difficulties and constraints arise, as the intervention uncovers hidden features of the building. This does have an impact on the construction budget for all parties involved - installers, designers and the owner. This risk can be reduced by a more detailed and intensive building survey and analysis, but may not be eliminated. Therefore, it is also necessary to make allowances in the budgets for unexpected changes.

Considering the above lessons, the approach to systemic renovation through the application of the kits developed within iNSPiRe is applicable in commercial projects. Improvements have to be made in order to reduce friction during the planning phase and to facilitate the implementation and use phases.

4.2 DEMONSTRATION BUILDING IN MADRID, SPAIN



This demonstration building, selected by the project partner EMVS (Empresa Municipal de la Vivienda y Suelo de Madrid), is located at Ciudad De Los Angeles in Madrid.

This building was commissioned in 1960 and its foundations were partially renovated back in 2003. This property is located in the area for integral Renovation of Ciudad De Los Angeles since 2008.

The condition of this property prior to the renovation showed a number of defects, in particular foundation problems derived from the structure's differential settlement, which caused significant cracks on the building facade. Besides, 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.

Moreover, the limited income levels of the owners and occupants of this building's dwellings made a major renovation project out of their own financial resources unfeasible. As such, they were selected as beneficiaries of EMVS (Empresa Municipal de Vivienda y Suelo) Renovation Plan as well as new installations thanks to Project iNSPiRe at very limited costs.

Given the level of deterioration observed in the building, the property owners were left with no option but to explore the different alternatives: either renovate or demolish and rebuild.



Finally the Owner's Association decided not to demolish it and carry out a complete renovation including new features as a lift shaft attached to the external building envelope improving access to the properties, redesigning the stairway from two flights to a single one, rebuilding the stairwell. All of these works were carried out with the occupiers remaining in premises throughout the duration of the project.

Two of the technologies developed were implemented in this demonstration site. The first technology is the Energy Management System composed of a number of Energy Hubs distributed within the new centralised heating and cooling systems, and one energy Manager installed in the technical room of the building.

The second technology is the integration between the aluminium radiant ceiling panel and recessed luminaires.

In contrast to the demo site in Germany, here the technologies are used to setup the new centralised heating and cooling system, while commercial solutions are used to retrofit envelope and windows.

Also in this case, the planning phase of the technologies and market available solutions requested a long time within the research program timeframe, while the installation stage has been relatively fast.

This is due to the need of coordination among different working teams, with different backgrounds and expertise. Moreover, the ownership of the building considered in this document is diffused (one owner per dwelling): project partners EMVS and ACCIONA participated in the retrofit design phase and, in parallel, liaised with the occupants and managed their expectations. This non-technical activity took a significant amount of time out of the project.

The building is now retrofitted, while monitoring is on-going. The commercial solutions employed and the radiant ceiling + recessed luminaire Kit are ready for direct replication in similar applications.

On the other hand, some more work is needed to industrialise the Energy Hub solution, including the CE accreditation of the thermal energy metering units included.

The main lesson learned is that coordinating the design, together with gathering the needed agreement by the owners, were the most challenging tasks, far behind the development of the technical solutions.

4.2.1 Building status before renovation

The use of the building is fully residential. It contains ten dwellings distributed on five floors, being the main entrance of the building at the same level of the two dwellings of the ground floor.

The useful area of each dwelling is 50m² with a free height of 2,48m, shared among three bedrooms, one bathroom, one living-dining room and one kitchen. The inner distribution of each dwelling is shown in the plan of Figure 55.



Figure 55: Building vertical view

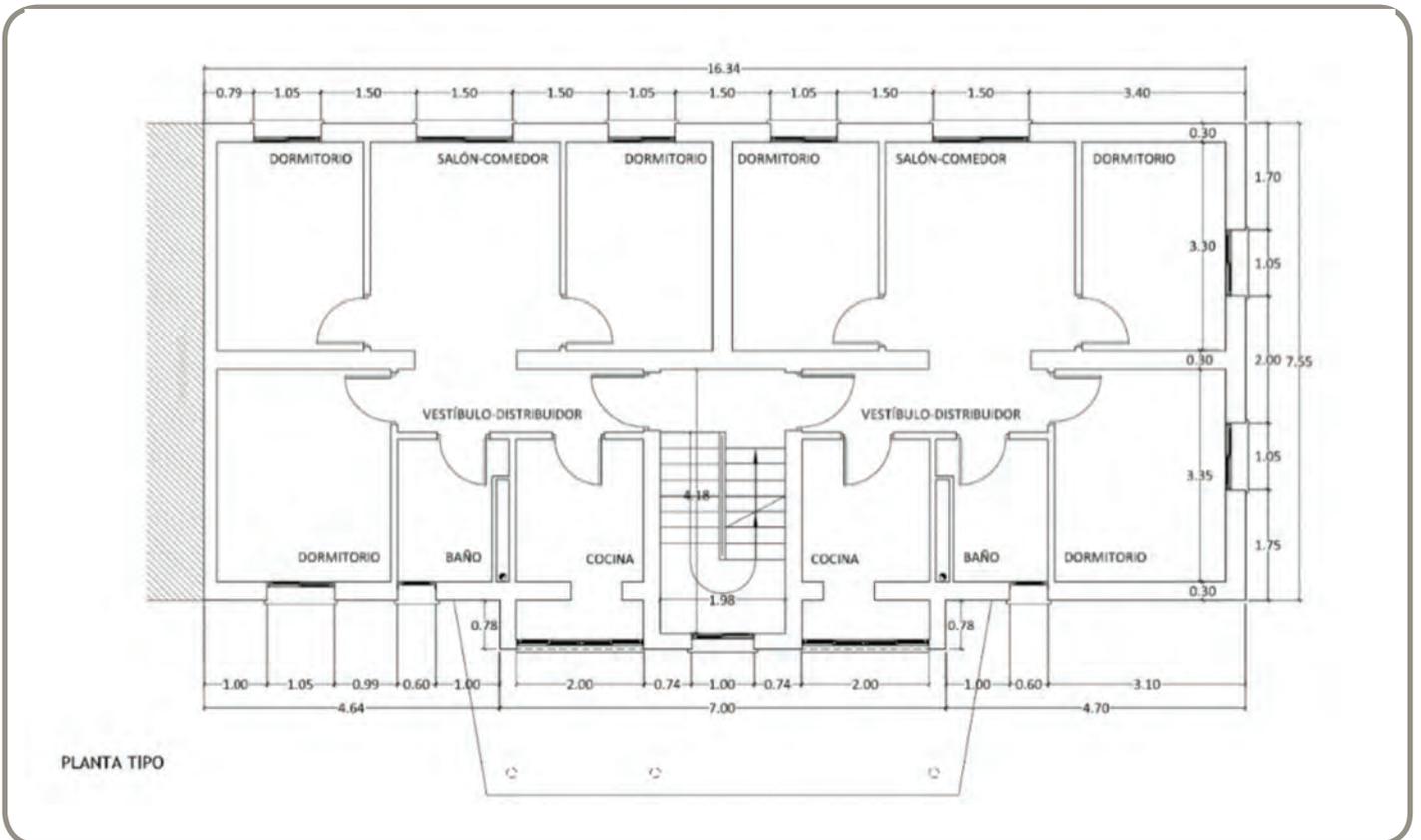


Figure 56: Building floor plan

The gas piping distribution, phone lines and electricity wiring are all located along the façade. The stairs that gave access to the dwellings of each floor were U-stairs with half landing. In the fourth floor, the last flight of stairs, provide access to the roof.

The roof was accessible but used only for maintenance works. The small technical room located on the roof housed the electrical meters of the ten dwellings.



Figure 57: Gas piping



Figure 58: Telephone lines



Figure 59: Electricity wiring

The existing windows were of two types:

1. Single window, single clear glazing 6mm.
Aluminium window frame (no thermal break)
u value estimated equal to 5.8 W/m²K

2. Double window with air cavity 10 cm. Single clear glazing 6mm per window.

Aluminium window frames (no break)
u value estimated equal to 3.1 W/m²K

Most of the bedrooms and dining rooms windows has white roller blinds installed to avoid overheating in summer, sunlight during the day and exterior artificial light during nights. In all cases, the mechanism is manual.

Some windows facing west orientation were also provided with textile awnings.

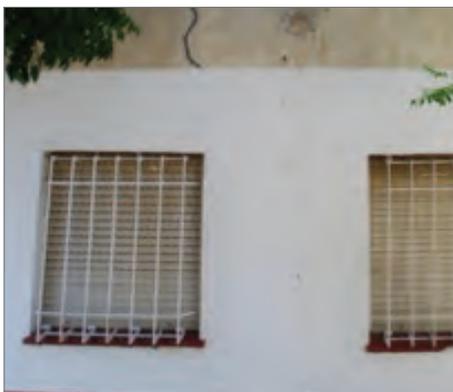


Figure 60: Blind 1



Figure 61: Blind 2

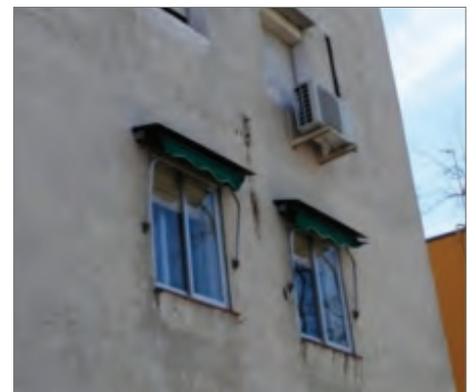


Figure 62: Overhangs



Figure 63: Electric heater



Figure 64: Gas boiler



Figure 65: Electric radiator



Figure 66: Butane heater



Figure 67: Radiator



Figure 68: A/C split

Each dwelling had its own HVAC system setup. All dwellings are setup with a DHW and space heating system. Most commonly, natural gas or electric boilers were used; in some cases however, butane gas boilers were still used.

The dwellings gas boilers had radiators installed, while independent electric radiators or butane heaters were used in the other apartments.

Three dwellings had cooling via single split units installed.

No ventilation systems were present in the dwellings.

4.2.2 Integral building renovation

The general condition of this building prior to renovation was poor and deteriorated, with significant cracks on structure and envelope, damaged fittings, fixtures and joinery, construction flaws as well as unfinished renovation works.

The scope of the initial building survey involved understanding what renovation work was carried out in 2003, the quality and condition of that works, plus other identified defects.

Another activity in this initial phase was the identification of requirements for obtaining a new energy rating for the property in order to apply for public funding aids from EMVS.



Figure 69: Cracks inside sleeping room

The planning application covered both, renovating the building as well as improving accessibility by means of an external lift attached to the main building facade.

A geotechnical survey was carried out in order to analyse and determine the best course of action for foundation renovation, which had already been identified as a major task in this project.

The renovation process went through a number of actions, starting from the structural reinforcement of the building, the thermal insulation of the envelope and the installation of a centralised heating and cooling system.

The structural works can be summarised as follows:

1. Execution of micropiles and caps, planned back in 2001 but not carried out during the previous renovation works in 2003, which would complete thereafter all foundation works and their interconnection. More precisely those micropiles on traversal walls supporting stairways and short facades.
2. The existing caps from 2001 are built in 9 different sections and are not interconnected. By means of the new caps and mechanical-chemical bindings all existing and new sections have been interconnected providing a solid foundation.
3. Double bracing at building joint using steel adjustable tension stringers and brackets attached to concrete walls. These have been replaced at a final stage with metallic squares anchored to concrete walls.
4. Construction of lift shaft with concrete walls, which contributes to the overall building stability acting as a buttress.
5. In order to build the new lift shaft, the existing stairwell had to be demolished and a new one put in place. It is worth to keep in mind that during all this process the building was inhabited by owner-occupiers.
6. Construction of a new roof structure by means of a metallic ring structure braced with steel stringers and connected to the new lift shaft structure. The former has been finally replaced by a permanent concrete slab attached to structural walls.



Figure 70: Lift shaft during installation and at the end of the retrofit

7. Repair facade cracks, eliminate external artefacts (aerials, satellite dishes, etc...) and consolidate boiler exhausts and vents in order to increase the aesthetical value of the property.

The façade was coated with an external thermal insulation system in order to improve the thermal behaviour and meet existing regulations in Spain.

New double glazed windows have been setup, as well as passive protection lattices where appropriate. The heat generation system is a reversible 20 kW air to water double circuit heat pump: one circuit is always turned in heating mode and connected to a 500 litres hot water storage for domestic hot water preparation, the other is turned in heating mode in winter and in cooling mode in summer. A 22 m² solar thermal plant feeding an 800 litres thermal storage is the main system for DHW production.

The distribution system is a four pipes system for DHW, and heating or cooling distribution. All the pipes from the technical room on the roof to the dwelling's hydraulic stations have been placed under the facade insulation, on the external side of the walls.

In the dwellings, the heating and cooling system is distributed by means of radiant ceilings. Pipes distributing water from the mains to the dwellings have been installed in the false ceiling on the staircase and in the main corridor of each dwelling.

Before: Work begins on the demo building

The demo building is located in Ciudad de Los Angeles, on the outskirts of South Madrid, an 'Urban Renovation Area', managed by EMVS. The area was developed around the 40-50s directly and was linked to the nearby Barreiros car factory.

After nearly a year of discussions, EMVS reached an agreement with the owners and this multi-family dwelling became the second site used to demonstrate iNSPiRe solutions. The block had five floors, 10 apartments, with no lift and no insulation. The building was in poor condition and had been badly preserved. Now, after several months of work, it stands testament to how good renovation can vastly improve both the aesthetic quality of a building as well as its energy efficiency and levels of comfort.

Two iNSPiRe kits were installed as part of a general retrofitting work plan managed by project partner EMVS. The work began in November 2014 and was finished in early 2016. Importantly, residents were involved in much of the decision-making regarding the installations and had influence on aspects of work such as the size of the ceiling panels being fitted. Standard insulation has been applied to the new façade which also incorporates new windows. A centralised heat pump drives the entire heating and cooling system and this is helped by solar thermal collectors mounted on the façade.

The kits installed were:

1. The standard hydronic module for the distribution, control and management of the heating, cooling and hot water in each of the apartments in the building.
2. Multi-functional ceiling panel installed in the apartments, providing a radiant ceiling for heating and cooling as well as energy-efficient lighting.

CONSULTATION

Following the consultation with residents, it was agreed that a centralized heating/cooling iNSPIRe package would replace the individual systems they had in place.



RENOVATION STARTS

On site works for the renovation of the whole building have started in November 2014 with a foreseen span of 12 months



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MAKING AGREEMENTS

The agreement with the owners – which took more than a year – was that they would get the iNSPIRe energy retrofitting kits and packages for free, and in doing so they agreed to collaborate in the project and allow reporting of the implementation process and the results.



STRUCTURE

The same structure including the lift is used to provide structural strength to the entire building, prolonging its lifetime

ENERGY HUBS

Four energy hubs per floor (2 for each dwelling) and four in the technical room were finally located and connected despite the lack of room in the staircase. The 24 energy hubs manage the entire system in terms of heating, cooling and domestic hot water production, water distribution to the dwellings and heat and electricity metering.



HEAT PUMP

The iNSPiRe retrofit package consists of a heat pump system assisted by solar thermal panels installed on the parapet of the roof. The new technical room (not existing before) has been constructed on the flat roof.

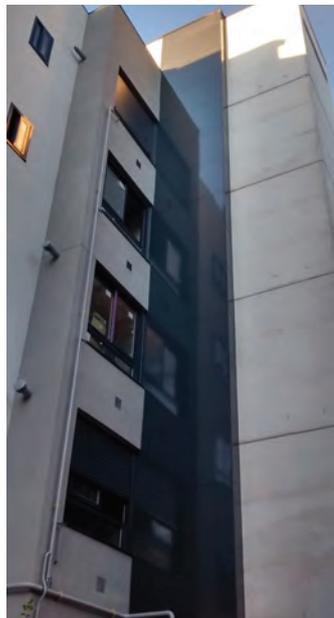


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RETROFITTING

During the renovation process the whole retrofitting was carried with people living inside. Therefore the new pipelines from the technical room to the single dwellings have been installed on the outside of the existing structure



CEILING PANELS

Radiant ceiling panels for the distribution of heat and cold are installed in each room and dwelling. The panels also incorporate energy efficient LED lighting.

HEATING AND COOLING

A main concern for residents has been aesthetics. The distribution pipes for heating and cooling water entering the dwelling through the corridor from the staircase have been covered with plasterboard.



9

iNSPiRe

The iNSPiRe demo process has raised huge interest among professionals and academia (Students from Universidad de Alcala de Henares Sustainable Energy Renovation Course visiting the demo in October 2015)



10

AFTER:
Renovations
are completed



4.2.3 Lessons learnt

The level of disruption was acceptable for the residents during the construction process. Besides the lift shaft erection and staircase renovation, and with reference to the iNSPiRe measures adopted, the highest level of disruption was caused by the installation of the ducts inside the property, which required good coordination with the residents.

The erection of the pipelines shaft, technical room and Energy Hubs was unproblematic to the inhabitants. The main lesson learned is that gathering the needed agreement by the owners, were the most challenging tasks. Project partners EMVS and ACCIONA participated in the retrofit design phase and, in parallel, acted as facilitators of the rehabilitation process towards the inhabitants.

An improvement for the future would be to clarify exactly the scope and the investment costs of the retrofit project at the beginning of the planning phase, in a way to get the owners agreement and a signed framework program from the beginning.

With such a complex planning and installation process, it is essential that the share of work and responsibilities of the partners involved in the different phases, and responsible persons are identified initially. This also allows also minimising the volume of documentation exchange and facilitates the communication. The main coordination role was kept by the architect. The conceptual planning was carried out within the research partners of iNSPiRe, whereas the detailed plans and approval were carried out by the architect and the professionals responsible for the installations.

Two of the kits developed were implemented in this demo site. Professionals are not aware of how to optimally use and install such systems: as such, the setup phase has taken longer than expected and technical issues have been solved on site as far as the installation was proceeding, with unexpected additional effort needed.

In future demonstration projects, time should be spent 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 creating a network of trained professionals that could be employed for the installation and maintenance of own systems.

Finally, a deep rehabilitation process does not only involve the implementation of energy efficiency measures. It usually accounts for structural reinforcement of the building and update to the latest regulations, for instance eliminating architectural barriers, updating electric wiring and water pipelines, etc. The structures devoted to the implementation of energy efficiency measures often facilitate such an update.

Consequently, after the renovation, the property has not only higher energy efficient 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.



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