

PREFABRICATED TIMBER ENVELOPES FOR RETROFIT WITH INTEGRATED HEATING SYSTEM AND BUILDING SERVICES

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SUMMARY

The objective of the EC-funded project iNSPiRe is to reduce the problem of high-energy consumption of existing buildings by producing systemic renovation packages that can be applied to residential and tertiary buildings. The renovation packages aim to reduce the primary energy consumption of a building to lower than 50 kWh/(m² a) for ventilation, heating/cooling, domestic hot water and lighting. These renovation packages need to be suitable for various climates in Europe while ensuring optimum comfort for the building users. One major goal of iNSPiRe is the development of multi-functional renovation kits that make use of innovative envelope technologies, energy generation systems (including RES integration) and energy distribution systems.

A set of three kits is developed based on the use of timber frame prefabricated elements (TES) for retrofitting of residential buildings. The first kit introduces a mechanical ventilation with heat recovery (MVHR) unit with active heating and distribution ducts built inside the prefabricated façade element. The second kit proposes a strategy to install new water, sewage and electrical pipes, together with a prefabricated vertical distribution shaft. The third kit integrates a large scale solar thermal collector using an industrialized approach.

Applying these deep renovation measures combined can extend the life span of the building by some additional 50 years by bringing its envelope and skin to up-to-date standards, comparable –and often overmatching– new build standards. Therefore, it becomes a highly cost-effective alternative to demolishing and building new, reducing the impact on the environment, tenants and cities.

The technologies and renovation approaches developed within the iNSPiRe project are installed and tested in two residential demo buildings (D, Es). In this paper, the approach to the three kits will be described, and a main focus set on the assessment of the performance of kit 1: MVHR with active heating and the implementation in the demo building in Ludwigsburg (from the housing company WB-L).

PRACTICAL IMPLICATIONS

Different renovation packages can result from the combination of these kits, offering the integration of the following functions along with the timber envelope: MVHR with or without air heating, air distribution ducts, distribution pipes for domestic hot and cold water and heating, sewage pipes, electrical cabling and energy generation by solar thermal and/or photovoltaic panels.

KEYWORDS

deep renovation, industrialized renovation kits, timber frame façade, MVHR, micro-heat pump, simulation, monitoring

1 INTRODUCTION AND MOTIVATION

The vast majority of the existing buildings in Europe present an energy performance far beyond our ambitious goals. A large part of it has been built in the mid and late 1900's, and is rapidly achieving the end of its life time. Building fabrics have insufficient insulation values, often present thermal bridges and mold growth, windows are in poor conditions and present severe infiltration problems. In most cases, the building services have been modified and repaired several times, and rapidly achieve a point where a complete renovation is necessary. The need for deep renovation is therefore not only intended to save energy, but mainly to replace a building which can no longer be in operation.

For these cases, deep renovation solutions are developed within the framework of the European project iNSPiRe (iNSPiRE, 2016), and implemented in its demonstration residential building in the Karl-Dieter-Strasse in Ludwigsburg, Germany from the housing company Wohnungsbau Ludwigsburg (WB-L).

A prefabricated timber envelope is manufactured in the factory of Gump & Maier GmbH in Binswangen, and craned to form a new skin around the existing building. This envelope provides insulation, air tightness, and incorporates prefabricated windows, sun shading and cladding. The level of prefabrication is maximized in order to reduce the impact and disturbance to the tenants and the neighbourhood by reducing time and works on site. Construction works inside the flats are reduced as far as possible in order to minimize the disruption to the tenants, allowing them to stay in the flats during construction works. Temporal relocation of the tenants is usually neither economical for the owner nor a comfortable option for the residents.

In line with this principle, the kits are designed to minimize disruption during installation, and to make sure the construction does not interrupt the regular operation of the dwelling.

The air distribution ducts (kit 1) are integrated as far as possible in the prefabricated envelope, as shown in Fig.1.a. The MVHR units are placed inside the insulation layer of the new skin, accessible from the outside. Only the pre heated fresh air supply ducts are driven directly to the inside. In case of installation of the supply ducts in the façade, proper dimensioning and planning is necessary to avoid high pressure, and thermal losses.

An off-site manufactured shaft shown in Fig. 1.b is installed connecting the envelope to the technical room, and distribution lines are installed around the existing walls from the outside, minimizing the installation works inside the flat.



Figure 1.a) air distribution ducts and MVHR units integrated in the insulated timber frame envelope.

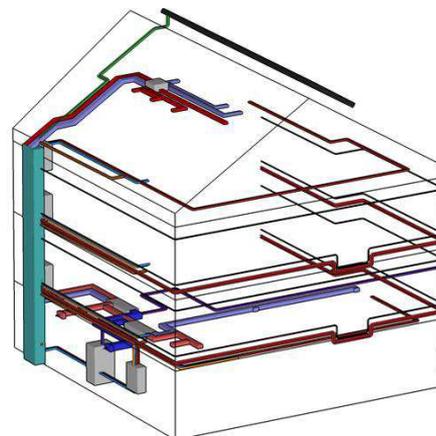


Figure 1.b) vertical distribution shaft with the water and electrical lines around the existing building together with a solar collector.

2 THE KITS

Kit 1: Offers the possibility to install a mechanical ventilation system with heat recovery to an existing dwelling. Air heating is integrated into the system. Its heat supply is adapted to the very low consumption after the renovation. A down-grade can be offered by including MVHR only.

Kit 2: Offers the possibility to renew all water and sewage pipes from the outside of the building, penetrating the internal space only punctually where needed. A prefabricated shaft can replace the main distribution system.

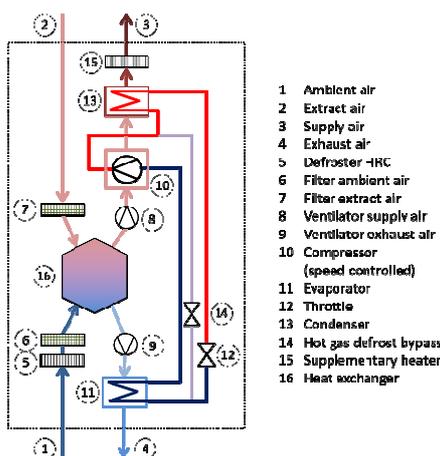
Kit 3: Offers the possibility to harvest solar energy by the attractive integrated solar thermal collector and its pipes installed through the new envelope.

Each kit has a strategy for the integration to the façade, which depending on their specific requirements, have different approaches:

2.1. - Kit 1: MVHR system with active heating.

The compact unit represents a solution for ventilation, heating and optionally cooling for very energy efficient buildings with a specific heating load in the range of 10 W/m^2 (such as PH or EnerPHit, (Feist et al., 2012)), where central systems are not feasible. The micro-heat pump is developed by University of Innsbruck together with the Austrian Company Siko Energiesysteme (with support of Pichler Luft and WGT Elektronik). The German company Gump and Maier which has already long experience with prefabricated timber frame façades is responsible for the façade integration.

The exhaust air of the MVHR is the source of the micro-heat pump with a heating power of approx. 1 kW. A pre-heater (defroster) and backup heater for peak load coverage are required. For comfort reasons an additional bathroom radiator is recommended. Domestic hot water preparation is not covered, it can be provided separately e.g. using an additional DHW-HP. A simplified hydraulic concept and photos of the functional model are shown in Fig. 2.



2.a)



2.b)



2.c)

Figure 5. a) Hydraulic scheme of the micro-heat pump; b) photo of MHVR (Pichler Luft) and evaporator (Siko Energiesysteme) c), compressor and condenser (Siko Energiesysteme).

As shown in Fig. 2.a, the ambient air (1) is pre-heated with the defroster (5) if the ambient temperature drops below $-3 \text{ }^\circ\text{C}$ (optionally $-5 \text{ }^\circ\text{C}$). The filter for the ambient air (6) is situated in front of the heat exchanger (16). The ventilator for the supply air (8) is situated after the heat exchanger. The supply air is heated in the condenser (13) of the micro-heat pump. If the

temperature of the supply air after the condenser is too low to cover the heat load a post-heater (15) heats the supply air (3) up to max. 55 °C. The extract air (2) of the room is filtered (7) before the heat exchanger. The ventilator for the exhaust air (9) is installed after the heat exchanger. The compressor of the heat pump is situated in the air flow of the supply air before the condenser (13). The expansion valve (12) reduces the pressure between condenser and evaporator. Hot gas defrost (14) is necessary in case of ice formation in the evaporator (11).

The extract air ducts with their silencers have been integrated to the prefabricated timber wall elements in the factory, and need no further connections on site. The prefabricated unit is designed as a compact system suitable for façade integration and thus minimal space use. The supply air providing heating is designed to penetrate the internal space directly from the unit, to “build” the most direct and simplest route into the dwelling. The integration of heated supply air is to be avoided due to longer routes and heat losses through the fabric around them, see Fig. 3.a and 3.b.

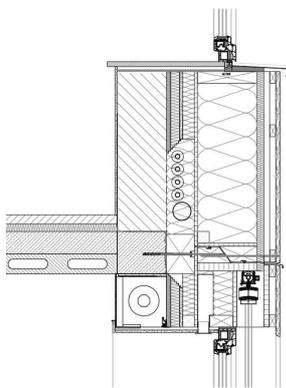


Figure 3.a) Detail showing the position of pipes, ducts and inlets in the layer between the old and the new walls (Source: Gumpp & Maier GmbH)

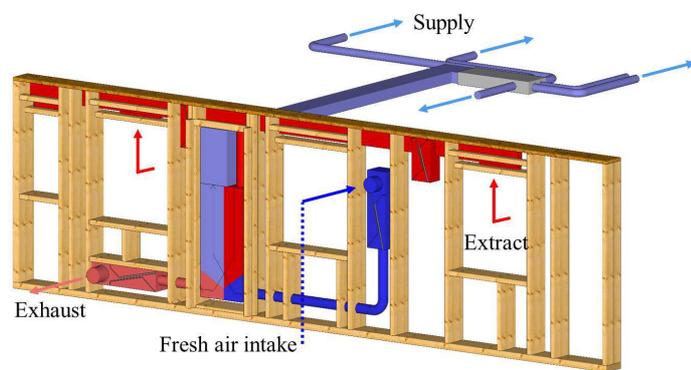


Figure 3.b) Scheme of the components and ducts of KIT 1 (Source: Gumpp & Maier GmbH)

2.2. Kit 2. - Prefabricated distribution shaft with water, sewage, ventilation and electrical pipes.

A vertical distribution shaft is manufactured on site, including all ducts and pipes of the sewage, domestic water and water based heating, and ventilation for the upper floors. All pipes and electric cables are installed on the existing wall before the new envelope is erected, placed on an insulation gap between both layers. The pipes penetrate the existing building fabric on the exact points where they have to be connected. These connections can be carried out independently from the main renovation works. They are usually connected along with a standard internal renovation of kitchens and bathrooms, which are regularly part of a continuous process offered by the housing association.



Figure 4.a) Installation of the water and sewage distribution pipes (Gumpp & Maier GmbH)



Figure 4.b) Cranage of the shaft on site (Gumpp & Maier GmbH)

The prefabricated shaft is designed to rapidly enable the installer on site to connect (plug and play) to the main lines, having solved the challenging connections and fire issues in the factory. The shaft may be seen as a complex box, from where the new distribution system can easily be connected. The box is designed for fire safety, with a high performance insulation to avoid a thermal bridge, and for stability for transport and craning. In this project, satellite modules (from Vaillant) for the preparation of domestic hot water and heating /through heat exchangers) were also installed off site.

2.3 Kit 3. - Integration of an in-roof solar thermal collector:

An in-roof integration of a solar thermal collector (Siko Energiesysteme and Vaillant) has been developed and implemented of a large size collector of 21,1 m² prefabricated in two parts of 2.1 x 5.2 each (overlapping), see Fig. 5a..

The integration of the large solar thermal collector on the roof 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 5.a) Installation of the solar thermal collector (Gumpp & Maier GmbH)

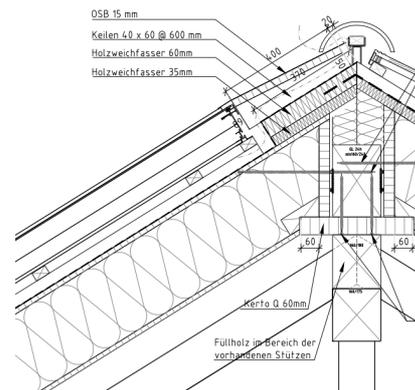


Figure 5.b) In roof integration of the collector (Gumpp & Maier GmbH)

3 DEMO BUILDING AND INSTALLATION PROCESS

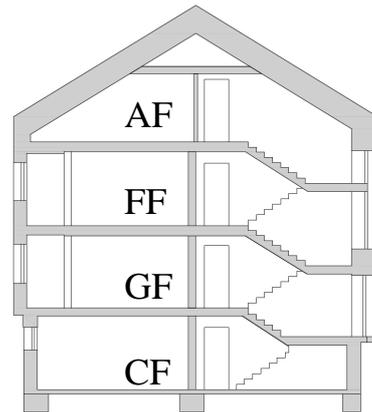
The demo building, a Multi-family house, is located in a town area in the southeast of Ludwigsburg (Wohnungsbau Ludwigsburg GmbH). The 1971 residential building consists of

four flats: Basement floor with living area approx. 40 m²; Ground floor: 1 flat, living area approx. 90 m² (with south loggia); First floor: 1 flat, living area approx. 90 m² (with south loggia); Attic storey: 1 flat, living area approx. 60 m² (with west balcony); The east wall is adjacent to another multi-family house, see Figure 6. In the 80's the façade (including the outside basement wall) was insulated with 5 cm external insulation. The timber roof, the ceiling of the attic storey and the basement floor are not insulated. The heating demand of the existing building is calculated with a calibrated PHPP to about 95 kWh/(m² a) for standard conditions and a treated area of 332.5 m² (and 195 kWh/(m² a) before the first renovation).



6.a)

Figure 11 a) South façade of the existing multi-family house, with adjacent neighbouring building, b) section after the renovation; CF: cellar floor, GF: ground floor, FF: first floor, AF: attic floor, Wohnungsbau Ludwigsburg



6.b)

After renovation with the prefabricated façade elements (see Fig. 7) the heating demand can be decreased to about 30 kWh/(m² a) according to predictions with PHPP. The aim of 25 kWh/(m² a), EnerPHit, could not be reached for some project specific reasons, e.g. because the cellar flat could no insulated towards the ground. However, the calculated heating demand of the ground floor flat, where the micro-heat pump is tested is in the range of 10 kWh/(m² a) to 15 kWh/(m² a). The retrofitting process starts by a tachymetric and constructive survey, carried out during the planning phase of the project. It generates a precise 3D model of the building, with detailed information about the geometry and position of the relevant structural and constructive elements. The unevenness of the façade was measured. The precise composition and structural characteristics of the required elements were assessed with a partially destructive survey.

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 planners (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.

The wall elements were assembled in the factory, including insulated timber cassettes, internal OSB layer and external cladding.

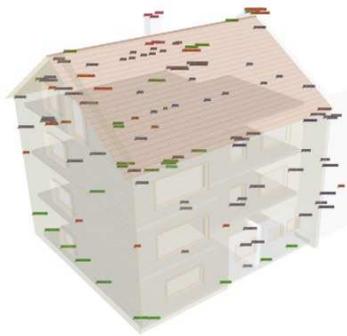


Figure 7.a) Detail section of the shaft
(Source: Gumpp & Maier GmbH)

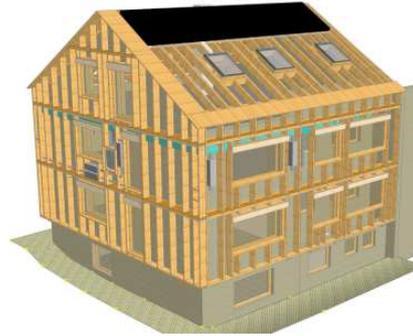


Figure 7.b) Cranage of the shaft on site
(Source: Gumpp & Maier GmbH)



Figure 7.c) Section of the integration of the solar collector, detail below
(Source: Gumpp & Maier)

The micro-heat-pump was delivered plug & play by the manufacturer, and installed in the factory in the opening planned for it. In this system, the MVHR was connected to the micro-heat pump in order to use the energy contained in the 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.

During the prefabrication process, preparation works are carried out on the existing building. 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 for structural anchoring.



Figure 8.a) Steel supports of the timber frame wall



Figure 8.b) Erection of the prefabricated wall elements



Figure 8.c) Timber envelope finished

The structural steel supports were mounted to the concrete structure with chemical glued steel rods. 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. The prefabricated shaft was the first element of the envelope to be installed on site, in order to complete the installation of the pipes before the rest of the envelope. It was transported to site in a horizontal position.

The installation of the pipes on the existing façade was carried out from the scaffold, in the stripes between the structural connectors as shown in figure 8.b. The CAD-CAM model had provided the chance to predict and solve possible collisions between the structural connections to the existing wall and the installation pipes on the façade. Structural timber elements were carefully designed to allow for the necessary intersection points, and incorporated the openings for the necessary perforations from the digital modelling. After the sewage and water systems were tested and commissioned, the gap was insulated, and the wall

elements were mounted between the scaffold and the existing, on the gap with all installations. A similar process was carried out for the roof. Because of its large dimensions, the solar thermal collector was mounted on site, which resulted more cost and time efficient than in the factory. The collectors were prefabricated in two large parts, which allowed installation in one morning. After finishing works on the cladding, and external works, the scaffold was removed, exposing the end result as shown in figure 8.c.

The renovation process on site took a total of 7 weeks from the first demolition tasks to the removal of the scaffold. In future installations installation time is expected to be reduced to 30 days. Two of the four flats remained occupied during the renovation works, showing a good example of resident engagement and cooperation.

5 CONCLUSIONS AND OUTLOOK

A novel approach has been developed and demonstrated within the project iNSPiRe, which offers a deep renovation system for buildings which are achieving their end-of life. The retrofitted building achieves the goal of nearly zero energy, by its primary energy consumption of less than 50 kWh/(m² a) for heating, domestic hot water preparation, lighting and auxiliary energies.

The developed solution and its process proved to have a low impact on the residents, who stayed in the flats during the retrofitting works. These apartments were not connected to the new water and sewage installations, which will be completed when these rooms are renewed. This leaves space for new ideas and improvement.

The complexity of the planning process and site coordination has been again proven to challenge all parties involved. The high effort required from the planners and the contractors caused higher costs on each trade, and remain a threat for the further development of the system.

The airtightness achieved was $n_{50} = 1,5$ 1/h, slightly higher than the original goal of 1,0. The seals between the elements need to be redesigned, as they seem to not work as foreseen.

Three functional models of a so-called micro heat pump were built for testing in so-called PASSYS test cells for the assessment of the thermal performance and for tests in the acoustic test rig at UIBK. Experimental results were used to validate a new coupled physical model for MVHR and heat pump. The physical model is used to create the performance map data required for system simulations. Combined building and HVAC simulations are performed to investigate the energy performance of the micro-HP on building level and to optimize the control strategy. The performance of the system is investigated for different renovation standards (EnerPHit and Passive House) and for seven different European climate conditions. Different control strategies are investigated and a frosting model is used to optimize defrosting control and thus to reduce energy demand.

A functional model is installed in one of the flats of the demo building in Ludwigsburg, Germany. Monitoring started, results are promising. Detailed analysis will be available in the near future.

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