4RinEU

Reliable models for deep renovation

D5.3

WP5

Report on deep renovation packages as tailored and implemented in the demo cases

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Foreword

Despite the low energy performances of the European building stock, the yearly renovation rate and the choice to perform a building deep renovation is strongly affected by uncertainties in terms of costs and benefits in the life cycle.

The project 4RinEU faces these challenges, offering technology solutions and strategies to encourage the existing building stock transformation, fostering the use of renewable energies, and providing reliable business models to support a deep renovation.

4RinEU project minimizes failures in design and implementation, manages different stages of the deep renovation process - from the preliminary audit up to the end-of-life - and provides information on energy, comfort, users' impact, and investment performance.

The 4RinEU deep renovation strategy is based on 3 pillars:

- *technologies* - driven by robustness - to decrease net primary energy use (60 to 70% compared to pre-renovation), allowing a reduction of life cycle costs over 30 years (15% compared to a typical renovation);
- *methodologies* - driven by usability - to support the design and implementation of the technologies, encouraging all stakeholders' involvement and ensuring the reduction of the renovation time;
- *business models* - driven by reliability - to enhance the level of confidence of deep renovation investors, increasing the EU building stock transformation rate.

4RinEU technologies, tools and procedures are expected to generate significant impacts: energy savings, reduction of renovation time, improvement of occupants IEQ conditions, optimization of RES use, acceleration of EU residential building renovation rate. This will bring a revitalization of the EU construction sectors, making renovation easier, quicker and more sustainable.

4RinEU is a project funded by the European Commission under the Horizon 2020 Programme and runs for four years from 2016 to 2021.

The 4RinEU consortium is pleased to present this report which is one of the public deliverables from the project work.

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Disclaimer

Table of contents

Executive Summary

This document aims at describing the execution plans for the deep renovation for the four demo-cases. Starting from the concepts and preliminary design defined in the D5.2, here the implementation of the renovation packages is reported, considering both the detailed design and technical specifications developed during the renovation process.

Figure 1 Norwegian Demo renovated building

Haugerudsenteret 17-19 consists of eight apartments, each with an area of approximately 40 m^2, with an architecture giving the appearance of small, detached houses. Four apartments are connected to each of the two indoor staircases.

The renovation package with added insulation aims at reducing the heat loss through the floor by reducing the wall-floor thermal bridge and through the façade and roof by increased thermal resistance when using prefabricated elements.

A total of 26 façade elements and 10 roof elements were produced off-site and mounted directly outside the existing building.

New energy efficient windows were integrated in the façade, even if the existing windows were not the original ones.

Ventilation supply ducts from the technical room to the bedrooms were installed off site in the north façade elements. The supply air for the living room and the exhaust ducts from the bathroom and kitchen were installed in the stairways using a traditional approach.

The technical rooms with air handling units (AHU) were constructed as a prefabricated module on north façade. Two AHUs and shaft ductwork were installed on site in each room. Each AHU is serving two apartments on the same floor. Access to the technical rooms is from the outside to minimize tenant disturbance and ensure good maintenance. Both the air intake and exhaust are placed in the exterior wall of the prefabricated shaft on the north façade

PV panels were integrated above the windows in the prefabricated elements on the south façade as part of the off-site production of elements. There are in total 16 panels corresponding to an installed peak power of 4.56 kW.

The on-site construction was finished in 8 weeks (40 days). The installation of the elements had a duration of only two weeks, including removal of old windows. Then some on site work was necessary, like for the new entrance areas, ductwork in the stairways as well as supporting electrical work.

Although standard renovation time is hard to estimate since each project is unique, it has been claimed that this renovation provides a really time-efficient project with short preparation time and short time at site.

The project of this demo case has successfully demonstrated how a low-rise timber-based apartment building can be renovated to reduce the energy demand for space heating using prefabricated elements with integrated photovoltaic panel, ventilation ductwork and balanced ventilation with recovery ventilation. The solution is considered as market-acceptable and replicable for deep renovation of existing buildings.

The main success factors are identified as early inclusion of manufacturer, close collaboration on design, transfer of knowledge to construction site, early information and gently handling of tenants, as well as inclusion of participants from different stages of the renovation process in identifying risks and opportunities.

Figure 2 Dutch Demo renovated building

In the Dutch demo building, the 4RinEU renovation approach have been applied on 15 of the 72 dwellings, mainly consisting of mounting prefabricated façades on the exterior side of the existing façades.

The 15 apartments in the South-East wing of Marienheuvel have new prefabricated facades with three additionally integrated technologies: shadings, ventilation with heat recovery (mainly ducts) and summer night ventilation. Mechanical ventilation is provided by the Climarad technology. It allows for air supply and exhaust with heat recovery, by-pass ventilation for summer night ventilation, pre-heating ventilation air in the combination of the radiator and the ventilation device. The Climarad ventilation unit has a specific summer night ventilation mode which activates when needed. This can also be manually done. In addition, a new tilted window has been introduced to have more window operation modes. The ventilation units have been integrated behind existing radiators, while the duct for inlet and exhaust air have been prefabricated through the new envelope.

In this renovation process the tenants' impact has been quite high but during a short period. Probably, this is mainly since standard and deep renovation processes were coexisting at the same time (e.g., scaffolding, kept on the building for 9 months, was used for standard renovation but not strictly necessary for 4RinEU approach)

Furthermore, some issues have been arisen due to the coexisting of both main constructor and prefabricated façade supplier.

In general, this demo renovation provided an increase level of indoor comfort through an improved ventilation system with heat recovery, together with a consistent improvement of the envelope thermal characteristics.

Production of façade elements started in December 2019. The renovation works were supposed to start by March 2020 with a view to be completed by May of the same year. Due to the global emergency caused by COVID-19, the building site had to stop its activities for a few months. Despite this, the production of prefabricated façade modules could go ahead as planned. Overall, the works on the construction site lasted 24 days and ended in July 2020.

Figure 3 Spanish Demo renovated building

In the Spanish demo all the dwellings have been included in the renovation action, although in different degree. Due to financial restrictions, the envelope's increase of insulation is exclusively implemented on the roof and on the East-façade. In the West façade, just some improvements have been carried out –to control ventilation/infiltrations and sun radiation-.

In particular, the 4RinEU solution for renovating the building is the timber prefabricated multifunctional façade, that was applied in the East façade. The solution was implemented just in 1st and 2nd floor due to urban regulations and cost limitations. 10 PMF Panels of 3x6/7m allowed to deep renovate 209m^2 of façade surface.

To complement this action and achieve 60% reduction of primary non-renewable energy demand other conventional retrofitting solutions have been applied in the whole envelope of the building. The actions selected are mainly external solutions, so the tenants could continue using the building while the renovation was taken place.

Other 4RinEU technologies used for this demo case have been the Early-Reno tool – to optimize the PV panels placement also integrated within the timber façade- and the Data Handler -to interact with the tenants after the renovation.

To accomplish regulations, it was necessary to design the ventilation system. For that reason, mechanical ventilation units were installed in all dry rooms - east and west façade - and extractor-fans in the bathrooms. Hence, the PMF openings include in the top part of the balcony, mechanical ventilation units with air filter and heat recovering. Air ducts have been prefabricated in the new envelope as well.

In conclusion, the prefabricated multifunctional façade installation – covering a façade surface of 209m^2- and all the finishing works related to integrated components took around 15 days to be built off-site and were implemented on-site in 35-38 days.

Finally, the PMF panels allowed to strongly reduce the construction time on-site and offered higher standards of energy efficiency and comfort for the tenants.

Figure 4 Italian Demo renovated building

The main technologies developed within 4RinEU and used in Pinerolo concern the installation of equipment developed by the partner company Thermics, which supplied the two main components of the new heating and cooling system: the modulating heat pump and the NRGate Box™ hydronic modules.

In particular, NRGate Box™ <are able to manage the technical water arriving from the heat pump, which is used during the winter for heating and the production of domestic hot water, while for cooling during the summer season.

In addition to the management of the circuits, obtained through pumps, heat exchangers, diverter and mixing valves, NRGate Box™ provides for the metering of the thermal energy sent to each user, to have a direct share of the thermal energy consumed.

The NRGate Box™ solution, associated with the modulating heat pump, is an application that lends itself very well to building renovation works, especially to switch from autonomous heating systems to centralized systems for condominiums. This is because the heat pump and the hydraulic modules were easy to install and the latter were compact in size, requiring no large space for installation.

Significant results will be visible at least one year after installation, when a heating and a cooling season will have passed, but a considerable decrease in the natural gas used by the building's lodgings and recorded in the bill is expected.

Introduction

In this deliverable, for each of the four demo cases, the whole renovation process is described in detail. For each demo a section is dedicated describing the different aspects which led from the design concepts to the tailored solutions.

At the beginning of each of the four sections, the procurement procedure and a brief description of the actors involved in the renovation process are described.

Then, after recalling the design targets, the chosen renovation packages to be applied are described in detail, as well as their integration in the demo building and, if possible, the expected simulation results considering the chosen renovation packages are reported.

Once the main renovation approach is described, a sub-section explaining in detail the execution of the project is reported, also focusing on times and costs of the intervention.

In each section conclusion, lesson learned along the renovation process and possible recommendations are mentioned for each of the four demo cases.

Norwegian Demo Case

Figure 5 Norwegian renovated demo

1.1 Project Management

1.1.1 Project context

Haugerudsenteret 17–19 is part of a housing co-operative project built in the early 1970s. It is situated nearby Haugerud metro station and Haugerud shopping center in the suburb of Alna, located east of the Oslo city center. The project consists of 6 wooden buildings with a total of 130 apartments. The buildings are owned by *Oslo kommune Boligbygg KF,* Oslo municipality's housing company.

Figure 6: Pictures of Haugerudsenteret 17-19 before renovation (left) and after renovation (right)

Haugerudsenteret 17-19 consists of eight apartments, each with an area of approximately 40 m^2, with an architecture giving the appearance of small, detached houses. Four apartments are connected to each of the two indoor staircases.

The tenants may belong to a vulnerable group with special needs and the renovation works should result in as little disturbance as possible. Boligbygg oversees the general maintenance, operation as well as the renovation of the buildings. Technical solutions need to be robust.

1.1.2 Design team

Filter arkitekter has been the responsible applicant (SØK) and designer for Architecture (ARK). Sweco has been a responsible designer for Constructional safety (RIB) and Energy efficiency (RIEn).

As seen in Figure 7, Norconsult, and Firesafe were also a part of the Design team through the framework agreement with Sweco/Filter Arkitekter. Norconsult has been a responsible designer for Ventilation (RIV) and Electricity (RIE) and first entered the design team at the detailed design phase.

Lindal, the element manufacturer, plays a particular role in this project. They were involved already in the design team in the detailed design stage, as well being a contractor for the manufacturing of the elements, transport and installation onsite. The owner and general manager of Lindal have been directly engaged in the project. The fact that the same company was able to both produce and install the elements was a large benefit for production-optimized design, minimizing the risks and transfer the knowledge all the way to the final upgraded building. In practice, many of the key persons were part of the whole process. The design of the BIPV system was done by FUSen, who was a subcontractor for Lindal.

For the site management, HR Prosjekt holds a framework agreement with Boligbygg. Use of site manager is standard procedure at Boligbygg.

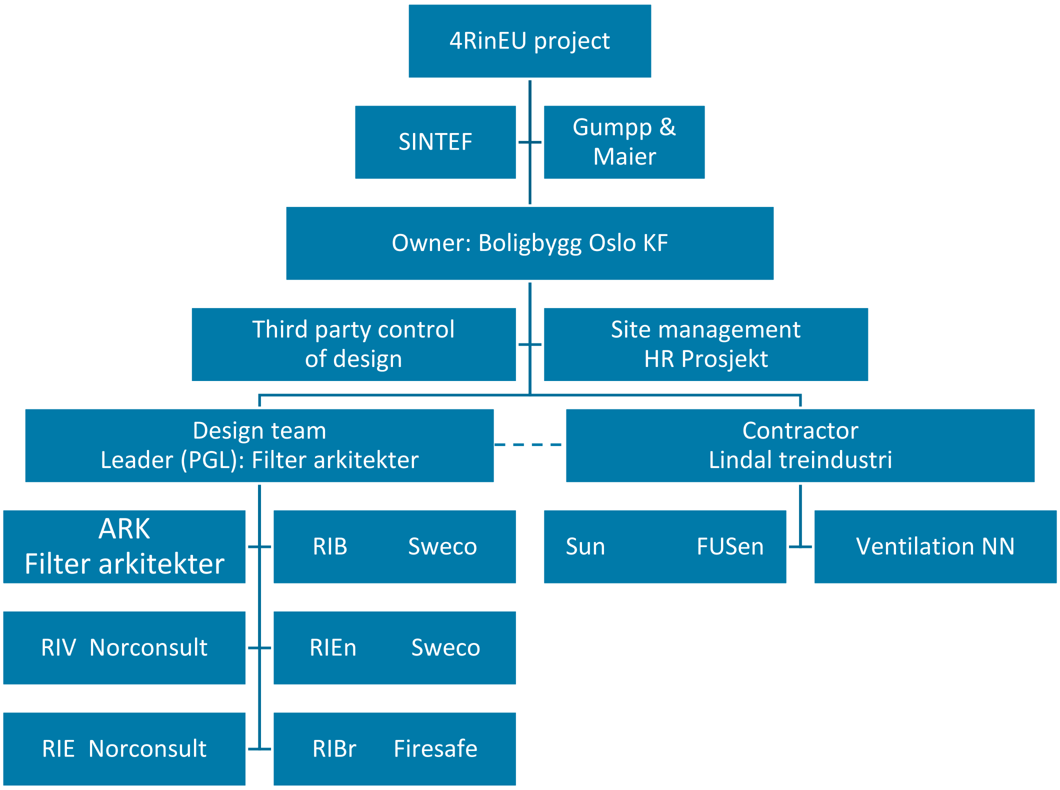


Figure 7 Design team overview. Replicated from D5.2 Concept design and performance targets for the demos.

1.1.3 Main decisions

Major decision points are summarized in the table below. Dates are not set precisely, but the decisions are listed chronologically.

Table 1: Major decision points summarized.

Date	Milestone/decision point	Participants	Conclusions
Pre 2016	Project participation and selection of demo case building.	BBY SINTEF	Participation in 4RinEU project. Selection of demo case building based on building stock, need for renovation and with suitable size. Decision on concept design with prefabricated façade elements with integrated ventilation. Decision on overall energy target of passive house standard for renovated building.
2017-Q1	Type of procurement process	BBY	Decision on competence requirements for design team leader and design team. Decision on using a mini-contest for the selection of design team leader and design team.
2017-Q1	Selection of design team leader and design team	BBY	Selection of team with Sweco and Filter arkitekter. Filter arkitekter gets architect and design team leader, Sweco majority of the Technical design.
2017-Q1	Search for local manufacturer	SINTEF, BBY, Design team	Use external consultants such as 3Con and Byggevareindustrien to find competence requirements and possible names for local manufacturer. Competence requirements for the local manufacturer

2017-Q3	Adjust concept design based on building state analysis	SINTEF BBY Design team	Change in initial concept design due to new knowledge on the state of the building. The prefabricated elements could not be mounted at the existing building because of load bearing problems. Extension of the scope to also include foundations for the façade and roof elements. Adjust overall energy target for passive house standard based on initial energy simulations and constraints regarding the floor of the building.
2017-Q4	Selection of local manufacturer	BBY, SINTEF Design team	Selection of local manufacturer Lindal Smith elements. Start of Technical design stage.
2018-Q1	Design of façade and roof elements	Design team Lindal BBY G&M SINTEF	Decision on element layout. Element technical design. Preparation of BIM for production of elements.
2018-Q2	Production of elements	Lindal	
2018-Q2	Installation	Lindal HR	

1.1.4 Procurement

Design group

Boligbygg as a building owner does not have an in-house department for design or construction site management. However, the organization has a legal department for procurement and useful technical competence for procurement of renovation and construction projects. Boligbygg follows the public procurement process regulated by the «Public Procurement Act» and «Public Procurement Regulations». These laws define the budget threshold values and how the procurement announcement should be made.

Framework agreements, offered as regular public procurements, with different teams of professionals are entered by Boligbygg. When signed, Boligbygg cannot freely contract other companies or teams without providing an exclusive offer to the teams with the framework agreement. If an offer is rejected from all companies/teams within the framework agreement, Boligbygg can freely choose or invite someone else to bid for the contract.

The design team was contracted through Boligbygg's framework agreements. The process was conducted as a mini-competition where the four companies with a framework agreement were invited to bid. Two of these chose to bid for the contract, and both were subject to interviews and evaluations to ensure the right competence. The Architect had the design team leader role.

Local manufacturer

Gumpp & Maier is the timber element manufacturer company in the 4RinEU project team willing to share its competence, however a local forward-leaning element manufacturer had to be found. Moreover, to ensure producibility and avoid technical problems with transportation or installation, SINTEF and Boligbygg wanted to include the manufacturer in the design team.

Before the tender procedure started, a third-party consultant and Gumpp & Maier were used to specify critical requirements in the tender and ensure that the invited manufacturers had the right competence.

Choosing the right tender procedure and contract was not straightforward. Legal expertise at Boligbygg as well as at the national level for procurement rules were consulted. The choice of a local manufacturer was conducted nearly as an innovative tender process. In an innovative tender process, Boligbygg can invite different manufacturers into the tender process and discuss with them during this process.

The contract form was adjusted to suit the project by legal department of Boligbygg, close to an open-book participatory contract model, with a PV specialist producer as a subcontractor.

In Norway, there are many manufacturers of prefabricated elements, however few with a suitable and advanced production line. The search to find an appropriate manufacturer willing and able to take part in the project started early together with the building industry branch organizations, SINTEF's contacts within the element producer industry as well as through the building industry media. In the end, two bidders answered the tender, and Lindal was contracted. Lindal was also offering to use their organization for the installation of the elements and necessary at site work.

1.1.5 Digital design process

The use of Building information modelling (BIM) was decided at a very early stage. Norway is a frontrunner in this field and most large consultants are skilled in the use of this technology. However, this was not a standard requirement by Boligbygg as most of their projects are renovation of smaller buildings.

The BIM process forms a 3D graphical model of the building. This model is often called the BIM model, or as ISO 19650 suggests, the *Project information model* (PIM). The international standard ISO 19650 seek to distinguish between a *project* model used in the design and construction stages and an *asset information model* (AIM) tailored for the operations stage of the building lifecycle.

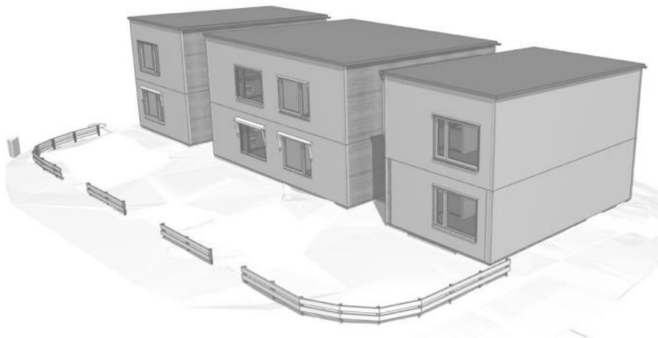


Figure 8: Architect mode of the existing building before renovation, by Filter Arkitekter.

An architect BIM model of the existing building was established by using a combination of laser scans of the building and manual control. The point cloud was transformed to a line model accurate enough to work as digital model for further design. Old paper drawings were not available. In this architect model, the overall design and aesthetics of the new building was formed, as shown in Figure 8.

When the local manufacturer was contracted, the detailed design started in form of workshops especially between architect, RIB and manufacturer. SINTEF was part of design group meetings for important discussions and advice, especially in issues related to connection of old and new construction and the resulting building physics. Skype meetings were held with Gumpp & Maier for knowledge transfer and discussions like fitting details at site or details of importance to ease production of the elements with integrated technology. This process denotes technical design like production and fitting details to avoid extra time-consuming production operations. This includes design of fitting details for integrated ventilation ducts for smooth connection of elements.

Figure 9: Architect model by Filter. South façade left, north façade right

The design BIM was then transferred to Lindal and transformed to a digital production BIM. As seen in Figure 10, the façade and roof were then divided into separate elements suitable for production, transportation and installation. When this design was finished, the BIM objects for the façade and roof elements could be used directly into Lindal's production line where CNC machines automated parts of the production (pre-cut, laser layout of element on a production table etc.). This process also optimizes use of beams and minimize waist. The final assembly of each element, and installation of ventilation ducts, windows and PV panel were done manually.

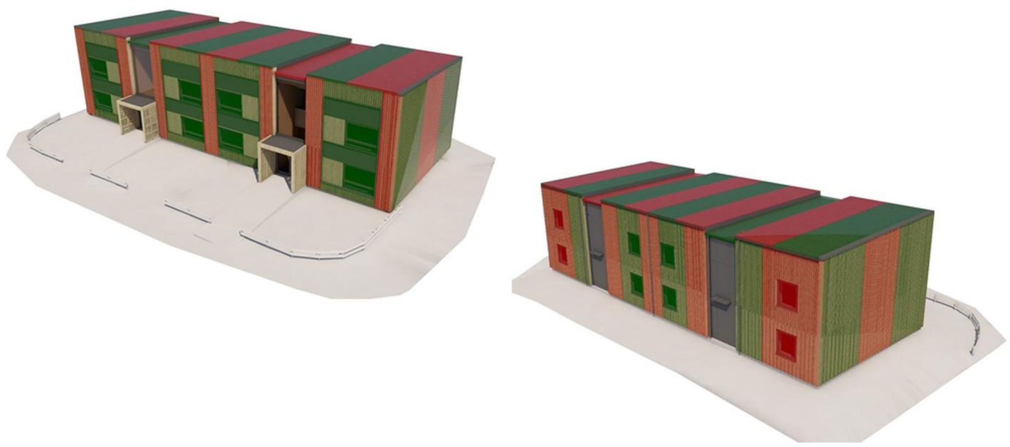


Figure 10: Layout of elements mounted on the building. Each colored element represents one façade element and the corresponding BIM object

1.2 Design

1.2.1 Design targets

1.2.1.1 Energy efficiency

The 4RinEU energy performance target is to reduce the primary energy use with at least 60% compared to pre-renovation levels.

The starting point for the Norwegian case study was a poorly insulated wooden building from 1970'es with slab on ground floor, a small cold attic, natural ventilation and electrical heating and boiler. Façade renovation as well as improved thermal comfort and ventilation were important.

Table 2 Selected design goals for the renovation.

	Before renovation EN ISO 6946/ 113370	NS 3700	Expected value demo	TEK 17 14-3 minimum requirement	TEK 17 14-2 model of measures
U-values (W/m²K)					
-Roof	0.30	0.13A)	0.11	0.18	0.13
-Façades (mean value)	0.36	0.15B)	0.13	0.22	0.18
-Window	1.8	0.8	0.8	1.2	0.8
-Door	2	0,8	1.0C)	1.2	0.8
-floor	1.2 C)	0.15	1.2	0.18	0.1

Equivalent u-value	0,51	0.03 D)	0.43		0.07
Ventilation rate	Unknown	NA	1.2 m^3/h m^2 (E)		
Ventilation heat recovery	-	≥80%	≥80%	≥80%	≥80%
Specific Fan Power (SFP) kW/(m^3/s)	Not relevant	1.5	1.5	1.5	1.5
Air tightness (N_{50}) F)	2.8 h^{-1}	0.6 h^{-1}	1.0 h^{-1}	1.5	0.6

A) 3700 :2010: normative minimum 0,13. 2013: Informative typical values 0,08-0,09

B) 3700 :2010: normative minimum 0,15. 2013: Informative typical values 0,10-0,12

C) Slab on ground floor

D) Can be deviated in deep renovation projects where impossible to fulfil

E) Ventilation requirements cannot be expressed by a single number but given as the general rate for occupied rooms. Designed according to current building codes.

F) Measured before renovation. Expected value after is according to low energy buildings class 1 in NS 3700, as 0,6 is regarded optimistic for the deep renovation concept.

Total net energy demand for new apartment buildings is 95 kWh/m^2 heated area per year according to Norwegian building code requirements (TEK 17). Table 2 gives an overview of minimum requirements and model of measures that can be used to fulfil the energy efficiency demand in dwellings.

For the deep renovation, the primary target was passive house standard in compliance with Norwegian Standard NS 3700. Early in the process, preliminary simulations showed that full passive house standard was impossible to reach. It was then decided to follow the criteria in passive house standard as far as possible. This was within reach for the ventilation system and building elements except the slab-on-ground floor.

The ground floor was uninsulated, and no further insulation could be introduced without large indoor interventions and/or reduction of ceiling height. An intervention like this would not comply with the requirements of Boligbygg to minimize impact on tenants. The expected wall mean value is suffering from the Siporex in first floor.

Also, the compactness of the building was a problem. Adding an extra floor was discussed but not possible because of height limitations. The building was made more compact and the slab on the ground floor perimeter was decreased by adding the technical room and expanding the entrance area and including it in the heated area.

The expected values after renovation are given in Table 2. For more details, see Deliverable 5.2. *Concept design and performance targets for the demos*.

1.2.1.2 Indoor climate

Increased airtightness, improved insulation, and balanced ventilation with high heat recovery are all measures that will improve thermal comfort and indoor climate. A common problem in old buildings with natural or exhaust ventilation is a cold draft from inlet ventilation openings and air leakages, especially in winter. Air inlets are often closed as a countermeasure, resulting in new problems with bad air quality and condense.

Thermal bridges and transmission loss in façade can also cause temperature gradients within the room as well as asymmetric temperatures.

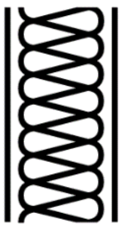
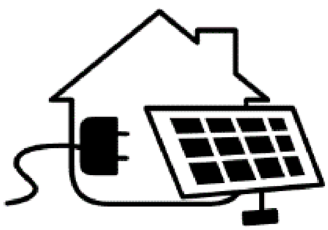
Installing façade elements for improved insulation and balanced ventilation will solve these problems if done correctly. The solution improves both energy efficiency and indoor climate through increased supply air flow rate and high heat recovery. Successful use of balanced ventilation involves correct balancing of the system to avoid draft and noise problems and finetuning the correct setpoints for stable and preferred temperature.

The Norwegian requirements for ventilation rates can be challenging for small apartments. Rates for extract ventilation from bathrooms and kitchen are independent of apartment size, resulting in high air change rates for small volumes. This is a known problem without a proper solution, and precautions must be taken in the commissioning phase.

1.2.2 Relevant innovative technology packages

The renovation of the Norwegian demo case was implemented using 4RinEu renovation package with Insulation, ventilation and RES production (photovoltaic), as shown in table 3.

Table 3: Use of technologies in Haugerudsenteret 17-19

Package	Description
Insulation 	The main contribution to increased energy efficiency and the fulfilment of design targets was use of prefabricated walls and roof elements, including new windows. This measure will improve airtightness and reduce heat loss. The only indoor work associated with implementing this technology package was the removal of the old windows and fulfilling the lining around the new windows and existing window openings.
Ventilation 	The installation of balanced ventilation system was the main contribution to the design targets for improved indoor climate and an essential contribution to energy savings. Draft risk significantly reduced and proper ventilation rates secured. When upgrading to a balanced system, the space for supply air ducts and air handling unit was missing. The use of new elements allows for space for supply ducts, even pre-installed. A prefabricated technical room or shaft formed as a building module was planned on the backside of the building and connected to façade and roof elements. The technical room allowed space for air handling units, ducts as well as RES technical equipment (inverter etc.)
RES production (PV) 	Installation of photovoltaic (PV) panels for RES production was in accordance with the environmental profile of the owner. Photovoltaic panels were preferred to solar thermal panels since the existing heating system was purely electric.

	PV panels were integrated in south façade elements, not optimized for maximum production or maximum export to grid etc. Boligbygg is not allowed to sell electric power to the tenants, and therefore the produced electricity can only supply heating and technical equipment in common areas.

1.2.3 Early-stage investigations

Early-stage investigations are important to reveal problems for the design and implementation stage, and could lower the risk for build in problems, damages and extra costs in the operation phase.

Limitations and serious barriers for the renovations can be revealed. At an early design stage, measures can be taken or change of concept can be done with limited extra costs. This is an important key to successful risk management.

1.2.3.1 Building condition assessment

During the concept design stage, a building condition assessment was carried out in August 2017. A thorough assessment of the renovation object is necessary to obtain knowledge of the building's condition and the possibilities for renovation. The photos below show the construction and insulation when the façade was opened to analyse existing condition and load bearing capacity.


Figure 11: The façade was opened, and the state of the load-bearing constructions was analysed. The aerated concrete bricks are clearly visible. The outer wall does not seem to have major damages or faults. The state analysis shows that the construction is in good shape, with no sign of moisture damages.

The main conclusion from the inspection was that the state of the building was overall good. There was no sign of moisture damages, and the outer wall did not have any major damages or flaws. The state of the cladding was such that the cladding did not have to be removed. Minor faults were locally repaired or removed. The existing cladding was kept and built into the renovated outer wall.

1.2.3.2 Load bearing capacity

The initial plan was to use anchored prefabricated elements. When opening the construction, the assumed timber construction was only applied in the upper part of the construction, while ground floor construction was made by Siporex. This expanded concrete has low load-bearing capacity.

As with most brickwork, loads are led vertically down through the wall, and the tensile properties are far inferior to the compressional. Expanded concrete bricks are very brittle and require special measures to withstand even small loads hung onto the façade. Thus, it was decided that there was a need to construct a new foundation around the building, similar to the existing foundation. The new foundation would carry the loads of the façade and roof elements.

1.2.3.3 Hazardus materials

Mapping of hazardous materials at an early stage is important to reduce process risk. Finding of such materials often lead to stop in renovation work and extra costs. No hazardous materials were obtained in the early investigation, but some asbestos was determined in one apartment during the renovation.

1.2.4 Description of the chosen solutions

The revival the low load bearing capacity was a setback. The design changed from use of anchored elements to elements mounted on foundations. This decision also influenced the original planned at site renovation of the roof to use of roof elements. The new constructions fulfil requirements to snow loads as for new buildings.

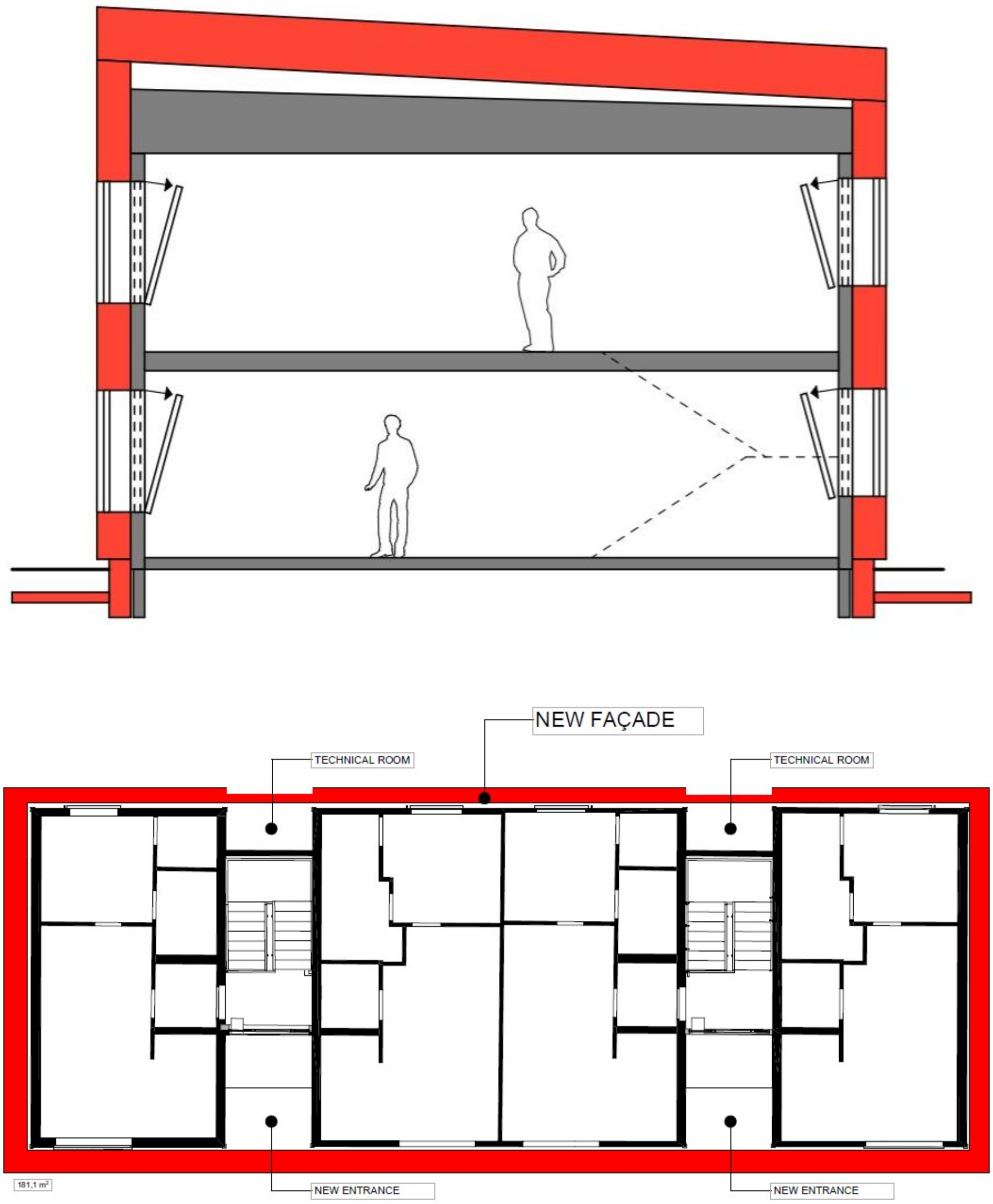


Figure 12: New elements around the existing building as. Illustrated by Filter Arkitekter

1.2.4.1 Foundation for façade and roof elements

The new foundation was constructed from prefabricated Styrofoam casting moulds produced by Vartdal Plast AS, as shown in Figure 13 below. The casting moulds are put together on-site before steel reinforcement is added and concrete is poured into the mould. The moulds are not removed but act as insulation for the foundation, thereby reducing the thermal bridge of the wall-floor junction.

The expected result after renovation is better-insulated edges of the floor, reduced thermal bridge and lowered the equivalent U-value of the floor.

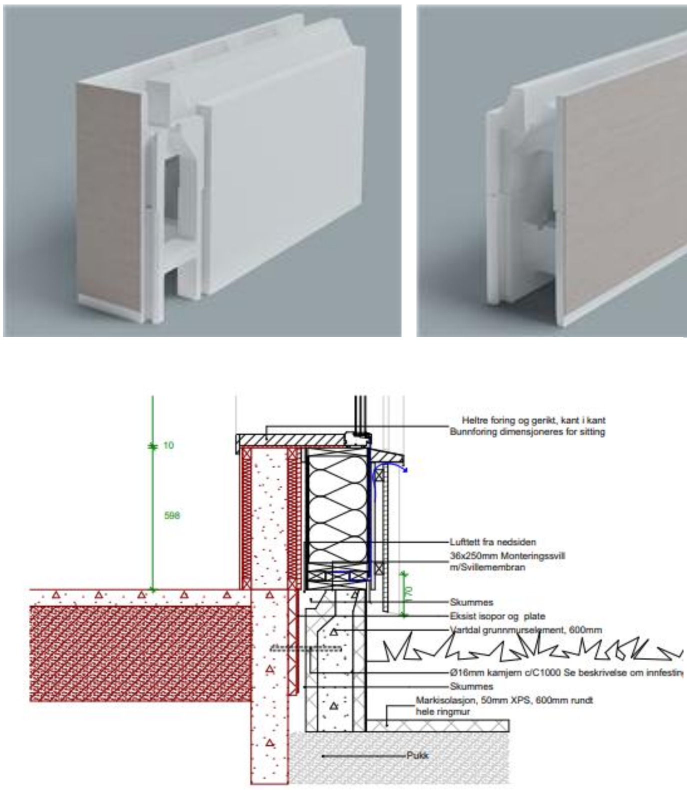


Figure 13. Vartdal Plast's prefabricated foundation element. Above: The images show the casting molds alone, and below an example of the foundation as used in a single-family house.

1.2.4.2 Added insulation in façade and roof

The renovation package for added insulation would influence the heat loss through the floor by reducing the wall-floor thermal bridge and through the façade and roof by increased thermal resistance when using prefabricated elements.

Figure 14 shows cross-section of the building with the elements are mounted directly outside the existing building. A total of 26 façade elements and 10 roof elements were produced off-site.

The materials used for the roof and façade elements are shown in Table 4. For the roof elements, the added insulation is 450 mm, a factor of four increase from the original insulation thickness of 150 mm. It is expected that the average U-value is reduced from 0.30 W/m²K before renovation to 0.11 W/m²K after renovation.

For the façade elements, the added insulation is 198 mm. This more than doubled the original wall thickness of 70–100 mm and the average U-value is expected to be reduced from 0.36 W/m²K before renovation to 0.13 W/m²K after renovation (0,12 for standard wall, 0,14 for siporex wall).

Table 4 Overview of the materials and corresponding properties used in the roof and façade elements

Layer	Material	Properties
Roof	Protan	
	OSB board (wood)	18 mm
	Tyvek Windbarrier	
	Asphalt sheet	19 mm
	Insulation rockwool	450 mm
	OSB board + wind barrier	9 mm
	Masonite HB500 I-beams	
	Etafoam	
Wall/façade	Insulation Rockwool	198 mm
	OSB board (wood)	9 mm
	Gypsum board	9 mm
	Tyvek Windbarrier	
	Bedroom windows: NorDan NTech	Triple-glazed, U= 0.78
	Livingroom windows	Triple-glazed, U= 0.81

Nothing was done to the existing construction regarding airtightness, as the new element include the airtight layer. Joints of elements, and at ground level against fundaments and existing construction was also in focus.

The new façade elements are made of a solid wood exterior cladding based on slow-grown thermo-treated pine (heat treatment to improve timber stability). In the elements, both the OSB board on the inner surface and the outside wind barrier provide airtight layers within the building envelope. All joints between boards in each element were taped. Joints between elements had a strip of wind barrier membrane for completion on site. The requirement for airtightness is imposed on the building as a whole and not each apartment.

New energy efficient windows were integrated in the façade, even if the existing windows were not the original ones. Replacement of windows is considered a cost-effective measure to improve energy efficiency. U value windows are given as a total of glass and frame. Windows in bedrooms and living room are energy efficient standard produced windows integrated in new façade elements, while the windows in new entrance area are built in a façade system.

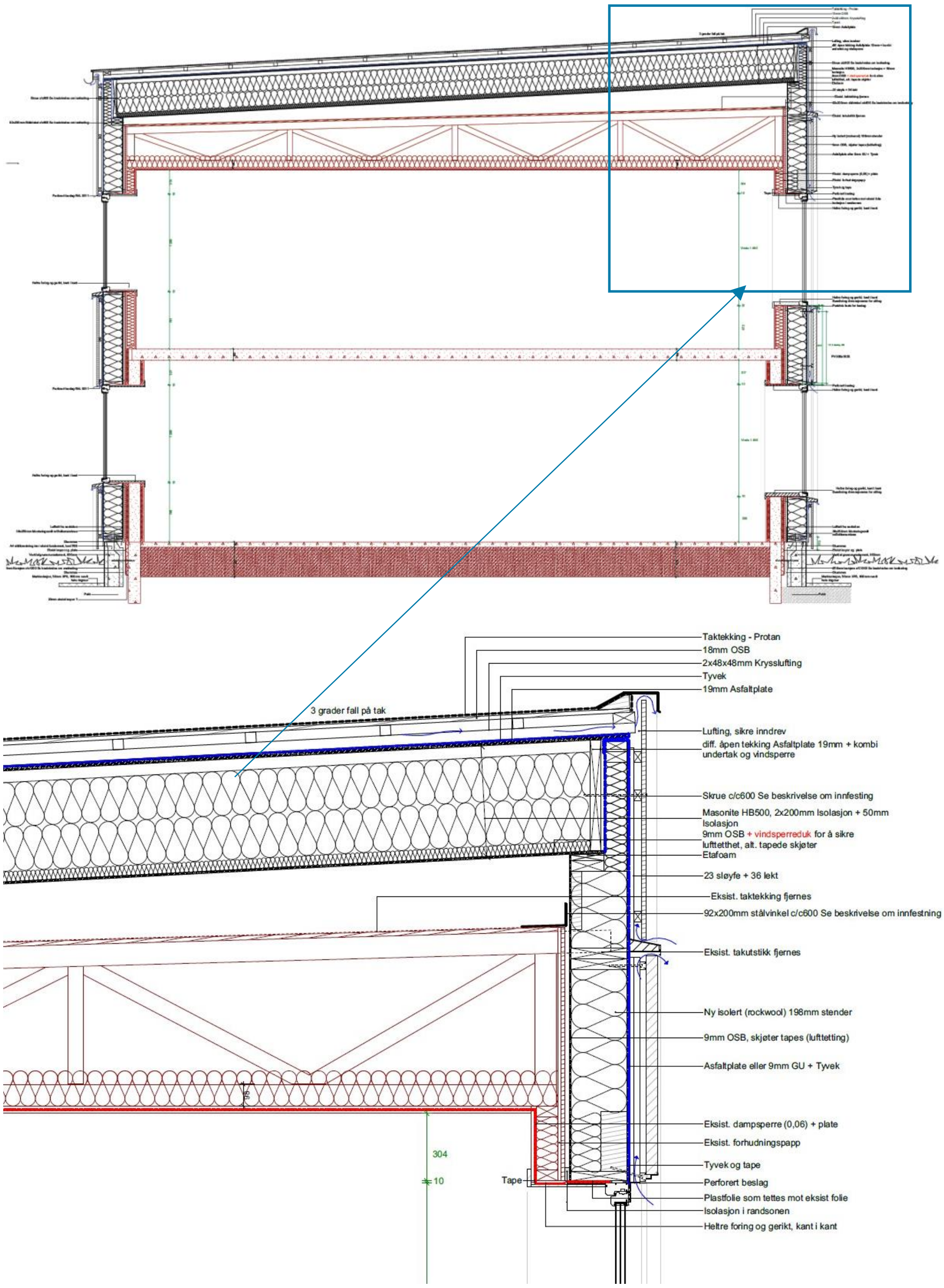


Figure 14 Upper: Vertical cross-section of the renovated building showing the façade and roof elements (black) mounted on the outside of the existing building (red). Lower: section enlarged.

1.2.4.3 Balanced ventilation

The demo building had natural ventilation through vents and windows, which often gave draft problems in the winter. The new building envelope would improve airtightness and reduce the infiltration. Thereby an already low ventilation rate is decreased if no measures are taken. A deep renovation in the Nordic climate will typically require an upgrade to balanced ventilation, both concerning energy use and indoor air quality.

Ventilation supply ducts from the technical room to the bedrooms were installed off site in the north façade elements as seen in Figure 15 and Figure 16. The supply air for the living room and the exhaust ducts from the bathroom and kitchen were installed in the stairways using a traditional approach.

The technical rooms with air handling units (AHU) were constructed as a prefabricated module on north façade. Two AHUs and shaft ductwork were installed on site in each room. Each AHU is serving two apartments on the same floor. Access to the technical rooms is from the outside to minimize tenant disturbance and ensure good maintenance. Both the air intake and exhaust are placed in the exterior wall of the prefabricated shaft on the north façade

Special focus was given to designing of the joints from the integrated ducts and the technical room, see section 1.3 for at site pictures.

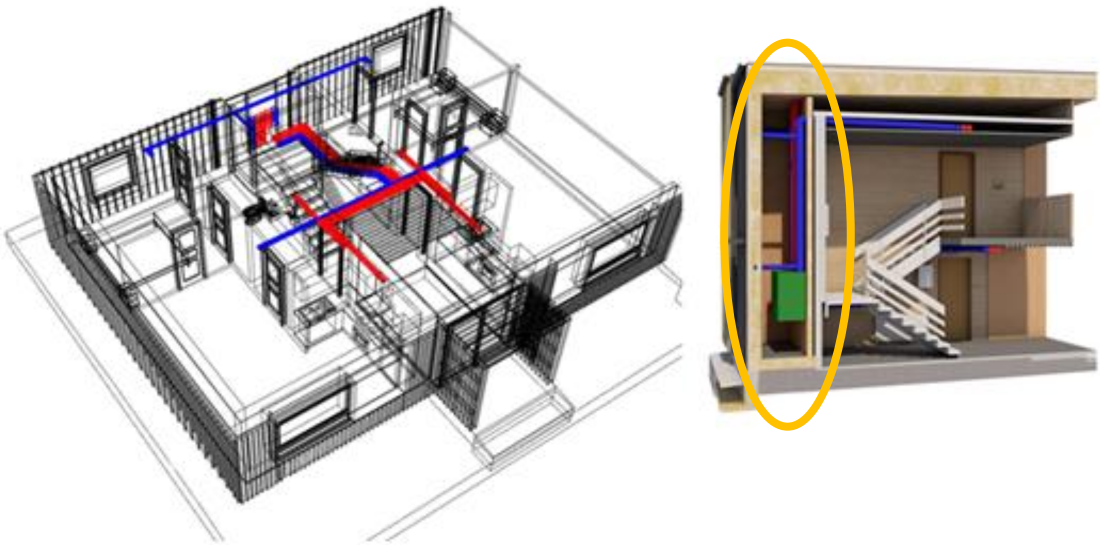


Figure 15: The new integrated ventilation system. Blue lines indicate supply air ducts, red exhaust ducts. The yellow circle shows the technical room/shaft.

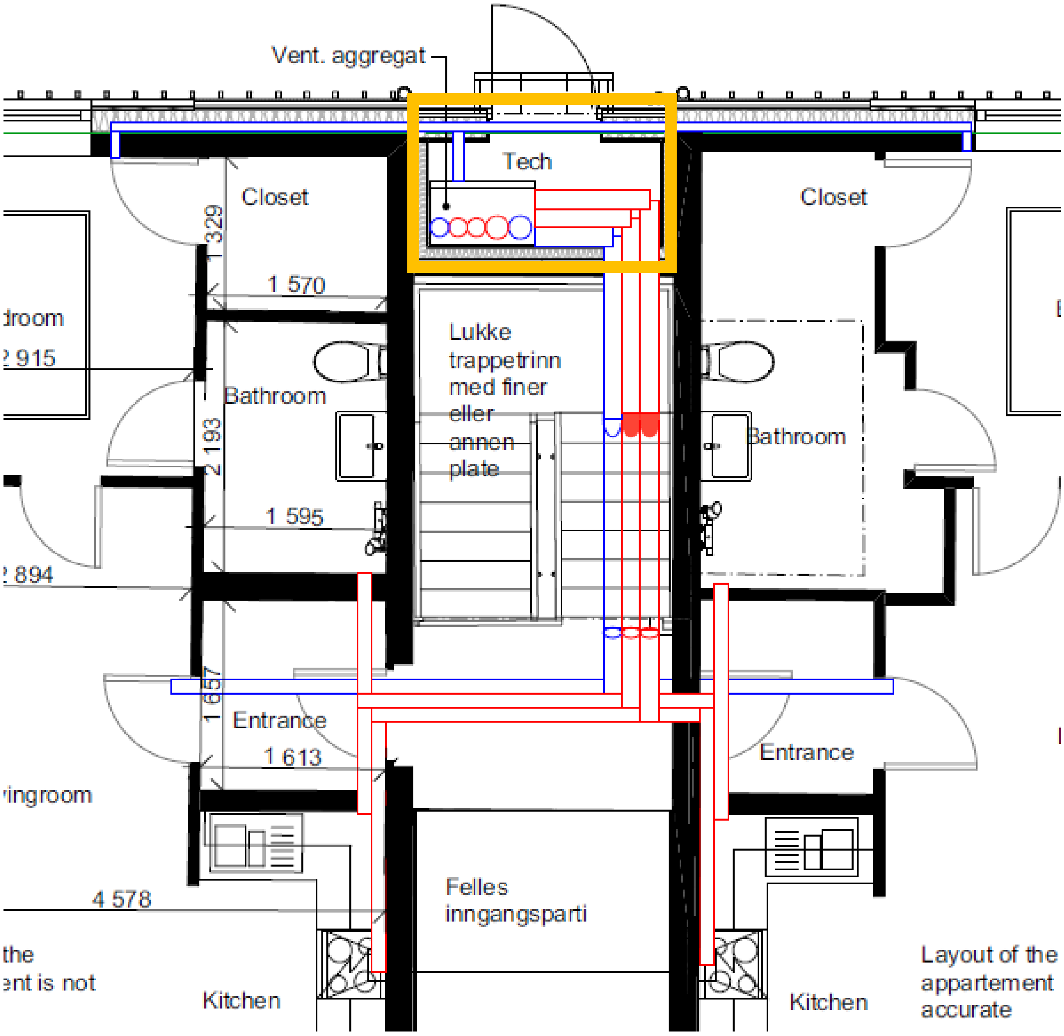


Figure 16: Layout of ventilation ducts in one stairway area. Blue lines indicate supply air ducts, red exhaust ducts. The prefabricated technical room/shaft is marked by the yellow rectangle. Two air handling units are placed here, each serving two apartments on the same floor. In the drawing marked as one, at site placed one at each side.

Figure 17 Air Handling Unit (AHU) Flexit Uni 3

The air handling unit includes standard filters, supply- and exhaust air fans, see Figure 17. Rotary heat wheel and electrical heating element ensure stable inlet temperature (19 °C). No cooling installed, which is the common solution for new apartments in Norway.

The ventilation rate is controlled by a frequency transformer. The Flexit unit 2 have a highly efficient heat recovery (up to 85%) and SFP 1.5 kW/(m^3/s), which meets the requirements for passive house dwellings, according to Norwegian Standard NS 3700/2013.

1.2.4.4 PV panels and RES production

PV panels were integrated above the windows in the prefabricated elements on the south façade as part of the off-site production of elements. There are in total 16 panels, each 1.7x1.0 m2, and total 27.2 m2. The installed power is 4.56 kWp, and the panels are said to have a nominal efficiency of 19.5 % Integration in wall elements require safety glass in the PV panels to prevent accident in public places.

As shown in Figure 18, the PV panels are attached to the battens on the façade elements, with a fully weather-safe cladding behind the panel. Both the panel and the cladding are ventilated. From the start, it was recognized that the expected lifespan of the PV panels is longer than the expected lifespan of the façade. Considering integrating circular economy in this project, the panels are installed in a way that make them easy to dismantle and re-use in another building. This solution also allows for postponing the installation of PV if the renovation budget had been limited.

The prefabricated technical rooms allow space for inverters. The inverters are from Fronius, model Galvo 2.0-1. Two inverters were installed. The electricity and infrastructure needed for the panels to perform were installed on site.

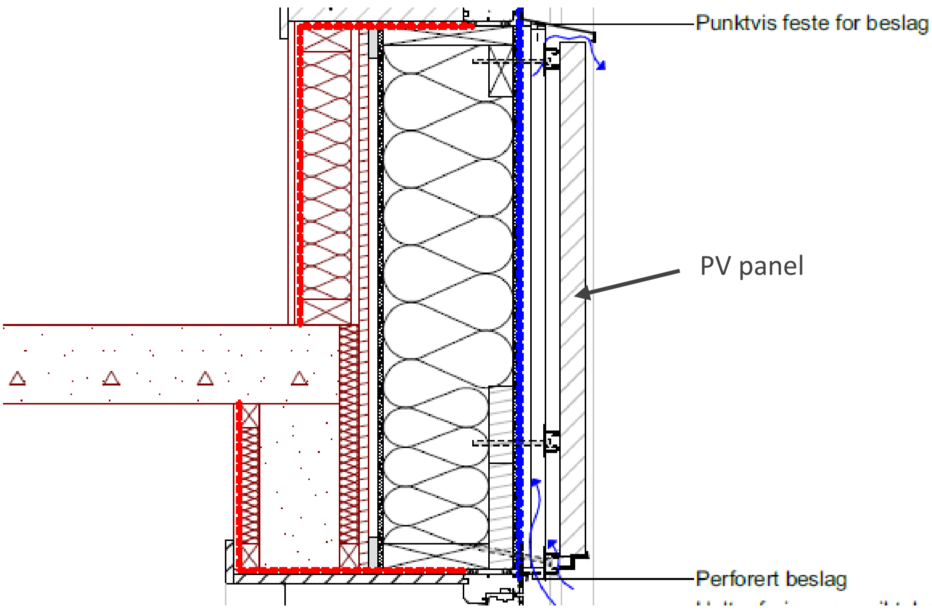


Figure 18: Mounting of PV panel in the elements. The drawing shows the panel between the first and second-floor windows. The panel is mounted on brackets with a fully weather-safe cladding behind the panel. Both the panel and the cladding are ventilated, as the two blue arrows indicate

1.2.5 Energy efficiency assessment of retrofitted building before implementation

1.2.5.1 General assumptions of the energy model

Energy simulations to assess building performance before and after renovation was performed and explained in detail in D5.2 subsection 2.6. A short summary is provided in this chapter.

Due to the constraints of the building performance calculation (BPC) tool, the building was divided into two zones, the first-floor and second-floor. Two different modelling approaches were used; 1) standard model: values from *NS 3031:2014 - Calculation of buildings' energy performance - Method and data*, and 2) calibrated model approach with realistic indoor temperatures according to expected use.

The airtightness was thus simulated with 2.80 h^{-1} and 0.60 h^{-1} (passive house *NS 3700:2013* standard value) for before and after renovation, respectively. The expected after value changed to a more realistic value of 1 h^{-1} during the process, but was not implemented in the simulations.

As the calibrated model in the simulation more fitted to the actual use of the building, the internal losses in the building were set to 45 % for the DHW. The standard value in *NS 3031:2014* is 29.8 kWh/m^2 and corresponds to the net energy demand, while the 54.2 kWh/m^2 corresponds to the delivered energy for the DHW. It is to be noted that the value for delivered energy takes into consideration circulation losses, while the apartments have electric boiler installed under the sink without circulation.

The minimum requirement for ventilation according to *NS 3031:2014* is in general 1.2 m^3/h m^2, while ventilation rate for small apartments has be calculated according to a formula that corresponds to the exhaust demand that will be the dominant requirement for this size of dwellings. The ventilation rate used in the simulations was calculated based on the dimensioned exhaust rate of 2.38 m^3/h m^2.

Furthermore, the heating setpoint (electrical radiators) according to *NS 3031:2014* is set to 21/19°C, 16/8 h while for the calibrated model is set to 23°C, 24 h according to expected use. This is up to 4 °C higher than in the standard model.

1.2.5.2 Results of the simulations

Figure 19 summarizes the achievements for delivered energy for the standard and calibrated model. More detailed can be found in D5.2 section 2.6.

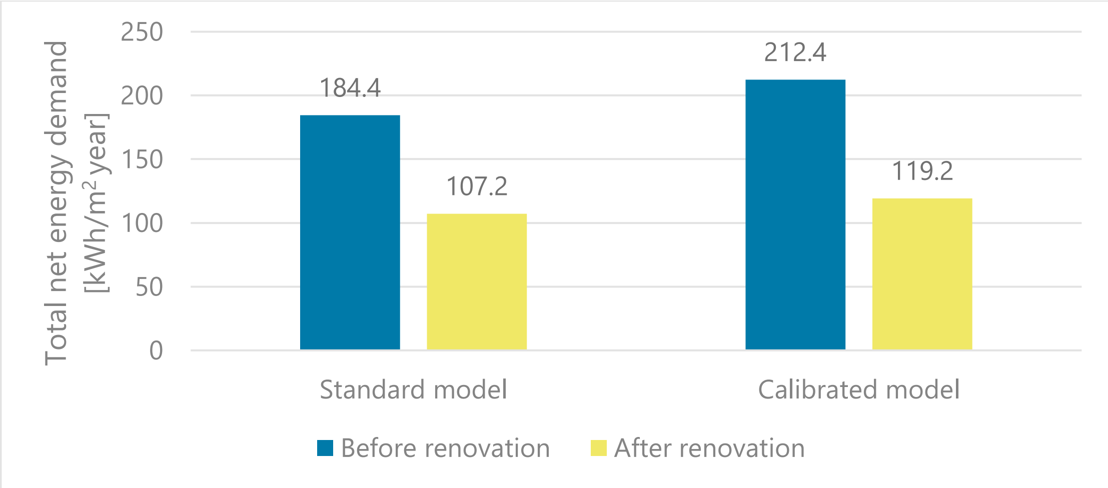


Figure 19: Total net energy demand before- and after renovation

Table 5 gives an overview of the results of the energy simulations before and after the foreseen deep renovation for the standard model and the calibrated model.

Table 5 Overview of energy simulations before and after deep renovation

	Before renovation [kWh/m² y]	After renovation [kWh/m² y]	Difference before vs after [%]
Standard model [1)]			
Tot. net energy demand	184.4	107.2	-42
Tot. delivered energy	185	107.8	
Calibrated model [2)]			
Tot. net energy demand	212.4	119.2	-44
Tot. delivered energy [3)]	236.8	136.3 / 143.8	-42/39
Baseline total delivered energy used	247		
Expected PV production	-	7.5	
Tot. net energy demand standard model, PV self consumption	-	99.7	46

1) 21/19 °C, 16/8 h, $\eta_{tot, DHW}$ =0.98
2) 23 °C, 24 h, $\eta_{tot, DHW}$ =0.55
3) With and without PV production

The renovation effects achieved 42 % lower energy demand with the standard model and 44 % with the calibrated model.

The deep renovations' practical delivered energy target of 60 % energy use was calculated to 60.3 kWh/m² without PV production and 53.2 kWh/m² with PV production with the use of the calibrated model. This target is calculated based on the reduction in space heating, and was determined at the beginning of the project period. More information about the practical delivered energy target can be found in D5.2, Section 2.6.8.

According to the energy target of the deep renovation of 60 %, the simulation showed an achieved 60.6 % reduction in energy use (calibrated model) with a margin of 0.6 % without PV production. With the PV production, the margin is 7.1 %. More information about the results can be found in D5.2, Section 2.6.8.

However, a few uncertainties need to be addressed from the simulations, which may have affected the results. The standard simulation model has used input data from *NS 3031:2014* for technical equipment, lights, and DHW. However, the losses in the DHW system can be discussed. The net energy demand calculations are calculated with a 2 % loss (standard model), while the delivered energy calculations are calculated with 45 % loss (calibrated model). An ongoing research project, VarmtVann2030 (https://www.sintef.no/projectweb/varmtvann/), investigates the actual use of DHW in different type of buildings and accurate internal loss in the DHW systems. From the results so far, it is indicated that the existing values are high.

Likewise ventilation rates for apartment buildings, especially for smaller apartments are up for discussions in another ongoing research project, Urban Ventilation (https://www.sintef.no/projectweb/healthy-energy-efficient-urban-home-ventilation/). Small apartments like those at Haugerudsenteret will have a higher air change rate than usual, which could result in low RH during wintertime as well as increased energy use per m^2. For the calibrated model, we have the uncertainty that many people in Norway sleep with the bedroom window open even in wintertime, but this is very individual dependent.

The heating setpoint (electrical radiators) is also up for discussion since this is a generalization based on conversations with the occupants and inspections in the apartments before renovation, not based on a predefined and unchangeable setpoint.

1.2.5.3 Energy labeling according to simulations

According to NS 3031, dynamic energy calculations are required. In addition, energy labeling of Haugerudsenteret 17-19 has been performed. The Norwegian system at the time differed from the standard European approach. The building energy state is based on one *energy grade* and one *heating grade*. The energy grade A – G is based on the delivered energy. Table 6 gives an overview of delivered energy demands to achieve different energy grades for apartment buildings in Norwegian context.

Table 6 Energy grades for apartment buildings according to Norwegian Energy Label system

Label	A	B	C	D	E	F	G
kWh/m²	85	95	110	135	160	200	>F

Energy labelling is according to calculated delivered energy based on normalized use according to NS 3031:2014 and should reflect the energy standard of the building, not the use. For Haugerudsenteret 17-19 this corresponds to the calculated values for <u>standard</u> model in Table 5. The 185 kWh/m^2 before deep renovation classifies for energy label F, and the 99.5 kWh/m^2 after for an energy label C. Early simulations were performed with the ventilation rate of 1.2 m^3/h m^2 which led to 94 kWh/m^2, resulting in energy label B which was previously reported in other presentations of the demo.

The *heating grade* is based on a five-coloured grade system from red to green and indicates the amount of fossil fuel and directly electricity used by the heating system, se Table 7. The colour of the label is thus depending on the heating grade. For the Norwegian demo, the label is red both before and after renovation, as the PV production is relatively low and there is no heat pump installed.

Table 7 Heating grade according to Norwegian Energy Label system

Oppvarmingskarakter				
▼				
30,0 %	47,5 %	65,0 %	82,5 %	100,0 %

1.3 Implementation of the renovation

1.3.1 Off-site production of façade and roof elements

Lindal Smith Elementer produced the façade and roof elements in their modern production line at Akland in southern Norway. The elements were produced during a period of eight weeks in March and April 2018.

Most of the production went according to plan. The objects from the BIM model of the building were fed directly into Lindal's production control system.

Lindal's factory has automated computer-controlled cutter machines (CNC machines) for pre-cut of studs, beams etc. The assembly of studs, sills, and beams in the elements are done manually using a laser-guided system on a production table, se Figure 21. The elements are insulated, and other layers and exterior cladding added. A wrong delivery of parts of the cladding and too long re-ordering time led to on-site mounting of cladding on some north façade elements as seen in Figure 34.

Figure 20: Lindal's CNC saw for precutting of studs and beams

In this project, the PV panels needed extra attention. The PV panels were installed on mounting brackets without breaking the wind barrier layer and ventilation behind the panels. The PV-panels thus function as an exterior cladding that can also be replaced without significant interventions. The PV panels had to be covered during transportation to prohibit the generated power from being of any potential risk to workers.

Standard ductwork was integrated in the north façade elements without problems.

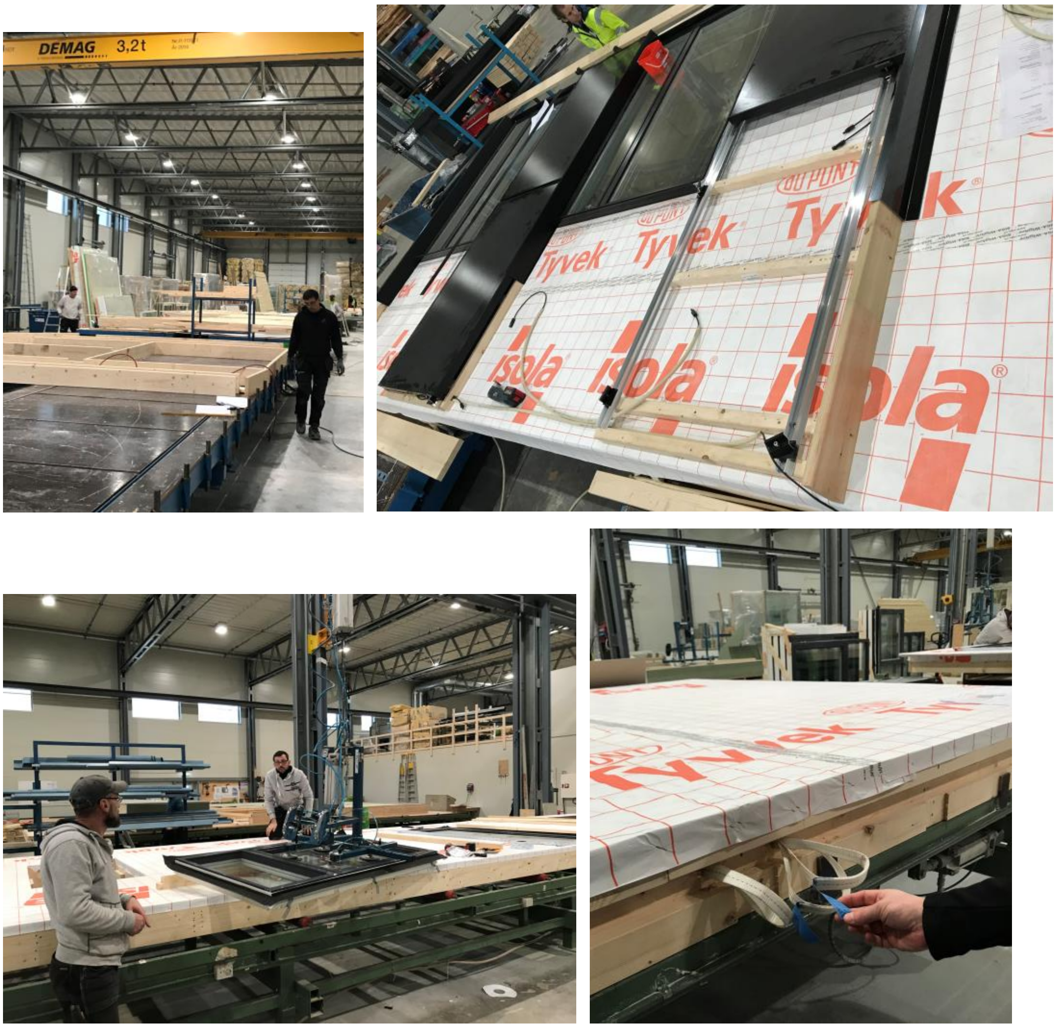


Figure 21: Laser guided production table. Battens and mounting brackets for PV panels are mounted outside the wind barrier (Tyvek). Handles for craning are implemented during production.

1.3.2 Transportation

The transportation from element producer was aligned with current roads and narrow site. Norway has high quality Europeans standard roads, but some roads are narrower and curvier, and there are a lot of tunnels. The total distance from the of site production at Akland to the construction site in Oslo is approximately 230 km, with a transportation time just below 3 hours. Lindal uses standard solution pallets for trucks as shown in Figure 22. An often use size is 2.5m x 10 m, and the truck normally allows a height of 2.5 m. Elements are in general produced to fit to this size and are placed on these pallets when finalized. Special precautions were made for the PV panels since these were already mounted at the elements. Handles for craning are as standard implemented in the elements during production.


Figure 22: Elements placed on pallets, ready to be loaded on trucks.

Trucks can drive through the production area and loaded. Elements were transported to the site just in time. The construction site is narrow, with a challenging last curve before entering the very site, and short distance to neighbouring buildings. Trucks and crane were carefully chosen for the task and no problems occurred.


Figure 23: Narrow access from back side. Challenging curves to enter front side

Figure 24: Narrow site and short distance to neighboring buildings

1.3.3 On-site construction and assembly

1.3.3.1 Site preparations – dismantling of obstacles

Figure 25: Haugerudsenteret 17-19 during renovation June 2018. Half of the building was renovated at a time. The upper picture right side show existing building with dismantled protruding parts of roof and windows.

The construction site was rigged during week 23 of 2018. Existing entrances were dismantled. Groundwork for foundations was prepared around the building. At the same time, any object penetrating or mounted on the building envelope, such as electric cables, water pipes for outdoor faucets, ventilation opening and grilles etc., had to be removed to prepare for the mounting of new façade elements.

The same applied to protruding parts of the roof. To avoid water leakages, only one part of the building was prepared at the time.

1.3.3.2 Construction of foundation

The Styrofoam moulds for the foundation were set up around the building (see figure below) and then filled with concrete. Depending on where to build in Norway, it is common to use horizontal ground insulation outside the foundation to prevent the ground from freezing and causing damages due to expansion of the ground.

Figure 26: Foundation molds before casting (left) and after filling of concrete (right)

1.3.3.3 Mounting of elements

Cranes were used to install the façade and roof elements during two weeks' time. One-half of the building (with four apartments connected to the same staircase) was renovated at a time. Old fittings between wall and roof were removed, and new elements mounted. When the façade elements were in place, they were rigidly attached to the building with steel brackets When installing an element, old windows were removed from the inside before nightfall. This to maintain fire escape routes for the tenants. When the façade elements on both sides of the building were in place, the roof elements were mounted on top. The technical room was constructed as a separate module and attached to the adjacent elements. Then elements for the other half of the building were installed in the same manner. The pictures below show the progress.

The existing roof was covered with tarp to prevent water leakages through the existing perforated roofing during the operations. However, one such leakage occurred in one apartment during a night as heavy wind and rain resulted in a torn tarp.

Figure 27: installation of south façade elements with PV

Figure 28: Safe craning and careful securement of element, right on spot without tolerance problems

Figure 29: Important details: Airtight connection to other elements and foundation

Figure 30: Details – securing of wall element and wall element mounting on new foundation

Figure 31: Mounting of the roof construction. Photo: Boligbygg

1.3.3.4 Dismantling of existing windows and indoor completion

When the facade element with new windows had been installed, the old windows needed to be dismounted and removed from the inside. The window bay was then covered with window casement boards and casing. The amount of work inside each apartment related to the replacement of windows was finished within one day. The tenants could stay in the apartments during the whole process since the fire escape routes were never blocked due to renovation activities.

Figure 32: Installation of the windows in the prefabricated elements

1.3.3.5 Ventilation and prefabricated technical room

The prefabricated technical room/shaft was place in front of the building before mounting on the north facade. The installation of the ventilation system with air handing units and ductwork was this time done at site.

Figure 33: Prefabricated technical room/shaft in front of the building before installation left). Technical shaft (center) with air handling units seen from above before installation of ductwork, and seen from below after installation

Figure 34: Ventilation duct to bedroom included in-wall element (left) and Entrance to technical room/shaft. Exhaust and inlets can be seen above the door (right).

Figure 35: Ventilation ducts in the technical room / shaft. Left: Top of air handling unit is visible, right: magnified while connection to supply air duct in wall elements.

1.3.3.6 Entrance and stairways area – traditional methods

Figure 36 Left: old entrance. Right: new entrance.

Figure 36 shows the entrance before and after renovation. The new façade of the stairways was traditionally constructed on-site and not with prefabricated elements. As seen in the pictures below, the new wall consisted mainly of glass, with the glass entrance door on the ground floor and a large window on the second floor. The interior of the stairway was kept as is.

Figure 37: Above: Entrance area. Old red entrance door and wall/window above can be seen between new elements. The new entrance door is moved to align with the new façade. Below: New entrance area seen from the open space at the position of the originally window

Though the exterior walls were built into the new parts of the stairway and got new indoor cladding.

See below for duct pathways between the stairway area and the apartments.

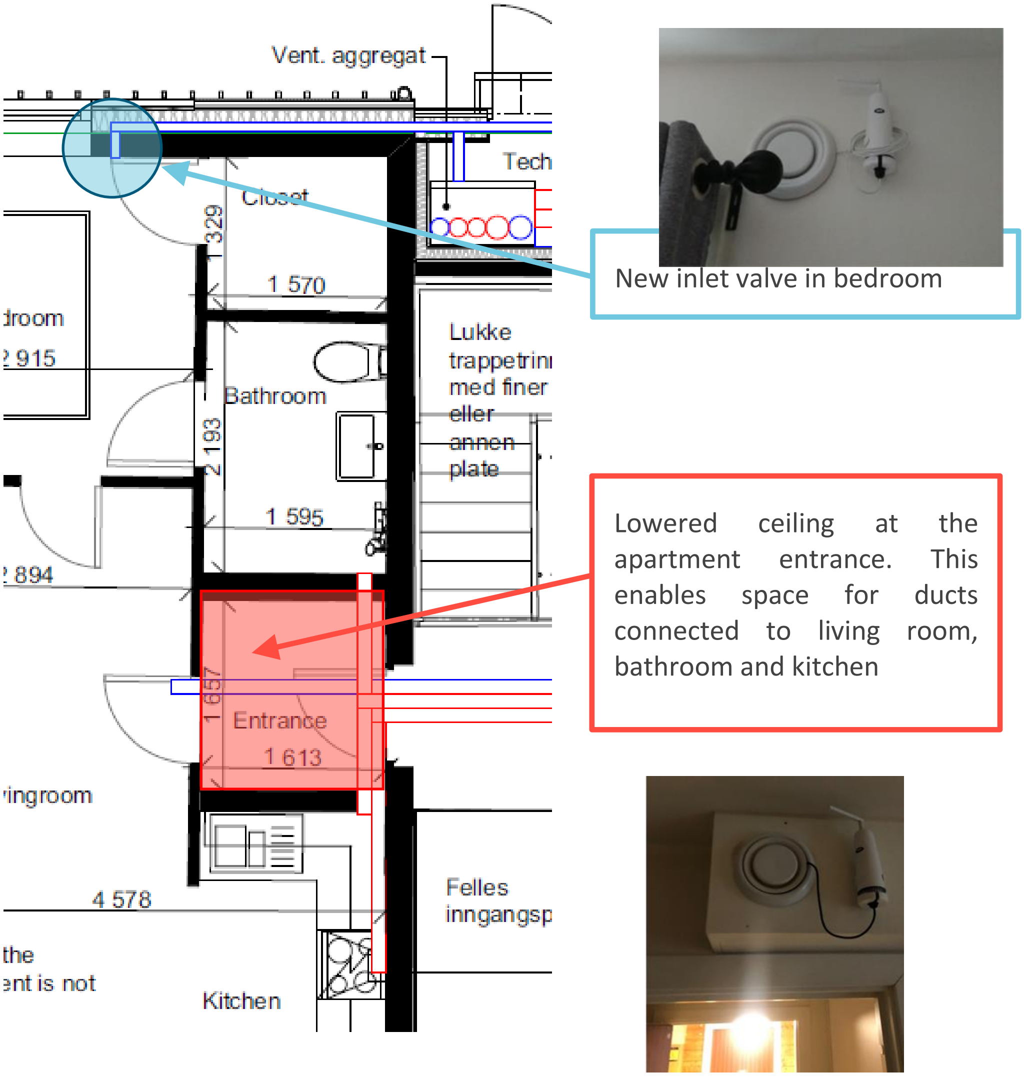


Figure 38: Indication of necessary work done from stairway to inside the apartments. A new inlet valve was installed in the external wall in the bedroom. The ceiling at the entrance of the apartment was lowered to provide space for supply air ducts to the living room and exhaust ducts from the bathroom and kitchen

Figure 39:Ductwork from entrance in apartment to main entrance, to be connected to ducts underneath the stairway

The supply air ducts for the living room and the exhaust ducts from the bathroom and kitchen were integrated under the stairways as shown in Figure 40. This installation was chosen to minimize the impact on the tenants. Integrating supply air ducts in elements to living room was not chosen since this would have implicated ducts around half of the building.

The only need for interventions inside the apartment were short ducts between the entrance area of each apartment and the stairs as seen in the figure above.

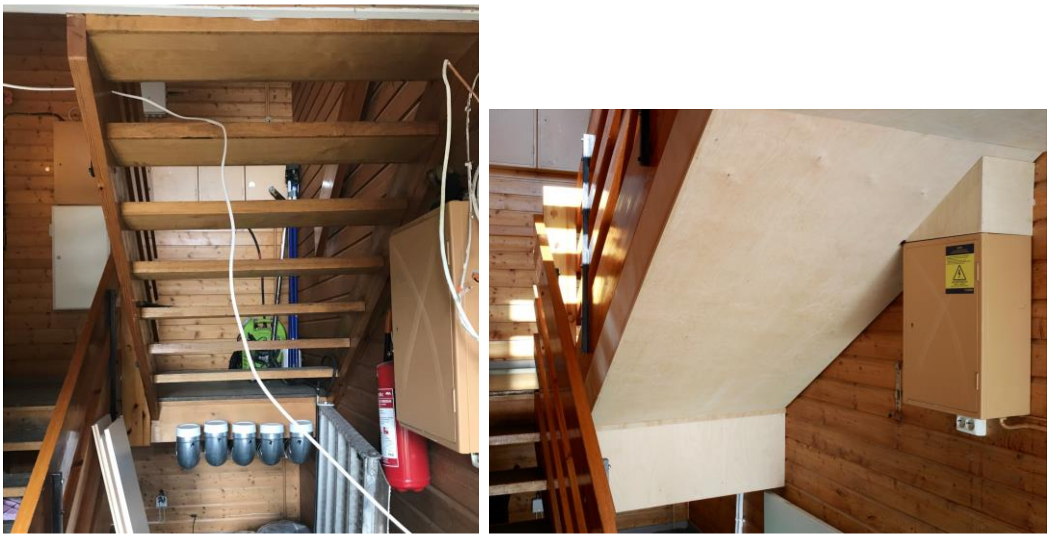


Figure 40: Ventilation ducts in staircase to/from technical room

1.4 Evaluation

1.4.1 Time

The progress of the project went according to plan. Some last details for the advanced elements were solved also during the off-site production period of the more standard elements.

The on-site construction was finished in 8 weeks (40 days). The installation of the elements had a duration of only two weeks, including removal of old windows. Then some on site work was necessary, like for the new entrance areas, ductwork in the stairways as well as supporting electrical work.

A night of really bad rain and windy weather caused some water leakage at the end of the installation, which caused some related repairs. This is included in the reported hours for on-site construction works.

In one of the apartments, asbestos was discovered inside the apartment. Person-hours related to removing asbestos are not included as this was not a part of the original project nor the execution plan.

A Gantt diagram of the actual progress of the project and on-site construction is shown in Table 8.

Table 8: Detailed Gantt of the process

Activity	2017	Jan	Feb	Mar	Apr	May	June	July	Aug
Building matter									
Concept/developed design									
Technical Design									
Production (off site)									
Construction (on-site)									
Site preparations									
Demolition/dismounting									
Ground work, foundation									
Façade and roof elements									
Ventilation/stairways									
Completion PV system									
Completion indoor									
Exterior finish									
Handover and Close out									

Comparable time of traditional deep renovation is not available from Boligbygg. Standard renovation time is hard to estimate since each project is unique. Comparable buildings are normally given a façade renovation. Nevertheless, it is regarded as a really time-efficient project compare with short preparation time and short time at site.

Despite the challenge of tolerances when fitting new elements to the existing building, the producer Lindal reports in interviews in the reporting period that the installation time was comparable to use of elements in new buildings. Joints between foundations, elements, and roof were up for discussions in the design phase, and especially joints between elements with integrated ducts and technical room. This went without problems or delays at site.

The total time for the detailed design was quite short for this project. Prefabrication needs early ordering of materials and installations. This was a challenge for the PV panels and some of the cladding materials. PV panels arrived in time, but a wrong delivery of cladding materials resulted in imperfect cladding at a few elements from off-site production. This was smoothly handled at site with no delays.

1.4.2 Cost analysis

1.4.2.1 General considerations

Boligbygg's main purpose is to provide affordable housing to residents with specific needs for help and support. As a public building owner, Boligbygg gets funding according to political priorities in the municipality. The allocated yearly budget is prioritized by Boligbygg according to relevant urgent tasks and planned renovation projects. Originally, Haugerudsenteret was planned with a limited budget for façade renovation. By participating in the 4RinEU project, a significant higher budget was allocated to allow for a deep renovation and renovation process fit for the future.

1.4.2.2 Rent

A possible regulation of rent is not expected to help the investment. As for a private owned building, the rent is likely to increase when renovating the building to a higher standard. In the public area, the rent is strictly regulated through the Rent Act. The rent is regulated according to the so-called current level of rent, which is a kind of average of similar type of dwellings offered at same conditions in similar area. This kind of rent has a delayed regulation and is usually below market rent. Accordingly, the deep renovation cannot directly count on an increased rent. However, improved ventilation and indoor climate is highly valuated among the tenants.

1.4.2.3 Saved and produced energy

The improved energy efficiency and energy production will influence the building owner marginally. Energy bills are paid by the tenants, and PV production is expected to be a marginal income when selling to the grid. However, public owners are expected to be frontrunners for development towards energy efficient and low carbon solutions for buildings and areas. Oslo municipality will in future projects demand both investment- and CO_2 budgets. Energy efficient buildings with the use of PV gives a good reputation and is attractive for building owners.

1.4.2.4 Aids and subsidies

Relevant Norwegian financial instruments were investigated, but no relevant aids and subsidies were found to fit the deep renovation of the demo.

1.4.2.5 Costs related to tenants in a standard renovation project

In a renovation project, costs are not only connected to the very construction work. When approaching an apartment building with vulnerable tenants, a large team is effectuated. Entering every apartment is a time-consuming and challenging process, as a visit must be announced 14 days up front, and the visit must be planned according to the tenants' needs and form of the day. Therefore, the tenants are often relocated during the renovation process. Even this can be challenging due to health conditions. A low tenant disturbance is thus highly appreciated.

Costs saved for alternative accommodation is calculated to be 910€/week per tenant. With tenants in this building and compared with a traditional renovation duration of 16 weeks, this equals 116,480 € saved.

1.4.2.6 Priorities for costs

Regarding cost aspects within the project, the following priories have been made:

- Deep renovation from outside, the tenant could stay. Saved costs.
- A close to marked solution, not a one-of-a-kind lighthouse, with marked acceptable production methods and related cost
- Integration of standard ventilation and PV solutions, the innovation is with the integration, not the product.
- Reinforced design group to develop innovative and safe solutions and methods. This was necessary also since it was hard to identify suitable producers and their relevant skills.
- Innovative procurement for close collaboration and trust.
- Separate site management for safe installation process
- The same partner is responsible for production and installation of elements, which ensures correct handling and saves cost for transfer of knowledge.
- Early investigations of existing conditions to avoid costly surprises in the installation phase.
- Use of scan and BIM. Close control of tolerances, correct installation, and safety to avoid extra costs.
- Light rig low waist at site. Installation by crane as far as possible.

1.4.2.7 Design related costs

In this demo project, Boligbygg hired a traditional design group to follow the project, even though the element producer was expected to have some of the same skills inhouse. The producer was included in the design stage, and the procurement and execution were conducted in a new, innovative manner. All these factors increased the cost in the design stages. Then of course in a research project, extra time is spent to explore the methods and develop the new solution sets.

As seen from the figure below, there is a considerable cost also for the building owner (11.1%), mainly related to the procurement and design phase. In this case, these extra costs are covered by the 4RinEU project. There were also some marginal extra site management costs (2.5%) since Boligbygg uses a separate site manager in their projects. The total cost includes costs related to both the planned works and unforeseen events such as discovering asbestos.

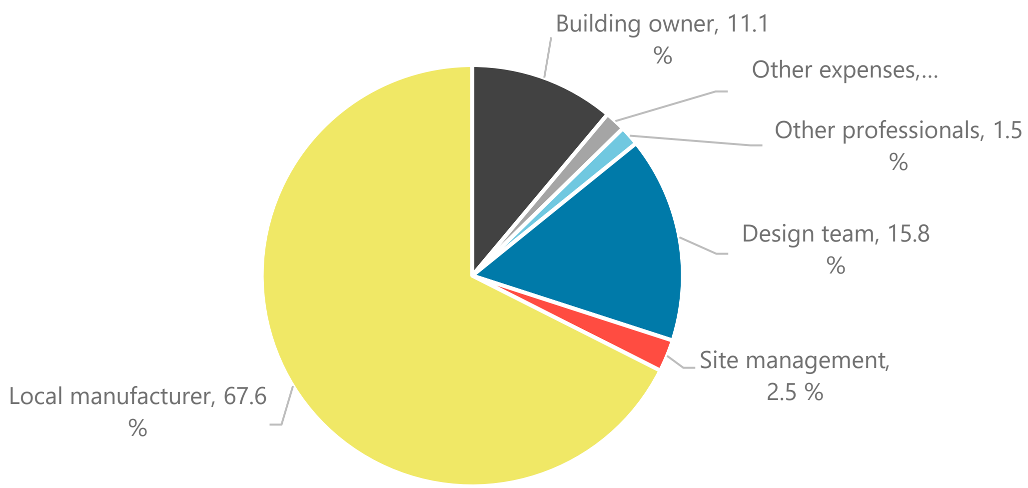


Figure 41: Distribution of invoiced cost per role/activity

For a new project, most of the competence needed at design stage will be covered inhouse by the manufacturer. A good architect and well qualified third-party supervisor are recommended. In the Norwegian market, about 3 companies are able to do a project like this. Based on the lessons learned from this case, costs for the design stage are expected to be reduced by 40% for the next project.

1.4.2.8 Off site production and on-site installation invoiced costs

Costs

Total costs for prefabricated elements excluded VAT are approximately 516,000 €. This includes production, transportation and mounding of the elements, as well as technical equipment, on site work and materials, rig, waste handling and exterior work. With a total floor area of approximately 400 m^2, the total cost was approximately 1,290 €/m^2. The very element costs form approximately half of the costs.

Identified cost drivers:

- Few apartments and low total volume of the building results in a high number of square meters external surface per apartment. This implicates a high number of square meters prefabricated elements for each apartment. A larger building or adding an extra floor of apartments to the existing building would have improved the renovation cost per square meter floor area significantly.
- For each element, the prize is very dependent on the type of cladding.

- The cost for increased insulation thickness is neglectable but including it in a construction that need a standard size beam and an extra 5 cm beam adds an operation and related labour cost per element. Higher quality insulation is preferred.
- Prize of PV elements integrated in wall elements can be double of standard PV panels mounted on roof, if safety glass is needed (public spaces)
- Elements with integrated technologies are more costly to produce, but according to Lindal, integration off-site normally saves 12-15 % compared to doing the installations at site.
- Elements with foundation was necessary due to Siporex with low load bearing capacity. Use of foundations and related roof elements are more costly than elements mounted on anchors. Joints between wall and roof elements could then have been solved differently.

Improved costs next project?

The production line at Lindal is already modern and flexible enough to handle the production of the prototype elements. The cost of the element production is not expected to be much lower. However, a different shape/size and loadbearing capacity would have changed the cost picture per square meter.

1.4.2.9 Saved costs

- As previously mentioned, integrated technologies save costs in the total cost picture. According to Lindal, integration off-site normally saves 12-15 % compared to installations at site.
- Element costs include rig costs. This is normally 15-18 % of the total costs at site.
- Early investigations of existing construction condition revealed that existing cladding and insulation could stay. Extra demolition costs and waist costs were avoided. Demolition costs are not estimated.
- The tenants could stay throughout the process. Extra accommodation costs were saved., estimated to 116,480 €.

1.4.2.10 Budget cost for façade renovation

Lindal offered the total contract for the production and construction part of the renovation, including transport and mounting of the elements.

Along with the offered price for the works, an estimate provided by the Norwegian carpenter's association of the cost for the same job executed as a traditional contract is included. They clearly state that the numbers are not based on on-site visit, but on architect drawings and pictures from early investigations of existing conditions.

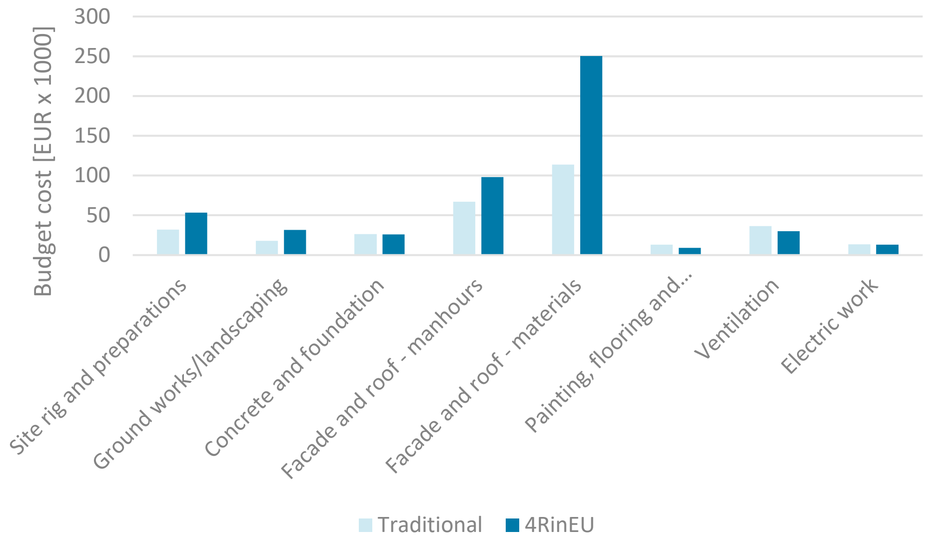


Figure 42 – Budget costs for a traditional renovation and the 4RinEU renovation. A traditional approach is typical values and estimates not based on on-site visits and/or architect drawings.

In general, the estimate for traditional renovation method seems a bit lower than expected. However, the comparison cannot be made straightforward. For example, the cost for groundwork and landscaping can be assumed to be approximately the same for both execution models, given the same starting point for the offer.

Where the budget numbers are less dependent on the specific site's knowledge, the number tends to be much more similar. Examples are the cost for concrete works (foundation and new floors in the entrances) and electric works.

The main differences are found for the façade and roof elements, including material cost and man-hours related to the job. The number of *invoiced* person-hours for the project was 1,250. This includes approximately 175 man-hours for repair after the water leakage and removal of asbestos. For the traditional approach, the estimate is approximately 1,280 man-hours. This corresponds to a 17 % reduction in needed man-hours.

For the materials, there are large differences between the stipulate costs from the Norwegian carpenter's association and the prefabricated elements. The materials from the Norwegian carpenter's association would provide similar energy efficiency as the prefabricated elements, including thickness, amount of insulation, and window type. The specified cladding is the same as the cladding before the renovation, which is more straightforward than the one specified for the prefabricated elements. In the cost estimated, the cost for ventilation ducts within the elements and transportation costs are included. The cost for PV panels is excluded in the cost estimates.

Figure 43 Early-stage planning at Lindal. Foto: SINTEF

1.4.3 KPIs linked to the construction stage

The full list of construction stage key performance indicators (KPIs) is found in D3.6. A summary of KPIs with a measured quantity for the construction stage are reported below. These are related to the off-site production of elements and on-site construction works are separated into two tables.

Many of the KPIs are reported as "per square meter", and the area used for normalization is the total heated area 396.8 m^2 BRA (abbreviation: bruksareal, usable area according to NS 3940) of the renovated building.

Table 9: KPIs linked to on-site construction. KPIs with no information is not reported.

	Name	Description	Formula	Unit	Result	Comment
WSS - EC	Electricity consumption	Total electricity consumption during works compared to the total amount of built-surface	electricity (KWh) / Built-surface (m^2)	[KWh / m^2]	5.4	Based on the common meter in each stairway. Number for average month
WSS - OC	Oil consumption	Total oil consumption during works compared to the total amount of built-surface	Oil (liters) / Built-surface (m^2)	[liters / m^2]	0.42	Crane hired for ca. 3 weeks, and used 42 hours for hoisting. Estimated consumption 4 liters diesel/hour.
WSS - WC	Water consumption	Total water consumption during works compared to the total amount of built-surface	Water (m3) / built-surface (m^2)	[m^3 / m^2]	0	No water was used on site except for water to clean tools after concrete work. The water used to mix the concrete is excluded in this KPI because the delivered concrete is premixed and ready to use to the site.
WSS - RUR	Re-using rate	Total weight of material reused in the works compared to the total amount of built-surface	Reused material (Tn) / Built-surface (m^2)	[Tn / m^2]	0	Although the existing building is still a part of the construction, it is not included in this KPI, therefore 0.

WSS - LR	Landfill rate	Total weight of material sent to landfill compared to the total amount of built-surface	Landfill waste (Tn) / Built-surface (m2)	[kg / m2]	20.05	Landfill mass from the new foundation
PTM-TWD	Total works duration	Duration of all the works of the retrofitting	Duration in working days	[Days] [hours]	40 d / 10 h	The grand total was 47 days and 10 hours for the entire renovation (1250 manhours in total). This includes an estimate of 100 manhours for extra work and re-work related to the water leakage, but does not include an estimate of 7 days (75 manhours) related to removal of asbestos.
PTM-TD	Task duration	Duration of a specific task of the renovation	Duration in working days, Duration in working hours	[Days] [hours]	17 d / 10 h	Foundation work (concrete): 10 working days Mounting of façade elements: 7 days and 10 hours Mounting of roof elements: 2 days and 8 hours Total amount 17 working days and 10 hours.

PTM - IR	Time impact of repairs	Number of hours of repairs compared to the total amount of hours	Time in repairs (h)*100 / Total hours (h)	[%]	9	Estimate of 100 manhours related to repair for water leakage divided by the total of 1175 manhours.

Table 10: KPIs linked to off-site production of elements

	Name	Description	Formula	Unit	Result	Comment
WSS - RCR	Recycling rate	Total weight of material sent to recycling plant compared to the total amount of built-surface	Recycled waste (Tn) / Built-surface (m^2)	[kg / m^2]	19.92	
WSS - RUR	Re-using rate	Total weight of material reused in the works compared to the total amount of built-surface	Reused material (Tn) / Built-surface (m^2)	[Tn / m^2]	0	

1.5 Commissioning

The project's most relevant commissioning tasks have been testing and checking the airtightness, control of airflow rates, and setpoints for the ventilation system. These properties of the building are crucial to finding if the energy design has been designed properly. Further, commissioning tasks such as noise measurements can be relevant but are kept outside this report.

1.5.1 Airtightness

Blower door measurements were performed in 2020 by Oslo Termografi and Byggteknikk AS according to NS-EN ISO 9972:2015 using Energy Conservatory Model 4 fans and Energy Conservatory SG 700 micromanometers. Air leakages were visualized using indoor thermography at - 50 Pa (Outdoor – indoor air pressure) according to EN 13187 and smoke generators at 50 Pa.

A blower door measurement was performed in January 2018 before the renovation started and showed a resulting air leakage of 2.55 h^{-1}. The first blower door measurement after the renovation was performed in January 2020 and air leakages was found in different places in the building envelope. The resulting air leakage from the first blower door measurement was 3.58 h^{-1}. Measures to find and stop the air leakage was scheduled together with a new blower door test later in 2020.

Figure 44: Smoke in the passage for downpipes, before sealing

The second blower door measurement was performed in September 2020 with all the Norwegian partners and involved actors present. The initial smoke detection tests showed air leakage in the downpipes. Smoke was emerging from the ground around new fundaments, through holes in the façade in the newly established technical room, at vent pipe guards on new roof elements, and between wall and roof elements. Metal sheet coverings made the exact observation of leakages difficult. Minor leakages were also observed around a few windows and doors. Where accessible, the detected leaks were remediated by expanding polyurethane foam, or with the aid of airtight spun bond polyethylene fabric (housewrap) and tape.

Figure 45: Blower door measurement performing while Lindal personnel is checking the sealing of the roof

After remediation of the accessible leakages, the resulting air leakage from the blower door measurement was 2.82 h^{-1} for Haugerudsenteret 17-19.

The target of air leakage of 1.0 h^{-1} was not reached after deep renovation for the Norwegian demo case Haugerudsenteret 17-19. Generally, there are no usable method for quantifying individual leakages in an existing building, and any estimates of airtightness post-refurbishments are uncertain. It was assumed that many of the leakages would be addressed as newer and more airtight windows and doors would be more tightly sealed against a continuous external housewrap. Even if the achievable improvements were only roughly estimated, it came as a surprise that airtightness deteriorated through the refurbishment process, especially as there was a close focus on joint details between elements and elements and foundations. Some of the leakages were due to insufficient attention to known penetration of sewage pipes and cables. These can be prevented by improving penetration details in production and mounting, and ensuring compliance, e.g. via checklists. The leakages from the ground occurred due to unexpected/unknown properties of the existing construction and could only have been prevented by a more thorough assessment and analysis before refurbishment. In general, more focus is needed towards airtightness details below ground and existing condition when doing a deep renovation.

Some leakages occurred post refurbishment. Examples are ventilation ducts penetrating walls that later were moved without sealing the original opening, and internal drainpipes that were lead through the façade elements. The latter can serve as examples of actions that are typically out of control by the building entrepreneur.

1.5.2 Balancing of the ventilation system

A technical room is installed behind the staircase in Haugerudsenteret 17 and 19. Each technical room allows space for two air handling units. Each unit supports two apartments.

The results from the balancing of the ventilation system show a slight under pressure in all apartments. A balance or slightly under pressure is recommended to avoid moisture problems.

The Norwegian building code for ventilation of dwellings are given by several criteria. For small apartments, the minimum requirement for exhaust air is the dominant. Ventilation rates for kitchen are 36/108 m^3/h and bathrooms 54/108 m^3/h for basic/forced ventilation. The total basic rate will then be 90 m^3/h.

The Norwegian building code requirement of 1.2 m^3/h m^2 is based on the older requirement of an air change rate of 0,5 h^{-1} and a standard ceiling height of 2,4m. It is a known challenge that the minimum requirement for exhaust air leads to higher air change rate in small apartments, which is up for discussions. A base rate of 90 m3/h implicate an air change rate of 0,94 h^{-1}.

As seen in table 8, the design value for the ventilation is set to 160/175 m^3/h. This is approximately equal to base rate in one room and forced ventilation in another room. Reasonable airflow deviation was found during the control measurements after the balancing of the ventilation system. The air handling units can normally be regulated to a low, normal, and high airflow rate. The balancing report show a ventilation rate at "high" in compliance with forced ventilation of both bathroom and kitchen at the same time, while the "normal" fulfil the requirements of one room at base ventilation and one room at forced ventilation. This is according to SINTEF a strict and unfortunate interpretation of the requirements in a small apartment, and result in an air change rate of 1,7 h^{-1}.

The setpoint temperature for the supply air is registered to be 20°C.

Table 11 Designed and measured airflow rates.

	Location	Supply air (h^3/h)	Extract air (h^3/h)

		Designed	Measured	Designed	Measured
Haugerud 17	1st floor left	160	150	175 (220)	173 (221)
	1st floor right	160	160	175 (220)	174 (224)
	2nd. floor left	160	155	175 (220)	172 (229)
	2nd floor right	160	167	175 (220)	181 (233)
Haugerud 19	1st floor left	160	165	175 (220)	173 (231)
	1st floor right	160	158	175 (220)	178 (231)
	2nd. floor left	160	159	175 (220)	184 (229)
	2nd floor right	160	163	175 (220)	171 (220)
Total		1280	1277	1400 (1760)	1406 (1818)

Figure 46: Kari Thunshelle from SINTEF (left) and Vera Lukina (right) outside the technical room inspecting the installation of the ventilation system.

Extract and inlet air were initially placed in a combo unit. Due to contamination problems, extract outlets were moved to a higher position on the technical room external wall.

1.5.3 RES production

The PV panels, BIPV are fully operating, and live production (5-minute intervals) can be found at www.solarweb.com. There are in total 16 panels, each 1.7 m^{2,} and total 27.2 m^2. The installed power is 4.56 kWp, and the panels are said to have a nominal efficiency of 19.5 %. More information can be found in Deliverable report 5.2 *Concept design and performance targets for the demos*. Indications on production so far for 2018-2020 is presented in the figures below, with a maximum of 400 kWh in April 2019. The systems are working well and performing as expected. Due to restrictions on distributing produced energy to tenants, the generated energy is so far mainly transferred as feed into the grid.

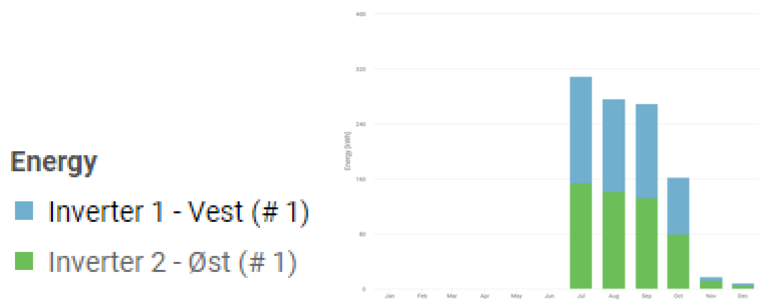


Figure 47: PV production during 2018. The PV panels were fully operational from July

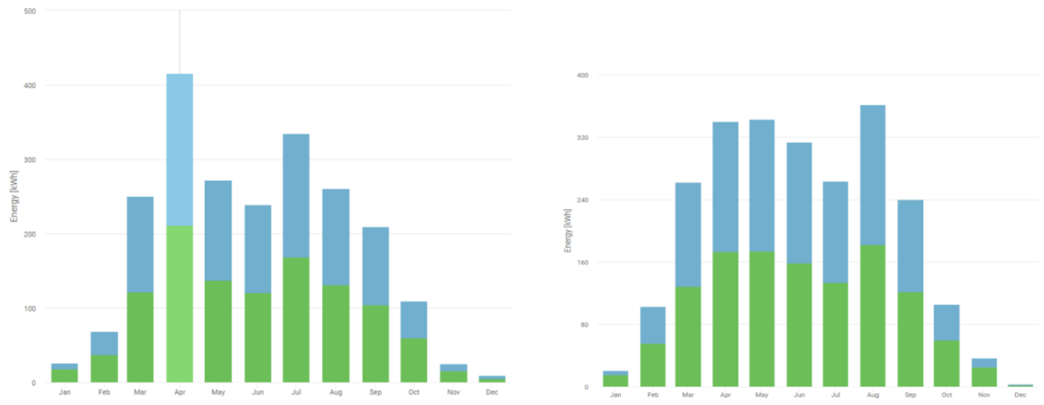


Figure 48: PV production during 2019 (left) and 2020 (right). Maximum production of 400kWh April 2019

Figure 49: Haugerudsenteret south façade after renovated. Photo: Filter Architects

1.6 Conclusions

1.6.1 Lesson learned

The project has **successfully demonstrated** how a low-rise timber-based apartment building can be renovated to reduce the energy demand for space heating using prefabricated elements with integrated photovoltaic panel, ventilation ductwork and balanced ventilation with recovery ventilation. The solution is regarded market-acceptable and replicable for deep renovation of existing buildings.

Adapting new prefabricated façade and roof elements to an existing building requires **thorough and detailed planning**, focus on joints of elements, penetrations and special attention to tolerances. **BIM** as both a design and production tool is considered one of the key success factors for this. The digital process also allows for optimized use of materials and reduced waist. Advanced production line allowed for easy integration of technical installations, which saves time and costs on site. **Prefabricated technical room**/shaft allowed space for balanced ventilation, air handling unit with heat recovery and other technical equipment where initially no space was available.

Detailed planning applies both to the design of the elements, the construction site's preparation, and the existing building. **Mapping of existing condition**, potentially hazardous materials, infrastructure (cables, water pipes, antennas etc.), and vital components in the existing building are crucial to planning of load bearing concept, need to remove parts of existing construction (insulation or cladding if damaged), and aligned design of new elements. The load bearing capacity for the existing building was a challenge. However, the existing cladding an insulation was in good state and could stay.

Use of prefabricated elements is an attractive solution when **short on-site construction time** and **minimum disturbance of tenants** is essential. All on-site work was performed without the need for tenants to move out of the apartment. During on-site work, fire escape routes were never blocked during night-time. Interventions within each apartment, both in time and complexity was minimized to only a few hours per apartment. All in all, the project has shown that renovation of an existing building can be performed within a matter of weeks.

The main **success factors** are identified as early inclusion of manufacturer, close collaboration on design, transfer of knowledge to construction site, early information and gently handling of tenants, as well as inclusion of participants from different stages of the renovation process in identifying risks and opportunities.

Deep renovation to a high energy ambition level can be challenging. The initially energy target of passive house level was not possible to reach for this building. Existing shape and construction method prevented deep renovation to the initial target of passive house level. Existing slab on ground floor could not be upgraded without unreasonable tenant disturbance, height restrictions limited the possibility for adding an extra floor. However, criteria for different buildings parts and technical equipment could be kept, and the new foundation also improved the insulation for slab on ground floor.

The blower door measurements unexpectedly showed low improvements in the air leakages, despite close focus on joints of elements. A large smoke test and investigation by involved parts revealed insufficient attention to penetration of pipes and cables, and possible improvements of the details between roof and wall element. Probably the largest contribution was from construction and airtightness details below ground. The air leakages are not representing cold draft and decreased comfort, but probably have a semi-heated pathway between old and new construction. This is already being addressed as improvements for a next project.

The integration of the of PV panels prefabricated façade elements and belonging technical equipment in the prefabricated technical room open for local RES power generation. This is mainly feed-in to grid since regulations prevent distribution to the tenants.

Figure 50: Contented tenants watching their homes being renovated. Photo: Boligbygg

1.6.2 Main further recommendations

The project has been a great success despite the challenges with the existing construction. Use of collaboration contract was an important factor for being able to do a project like this. The combination of skilled actors, and including the manufacturer in the design process is recommended in future projects as well. Probably the manufacturer together with an architect and a skilled 3 party controller will be sufficient. Of great importance is also the transfer of knowledge to the installation at site, and a general contractor for the whole process is recommended.

The use of scan of old building, design BIM and production BIM is highly recommended in future projects. This eases the control of tolerances, gives precise production with low waste, and easy mounting of advanced elements with integrated technology at site. Integrated technology saves time and costs at site.

The Norwegian team, and especially the manufacturer is already considering new deep renovation projects with advanced prefabricated elements. The concept and method are good, and some improvements in construction details will help future projects. The lesson learned from the air leakage test will result in more focus on construction details towards ground, improved details for pipes and a checklist for controlling unexpected penetration of new elements.

For future projects, the early design phase and assessment of existing condition will be important to consider if the actual deep renovation is best off by prefabricated or standard methods.

Prefabrication of technical room and integration of supply air ducts in the elements are an enabler that for sure is valuable for deep renovation and will be used in future projects. Small apartments like in this demo have a challenge with the existing building code resulting in a too high air change rate and discussions on interpretation of ventilation strategy. This is a challenge that is addressed in another ongoing national research project.

Figure 51: Haugerudsenteret in full operation after renovation, December 2018

Dutch Demo Case

Figure 52 Marienheuvel before and after renovation

1.1 Design management

1.1.1 Project context

The residential building which is the demo case, Mariënheuvel, is one of two residential buildings (in total 150 apartments) to be renovated and is located on a site in Soest consisting of three buildings; the third is a care-centre. The latter will be demolished and replaced by a new building. The two residential buildings will be renovated to current Dutch standards. The insulation of the roof construction will be changed and improved to a level of new constructed buildings. The cavity walls will be filled with insulation, the glazing will be replaced by double glazing of the highest insulation level. The entrances will be enlarged and refurbished, the corridors refurbished, and bicycle storage rooms will be added.

On top of this renovation, the 4RinEU project will be applied on 15 of the 72 dwellings, mainly consisting on mounting prefabricated façades on the exterior side of the existing façades.

Until 2018 the proposed demo case was Mariënburg, the central building on the same plot. Mariënburg is a combination of residential rooms with in-house care services. The Mariënburg case has been studied in depth from multiple angles: façade renovation, ventilation integration, renewable energy applications, and by defining the demonstration solutions and energy performance. The user requirements in terms of spatial needs conflicted with the existing floor plans and did require too extensive reconstructions. Therefore, it has been decided to replace Mariënburg with a new built scheme at the same location. The 4RinEU demo case therefore moved to the neighboring apartments building, namely Mariënheuvel.

1.1.2 Design team

The overall design team consists of two Woonzorg employees, a development project manager and a technical project manager. An architect office is represented with two members, the architect himself and his technical manager. A system engineer completes the overall design team. They are the core-team.

For the demo case the design team is supported by the manager of sustainability of Woonzorg (Wim Bakker) and the consultant of sustainability of the demo case project (TRECODOME, Chiel Boonstra).

To represent the residents in the design team there are two employees of Woonzorg who attended the meetings.

1.1.3 Management process

The development project manager of Woonzorg is in the lead of the overall project and responsible for the feasibility. The technical project manager of Woonzorg is responsible for the technical issues, all drawings and descriptions and the documents for the procurement. The architect is responsible for the aesthetic and technical engineering, the system engineer for the system engineering.

The sustainability manager of Woonzorg (Wim Bakker) and the sustainability consultant of the demo case project (TRECODOME, Chiel Boonstra) are providing the information of the 4RinEU demo case.

The Woonzorg employees responsible for the residents are taking care of the interests of the residents.

The architect used 3D software to design the project. The contractor used traditional and partial drawings for the renovation works. For the 4RinEU façade a digital point cloud was made to know the exact dimensions of the existing façade. The prefabricated façade has been designed in 3D by the selected façade manufacturer. These drawings also functioned as production drawings.

1.1.4 Main meetings

In the following chapter, a description of main workshops and meetings carried out is described:

1 December 2016

LDWG Soest

Kick-off meeting of the demo case project in site (Mariënburg SOEST, the NL)

Attendants: Roberto Lollini, Chiel Boonstra, Wim Bakker, community of Soest, among others

20 January 2017

Visit to Gumpp & Maier in Germany

Exchange of data of the buildings of the demo case, exchange of possible technical solutions for the prefab wooden façade.

Attendants: Alexander Gumpp, Maximilian Schlehlein, Chiel Boonstra, Judith Tillie, Wim Bakker

17 March 2017

Visit Gumpp & Maier to the Dutch demo case in Soest

Research existing construction of the buildings, including demolishing cavity wall on several places.

Attendants: Alexander Gumpp, Maximilian Schlehlein, Chiel Boonstra, Judith Tillie, Wim Bakker

5 April 2017

LDWG at Woonzorg in Amstelveen, the NL

Discussing the advances of the technical aspects of the project, such as wooden prefabricated façade and HVAC systems

Attendants: all 4RinEU members involved in the Soest demo case presided by ACCIONA, Diego Romero Pascual.

12 July 2017

Skype meeting with Eurac, Roberto Lollini

Discussing the advances of the technical aspects of the project, such as wooden prefabricated façade and HVAC systems

10 August 2017

LDWG at architects office Amersfoort, the NL

Discussing the advances of the technical aspects of the project, such as wooden prefabricated façade and HVAC systems

15 February 2018

LDWG Skype-meeting presides by ACCIONA, Diego Romero Pascual

12 April 2018

LDWG at architects office Amersfoort, the NL

Discussing the advances of the technical aspects of the project, such as wooden prefabricated façade and HVAC systems

Maximilian Schlehlein was connected with Skype, commenting the draft drawings of the architect.

In between above meetings, multiple bilateral meetings between experts and architects, and internal meetings at Woonzorg took place addressing the progress and content of the 4RinEU demo case in The Netherlands.

The process is further described in the chapter about construction works.

1.1.5 Design targets

This chapter presents the targets of the renovation (for further details on design target please refer to Project Deliverable 5.2).

1.1.5.1 Energy

1.1.5.2 The energy targets for the main renovation - Minimum requirements provided by law and local regulations

This section reports the minimum requirements of the Dutch law in case of building renovation.

Figure 53 Logo of Dutch building energy label

In the Netherlands energy performance of the building stock is determined in Energy Labels(Figure 53). Each apartment has its own Label. For existing residential buildings there is a National Agreement (not ratified by law) that after renovation the Label should be at minimum B. This is the aim of the standard renovation of the 151 apartments in Soest; to improve the Energy labels from E and D to minimal B for all apartments.

- *Minimum envelope requirements of the National Regulations:*

Table 12 Energy characteristics of Marienheuvel: current, standard renovation, minimum requirements and 4RinEU targets

Building element	Current situation	Ordinary energy renovation*	Minimum requirements for existing buildings	4RinEU targets
Facade	Rc = 0.35 [m^2K/W]	Rc = 1.3 [m^2K/W]	Rc=1.3 [m2K/W]	Rc = 6.5 [m^2K/W]
Roof	Rc = 0.35 [m^2K/W]	Rc = 3.5 [m^2K/W]	Rc=2.0 [m2K/W]	Rc = 6 [m^2K/W]
Ground Floor	Rc = 0.15 [m2K/W]	Rc = 2.5 [m2K/W]	Rc=2.5 [m2K/W]	Rc = 3.5 [m^2K/W]

Glazing	U = 2.9 [W/m²K]	U = 1.8 [W/m²K]	U = 2.2 [W/m²K]	U = 1.0 [W/m²K]
Average U-value				
G-value glazing	0.7	0.6	-	0.5
Ventilation	Mechanical (centralized)	Mechanical (centralized)	-	Decentralized
Air tightness	-	-	-	n50 =1.5
Energy Label	D	B	B	A or A+

Dutch building regulations require different standards depending on the building type and status of the renovation. For new buildings the Energy performance building regulation requires a regulated energy calculation, however with minimum performance standards for insulation.

For existing buildings, the energy performance is calculated with a regulated method for existing buildings. Also for existing buildings, minimum insulation values apply for different situations.

Table 13 Minimum insulation values for new construction as defined in the Building Code

Minimum insulation values for new construction			
			for International comparison
	Rc value	U value	U value
	[m²K/W]	[W/m²K]	[W/m²K]
Roof	6.0	-	0.16
Facade	4.5	-	0.21
Glazing		2.2	2.2
Window frames		2.2	2.2
Floor	3.5	-	0.27

Source: Bouwbesluit, artikel 5, tabel 5.1

Almost similar minimum insulation values are valid for a major renovation. However, in practice not many projects are entitled as major renovation. Also, the values only apply if the component is being renovated.

Table 14 Minimum insulation values for major renovation as defined in the Building Code

Minimum insulation values for major renovation			
			for International comparison
	Rc value	U value	U value
	[m^2K/W]	[W/m^2K]	[W/m^2K]
Roof	6.0	-	0.16
Facade	4.5	-	0.21
Glazing		2.2	2.20
Window frames		2.2	2.20
Floor	3.5	-	0.27
Source: Bouwbesluit, artikel 5, tabel 5.1			

If an insulation measure is applied on an existing building, the following values are the minimum requirements. These values date back from very early new built regulations in the 1980s.

Table 15 Minimum insulation values for measures on existing buildings as defined in the Building Code

Minimum insulation values for measures on existing buildings	
	for International comparison

	Rc value	U value	U value
	[m²K/W]	[W/m²K]	[W/m²K]
Roof	1.3	-	0.69
Facade	1.3	-	0.68
Glazing		2.2	2.20
Window frames		2.2	2.20
Floor	1.3	-	0.68
Source: Bouwbesluit, artikel 5.6 lid 1			

Table 16 Minimum insulation values for measures on existing buildings when replacing insulation as defined in the Building Code

Minimum insulation values for measures on existing buildings, when replacing insulation			
			for International comparison
	Rc value	U value	U value
	[m²K/W]	[W/m²K]	[W/m²K]
Roof	2.0	-	0.47
Facade	1.3	-	0.68
Glazing		2.2	2.20
Window frames		2.2	2.20
floor	2.5	-	0.37
Source: Bouwbesluit, artikel 5.6 lid 2			

The insulation values of the existing building Marienheuvel are rather low. There is no cavity wall insulation, very little roof insulation and no floor insulation. Only the original single glass panes have been replaced with double glazing in a previous renovation.

Trecodome and Woonzorg Nederland have made energy simulations to compare the impact of the various scenarios. Trecodome has used the software UNIEC 2.1 for the Energy label simulations, and PHPP9 in order to have a good insight in monthly energy flows.

Table 17 Current insulation values and calculated net heat demand for space heating in the existing situation of Mariënheuvel

Existing Marienheuvel			
			for International comparison
	Rc value	U value	U value
	[m^{2}K/W]	[W/m^{2}K]	[W/m^{2}K]
Roof	0.4	-	2.04
Racade	0.2	-	3.13
Glazing		3	3.00
Panels in window frames		2.2	2.20
Floor	0.2	-	3.13
Extract ventilation			
Net heat demand			**kWh/m^2**
PHPP			**125**
UNIEC			**132**

The standard renovation of Marienheuvel is very typical for an energy renovation project in the Dutch market in 2020. The targeted energy label is B. Usually, using the minimum insulation values for existing buildings, combined with mechanical exhaust ventilation and a new condensing gas boiler, is enough to achieve energy label B.

In the case of Marienheuvel, the standard roof insulation reaching new-construction performances is a first spin-off in the demonstration project.

Standard façade insulation in The Netherlands is the use of cavity wall insulation. By filling the cavity with 5-6 cm of insulation the minimum requirements are being met. It is a cost-effective measure because the costs are low, and a part of the heat losses is being reduced. However, the insulation level is not enough to achieve a deep renovation energy performance.

Standard renovation in this case results in a net heat demand around 70 kWh/m^2. Given that the real energy performance of the existing building is just above 100 kWh/m^2, it is clear that a standard renovation in reality results in a space heat demand reduction around 30%. This is much lower that the theoretical 50% which could be concluded if one compares the calculated net heat demand before renovation with a standard renovation.

Table 18 Standard insulation values and calculated net heat demand for space heating for the standard renovation of Mariënheuvel

Standard renovation Marienheuvel			
			for International comparison
	Rc value	U value	U value
	[m^{2}K/W]	[W/m^{2}K]	[W/m^{2}K]
Roof	6.0	-	0.16
Facade	1.3	-	0.68
Glazing		1.8	1.80
Panels in window frames	1.5	0.6	0.60
Floor	3.5	-	0.27
extract ventilation			
Net heat demand			**kWh/m^2**
PHPP			**67**
UNIEC			**70**

The 4RinEU demonstration project shows significant improvements over and above a standard renovation. The façade insulation improved because of the new prefabricated façade in front of an insulated cavity wall and a prefabricated façade with new windows instead of low performing window frames. The prefabricated façade also improves the insulation of the panel parts below the windows. The Dutch building code allows such panels to be insulated at the same level as glazing.

Table 19 4RinEU insulation values and calculated net heat demand for space heating in for the 4RinEU demo renovation of Mariënheuvel

4RinEU Demo renovation Marienheuvel			
			for international comparison
	Rc value	U value	U value
	[m²K/W]	[W/m²K]	[W/m²K]
roof	6.0	-	0.16
facade	8.0	-	0.12
glazing		1	1.00
panels in window frames		0.17	0.17
floor	3.5	-	0.27
decentralized ventilation			
Net heat demand			**kWh/m2**
PHPP			**20**
UNIEC			**19**

Energy performance target

- ***Regular renovation; energy label B***

  The objective of the standard energy renovation is to achieve Energy Label B

- ***4RinEU renovation: energy label A or A+***

  The objective of the demo energy renovation is to achieve Energy Label A or better, but more importantly to demonstrate a very low energy demand for space heating.

Table 20 Comparison of U values, ventilation system and net heat demand for the existing situation, minimum requirements, standard renovation and demo renovation

Renovation Marienheuvel				
	EXISTING	Min. REQUIRED	STANDARD	4RinEU demo part
	U value	U value	U value	U value
	[W/m²K]	[W/m²K]	[W/m²K]	[W/m²K]
Roof	2.04	0.47	0.16	0.16
Facade	3.13	0.68	0.68	0.12
Glazing incl frames	3.00	2.20	1.80	1.00
Panels in window frames	2.20	2.20	0.60	0.17
Floor	3.13	0.37	0.27	0.27
Ventilation	extraction	extraction	extraction	decentralized
Net heat demand	**kWh/m²**		**kWh/m²**	**kWh/m²**
PHPP	125	-	67	20
UNIEC	132	-	70	19
Monitored	108	-	-	-

The resulting Energy labels for the existing, standard and demo-renovation are as follows:

Table 21 Comparison of the Energy Labels for the existing situation, standard and demo renovation. Calculation refers to a reference room with 51 m² area.

Energy performance expressed in units of the national energy labelling system		existing	standard	4RinEU
Specific energy performance (calculated primary energy / m2)	MJ/m^2	1,161	782	508
Characteristic energy use (calculated primary use)	MJ	59,199	39,857	25,906
Allowed characteristic energy use	MJ	24,394	24,394	24,394
Energy-Index	-	2.04	1.38	0.9
Energy label		D	B	A

Fire safety requirements that can affect 4RinEU renovation approach

There are no fire safety requirements that can affect the 4RinEU approach, but general fire safety rules have been respected in the design of the measures for Marienheuvel in Soest. For example, to avoid that vertical ventilation ducts could connect fire between apartments.

Structural safety

The structural safety of the building may not reduce due to the deep renovation works. This item was relevant when assessing the possibilities to make additional shafts for ventilation. Because there was no structural flexibility to do so, the 4RinEU concept has been developed within the constraints of the existing buildings.

Other targets

Marienheuvel is populated with elderly people. Since the renovation happens with people living in the apartments, the objective should be to minimize the impact of the renovation works itself and to seek for solutions for the tenants at the specific time of significant works happening at the facades of the apartments and the replacement of full window frames by prefabricated facades.

- **Net primary energy use reduced by 60%** compared to pre-renovation

The Marienheuvel demonstration project meets the requirement of a net primary energy use reduction for the heating related energy flows: space heating, hot water and its necessary systems. In future, the net primary energy will reduce even further when PV panels will be mounted on the roofs. The success of the project is to achieve its objectives by focusing on significant energy demand reduction, and good indoor climate conditions.

Table 22 Energy performance expressed in primary energy figures as defined the Dutch energy labelling method. Calculation is referred to a reference room with 51 m² area

Uniec 2 – Energy Performance summary Marienheuvel Burg Grothestraat						
Yearly primary energy use per function			existing	standard	4RinEU	% reduction expected by 4RinEU renovation respect to existing condition
Space heating		MJ	29,938	15,828	4,132	-86%
Auxiliary energy (e.g. fans and pumps)		MJ	3,823	3,733	3,658	-4%
Domestic Hot Water		MJ	12,470	12,470	12,470	0%
Auxiliary energy for DHW (e.g. pumps)		MJ	2,063	2,063	2,063	0%
Cooling		MJ	0	0	0	-
Summer Comfort (achieved by the use of glazing with lower g-value and shading)		MJ	1,163	702	781	-33%
Fans (originally there were central AC extraction fans. In the standard renovation there are DC fans. In the 4RinEU case there is demand controlled ventilation.)		MJ	7,392	2,710	452	-94%
Lighting		MJ	-	-	-	-
	TOTAL	**MJ**	**56,849**	**37,506**	**23,556**	**-59%**

The primary energy reduction of the energy flows is 59%. The space heating reduction is 86%.

1.1.5.3 Comfort

Hygro-thermal targets according to the national regulation or internal objectives or 4RinEU objectives. In fact there is no regulation on indoor temperature levels. There are common assumptions in simulation software. Installers typically guarantee that certain temperatures can be achieved, but these are private agreements with the client.

Typically, buildings can be heated to 20 - 22 degrees Celsius, and the relative humidity should most of the time be between 30 - 70%.

1.1.5.4 Indoor air quality

Ventilation rate targets / CO_2 concentration targets according to the national regulation or internal objectives or 4RinEU objectives. The building code requires minimum ventilation rates to be possible, and ventilation systems are specified according to these standards. The objective behind the building code is to achieve a maximum CO_2 level of 1200 ppm in domestic buildings.

1.1.5.5 Noise

Noise insulation according to the national regulation or internal objectives or 4RinEU objectives. For existing buildings sound insulation standards at the time of construction apply. The sound of new systems should not exceed 30 dB(A) inside habitable spaces.

1.1.5.6 Expectations of the owners (wish list)

- To have a more comfortable building for the special target living in Marienburg: elderly people
- To have a more future-proof building in terms of sustainability (better insulation, more economic systems, reduction of energy consumption), functionality and aesthetics.

1.1.5.7 Specific constraints

Most important is that during the renovation works the residents stay in their apartments. The impact on daily life must be reduced to the minimum.

The residents are elderly people. These are very fragile people. It has to be taken into account during preparation and realization of the renovations.

1.1.6 Description of the renovation and its innovative technology packages

How 4RinEU technologies have been adapted and will be implemented in this demo.

1.1.6.1 Design drawings

Some of the main details referring to the design of the intervention are reported. In particular, the existing configuration drawing and the retrofit condition drawings are compared. Here below the part of the demo building where the 4RinEU approach has been applied.

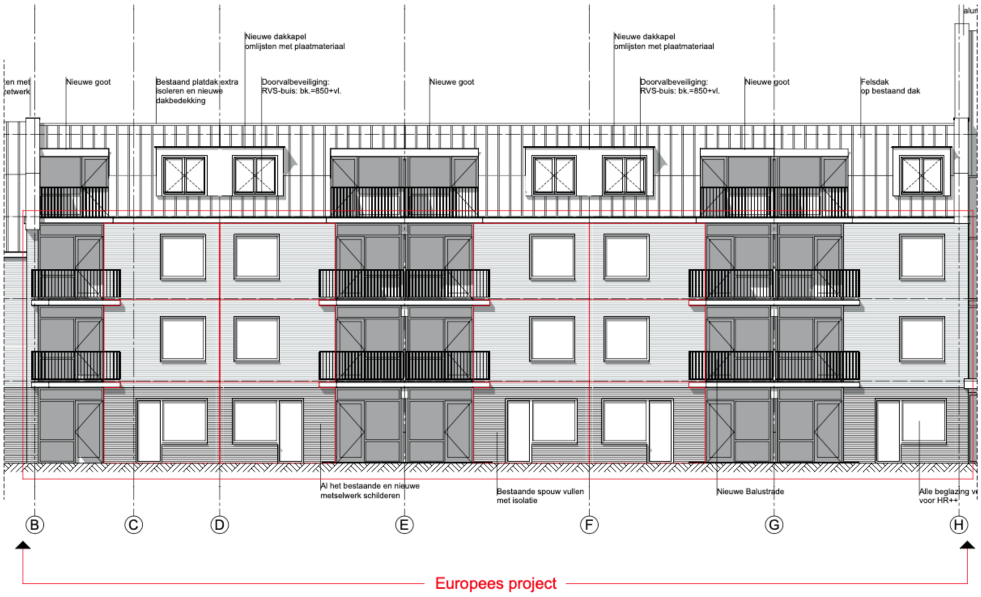


Figure 54 Northeast front view of the 4RinEU demo façade renovation in Mariënheuvel, Soest

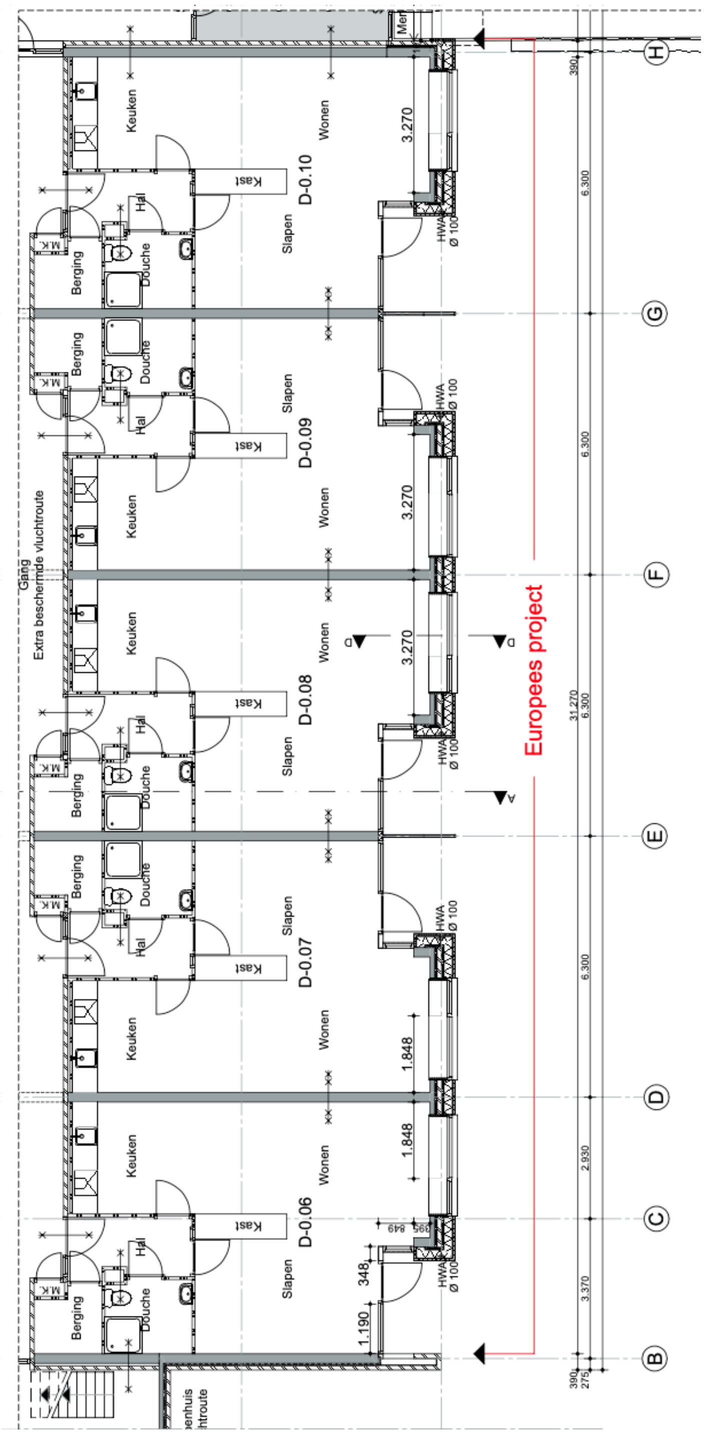


Figure 55 North East floor plan of the 4RinEU demo façade renovation in Mariënheuvel, Soest

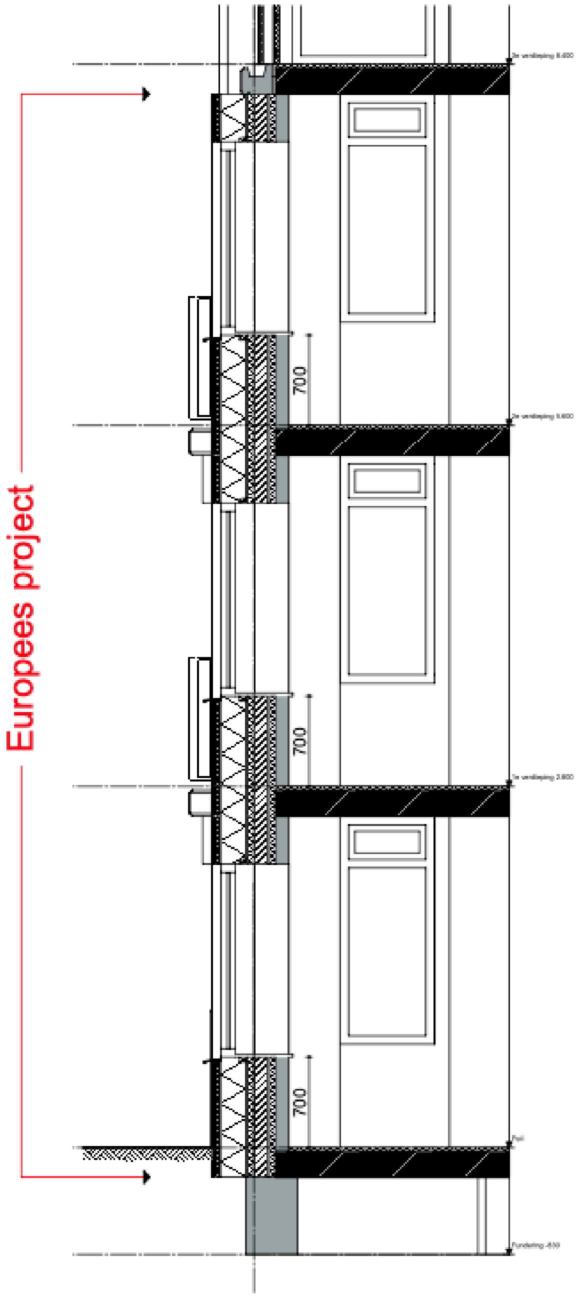


Figure 56 Schematic cross section of 4RinEU demo façade renovation in front of the existing cavity wall construction

In the pictures below, some drawings showing stratigraphy details. Corresponding transmittance values have been used in simulations.

Living room façade

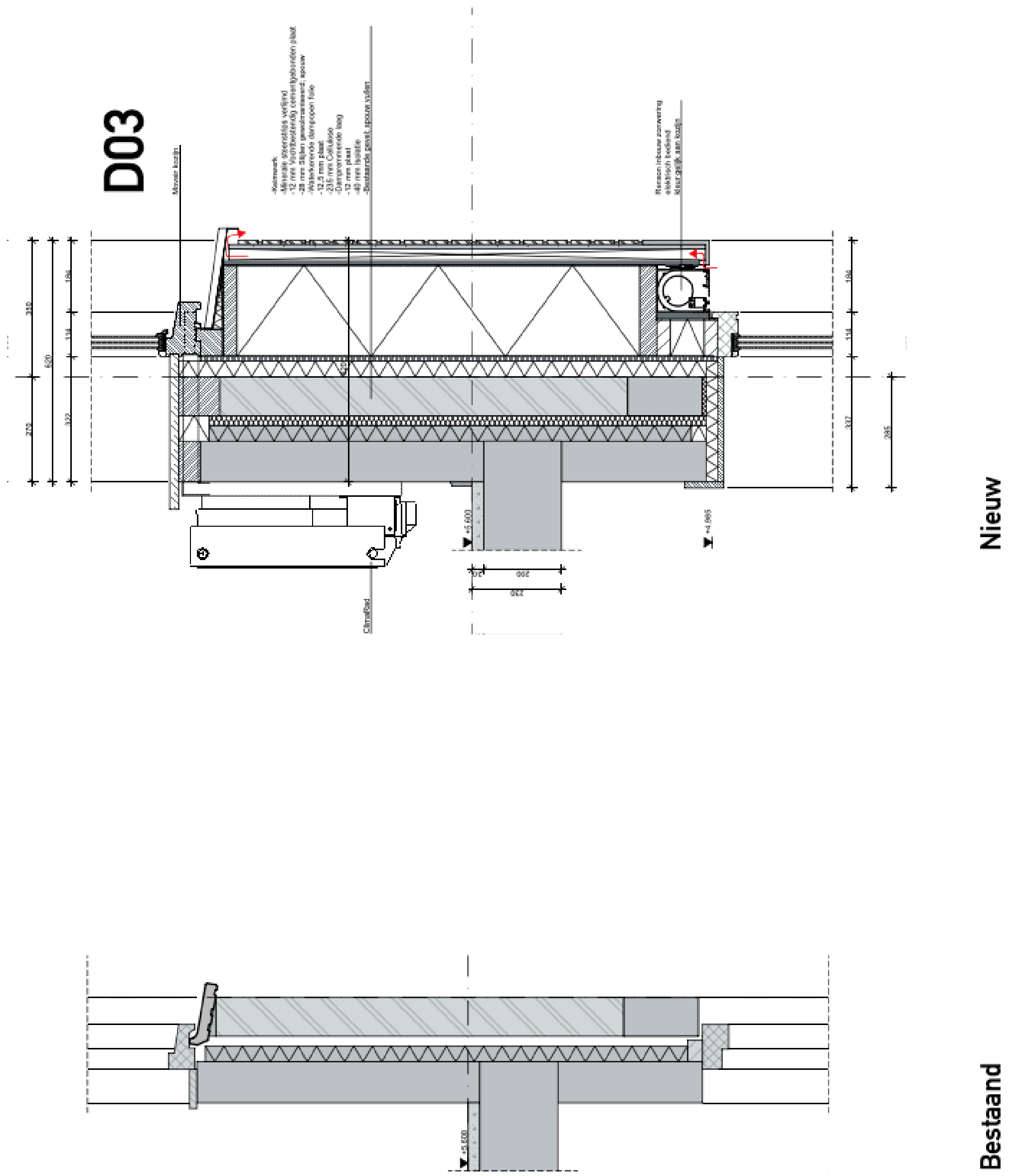


Figure 57 Cross section existing (left) and 4RinEU demo (right) façade in front of the existing cavity wall

Balcony façade

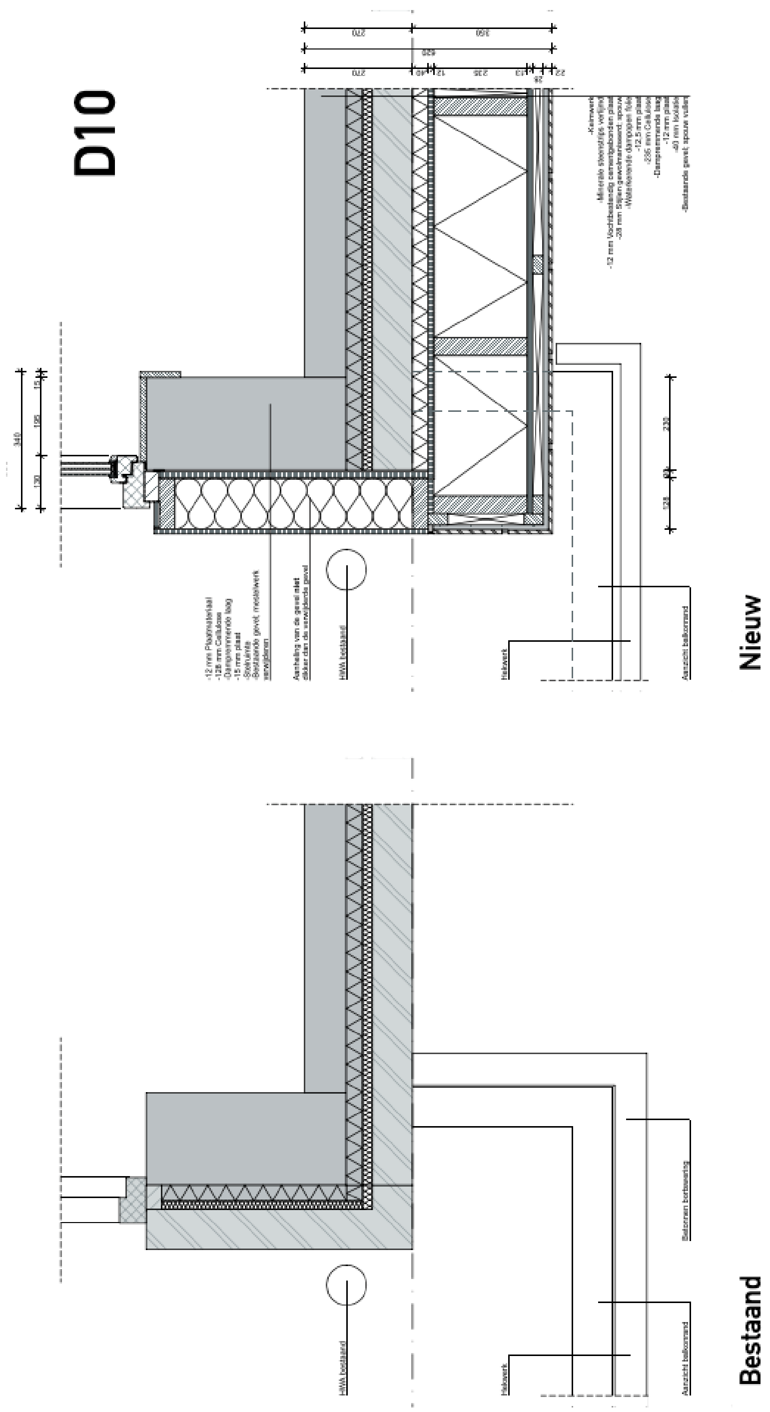


Figure 58 Horizontal cross section of the pre-retrofit condition (left) and new prefabricated façade (right) in front of the cavity wall and around the balcony. Due to the position of the rainwater sewage, the thickness of the prefab façade has been adjusted at the side of the balcony.

Bedroom façade

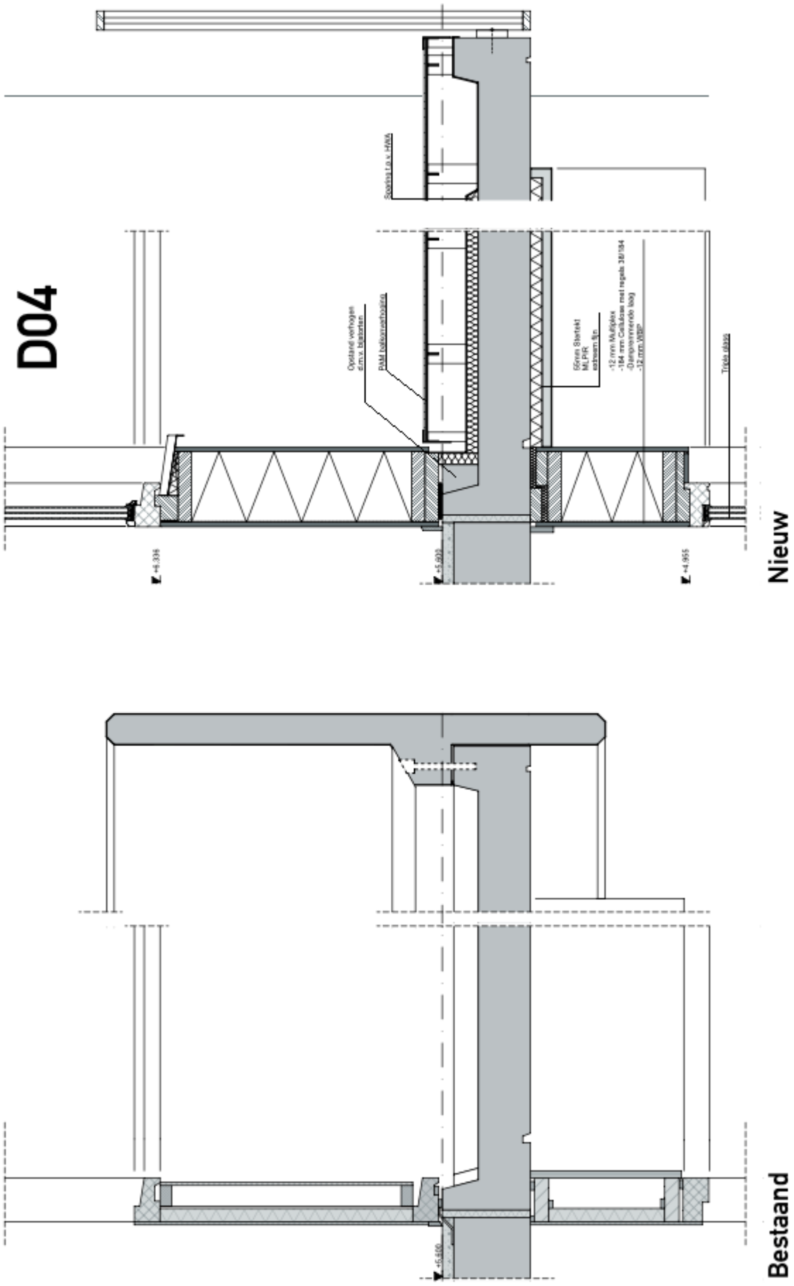


Figure 59 Cross section of the existing window frame façade between the bedroom and the balcony (left). The opaque insulation in the retrofit condition (right) is much better than normally required. Also, the thermal bridge impact of the balcony has been reduced by adding insulation on top and under the balcony slap. A new balcony floor eases the step between the bedroom and the balcony.

1.1.6.2 Other envelope renovation actions

The standard renovation of Marienheuvel and Marienhorst involves the renovation of the roof and its window openings, standard insulation of facades, replacing glazing with double low E glazing, floor insulation and replacing the communal mechanical extract ventilation with individual boxes per apartment (In the standard renovation there is a standard extraction box. In the 4RinEU part there is a special Climarad extraction box which communicates with the Climarad decentralised heat recovery ventilation). Also entrances are being renewed and all facades will be painted to improve the aesthetical quality.

1.1.6.3 HVAC system renovation

The heating and hot water system in the project have not been changed, due to a previous modernization, which is not at the end of its lifetime yet. Heating can be controlled by tenants by using thermostatic valves. The supply temperature of the system is adjusted on the basis of the outdoor temperature.

Hot water is provided by separate condensing gas boilers which supply a circulation network. It is required that the temperature is constantly above 60 degrees at the return point of the system so that legionella bacteria cannot develop.

The decentralized room ventilation system has been selected under the assumption that there is partial unbalance in the system, due to the combination of balanced ventilation and extract ventilation.

- Ventilation
  - Both in the demo parts in Marienburg and Marienheuvel heat recovery ventilation solutions have been investigated in depth.
  - Many discussions have addressed the pros and cons of whole apartment heat recovery ventilation and decentralized ventilation.
  - The advantage of whole apartment ventilation is that a balance is created between supplied and extracted air, thus achieving maximum benefits of heat recovery.
  - The advantage of decentralized ventilation is that limited ductwork is needed, and thereby facade integration becomes a possibility.
  - The disadvantage is that extraction of air from kitchen, bathroom and toilets cannot be combined with a decentralized unit.

- Ventilation solution for *Marienburg* as renovation project
  - A whole building solution for Marienburg was rejected because of the spatial impact of ductwork.
  - The ventilation solution for Marienburg was to use one whole house heat recovery unit for two care units. The air volumes needed for two bathrooms in the care sector matches the volumes provided by MVHR units available on the market. It was proposed to use the Zehnder Q350 for two units.
  - The necessary ductwork could be designed behind false ceilings above the bathrooms, and thus avoid ductwork in the bedrooms/living rooms of the care units.

- Ventilation solution for Marienheuvel demo
    - The initial choice for Marienheuvel was to use whole apartment heat recovery ventilation in order to maximise the energetic benefits of the technology.
    - However, the implementation of it would require either supply ducts from the façade and exhaust ducts to the roof or supply and exhaust ducts from and to the roof.
    - Both solutions were rejected because of the spatial impact in case of a supply duct through the living space of the apartment, and in the other case because of the structural difficulty to create additional vertical shafts through the floors.
    - Therefore, decentralized ventilation came into play as the best solution for these apartments.

- Supply chain considerations decentralized ventilation
    - Woonzorg Nederland selected two decentralized solutions out of a longer list with the main criterion to use a supplier which is able to provide maintenance service in The Netherlands. Thereby the two options were:
        - Climarad, a Dutch company specialized in decentralized ventilation, in particular by combining radiators and heat recovery ventilation into one product.
        - The other options were to use standalone decentralized heat recovery ventilation units, which are sold on the Dutch market by well-known companies like Zehnder and Brink Climate Systems.

1.1.6.4 Deep renovation 15 apartments Marienheuvel

15 apartments of Marienheuvel have used 4RinEU approach to demonstrate the feasibility of more advanced energy strategies.

Figure 60 Façade of the 4RinEU demo part: new prefab façade with new triple glazed windows, integrated shading and thermal bridge insulation around the balcony

The 15 apartments in the South-East wing of Marienheuvel have new prefabricated facades with three additionally integrated technologies: shadings, ventilation with heat recovery and summer night ventilation. The Climarad ventilation unit has a specific summer night ventilation mode which activates when needed. This can also be manually done. In addition, a new tilted window has been introduced to have more window operation modes.

- Passive elements
  - supply and installation of steel corner lines ground floor for mounting insulated façade elements, etc. in accordance with the manufacturer's specifications.
  - supply and installation of insulated facades for 15 apartments. An insulated facade element is installed on the existing facades. Structure from inside to outside will be:

- mineral wool approx. 40 mm (seal between element and existing outer leaf)
- 12 mm underlayment approximately
- cellulose insulation 234 mm
- cement-bonded plate 12 mm
- vapor-opening water-retaining foil
- cavity 18 mm
- cement-bonded plate 12 mm
- mineral stone strips 11 mm glued on cementitious slabs, attached and fitted with corner pieces (suitable for further finishing)

Figure 61 The existing insulated cavity has been post insulated. The exterior wall has been cladded with insulation before the prefab facades were mounted.

Figure 62 Scaffolding has been placed to renovate the roof and the balconies. The scaffolding has been placed on a distance to allow the mounting of the façade elements.

- frames are included for windows mounting, combined with a sun protection device.

Figure 63 Window frames and glazing were pre-installed in the factory.

Figure 64 Prefabricated elements delivered to the site and waiting to be mounted

- on site, a suspension structure is pre-set on the existing façade and installed consisting of a mounting rail that is attached to the existing façade with screwed anchors (after checking, by means of tensile tests, that the existing structure has a sufficient bearing capacity for supporting the new façade).

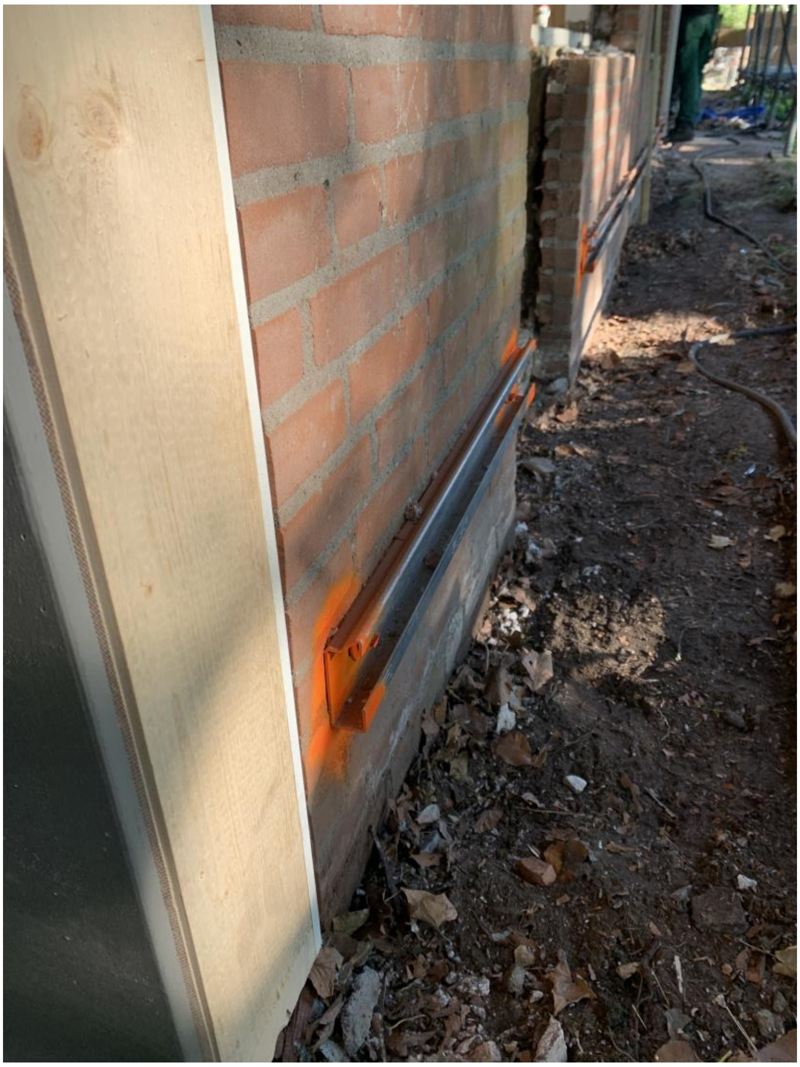


Figure 65 The first Hilti rail mounted on the exterior of the cavity wall construction.

Figure 66 Hilti railing system is mounted on the exterior façade. This method has been successfully used in previous project by Prefabfabriek Culemborg.

- after transportation, the elements are placed in their locations, fixed to the existing façade and interconnected by means of screws. After setting, the elements are mutually air-tight finished (aiming at n50 = 1,0 for the facade elements and 1,5 for the whole apartment).

Figure 67 During two workweeks a temporary wall was constructed between the living room of the tenants and the work area for the façade renewal and prefab façade application.

Figure 68 Very small daylight opening in the temporary wall.

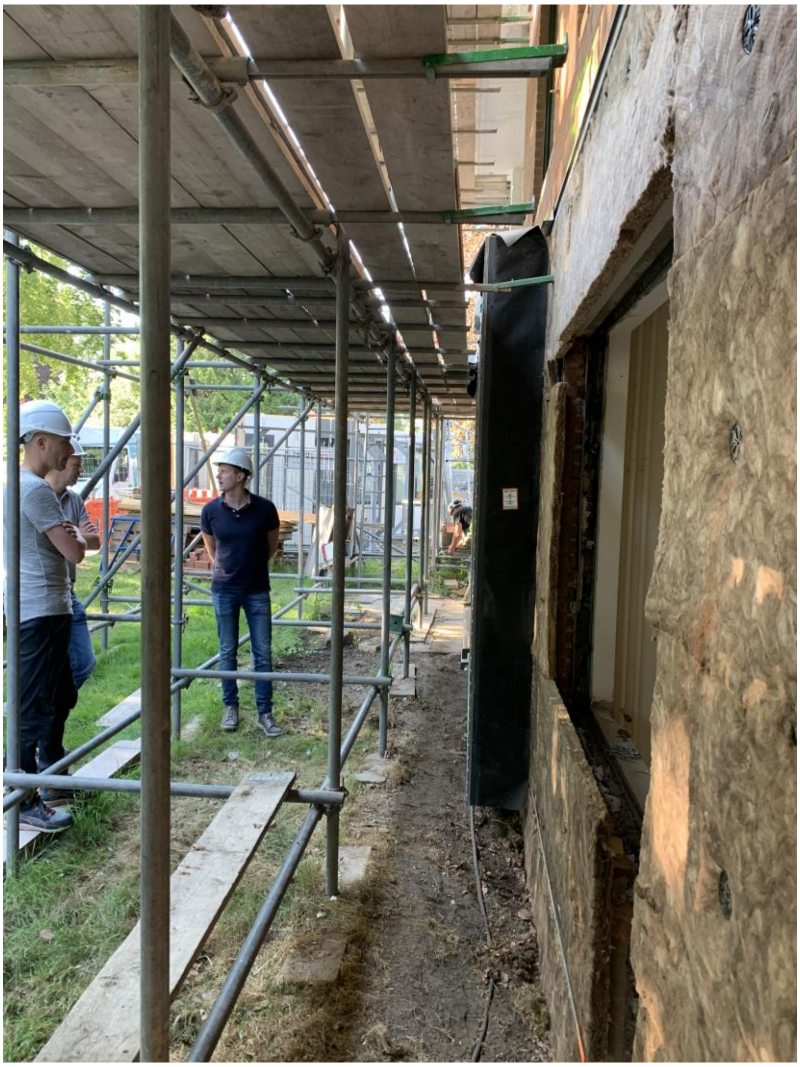


Figure 69 The prefab elements have been mounted horizontally. This reduces the disturbance and presence of construction workers. The original plan was to mount the elements vertically, which is easier from a technical perspective. The argument of tenants disturbance prevailed because of pandemic prevention measures.

Figure 70 Mounted prefabricated façade elements after a two-weeks period for all 15 apartments.

- an insulated façade element is installed at the location of the balconies. Its structure from inside to outside is:
    - plywood, painted 12 mm
    - vapor barrier film
    - supporting structure 38 x ~160 mm with cellulose
    - vapor-proofing film according to the manufacturer's advice
    - Multiplex WBP 12 mm, three-layered factory-painted

Figure 71 The width of the façade element adjacent to the balcony has been designed to leave space for the rainwater gutter.

Figure 72 The temporary separation wall between the new balcony façade and the apartment.

- on the inside, at the location of the connections of the façade elements to the walls, wooden windowsills (melamine faced chipboard) and a simple trim are installed.

Figure 73 Installed prefab façade elements around the balcony. Afterwards thermal bridge insulation has been added on the floor and ceiling of the balconies.

Figure 74 Connection of prefabricated façade and cavity wall façade near the building entrance

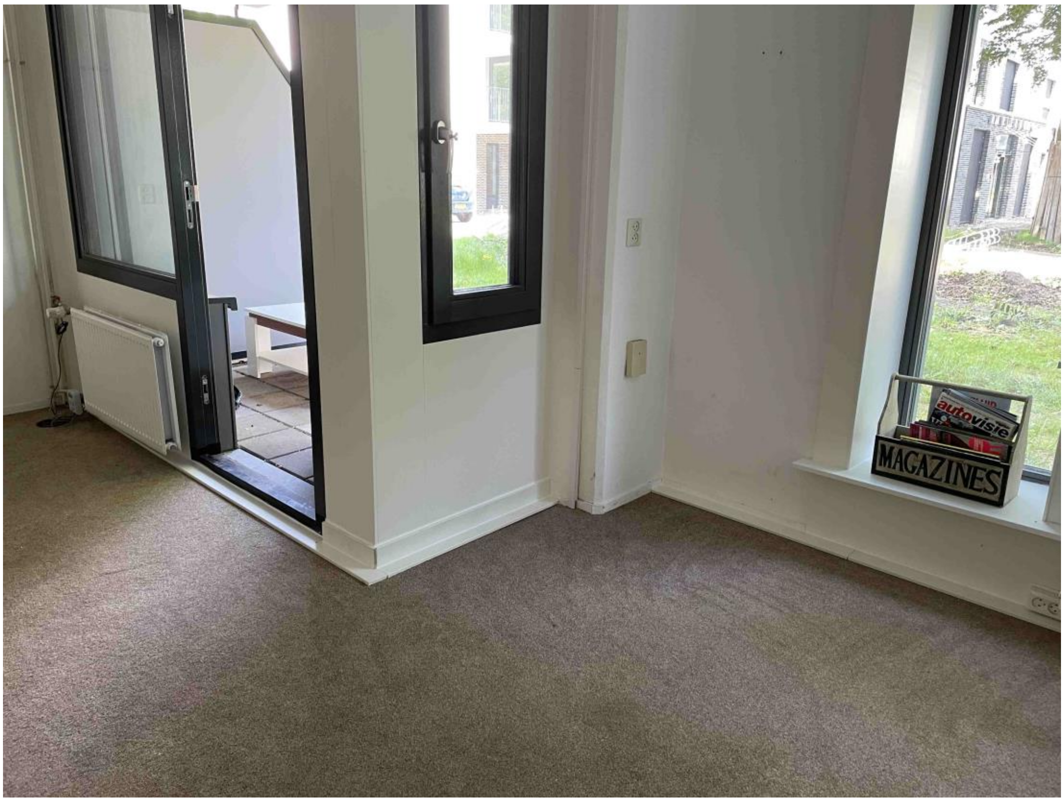


Figure 75 Finished façade elements seen from the inside.

- widening and adjusting the balcony edge for the placement of insulated façade elements.

Figure 76 Detail of the connection of the prefab façade element with the existing balcony floor slab. It shows the complications of the existing structure and the precision in the design, manufacturing and mounting process, which went well without failures.

- Integrated elements
  - In order to use the Climarad technology, the required facilities for installation have been included in 15 frames in accordance with Movair's patented system. The Climarad technology allows for:
    - air supply and exhaust with heat recovery
    - by-pass ventilation for summer night ventilation
    - pre-heating ventilation air in the combination of the radiator and the ventilation device.

Figure 77 Climarad installed behind the radiator and throughout the new envelope

The ClimaRad 2.0 is a highly innovative ventilation unit with a built-in heat exchanger and sensors for CO2, humidity and indoor and outdoor temperatures. The ventilation unit (WTW) is 'hidden' behind a tiltable radiator. This hardly takes up space. The ClimaRad 2.0 provides ventilation and heating per room and is placed against an exterior wall. Supply and discharge of air thus takes place directly through the facade, whereby the supplied air is preheated. The maximum air volume is 125 m3/h at a low fan power demand of 0.12 W/m3/h

- a sun protection device (1 per apartment) is integrated in the timber frame façade.

- the air supply and exhaust of the decentral ventilation system is integrated in the window frame and windowsill.

- additional operable windows have been designed to support natural summer night ventilation.

In the picture below it is possible to see from left to right: the decentral ventilation radiator, the inner leaf, the existing cavity with extra insulation, the outer leaf, the new insulation layer, the prefab facade element with a ventilated facade system covered with fake brick. The ventilation air supply and exhaust follow a path under the window sill and through the window frame. Also the integrated shading is visible.

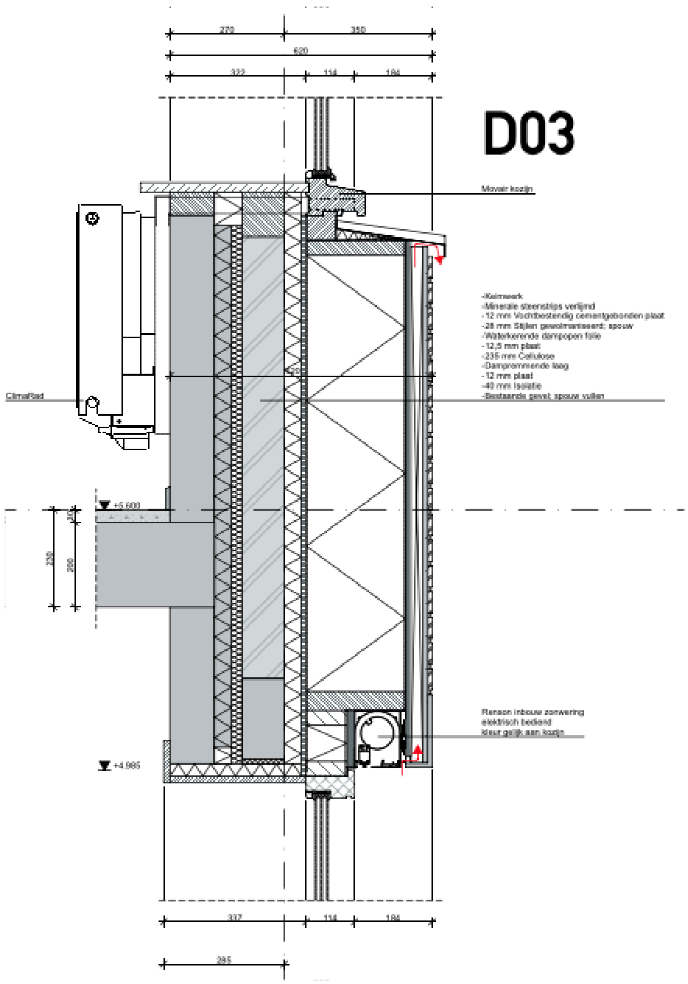


Figure 78 Window sill and integrated shadings details

Figure 79 The existing radiator has been dismantled to be replaced with the Climarad decentralized heat recovery radiator.

Figure 80 Specific timber device which guides fresh air from the façade into the decentralized ventilation unit.

Figure 81 Ducts connecting the façade to the interior (supply and exhaust air)

Figure 82 The completed decentralized ventilation radiator

Figure 83 Climarad exhaust fan for bathroom, toilet and kitchen in the 4RinEU demo-apartments.

1.1.6.5 Integration of the Energy Hub

Key issue is that Marienheuvel and Marienhorst have a communal heating and hot water system, which is vertically structured. In fact, there are multiple entry points of heat in each apartment. An energy hub system does require a full rearrangement of the warm water pipes, so that there is a single-entry point.

The key logic behind the rearrangement is to have a lower circulation temperature for hot water, since the energy hub ensures legionella free hot water generation at lower temperatures.

Secondly the control of heat flow would allow absolute heat monitoring instead of the current relative heat use monitoring.

Multiple arrangements have been analysed. The 15 demo apartments are part of a wing with 40 apartments:

- Option 1: Energy Hubs for the South East wing of 20 apartments
- Option 2: Energy Hubs only for 10 top apartments

In all cases the need of adding horizontal pipe work inside apartments was considered as problematic. Therefore option 2 could offer some comfort to the local design team by rearranging pipework through the new roof insulation.

Creating an exception for 10 or 20 out to 40 (and in total 150 apartments) was not considered as logic by Woonzorg because it would require two methods of billing heat in the same complex.

1.1.6.6 RES exploitations: results from Early Reno evaluations

Early Reno has been used to analyse the potential for PV for Marienburg. The roof and south façade had the highest potential.

In the demo apartments only the slightly Northeast oriented façade is available for demonstration.

The application of PV has been considered as part of the balcony solutions, e.g. as part of a glazed balcony façade.

However, the glazed balcony was rejected by the tenants' department of Woonzorg Nederland.

Woonzorg Nederland has recently launched a policy for PV application on their buildings. Marienburg, Marienhorst and Marienburg in future may have PV panels on the roof, connected to communal electricity uses in the building, such as general lighting, elevators and fans and pumps.

1.1.6.7 Smart Ceiling Fans

The integration of smart ceiling fans has been prepared and agreed with a number of tenants. However, at the end of the process it turned out that the fan manufacturer could not provide fans which could be applied within the available floor to ceiling height in this project. Due to European regulations, the minimum height from floor to ceiling fan must be 2.30 m. The floor to ceiling height is 2.60 m in this project, which is a rather standard height in Dutch residential buildings.

Ceiling fan devices are actually 40cm, therefore their application in the demo could not be performed.

1.1.7 Tender process description

In the Netherlands not-for-profit housing foundations as Woonzorg are not obliged to select their contractors by a multiple selection on price, when only dwellings are involved. This is the case both for new construction and for renovation works.

The tender process for the residential buildings Mariënheuvel and Mariënhorst (151 apartments all together) is best described as a 'best value'-like approach, although it did not happen completely in this way. It was not a selection where a completely engineered plan in documents and drawings was brought to the market and the price of the contractors was the only decisive KPI. Also other aspects have been taken into account.

The three aspects are: financial, technical and communication approach (communication to the residents). In this phase only a rough price is presented, to enable the owner (Woonzorg) to know whether the investment will fit to the budget.

It is a hybrid process, where after the contractor is selected, a second phase should start. Here the design team have been enlarged with the selected contractor and his subcontractors. This enlarged team elaborated the further engineering of the project together with the detailed pricing. After two months the price is determined, then the commissioning taken place.

After the commissioning there is still the possibility for a detailed engineering of parts of the project.

1.1.8 Prefab wooden-based façade system

1.1.8.1 Selection of local manufacturer

In the Netherlands the contractors and subcontractors in general are used to apply all kinds of prefabricated products, including wooden-based façade systems. Mostly all concrete elements in the Dutch construction market are prefabricated. Dutch construction is developing into an assembly-on-site industry, with the main contractors as specialists in the logistics.

Prefabfabriek Culemborg was selected by Woonzorg Nederland because of their experience with prefabricated façade elements, both in multifamily buildings (e.g. Kanaleneiland Utrecht and in low rise (e.g. Goese Polder, Goes, and earlier projects).

Prefabfabriek Culemborg combines the knowledge of a manufacturer and the experience as a main contractor. In this project Prefabfabriek Culemborg acted as subcontractor to the main contractor Heijligers.

1.1.8.2 Production time (off-site work time)

Work preparation started at the end of 2019, until week 12. A mechanical test was executed to correctly define the mounting system.

The elements were produced in the period from week 13 to week 22. All elements were completed in week 22.

1.1.8.3 Transportation time and problems

Due to Covid Pandemic there has been a time gap between the production and the mounting. The elements were first stored in the Prefabfabriek, and later on site.

1.1.8.4 Installation time (on-site work time)

The installation time happened in the foreseen timespan of two weeks for the 15 appartments. Preparation works have been carried out before and finishing works after the mounting of the façade elements.

1.1.9 Programme of the works (a detailed Gantt)

Tender dates:

3 October 2018 Presentation of the contractors (financial, technical and communication approach)

10 October 2018 Selection of the contractor

23 October 2018 Decision in Tenderboard Woonzorg

Start detailed engineering in design team (enlarged with contractor/subcontractors)

March/April 2019 Start construction works. The first phases were dedicated to the standard renovation.

December 2019 – July 2020 4RinEU project execution

July 2021 End of standard renovation in Marienhorst

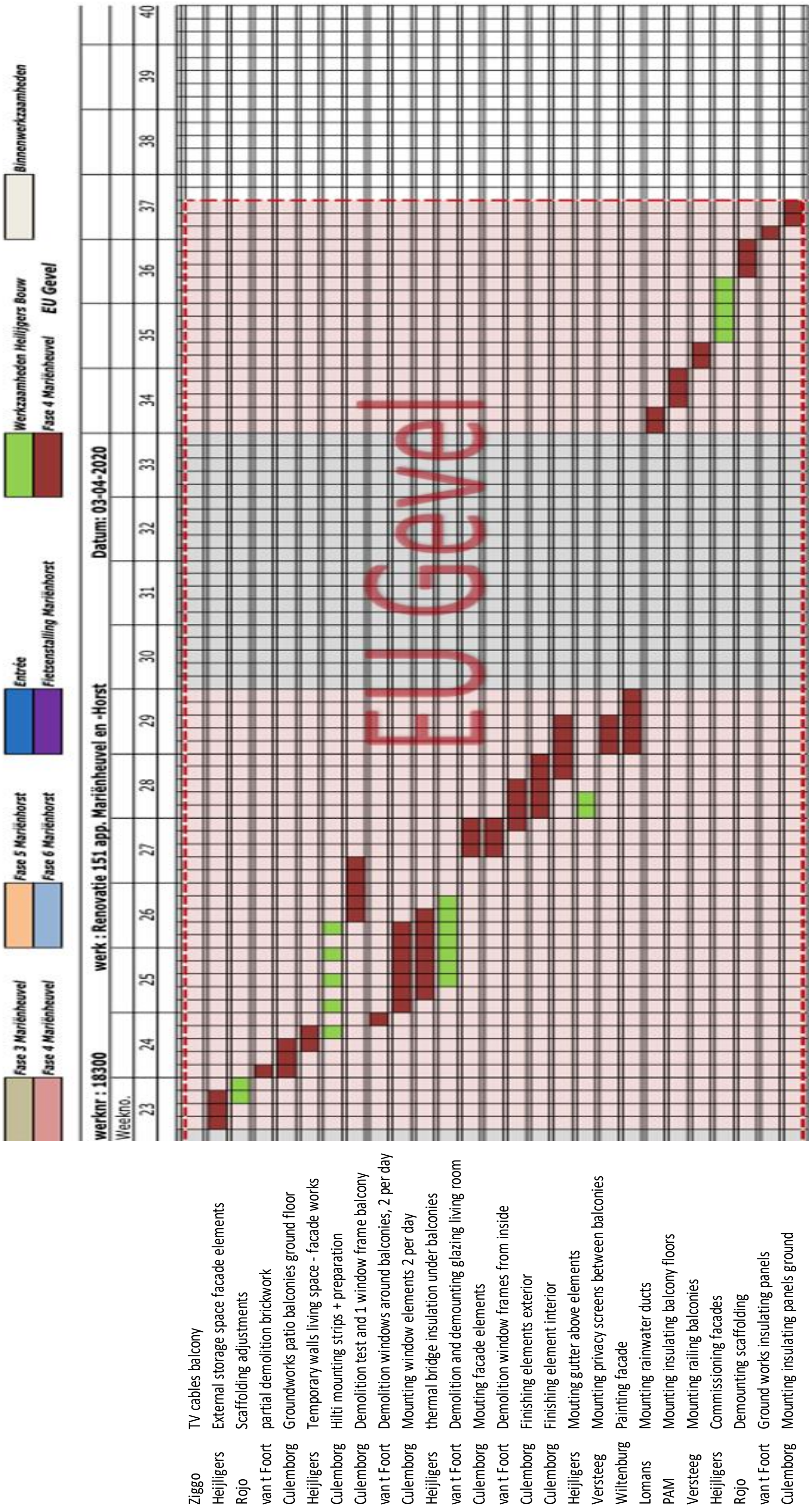


Figure 84 Detailed Schedule for Renovation Works for 4RinEU part

1.1.10 Renovation concepts: evaluation of KPIs

This section reports the results of the comparison among the proposed renovation concepts in terms of the Key Performance indicators of the 5 thematic areas.

1.1.10.1 Area 1: Energy

The Marienheuvel demonstration project meets the requirement of a net primary energy use reduction for the heating related energy flows: space heating, hot water and its necessary systems. In future the net primary energy will reduce even further when PV panels will be mounted on the roofs. The success of the project is to achieve its objectives by focusing on significant energy demand reduction, and good indoor climate conditions.

Table 23 Energy performance expressed in primary energy figures as defined the Dutch energy labelling method. Reported values refer to the simulated reference room with 51 m2 area. The primary energy reduction of the heating related energy flows is 59%. The space heating reduction is 86%

Uniec 2 - EP summary Marienheuvel Burg Grothestraat						
			exist	standard	demo	
Yearly primary energy use per function						
Space heating	EH;P	MJ	29.938	15.828	4.132	-86%
Auxiliary energy		MJ	3.823	3.733	3.658	-4%
Domestic Hot Water	EW;P	MJ	12.470	12.470	12.470	0%
Auxiliary energy		MJ	2.063	2.063	2.063	0%
Cooling	EC;P	MJ	0	0	0	
Auxiliary energy		MJ	0	0	0	
Summer Comfort	ESC;P	MJ	1.163	702	781	-33%
Fans	EV;P	MJ	7.392	2.710	452	-94%
Lighting	EL;P	MJ				
			56.849	37.506	23.556	-59%

Table 24 Net heat demand in Marienheuvel using UNIEC and PHPP9

		EXIST		STANDARD	DEMO
Net heat demand		kWh/m2		kWh/m2	kWh/m2
PHPP		125		67	20
UNIEC		132		70	19
Monitored		108			

1.1.10.2 Area 2: Comfort

In the 4RinEU demo project much attention has been given to achieve better indoor conditions and better energy performance at the same time.

- In the first place the prefabricated façade is airtight, well insulated and the window frames contain triple glazing. This concept results in comfortable surface temperatures, also near the facades and windows.

- Secondly fresh air is provided via a decentralized heat recovery unit. The particular product Climarad combines a decentralized unit with a radiator. Thus, heating and ventilation is combined in one product. Thereby heat recovery and eventual heating ensure a comfortable air supply temperature.
- Thirdly windows have been designed with external solar shading in the living room, whereas the windows of the bedroom benefit from the overhang of the balcony.
- Finally, a strategy for summer night ventilation has been integrated: the Climarad automatically turns into bypass mode when summer temperatures require this mode. In addition, there is a manual override to increase the air volume. Also, windows can be operated. A dedicated tilt and turn windows' control have been included to allow additional natural ventilation when desired.

The indoor conditions are expected to be better than in before and in standard renovation conditions.

- The insulation values of the standard renovation are such that radiators are needed to achieve a comfortable zone near the windows.
- In the standard renovation fresh air is supplied via ventilation grilles in the windows. Because the heat demand is lower than before renovation there is the risk of a too low heat capacity to comfortably heat the incoming air in winter conditions. It is common practice that tenants close ventilation grilles to avoid draught of incoming air.
- Shading is not part of the standard renovation; however individual tenants have installed their own external shading devices.
- The option of summer night ventilation is available through window operation only.
- The ventilation systems have been designed to achieve a CO2 concentration lower than 1200 ppm.

1.1.10.3 Area 3: Environment

The project Marienheuvel has focused on the reduction of the energy demand as means to achieve the 60% reduction of heating related energy flows and its CO2 emission.

Table 25 CO2 emission calculation based on the national energy label simulation method

			exist	standard	demo	
Natural gas excluding cooking						
Building related systems		m3aeq	1.206	805	472	-61%
Electricity use						
building related systems		kWh	1.822	1.254	1.009	-45%
non building related systems		kWh	1.430	1.430	1.430	
On site generated & used elektricity		kWh	0	0	0	
Exported electricity		kWh	0	0	0	
Total		kWh	3.251	2.684	2.439	
CO2-emission						
CO2-emission	mco2	kg	3.175	2.140	1.410	-56%
				-33%	-56%	
Energy performance			exist	standard	demo	
Specific energy performance	EP	MJ/m2	1.161	782	508	-56%
Quaracteristic energy use	EPtot	MJ	59.199	39.857	25.906	-56%
Allowed quaracteristic energy use	EP;adm;tot;bb	MJ	24.394	24.394	24.394	
Energy-Index	EI	-	2,04	1,38	0,9	-56%
Energy label			D	B	A	

Further reduction is possible by the application of PV on the roof, which is being investigated by Woonzorg as a strategy for their portfolio. The key message from this demonstration project is that 60% reduction can be achieved by applying energy demand reduction measures.

1.1.11 Cost analysis

Measurements and budgets of the project. Targets of 4RinEU project

- **Cost reduction of at least 15%** compared with a typical renovation (i.e. a renovation that meets current minimum requirements of existing building regulations). We considered the expected costs for energy, maintenance, end-of life and initial construction costs and we estimated the NPV along 30 years of projected life for the demo-cases for both standard renovation and 4RinEU.

  The energy performance of the 4RinEU package is much better than the standard renovation. There is no information about the cost of achieving the 4RinEU performance in a standard way.

The costs have been compared between a standard renovation and the 4RinEU renovation package. **Since the project Marienheuvel was primarily developed as a standard renovation, the costs for the 4RinEU demo renovation could be expressed as over cost in comparison with the standard renovation, as reported in the table below.** In red, the results of the evaluation are highlighted: 27,649€ for the standard renovation and an over cost of 25,761€ for 4RinEU package.

Table 26 Cost comparison between the Marienheuvel standard renovation and the over cost of the 4RinEU demo renovation.

4RinEU Cost Template	Standard renovation		Extra for demo renovation	
Project name	Marienheuvel, Soest			
Location	Soest			
Cost level at date	01/03/2020			
Number of apartments				
Treated Floor Area				
All Costs are direct costs, excl VAT and excl contractors indirect costs				
0 Total Capital Cost ('1' + '2' + '3')				
1 Capital Construction Costs	27.649		25.761	
		3.088		1.084
5 General	652			
5 Construction site costs	617		305	
10 Demolition works	905		633	
10 Sizing and measuring	31			
12 Ground works	61		53	
14 External sewage systems	10		150	
20 Foundation works	41			
21 Concrete works	18			
22 Brickwork	715		-58	
23 Prefabrication	38			
24 Structural carpentry	1.355	ex VAT and margins		
		1.355		
Roof structure entrance		93		
Dormers		805		
Raising eaves		186		
Carpentry general		76		
Roof terraces		25		
Bicycle shed		11		
Firesafety ventilation shaft		159		
			15.229	
25 Metaalconstructiewerk	66			
26 Bouwkundige elementen	79			
30 Kozijnen ramen deuren	2.020		-1.181	
		ex VAT and margins		
		4.107		
		2.112		
32 Trappen en balustrades	1.914			
33 Dakbedekking	2.371			
34 Beglazing	1.082	1.082		
36 Voegvullingen	113			
37 Naisolatie	912	912	1.035	
Marienheuvel en Marienhorst				
Vloer		536		
gevel		210		
dak		163		
balkon bij entree		3		
		3.115		
38 Facade screens	59			
40 Stucco work	38			
41 Tiling works	22			
42 Dekvloeren	6			
43 Metal and plastic works	336			
44 Ceiling systems	23			
45 Finishing carpentry	417			
46 Paintwork	1.567			
47 Interior works	196			
48 Flooring	451			
52 Mechanical Engineering	3.096		4.429	
		8.439		5.165
70 Electrotechnical installations	1.346		352	
84 Scaffolding	1.139		-	
Project works	1.552		1.673	
Construction site	549		408	
General costs	1.904		1.612	
Profit and risks	771		986	
Price increases	900			
Bank quarantee	278		133	
		1.672		11.663
Consultancy (architect etc	1.672		3.000	
4RinEU PMs			5.750	
Travel costs			1.247	
Monitoring			1.667	
		2.952		1.751
Legal costs	265			
Rental costs	695			
General costs	1.303		1.515	
Interest	689		236	
Unforeseen	1.430		1.792	

Breakdown of costs for ventilation

Table 27 Costs for ventilation improvement under standard renovation and the over costs of the 4RinEU demo renovation (left column refers to standard renovation total costs, right column for 4RinEU added part)

Mariënheuvel + Mariënhorst	3.096	
Rainwater sewage replacement	155	
New rainwater sewage	6	
Ventilation inside appartments	1.811	
Ventilation shafts	364	
Ventilation communal corridor	29	
Test house	11	
Internal costs	146	
Risks and margins	274	
construction works M&E	299	
		ex VAT and margins
EU-project Mariënheuvel		4.429
Ventilation appartments		583
Climarad 2.0		3.082
Internal costs		296
Risks and margins		423
construction works M&E		46

Breakdown of costs for prefabricated façade

Table 28 Costs of the prefabricated façade including related works per apartment

	15.229
Steel angle line - facade mounting	262
Additional works subcontractor	280
Detailed cost breakdown	
Prefabrication elements including external cover	3.871
Window frames and glazing including ventilation integration	3.652
Solar shading, delivery and mounting	1.333
Ground works and foundation insulation	305
On site mounting including transportation	1.709
On site carpentry and ventilation provisions	768
Engineering and preparation	839
Blower-door-test	50
Guarantees and follow up service	70
Internal costs and margins	1.562
Eaves and new gutter line	528

Table 29 Cost analysis of the prefabricated façade including related works

	Cost analysis per m2		
	Total facade	Windows and doors	Opaque parts
	328	126	202
	697		
Steel angle line - facade mounting	11,98		
Additional works subcontractor	12,82		
Detailed cost breakdown			
Prefabrication elements including external cover	177,25		288,03
Window frames and glazing including ventilation integration	167,19	434,71	
Solar shading, delivery and mounting	61,05	158,73	
Ground works and foundation insulation	13,95		
On site mounting including transportation	78,26		
On site carpentry and ventilation provisions	35,18		
Engineering and preparation	38,43		
Blower-door-test	2,29		
Guarantees and follow up service	3,21		
Internal costs and margins	71,54		
	-		
Eaves and new gutter line	24,16		

In the table above the analysis has been made against the total façade area. Windows and frames have also been analysed against its own area. Most striking figures are the costs of the opaque insulation, analysed at its own surface area. The figure includes the external cover of the façade, which in this case was chosen to have an identical appearance as the cavity wall construction. Therefore, intensive work had to be done as part of the prefabrication process.

It is recommended to design prefabricated facades in combination with dry, prefabricated cladding methods. In this way the maximum benefits of prefabrication can be gained.

- Cost connected to time saved during installation phase

Prefabrication results in time saving in the installation phase. It is not possible to install external insulation including façade covering at the same time. Also external insulation works depend on weather conditions, whereas prefabricated elements can be installed under most conditions, except too windy weather.

- Cost saved because tenant/user can stay at home

There is a cost saving when the tenant or user can stay at home. The standard renovation and the 4RinEU demo renovation both allow the tenants to stay at home. Also external façade insulation can be mounted around buildings in use. Therefore, in this demo renovation case, there is no cost advantage for the one technology over the other.

Table 30 Cost comparison investments versus savings average apartment Marienheuvel before, standard and demo renovation

Investment		Before	Standard	Demo	Demo - extra
	Euro		€ 27.649	€ 53.410	€ 25.761
incl VAT and margins	Euro		€ 34.976	€ 67.563	€ 32.587
maintenance	percentage		30%	30%	
energy improvement	percentage		40%	40%	
other improvements	percentage		30%	30%	
Investment energy improvement	Euro		€ 13.990	€ 27.025	€ 13.035
Gas	m3 gas	1206	805	472	
Electricity	kWh	1822	1254	1009	
Variable energy costs	Euro / year	€ 1.425,94	€ 960,13	€ 623,18	
Saving compared to before	Euro / year		€ 465,81	€ 802,76	
Saving compared to standard	Euro / year				€ 336,95
Simple pay back	years		30	34	39

1.2 Procurement and implementation

1.2.1 Timing of the construction site

1.2.1.1 Analysis of the typical duration

The contractor has made a post evaluation and compared the time needed for the standard renovation and the demo renovation:

4RinEU demo Mariënheuvel Soest	Preparation:18 weeks Execution:10 weeks	28x5=140 working days

Standard 79 appartments Mariënheuvel Soest	Preparation:8 weeks Execution: 23 weeks	31x5=155 working days

It is clear that there is a time shift from execution to preparation, which shortens the time of on-site works. Also, it was concluded that there were no mistakes or surprises in the demonstration project due to the careful preparation.

1.2.1.2 4RinEU target

- **Reduction in time needed for renovation by a factor of 2** at least compared to typical nowadays renovation.

The renovation time needed for the demo renovation time in comparison to a typical nowadays renovation appears to take longer, due to the more intense measures taken. Standard renovation involves cavity wall insulation, which is done within a couple of hours for a single apartment. Mounting a prefabricated façade costs one day per apartment, and finishing works may remain afterwards.

Achieving the same quality as the demo project does cost more time, since external wall insulation requires a number of sequential steps, which cannot be done within one day per apartment.

It seems that, in this application, reduction in time compared to this particular standard renovation is hard to be achieved.

1.2.2 KPIs linked to the construction phase

Name		Description	Formula	Unit
	Number of accidents	Number of accidents in comparison with the number of workers in the same period.	Number of accidents (nr.) / average number of workers (nr.)	[-]

4RinEU demo Mariënheuvel Soest	Number of (almost) accidents is 1	The hoist loop of one prefabricated facade element has been snapped during hoisting work. Prefab Fabriek Culemborg conducted an investigation and concluded that the confirmation of this hoisting loop was not in accordance with the regulations. Lift loops have been further checked and repaired.	Number of (almost) accidents is 1 in 8 employees.	number
Renovation 79 app. Mariënheuvel Soest	Number of (almost) accidents is 3.	Loose scaffolding that is not laid back after work has been completed. Painter stumbles on scaffolding due to inattention over his instant spray. Glazier cuts in his finger during replacement glazing in the facade frames .	Number of (almost) accidents is 3 in 35 employees.	number
	Frequency of accidents	Number of accidents to be reported in a period compared to the working hours on the site	Number of accidents (no.) / Man * hours (h)	[Number / h]
4RinEU demo Mariënheuvel Soest	Number of (almost) accidents is 1		Number of (almost) accidents is 1 in 8 * 40 man-hours employees.	number
Renovation 79 app. Mariënheuvel Soest	Number of (almost) accidents is 3.		Number of (almost) accidents is 3 per 35 * 40 man-hours employees.	number
GS - AC	**Accidents costs**	Direct and indirect costs of accidents over a period of time	Costs of accidents (€)	[€/h]

		compared to working hours at the location	/ Man * hour (h)	
4RinEU demo Mariënheuvel Soest	Number of (almost) accidents is 1	In this accident, direct and / or indirect costs have been incurred. Repair costs were also not applicable.	.	
Renovation 79 app. Mariënheuvel Soest	Number of (almost) accidents is 3.	Painter suffered a sprained arm, resulting in 3 days of absence (unable to work)	1 painter at € 45.00 / hour x 3 * 8 man-hours	
	Transport optimization	Total hours of unnecessary movement and handling of goods compared to the total transport hours	Unnecessary machine hours (h) * 100 / Total machine hours (h)	[%]
4RinEU demo Mariënheuvel Soest		With this elaboration of prefabricated facade elements, the transport with crane hours is coordinated with each other throughout the filled days. No notable waste.	.-	
Renovation 79 app. Mariënheuvel Soest		Because the jetty cannot be fully loaded with material / equipment, it must be periodically sacrificed. This often requires shorter periods of crane deployment and / or deployment of various locations of this mobile crane	4 pieces of mobile 70 tons per 2 crane hours required but minimum decrease is 3 crane hours. A total of 4 tap hours of unnecessary machine hours	
	Inventory surplus	Total cost of excess inventory compared to total cost of works	Cost of inventory deductible (€)*100 / Total cost of the works (€)Total cost of excess inventory compared to the total cost of the works	[%]

4RinEU demo Mariënheuvel Soest		There is no excess in terms of materialization in this elaboration of prefab facade elements. Leftover sheet material or fitting pieces are used in other elements for reuse.	.-	
Renovation 79 app. Mariënheuvel Soest		In view of the equivalent activities as the EU facade, we have an excess in stock with the following parts: - joint mortar (repair jointing); - sheet material (replacing parapet; - mineral wool insulation (post-insulation parapet)	excess in inventory costs - joint mortar (sand and cement) € 557.00 - sheet material (plywood) € 154.00 - rock wool insulation € 85.00 - waste container in connection with not able to reuse € 225.00 Total approx. 2% cost of excess	
	Delay due to inventory manageme nt	Total hours of delay due to lack of stock compared to total hours of work	Total hours of delay (h)*100 / Total hours of work (h)	[%]
4RinEU demo Mariënheuvel Soest		None	.-	
Renovation 79 app. Mariënheuvel Soest		None	-	
	Net profit (Confidentia l data of the construction company)	Profitability of the construction: Net profit after tax compared to the total proceeds of the works	Net profit (€)*100 / Total turnover (€)	[%]

4RinEU demo Mariënheuvel Soest		The pre-forecasted net profit of 4% was not achieved due to overrun planning, more deployment of workers and repair work. Total net profit left over is 1.5%	pre-forecasted net profit of 4% = 14,785.05 remaining net profit is 1.5% = 5,544	
Renovation 79 app. Mariënheuvel Soest		The pre-forecasted net profit of 3% is partly achievable due to the delay in the Corona schedule and agreed additional/less work. Work is still active, forecast total net profit remaining is 2.0%	pre-forecasted net profit of 3% = 116,421.49 remaining net profit is 2.0% = 77,614	
	Change cost factor	Total cost of changes to the works (due to design errors) compared to the original budget of the works	Cost of changes (€)*100 / Total initial cost (€)	[%]
4RinEU demo Mariënheuvel Soest		Due to the lengthy work preparation and mutual coordination/determination of the design, no design errors occurred. However, the advice of Prefab Factory Culemborg for a follow-up project is to look at an alternative construction of the elements that are less thick but contain the same Rc value. Extra manpower has been deployed on planning / work sequence to limit run-out in the planning	Extra workers 2 men á 2 weeks = 160 man hours á 45.00 = 7,200	
Renovation 79 app. Mariënheuvel Soest		The work of the regular renovation has been accelerated with a short preparation time. As a result, it is sometimes necessary to look for solutions on location that have not been sufficiently investigated in advance, for example the construction of the steel seam cladding.	Construction of steel seam cladding, must nevertheless be applied with ventilation. Additional costs as a result of a design error amount to approximately € 25,000	

	Impact of repairs (internal)	Total direct cost of field rework compared to total cost if no repairs	Cost of repairs (€)*100 / (Total costs - Cost of repairs) (€)	[%]
4RinEU demo Mariënheuvel Soest		Repair work was carried out by the painter and by Prefab Fabriek Culemborg. Painter for repairing / neater finishing of the cladding on the inside / outside, including carpentry. PFC for repairing the mutual seams/dilitations with associated brick slips.	Extra painting work that we had not foreseen in advance amounts to € 6,750. Additional repair work for PFC amounts to € 3,750	
Renovation 79 app. Mariënheuvel Soest		Because we are dealing with partial deliveries and work has gone through phases with the same disaplines, the costs for repair work have been limited to date. Or problems should arise after delivery within the warranty period	-	
	Total duration of the works	Duration of all works of adaptation	Duration in working days	[Days]
4RinEU demo Mariënheuvel Soest		Preparation:18 workable working weeks Execution: 10 workable working weeks	28x5=140 workable working days	
Renovation 79 app. Mariënheuvel Soest		Preparation: 8 workable working weeks Execution: 23 workable working weeks	31x5=155 workable working days	
	Job Delay (to be measured in	Total hours of delay in a specific task	Total number of hours delay	[%]

	the main tasks of the project)	compared to the original schedule	in a specific task (h) * 100 / Planned duration of the task (h)	
4RinEU demo Mariënheuvel Soest		In the end, the work was carried out in accordance with the agreed schedule.		
Renovation 79 app. Mariënheuvel Soest		The work was carried out within the agreed schedule. approx. 10 workable days saved		
	Time impact of repairs	Number of hours of repairs compared to the total number of hours	Time in repairs (h)*100 / Total hours (h)	[%]
4RinEU demo Mariënheuvel Soest		The repairs were carried out within the overall planning.		
Renovation 79 app. Mariënheuvel Soest		The repairs were carried out within the overall planning.		
	Plan again	Number of times the schedule is renewed compared to the total duration of the works (in months)	Number of times the schedule is rerun (no.) / Run time (months)	

4RinEU demo Mariënheuvel Soest		Due to the corona measures, we have changed the assembly sequence from the original from bottom to top to build from left to right. This is to be in the house as short as possible (5 workable working days) As a result, the planning has changed, but the lead time has been preserved.	1x	
Renovation 79 app. Mariënheuvel Soest		Due to the corona measures, the project has been stopped for approximately 8 weeks to await the corona control measures and to make a new plan of approach.	1x	
	Electricity use	The total electricity consumption during the works compared to the total amount	electricity (KWh) / Built area (m2)	[KWh / m^2]
4RinEU demo Mariënheuvel Soest		The total electricity consumption (Manufacturing elements and mounting elements) is 30663.09 kWh		
Renovation 79 app. Mariënheuvel Soest		The total electricity consumption (during regular construction work) is 39180.50 kWh		
	Oil consumptio n	Total oil consumption during the works compared to the total amount	Oil (liters) / Built-floor area (m^2)	[liters / m^2]

4RinEU demo Mariënheuvel Soest		The total fuel consumption (transport elements and mounting elements) - delivery material PFC 225L - transport 225L - crane hours 800L	1250L	
Renovatie 79 app. Mariënheuvel Soest		Total oil consumption (transport and assembly) - delivery material 475L - crane hours 800L	1275L	
	Deposit rate	Total weight of the material sent to landfills compared to the total amount	Bulk waste (Tn) / Built surface (m2)	[Tn / m^2]
4RinEU demo Mariënheuvel Soest		Number of waste containers used 1x 6m³ wood = 1,800 kg 1x 6m³ unsorted = 2,160 kg 0.5x 6m³ rubble = 3,000 kg	6960 kg	
Renovatie 79 app. Mariënheuvel Soest		Number of waste containers used 4x 6m³ wood = 7,200 kg 8x 6m³ unsorted = 17,280 kg 3x 6m³ rubble = 18,000 kg	42.480 kg	
	Recycling	Total weight of the material sent to the recycling plant compared to the total amount	Recycled waste (Tn) / Built area (m2)	[Tn / m^2]
4RinEU demo Mariënheuvel Soest		Number of waste containers used 1x 6m³ wood = 1,800 kg	4.800 kg	

		0.5x 6m³ rubble = 3,000 kg		
Renovation 79 app. Mariënheuvel Soest		Number of waste containers used 4x 6m³ wood = 7,200 kg 3x 6m³ rubble = 18,000 kg	25.200 kg	

1.3 Commissioning

Commissioning tasks done over the HVAC and other facilities installed to ensure that they perform properly.

1.3.1 Prefab façade in the factory

All prefabricated façade elements have been tested by Blowerdoortest of the prefabricated facades in the factory.

1.3.2 Facility Prefab façade on site

One apartment has been tested by a Blower-door test in the apartment.

The result was almost as good as aimed for. The n50 value was 1.7 ach whereas the objective was 1.5 ach, as presumption in the energy simulations for the 4RinEU demo project. Specific leaks between the prefabricated window element and the floors were identified. Since the flooring material of apartments remained in place it is hard to improve this specific small gap afterwards. In one apartment these corrective measures were taken. In this case a new blower-door test resulted in the required n50 value of 1.5 for the whole apartment.

Figure 85 Blower-door test in an unoccupied apartment in Marienheuvel, Soest

1.3.3 Facility building works and HVAC

Normal commissioning of construction works has been done by the contractor and the installer carried out tests of settings of the HVAC installations, in this case the Climarad heat recovery radiator.

1.4 Conclusions

1.4.1 Lesson learned

The main lessons from Marienheuvel Soest are that there is a real added value in insulating well above minimum values.

Net space heating demand

- From 100-120 kWh/m^2 year (pre-renovation levels)
- to 70 kWh/m^2 year (normal renovation)
- to 20 kWh/m^2 year (deep renovation)

These reduced figures for deep renovation are in line with macro scale scenarios, such as the IEA Pathway for 2050. This scenario requires at least two third energy demand reduction, to allow for a renewable energy supply for the remaining one third.

The technical innovations are:

- better façade insulation – normally cavity wall insulation.
- better parapet insulation – normally the parapet is insulated to the level of low E glazing instead of the demonstrated values in this demo project.
- Triple glazing, which is not yet standard in the Dutch construction market.
- Shading, integrated in the façade element, which is not common in the Dutch residential market.
- Decentralised ventilation with heat recovery, which is uncommon. In most cases there is direct fresh air supply via ventilation grilles in windows.
- Summer night ventilation is not common yet, though since 2021 the concept has become a variable in building regulations for new construction.

Process

- Tenants' impact has been high;
- but during short period.
- Because of the combination of standard and deep renovation, the tenants have experienced 9-month scaffolding.
- The scaffolding resulted in a revision of the prefabricated mounting system. The prefabricated façade works on the façade and the elements around the balconies did not require full time scaffolding and has therefore been revised on the basis of the presence of scaffolding.
- There have been issues between main contractor and prefabricated façade supplier working at the same site. These issues were mainly related to the two parts having different views on the necessary approaches.
- Prefabricated methods should be based on dry construction methods instead of mix with 'fake' brick look, as chosen by the architect and the city council to achieve an architectural appearance which is line with the traditional construction method, e.g the appearance of a brick façade. This solution creates a wet workflow on a dry prefab system and increases the costs of prefab elements.
- The amount of work off site minus work on site plus the time for connections should be further developed to increase the share of off-site work. In this case some finishing works have been left as on-site work, such as timber paintwork and final painting of the fake brick façade. If a dry cladding method was chosen there would have been less on-site work for the solution.
- Good integration in total site renovation. The 4RinEU with its integrated ventilation system, the integrated shading and the 300 mm thicker wall is hardly visible for those who are not aware of the demonstration project.

1.4.2 Main further recommendations

In future cases there should be a comparison of solutions: either thick insulation with low environmental impact or thin insulation with higher impact, but easier to handle. In this project the choice for a renewable insulation material was made, which has a lower insulation value than most standard insulation materials. Given the desired insulation value the selected façade structure was 10 cm thicker in comparison to an equally insulated traditional EPS of PUR based one.

There should be more discussion before on acceptable tolerances between elements. This matured at the point where 4 elements meet. How many millimeters difference between elements should be allowed, or could be avoided by design or should be acceptable as compared to the other parts of the building.

There should be a better discussion on the connections between the new elements and the existing structure, to avoid discussion on airtightness between existing and new components. In particular when external parties mount elements in a project.

Expectation management is needed, both towards tenants and among professionals. It is important to explain the impact for tenants in advance in order to achieve the willingness to accept the works, and to know what to expect in advance. Among professionals there is the need to agree on tolerances and the level of perfectness of prefabricated elements mounted to an existing building. A common understanding is needed to achieve mutual understanding of not acceptable and acceptable tolerances in an existing building.

Spanish Demo Case

Figure 86: Spanish demo with the renovation almost finished.

1.1 Design management

1.1.1 Project context

Agencia de l'habitatge de Catalunya (AHC) is a public entity in charge of implementing the Catalan government housing policies. One of its functions is to manage, maintain and renovate the social housing stock of the Catalan government. According to CTE[1]

[1] CTE: Acronym for the Spanish Technical Building Code ("Código Técnico de la Edificación"). It was approved by RD 314/2006, in 17th of march, and it regulates the Building basic standards. https://www.codigotecnico.org/.

regulations, in Catalonia, zones D and E are the regions where the climatic conditions are more extremes, and consequently buildings have a higher level of energy consumption. In Lleida province, these harsh climatic zones, are quite common.

Bearing in mind this aspect and taking into account the high standards of energy renovation that 4RinEU solutions provide, AHC, considered to select the demo-buildings between the residential blocks of Lleida province with identified problems of energy poverty.

Until 2018, the proposed demo case was a residential building in num.6 of Alsamora street in Lleida city -climatic zone D3-. This five-story block, in the ancient city center, had 23 dwelling addressed to users with risk of social exclusion. The case was studied in depth from multiple angles: façade renovation, ventilation integration, renewable energy applications, and defining the demonstration solutions and energy performance. The building singularities (i.e. curved façade, difficult access to the building site with big trucks) caused an increase of the 4RinEU solutions cost, that was not foreseen initially, and to proceed with this demo case's renovation turned to be unaffordable. In addition, there were external difficulties to obtain municipalities agreement regarding the increase of the main façade thickness.

Therefore, it was decided to replace this first demo case with another residential building, in a new location -in num.9, La Vall street, in Bellpuig town- same climatic zone D3-. It is a four-story building, divided in two blocks in a row due to the terrain's topography. They have a unique entrance, in the East façade -street façade- between both blocks. They also share a common stair, that connect the common corridors placed in the west-façade -inside façade-and built as open spaces. The basement is half-underground and allocates the car park. The other 3 levels have a residential use – 5 apartments/floor- with a total of 15 dwellings. *A more detailed description of this 4RinEU new demo case building is explained in Project Deliverable D5.2. Concept design and performance targets for the demos.*

Regarding the project, all the dwellings are included in the renovation action, although in different degree. Due to financial restrictions, the envelope's increase of insulation is exclusively implemented on the roof and on the East-façade. In the West façade, just some improvements have been carried out –to control ventilation/infiltrations and sun radiation-.

In addition, urban regulations limited the thickness of Ground floor street façade. Therefore, the 4RinEU solution of the Prefabricate Multifunctional Façade (PMF), thicker than normal insulation, is applied in first and second floor -including balconies replacement-, while the Ground floor envelop is solved with a conventional ETICS with EPS- and no improvement in the openings-. As a result, the Ground floor level, achieve lower standards of insulation than the part renovated with 4RinEU solution.

This regulation has been recently reviewed and modified the, through RD 732/2019, approved the 20th December 2019, during the 4RinEU project.

1.1.2 Design team

To identify the overall design team, it is necessary to split the Design Procedure in two phases: the *Execution Project* -that allowed to open the public construction procurement tender – and the *review before the construction works* -with the timber manufacturer on board-.

In the first phase, the design core-team consisted in a collaboration between *Agencia de l'habitatge* employees and external collaborators. The structural architect, Jorge Blasco, from *Estudio M103*[2] office, and Josep Bunyesc, from *Bunyesc Arquitectura*[3] office - specialized in sustainable timber buildings- carried out a technical advisory to adapt the timber façade construction details to local practices.

In this phase, it was also important the contribution of the 4RinEU partners directly involved in Local Demo Working Group (LDWG) of the Spanish demo-case. Those partners are: *Acciona, Aiguasol, Aderma, EURAC and Gump&Maier.*

In the second phase, the *Agencia de l'habitatge* team, still worked in collaboration with *Estudio M103*, and incorporated the construction company that was selected in the procurement tender procedure, *Construccions Arids i formingons* (Grup *Viscola)*[4], with its subcontracted timber manufacturer, *Tall Fusta*[5].

1.1.3 Management process

In this chapter, a description of the relationships between the roles is reported.

Regarding the *Agencia de l'habitatge* team, it was integrated by several employees from different Departments. A Project Manager supervised and coordinated the tasks of several professionals involved: architects, engineers and proximity managers. The specific contribution and responsibilities were distributed between three main internal services.

- **External Action Team** of *Agència de l'habitatge* –technicians Anna Mestre and Ines Fabregas-, were in charge of the Project Management. They were in the lead of the overall project, responsible for the aesthetic, all drawings and the documents for the procurement, in addition, responsible for the feasibility of the project.

- **The technical Dpt.** of *Agència de l'habitatge* led by Director Josep Linares with a multidisciplinary team -including architects and engineers- provided the information of the 4RinEU demo case, wrote the engineering part of the renovation project (photovoltaic system, ventilation system, etc), as well as supervised the content of the global Executive Project for the procurement.

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[2] https://estudi-m103-slp.negocio.site/

[3] http://www.bunyesc.com/

[4] http://www.viscola.com/

[5] http://www.tallfusta.com/

- The **Lleida's delegation** of *Agència de l'habitatge*, led by Architect Cristina Casol, gave support in the relation with tenants (to obtain information and permissions) as well as taking care of the interests of the residents. In addition, they have lead the works of the renovation, assuming the Work's Direction -Jordi Arqué- and adjusting the Executive Project to the Construction works on the building site.

The *Estudio M103* office – represented by Jorge Blasco- is responsible for the structural engineer calculations of the timber structure in PMF facade, as well as the calculations of the anchoring system. Moreover, it is the official author of the global renovation project.

The consultant in sustainable timber construction – Josep Bunyesc – reviewed the construction details of the PMF facade, to improve them and adapt then to local practices. He also prepared a report about the PMF facade maintenance needs in the future taking into account the local context.

Regarding software, the team worked with a mixture of traditional and modern ones. In the First Phase, the design team uses conventional CAD software to design the project and WIN-EVA software to do the structural calculations. After, the selected building company, worked with a BIM based software to design the Prefabricated Façade Models.

1.1.4 Main meetings

In this chapter, a description of main workshops and meetings carried out is presented.

18th October 2016

Lleida's Municipality Meeting I

To explain to the municipality the 4RinEU project and the idea of implement its solution in a Demo-case in Lleida (the first Spanish Demo-case after discarded).

Attendants: Lleida's Municipality (Joan Blanch i Ripoll), AHC (Cristina Casol, Cristina Cardenete)

13th December 2016

LDWG in Lleida I

To visit the Demo-case. Planning of auditing activities and expected results, definition of working approach and responsibilities, alignment on demo-case state, needs, targets, planning and scheduling activities.

Attendants: AHC (Anna Pujol, Gerard Valls, Anna Mestre, Cristina Casol, Jordi Arqué, Cristina Cardenete, Josep Linares, Neus Parera), AIGUASOL (Aleix Vallverdú, Jordi Pascual), EURAC (Roberta Pernetti, Roberto Lollini), ACCIONA (Diego Romera), ADERMA (Marco Guiliani).

24th January 2017

LDWG in Lleida II

To select the Kit of 4RinEU solutions for Spanish demo-case. To analyse the timber manufacturers market. To define strategies and calendar for next actions.

Attendants: INCASOL (Gonçal Marquès, Cristina Clotet), AIGUASOL (Aleix Vallverdú, Jordi Pascual), AHC (Josep Linares, Gerard Valls, Anna Pujol, Blanca Badia, Cristina Cardenete)

11th July 2017

Lleida's Municipality Meeting II

To receive information about the technical and administrative documents need to obtain the Works License.

Attendants: Lleida's Municipality (Montse Plemsa), AHC (Blanca Badia, Inés Fàbregas)

19th October 2017

LDWG in Lleida III

To interchange knowledge, between the LDWG partners and local timber experts, regarding the timber construction systems available - technical and administrative singularities of the Catalan context.

Attendants: AIGUASOL (J.Pacual), EURAC (Francesco Babich, Riccardo Pinotti), G&M (Maximilan Schlehlein), INCAFUST (Jordi Gené, Eduard Correal, Marcelo), AHC (Jordi Arqué, Anna Mestre, Anna Pujol, Gerard Valls, Inés Fabregas)

6th November 2017

Industry Technical Development Centre Meeting[6] (CDTI Meeting)

Meeting to clarify doubts about the eligibility of each cost AHC had related to 4RinEU implementation, as well as, to understand the procedure to registrate each cost.

Attendants: CDTI (MªPilar González), AHC (Inés Fàbregas, Anna Mestre, Jose-Pablo Rodríguez)

20th March 2018

LDWG in Barcelona I

To expose to the partners the technical and financial difficulties of first Spanish Democase (in Lleida) and achieve an agreement to change the demo-building in Spain.

Attendants: EURAC (Roberta Pernetti, Roberto Lollini, Francesco Babich), ADERMA (Marco Giuliani), AIGUASOL (Jordi Pascual, Sara Fuste), Gumpp & Maier (Maximilan

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[6] Translation of the official name Centro de Desarrollo Tecnológico Industrial (public national entity)_ http://www.cdti.es/

Shlehlein), ACCIONA (Diego Romera), THERMICS (Stefano Mauro), AHC (Cristina Casol, Inés Fàbregas, Anna Mestre, Gerard Valls, Anna Pujol)

15th May 2018

Bellpuig's Municipality Meeting

To explain the 4RinEU project in the current Spanish Demo-case of Bellpuig town.

Attendants: Bellpuig's Municipality (Jordi Bosch, Esther Montoy, Núria Pons), AHC (Jordi Arqué, Inés Fàbregas)

6th November 2018

Catalan Carpenter's Association[7] Meeting I

To meet the Coordinator of the Catalan Carpenter's Association and to ask for cost estimation regarding timber windows as AHC normal renovation projects use just aluminium o PVC windows.

Attendants: AHC (Inés Fabregas, Mª Rosa Soler, Anna Mestre, Idoya Saez) Gremi de Fusta I Moble (Salvador Ordoñez), Several companies specialized in timber windows: FUSTERIA ALEGRET, FUSTERIA MOLA, CARIMBISA, ROI

7th November 2018

LDWG Barcelona II

To review the monitoring system and the Prefabricated Façade solution in Bellpuig. As well as to analyze the different type of Public procurement tenders, depending on costs restrictions and time available.

Attendants: ADERMA (Marco Giuliani), AIGUASOL (Jordi Pascual), ACCIONA (Ignacio González), EURAC (Riccardo Pinotti), G&M (Maximilan Schehlein, René Schröttle), AHC (Jordi Arqué, Blanca Badia, Jorge Blasco, Inés Fabregas, Gerard Valls, Anna Mestre, Anna Pujol)

23rd November 2018

Catalan Carpenter's Association Meeting II

To explain the Renovation project of 4RinEU, specially the PMF façade, in order to obtain information about the timber construction sector in Catalonia -capabilities, technologies, type of services-.

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[7] Catalan Carpenter's Association official name is "Gremi de fust i mobile de Catalunya" (https://gremifustaimoble.cat/)

Attendants: Gremi de Fusta i moble: (Salvador Ordoñez), AHC (Jordi Sanuy, Josep Maria Enrich, Blanca Badia, Anna Pujol, Inés Fabregas), Estudio M130 (Jorge Blasco)

28th November 2018

Catalan Carpenter's Association Meeting III

Open presentation of the technical details for the PMF façade was organized in the Carpenter's association. The objective was to explain the project to the timber manufacturers and ask them to present estimation costs adapted to the catalan market – as AHC had no previous examples of costs and need a detailed estimation cost to open the tender procurement. It is important to add, that the conventional Spanish/catalan data base with construction prizes references, did not have any example similar neither.

Attendants: Gremi de Fusta i moble (Salvador Ordoñez), AHC (Anna Mestre, Inés Fabregas), *Estudio M130* office (Jorge Blasco), *Bunyesc* office (Josep Bunyesc), *ML I associats* office, Arquima, Tall fusta.

3rd April 2019

INCASOL Meeting

To inform INCASOL about the renovation works of the Demo-case and its cost, as building owner and to arrive an agreement about the financing procedure.

Attendants: INCASOL (Ferran Casanovas, Fernando Aranda, Joan Estrada), AHC (Anna Mestre, Inés Fabregas)

In between above meetings, several on-line meetings between LDWG partners, took place addressing the progress and content of the 4RinEU demo case in Spain. In addition, there were multiple internal meetings at *Agencia de l'habitatge*.

It is also important to remark, that AHC had conversations – by email and calls- with:
- The Fireman's Department in Lleida, in order to obtain its acceptance regarding the new PMF Façade, due to its timber structure.
- Different departments of *Generalitat de Catalunya* (Catalan Government) to search for extra funds for the renovation (ERDF)

1.1.5 Design targets

This chapter presents the targets taken into account during the design of the renovation project, summarizing the values presented in *Deliverable D5.2 (chapter 3.4.2) of 4RinEU project.*

1.1.5.1 Energy

As it is explained in *Deliverable D5.2*, the renovation project aimed to achieve of 60% of energy savings, as it was one of the targets of 4RinEU project.

In addition, the renovation had to accomplish national regulation, which stablished specific standards regarding the energy demand in buildings (DB-HE[8] from CTE version 2013). During the development of the 4RinEU project, these building national standards (CTE) were modified through RD 732/2019 in order to accomplish the Energy Performance of Buildings Directive (EPBD) 2010/31/UE to achieve Nearly Zero Energy Buildings. The new regulation CTE version 2019 had a period of voluntary compliance between the approval of the new RD 732/2019 -the 28th December 2019- and its compulsory implementation, on the 24th September 2020.

The executive project of the *"Coma del Forn"* Building Refurbishment, as well as the work's tender procurement and the Municipal license were done during this voluntary compliance period. However, the initial concept designs and studies were all done before the 28th of December 2019, therefore the building refurbishments based in the standard CTE version 2013, previous to the nZEB regulations.

Table 31 Minimum envelope requirements in [W/m2K]

Building elements	Current situation	CTE standards for Climatic zone D3[9]		4RinEU targets
		Ordinary energy renovation*	Minimum requirements for new buildings*	
East Façade *[W/m²K]*	0.64	0.66	0.60	0.37 (G. Floor) 0.16 (1st-2nd Floor)
West Façade *[W/m²K]*	0.64	0.66	0.60	0.64
Side-façade *[W/m²K]*	1.22	-	0.85	1.22
Roof *[W/m²K]*	0.53	0.38	0.40	0.37
Ground Floor *[W/m²K]*	0.64	0.49	0.40	0.64
Glazing	-	-		-
Average U-value *[W/m²K]*	3.82-4.13	2.90**	2.70	1.43 (just in the renovated façade)

[8] DB-HE is the Documento Basico de Ahorro Energético (Basic Document for Energy savings) included in the Spanish CTE

[9] The DB-HE from CTE, identifies different climatic zones in the Spanish Territory. The demo-building is placed in Lleida region, with an altitude of 308m. This corresponds to climatic zone D3. So, the values exposed are the requirements from this specific climatic zone (other climatic zones have different requirements).

G-value glazing	0.75	-	-	0.63
Ventilation	0.80[1/h]	-	-	0.63[1/h]
Air tightness	50[m^3/hm^2]	-	27[m^3/hm^2]	27[m^3/hm^2]

*These data were obtained from current Spanish National Building Regulation (known as CTE) and regarding energy renovation in buildings, there exist minimum requirements just if the renovation affect more than 25% of the building's envelop. In case the renovation those do not achieve some of the specific targets, it will have to guarantee that the global energy savings will be at least equal. This Spanish National Building Regulation is being reviewed in this moment and a new version will be approved during the following months, with more restrictive requirements concerning Energy Saving in buildings.
** This value is applied just when the Opening are placed in E/W façade and represents the 30% of the façade (as is the Bellpuig Case).

Moreover, in order to participate in FEDER Catalunya 2014-2020 Program, and be eligible for the rehabilitation grant, the building's energy certificate had to be improved by at least one letter in its emissions score.

Table 32 Energy certificate improvements

Energy Certificate improvements	Current situation	4RinEU targets
Energy consumption (kWh/year)	81,991.63	54,191.43
Final energy consumption to public infrastructures or companies (ktoe/year)	705	465.96
Primary energy consumption in public buildings (kWh/year)	146,765.02	97,002.66
Greenhouse gases (tCO2 eq/year)	42.72	28.23

The target for photovoltaic production was initially marked by the Grant Agreement (19% of the energy demand), but due to the Real Decreto 900/2015 published the 9th of October, a law commonly called "Sun Tax" in Spain, the set goal could not be reached and collective self-consumption was not allowed, therefore, only photovoltaic production could be installed for the common areas, with a very low consumption, making not cost-efficient the installation.

Finally, in 2019, Real Decreto RD 244/2019 was approved in Spain, eliminating taxes related to self-consumption in installations with a capacity of more than 10kW and allowing collective self-consumption. Thanks to this standard, the option of a larger photovoltaic installation could be reconsidered to cover 19% of the building's consumption.

1.1.5.2 Comfort

The National regulation on Buildings (CTE) determines a comfort range between 21 and 25°C for householdings, and a relative humidity between 40-60%.

There were also checked on the Predicted Mean Vote (PMV) and the Predictive Percentage of Dissatisfied (PPD), and assessed their improvement through the new designed solutions.

Moreover, another target was the improvement of the number of overheating hours (T>26ºC) and underheating hours (T<18ºC).

On the other hand, the owner's expectations for the renovation were to improve the indoor environmental quality, especially the issues regarding thermal comfort and moisture.

1.1.5.3 Indoor air quality

Ventilation rate targets / CO_2 concentration targets have been set according to the national regulation or internal objectives or 4RinEU objectives.

Indoor air quality in buildings is regulated by CTE-DB-HS[10], which remained the same for version 2013 and version 2019 of the CTE. The minimum requirements are established in section *HS-3; Indoor Air Quality* and are the following:

- For dwellings, a sufficient outdoor air flow will be provided to ensure that in each room the average annual concentration of CO2 is less than 900ppm and that the annual accumulation of CO2 exceeding 1,600 ppm is less than 500,000ppm.

- The external air flow provided must be sufficient to eliminate pollutants not directly related to human presence. This condition is considered satisfied establishing a minimum flow of 1.5 l/s per habitable premises during periods of non-occupancy.

The above two conditions are considered satisfied by establishing a constant flow ventilation in accordance with the following table (from the CTE-DB-HS)

Table 33 Minimum air flow (l/s) according to CTE-DB-HS

Minimum air flow in l/s					
Type of Apartment	Dry rooms			Humid rooms	
	Main Bedroom	Other rooms	Dining room/Living	Minimum in total	Minimum x room
0/1 bedroom	8		6	12	6
2 bedrooms	8	4	8	24	7
3 or more bedrooms	8	4	10	33	8

[10] CTE-DB-HS: Acronym for the Basic Document of Healthiness of the CTE. This Document is divided into sections with different topics (HS-1,HS-2…)

In addition, the cooking area of the kitchen must have a system that allows the extraction of pollutants produced during its use, independently of the general ventilation of the living space. This condition is considered satisfied if there is a system in the cooking zone that allows a minimum flow of 50 l/s to be extracted.

The specific requirements for each floor are:

Table 34 Specific requirements for each floor

CONSTANT AIR FLOWS REQUIREMENTS (l/s) FOR "COMA DEL FORN" APARTMENTS (2 BEDROOMS)	
Room 1	8
Room 2	4
Kitchen	7
WC	7
Saloon	8
Total air supply (with minimum humidity) (l/s)	20
Total air extraction (with minimum humidity) (l/s)	14 (min. 24)
Air Flow (m^3/h)	86.4

Given the characteristics of the homes to be renovated (with 2 bedrooms), the two previous conditions will be met with the new ventilation measures that will provide a constant flow of at least 86.4 m^3/h.

Specifically, the project proposes a modification of the existing ventilation system in the apartments through the following actions:

- On one hand, a higher reduction of the air infiltrations by replacing the existing balconies with new ones of similar dimensions, but more airtightness (air permeability Class 4 according EN-12207)[11]. To accomplish regulations these balconies have a total practicable surface (CTE stablishes that at least the practicable area has to be twenty per cent of its useful surface).

- On the other hand, a controlled ventilation rate, through the use of mechanical ventilation units with heat recovery in dry zones (living room and rooms facade) and a mechanical air extractor in humid zones (the bathroom, as in the kitchen is no action executed to increase its ventilation). See section 1.6 to see the ventilation units features.

1.1.5.4 Noise

[11] Class 4 for air permeability in openings (according UNE-EN-12207) is equal or lower than $3m^3/hm^2$ (in 100 Pa -46 km/h-)

4RinEU objectives do not defines any specific objective regarding noise. No tests or specific studies were developed during the project regarding noise reduction related to the PMF façade installation or other actions of the refurbishment project.

Regarding national regulations, the “DB- HR” from CTE stablishes some minimum requirements for residential buildings, hospitals, schools and other cultural/administrative buildings depending on the surrounding noise level.

As we did not have specific information about Bellpuig’s town Noise index during the day we considered the Ld<60dBA (as it is suggested in DB-HR), that means that the inside spaces of the residential “Coma del forn” building that are in contact with the outside have to guarantee, at least, a noise reduction of 30dBA.

Table 35 Basic Document DB-HR of CT. It stablishes an Aerial noise reduction (D) inside Buildings depending on the Noise Index during the day (Ld).

L_d dBA	Uso del edificio			
	Residencial y hospitalario		Cultural, sanitario(1), docente y administrativo	
	Dormitorios	Estancias	Estancias	Aulas
$L_d \leq 60$	30	30	30	30
$60 < L_d \leq 65$	32	30	32	30
$65 < L_d \leq 70$	37	32	37	32
$70 < L_d \leq 75$	42	37	42	37
$L_d > 75$	47	42	47	42

(1) En edificios de uso no hospitalario, es decir, edificios de asistencia sanitaria de carácter ambulatorio, como despachos médicos, consultas, áreas destinadas al diagnóstico y tratamiento, etc.

Since this demo building was built in 2006, it already accomplishes that standard, so there was no need to increase the noise protection in the refurbishment project. Therefore, the opaque part of the PMF façade panels – that are added on to the existing façade - do not need to achieve any particular level. Its installation will just improve the existing conditions. As an exception, it was necessary to verify the openings.

Table 36 Acoustic reduction index in the openings

ACOUSTIC REDUCTION INDEX IN THE OPENINGS	
DB-HR standards (CTE) for inside spaces in zone with Ld<60dBA	Rw > 30dB
Current existing balconies (replaced in the East Façade)	Unknown
New balconies included in the PMF Façade	Rw > 38 (-1,-5)dB.

In addition to the noise reduction index that it is necessary to achieve in the inside spaces, it is also necessary to control the noise caused by the new ventilation machine components installed in the renovation, in order to guarantee user’s comfort.

Table 37 Ventilation machines

Ventilation machines used in the Refurbishment project	Sound Level

Type 1_Decentralized mechanical ventilation units with heat recovery system in PMF Façade (airflow 15-41m^3/h)	~30db
Type 2_Decentralized mechanical ventilation units with heat recovery in west Façade (airflow 25-45m^3/h)	23db
Type 3_Extractor fans in the bathrooms (airflow between 15-54m^3/h)	32db

1.1.6 Description of the renovation

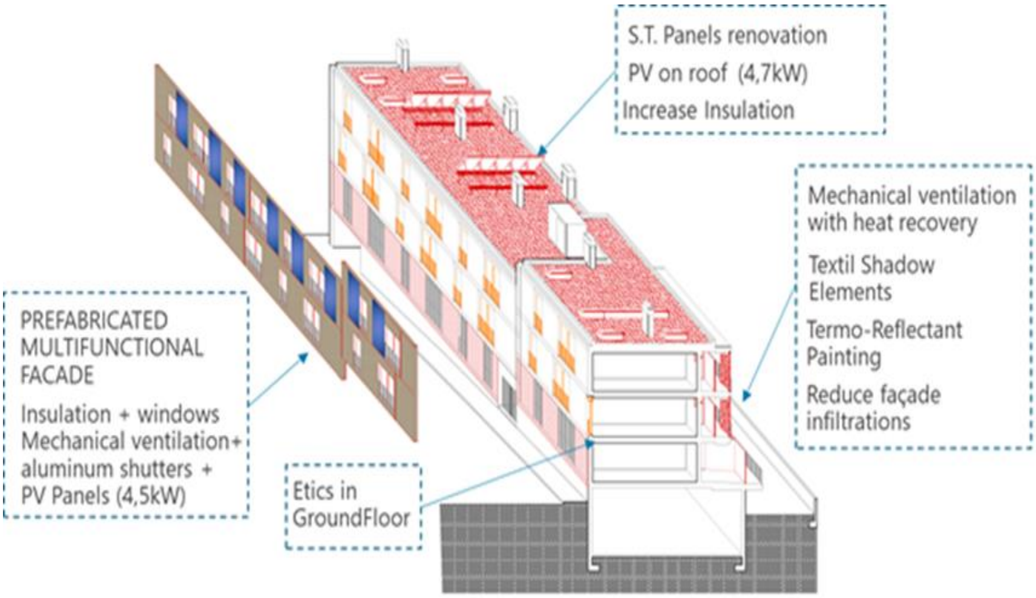


Figure 87. Concept Design of the Renovation Project

Regarding 4RinEU Solutions for renovating the building, the one used in this Democase is the PMF façade, that was applied in the East façade. The solution was implemented just in 1st and 2nd floor due to urban regulations and cost limitations. 10 PMF Panels of 3x6/7m allow to deep renovate 209m^2 of façade surface.

To complement this action and achieve 60% reduction of primary non-renewable energy demand there are other conventional retrofitting solutions applied in the whole envelope of the building. The actions selected are mainly external solutions, so the tenants could continue using the building while the renovation was taken place.

Other 4RinEU technologies used for this demo case have been the Early Reno tool – to optimize the PV panels placement- and the Data Handler -to interact with the tenants after the renovation. The Smart Ceiling Fan was considered in some apartments but finally discarded due to insufficient distance available at floor-to-ceiling height.

1.1.6.1 Description of the main actions

The main tasks estimated in the Execution Project[12] for the Work's Procurement tender were the following:

Table 38 Execution projects main tasks

<table>
<tr><th>Package</th><th>Description</th></tr>
<tr><td>INSULATION</td><td>
<u>East Facade</u>
The Prefabricated Multifunctional panels are implemented in 1st and 2nd floor and it included the replace of balconies and the roller-shutters. Improving the insulation of the opaque part and the openings.
In Ground-floor level, due to urban regulations, that limited the thickness of the solution, the insulation is applied through a conventional ETICs (and no windows or shutter are replaced.
<table>
<tr><td colspan="5">U values (W/m^2K)</td></tr>
<tr><td>Initial Façade</td><td>Existing Façade+ PMF</td><td>Existing Façade + ETICs</td><td>Initial balconies</td><td>New balconies</td></tr>
<tr><td>U=0.64</td><td>U=0.16</td><td>U = 0.31</td><td>U = 3.9</td><td>U=2.12</td></tr>
</table>
<u>Floor</u>
The Underground level –use as garage- was not insulated, as it was difficult to execute due to the several installations ducts on the ceiling. Neither was possible to insulate the external common corridors of the west façade.
On the other hand, the area of the External Common Hall, with the slab between Groundfloor –Hall- and 1st floor –apartment-, it was insulated -4cm of rookwall (0.04 W/mK)- in order to reduce the thermal bridge in the 1st floor apartment.
<u>Roof insulation</u>
The renovation installs a new layer of insulation – 6cm XPS (0.035W/mK) - over the existing one.
<table>
<tr><td colspan="2">U values (W/m^2K)</td></tr>
<tr><td>Initial Roof</td><td>New Roof</td></tr>
<tr><td>U=0.53</td><td>U=0.28</td></tr>
</table>
</td></tr>
<tr><td>Ventilation system</td><td>The ventilation system is just renovated in the apartments that have the PMF façade -1st and 2nd floor-.</td></tr>
</table>

[12] More information of the actions previewed in the renovation project can be found in Deliverable D5.2 (Chapter 3.7 Renovation Concepts).

To accomplish regulations, it was necessary to design the ventilation system integrating all the rooms of the apartment – not just the rooms directly related with the PMF solution-. For that reason, mechanical ventilation units were installed in all dry rooms - east and west façade - and extractor-fans in the bathrooms.

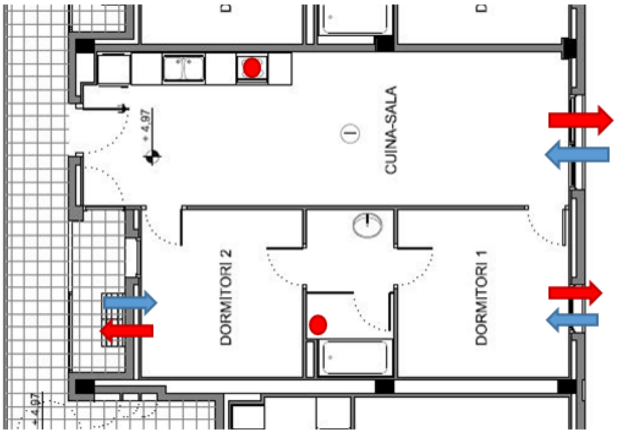


Figure 88 Scheme of Ventilation system inside the apartments

East Façade

The PMF openings, include in the top part of the balcony, mechanical ventilation units with air filter and heat recovering (74%). The model selected is *Thesan Air Care ES* (air-flow 15 m^3/h- 41 m^3/h) (https://www.thesan.com/)

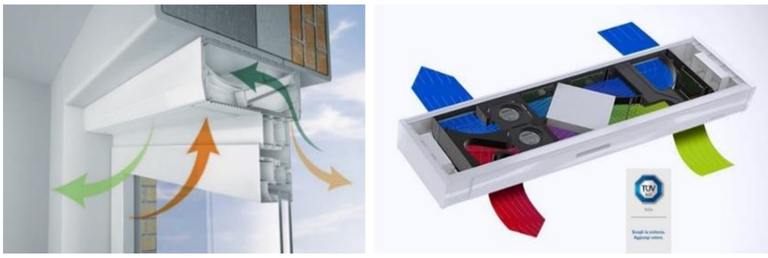


Figure 89. Mechanical Ventilation unit of the PMF facade

West façade

To complete the ventilation system in the apartments of the PMF, it was necessary to have mechanical ventilation units with heat recovering (75%) in the rooms of west facade. The units were placed in the inside of the existing façade and a duct (10cm diameter) makes the interchange with outside. The selected machine is Ecoroom de S&P (airflow 25 - 45m^3/h). In addition, the airtightness of the perimeter of the existing openings -windows, balconies, doors- was improved.

	 **Figure 90. Mechanical ventilation unit in West Facade** Inside the apartments To complete the ventilation system an extractor fan had to be installed in the bathroom air-grill. In addition, to improve comfort in summer, it was initially foreseen to implement the *Smart ceiling fan*, in at least 3 apartments. However, the solution was discarded, mainly due to the Smart Fans dimensions. Its height - 40cm - was not compatible with the apartment free height - 2.40. It could happen that users could touch them, even by involuntary movements damaging the technology or even themselves.
RES **Production** 	• **Solar thermal system** An existing ST system provide DHW to the apartments, through individual tanks in the laundry area. Individual electric boilers supply extra heat one necessary. The overall Solar thermal system has more than 12 years, and its contribution to the DHW has reduced from the initially previewed 60% to under 50%. Roof To improve the performance of the system, in the renovation works the 10 existing solar thermal panels of the roof are replace by new ones -just the panels while the rest of the elements are maintained. The new panel model is ***Baxi Mediterraneo 250***, and as they are bigger than the originals; the global surface of ST panels increased from 18m^2 to 24m^2. • **PV panels system** The renovation project previewed a Photovoltaic system (9Kwh) to provide electricity for the tenants. This could be done thanks to a new national regulation approved in 2019, during the execution of the project RD900/2015. The energy generated is distributed between the apartments depending on its participation (in this case was the same % for all the 15 apartments). The energy not consumed is load on the electric grill, and the tenants receive a discount in its electric invoice as compensation. The system has two invertors, to transform all the DC into AC, and are placed on the roof, while the photovoltaic surface is split in two zones:

Roof

18 Panels are installed on the remaining free space of the roof. They are south oriented and with a 28º tilt. The Panels selected are polycrystalline, have a power of 250W and a surface of 1.65mx0.99m- this represents a global photovoltaic surface of 29.46m2.

Figure 91. 18 Photovoltaic panels are placed on the roof

East Façade (PMF)

On the roof there was little space for PV panels due to the existing ST panels, for that reason it was interesting to use the East Façade too. The PMF allows using the 20 Photovoltaic panels as external cladding. The position of these panels – just in 2^{nd} floor – was decided considering the cost-efficient Early Reno analysis and aesthetical criteria of the architecture project.

The Panels selected are polycrystalline, have a peak power production of 236W and a surface of 1.5mx1.20m -this represents a global vertical surface of $36m^2$.

- **Sun radiation protection**

East façade

The PMF façade includes new balconies and folding shutters to replace the existing balconies and roller shutters. The new openings-with timber frames colored in grey- have on the top, the aluminum folding shutter. This type of shutter allows to reduce thermal bridges in the façade and to increase the height of the balconies. In addition, its dimensions make the solution compatible with the installation of the mechanical ventilation unit on the top.

Figure 92. New aluminum folding shutter compatible with ventilation ducts

West Façade

This façade is exposed to a high solar radiation during summer, and the metallic surfaces of the laundry area enclosures, increase the risk of overheating. Therefore, textile protections – vertical curtains- are installed in the corridor, to protect this common area from sun.

Figure 93. West facade with the sun protection curtains

1.1.6.2 Prefabricated MultiFunctional façade (PMF)

The prefabricated timber panels are use just in 1st and 2nd floor of East façade. More information regarding the main reason to limit its implementation -and some information about its design - can be find in *Section 1.1Project context* of this deliverable and in *D5.2. Concept design and performance targets for the demos.*

The PMF Façade is finally composed of 10 horizontal panels (1panels each apartment) with a maximum height of 3m (between slabs) and 6/7m width. In the project it was initially previewed to have just 8 panels, but dimensions were reviewed during works attending to transport limitations, to manufacture requirements and structural logics.

The PMF has a thickness around 30cm and it contains 2 layers of insulation. Firstly, a mineral wool insulation – 2cm- in the back of the panel – to guarantee its contact with the existing façade –. Then, in the inside of the panel, it has 14cm of mineral wool. The active solutions integrated are the PV panels -as part of the external cladding- and the ducts of the ventilation mechanical units with heat recovery.

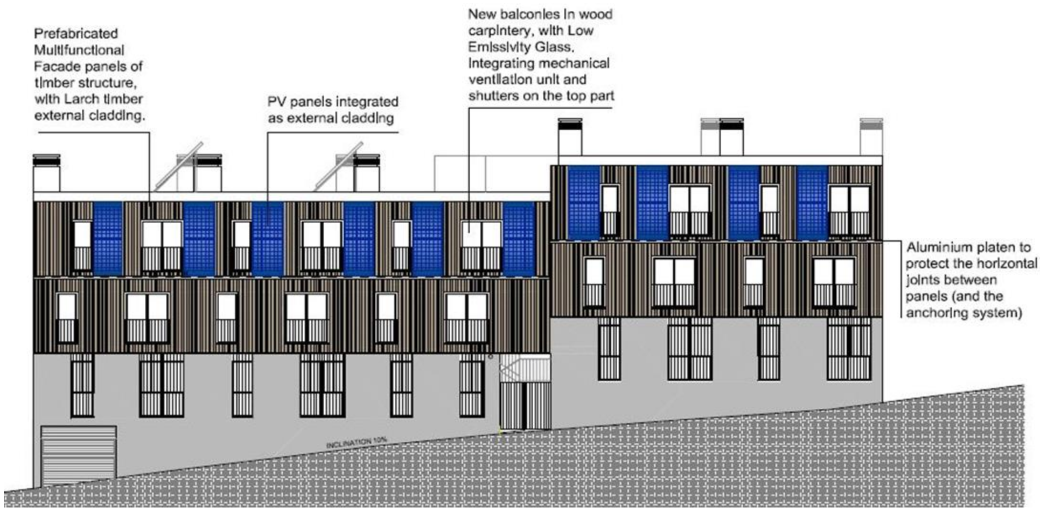


Figure 94. PMF elevation -integrating PV panels, balconies and the ducts for the ventilation units

Concerning the timber structure of the panels, each element has a section of 60x140mm and is classified as C24 (timber resistance). The project initially defined a pine wood – although finally fir tree wood with a biotic treatment was used.

Figure 95. Structural composition of the PMF with the final 10 panels horizontal panels division

Each panel has to balconies, just slightly smaller than the existing ones (to have tolerance for the installation). They integrate the new balconies and a folding shutter on the top part.

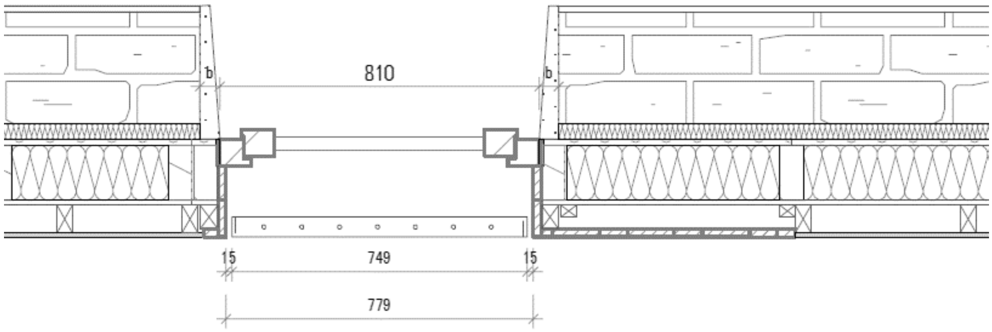


Figure 96.Plan of the balconies integrated in the PMF, horizontal section

Even if in the project it was previewed a cavity inside the PMF to integrate half of the ventilation unit, finally it was decided to integrate only the ducts, leaving the machine inside the apartment, hidden in a drywall box.

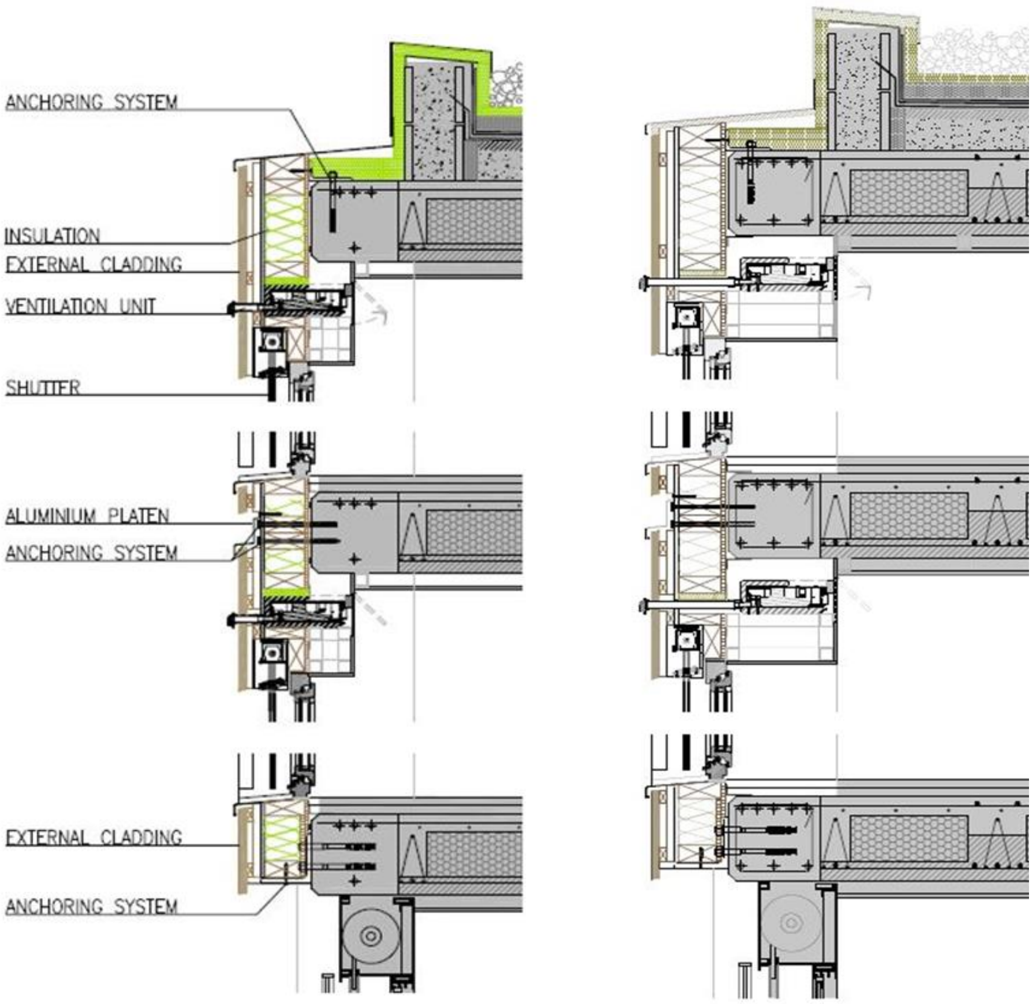


Figure 97. (left) Section of the ventilation unit in the PMF in initial project. (right) Final section detail of the PMF installed in the demo case

Concerning the anchoring solution, it was designed to connect the PMF loads directly to the edge of the slab. It was also taken into account the fact that external cladding was installed in the construction site so that all the anchoring had to be done in the bottom or top part of the panels. The top parts of the panels, although they are not transferring weight, are fixed to the slabs' edge to avoid tipping over (horizontal forces). While the vertical forces (weights) are transmitted to the lower panels and to the bottom anchoring system.

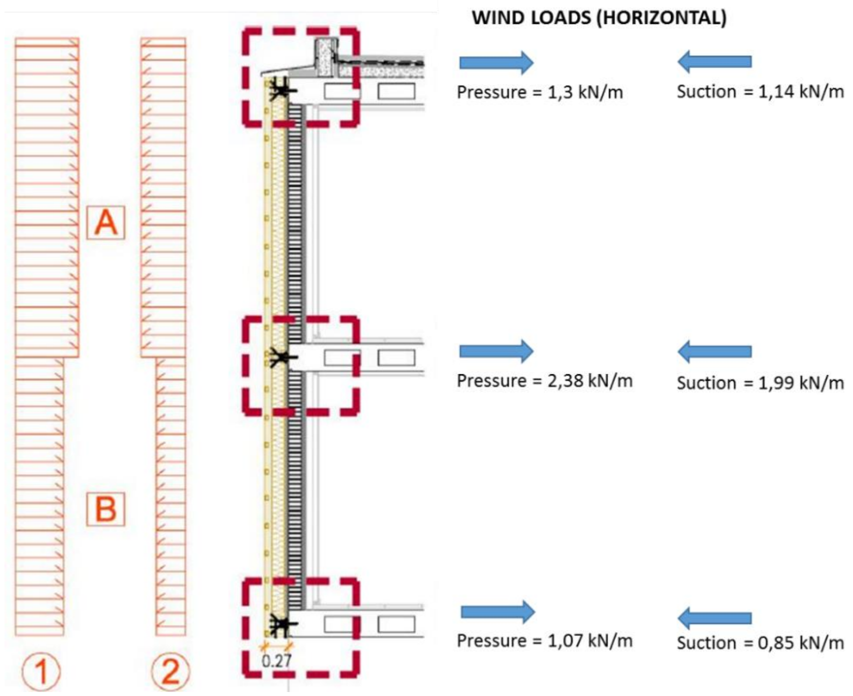


Figure 98 Horizontal forces considered in the anchoring system to accomplish CTE regulations

Regarding the external cladding, the solution uses ventilated façade system with a timber support structure and a timber cladding. Pieces are placed in vertical position -to avoid water concentration in the joints-. The used timber was treated in advance with a thermo-treatment in order to guarantee its perdurance in front bad weather conditions and biotic agents.

In addition, in some parts of the façade, some of the cladding has been replaced by PV panels.

1.1.7 Energy efficiency of the retrofitted building

1.1.7.1 General assumptions of the energy model

The building was simulated with TRNSYS simulation tool. The weather data is specific for the location and comes from the METEONORM weather data tool.

1.1.7.1.1 Zoning

The zoning of the building took into consideration the two different flat types per floor. Inside each flat were defined two zones.

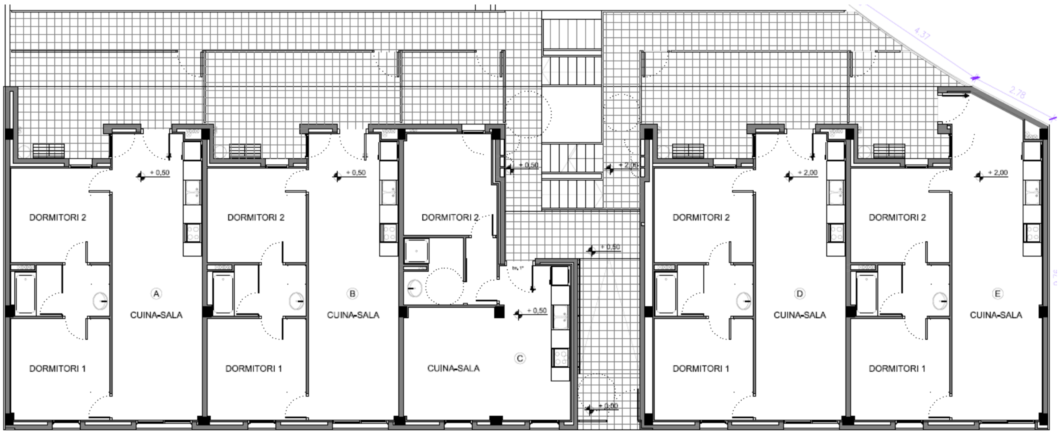


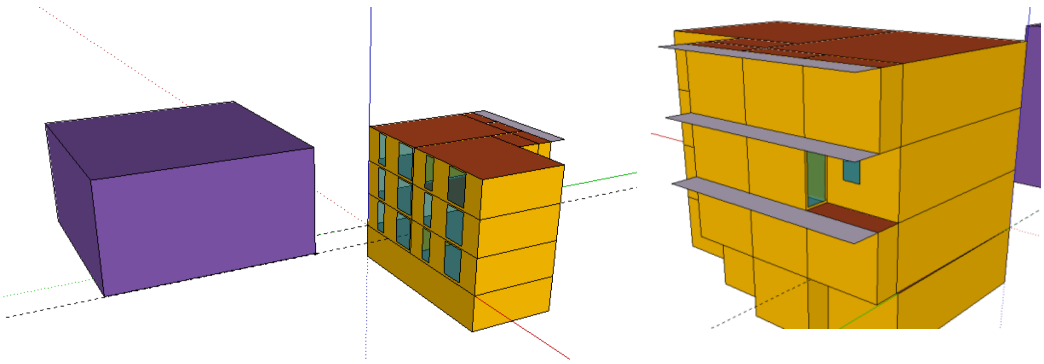
Figure 99 Floor plan view

The zone where the heater is located is considered without internal heat gains, not heated nor cooled and with continuous ventilation with the external environment through ventilation grids.

The rest of the apartment is considered the same thermal zone.

The ground floor is a bit different, but it is considered like 1st and 2nd floors as the interest is on the boundary conditions, the intervention is not tackling the dwellings on the ground floor.

The building model includes a basement in order to simulate the improvement on the lower slab.



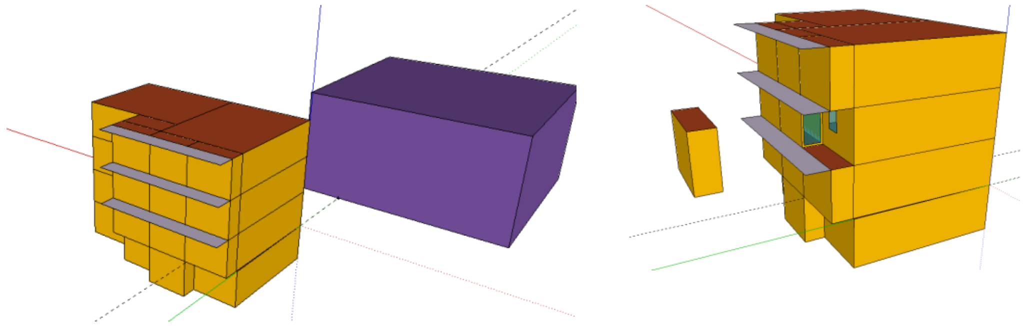


Figure 100 Simulated building model in TRNSYS

1.1.7.1.2 Building envelope

The existing building has quite high transmittance values for the envelope. In the following table these values are shown as well as the current transmittance values according to building codes.

Table 39. Building envelope properties

ELEMENT	Ucurrent (W/m2K)	U CTE (W/m2K) (building codes)
East façade (without thermal bridges)	0.64	0.66
French window A (2.30 x 0.90)	3.73	2.90
French window B (2.30 x 1.80)	5.49	2.90
West façade (without termal bridges)	0.64	0.66
Window C (1.30 x 0.75)	5.27	2.90
French window A (2.30 x 0.90)	3.73	2.90
Roof	0.53	0.38
Low slab	0.63	0.49
Slab in contact with the soil	5.94	
Basement wall	0.74	

- Thermal bridges are included as 20% of additional losses.
- Percentage of openings in the building envelope is 30%.

1.1.7.1.3 Heating and cooling setpoints

No temperature setpoints are applied.

1.1.7.1.4 Infiltration and ventilation

The ventilation is considered natural ventilation.

The infiltration considered is based on the Blower door test results.

Two tests have been carried out and the second one appears to be more representative, according to the technical responsible of the test. Results are these ones:

- 1st test: 0.8148 for P1.2 and 0.9119 for P2.1
- 2nd test: 0.3742 for P1.2 and 0.5792 for P2.1

1.1.7.1.5 Occupancy

The occupancy of different dwellings has been analysed and the occupancy profile which has been considered in the simulations is the average of the most representative dwellings. See D5.2 for

1.1.7.1.6 Lighting and appliances

The dwellings have also been studied to make an inventory of the lighting devices and appliances. The list of the appliances can be seen in D5.2

1.1.7.1.7 HVAC system

The existing heating system is not common in all dwellings. In general, electric radiators are used; however, 45% of dwellings have replaced its use by butane stoves in order to save money.

The renovation project does not include any intervention in the heating system. It is out of the scope.

When assessing the energy performance of baseline and renovated scenarios, the following assumption has been done: the heating and cooling system considered in the simulations is a heat pump with COP 1.5 for each dwelling.

1.1.7.2 Envelope improvements assessment

1.1.7.2.1 Analysis of the thermal bridges and the condensations risk

The critical constructive solutions of the prefabricated façade and its connection system to the existing envelope have been analyzed to assess the potential condensation risk.

Thermal simulations have been performed with the software THERM 7.7. The thermal flows calculations and the minimum interior surface temperature were calculated following the norm UNE-EN ISO 10211.

The assessment on the potential risk condensation was performed following the national regulation CTE DA-DB-HE-2 and with the minimum, mean and extreme outside temperatures for the Bellpuig area.

Three critical nodes were studied:

D1- External façade with dividing wall

D2 – External façade with roof

D3 – External façade with floor

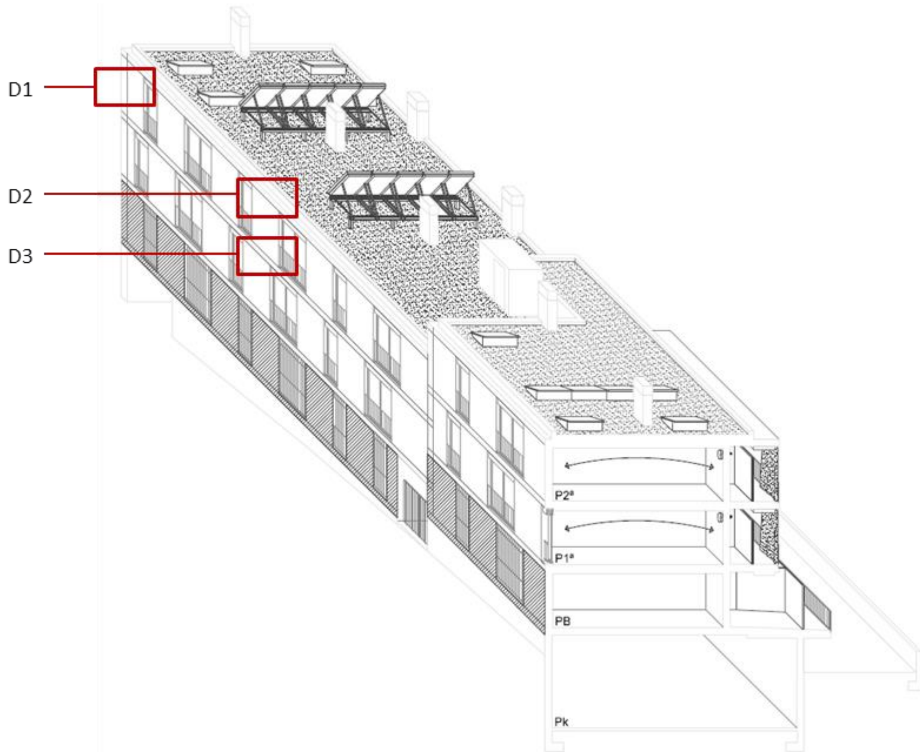
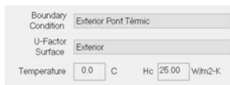
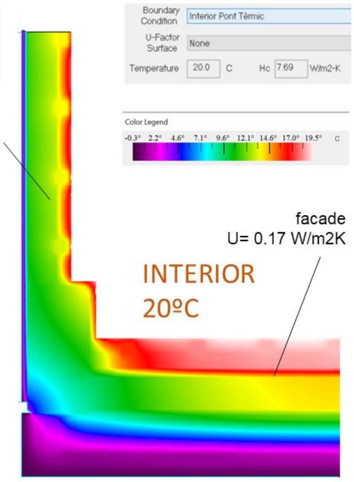


Figure 101 Thermal bridges analyzed

D1- External façade with dividing wall





Linear termal flow→ $\boldsymbol{\Psi} = \frac{\Phi}{\Delta T} - \sum U \cdot b$

$$\boldsymbol{\Psi} = \frac{42{,}401}{20} - \left((0{,}17 \cdot 1{,}00) + (1{,}14 \cdot 1{,}00)\right)$$

$$= \boxed{0{,}81\ W/mK}$$

	U-factor W/m2-K	delta T C	Length mm	Rotation		Heat Flow W	Heat Flux W/m2
Interior	1.7288	20.0	1226.31	N/A	Projected Y	42.4015	34.5766
Exterior	1.1866	20.0	1786.75	N/A	Projected Y	42.4019	23.7314

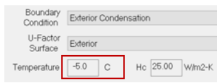
Figure 102 Thermal bridge study

Interior surface temperature factor

$$f_{Rsi} = \frac{T_{si} - T_e}{20 - T_e} = \frac{11{,}8 + 5}{20 + 5} = \boxed{\mathbf{0{,}67} < 0{,}61}$$

$$f_{Rsi} > f_{Rsi,\min}$$

√ No condensations



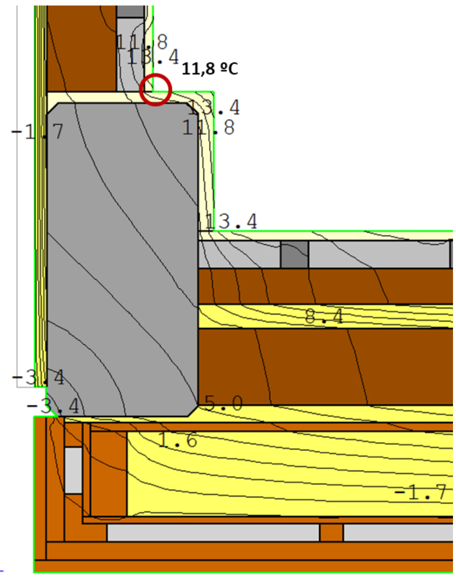
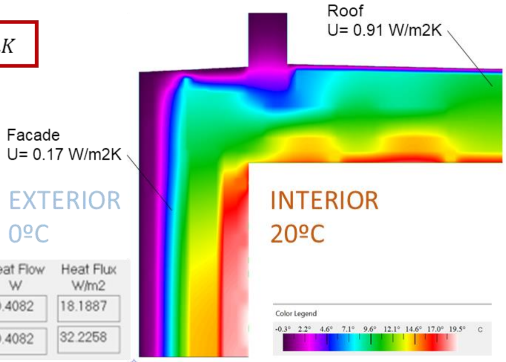


Figure 103 Isotherm lines and surface condensation issue analysis

D2 – External façade with roof

$$Linear\ thermal\ flow \rightarrow \mathbf{\Psi} = \frac{\Phi}{\Delta T} - \sum U \cdot b$$

$$\mathbf{\Psi} = \frac{30{,}408}{20} - ((0{,}17 \cdot 1{,}00) + (0{,}91 \cdot 1{,}00)) = \boxed{0{,}61\ W/mK}$$



	U-factor W/m2-K	delta T C	Length mm	Rotation		Heat Flow W	Heat Flux W/m2
Exterior	0.9094	20.0	1671.82	N/A	Projected Y	30.4082	18.1887
Interior	1.6113	20.0	943.599	N/A	Projected Y	30.4082	32.2258

Figure 104 Thermal bridge study

Interior surface temperature factor:

$$f_{Rsi} = \frac{T_{si} - T_e}{20 - T_e} = \frac{13{,}5 + 5}{20 + 5} = \boxed{\mathbf{0{,}74} > 0{,}61}$$

$$f_{Rsi} > f_{Rsi,\min}$$

√ No condensations

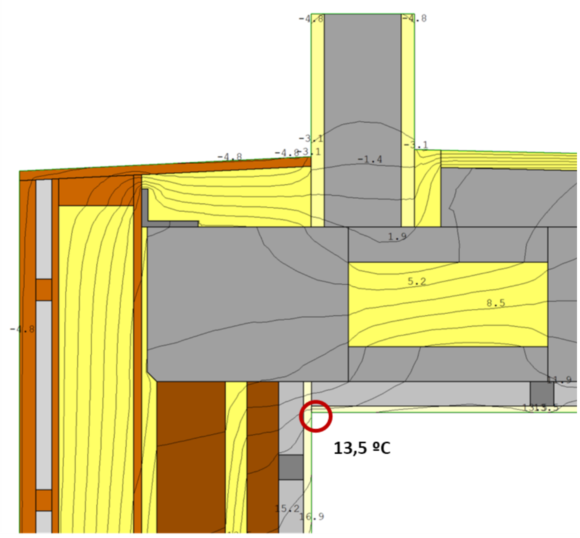
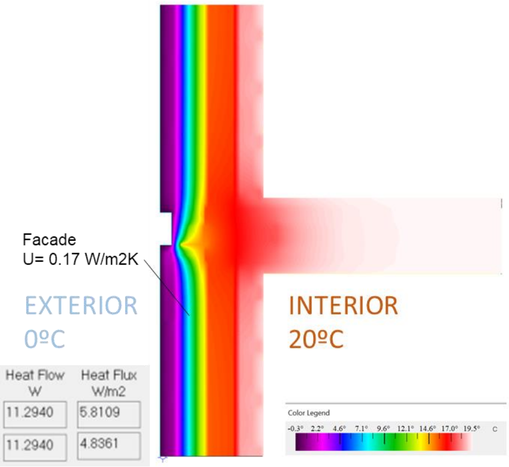


Figure 105 Isotherm lines and surface condensation issue analysis

D3 – External façade with floor

$$\text{Linear thermal flow} \rightarrow \Psi = \frac{\Phi}{\Delta T} - \sum U \cdot b$$

$$\Psi = \frac{11{,}294}{20} - 0{,}17 \cdot 2{,}00 = \boxed{0{,}22\ W/mK}$$



	U-factor W/m2-K	delta T C	Length mm	Rotation		Heat Flow W	Heat Flux W/m2
Interior	0.2905	20.0	1943.6	N/A	Projected Y	11.2940	5.8109
Exterior	0.2418	20.0	2335.36	N/A	Projected Y	11.2940	4.8361

Figure 106 Thermal bridge study

interior surface temperature factor:

$$f_{Rsi} = \frac{T_{si} - T_e}{20 - T_e} = \frac{18{,}0 - 0}{20 - 0} = \boxed{\mathbf{0{,}90} > 0{,}61}$$

$$f_{Rsi} > f_{Rsi,\min}$$

√ No condensations

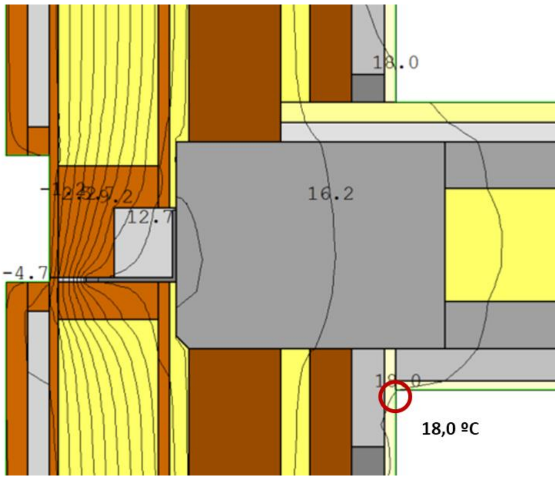


Figure 107 Isotherm lines and surface condensation issue analysis

1.1.7.3 Results of the simulations

1.1.7.3.1 Analyzed scenarios

Six scenarios have been analyzed (for further details refer to Deliverable 5.2, section 3.9.1), all for real conditions and most for theoretical ones (considering FprEN 16798 basis and theoretical conditions agreed with EURAC explained in D2.1 Geoclusters and building archetypes). These ones have been all analysed for real conditions and most for theoretical ones (considering FprEN 16798 basis and theoretical conditions agreed with EURAC explained in D2.1 Geoclusters and building archetypes).

Considerations to be taken into account:

1. The introduced simulations should be interpreted as a support analysis to take decisions and to justify the achievement of the 4RinEU goals. These are not simulations to verify the accomplishment of national regulations (different hypothesis and operational conditions).
2. Scenarios 2b and 2c are used internally (AHC) for comparison purposes (scenarios without 4RinEU solutions).
   - These scenarios are only analysed for real use conditions of the apartments (not theoretical ones).
   - These scenarios do not consider mechanical ventilation neither smart fans. Moreover, the energy consumption variations, the comfort conditions will vary (it is not always possible to detect for integrated values).
3. PV production is not part of the current simulations, but an output of EarlyReno (neither other no HVAC consumptions).

	Base case	Scenario 1	Scenario 2	Scenario 2b	Scenario 2c	Scenario 3
Base conditions	X					
PTF at East facade (1rst and 2nd floor) including windows replacement and internal manual screens		X	X			X
Integrated mechanical ventilation		X	X			X
Roof insulation improvement		X	X	X	X	X
Sealing improvement (shutter box insulation, window and doors weatherstrip)		X	X	X	X	X
Canopies at West facades (1rst and 2nd floor)		X	X			X
Relective painting for external finishing of the utility room		X	X	X	X	X
Smart ceiling fans (1rst and 2nd floor)		X	X			X
First floor insulation improvement			X	X	X	
Connentional retrofit for East facade (1rst and 2nd floor) with injected insulation (11cms) and windows replacement				X		
Connentional retrofit for East facade (1rst and 2nd floor) with EPICS (8cms) and windows replacement					X	
Windows replacement for East facade ground floor						X
Extra consideration (EarlyReno) - PV integrated in East facade and Roof		X	X			X

Figure 108 Scenarios analyzed

1.1.7.3.2 Energy performance evaluation

- Results: RENOVATION SCENARIOS IN REAL CONDITIONS

In the following table, the results for the renovation scenarios under real conditions are shown. It can be observed that the heating demand is decreased between 45 and 50% (excepting for 2b and 2c), according to the scenario. Overheating hours are slightly increased while underheating is much improved.

Table 40. Energy results from Trnsys for each of the renovation scenarios under real conditions (values)

		Base case	Scenario 1		Scenario 2		Scenario 2B		Scenario 2C		Scenario 3	
			Value	%	Value	%	Value	%	Value	%	Value	%
QHEAT_TOT	[kWh/m²]	32,61	18,07	44,6%	17,18	47,3%	24,20	25,8%	24,82	23,9%	16,34	49,9%
QCOOL_TOT	[kWh/m²]	0,00	0,00	--	0,00	--	0,00	--	0,00	--	0,00	--
QLAT_TOT	[kWh/m²]	0,00	0,00	--	0,00	--	0,00	--	0,00	--	0,00	--
QUA_TOT	[kWh/m²]	-80,26	-68,81	14,3%	-67,47	15,9%	-67,41	16,0%	-68,48	14,7%	-65,40	18,5%
QGCONV_TOT	[kWh/m²]	-4,75	26,80	663,7%	26,80	663,7%	-5,01	-5,4%	-4,76	0,0%	26,80	663,7%
QSOLTR_TOT	[kWh/m²]	33,55	8,04	76,0%	7,91	76,4%	8,44	74,8%	8,46	74,8%	7,25	78,4%
QINF_TOT	[kWh/m²]	-26,71	-15,19	43,1%	-15,47	42,1%	-15,66	41,4%	-15,48	42,0%	-15,60	41,6%
QVENT_TOT	[kWh/m²]	0,00	-23,91	--	-24,16	--	0,00	--	0,00	--	-24,25	--
TAIR_TOT	[ºC]	24,94	25,06	-0,5%	25,20	-1,1%	25,24	-1,2%	25,15	-0,9%	25,26	-1,3%
PMV_TOT	Average	0,68	0,61	10,0%	0,64	5,6%	0,74	-8,6%	0,72	-6,0%	0,66	3,5%
PPD_TOT	Average	34,42	30,68	10,9%	31,37	8,9%	34,92	-1,4%	34,53	-0,3%	31,62	8,1%
TMR_TOT	[ºC]	24,93	25,06	-0,5%	25,20	-1,1%	25,22	-1,1%	25,13	-0,8%	25,28	-1,4%
TOP_TOT	[ºC]	24,94	25,06	-0,5%	25,20	-1,1%	25,23	-1,2%	25,14	-0,8%	25,27	-1,3%
OVER_TOT	[h]	3.314,05	3.542,16	-6,9%	3.588,90	-8,3%	3.514,57	-6,1%	3.469,69	-4,7%	3.632,05	-9,6%
UNDER_TOT	[h]	771,50	571,47	25,9%	553,70	28,2%	567,70	26,4%	579,66	24,9%	531,28	31,1%
Occupancy hours	[h]	6.440,00	6.440,00	--	6.440,00	--	6.440,00	--	6.440,00	--	6.440,00	--
Balance	[kWh/m²]	-45,56	-55,00	-20,7%	-55,21	-21,2%	-55,44	-21,7%	-55,44	-21,7%	-54,85	-20,4%

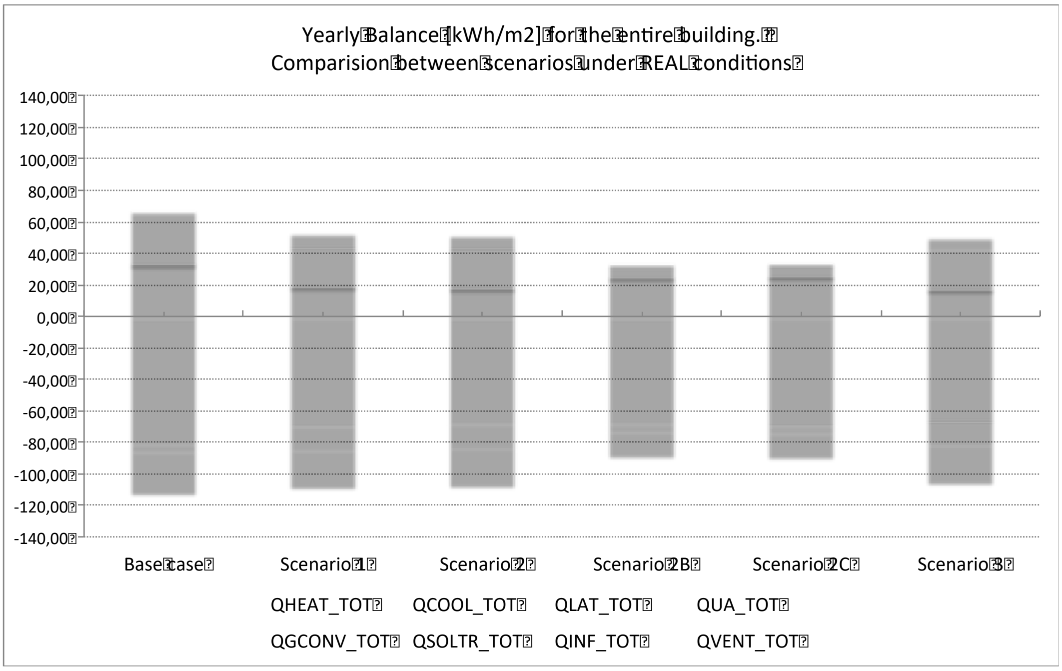
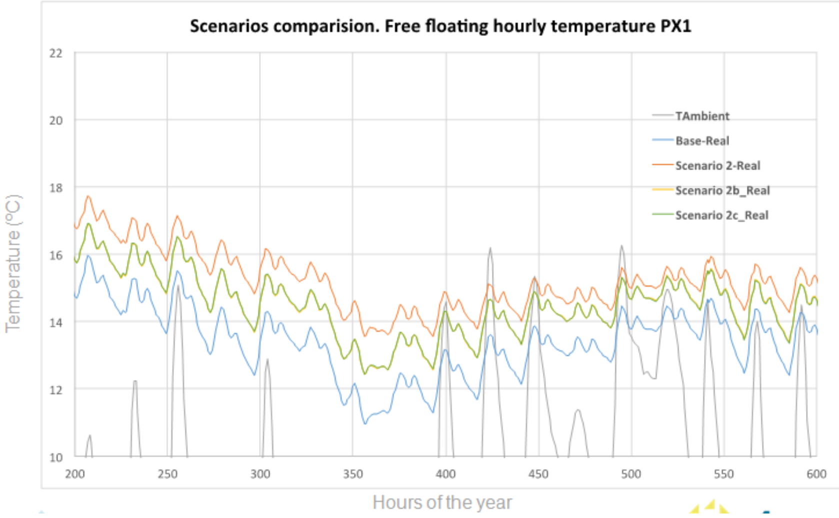


Figure 109. Energy results from Trnsys for each of the renovation scenarios under real conditions (graphs)

In the following graph, another way to present the comfort improvement is presented. It consists on showing the free-floating temperature (when no energy is provided) inside the apartments. The curves show that the base case (blue) has de lowest temperature (winter season) and scenario 2 is improved in terms of indoor temperature (red).



Free floating temperatures in winter season clearly improved from scenario 2 compared to base case. Scenarios 2b and 2c are worst than Scenario 2 (smart fan effect is not represented).

Figure 110. Free floating temperatures for each renovation scenario

- Conclusions

- Related to the improvement actions:
    - Roof improvements (at least, for the dwellings attached to the roof) are quite relevant for energy savings (or comfort improvements)
    - Weather-strips. They have low influence, but reduced investment cost and could be relevant when considering different single cases at the same time.
    - First floor refurbishment could have a significant effect for the ground floor inhabitants (but more limited than the roof improvements, and less relevant for the rest of the building).
    - West windows. Quite poor relative effect, because of the quality of the new solutions proposed. Considering high investment costs and that part of the effect is due to the improved air-leakage conditions, to be considered not to remove the current solutions, but to install weather-strips and other solutions for the shutter-box.
    - Laundry-room external enclosure. Proportional relevant influence, considering too the low investment cost.
    - West movable/variable shading elements. Waning, movable slats or vegetation based, relevant effect (for sure when considering that no cooling systems will be implemented).
    - East G&M solutions. Most relevant savings, but insignificance difference on use ETICS for the first floor or just improve the windows (considering the investment costs)

- Related to the improved scenarios
    - For the analysed cases, the improved scenarios show significant energy demands savings: about 37% for heating and 40% for cooling (theoretical

cases, and 47% for heating for real cases). There are also more similar values for different floors.

- The air leakage reduction is evident: Qinf (infiltration heat losses) reduction about an average of 47% (42% in real cases). The combination of such improvement with the implemented mechanical ventilation will result in an evident improvement in indoor air quality (avoiding also moisture problems)
- The comfort conditions are improved for the analysed retrofitting scenarios by reducing the number of hours out of the comfort ranges (]-1,1[) and harmonizing the divergences among floors.
- The comparison with no-4RinEU retrofitting scenarios offers worst energy demands savings (average one's of 25% in front of the 47% of the 4RinEU solutions for real conditions).

By implementing a rough* analysis on energy consumptions for the theoretical conditions, the following results have been obtained:

Table 41. Summary of energy results for the selected renovation package (scenario 2)

	Base Case	Scenario 2	Savings (%)
Average no HVAC consumption (from electricity bills) [kWh/m2 year]	-42,06	-42,06	0%
Heating consumption [kWh/m2 year]	-35,74	-22,41	37%
Cooling consumption [kWh/m2 year]	-11,81	-7,52	36%
PV production [kWh/m2 year]	0,00	24,73	--
Total final energy consumption [kWh/m2 year]	**-89,61**	**-47,26**	**47%**
Total final energy consumption – only HVAC [kWh/m2 year]	**-47,55**	**-5,20**	**89%**

* Main considerations:

Analysis for theoretical cases (cooling demands also considered), but considering no-HVAC consumptions from real cases (without including no electric consumptions)

HVAC seasonal performance ratio of 1.5

Estimated PV production from the EarlyReno PV surface proposed (both, for roof and East façade) and considering self-consumption

The selected scenario 2 obtains in theoretical conditions 89% energy savings in terms of heating, cooling and ventilation, including PV generation. When considering all energy uses, savings are 47%.

1.1.8 Cost analysis

This chapter presents the estimation cost of the Executive project for the Global of the Renovation works previewed in the "Coma del Forn" Building. Not all the tasks proposed are related to 4RinEU solutions, indeed, it is possible to distinguish 3 types of actions depending on the degree of relation that they have with the 4RinEU solutions.

Type A) These tasks are clearly related to 4RinEU solution; they include all the actions for manufacturing the PMF Façade panels and its anchoring in the building.

Type B) These tasks had to be done in order to adapt the building to the PMF Façade active systems. I.e. the installation of the inverter and all the electric elements that allowed to connect the PV panels of the PMF Façade with the electric system of the building. Another example is the ventilation system to complement the ventilation units of the PMF Façade; hence, it was necessary to introduce ventilation machines in West façade and bathrooms, otherwise, the apartment would not have accomplished the ventilation standards for renovating buildings. Also, the action of removing the existing balconies and performing the internal finishing -as install floor, electric connections for the shutters and the ventilation units, painting- are clearly related with PMF Façade.

Type C) These are tasks previewed to accomplish the goal of reducing 60% the energy demand of the building (target of the 4RinEU project). Although the actions are conventional solutions not innovative. There are also few actions of maintenance of the building and complementary tasks existing in all constructions works (Health & security measures and waste management)

Table 42 Renovation actions costs

RENOVATION MAIN ACTIONS		ESTIMATED COST (21% Tax included)	
Actions (type A)	**4RinEU_PREFABRICATION OF P.M.F FAÇADE PANELS (Surface~209m^2)**	**135,460.42 €**	**4RinEU Solution Cost 217,740.42 €** (1,041.82 €/m^2)
	4RinEU_INSTALL P.M.F. FAÇADE PANELS (Surface~209m^2)	**82,280.00 €**	
Actions (type B)	TASK INSIDE APPARTMENTS (Ventilation/finishing related to PMF)	16,939.19 €	
	PV PANELS ON THE ROOF & COMPLETE SYSTEM (INVESTOR, CABLES…)	22,329.85€	
Actions (type C)	SOLAR PANELS RENOWED	18,724.52 €	
	ROOF INSULATIONS	19,915.39 €	
	EAST FACADE (ETICS in ground floor)	9,214.86 € (92 €/m^2)	
	WEST FACADE (infiltrations / solar protection)	23,360.29 €	
	OTHER MAINTENANCE COSTS	8,101.57 €	

	WASTE MANAGEMENT + HEALTH & SECURITY TASKS	13,963.40 €
	RENOVATION GLOBAL COST (21% Tax included)	**350,289.48 €**

This global cost was reduced after the "*Coma del Forn" renovation work's procurement tender*. Discounts in the Global Estimated Cost is one of the criteria used by Public entities – as *Agencia de l'habitatge* - to evaluate and select the best offer among the different companies that compete for the works.

Therefore, we have a **final global cost for the whole renovation of 332,039.52€ (Tax included),** as the selected offer presented an 8% reduced cost from the initial Global cost. This discount is applied globally -to all the actions previewed in the Executive Project-. Then the final cost of the Prefabricated Multifunctional Façade cannot be completely estimated as this is just a particular context, with specific renovation tasks complementing the 4RinEU solution.

In addition, during the works period, and due to the pandemic situation during 2020-2021, the cost of wood increased in Catalonia. It had no impact in our renovation project, as we already had the stock, but this shows, that the cost of the solution can fluctuate depending on timber costs, and material costs in general.

1.2 Procurement and implementation

1.2.1 Tender process description

In Spain, public entities as Agencia de l'Habitatge de Catalunya, are obliged to select their contractors following the Spanish Public Procurement Law 9/2017, 8th November, related to the European directives 2014/23/UE and 2014/24/UE, 26th February of 2014. This law defines different types of tender depending on the Action to carry out (works or supply and services), its cost and its duration.

Table 43 Types of tender

Types of Tender	OPEN Simplified Abbreviated	OPEN Simplified	OPEN no SARHA[13]	OPEN SARHA
Supply and Services	VEC[14] ≤ 35,000 €	VEC ≤ 100,000 €	VEC < 221.000€	VEC ≥ 221,000€

[13] SARHA: Tender procurement contract subjected to harmonized regulation

[14] VEC: the contract estimation cost not including TAX – but including and over cost estimation due to extensions and modification.

Construction Works	VEC ≤ 80,000 €	V(EC ≤ 2,000,000€	VEC < 5,548,000€	VEC ≥ 5,548,000€

The tender process for the Renovation of "Coma del Forn" building in Bellpuig (15 apartments) it was an **Open Simplified Works Tender**, due to its cost. For the procurement it was necessary to prepare a completely engineered plan in documents and drawings in order to ask for the price of the contractors.

Other administrative complementary tasks were also carried out i.e. defining the technical and, economic criteria that will be used to select the Construction Company. More detailed information can be found in *D5.2 Concept design and performance targets for the demos.* In addition, it was also necessary to stablish a specific Agreement with INCASOL -the owner of the building- to stablish the financing conditions for this renovation.

This **Open Simplified Works Tender** was expected to take 6 months, although it did not happen completely in this way. The procurement tender was prepared and published during half a month in the official site of Generalitat de Catalunya[15], although it ended to be without offers.

Tender Opened → 03/12/2019 (Publication on website)

Tender Closed → 20/01/2020 (end of publication and no offers presented)

Following the Spanish Public Procurement Law, when an Open Simplified Works Tender ends empty it is possible to move to Negotiated tender. This type of contract is an hybrid procedure, where at least three contractors are directly contacted and invited to present offer to the procurement tender that had ended empty. The terms of the contract (technical and economic) have to be exactly the same as in the previous tender, no changes can be done.

Therefore, before starting this new contract procedure, *Agencia de l'habitatge* made some research between the timber manufacturers sector in order to understand the negative results of the **Open Simplified Works Tender**. Four main causes were identified:

1- Bad Calendar Dates to open a tender procurement.
   It was between December/January, and it is not a period to look after new projects/tender procurements. Those dates are to make balance & prepare the companies for next year. In addition, there was the Christmas vacation period -in Catalonia goes from 24/12 to 07/01-, so the companies had not human resources to prepare the documents.
2- The Open tender represents to invest hours of work without a return guaranty.

[15] The Catalan Government publishes all its public procurement tender in the following website; http://governobert.gencat.cat/es/transparencia/Contractacio/registre-elecronic-dempreses-licitadores-reli/

They had no idea if there would be a high concurrence. They were afraid to dedicate time & Resources to develop the tender documents without having guaranties of succeed.

3- The timber companies have high charge of work.
Companies were not concern about work opportunities. Construction sector is increasing in Spain and timber construction is rising due to sustainability criteria.

4- The Spanish refurbishment market has not an assembly-on-site industry. Timber Manufacturers are not use to Public offers and seem not interested in assuming the global responsibility of the works or in developing other construction tasks -not related with timber-. While, on the other hand, for Construction Companies this works represents a low economic benefit, as they need to subcontract to the timber manufacturer at least 45% of the work's budget (timber facade).

Two of the listed issues were minimized with the solution of the **Negotiated tender** – as it limited the concurrency and the calendar dates previewed were February/May-. Regarding the two other issues, it was necessary to make some work in order to incentivize and motivate the market. Indeed, a meeting was organized in the Catalan Carpenter`s association inviting companies, in order to explain in detail the Procurement procedure.

The research of the companies was carried out during February 2020, and it was previewed to start the Negotiated tender in March 2020, with 3 companies confirmed:

- 2 Constructive Companies from Lleida province:
  - Garrofé, S.A.
  - Construïm-10 S.L.
- 1 Constructive Company from Barcelona province
  - Costruccions, Arids i Formigons S.A. (Viscola group)

Nevertheless, the COVID pandemia lead the Spanish Government to Declare a National State of Alarm through RD 463/2020 published in 14.03.2020, and it suspended all the Public tender Procedures. Just in 21.06.2020, with the end of the State of Alarm it was possible to continue with the Negotiated tender. This unforeseen situation, delayed the contract procedure and reduced to just two, the companies that finally presented offers.

- Garrofé, S.A.
- Costruccions, Arids i Formigons S.A. (grup viscola)

Between July/September the Agencia de l'habitatge evaluated both offers and selected the company. During October, several administrative tasks were carried out to finally sign the contract with *Construccions, arids I formigons S.A (Viscola group)* that subcontract the timber Prefabricated Multifunctional façade to *Tall fusta*.

1.2.2 Selection of local manufacturer

In Spain is not so common to apply all this kind of prefabricated products, including wooden-based façade systems, with different elements (Photovoltaic panels, ventilation units, balconies…). Usually, all renovation solutions for envelope are done on-site, as in example ETICS or small-scale insulation panels, supported by aluminum/steel profiles.

In this sense, there were not too many local timber manufacturers with the knowledge and capability to develop the Prefabricated Multifunctional Façade. The existing ones were contacted through *INCAFUST* and the *Catalan carpenter's Association.*

However, as explained above, the contract related to the global refurbishment works tender, already included a timber manufacturer on board. No timber manufacturer presented an offer to the public procurement, as they used to have little experience with the administrative public procedures and not enough technical capacity to assume the global renovation works. Therefore, the manufacturer was indirectly selected, when the construction company was chosen, as it was part of his team.

1.2.3 Programme of the works (a detailed Gantt)

The initial idea was to finish the works in 4-5 months, however, some delays in the arrival of materials and elements, and two vacations period in the middle (Christmas and Easter), as well as COVID restriction regarding access to the apartments or concentration of workers, increased the global duration up to 7 months and a few days.

The final chronogram for the Works is reported in the following table.

Table 44 Final works chronogram

RENOVATION WORKS MAIN ACTIVITIES	M 50 (Nov'20)	M 51 (Dec'20)	M 52 (Jan'21)	M 53 (Feb'21)	M 54 (March'21)	M 55 (April'21)	M 56 (April'21)
4RinEU_PREFABRICATION MULTIFUNCIONAL FACADE (P.M.F)							
4RinEU_INSTALLING PREFABRICATED PANELS (P.M.F)							
IMPROVING INSULATION OF EAST FACADE (Ground floor)							
4RinEU_TASK INSIDE APARTMENTS							
ACTIONS IN WEST FAÇADE (tightness + reflective painting)							
IMPROVING INSULATION ON THE ROOF							
IMPROVING SOLAR ENERGY INSTALLATIONS							
ACTIONS IN COMMON CORRIDORS (Curtains + Fals ceiling)							
WEST MANAGEMENT ACTIONS							
HEALTH & SAFETY ACTIONS							

1.2.4 4RinEU Prefab wooden-based façade system

1.2.4.1 Production time (off-site work time)

Officially, the renovation works for "Coma del forn" building started in 9th of November 2020. The first days were needed to organize some actions on-site (i.e. the information Panel, the shed for workers). Then the works on-site –for the renovation solutions that complemented the PMF façade – and the works off-site, started in parallel.

For the PMF production the main steps were:

- 1st STEP: REVIEW DETAILS & ORDER MATERIALS (From 9th November until 31st January)

It was in this initial phase when a detailed measurement of the existing façade (east façade) was carried out to detect irregularities on the façade surface and to have real dimensions to adapt the Panels and the openings. For this raison, the details of the Execution Project had to be review. In addition, the timber manufacturer, with his capabilities and experience, modified also some aspects of the original design. There were also some decisions, not yet stablished in the Execution Project –as the type of external cladding- that were taken in this phase.

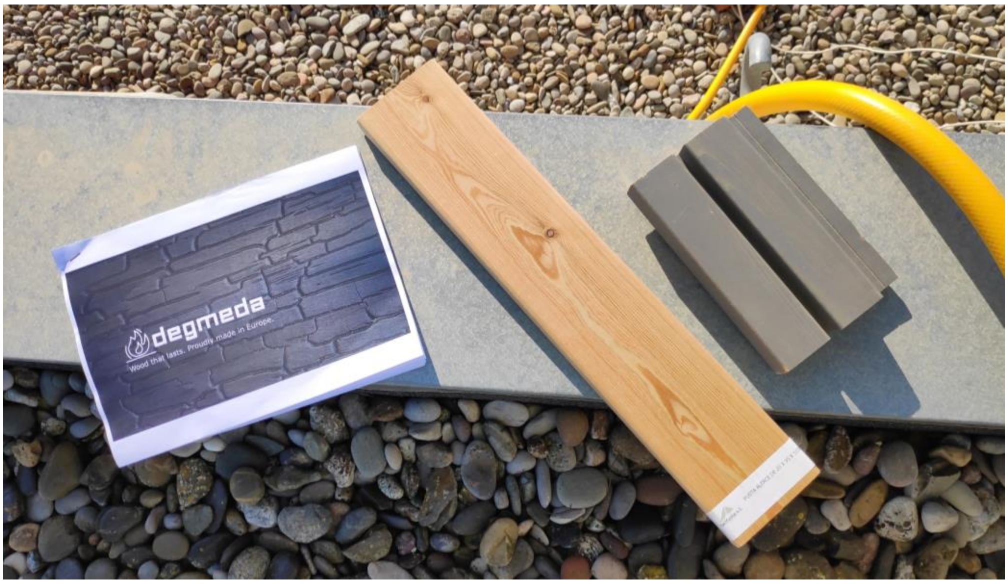


Figure 111 The different types of finishing considered for the timber external cladding (from left to right); *Yakisugi* **treatment (burn timber surface as external protection), thermo-treated (heat treatment to improve timber stability), grey colored coating for protection.**

Finally, the detailed plans for the PMF were execute with a BIM model, in order to directly connect the information of the drawings – the dimensions of each piece – with the numerical control cutting machine, that automatically prepared the pieces.

Figure 112 Picture (left) The BIM model prepared by the timber manufacturer. Picture (right) the different timber elements cutted and waiting to be assembled.

In parallel, to this procedure, the different materials and components of the PMF façade were order. This part, the arrival of all the products to the workshop, was more time consuming that expected. The key moments of this phase are described below:

- 25th of November 2020: The technicians proceed with a detailed Measurement of the existing façade in order to re-adapt the measures of the elements to real dimensions.

- 27th of November 2020: An online workshop was organized to share knowledge and experiences. The timber manufacturer team, The AHC Design Team and even some 4RinEU partners participated in it.

- 2nd STEP: MANUFACTURE OF PANELS (First 15 days of February)

When all the timber elements were cut in the necessary dimensions, the assembling procedure started. Firstly, by forming the timber structure of the panels. Secondly, by placing the external panels – the OSB in the background side and the plasterboard on the front side – at the same time that they were filled with the insulation (rockwool).

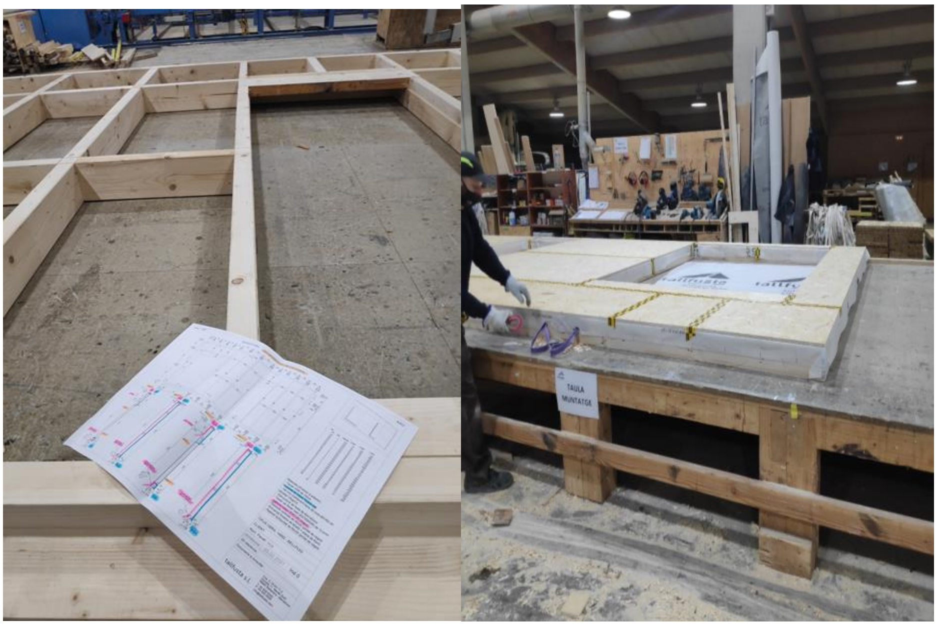


Figure 113 Picture (left) Forming the timber structure. Picture (right) Placing the OSB background panel

Finally, the panels were covered with a waterproof layer – made of polypropylene- and on them it was fixed the timber substructure that fixed the external cladding from thermo-treated wood, with expansion joints of minimum 0,5-1cm.

Figure 114 Picture (left) waterproof layer installation. Picture (right) Mounting external cladding

The complementary components as the balconies, the photovoltaic panels and the ducts from the ventilation units were the last elements to be assembled on the workshop.

Regarding photovoltaic panels, they were panels tailor-made and without frame. This increased their cost, but were easier to integrate them in the façade and provided higher efficiency.

Another aspect to remark is the timber frame of the balconies. They have a metallic appearance, but actually they are made of timber painted in grey-metallic – to be similar to the existing aluminum balconies/windows of the rest of the façades-.

In this demo-case, the shutters and the railings were installed on-site for different reasons:

- The shutters arrived on delay, and it was necessary to proceed with the installation of the panels;

- For the railings, it was decided to re-use the ones existing in the building for circularity criteria and economic benefits. It was not possible to remove them from the existing façade before installing the new panels, for security reasons. Therefore, the railings, were added to the PMF façade, just once the panels were anchored to the building.

To sum up, the PMF façade panels were built in less than 15 days on the manufacturer workshop.

Figure 115 PMF façade panel from 1st floor almost finished and stored in the Workshop.

1.2.4.2 Transportation time and problems

The timber manufacturer Workshop was in *Balsareny* town (Barcelona), at 94,3 Km from Bellpuig (Lleida). This means that the transportation time was close to 1:30 hours (to load the panels on the truck and carry them to the site). Since all the panels were planned to be installed in 2 days, the transportation was also performed in 2 rounds.

- 1st transport with 4 panels (Thursday 18th of March 2021)
- 2nd transport with 6 panels (Monday 22nd of March 2021)

Figure 116 Arrival of the 1st PMF Façade panels to Bellpuig (date:18.03.2021)

No problems appear during the transportation, and there were no access problems to the demo-site either, as "Coma del Forn" Building is well located close to a main street. Even though, due to the slope of the street -close to 10%- it was necessary to select a gooseneck truck. This type of truck with higher wheels on the front cabin, facilitated the procedure of elevating the panels with the crane, by creating a more horizontal position thanks to the difference of height between the cabin and the rest of the truck.

Figure 117 (left) Map with the circuit of the long truck. Picture (right) of the crane picking a PMF façade panel from the gooseneck truck.

1.2.4.3 Installation time (on-site work time)

The panels were anchored to the existing façade the same days of their arrival to the site. The first day of the installation - Thursday 18th of March 2021-, some previous preparing works were done. The installers started by fixing the bottom metal angular plates to the existing façade – in the slab area- and lately the panels of the 1st floor were anchored to them. Afterward, the existing aluminum sill of the balconies were removed, while the railings and the balconies remained on place - for security reason were removed after the installation of the PMF panels-.

Then the same day, at midday, the first 2 panels were installed between the 1st floor and 2nd floor, starting from the south-east corner. This two first panels from the corner had to be put carefully in order to guarantee their correct correspondence with the existing openings. Having them installed, the remaining 2 were much easier and quicker, as the guideline was already stablished. At the end of the day, 4 panels were already anchored.

Figure 118 (left) The metal angular plates installed. (right) Installation of 1st PMF panel

Then, with a second day of transport/installation – Monday 22nd of March 2021- it was enough to have the 10 panels anchored. Then the rest of the week, the procedure continued, from the outside, with some finishing tasks on the perimeter of the façade (sides, and upper parts of the panels).

Having the panels on their place, then the second step was to remove the existing balconies, replace the railings -and cut to adapt to PMF-, as well as install the ventilation units and the shutters. In addition, several inside finishing tasks were necessary - in walls, floor and even ceiling-. This part took about one month. This is more than what it was initially expected- due to delays in the arriving of the components, to COVID restrictions about the number of workers and to the complexity of coordinating the tenants.

Figure 119 (left) PMF Façade panels anchored. (right) Inside finishing works

Regarding the connection of the PV panels of the PMF Façade, it was quite fast, as the part of the circuit not integrated in the PMF façade – PV panels on the roof, the electric inverter - was already mounted and a connection was only necessary.

To sum up, the PMF façade panels – covering a façade surface of 209m^2- were implemented on-site in 35-38 days. But if the decisions to reuse the existing railings was not taken the global time for the installation might have been reduced to 25 days.

1.2.5 Timing of the construction site

1.2.5.1 Analysis of the typical duration

To insulate a surface of 209m^2 in a conventional ETICS solution, it would have taken approximately 30 days – including mounting/ dismantle the scaffolding and applying the insulation-. In addition, this solution would not have included the windows/shutter replacement or the installation of ventilation units either.

The other tasks related with the façade deep renovation -balconies/shutters substitution and ventilation units installation- in a conventional solution would have taken a similar time that in 4RinEUproject – another 30 days-. Therefore, in global, a conventional renovation the complete duration would have been close to 2 months or 60 days.

This estimation is done, without considering the fact of installing PV panels in façade, that for technical limitation would had been difficult and time consuming. On the other hand, it would not have been possible to substitute the PV panels on the façade with more panels on the roof as there is no space. Therefore, the conventional solution would have been much more time consuming and with less self-production of renewal energy.

In addition, with a conventional solution, it would not have been possible to achieve such a high level of insulation -we have no previous experience of adding insulation layers of 14-16cm thickness-.

1.2.5.2 Final duration of the works measured on site

The 4RinEU Objective2 (on robustness) is to reduce impact of deep renovation process on occupants. In particular, the 4RinEU project proposes the renovation implementation time as the main indicator to evaluate this objective. The 4RinEU target is to reduce of factor 2 compared to a conventional renovation process. This means to achieve 50% of time reduction on site works.

To estimate if the achievement of the 4RinEU target, we have to focus just on the duration of the PMF façade implementation on-site – close to 35 days including outside and inside works-. The complementary tasks done with conventional solutions -as roof or west façade actions- are not considered in this analysis. If we compare the 25-35 days of PMF façade, with the estimated 60 days of a typical renovation, this means that we have reduced the construction time on-site a 50%.

To sum up, the PMF panels allowed to reduce almost half the construction time on-site, and offered higher standards of energy efficiency and comfort for the tenants.

1.2.6 KPIs linked to the construction phase

The 4RinEU KPIs where difficult to follow during the construction works due to several reasons (different companies participating, private data, difficult to separate the specific information required). The data selected to control the progress of the works was the following:

Regarding Duration of the renovation:

- Time duration of works on-site (combining all the actions implemented not just the 4RinEU solution): 6 months
- Time duration of PMF façade manufacture on workshop: 15 days
- Time duration of PMF façade installation (outside & inside works): 35 days

Regarding Energy consumed

- During manufacturing works: not available
- During on stie works (considering all the actions of the renovation not just the PMF): estimated about 200kWh

Regarding the Average of workers

- During manufacturing: not available
- On-site works (considering all the period of the renovation works not just the PMF): 3 workers

Cost indicators:

- Cost of the renovation/apartment (considering all the renovation works not just the PMF): 22,135.96€

1.3 Commissioning

Here below the commissioning tasks done over the HVAC and other facilities installed to ensure that they perform properly are described.

1.3.1 Facility 1- PV system

The PV system has to be inspected by the maintenance company subcontracted by AHC. They had to provide a certificate of each inspection, and the minimum actions to be executed are the following:

- PV panels: inspected, to check the connections between panels, the watertightness of the connection boxes, and to clean the panels surface with non-abrasive detergents.
- Control the inverter: its status and performance (Leds, alarms, status indicators...)
- Electric control panels. All the electric connections and protections have to be checked. In addition, it has to be cleaned and guarantee its watertightness.
- To guarantee the correct performance of the electric energy measurers. Check if new batteries are need or if it is necessary any reparation.

In addition, once a year it is necessary to do an analysis of the system with the thermographic camera, to detect if there is any hot point that could cause trouble.

1.3.2 Facility 2- Ventilation units

Filters will have to be replaced from the inside of the apartments.

1.3.3 Facility 3- PMF External cladding

No maintenance is previewed as the external cladding has been protected with a thermo-treatment (exposing timber to high temperatures in order to improve its durability).

1.4 Conclusions

1.4.1 Lessons learned

Successful installation of elements by crane, 1 week for oustside works at demo site. The inside finishing tasks -performed with conventional actions –took 4 weeks for 10 apartaments.

- Current regulations restrict the replication potential of PMF, especially due to the increase of thickness of the existing façade.
- The solution is remarkable when it is necessary to increase to high levels of insulation (minimum required 12-14cm), as the timber panel structure requires a minimum thickness.

- PMF façade is more suitable in flatten facades. Depending on the geometry of the existing façade, the PMF can have serious difficulties to be integrated, e.g. curved facades or complex geometries (with balconies or other irregularities).
- Outside works duration are drastically reduced with PMF solution, however inside and finishing actions, when windows are replaced or electric connections are done, are as time consuming as in a conventional renovation.
- The cost of the global solution is related to the cost of timber as it is the main component. In this moment timber cost is increasing in the European market due to its increasing demand.
- To introduce active solutions as PV in prefabricated façade, can be interesting when there is not enough space on the roof -as it was the "Coma del Forn" demo-case situation.
- The transportation phase might conditionate the dimensions of the panels or even the viability of the solution in a particular plot.
- The anchoring system has to be adapted to the specific structure of the building and have to be studied carefully in order to reduce as maximum as possible on-site works for finishing.

1.4.2 Main further recommendations

It is extremely important to have a detailed control of the correct measures during the prefabrication procedure. The connection layer - between the prefabricated panels and the existing facade – had an important role to guarantee the airtightness and to absorb the irregularities of the existing facade Surface. Extreme attention has to be paid to the airtightness in the additional components integrated in the facade – balconies, ventilation ducts, electric connections -.

As a conclusion, the PMF facade is more suitable if the existing façade is a flat and has easy access from the surrounding area. In addition, it is especially interesting when high levels of insulation are needed, and it integrates active solutions (as PV). Also, if it is necessary to reduce works time on-site or disturbance to the tenants.

Italian Demo Case

1.1 General Description

The Italian Demo Case building is a residential multi-family house, with no. 13 dwellings, located in Via Tabona no. 5 in the city of Pinerolo, in Piedmont region, Italy.

The area is characterized by a climate with hot and humid summers and severe winters, therefore by a wide seasonal temperature range. It is located at the bank of a small river that flows into the city.

The ownership of the building belongs to TECNOZENITH srl, a partner company of the project, which operates in the design, installation and maintenance of HVAC and BMS systems, as well as the efficiency of residential buildings, as Energy Service Company.

1.1.1 Overview

The building was built in 1980s, and it is developed in length, with only two floors, where 13 dwellings are present, six on the ground floor and seven on the first floor. Dwellings are quite small, from one to three rooms, from 35 to 60 m^2 each one.

Building has a reinforced concrete structure, with central lowered beams that run along its length, non-load bearing walls and a wooden pitched roof, masked on the outside by a bronze-colored paneling that give the effect of a flat roof. External walls were not insulated, with two layers of brick with an air gap between them.

Regarding envelope and systems, in the past ten years, building has undergone a first series of renovation. Condensation gas boilers were installed for every apartment, in substitution to traditional old ones, providing hot water for heating by radiators as well as domestic hot water production. The energy carrier used was therefore natural gas, which produced energy for heating and domestic hot water. No cooling system was present inside the building.

Figure 120 External view before 2020 interventions

A new photovoltaic system was installed in 2016, with 8 kW of peak, and a single Point of Delivery (POD) for electricity was installed for the whole building, where apartments, common parts and photovoltaic are connected: the measurement of individual consumption and photovoltaic production is read by special meters, connected to a remote reading system.

Figure 121 Photovoltaic System

The last intervention regarded windows: in fact, all the external windows of the dwelling were replaced with double glazed windows compliant with the energy regulations of that period.

In this situation, the building still led to situations of ambient discomfort, with the presence of humidity and mold inside the premises, due to poor insulation, as well as being strongly linked to a fossil source as an energy vector. For these reasons, the owners have taken the decision to intervene with a strong energy efficiency intervention, as already achieved for other residential properties, but including within these works the solutions and technologies developed within the 4RinEU project, in addition to those of another project, where this building was also a Demo Case: BuildHEAT.

1.1.2 BuildHEAT Renovations

In 2019, Tecnozenith joined the consortium of the European Commission H2020 project named "BuildHEAT" (GA 680658) - Standardized approaches and products for the systemic retrofit of residential Buildings, focusing on heating and cooling consumptions attenuation. Tecnozenith was involved as Pilot partner.

In this project, Via Tabona building was one of the three Italian Demo Site where the solution and the technologies developed during the project were applied and verified.

Interventions done within BuildHEAT Project are here resumed and briefly described, in order to better understand the situation in which the demo case was when it was introduced as a demo site of the 4RinEu project, and to better evaluate the boundary conditions in which the installed technologies developed by the 4RinEU project were designed and operated.

1.1.2.1 Ventilated Façade

In BuildHEAT project a new ventilated facade was installed, provided by the project partner Halfen. The façade consists of a coating made by two layers of glass wool panels, installed on the existent external walls, fixed on metals support. These supports also hold the closure of the ventilated façade, consisting in grés tiles.

Tiles, in addition to finishing the facade of the building from an aesthetic point of view, also create the ventilated cavity, a fundamental feature of the vented wall, with an air gap between themselves and the layers of insulation.

With the façade installed within BuildHEAT project, Via Tabona building has started to have a proper insulation on external vertical walls, with a thermal transmittance of only 0.190 W/m^{2}K.

Figure 122 Details of the finished ventilated façade by Halfen

This installation also has a very important impact on the interventions carried out in the 4RinEu project. In fact, having in the façade installation phase already foreseen further interventions on the building systems, which would lead to a centralized HVAC system for each accommodation, the ventilated façade was used as a shaft for housing the technical equipment.

Air ducts, electrical wires and cables and water pipes were placed behind the insulation layers of the façade, connecting the attic, the future HVAC station, to each dwelling: taking advantage of the new façade, the internal interventions in the apartments have been reduced to a minimum, avoiding drilling for the passages of the systems, moreover they remain protected from external weather, and isolated, from the façade itself.

Figure 123 Installation of ventilated façade with ducts passage

1.1.2.2 Insulation

To complete a suitable insulation of the building, even the residual envelope parts of the building have been insulated, in order to minimize heat losses and to make the best use of the new air conditioning systems.

In particular, it was insulated the portion of the external wall below the ventilated wall, adjacent to the crawl space located below the raised floor of the building, consisting of a plinth with a height of about 50 cm, along the entire perimeter of the building. This insulation was achieved by laying a traditional 8cm o EPS coating.

The main intervention in that sense regarded the attic: this space was already considered for hosting all the new equipment of HVAC system. It was an empty space slightly insulated towards the dwellings with rock wool in a state of deterioration.

Figure 124 Attic situation before 2020 interventions, with the damaged mineral wool insulation

In this case, the old insulation was removed, to allow the installation of a 4 cm EPS cladding followed by a cast of lightened concrete with expanded polystyrene, with the dual function of insulating but also creating a suitable base to host the new systems equipment.

Figure 125 Attic during EPS coating (on the left) and the final result with light concrete slab (on right)

1.1.2.3 Ventilation System

Previously absent, the ventilation system has been designed and installed to allow better air circulation inside the various rooms.

In fact, in many accommodations, tenants complained about problems of humidity and mold, due to insufficient internal air renewal, aggravated by the previous condition of no insulation on the external walls, which were cold, and by the sealed windows, replaced in 2016, which did not allow the passage of drafts which can constitute a minimum exchange of air.

Only an air extraction system in the bathrooms on the first floor was present, as these have no windows.

The new centralized ventilation system consists in two fans, one to supply fresh air from outside, the other to extract exhaust air. Two main steel round ducts run in the attic, connecting the fans with the 13 static heat recovery units.

Each of these recovery units, with an efficiency around 85% supply the fresh air from the attic to the main room of the dwelling, while the exhaust air is always extracted from bathroom, then passes into the recovery unit and it is taken away.

Figure 126 Ventilation ducts and recovery units during installation

Ducts connecting recovery units and ambient passes into the ventilated façade. In the dwellings, ventilation system consists of a wall grill, in the wall or embedded in a specially made plasterboard box, or ceiling mounted with Coanda effect deflectors.

1.1.2.4 Heating and cooling system

In order to carry out a major renovation of the building, it was decided to install a centralized heating system with a heat pump, which can exploit the electrical energy of the photovoltaic system and at the same time can function as a cooling system for the summer.

This decision led to the choice of the building as a Demo Site for the 4RinEu project, in order to install innovative solutions in this sense, but already during the work of the BuildHEAT project this decision was taken into consideration, preparing the necessary systems.

New pipes for air conditioning and sanitary water were passed inside the ventilated wall, as well as electrical pipes, connecting attic to the dwellings and the gas boilers, as preparatory work. In each room of the dwellings, a fan coil was installed in the ceiling, to establish as new terminals of the system.

The choice fell on of fan coils because they can be electrically controlled by BMS system, they can act as heating and cooling terminals and they provide heating/cooling quickly in the ambient. They are placed in the already present false ceiling of dwellings, with a supply grill and a snorkel grill, or in drywall placement built for this purpose.

Figure 127 New fan coils hidden in the false ceiling

A new drainage system was installed to take outside condensation water during summer cooling. Condensing water taken from fan coils of the first floor is taken with a pipe to the external garden to water the garden in summer.

1.1.2.5 Other Interventions

While the insulation and preparation work for the new heating and cooling system were proceeding, the owners carried out some other efficiency works, other than BuildHEAT and 4RinEU project.

All the windows and external doors of the common areas of the building have been replaced (not yet replaced in 2016, in which the intervention concerned only those of the apartments), with windows and doors that comply with the new regulations on sealing and insulation. The windows replaced were those of the corridor on the first floor and the atrium, as well as the entrance door to the atrium itself.

In order to ensure natural lighting for the blind bathrooms on the first floor, "light tubes" have been installed that capture the sunlight from the roof and transport it, thanks to the large internal reflective piping, to the bathroom ceiling, where they look like a ceiling light.

Figure 128 External intake and internal effect of light tunnels

With this intervention, in addition to improve the feeling of comfort in the bathroom, the aim is to reduce consumption for the artificial lighting of the room itself.

To align the consumption of the heat pump with the production of the photovoltaic system, especially during the heating period, an electrochemical storage was installed on the existing photovoltaic system.

Figure 129 Electric Storage of PV system

The storage is located on the direct current side, between the panels and the inverter and has a capacity of 12 kWh, in order to make the most of the self-consumption of the energy produced on site.

1.2 Project Management

1.2.1 Team

The design of the new HVAC system of 4RinEU project Italian Demo site was mainly entrusted to the partner of the Tecnozenith project, which also dealt with the construction of the systems and their integration within a single management system.

The design took place in consultation with the project partners involved, namely Thermics, which entirely designed and produced the heat pump and the NRGate Box ™

modules that were installed in this building, as well as the partner Eurac, as project coordinator and partner involved in the cataloguing and analysis of the output data resulting from the project itself, deriving from the various devices installed in the field for the regulation and control of the new systems.

1.2.2 Management process

Tecnozenith, having knowledge of the building, as well as the management of the previously existing heating systems, followed the design phase of the systems and installation of the equipment, with all the processes aimed at making the new technologies perfectly functional.

The design of the systems was carried out on traditional CAD, with a design that is based on the partner's know-how in the material of electrical and plumbing systems and building renovation. The solution of 4RinEu project adopted in this Demo Site have been integrated in a larger project of renovation of the building, including interventions outside the project itself but common in condominium renovations usually carried out by Tecnozenith.

Tecnozenith, with its employees, managed and followed the entire phases of the work: the communication to the tenants, the management of the construction site (including safety), the direction of the works, installations and the tests on the new systems.

Thermics was the partner who provided the main system components to be installed within the pilot site: the contribution was invaluable in helping to understand the operation of the heat pump and NRGate Box ™ in order to be able to size them, to install and operate with them correctly.

During the installation and testing phase, there were many contacts between the various partners involved, especially as regards the integration of the new components within the BMS management and communication system, to make the data acquired on site available for management and study.

1.2.3 Main Interaction

Communications and interactions between the partners were constant throughout all phases of the project. During the design phase, the contacts between the partners intensified to define the dimensions and the technical characteristics of the appliances supplied by Thermics, in order to identify the best system solution.

In the work phases, communications concerned the coordination of the heat pump and NRGate Box ™, in order to correctly manage the working site. Once supplied, the interactions were done in order to ensure a correct installation of the machineries.

In all these phases, all the involved partners were informed, including Eurac, the coordinator of the project to inform on the proceed of the demonstration of 4RinEu solutions.

Once works were finished, an on-site meeting has been involved between Tecnozenith and Thermics, to verify the correct installation, to make the PLC of NRGate Boxes ™ work and to connect them to the BMS system of the building.

Eurac also went on Via Tabona building to verify the goodness of works and to install some additional Ambiental meters (namely EQ-OX devices), in order to verify the indoor environmental quality provided by the solutions adopted (for further details on this please refer to Project Deliverable 5.4).

1.3 Design Targets

The reasons for the many interventions to which the building has been subjected are due to two main factors: the improvements of the healthiness and livability of the building and the improvement of the low performances from an energy point of view, despite the first interventions of previous years.

The ultimate goal of the demo site's efficiency is the reduction of the building's energy consumption, in particular the reduction of energy deriving from fossil sources, with an electrification of the HVAC system that can better exploit the photovoltaic system already present on site. The most suitable intervention in this sense is the installation of a centralized system consisting of a heat pump, which can directly use the energy produced by the photovoltaic system for heating and cooling purposes.

In addition to this, an important target in the renovation of this building is the improvement of the quality of life inside the premises of the building, not only as regards the thermal comfort, but also the healthiness of the environments.

The greatest challenge for achieving these objectives is to be able to obtain satisfactory results and functioning systems by limiting interventions inside the dwellings to a minimum, so as not to create annoyance to the tenants, minimizing entry in their homes, and integrating the new systems inside in a harmonious way from an architectural point of view.

1.3.1 3.1 Energy

Data of the energy situation of the building before 2019 and 2020 interventions were derived from gas bills and from the electric meters installed on site.

Natural gas was used for heating purpose and DHW production by gas boilers, but also for cooking, as there are gas stoves in each accommodation.

By looking at the bills and computing the data, comparing summer and winter situation, a baseline for heating consumption of the previous situation has been calculated, following UNI 16247 and UNI 11428. The calculated baseline results in 51.4 MWh/year (corresponding to 5,371 m^3/year).

This result was obtained by analyzing gas bills of various years, extrapolating the share part used for heating purpose and taking into consideration the working conditions of the heating systems, using the actual degree day factor of each year of heating, comparing them with the 2,815 nominal degree days of Pinerolo.

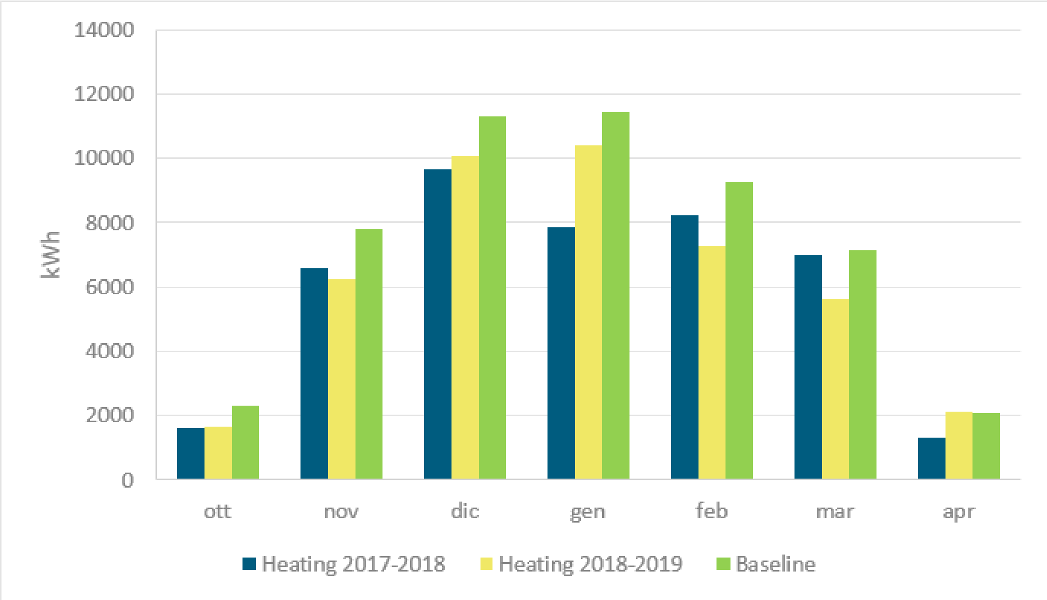


Figure 130 Heating consumptions and calculated Baseline in Heating season

Heating baseline obtained is quite high, comparing to the size of the building, due to the low efficiency of the heating systems and to the lack of insulation.

The baseline for DHW production is calculated in 14.4 MWh/year (corresponding to 1,505 m^3/year), distinguished in 9.6 MWh/year (1,003 m^3/year) in winter season (October-April) and 4.8 MWh/year (502 m^3/year) in summer season (May-September).

There are still then 5.7 MWh/year (595 m^3/year) used for cooking purpose.

The total amount of gas consumption measured by the 13 gas meters settles down to 70.5 MWh per year from a fossil fuel (7,500 m^3 c.a. of natural gas per year). This value leads in a poor evaluation on an Energy Performance Certification (E class for Italian laws), with 219,44 kWh/year of primary energy consumption.

This situation is referred to the condition before early 2020 interventions. In order to exploit well and test properly the new technologies of 4RinEU project from Thermics, it was necessary to provide the correct insulation of the building, realized in part as part of the BuildHEAT project, as explained in Chapter 1.2 and 1.3, as it is essential to have a building well performing from the point of view of heat dispersions, and to be able to install a heat pump that is not oversized and that should not be constantly operative due to the heat losses of the building.

With a proper insulation, heat pump can operate also with lower temperature, to feed the fan coils terminal by passing to the NRGATE Box™ for heat management and measures.

Considering the improvements realized on the building, with the new insulation and systems, including technologies and solution of 4RinEu project, the new primary energy consumption for heating expected will be 24.1 MWh/year.

This means a reduction of about 53% respect to the previous consumption for heating.

Regarding Domestic Hot Water production, it is hard to indicate with certainty how much post-intervention consumption can be for this purpose, as the renewal leads to a hybrid solution, with the gas boiler called to produce DHW during the summer, while in winter it is activated only as a back-up in case of low temperature sent by the heat pump. Tecnozenith previsions in this sense expect to obtain a reduction of about 3.7 MWh/year of fossil fuel carrier for this purpose during winter period, therefore with a total reduction of 26% on the total amount of gas consumed for DHW production. This will be one of the most interesting data to view and analyze once the system has been up and running for months, also knowing the effective water consumption for each dwelling.

The yearly overall primary energy consumption of the building will however increase, because of the new cooling system requiring electricity for the reversible heat pump to generate cold water. This increase will be measured during the 2021 cooling season, when the cooling system will come into operation for the first time.

Differently from winter, in this case the maximum thermal load will coincide with the maximum moment of production of the photovoltaic system, so there will be a direct self-consumption of the electricity generated on site.

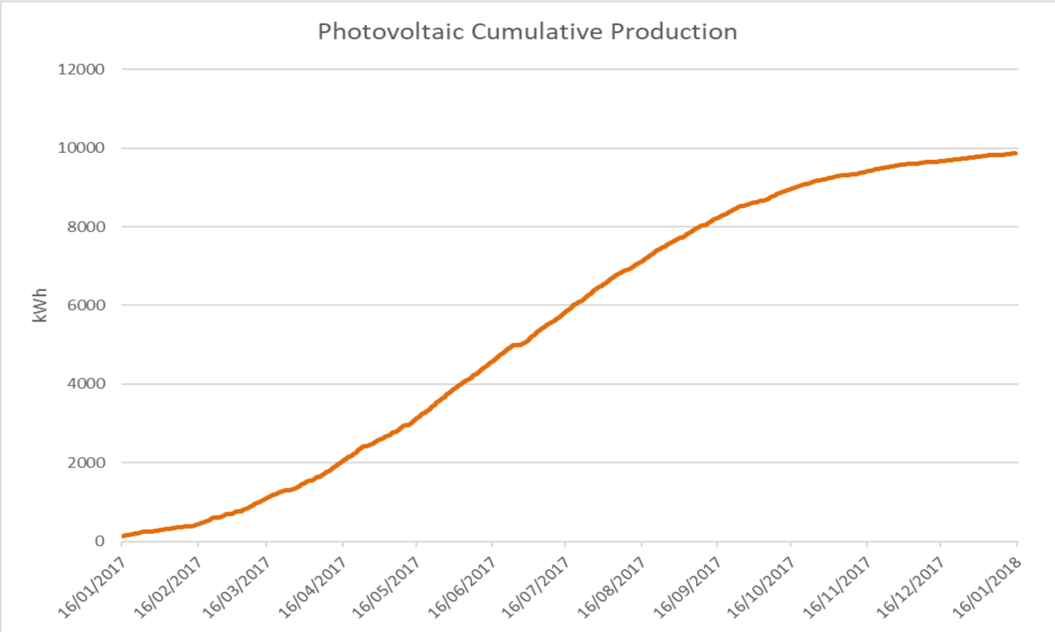


Figure 131 Energy Produced by Via Tabona PV system in 2017

At the end of the season, the owners will carry out a consumption analysis in order to evaluate if it is necessary to expand the existing photovoltaic system to properly feed heat pump in winter and in summer.

An important target in the energy field to achieve from the building is to have a better indication of energy consumption of the dwellings, with the possibility to investigate and monitor the thermal energy necessary for each accommodation and highlight significant variations in energy consumption, better if through a direct reading of the values.

1.3.2 3.2 Environmental Comfort

Comfort of the occupants was the second main reason why the interventions were decided and took place.

In fact, the tenants complained of a low habitability of the rooms, with problems reported especially during the winter period. During the cold season, there were frequent cases of condensation and mould on the external walls, of inadequate heating and, consequently, of unsatisfied internal comfort.

Figure 132 Presence of mold in dwelling 1 on the 1st floor

In summer, there was no possibility to achieve an internal comfort, because no cooling system was present, resulting in rooms with warm temperature during hottest months, especially those rooms facing south-east.

The problems occurring in winter had different causes: cold walls taking to condensation and mold depended on the lack of insulation on them, while the unsatisfactory heating of rooms was due not only by the heat losses, but also by the non-optimal installation of the radiators present, sometimes far from the external windows, which caused situations of asymmetric heating and local radiant discomfort.

Many of these problems due to discomfort hare been solved by the proper insulation of the envelope installed in 2020: ventilated façade and insulation of the attic.

Also, the solutions studied in the 4RinEu project act in the direction of improving thermal comfort: in fact, the fan coils fed by the heat pump are directed in such a way as to ensure a uniform and directed air flow in order to ensure homogeneous air conditioning of the entire space.

Furthermore, the heat pump itself, developed and supplied by Thermics, is modulating up to a power of 20%, ensuring a great continuity of service and, through the BMS system, it can be adapted to external climatic conditions, providing more power when needed, decreasing it in less severe conditions, in order not only to save energy, but to have the right temperature on the batteries of the fan coils, to be introduced into the room.

Fan coils are kept at the lower velocity of the fan, in the mode that has occurred be the best to ensure the necessary heat power to the environment, but also not to create noise, with a practically imperceptible blow, and not to create conditions of too strong currents in the rooms, which can cause discomfort.

1.3.3 3.3 Indoor Air Quality

Indoor air quality is strictly related to the paragraph above on internal comfort. Undoubtedly, moisture and mould greatly reduce indoor air quality, causing unpleasant odours and a feeling of un-healthiness.

The new ventilation system installed as part of the BuildHEAT project takes on the function of improving air quality, through forced mechanical replacement, for the main rooms of each apartment and for the bathrooms, from which extraction takes place, also from those with opening windows.

A support in these terms is also given by the fan coils integrated within the system developed in 4RinEU, since, unlike the radiators, they produce a greater movement of the air in the room, helping to prevent air stagnation and consequently problems of condensation or odours. The units are then equipped with a filter installed on board, which retains any particles preventing them from returning to the environment.

1.4 4RinEU Technology packages

This paragraph is dedicated to the detailed explanation of the innovative solutions developed within the 4RinEU project and installed in the Demo Site in Via Tabona in Pinerolo.

These solutions have been adopted and integrated within the wider renovation work described, in order to reach the targets described in the previous chapter.

The main technologies developed within 4RinEU and used in Pinerolo concern the installation of equipment developed by the partner company Thermics, which supplied the two main components of the new heating and cooling system: the modulating heat pump and the NRGate Box™ hydronic modules.

1.4.1 Heat Pump

4RineEU partner Thermics provided for the Italian Demo Case their air-to water heat pump “Duran” (previously known as Hydra-2). This unit is equipped with Twin rotary compressors, with on board inverters that allow a modulation in power up to 20% of the nominal power.

1.4.1.1 Characteristics

Duran unit consists of a monobloc machine, with a powder-coated galvanized steel casing, inside which there are all the circuits and devices necessary for its operation. In addition to the Twin rotary BLDC compressors, which are part of the refrigerant circuit, there are also extremely silent axial fans and the electrical and electronic equipment to make the heat pump work safely.

The refrigerant gas used is R410a. On the refrigerant circuit there is the stainless-steel plate heat exchanger for de-superheating and the plate heat exchanger for evaporation / condensation. In particular, the source side exchanger is made of copper pipes with aluminium fins painted with hydrophilic paint, while the user side exchanger is of the stainless-steel brazed plate type. A circulation pump for the user hydraulic circuit is present.

The fan is an EC brushless axial type with operating speed continuously adjusted by the machine control unit.

An electronic control system is installed on the system, which ensures the correct operation of the machine, its modulation, the reception of alarms and the control of safe operation. If necessary, the control unit automatically carries out defrost cycles by reversing the cycle. It has the possibility of communicating with other third-party devices using the Modbus protocol.

The unit installed at the Pinerolo demo site is of the "two-pipe" type. This means that there are 2 connections on the machine in order to be connected to a single hydraulic circuit, be it for heating / cooling purpose or for domestic hot water.

For this installation, the unit is connected to a primary circuit located in the attic of the building, with a loop circuit that feeds the various NRGate Box ™. The latter will continuously identify the need to use production for heating or DHW production (only during the winter season).

In the table below, the main characteristics of the heat pump installed in Pinerolo are listed.

Table 45 Main characteristics of the heat pump

	Unit	Value
Thermal Power Water Temp. 40-45°C Ext. Temp: 7°C	100% kW	30.92
	66% kW	20.16
	33% kW	9.39
Compressor absorbed Power	100% kW	7.82
Total absorbed power	100% kW	8.34
COP	--	3.71
Water flow	m^3/h	5.23
Cooling Power Water Temp. 12-7°C Ext. Temp: 35°C	100% kW	28.41
	66% kW	18.82
	33% kW	8.83
Compressor absorbed Power	100% kW	7.14
Total absorbed power	100% kW	7.66
COP	--	3.71
Water flow	m^3/h	4.89
Compressors	no.	2
Refrigerant	--	R410a
Refrigerant charge	Kg	11
Fans	no.	2
Air flow	m^3/h	13000
Electric supply	V/Ph/Hz	400-3-5

Connections diameters	Inches	1”1/4
Sound pressure at 1 m	Db(A)	62
Dimensions	L x H x P	1396x1724x481
Weight	Kg	349

1.4.1.2 Installation

In Pinerolo Demo Site, heat pump has been installed outside, on the roof.

Figure 133 Heat Pump in Pinerolo during installation

A new basement has been created, made by H-beams ang a grill, to support properly the machine, distributing its weight on a wider portion of the roof, and to allow an easier access for maintenance.

During installation, a mobile crane lifted the heat pump to the desired position. Here, it has been hydraulically connected to the primary circuit of the new centralized system of the building, located in the attic, as well as the necessary electrical connections, derived from the new electrical panel of the attic, with the suitable thermal magnetic protection switches, to allow the electrical power supply.

1.4.1.3 Working

Once the hydraulic system has been completed and is ready to operate, the heat pump has been tested on site by Thermics technicians, who have certified its correct installation and start-up. In this first start-up, Thermics technicians configured the machine, introducing the parameters suitable for the operation required for the demo site, with the correct working boundary conditions.

The heat pump works in perfect interface with the new BMS system of the building, with which it communicates through physical signals (dry contacts) and through the Modbus RTU protocol on an RS485 serial cable.

Figure 134 Heat Pump on board PLC

Operation is managed through a daily and weekly schedule, to control its switching on and off at certain times of the day. The temperature set point of the machine, which refers to the temperature of the water returning from the system, is defined continuously based on the external air temperature detected, in order to adapt its operation according to the real needs of the building. All the alarms from the machine are also collected and managed through the BMS system, which can send them to Tecnozenith, company in charge for the control of the system, in order to be able to intervene promptly in the event of a block or breakdown.

For a detailed description of the hydraulic circuit and the integration of the heat pump into the new centralized heating and cooling system, see paragraph 1.4.3.

1.4.2 NRGate Box™

The main innovation factor introduced within the Pinerolo Demo Site is constituted by the NRGate Box™ developed, produced and supplied by Thermics.

These ones are hydraulic modules, able to manage the technical water arriving from the heat pump, which is used during the winter for heating and the production of domestic hot water, while for cooling during the summer season.

In addition to the management of the circuits, obtained through pumps, heat exchangers, diverter and mixing valves, NRGate Box™ provides for the metering of the thermal energy sent to each user, to have a direct share of the thermal energy consumed.

1.4.2.1 Characteristics

NRGate Box™ is a compact module, 623x185x627 mm in size, to be mounted on the wall, with a white painted sheet metal casing, which hides the internal components and allows only the hydraulic and electrical connections to be seen from the outside.

The module, once mounted to the wall, must be connected to the heat pump circuit, with a connection for the water arriving from the heat pump and one for the delivery to the machine, as well as connections to the system terminals in the rooms and to the aqueduct and to the domestic hot water users.

Figure 135 Inside the NRGate Box™ during installation

Inside, the water supplied by the heat pump passes through an electronic inverter circulator, which leads it to a first three-way valve: this valve diverts the flow of water towards the heating and cooling circuit, if there is a call from the thermostat contact, or towards the DHW production circuit, if the need for a flow switch is detected in winter. In this case, the production of domestic hot water is always given priority over the heating system.

While the technical water sent to the systems is the same circulating inside the heat pump, in the case of domestic hot water production in winter, the water heated by the heat pump passes through a heat exchanger inside the NRGate Box™, which transfers heat to the water coming from the aqueduct. The correct DHW temperature to be sent to the user, fixed by means of a modifiable set point, is guaranteed through a second three-way mixing valve.

An ultrasonic flow meter is installed on the return pipe to the heat pump which, connected with a meter and two temperature probes, continuously calculates the power and thermal energy used by the users.

In the table below, the main characteristics of the NRGate Box™ installed in Pinerolo are listed.

Table 46 NRGate Box mai characteristics

	M.U.	Value
Maximum pressure	Bar	6
Working Temperature	°C	2 – 95
System connections	Inches	1”
DHW Connections	Inches	¾”
Maximum head loss at primary circuit at 1700 l/h	kPa	103.1

Maximum head loss at secondary circuit at 20 l/min	kPa	30
Maximum flow	m^3/h	3
Minimum flow	m^3/h	0.015
Electric supply	V/Ph/Hz	230-1-50
Maximum Power Input	W	96
Sound pressure at 1 m	Db(A)	62
Dimensions	L x H x P	1396x1724x481
Weight	Kg	349

1.4.2.2 Installation

Once the 13 NRGate Box™ arrived at the Pinerolo construction site, they were brought to the attic and fixed to the lowered beam that runs centrally to support the ridge of the roof.

Here they have been connected to the new pipes that connect them to the heat pump, always fixed to the beam, in an upper position, and to the sanitary pipes and fan coils arriving from the apartments, laid during the building insulation works during the BuildHEAT project works.

Figure 136 NRGate Box™ settled and to be connected during installation

In the connections, manual valves have been installed on pipes at the exit of the modules, in order to make easier maintenance and interception in case of works.

Electrically, NRGate Box™ has been connected to the new switchboards, once per dwelling, always fastened to the lowered beam, on the opposite side to the hydraulic modules. The electrical panels provide power to the NRGate Box™ and they contain controllers of the BMS system with which they interface.

1.4.2.3 Working

Once all the hydraulic and electrical connections have been completed and the new fan coil systems filled with water, the system has been tested.

For testing, Thermics' technicians went to the Demo Site to check the installation and to carry out the definitive programming of the PLC system installed on board.

The building's BMS system, in fact, acts in a general way on the modules, controlling their switching on and off, turning on some set points and reading the parameters and alarms via Modbus protocol. The management strategy of the pumps and valves of the module itself is instead entrusted to the PLC installed on board the NRGate Box ™, which has its own regulation strategy.

In normal operation, NRGate Box™ act as primary energy carrier for building heating and cooling system and for DHW production (only in winter). Its functioning is regulated with a calendar on the centralized BMS system, to make them work only if the heat pump is working.

The whole system of the building thus created is a hybrid system, as explained better in the next paragraph.

1.4.3 New centralized system

To make functional the new technologies provided by Thermics and installed at the Demo Case in Via Tabona 5 in Pinerolo, in order to create a centralized and innovative system for heating, cooling and production of domestic hot water, it was necessary to make changes to the systems existing previously, in addition to the installation of new circuits, new devices and new equipment, in order to integrate the different systems of the building.

The new systems and integrations have been studied a priori by Tecnozenith, with the creation of executive projects, in order to guarantee continuity of services inside the apartments and to interface the new systems with those already present.

1.4.3.1 Hydraulic System

The main processes of the new systems concerned the hydraulic systems.

The heart of the new system created is in the attic, where the 13 NRGate Box™ are positioned and where all the components and devices designed to make the system work safely and connected to the heat pump placed immediately outside have been installed.

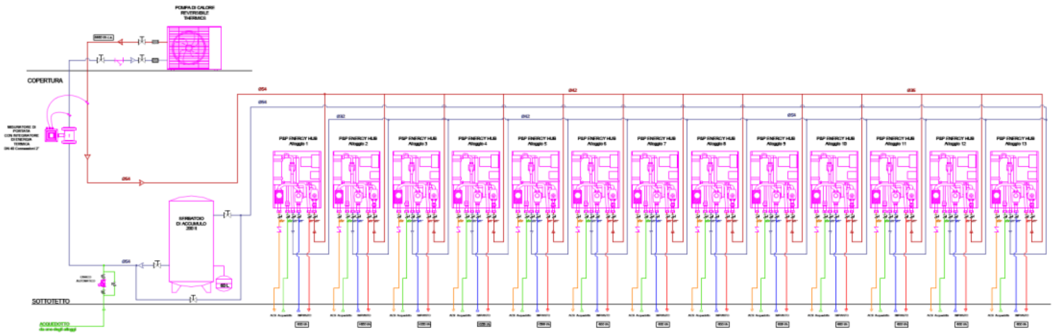


Figure 137 Project of the new centralized HVAC/DHW systems in the attic

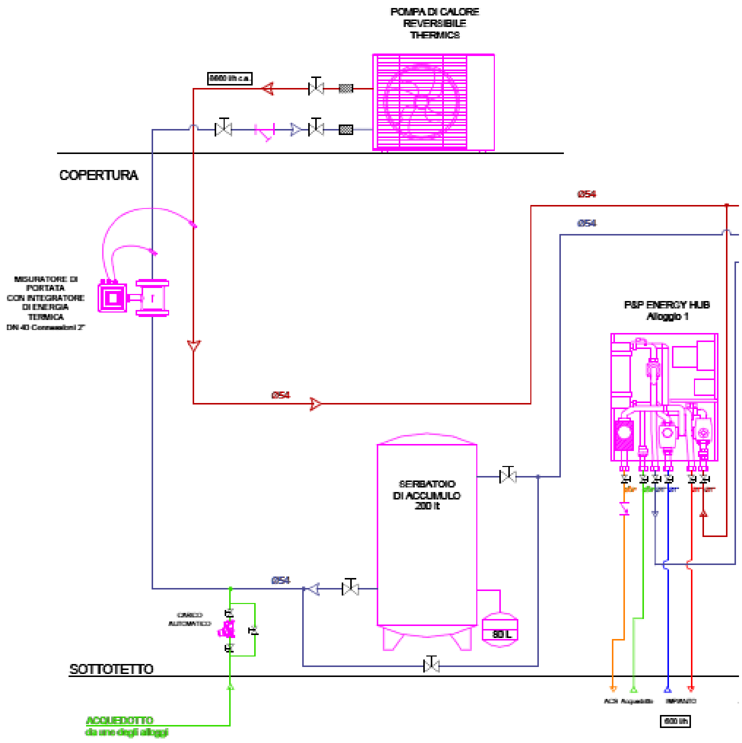


Figure 138 Detail of the system

Heat pump is directly connected to the 13 NRGate Box™, through stainless steel pipes of the "press fitting" type, which do not require welding for the connections, but are to be fixed by crimping, with special pliers.

In order to minimize the differences in the water supply to the hydraulic modules, as they are distributed along the entire attic, with a possible disadvantage of the NRGate Box™ located further away from the heat pump, the system is designed with a type of compensation reverse return. This solution, commonly adopted in hydraulic systems of a certain length, provides an additional pipe placed on the return from the user (in this case from the hydraulic module), to ensure that the user closest to the heat pump, favoured by the circulation pump, is instead the latter as regards the return of water to the heat pump.

By doing so, all the dwellings will have similar pressure drops on the primary circuit, avoiding having more disadvantaged users or vice versa in terms of flow rate and thermal energy supplied.

The main ducts from the heat pump have diameters of Ø54, reducing the size as the NRGate Box™ outlets are taken, in order to keep the linear pressure drop constant on the pipes. All the steel pipes of the system have been insulated with cups to avoid dispersions both during heating and cooling. The pipes that had been laid to reach the accommodations and connected to the various NRGate Box™ were instead in pre-insulated multilayer material.

On the return duct to the heat pump, 200-liters insulated inertial puffer has been installed, in order to make the system less subject to temperature changes when the heat pump is stopped due to defrosting.

On the puffer there is the safety valve, to guarantee expulsion of the water in case of too high pressure inside the system, to avoid dangerous situations or damage to the system itself. The safety valve is conveyed to a drainpipe. The expansion vessel is connected to the intermediate storage tank. From 80 liters, it guarantees elasticity to the water system, avoiding the creation of a rigid system with problems of water circulation and safety.

Figure 139 Hydraulic system during installation

On the return pipe to the heat pump there are still a "Y" filter, to protect the heat exchanger inside the heat pump, as well as an ultrasound flow meter, connected to a heat meter. In this way, it is possible to know the instantaneous power and the energy delivered directly by the heat pump to the system, in addition to that recorded and used by the various accommodations.

The hydraulic system is completed by manual shut-off valves, flanges, anti-vibration joints and the automatic filling unit of the system, in addition to the wells for housing the BMS system probes.

No changes have been made to the heating systems already present previously: the boiler with the radiators continues to be present in the apartments, with the possibility of intervening for heating automatically in case of failure or block of the heat pump or in situations more rigid external.

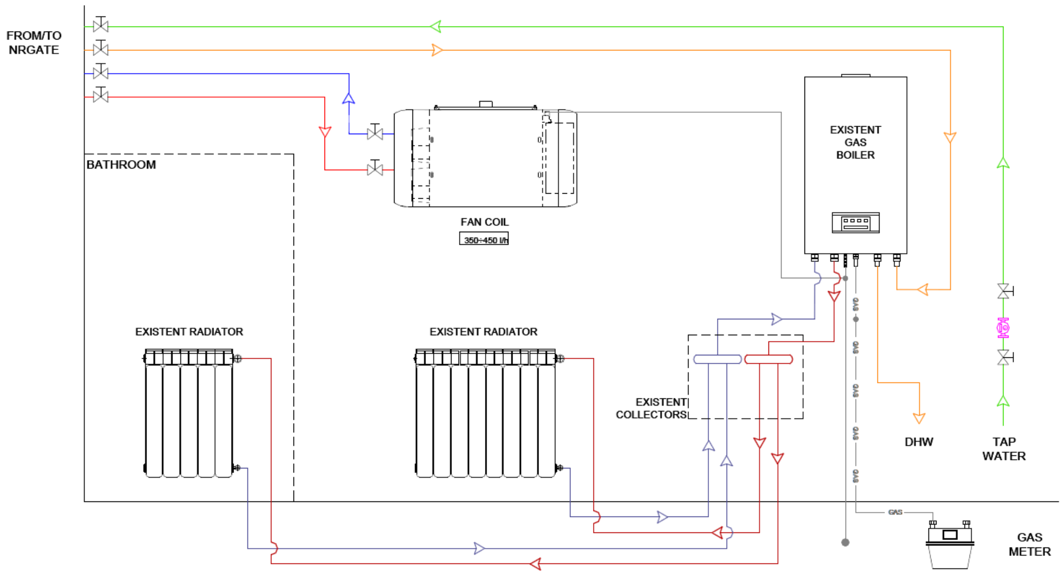


Figure 140 Hydraulic scheme inside dwellings

The domestic water arriving from the NRGate has been connected on arrival to the existing boilers: in this way, during the winter the boiler can intervene as a back-up if the NRGate Box fails to satisfy the temperature requested by the user; in summer the boiler remains the only source to produce domestic hot water.

1.4.3.2 Electrical System

The installation of new equipment powered by electricity in the attic required changes and additions also from the point of view of the building's electrical system.

The new electrical panel designed, wired and installed in the attic is powered by the POD of the building, the same where the photovoltaic system is connected, and which can therefore power the heat pump. Inside it there are the various protection devices, such as magneto thermic switches, differential switches, fuses for each of the different users served. In addition, for each of them there is a meter for the electricity consumed.

This main electrical panel of the system supplies, in addition to the heat pump, the lighting and electrical sockets of the attic, the fans of the ventilation system, the controller of the BMS system installed inside it and the communication system to the outside of the BMS itself.

All electrical connections needed to power the new devices have been made, including heat pump, fans and heating cables. These latter are cables positioned around the pipes placed outside, connected to the heat pump, below the layer of insulation: if activated, they heat the pipe and consequently, the water inside, to avoid freezing in conditions rigid. This installation was necessary because the water circulating in the system is not glycoled.

Figure 141 The main switchboard

To feed and act on the systems of each housing, 13 electrical panels were installed. These are powered by the electrical panels of the corresponding housing and power their NRGate Box, the boiler and the new fan coils, as well as the BMS controller for managing the individual dwelling. There is also a meter to measure the electric consumption of the HVAC-DHW systems of each dwelling.

This configuration makes the control of the system of each apartment independent: an electrical problem on one of them does not compromise the functioning of the remaining apartments.

Figure 142 HVAC Electrical panel of a dwelling

The electrical work carried out also includes the wiring of the new data network for internal communication of the BMS system and to the outside, for remote management. This consists of Cat.5e UTP ethernet cables, carried by each controller to the rack panel where the switch for connection and the routers for remote interfacing are located.

1.4.3.3 BMS System

Before the interventions of 2020, a first management system was already present in the building: it carried out the readings of the electrical parameters of this: the consumption of the housing and common areas and the production of the photovoltaic system.

In order to monitor, make more efficient and act remotely the new systems installed, new controllers of the Swiss Control System brand have been installed for this purpose.

The EXD10 controller in the main electrical panel is the one that manages the centralized system. The various wired and installed temperature probes are connected to it, for measuring the temperature of the water in flow and return, the external temperature and the temperature of the return air from the internal environments, after recovery.

This controller also interfaces, through the Modbus protocol, the electrical energy meters inside the panel, the meter of the thermal energy produced by the heat pump, the heat pump itself and the wireless room sensors.

In order to limit invasive interventions in the accommodation, in fact, to monitor the internal environmental conditions, temperature and humidity probes with Wi-Fi Mesh technology were installed for each room of each accommodation, able to create a network between them for the communication to reach the Gateway concentrator, located in the attic. The Gateway is the device that is interfaced via Modbus RS485 serial port and from which the parameters of the different probes can be read.

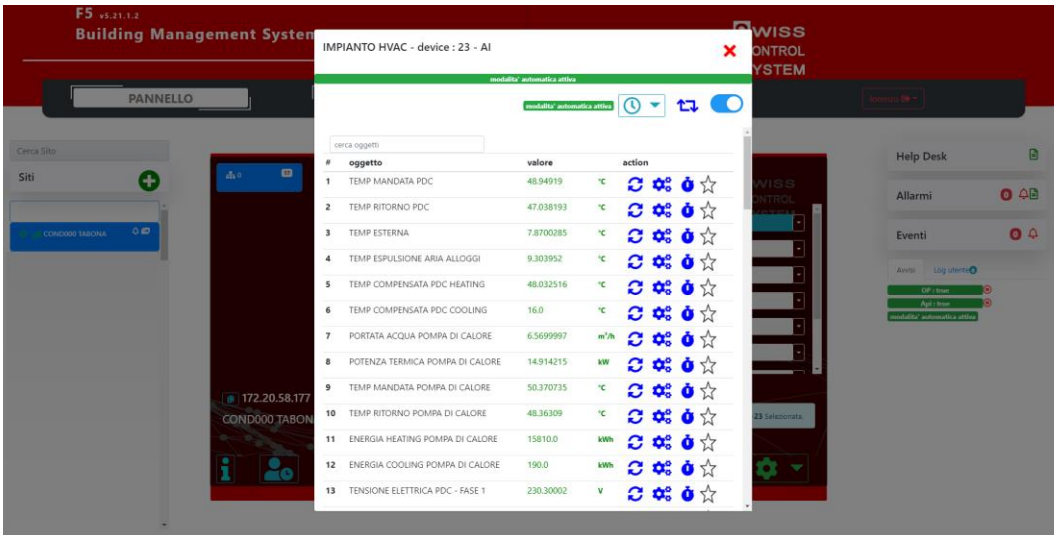


Figure 143 Parameters of Via Tabona BMS system visualized by remote

Controller also act on the system, by activating and switching off the fans, the heat pump and the heating cables, as well as writing, again with the Modbus protocol, the desired temperature set point for the heat pump.

EXD10 controllers on board of the various electrical panels of the dwellings are dedicated to the management of the internal systems of the corresponding accommodation.

Each of the 13 controllers communicates with its NRGate Box™, reading the thermal and energy parameters, acting on the domestic water temperature set point and activating the fan coils and the boiler with heating function if necessary.

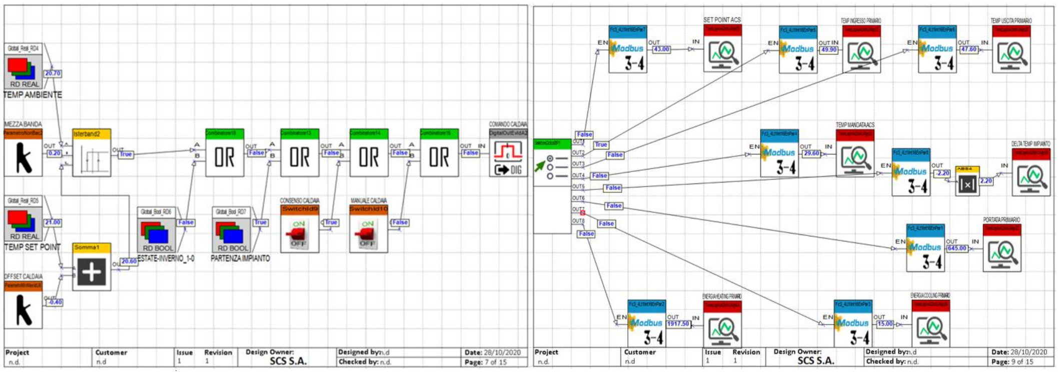


Figure 144 Pages from the regulation strategies of Via Tabona controllers

In addition to this, these controllers interface the electrical meter on board the electrical panel and measure the domestic hot water used, through a reed contact placed on a volume meter outside the NRGate Box™.

All the controllers installed in the Demo Case in Via Tabona in Pinerolo interface with each other, communicating data and parameters. For example, the controller inside the main panel notifies the others when the heat pump is running, to avoid unnecessarily turning on the NRGate Boxes if there is no active source. The same controller also sends to each of the others the temperature of the rooms of the corresponding dwelling, read by the Gateway of the wireless sensors, so that the controllers of the apartments, based on the room set point, can decide to activate or switch off the fan coils or the boiler as a back-up.

The strategy with which the system currently operates is as follows: the heat pump is activated according to a daily schedule defined on a weekly calendar. For example, it is turned off during the night, when all the heating/cooling systems are left off. When the heat pump starts, the various NRGate Boxes are activated: these are also equipped with their own clock, which corresponds to the clock for the system of each apartment, with the possibility of reducing their operating hours respect to heat pump. Once the hydraulic modules have been electronically activated, the fan coils are switched on and remain in operation until the desired set point temperature is satisfied in the room. The set point is set by the users within a limited range of values, both for summer and winter. To avoid continuous switching on and off for fan coils around the set point temperature, there is a dead band of 0.2°C within which the detected internal room temperature can oscillate.

In the event that in winter the internal temperature drops below -0.4 ° C compared to the desired set point, which can mean a blockage of the heat pump or a condition so severe that it is not able to satisfy the thermal load of the building, command is given to the boiler with heating function via radiators, until the environment is brought back to the set point condition.

The Swiss Control System BMS is freely programmable, with regulation strategies that can be implemented and modified at any time, even remotely. Any necessary algorithm can be rendered in terms of machine code by the IT engineers of Tecnozenith and implemented on EXD10 controllers. It can therefore be modified and adapted if necessary, once the behaviour of the system has been analysed.

Data from the Demo Site reach Tecnozenith partner server in Saluzzo, via UMTS connection. There, data are stored in a dedicated database and from here they can be sent outside the company, through API or SOAP protocols. In particular, during 4RinEU project, data acquired from the site are sent to Eurac partner, for analysis and research purposes, via API protocols. Data sent regard the functioning of the whole system and of the NRGate Box™.

1.5 Timing of the construction site

The construction site of the site in via Tabona 5 in Pinerolo had been defined in the design phase of the overall work to be carried out.

The planning was done in detail, due to the numerous and different processes to be performed, which included construction, mechanical, hydraulic and electrical works, so that interference between the various processes was minimized, reducing the risk of accidents, as well as minimizing the negative impact of the construction site on tenants.

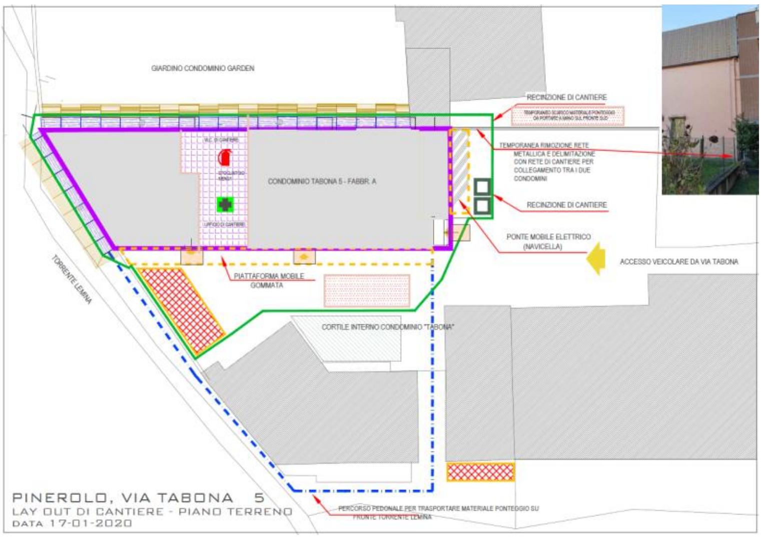


Figure 145 Definition of the working site spaces in the design phase

Planning involved an estimate of the times of the different work to be performed on the site, but also the definition of the site spaces, identified within the "Safety and Coordination Plan" document.

1.5.1 2019 Planned Gantt Diagram

During the design phase, a general Gannt Diagram was planned in order to identify the different processes and work, considering the times of each of them and the interferences that could between them.

In this first design phase, at the end of 2019, Tecnozenith was not yet part of the 4RinEU project, so the building in Via Tabona 5 was only, at that time, a demo site for the

BuildHEAT project. However, the owners' intention was already to install a centralized system for heating and cooling, for which the work concerning the new mechanical and electrical systems and the preparatory works to reach each apartment from the attic had already been planned.

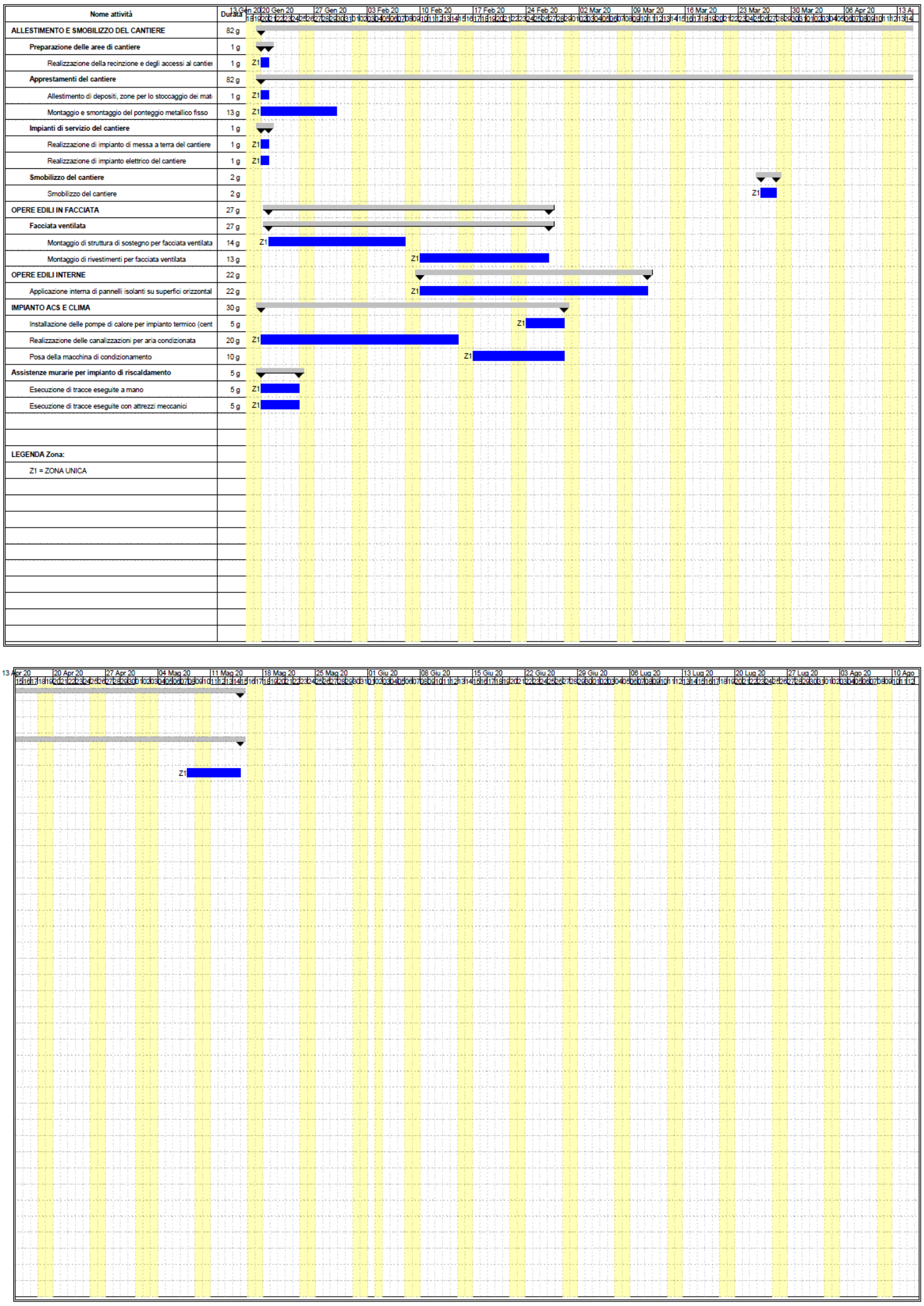


Figure 146 Gannt diagram planned in 2019 project phase

In this preliminary schedule, the works were expected to begin in the first half of January 2020, with the definition of the construction site area, the exclusive use of the condominium courtyard for this purpose and the delimitation of the workspaces.

All the works were expected to be completed by March, with the closure of the construction site and new functioning plants.

This time schedule was not respected both due to the fact that Tecnozenith joined the 4RinEU project group, inserting the building as a pilot site, consequently, requiring a more accurate study and design of the new plants, and also due to the Covid-19 pandemic.

1.5.2 4RinEU Gannt

Joining the 4RinEU group, it was necessary to define a new work schedule, this time referring only to the work for the systems, in order to define the timing between the partners of the Thermics project, which produces the components to be sent to Pinerolo, and Tecnozenith, which had to receive the equipment and install on site.

In the following table, a Gannt diagram is represented, considering February 2020 as starting month (Month 41 of 4RinEUproject) to May 2020 (M54) the last month of the project. Cells in blue represent the time schedule estimated during the start phase of the Case di Pinerolo Demo, with the addition of Tecnozenith as a partner of the project.

The cells in red, instead, referring to the same processes, show the actual timing that took place on site.

	MONTHS (41 = February 2020 – 54 = May 2021)													
	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Definitive design of the system														
NRGate and Heat Pump production														
Delivery of EH and Heat Pump														
Installation works														
Monitor system definition & installation														
Monitored data acquisition														

As it can be seen, the processing times were longer than those estimated, mainly due to the direct and indirect impacts of the pandemic, better explained in the following paragraph.

1.5.3 Real duration of the works on site

The construction site at the condominium in Via Tabona 5 in Pinerolo actually started at the beginning of January 2020.

In the first weeks, the works concerning the insulation of the building were carried out, in particular the ventilated façade of the BuildHEAT project. It is at this stage, in the first weeks of 2020, that the air channels and plumbing pipes were passed to the housing where the water passes today from the NRGate Box™ to the fan coils.

In this period, while the works proceeded according to schedule, the world experienced the Coronavirus epidemic. In particular, Italy was the first country in Europe deeply affected by the pandemic. This situation led to a first general lockdown of the Country, with a total block of non-essential processing, including the complete stop to the work of construction sites on the National territory.

It was possible to resume work only at the end of the lockdown, from Monday 4 May 2020, with the end of the first lockdown.

The two-month shutdown had a deep impact on the timing of the Pinerolo construction site, directly and indirectly. On the one hand, in fact, the preparatory work for the installation of the 4RinEU project systems was delayed, for example the insulation of the attic, with a lightened concrete cast as a screed on which to place the systems, which was only completed at the end of May.

On the other hand, heavy repercussions on material supplies not only for Tecnozenith, but also for Thermics were occurring. Components to complete the heat pump and NRGate Box™, especially as regards the part electronic and accounting were missing.

Heat pump arrived on site at the end of July and lifted with a crane on the roof and placed on the new metal base. In this way, the electrical and hydraulic connection work, already prepared in the previous weeks, began immediately.

NRGate Box™ arrived instead at the end of August. During the gap period at the beginning of August, switchboard and electrical panels were mounted in the attic, to be ready once NRGate were delivered.

In September 2020 all the NRGate were hydraulically and electrically connected to the system and the BMS system has established, after some interaction between Tecnozenith and Thermics on the communication protocol.

A first test of the heat pump happened at the beginning of October, while in 26-27 October 2020 Thermics Technician went in Pinerolo to put correctly into operation the Heat Pump and various NRGate. From these days, the new system began to work in normal operation, without significative problems. Just a parameterization error on the defrost cycles was resolved a few days later with telephone assistance between Thermics and Tecnozenith.

The last phase of the works concerned the definition of the monitoring and the sending of data from the building. Various meetings were held to define which parameters to monitor and acquire to verify the correct functioning of the systems: both internal parameters of the NRGate Boxes, and environmental and operating parameters of the building.

Once all of them interfaced correctly on the BMS Swiss Control System present, the computer engineers of Tecnozenith and Eurac exchanged information, to arrive at an automatic sending of data, carried out every 10 minutes, via API interfaces from Tecnozenith server.

The operating data of the systems designed within the 4RinEU project were thus made available for detailed viewing and analysis.

1.6 4RineEU Renovation costs

In the Italian demo site, the costs incurred for the implementation of the solutions and technologies developed in the 4RinEU project include a wide spectrum of items, as always happens in energy efficiency works and in construction sites similar to that of the building in Via Tabona in Pinerolo.

In fact, the costs include not only the actual supply of material, hydraulic and electrical, to make the new system work, but also the sensors integrated inside, the manpower for the installation of these systems, all the preparatory work modifications to the systems carried out (first of all, modifications from the construction and structural point of view) and the supervision and management of safety on site, especially during the phases of material handling and during work at height.

Here below, the cost items incurred for the sole installation and management of 4RinEU solutions within the efficiency works of the Italian Demo Site are reported and catalogued, to have a view of the share of incidence on total costs: the first table refers to the costs for the supply of material or qualified professional services, while the second table refers to the hours worked by Tecnozenith, partner of the project that carried out the work, for this purpose.

Table 47 Costs for the supply of material or qualified professional services

CATEGORY	DESCRIPTION of MAIN ITEMS	AMOUNT [€]
Contruction and preparatory works	▪ Support basement for HP and inertial puffer ▪ Heat Pump handling and lifting ▪ Brackets for NRGate, electrical panels, pipes ▪ Drilling, building modifications and repair for systems passages	780 €
Heat Pump hydraulic system	▪ Inertial Puffer ▪ Pipes, valves, fittings ▪ Safety valves, pressure gauges, Thermometers	6,321 €

	▪ Pipe insulation	
NRGate hydraulic system	▪ Pressfitting steel pipes ▪ Multilayer piping ▪ Fitting and joints ▪ Valves	3,076 €
Measurement system	▪ Electric meter for Heat Pump and NRGate consumption ▪ Flow and Thermal meters for Heat Pump production ▪ Wireless sensors for rooms ▪ Water volume meter for DHW	4,745 €
Heat Pump electric system	▪ Switchboard for heat pump supply and regulation ▪ BMS system for Heat Pump management and control ▪ Wires, switches, circuit breakers, raceways ▪ Rack panel, switches, network cables	4,583 €
NRGate electric system	▪ Switchboards for NRGate supply and regulation ▪ BMS system for each NRGate management and control ▪ Wires, switches, circuit breakers, raceways ▪ Network cables	5,304 €
Worksite Supervision	▪ Safety and coordination plan design ▪ Timing and time schedule management ▪ Construction supervision ▪ Safety on worksite supervision	6,000 €
TOTAL		**30,809 €**

Direct costs for supplies and procurement of materials are largely represented by electrical and electronic materials for powering, monitoring and controlling the new systems, affecting more than 45% of the work for the implementation of 4RinEU solutions, more than the hydraulic part did.

These data, however, are significantly affected by the fact that the main components of the new systems, the inverter air-water heat pump and the 13 NRGate modules were supplied by the manufacturer Thermics, another partner of the project, for which their procurement and shipping was not a cost incurred by Tecnozenith for the Italian Demo Site.

Table 48 Hours worked by Tecnozenith

MANPOWER	APPROX. WORKED HOURS [h]	APPROX AMOUNT [€]
Hydraulic Manpower	570	13,500 €

Electric Manpower	460	12,000 €
Construction Manpower	70	1,700 €
Office Works (system design, works supervision, orders, BMS programming, 4RinEU project management,…)	330	15,000 €
TOTAL	**1,450**	**42,200 €**

Looking at the cost of the personnel employed for the 4RinEU project, it can be seen that the cost of the hydraulic and electric manpower is practically equivalent.

The manpower used to create the new hydraulic circuits of the heat pump and the NRGates has in fact a substantial number of hours, having had to create a new large system, occupying the entire attic, and presenting longer processes, such as transport of the pipes, pressing and welding them and positioning of brackets machinery and accessories.

The electrical system also required a good number of hours, mainly used in the installation and wiring of the BMS electrical panels, each serving the accommodation and the NRGates. In this case, however, the manpower used is more qualified, having to pay close attention to the electrical connections that are safe and to the electrical connections to the BMS system, which are very delicate.

The main item is in any case constituted by the activities carried out by the offices. This item includes in the first instance the design of the new system and the sizing of all the components carried out by the company's engineers, the supervision during the execution of the works that these were carried out in accordance with what was designed, the orders of the material carried out by the various suppliers and final testing.

In addition to this, the implementation of the 4RinEU project in the Pinerolo condominium required intellectual work for the design of the control algorithms of the BMS system at the service of the centralized system and of the individual accommodations, the commissioning of this system with the interfacing to the various meters and devices present, the creation of a dedicated network for remote control and the implementation of a service for the remote and automatic sending of the collected data.

Lastly, the Tecnozenith office took care of the management of the 4RinEU project itself, with the communications between the various partners, in particular with the leader and with the supplier of the machinery, and the completion of the bureaucratic and technical parts required.

1.7 Conclusions

Within the demo site building in Via Tabona, the technologies developed by Thermics were used and perfectly integrated into a new intelligent and adaptive centralized system.

The NRGate Box™ solution, associated with the modulating heat pump, is an application that lends itself very well to building renovation works, especially to switch from autonomous heating systems to centralized systems for condominiums. This is because the heat pump and the hydraulic modules were easy to install and the latter were compact in size, requiring no large space for installation.

The coupling of the new systems with NRGate Box™ to the installed ventilated façade was very interesting. This solution can be replicated in other buildings that use this insulation solution, providing for the passage of cables and pipes inside, and to reach the different apartments. In this way it is also possible to install the NRGate Box™ directly inside the dwelling, and not in a single common space as happened in Pinerolo, by connecting them to a manifold near the heat pump. The integration of these solutions leads to minimally invasive interventions in the homes of end users.

Significant final results will be visible at least one year after installation, when a heating and a cooling season will have passed, but a considerable decrease in the natural gas used by the building's lodgings and recorded in the bill is expected, as the heat produced by the heat pump is widely exploited.

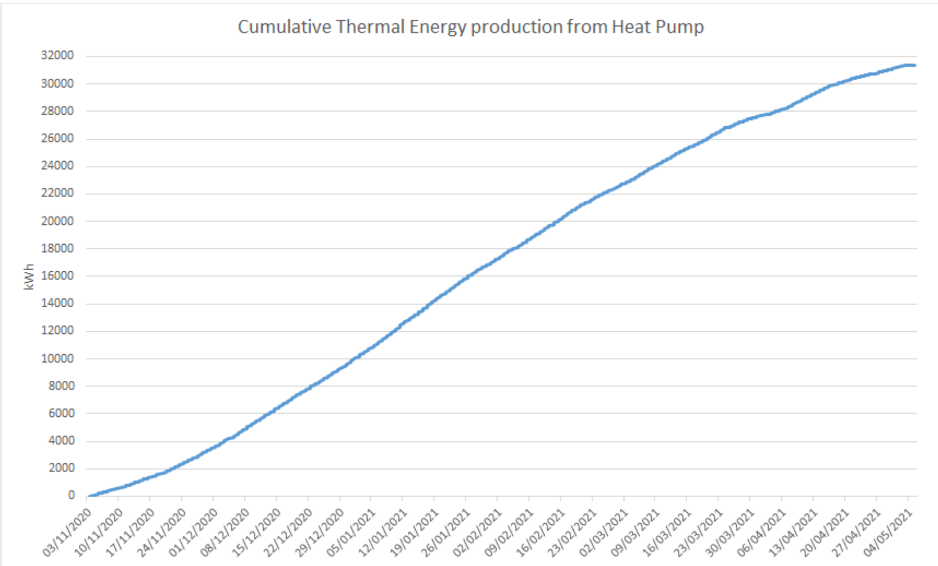


Figure 147 Thermal energy production by heat pump in the first heating season