4RinEU

Reliable models for deep renovation

D5.2

WP5

Concept design and performance targets for the demos

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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 2020 (extended to June 2021).

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

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Executive Summary

One of the aims of 4RinEU project is to demonstrate the robustness, effectiveness and viability of a deep renovation strategy. This is done by applying the developed technology solutions and methodologies (as a whole or partially) on four demo-cases in different European contexts: Norway, Netherland, Spain and Italy.

The four demo-cases follow a similar process, as developed in 4RinEU project, leading to the definition of the deep renovation packages. Such process is coordinated by demo-owners and a technical advisor for each of them and assisted by other project partners and local players contributing to the established Local Demo Case Working Group. The related meetings and participative discussions, based on expected impacts as defined in the call and supported by the preliminary audit, enabled demo owners, the local advisors, the technology suppliers and developers to share a context-tailored approach for the renovation. Specific needs and drivers for local deep renovation process towards the definition of the technology concepts have been defined, including in a coherent package both 4RinEU solutions and market products.

For each demo-case, once collected the key features of the building, targets, deep renovation needs and context constrains, as well as requirements of national regulation and local building code were indeed identified. Therefore, deep renovation concepts are formulated to achieve those targets and procurement procedures with different approach, again affected by the context, were launched to perform the chosen interventions allowing to face the identified needs.

Finally, preliminary planning of the renovation activities was defined, continuously updated and used by the LDWG.

1 Introduction

Within 4RinEU, two processes started almost in parallel: on the one hand, the technology and methodological approach development in WP2 and WP3 and, on the other hand, the organization of the renovation activities in the three demo cases as foreseen in WP5. During the very beginning of the project, the two processes flow almost independently, from one side working on the enhancement of already available technology solutions, as well as defining pro&cons figures and, on the other side, fixing local needs and targets of deep renovation actions. The defined possible technologies features and the identified demo performance targets represent the two factors needed to finalise the definition of the deep renovation packages to be applied in the three demo-cases, as well as in the fourth one introduced in 2020 for field demonstration of the plug&play energy hub functions and performances.

This document describes, for each demo case, the process leading to the definition of the 4RinEU renovation concepts including:

- The key features of the buildings
- The renovation needs and the main drivers
- The targets for the renovation (both specific minimum requirements provided by local laws and regulations and 4RinEu targets)
- The procurement procedure followed by the demo owners in case of renovation
- The Gantt of the renovation activities in the three demo cases in coordination with 4RinEU
- The specificities of the renovation concepts

1.1 The Local Demo Case Working Groups: roles and key actors

In order to facilitate the process, as already proven in other EU projects (e.g. CommONEnergy[1]), at the beginning of the project we established three Local Demo Case Working Groups (LDWG). The groups play a key role in the definition of the renovation packages for the demo cases. In fact, they aim to share the information among all the actors involved in the renovation chain of the demo cases, involving also the local design teams and, in the case of the prefabricated multifunctional façade (R1) also the local supplier of the components.

In particular, the groups include horizontal members, dealing with the demo cases and specific members, focused on one building. Each horizontal member has a specific role in the coordination of the LDWGs:

[1] Website: http://www.commonenergyproject.eu/

- ACCIONA/EURAC: coordination and overall supervision of local activities, planning and update Gantt, documentation and risks management of the renovation process in the demo-cases.
- EURAC: overall supervision of the activities, coordination of the contribution from the technology partners to the demo cases, technical support for solving management and technical issues and, in case of need, work on a contingency plan. Moreover, EURAC supported (i) to identify the opportunities, technical viability, requirements to integrate the PPEH system, and (ii) the design decision process for optimize RES harvesting through EarlyReno tool
- ADERMA: audit and monitoring activities before renovation, definition of deep renovation drivers starting from the main needs of the buildings identified within the audit, data storing, managing and accessibility
- THERMICS: supplying (manufacturing and installing) plug&play energy hub
- G&M: technical specification of the multi-functional prefab façade systems for tender procedure and participation in workshop with possible local suppliers
- IES: providing sensible building data handler (features and release) and deep renovation collaborative design platform
- Monitoring team (ADERMA, EURAC, R2M) organisation of the measurements after renovation (definition of parameters to be monitored, hardware specificities and data elaboration)

Supporting the horizontal members, the LDWG include players which are focused only on a specific demo case:

- Demo owners (BOLIGBYGG for Norway, WOONZORG for The Netherlands, AHC[2] for Spain and TECNOZENITH for Italy): identification of the deep renovation needs, local constrains and procurement procedures in the specific country, taking care of certification and specific local requirements, definition of deep renovation timing and responsibilities, implementation of deep renovation and monitoring system
- Local advisors (SINTEF for Norway, TRECODOME for The Netherlands, AIGUASOL for Spain and TECNOZENITH for Italy): facilitators of the communication and overall technical advisors for the building owners in order to define conceptual design of the deep renovation, definition of technical specification of the used materials in the procurement procedures.
- DESIGN TEAM: external contributors supporting the project partners to tailor the 4RinEU renovation packages to the specific requirements of the local laws and regulations for building renovation
- CONSTRUCTION TEAM: general contractor, local technology suppliers, craftsmen who will install the 4RinEU renovation packages.
- LOCAL AUTHORITIES potentially involved in the renovation process (e.g. actions dealing with the tender procedure and authorizations)

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[2] In case of Spain, the demo owner is INCASOL, nevertheless AHC is in charge of the maintenance and of the renovation of the building and it is more actively involved in the LDWG with the reported role.

The first round of LDWG in the three demo cases has been finalised at the end of 2016 with three physical meetings on site. After that, conference calls organised every 2-3 months occurred on a regular basis for each demo case and depending on specific demos' needs. Initially, only three demo cases have been foreseen (Norwegian, Dutch and Spanish). In these demos, the whole 4RinEU deep renovation process has been implemented, including the use of the prefabricated façade with integrated components. Later in the project (beginning of 2020), a fourth demo has been adopted in order to demonstrate the feasibility of the Plug&Play Energy Hub technology, which has not been used in any of the other demos.

2 Norwegian Demo Case: Haugerudsenteret 17-19, Oslo

2.1 Key features of the building

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 centre in the suburb of Alna, located east of the Oslo city centre, see Figure 1. 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 1. Satellite view of the demo building, highlighted with a red circle

*Haugerudsenteret 17-19 c*onsists of eight apartments, with an architecture giving the appearance as of small detached houses, see Figure 2. Four apartments are connected to each of the two indoor staircases.
The tenants may belong to a vulnerable group that has special needs and are to be as less disturbed by renovation works as possible. Boligbygg is in charge of the general maintenance, operation as well as renovation of the buildings. Technical solutions need to be robust.

Figure 2. Existing building South façade (left) and North façade (right)

Each apartment is approximately 40 m², standard room height 2,4 m, with a combined kitchen and living room, a bedroom, and a bathroom.

The entrance and living room are facing the south façade, while the bedroom is placed on the north façade, see *Figure* 3.

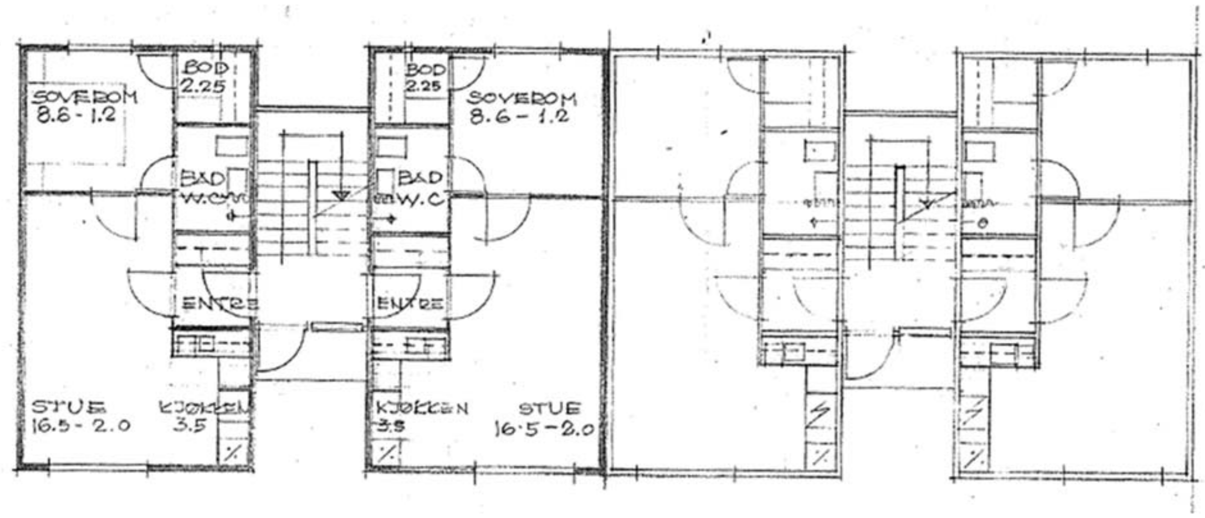


Figure 3. Existing building. Living room (stue) facing South, Bedroom (soverom) facing North.

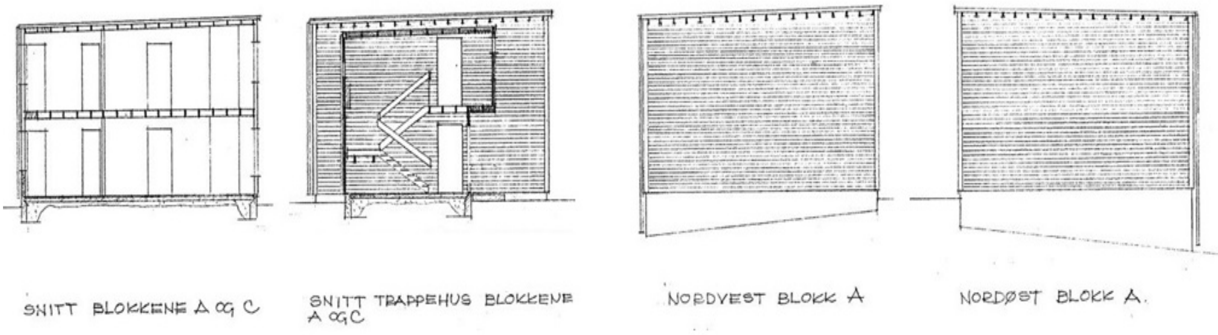


Figure 4. Existing building. Section and façade west and east.

The building dimensions are 24.4 m x 8.8 m There is no basement, only slab on the ground floor and the existing roof above a small cold attic.

The building has a wooden construction with poor fiberglass insulation (10 cm wall, 15 cm roof), according to building codes of 1969. When the building was opened for initial inspection, Siporex construction (expanded concrete), was detected in ground floor wall construction. See *Figure 5*. Original windows had been approved, but still not of today's standard.

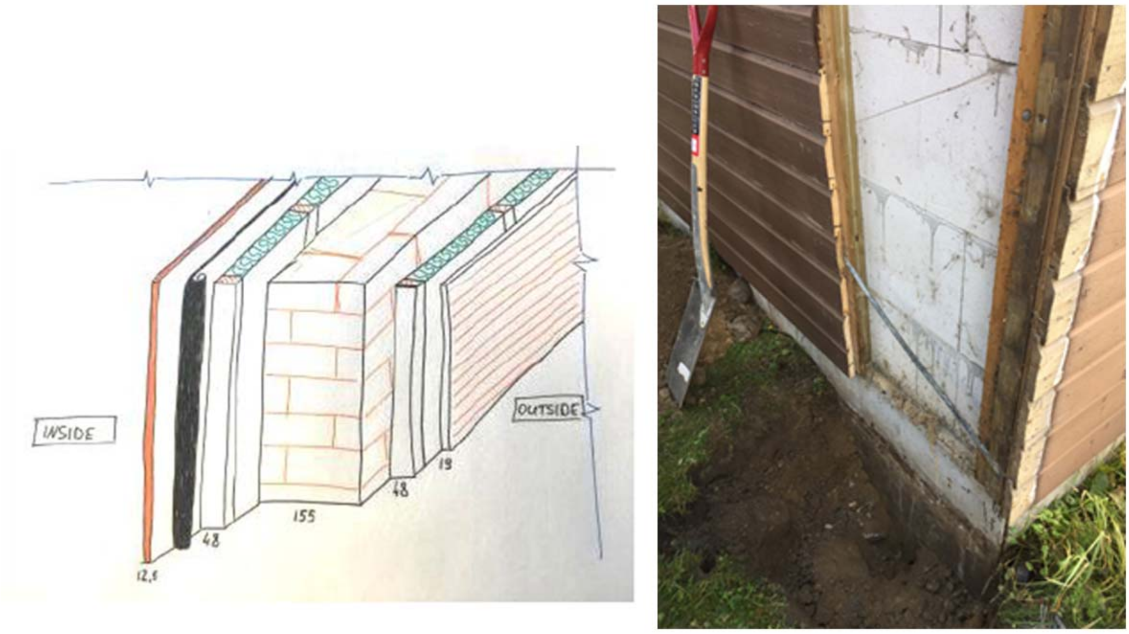


Figure 5. Inspection of existing construction. Early sketches of ground floor Siproex construction (top, left) and general wooden construction

The apartments were equipped with electrical heating and an electrical heated hot water tank for each apartment. No cooling installed, as normal in cold climate apartments. Natural ventilation with inlet openings in wall and integrated in window frame. Only some apartments had external sun shading, and of these most were in bad shape and with limited function. Internal curtains were often closed more than normal with respect to desired privacy.

Detailed descriptions are given in project deliverable D5.1 “Energy audit for the deep renovation in the demo cases”.

2.2 Drivers of the renovation

The general and building specific drivers that led Boligbygg to the renovation of the demo case-building within 4RinEU are described below.

General drivers

- Overall CO_2 reduction for the city of Oslo: Oslo has been announced as the European Green Capital of Europe for 2019 (https://ec.europa.eu/environment/europeangreencapital/winning-cities/2019-oslo/) and has high ambitions for energy efficiency, sustainability, and climate gas emissions related to the building stock. Boligbygg is obligated to follow up on these ambitions.
- More sustainable building stock: Boligbygg is a publicly owned social housing provider with a building stock of 11000 apartments throughout the city of Oslo. Since 2012, the ambitions have developed from passive house standards (2012) to energy-positive houses (2015) and fossil and emission-free construction sites (2017 and 2019). The minimum BREEAM ambition for new housing is "Very good".
- Social responsibility: Boligbygg provides social housing but does not want to offer "low-cost" housing for its tenants. The housing should be simple, but functional and robust fulfilling the tenants' basic need. Boligbygg aims at implementing innovative renovation approaches to account for both simple cost-effectiveness but also co-benefits for the users and tenants.
- Development of a renovation approach with high replication potential for the public residential stock of Boligbygg and Norway.

Building specific drivers

- Poor indoor air quality: The existing building had issues with indoor air quality due to poor ventilation of each apartment. Fresh air supply was only covered by natural ventilation, a source of draft problems in the winter period. The users often closed or blocked the inlet openings. Balanced ventilation with heat recovery is wanted to improve both indoor air quality and energy efficiency. No specific complaints about overheating.
- State of the building envelope: The renovation was originally planned as a pure façade renovation because the exterior cladding was old and needed to be replaced. Upon the decision of participation in the 4RinEU project, the ambition for renovation was raised to deep renovation according to the 4RinEU targets.

2.3 Key issues to consider for a successful renovation

This specific needs and success criteria defined by the LDWG and the demo owner was:

- Prefabricated wooden wall elements with integrated RES and technical installations

- Adaptation of robust technologies with minimum maintenance need for the building owner and minimum need for attention from the tenants. Robust means, in this case, an adaptation of technologies capable of enduring potential hard use and solutions that can be operated from the outside of each apartment.
- Low tenant disturbance. Short on-site construction time and "from outside"-deep renovation was emphasized very important. The need to enter apartments should be minimized and coordinated. The necessary visits were accompanied by “user contact” to protect the interest of the inhabitants.
- Improved indoor environment quality and reduced draft problems by installing energy efficient balanced ventilation with high heat recovery.
- Passive house criteria were used as performance targets. This is known to be challenging for renovation projects and depend on possible measures. (see 2.4 and 2.6 for more information). Additionally, the use of PV or solar thermal collectors. The general 4RinEU target of a 60 % reduction of primary delivered energy applies.
- Use of BIM throughout the process. This included a scan of the existing building, establish a digital twin for the existing building, design-BM for new and existing construction, digital twin for production, and towards production. Tolerances and the exact position of existing windows and openings are of great importance for success. The use of multidisciplinary BIM to lower risk of off-site and on-site production errors.
- Adding new elements, not adding new problems. Risk identification to secure a safe and healthy solution for new and existing construction. The use of prefabricated elements can additionally eliminate typical construction mistakes.
- The retrofitting of the building should be performed during spring/early summer to avoid any cold season problems. The planned execution of the on-site work is scheduled such that the building is finalized before the common summer vacation (last three weeks of July).
- Finding a company able to produce advanced prefabricated elements was the number one key issue for success since G&M will not enter the Norwegian market. The LDWG wanted to use a Norwegian producer and local companies for developing local know-how for the industry as well as enough knowhow for cold climate constructions.
- Early involvement of producer in design group. Tailoring new prefabricated elements with integrated building services requires a cross-disciplinary approach in all stages of the construction process. The solution should be well suited for production, transportation, and installation. Close-to-marked a cost-efficient solution.

2.4 Target of the renovation

2.4.1 Minimum requirements provided by law and local regulations

In this subsection, the minimum requirements provided by law and regulations are presented. The relevant requirements are mainly those for energy performance. Other performative requirements are mentioned below, but not repeated in detail.

The main principle in Norway's Planning and Building Act (2008) is that renovation projects shall fulfil the same requirements as new buildings for all relevant requirements (which requirements that are relevant in each project depends on the project itself). Because of this, there exists no explicit statutory requirements for the renovation of buildings, only requirements for new buildings. New buildings must follow the Building regulations and Technical Requirements for Construction Works (TEK17).

In a renovation project, not all building elements are renovated, and the main principle is that those building elements that are renovated are the ones that need to be upgraded to today's standards unless the upgrade is "unreasonably costly". If the measures needed are "unreasonably costly", this means a "full" upgrade may not be viable or even possible. Further explanations are presented in each paragraph below.
Further info can be found in the following documents:

- *TEK17. 2017. Regulations on technical requirements for construction works ("Byggteknisk forskrift - TEK17"). edited by Ministry of Local Government and Modernisation.*
- *Planning and Building Act. 2008. Act of 27 June 2008 No. 71 relating to Planning and the Processing of Building Applications (the Planning and Building Act - "pbl."). edited by Norwegian Building Authority: Ministry of Local Government and Modernisation.*

Energy performance
The current situation of the building, along with overall minimum requirements for new buildings and specified 4RinEU targets, are presented in Table 1. The values for the 4RinEU targets are found based on the overall project targets, as described in subsection 2.4.2.

However, when buildings are renovated or upgraded, the renovated building element should fulfil the relevant requirements at the time of renovation unless there are reasons related to unreasonably high costs, or in case small parts of the building element are renovated, e.g., replacing parts of a brick wall. Firstly, the target is as close as possible to up-to-date requirements within reasonable cost. For the latter, the performance of the existing building element is the target performance.

In the Oslo Demo case, the initial overall energy performance target was passive house standard in compliance with Norwegian Standard NS 3700 (2013) *Criteria for passive house and low energy buildings. Residential buildings.*

Passive house performance, either in the sense of NS 3700 or the definition provided by the Passive House Institute (PHI), is out of reach for this renovation because of the heat loss through the uninsulated slab on the ground floor is too high. Possible measures enabling passive house performance after the renovation was considered, but kept out from the renovation project, both due to lack of funding and too exhaustive interventions to the building.

Table 1. Building renovation requirements

Building element	Current situation [W/m²K]	Ordinary energy renovation [1]	Minimum requirements for new buildings [2] [W/m²K]	4RinEU targets [W/m²K]
Roof	0.30	–	0.18	0.11
Façade (av.)	0.36	–	0.22	0.13
1st floor	0.29	–		0.12
2nd floor	0.42	–		0.14
Ground Floor [3]	1.2/0.53	–	0.18	1.2/0.41
Windows incl. frame/sill	1.8	–	1.2	0.8
Door	2	–	1.2	1.0
Glazing [4]	–	–	–	–
G-value glazing [4]		–	–	
Ventilation	unknown	–	[5]	[5]
Air tightness	N_{50}= 2.8 h^{-1}	–	1.5	1.0

[1] *There are no explicit statutory requirements for ordinary energy renovation of buildings in Norway*
[2] *In Norway, the minimum requirement is the average of the individual building elements*
[3] *The ground floor is not renovated itself, but the new foundation for the façade elements improve the equivalent U-value. The equivalent U-value includes the thermal insulation of the foundation and ground and is calculated according to EN ISO 13370*
[4] *There are no separate requirements for glazing in Norway. Requirements are stipulated only for windows incl. sills/frames. G-values are not used in standard calculations.*
[5] *For HVAC/ventilation the requirements cannot be expressed by a single figure*

Fire safety requirements

Fire safety is often a not straight forward issue in renovation projects because older fire safety regulations were less strict than today's regulations. Fire safety was also an issue in this project, but in lieu of the main regulatory principle explained at the beginning of subsection 2.4.1, no new measures needed to be applied in this case.

The renovation of the building did not affect the fire design concept or evacuation plan. The number of tenants, the number of stories, or story height did not increase, resulting in new escape routes. The existing escape routes were not altered since the renovated windows had the same size, function, and placement as the old ones.

However, Boligbygg wanted to improve fire safety in staircases by painting new wall panels with fire-resistant transparent paint.

Structural safety

The renovation included replacement/upgrade of loadbearing constructions, i.e., façade and roof. Because of this, the new façade and roof elements must comply with today's requirements for structural safety, *i.e.*, compliance with requirements for self-weight and imposed loads.

The intention was to mount façade elements directly on the existing façade. This was not considered as possible due to the poor loadbearing capacity of aerated concrete bricks (Siporex) used in the building envelope. Thus, the new façade where ought to be placed on a separate and new foundation constructed outside the existing foundation. Loadbearing of the new roof was provided by the new prefabricated elements.

The main change in requirements for structural safety has been an increased tolerance for snow loads. The existing roof was built to withstand a load of 1500 N/m^2, which was the requirement in the 1970s when the building was constructed (Ministry of Local Government and Labour 1969). According to today's regulations, the national addendum in NS-EN 1991-1-3:2013+A1:2015+NA2018 *Eurocode 1. Actions on structures. Part 1-3: General actions.* Snow loads sat that requirement to 4500 N/m^2 for construction sites within Oslo municipality with an altitude between 150 and 250 m above sea level.

Acoustic requirements

The only parts of the building that are affected by acoustic requirements are the new ventilation system and façade elements. The renovation did not change interior separation walls, floor plan, or use of the building, so new requirements for sound insulation between apartments did not apply to the demo case.

Installation of balanced ventilation with heat recovery imposes requirements of noise from building services according to Norwegian Standard NS 8175:2012 *Acoustic conditions in buildings. Sound classification of various types of buildings.* The same applies to façade insulation and windows with respect to sound insulation and indoor noise levels from outdoor sources. The building is situated in a quiet area, outdoor noise level is not regarded as a problem

For the tenants, noise exposure during night-time should be kept well within the requirements in NS 8175.

Water and sanitary equipment will not be renovated and will still be within the range of the limit values that applied at the time of construction.

Table 2. Acoustic requirements

Acoustic requirement	Current situation*	Ordinary renovation**	Minimum requirements for new buildings
Noise from building services	$L_{p'A,eq} \leq 35$ dB	$L_{p'A,eq} \leq 30$ dB $L_{p,AF,max} \leq 32$ dB	$L_{p'A,eq} \leq 30$ dB $L_{p,AF,max} \leq 32$ dB
Noise from outdoor sources			
In bedrooms, living rooms etc.	–***	$L'_{p A,eq} \leq 30$ dB	$L'_{p A,eq} \leq 30$ dB
In bedrooms, nighttime 23–07	–***	$L_{p,AF,max} \leq 45$ dB	$L_{p,AF,max} \leq 45$ dB

** The current situation is stated as the minimum requirements at the time of construction [Norwegian Building code of 1969]*
*** As a starting point, renovated building elements must satisfy the same requirements as new buildings*
**** There were no national requirements for maximum indoor noise levels from outdoor sources at the time of construction [Norwegian Building code of 1969]*

Indoor climate and ventilation requirements

Requirements for the indoor climate is linked to air flow rates for both fresh air supply and exhaust air. Usually, the exhaust airflow rates from the bathroom is the design capacity for the ventilation system in the dwelling.

Table 3. Air Change Rate (ACH) requirements

Indoor climate requirement	Current situation[1)]	Ordinary renovation[2)]	Minimum requirements for new buildings
Fresh air supply			
General	Natural window ventilation	1.2 m^3/m^2h	1.2 m^3/m^2h
In bedrooms		26 m^3/h	26 m^3/h
Exhaust air flow rate			
Bathroom, base	Natural ventilation	54 m^3/h	54 m^3/h
Bathroom, forced		108 m^3/h	108 m^3/h
Kitchen, base	Natural ventilation	36 m^3/h	36 m^3/h
Kitchen, forced	Kitchen hood	108 m^3/h	108 m^3/h
Indoor air temp.[3)]	< 27 °C	19–26 °C	19–26 °C

[1)] The current situation is stated as the minimum requirements at the time of construction (1969)

[2)] As a starting point, renovated building elements must satisfy the same requirements as new buildings

[3)] These values are not strict requirements, but official guidelines for indoor air temperature. Today, upper limits can be exceeded for shorter periods of time. For the current situation, the indoor temperature can be 5 °C higher than the outdoor temperature when the outdoor temperature exceeds 22 °C.

2.4.2 Targets of 4RinEU project

The 4RinEU energy performance targets are:

1. **Reduction of primary energy use of at least 60%** compared to pre-renovation levels.
2. **Reduction by factor 2 in the time needed on site for renovation** compared to typical or traditional renovation today.
3. **Increase in Renewable energy production of 30–100 %** compared to pre-renovation levels.
4. **Reduction of renovation cost of at least 15%** compared to a typical renovation (i.e., a renovation that meets current minimum requirements of existing building regulations).
5. Quantification (number of buildings) of **potential for residential building renovation with 4RinEU approaches** for the building owner (contribute to the achievement of a 3 % renovation rate).
6. **Increase the number of market stakeholders** with improved skills, capabilities, and competencies on energy issues as much as possible.

7. **Reduce emissions of greenhouse gases** in the operational phase (tCO2/y) and **reduce the amount of construction waste** and **improve indoor environmental conditions and sustainability** as much as possible.

Reduction of primary energy use

Net primary energy is not a commonly used term in Norway, hence approved primary energy factors do not exist. Therefore, the 60 % reduction goal is related delivered energy in the Oslo demo case. Delivered energy is calculated within the system boundaries of Haugerud centre 17-19. This implies the losses of the electricity used for heating (efficiency): domestic hot water (DHW), electric radiator, and the heating batteries.

The design target for the energy performance is stated based on the measured, HDD adjusted overall electricity use over one year. The energy budget is shown in Table 4 below.

The measured data are subtracted standard stipulated values for technical equipment to find a value for the delivered energy related to the building (space heating, fans, pumps, hot water (DHW), lighting, and auxiliary energy) before and after renovation. The design target of delivered energy after renovation is then split up to form a design target for hot water, lighting, and the practical energy target (space heating, fans, pumps, and auxiliary energy).

Table 4. Energy targets for the renovation of the Oslo demo case

Parameter	Value	Unit	Reference
Annual measured, HDD corrected overall electricity use 2006–07	247.0	$kWh/m^2 y$	Boligbygg report: Energy efficiency and economic analysis (ENØK) and measurements from 2006-07 [1)]
- Technical equipment	17.5	$kWh/m^2 y$	Standard value stipulated in Norwegian Standard NS 3031
- Lighting	11.4	$kWh/m^2 y$	Standard value stipulated in Norwegian Standard NS 3031
- Hot water[2)]	54.2	$kWh/m^2 y$	Standard value stipulated in Norwegian Standard NS 3031
= Baseline prior to reduction	163.5	$kWh/m^2 y$	Delivered energy, excl. technical equipment
60% reduction	98.1	$kWh/m^2 y$	4RinEU target
Energy target	***65.4***	$kWh/m^2 y$	Delivered energy for space heating

[1)] ENØK - Norwegian energy-efficiency and economic analysis. Consultant assignment for Boligbygg.

[2)] Calculated from standard value in NS 3031 (29,8) to delivered energy with an efficiency of 0.55.

The “before and after” comparison of the ventilation concept of the building can be challenging. The natural ventilation is closely related to user behaviour, potentially being drastically decreased by closed openings in wintertime, while balanced ventilation is more predictable.

The PV system reduces the delivered energy to the building. However, PV production at Haugerudsenteret can only be used in common areas, as energy for heating in staircase and air handling units. Each apartment is equipped with its own electric meter, and used electrical energy is measured and billed by the local energy provider. Boligbygg is not allowed to provide or sell produced energy to the apartments. Surplus energy will be feed to grid.

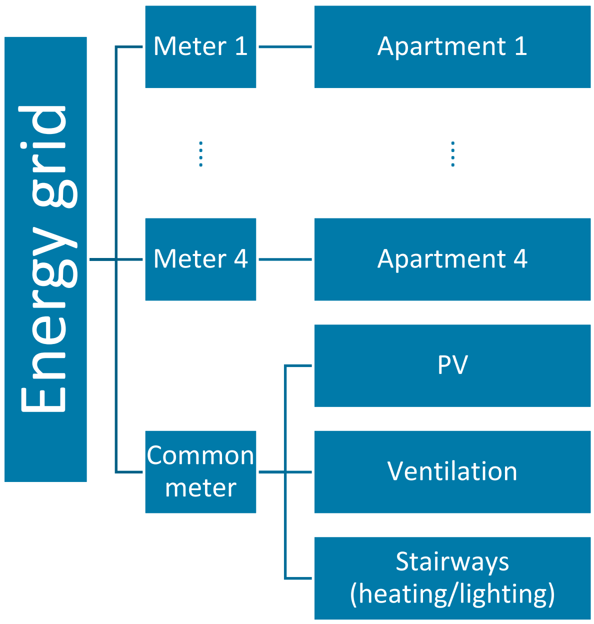


Figure 6. Installation of the PV system in common areas. Due to legislation, all energy delivered to meters (Meter 1—4 and the common meter) must be delivered by the grid owner. Local production only contributes "behind" one meter and cannot be "freely traded" across meters

The PV system is coupled to the common meter covering heating and lighting in the stairways and technical rooms, and operation of the ventilation system, see Figure 6. The RES production will not benefit the tenants but will benefit the building owner responsible for the electricity provided for the stairways and building services.

Reduction of renovation time on construction site
Time spent on the implementation phase is compared with estimates for on-site implementation time for an ordinary renovation. The time spent in the design stages of the process is excluded by the comparison.

For the comparison, a similar set of product deliverables (upgraded insulation, new roof, new windows, new balanced ventilation system, etc.) is investigated.

Optimization of RES generation and integration with the energy grid
Installation of the PV system will increase RES generation and support Boligbyggs strategy of providing "plus energy housing". With an installed PV system as described above, most of the production will be exported to the grid.

Since the generated energy cannot be feed to the apartments, optimization based on smart use is less fruitful than optimization with respect to generation and sale. Boligbygg accounts for the common meter covering the PV system and benefits from local RES production. These barriers are caused by legislation and agreements on how electric power is distributed and billed within and in buildings.

Cost reduction
Prefabrication is in general regarded as more costly than on site construction. However, cost reductions are foreseen in other aspects like shorter construction time at site and that tenant can stay at home. Use of BIM and implementing the producer in the design team will identify problems at an early stage. Then reduce costly re-design can be avoided and elements be designed for cost efficient production.

Acceleration of EU residential renovation rate
The approaches used in the Oslo demo case are immediately applicable to the remaining five buildings and 122 apartments of Haugerudsenteret. All buildings have the same basic floor plan, same foundation, and building envelope and ventilation concept.

On a larger scale, Boligbygg as well as other building owners, public or private, can investigate the possibility of adapting the solutions found for the Oslo demo case to other similar projects. The main goal for the Oslo LDWG is adaptable solutions with short distance from 4RinEU innovation to standard product line.

Revitalization of the EU construction sectors
The solutions found in the 4RinEU project will directly contribute to new competence for Boligbygg as a building owner, as well as Lindal as a producer and contractor. Furthermore, involved members of the Oslo demo design team will increase their competence in the possibilities of doing renovation using 4RinEU approaches.

Indirectly, the results of the project will be disseminated to the Norwegian building industry and building owners. So far, the project has caused great interest from the industry in Norway. Many are curious about the project solutions and its applicability to Norwegian conditions and building stock. Different results are disseminated at a wide range of conferences and meetings.

Improvement of outdoor pollution, indoor environmental conditions, and sustainability
The use of prefabricated elements reduces the amount of waste from the construction site. Construction site waste is a highly important topic, and the city of Oslo imposes requirements for sorting a minimum of 85 % of construction waste. The off-site element production is in general optimized for minimizing waste.

Improvement in indoor environmental conditions arises mainly from a better-insulated building envelope and the installation of balanced ventilation with highly efficient heat recovery.

2.5 Specific constraints (limitations)

There are a few specific constraints for the Oslo demo case.

- Electricity bills are paid in full by the tenants, and Boligbygg receives no direct benefit from the energy savings made. However, providing a good indoor environment and suitable accommodation to their tenant is important. Cost-efficient solutions more likely results in "obtaining more from the allocated budget" than savings in the future. Solution for low maintenance, however, is appreciated.

- Poor load-bearing capabilities for the discovered Siporex resulted in foundation-based wall elements.
- The existing floor is slab on the ground. Not able to upgrade this with other measures than extra insulation in connection with new foundations.
- Increased compactness: An extra floorplan was discussed to increase compactness, but not realized based on economy, loadbearing, and height. The existing modular shape was reduced to plane surfaces as much as possible.
- Roof elements were not included in the initial plan. Insulation of cold attic was also discussed, but the total construction process was decided to include also elements for the roof. This to ease connection wall/roof and construction time.
- The deep renovation was limited to "from outside" measures. No renovation inside the apartments was part of the scope. Then no upgrade of the electrical system nor DHW in the apartments was included as possible measures. The existing system was the main reason for choosing integrated PV, not integrated solar collectors.
- Boligbygg was not allowed to operate as an energy company and could not "sell" produced energy to the tenants. Produced energy could then only be used in common areas, energy for Air Handling Units and heating of staircases, the rest feed to the grid. Hence optimization of PV was not really possible. Standard size PV panels were placed on the south façade, optimized by architectural considerations and with respect to production and handling of prefabricated elements.
- Ventilation: The tenants should not have any responsibilities with respect to the operation of the ventilation system or other parts of the building (as before the renovation). Therefore, the air Handling Units (AHU) had to be placed outside each apartment to provide Boligbygg the opportunity to operate the systems without entering each tenants' apartment. (change of filter, fan-operation, setpoints). Since the space in the stairway is limited, the hook in the north façade was re-defined to technical space.
- Integrated ductwork was limited to supply air to the bedroom. This suitable length from AHU was regarded as proof of concept. Long ductwork around corners was avoided. To limit the disturbance of the tenants, exhaust air ductwork was placed underneath stairs and connected to the apartments from the stairway.
- AHU operates two apartments each. Space in the technical room, as well as operation point for necessary ventilation rates, are reasons behind the rotary heat recovery and are chosen to fulfil the requirement of more than 80 % heat recovery.
- Ventilation rates, according to requirements, can be high in small apartments. High air change rates might give low RH on cold days in wintertime. The problem is addressed in other research projects, but no specific measures taken for this demo case.
- The energy consumed by the residents varies much and is highly dependent on variations in indoor temperature and each tenant's use of the building. This makes it difficult to apply standard values.

- The approaches in the simulations are viewed for the whole building, whereas the building itself has two different floors. The first floor has a non-insulated slab-on-ground concrete floor, and the second floor has a heated apartment underneath it.

2.6 Building performances before and after renovation

In order to allow evaluations on the performance of the building, comparing the condition before and after renovation, energy simulations have been performed. This section describes the building performance simulation inputs and the results of the calculation.

2.6.1 Building simulation weather conditions

The weather file for the building simulations contains normalized hourly weather data prepared by the Norwegian Meteorological Institute and corresponds to a normal meteorological year during the period 1960-1990 (Eklima.no). The outdoor temperature, relative humidity and wind condition variation are presented in the figures below.

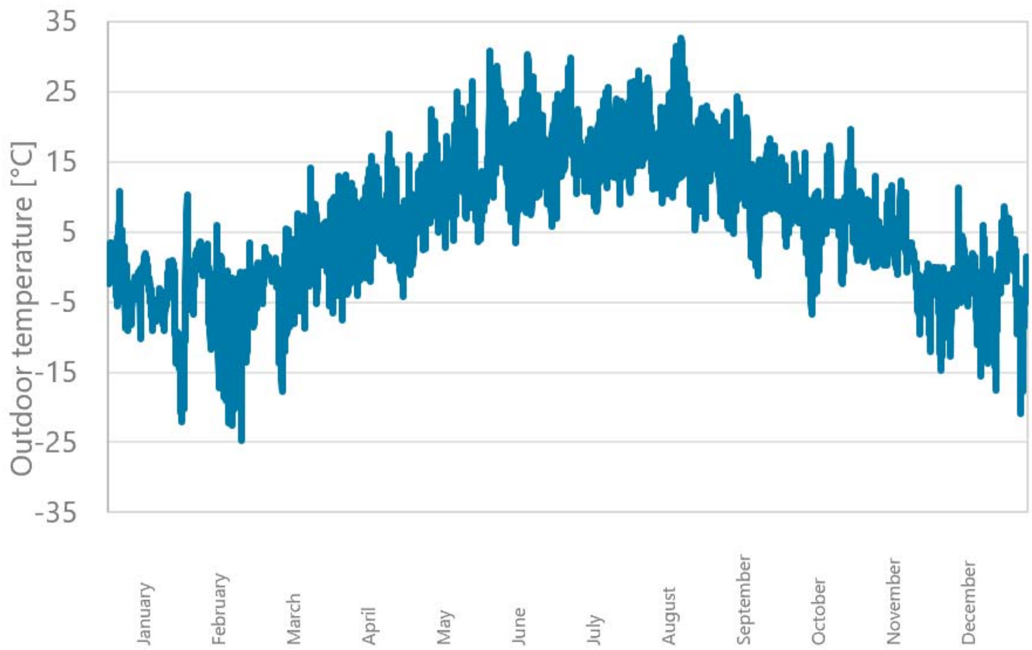


Figure 7. Outdoor temperature from Oslo weather file

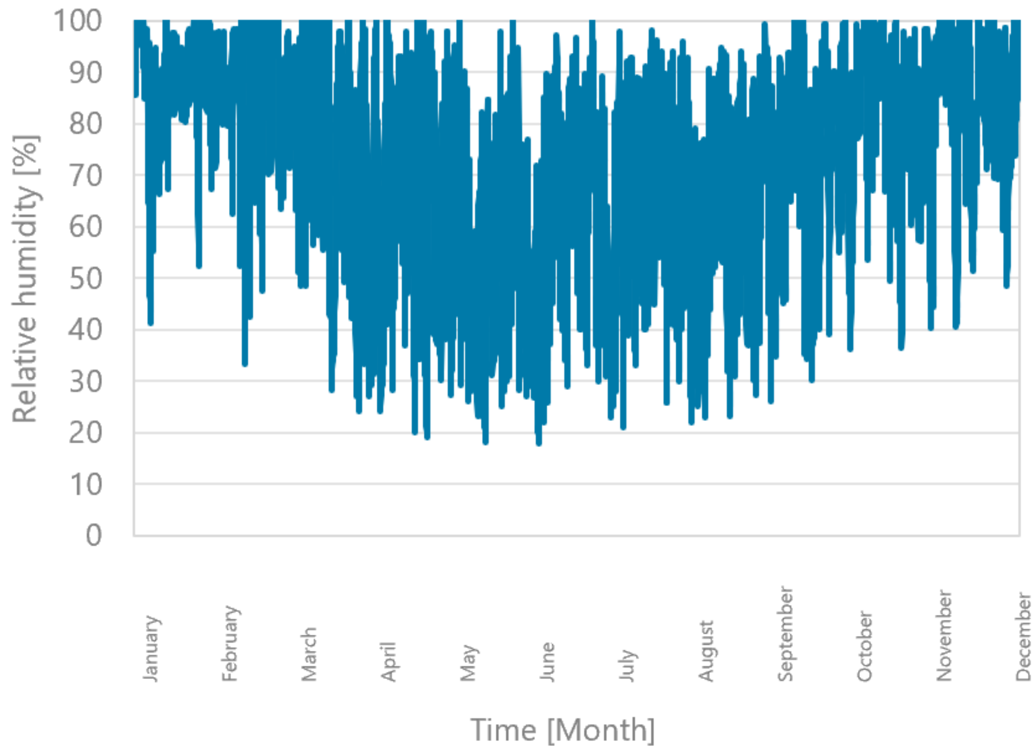


Figure 8. Relative humidity from the weather data file Norwegian Meteorological Institute (Eklima.no)

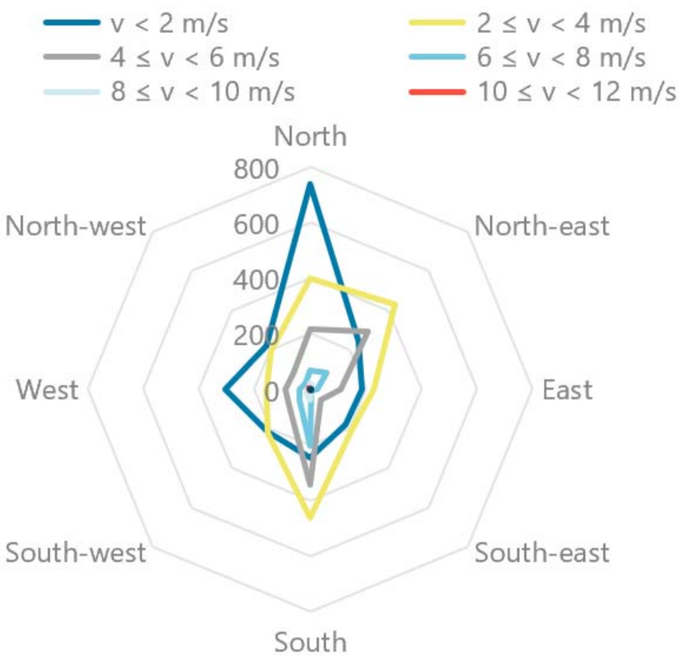


Figure 9. Wind speed and direction from the weather data file Norwegian Meteorological Institute (Eklima.no). The 0-direction and 0-wind speed were neglected in the calculations. The number of hours in the wind data are therefore 6574.

2.6.2 Building simulation model

SIMIEN calculates the energy framework according to *NS 3031:2014 - Calculation of energy performance of buildings - Method and data*, and has been the chosen building simulation tool to investigate the building performance before and after renovation.

For building performance calculation (BPC) purposes, it was decided to divide the building into two zones, the 1st floor, and the 2nd floor. This was mainly due to the BPC tool, which cannot carry out different U-values on the external walls and ceiling heights. The Norwegian Standard *NS 3940:2012 Calculation of areas and volumes of buildings* was used to determine building model definitions. The following table describes the dimensions of the building (Haugerud Center 17-19) used in performance calculations, before and after renovation.

The figures below describe the lengths and widths in a floor plan format before- and after renovation implemented in the BPC.

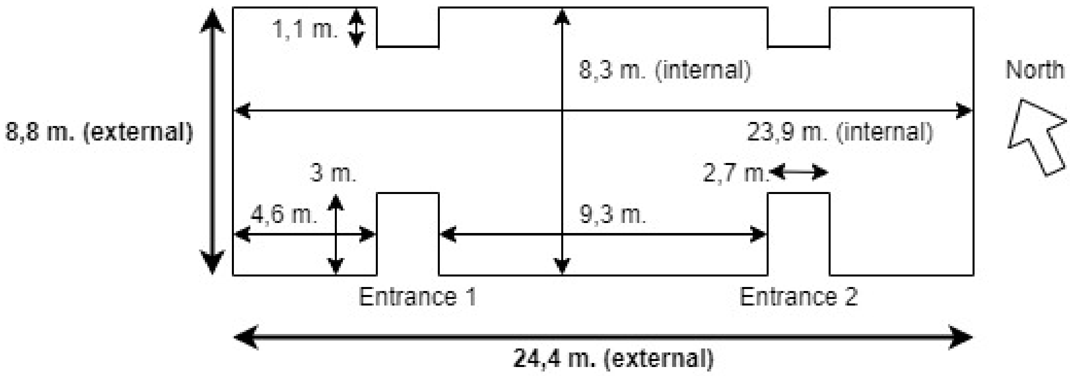


Figure 10. Ground floor - Building definitions before renovation, internal, and external measures are shown. The bolded lines and texts are external measures.

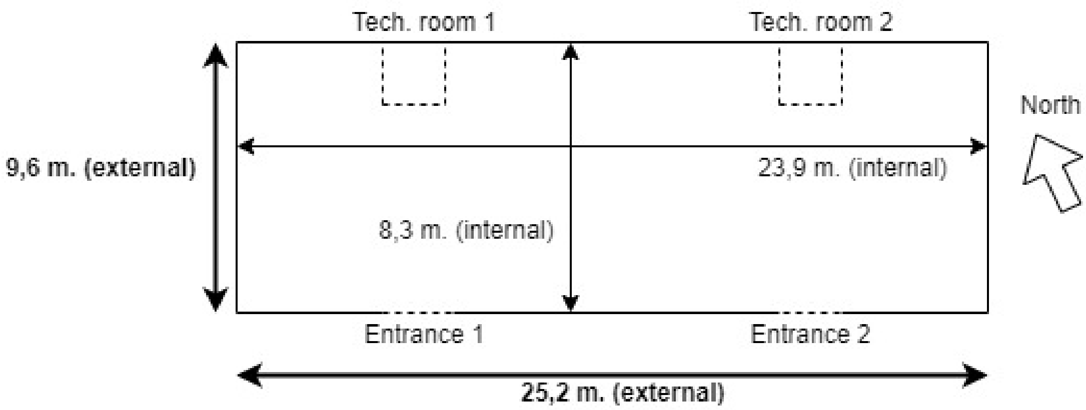


Figure 11. First floor - Building definitions after renovation, internal, and external measures are shown. The bolded lines and texts are external measures.

Table 5. Building model definitions. Dimensions are reported in compliance with Norwegian Standard NS 3940 Calculation of areas and volumes in buildings.

Parameter	Before renovation	After renovation
Main dimensions		
Internal length of building	23.9 m	23.9 m
Internal width of the building	8.3 m	8.3 m
External length of building	24.4 m	25.2 m

External width of the building	8.8 m	9.6 m
Internal story height 1st floor1)	2.50 m	2.50 m
Internal story height 2nd floor2)	2.48 m	2.81 m
Floors and roof		
Internal ground floor/roof area3)	180 m^2	198.4 m^2
Internal slab on ground floor perimeter4)	80.8 m	64.4 m
Floor area 1st floor (BRA) Heated floor area (BRA) four apartments Hallway Technical room	180 m^2 160 m^2 20 m^2 -	198.4 m^2 160 m^2 36.4 m^2 2 m^2
Floor area 2nd floor (BRA) Heated floor area (BRA) four apartments Hallway Technical room	180 m^2 160 m^2 20 m^2 -	198.4 m^2 160 m^2 36.4 m^2 2 m^2
Total heated floor area (BRA)	320 m^2	320 m^2
Façades		
Internal length of all façades facing North/South5)	23.9 m	23.9 m
Internal length of all façades facing East/West6)	16.5 m	8.3 m
Total internal façade area (including windows/doors)		
1st floor – North/South	59.8 m^2	59.8 m^2
1st floor – East/West	41.3 m^2	20.8 m^2
2nd floor – North/South	59.3 m^2	67.2 m^2
2nd floor – East/West	40.9 m^2	23.3 m^2
Total window area South	12.0 m^2	30.0 m^2
Total window area North	6.4 m^2	6.4 m^2
Door area	5 m^2	6 m^2
Volume		
Heated volume 1st floor	450.0 m^3	450.0 m^3
Heated volume 2nd floor	396.8 m^3	449.6 m^3

1) Measured from top of flooring to halfway through the floor between the 1st and 2nd floors
2) The height and volume of the existing roof is included in the heated volume in the renovated case
3) The internal ground floor area increases because the technical room is added, and the entrance area expanded
4) The slab on the ground floor perimeter decreases because the technical room is added, and the entrance is expanded. This makes the building more compact
5) The length of the façades facing North or South does not increase when the technical room is added, and the entrance expanded
6) The length of the façades facing East or West decrease when the technical room is added, and the entrance expanded

2.6.3 Building simulation envelope properties

The table below describes the building envelope properties.

Table 6. Building envelope thermal transmittance before and after renovation

U-value [W/(m²K)]	Reference [-]	Before renovation [W/(m²K)]	After renovation [W/(m²K)]
External wall 1st floor	EN ISO 6946	0.29	0.12
External wall 2nd floor	EN ISO 6946	0.42	0.14
Roof	EN ISO 6946	0.30	0.11
Slab on ground floor (U_f) Equivalent U-value ($U_{fg;sog}$)*	EN ISO 13370	1.20 0.51	1.20 0.43
Door	-	2	1
Window (frame and glazing)	-	1.8	0.8

* The equivalent U-value depends on the size and dimensions of the building and the thermal insulation of the foundation. Although nothing was done to the floor itself, the equivalent U-value is improved due to a more compact building envelope and additional insulation in the foundation of the façade elements.

Envelope airtightness before and after renovation is reported in the table below.

Table 7. Envelope airtightness before and after renovation

	Before renovation	After renovation
Airtightness (N_{50})	2.80 h^{-1}	0.60 h^{-1}

2.6.4 Input data

The input data both before- and after renovation are presented in Table 8. The reference for the chosen parameters is from *NS 3031:2014 - Calculation of energy performance of buildings - Method and data.*

Table 8. Load profiles in each of the eight apartments

Parameter	Value	Operation time
Internal load		
Occupancy	1.50 W/m²	24 hours / 365 days
Heating addition. occupancy	100 %	-
Lights	1.95 W/m²	16 hours / 365 days
Heating addition. lights	100 %	-
Technical equipment	3 W/m²	16 hours / 365 days
Heating addition. equipment	60 %	-
Domestic hot water (DHW)		
DHW effect	3.4 W/m²	-
Total efficiency grade (standard value)	0.98	-
Electric radiator		
Heating setpoint in operation time	21 °C	16 hours / 365 days
Heating setpoint outside operation time	19 °C	8 hours / 365 days
Total effect	50 W/m²	-
Part convection/radiation	0.5	-
Heat recovery ventilation		
Supply air flow rate (whole building)	2.38 m³/h m²	24 hours / 365 days

Exhaust air flow rate (whole building)	2.38 m^3/h m^2	24 hours / 365 days
Supply air temperature ventilation	19 °C	24 hours / 365 days
Heating coil efficiency	88 %	-
System efficiency heating coil	1	-
Heat recovery efficiency	0.8	-
SFP-factor	1.5 kW/m^3/s	-

2.6.5 HVAC system after renovation

In subsection 2.6.4, "*heat recovery ventilation*" describes the simulation inputs for the implemented balanced mixed ventilation after renovation. The air flow rate and air exchange requirements in Norwegian apartments are stated in subsection 2.4.1. More on the technical aspects of the ventilation system is provided in subsection 2.7.3.

The requirements result in two different design values because there are imposed limits value on both fresh air supply and exhaust. In a balanced ventilation system, the maximum value of these two becomes the design value for the system. In small apartments, the exhaust air flow rates are usually the highest one. The consequence is a higher fresh air supply than strictly necessary.

For the simulations, the daily total air exchange volume for all 8 apartments is divided by 24 hours, and the total heated floor area of the building to yield an hourly air flow rate per square meter. The kitchen range hood is not included in the ventilation calculations nor the energy calculations.

Table 9. Design values for the HVAC system of each apartment for the Oslo demo case

Design values for the HVAC system	Value
General requirement ventilation	1.2 m^3/h m^2
Minimum supply air per apartment	1.2 m^3/h m^2*40m^2 = 48 m^3/h
Minimum supply air in bedroom (1 person)	26 m^3/h
Standard exhaust rate in bathroom (23 h/day)	54 m^3/h m^2
Standard exhaust rate in kitchen (23 h/day)	36 m^3/h m^2
Minimum total exhaust rate	90 m^3/h m^2
Forced exhaust rate in both bathroom/kitchen (1 h/day)	2 x 108 m^3/h m^2
Design value for air exchange volume (whole building) normal ventilation	720 m^3/h
Design value air exchange volume per AHU, normal ventilation	180 m^3/h
Total exhaust air volume over 24 h	2286 m^3
Design value for 8 apartments a 40 m^2	2.38 m^3/h m^2
Supply air temperature ventilation	19 °C

2.6.6 Photovoltaic simulation input data

The decision process for the PV integration is further described in section 2.7.4. PV simulations are done with PVGIS-5 in compliance with PV-consultant, Fusen. The PV input data is described in Table 10.

Table 10. Simulation input data PV parameters

Simulation input data PV panel	Value
Number of PV panels	16 panels, each 1.7 m^2
Type	Crystalline silicon
Total effective area	27.2 m^2
Installed power	4.56 kWp
PV panel orientation	90 ° (vertical)
Solar orientation	209 °
Nominal efficiency	19.5 %
Loss factor panel	0.81
Loss factor inverter	0.95

The input data for solar radiation (direct and diffuse) presented in figure 12 are from Norwegian Meteorological Institute (www.Eklima.no), whereas monthly energy output and in-plane irradiation for project specific fixed angle are given in figure 13.

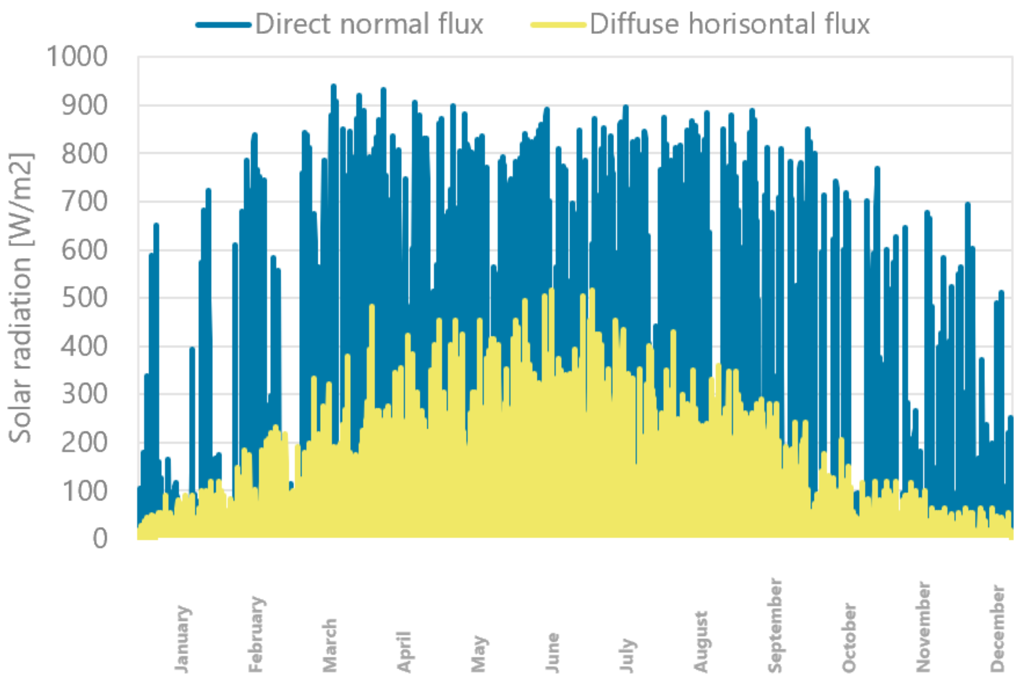


Figure 12. solar radiation (direct and diffuse) from the weather data file Norwegian Meteorological Institute (Eklima.no)

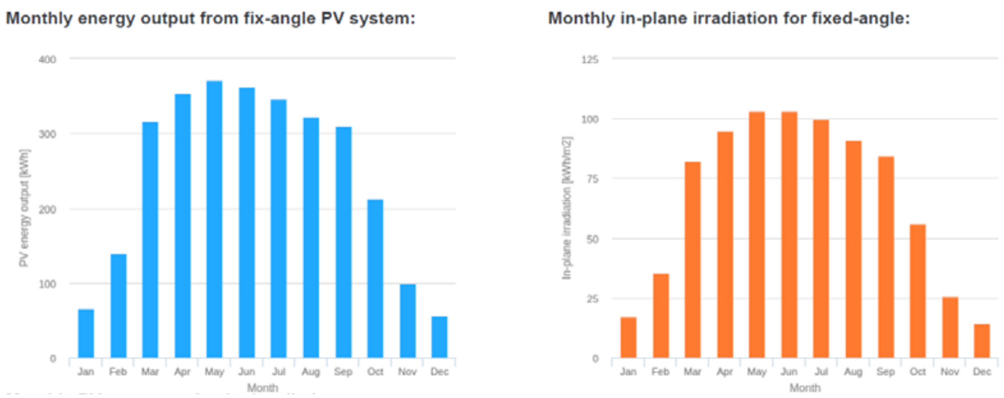


Figure 13. Monthly energy output from fix-angle PV system (left) and monthly in-plane irradiation for fixed angle (right) from PVGIS-5 calculations.

Estimated yearly PV production is given in Table 11.

Table 11. Design performances of BIPV system

Simulation output data PV panel	Value
Expected annual output	2959 kWh
Expected coverage of annual electricity	2959 / 54072 kWh

2.6.7 Building simulation performance outcome calibration

To calibrate the model to the baseline for the energy targets of the 4RinEU project, different input values than the standard values used for documentation of energy demand must be used. Two parameters are calibrated: the heating setpoint in the apartments, and the total efficiency grade for domestic hot water (DHW) production.

Calibration of the indoor temperature affects both the energy demand of the building and the delivered energy. Calibration of the efficiency grade for DHW does not affect the energy demand because the standard value for the energy demand is used, but the adjustment affects the amount of distributional loss and delivered energy to the building.

To compare the model performance with the baseline for the design targets for energy reduction, the delivered energy must be calculated and compared to the input value of the total HDD corrected delivered energy stated in subsection 2.4.1.

Calibration of indoor temperature

The adjustment in the heating setpoint is an increase in temperature from the setpoints of 21 °C during 16 daytime hours and 19 °C during eight night-time hours, to 23 °C continuous 24-hour temperature. The adjustment in temperature is made based on Boligbygg's knowledge about the tenant's habits and way of living. Based on visits to the building and informal chats with the tenants, many prefer to keep a higher indoor temperature than the standard 21/19 °C used for documentation of energy demand.

The reason for not having different temperatures during daytime and night-time is that the heat is regulated using electric heaters in each apartment. The tenants control the heaters and can adjust both the power and temperature within the limitations of the heater.

In the before situation, the draft from windows and cold areas of the outer wall may keep the room temperature lower than 23 °C on average in the room/building, but the heating systems and desired temperature may be set to 23 °C or higher to compensate for this.

Experiences from other projects show that the preferred indoor temperature is higher than the standard values also in new and well-insulated buildings. Tenants tend to "trade" some of the gains in reduced heat loss into comfort and higher indoor temperatures, and especially during winter. During summertime, sun heating often causes overheating of the apartment. A design value of 23 °C will be acceptable for the wintertime but will most probably result in higher temperatures during summer.

Calibration of the efficiency grade for DHW
The adjustment in the total efficiency grade for production, distribution, and use of domestic hot water involves moving from one standard value to another. It does not affect the energy demand, only the delivered energy.

The standard model uses the standard value 0.98 for the total efficiency grade for DHW production, distribution, and use. This follows Norwegian Standard NS 3031 and how simulations of energy performance are supposed to be carried out when the energy demand is simulated to compare to national regulations. The value should also be used for the energy labelling of buildings and comparisons of different energy sources. However, the adjustment is based on other standard values found in NS 3031. A hot water heater of some age usually has a production efficiency grade of approximately 0.9. The efficiency grade for distribution of DHW in single-family houses or dwellings with distributed heaters is usually around 0,6. Combined, a total efficiency grade of 0.55 is found for DHW in the calibrated model.

Table 12. Standard and calibrated values for simulation

Parameter	Standard values	Calibrated values
Domestic hot water		
Total efficiency grade	0.98	0.55
Electric radiator		
Heating setpoint	21/19 °C, 16/8 hours	23 °C, 24 hours

Table 13. Comparison of annual net energy demand for the Oslo demo case using the standard model and the calibrated mode before renovation.

Parameter	Standard model Before renovation 21/19 °C, 16/8 h $\eta_{tot,DHW}$ = 0,98		Calibrated model Before renovation 23 °C, 24 h $\eta_{tot,DHW}$ = 0,55		Difference std vs. cal. model [%]
	Total [kWh y]	Specific [kWh/m² y]	Total [kWh y]	Specific [kWh/m² y]	
1a. Space heating *	40224	125.7	49193	153.7	22
1b. Ventilation heat	-	-	-	-	-
2. Domestic hot water[1) *]					
a. Energy demand	9536	29.8	9536	29.8	0
b. Delivered energy	9730	30.4	17338	54.2	78

3a. Fans	-	-	-	-	-
3b. Pumps	-	-	-	-	-
4. Lights[1)]	4104	11.4	4515	11.4	0
5. Technical equipment[1)] *	5600	17.5	5600	17.5	0
6a. Room cooling	-	-	-	-	-
6b. Ventilation cooling (cooling batteries)	-	-	-	-	-
Total net energy demand (sum 1 to 6)	**59464**	**184.4**	**68844**	**212.4**	**16**
Total delivered energy	**59658**	**185**	**76646**	**236.8**	**29**
Baseline total delivered energy	**-**	**-**	**-**	**247.0**	**-**

* Divided by the total square meter apartments of 320 m^2

1) Values for DHW, lights, and technical equipment are standard values for energy demand from Norwegian Standard NS 3031 based on a wide range of building archetypes. More detailed information on these is not available, and the renovation did not affect any of them

The simulated total delivered energy in the calibrated model adds up to a specific delivered energy of nearly 240 kWh/m^{2}y. The measured energy consumption used for setting design targets for energy performance is 247 kWh/m^{2}y. The deviation is approximately 5 %.

2.6.8 Building simulation performance outcome: Delivered energy

Below, the results from the energy simulations are presented in Table 14 and Table 15. Both results from the standard model and the calibrated model is presented. The standard model is used to compare with design targets and requirements found in regulations and standards. The calibrated model to compare with 4RinEU specific design targets for energy performance.

Simulations with the standard model are only reported with energy demand and not delivered energy, because the latter is not a part of Norwegian requirements.

Table 14. Annual total net energy demand Oslo demo case simulated with the standard model before and after renovation

Parameter	Before renovation Standard model 21/19 °C, 16/8 h $\eta_{tot,DHW}$ = 0.98		After renovation Standard model 21/19 °C, 16/8 h $\eta_{tot,DHW}$ = 0.98		Difference before vs. after [%]
	Total [kWh y]	Specific [kWh/m^{2}y]	Total [kWh y]	Specific [kWh/m^2 y]	
1a. Space heating *	40224	125.7	8793	27.5	78
1b. Ventilation heat a. Energy demand b. Delivered energy	-	-	2069 2351	6.5 7.4	-
2. Domestic hot water[1)] * a. Energy demand b. Delivered energy	9536 9730	29.8 30.4	9536 9730	29.8 30.4	0 0

3a. Fans	-	-	4630	14.5	-
3b. Pumps	-	-	0	0	-
4. Lights[1)]	4104	11.4	4515	11.4	0
5. Technical equipment[1) *]	5600	17.5	5600	17.5	0
6a. Room cooling	-	-	-	-	-
6b. Ventilation cooling (cooling batteries)	-	-	-	-	-
Total net energy demand (sum 1 to 6)	**59464**	**184.4**	**35143**	**107.2**	**-41**

[*] Divided by the total square meter apartments of 320 m^2
[1)] Values for DHW, lights, and technical equipment are standard values for energy demand from Norwegian Standard NS 3031 based on a wide range of building archetypes. More detailed information on these is not available, and the renovation did not affect any of them.

The results from the standard model indicate that the net energy demand for the sum of space heating and ventilation heat is decreased with approximately 80 %.

The increase found in energy demand for DHW, lighting, and technical equipment for the whole building is merely a consequence of the increased heated area of the building, as described under subsection 2.6.2. The difference in the table is thus calculated using specific measures to conform with which parts of the building that underwent renovation.

Using the calibrated model, the results change somewhat for the energy demand, but more dramatically for the delivered energy. This conforms with the results presented in subsection 2.6.7. The results are presented in the Table below.

Table 15. Annual total net energy demand Oslo demo case simulated with the calibrated model before and after renovation

Parameter	Before renovation Calibrated model 23 °C, 24 h $\eta_{tot,DHW}$ = 0.55		After renovation Calibrated model 23 °C, 24 h $\eta_{tot,DHW}$ = 0.55		Differenc e before vs. after [%]
	Total [kWh y]	Specific [kWh/m^2 y]	Total [kWh y]	Specific [kWh/m^2 y]	
1a. Space heating *	49193	153.7	14321	44.7	71
1b. Ventilation heat a. Energy demand b. Delivered energy	- 	- 	424 482	1.3 1.5	- -
2. Domestic hot water[1) *] a. Energy demand b. Delivered energy	9536 17338	29.8 54.2	9536 17338	29.8 54.2	0 0
3a. Fans	-	-	4630	14.5	-
3b. Pumps	-	-	0	0	-
4. Lights[1)]	4104	11.4	4515	11.4	0
5. Technical equipment[1) *]	5600	17.5	5600	17.5	0
6a. Room cooling	-	-	-	-	-
6b. Ventilation cooling	-	-	-	-	-

(cooling batteries)					
Total net energy demand (sum 1 to 6)	**68433**	**212.4**	**39026**	**119.2**	**-43**
Total delivered energy	**76235**	**236.8**	**46886**	**143.8**	**-39**

* Divided by the total square meter apartments of 320 m^2
1) Values for DHW, lights, and technical equipment are standard values for energy demand from Norwegian Standard NS 3031 based on a wide range of building archetypes. More detailed information on these is not available, and the renovation did not affect any of them.

The results found with the calibrated model show the same behaviour as the standard model and indicate similarly approximately 40-45 % reduction in both net energy demand and delivered energy.

Compared with the design targets stated in subsection 2.4.1, the simulation results can undergo the same procedure in estimating the net reduction of energy demand for the Oslo demo case. The table below summarizes the results and design targets.

Table 16. Energy performance of the building when compared to the energy design targets, as stated in 2.4.1. The model is calibrated for higher indoor temperature and uses a calibrated value for the delivered energy for DHW

	Measured baseline [kWh/m²y]	Before renovation [kWh/m²y]	After renovation [kWh/m²y]
Total measured electricity use/delivered energy	247	236.8	143.8
Delivered energy tech. eq. (std)	17.5	17.5	17.5
Delivered energy lighting (std)	11.4	11.4	11.4
Delivered energy DHW (calibr.)	54.2	54.2	54.2
Baseline delivered energy (excl everything outside renov.) before renovation	**163.1**	**153.7**	-
60 % reduction	97.9	92.2	-
Practical delivered energy target	**65.2**	**61.5**	**60.3**
The expected reduction of delivered energy (60.3 vs. 153.7)			**60.6 %**

2.6.9 Monthly energy needs and PV panel production

The monthly energy need for electricity and the energy produced by the PV panels are described in the table below with standard values from PVGIS-5 (calculations in compliance with Fusen).

Table 17. Energy balance between electricity needs and electricity produced by the PV panel.

Month [-]	Total delivered energy [kWh]	Delivered energy (fans and vent. heating) [kWh]	Produced electricity by PV [kWh]
January	6787	511	66

February	5776	489	140
March	5213	437	317
April	3967	382	354
May	3387	394	371
June	3089	381	363
July	3190	394	346
August	3190	394	323
September	3325	381	310
October	4326	395	213
November	5399	422	100
December	6422	480	56
Sum	**54070**	**5060**	**2959**

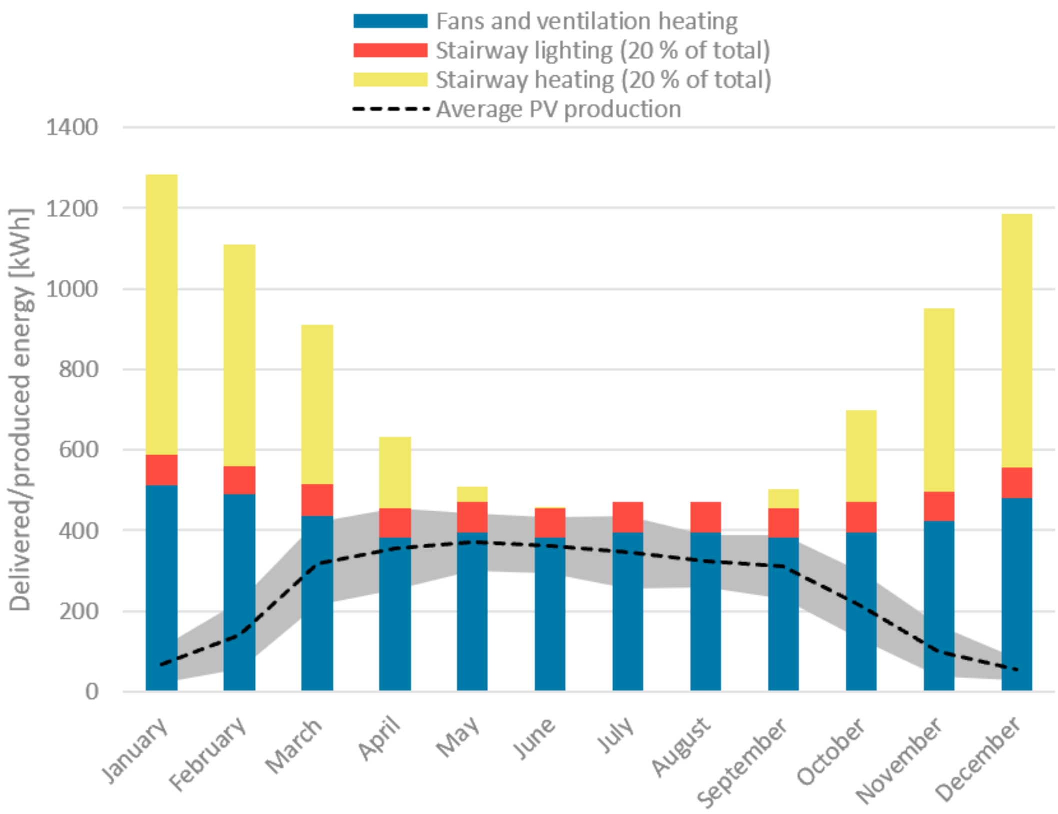


Figure 14. Monthly delivered energy to fans and ventilation heating, and 20 % of the total delivered energy to lighting and space heating (stairways being ~20 % of heated floor area) along with expected output from BIPV panels. The grey area is expected min/max limits for annual PV production based on typical weather variations.

2.7 Renovation concepts – technical description

2.7.1 Prefabricated Multifunctional Façade

Prefabricated multifunctional façade elements will be used to increase insulation and improve energy efficiency in the building. The façade elements are designed with integrated building services, e.g., ventilation ducts, and local RES PV-panels.

The façade elements were originally thought to be mounted directly on the existing façade. However, this was not possible due to the state of the existing façade, partly a masonry wall of expanded concrete bricks with insufficient load-bearing capacity.

To solve this problem, a secondary foundation will be constructed outside the existing foundation. The new foundation will serve two purposes; (1) carry the load of the façade and roof elements and all relevant loads imposed on the roof, and (2) reduce the heat loss through better insulation of the perimeter of the slab-on-ground floor and the wall-floor junction thermal bridge. Recalling that the slab-on-ground floor could not be further insulated, the second purpose above is, in fact, one way to reduce heat loss through the building elements and the ground. All windows will be replaced with new windows with improved thermal insulation and g-value. Integrated external sun shading was considered for the element production. However, sun shading is a repeatedly issue for problems for the maintenance department. Then the new facade was regarded complicated enough, and external shading will be installed at a later point if demanded by the tenants.

The elements are designed to ensure efficient production, dimensions for suitable transportation, as well as safe installation by crane, see Figure 15

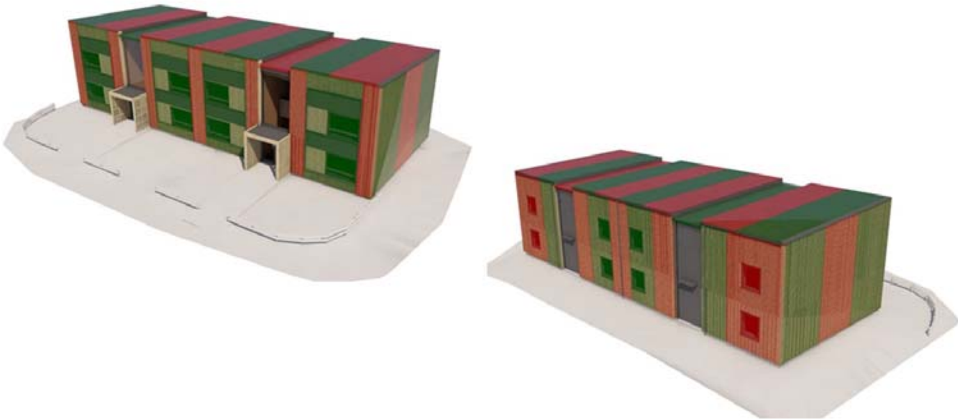


Figure 15. Layout of elements planned for the. Each coloured element represents one façade element and the corresponding BIM element.

Ventilation ducts for supply air to the bedrooms will be integrated into the façade elements on the north facade. Exhaust and supply air to the rest of the apartments will be installed in the stairways.

The PV panels are installed above the large windows on the south façade. See subsections 2.7.3 and 2.7.4, respectively, for more information on the HVAC system and PV panels.

2.7.2 Other envelope renovation actions

In addition to the façade, the roof will be renovated to achieve the targets for energy efficiency. New regulations require roofs to be designed for higher snow loads than at the time of construction of the existing building. Although the existing façade may be strong enough to carry both the self-weight and snow load of the roof, it has been chosen to install the roof elements on the new façade elements and its foundation. This eases the renovation process and solves the junction gap between the new façade and the existing roof.

To make the existing construction more cubic and minimize the cold surface, the recessed entrances will be aligned with the new façade and the extra volume included in the heated area. The existing shared entrance lobby will be increased to facilitate better access. It will be provided with a new glass facade and entrance door, see Figure 15.

In the back, the existing buildings have a niche in the building envelope as an architectonic element. This niche will be closed by a prefabricated technical shaft. The module will serve two purposes; (1) improve the compactness of the building, and (2) provide a technical room/shaft where air handling units, ventilation ducts, and control systems related to the PV can be installed. The technical room/shaft will have a separate entrance from the north façade to ensure minimum disturbance to the tenants also in the operation phase of the renovated building.

The entrance door to the stairway will be replaced. Doors between each apartment and the stairway will not be changed. The stairs itself will not be renovated, but parts of the interior surfaces in the stairways will be replaced.

2.7.3 Ventilation system renovation

After the renovation, the ventilation system at Haugerud Center 17-19 will be balanced ventilation with heat recovery. This is essential to reach an energy-efficient building in a cold climate. Beyond the state-of-the-art aspects are:

1) Integrated ventilation ducts for supply air to bedrooms in prefabricated elements (north façade)
2) Prefabricated technical rooms/shafts, including AHU, ducts, and PV inverters.

Mix mode cascade flow is used, supplying filtered and conditioned air to the bedroom and living room/kitchen, see Figure 16. Air transmission below door blade and air extraction from the bathroom and kitchen. The existing range hood is kept. Existing air inlet openings will be used for new ducted air inlet diffusers.

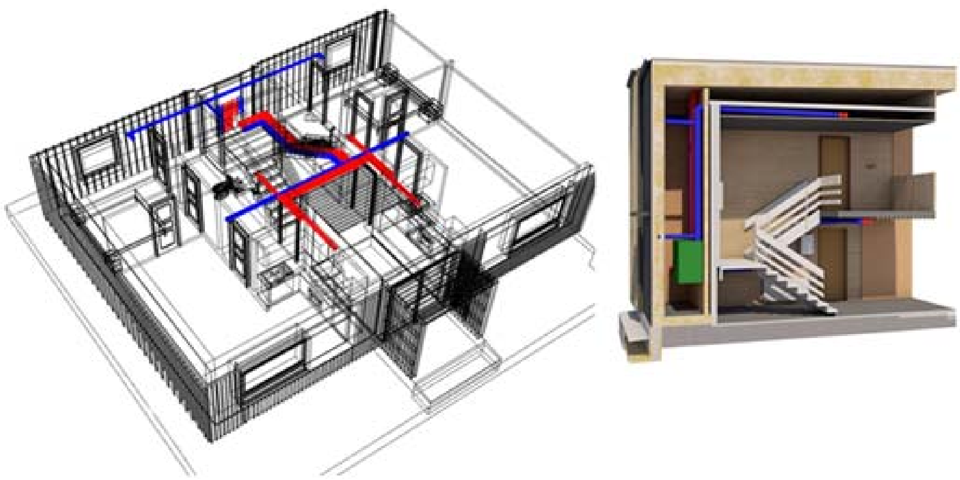


Figure 16. New ventilation system

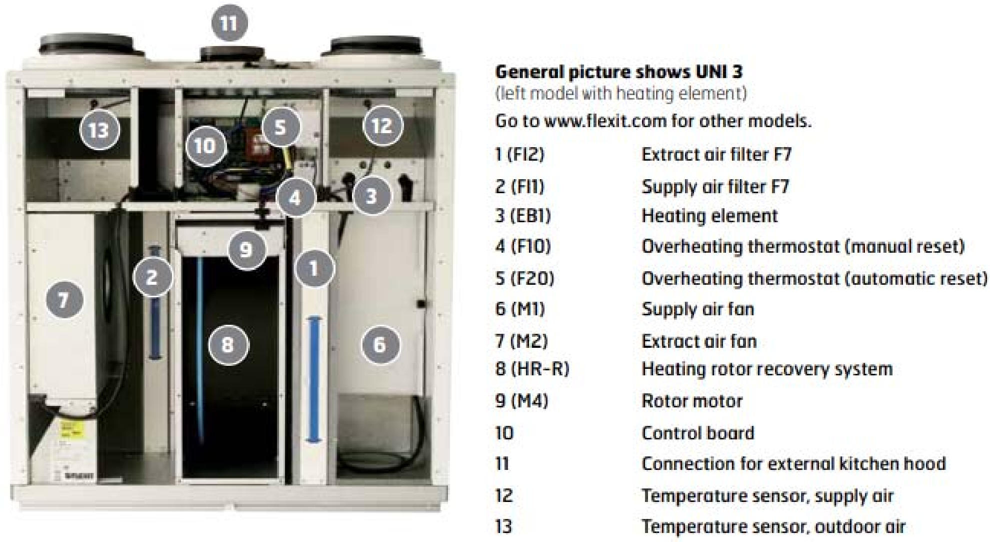


Figure 17. Air Handling Unit (AHU) Flexit Uni 3

The air handling unit includes F7 filters, supply- and exhaust air fans, see Figure 17. Rotary heat recovery and electrical heating element ensure stable inlet temperature (19 °C) No cooling installed, which is the common solution for new apartments in Norway. Occasionally, during the cooling season, the ambient outdoor temperature is higher than the supply air temperature, and the supply air temperature will be equal to the ambient outdoor air temperature.

The ventilation rate is controlled by a frequency transformer. Highly efficient heat recovery (>80%) SFP 1,5 kW/(m^3/s) according to minimum requirements for passive house dwellings, according to Norwegian Standard NS 3700/2013. Both the air intake and exhaust are placed on the North façade.

There are in total four AHU in the building, two in each technical room/shaft on the north façade. One AHU is serving two apartments on the ground floor, another AHU is serving two apartments on 1st floor, see Figure 16. Each AHU is handling two apartments since space for AHU is limited. Based on the requirements stated in table 3, the design values are given in Table 9.

2.7.4 RES exploitations: results from Early Reno evaluations

PV panels are regarded as the suitable RES solution as the existing building has electrical space heating and heating of DHW, and not part of the deep renovation. A preliminary version of the Early reno tool was tested for the Oslo demo.

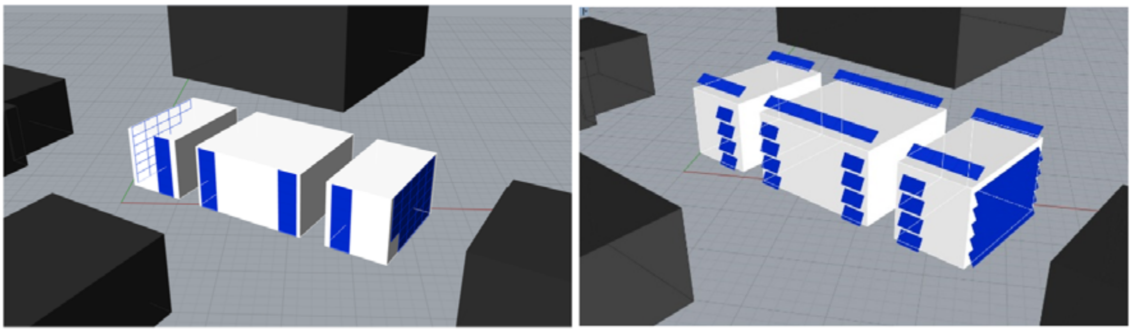


Figure 18. PV panel placement hypothesis form Early-Reno evaluation. Co-planar modules only facades optimized (left), non-coplanar fully occupied (right)

The concept to be demonstrated in the building is prefabricated wall elements with integrated building services. Non-coplanar solutions are not consistent with integrated solutions. Although a fully covered roof would generate more power, roof elements are not a part of the concept of the integrated building services. Since PV integration is more costly, both in the cost of PV panels and element construction, the roof area was regarded as not suitable for the final concept.

Hence the PV panels are integrated only in façade elements. Given the situation of not being able to partly cover energy needs in apartments, optimization is only possible with respect to generation and sale. Only minor consumptions for common are heating, and ventilation is possible, the rest is feed to the grid. Solutions with batteries are regarded as too costly. Boligbygg's intention is to demonstrate the concept, not being an energy provider. The integration of PV panels is then limited to integration in the south façade.

Standard PV panels of 1.0 m x 1,7 were chosen. The panels are robust and have reasonable ordering time-critical for the production. Then best/maximum integration in the sense of architecture, element production, and PV performance were evaluated. In total, 16 PV panels are placed on the south façade in pairs over the windows, as seen in Figure 19.

The integration concept is planned for a circular economy. PV panels can be integrated later and can also easily be removed for re-use in another building. The PV panels will for the Oslo demo be installed at the factory.

Figure 19. Design position for PV facade integration -PV panels are placed above windows

Information on the number of panels and the expected output is found in Table 11.

2.7.5 Integration of the sensible data handler

The Norwegian demo will mainly have temporarily post monitoring systems. PV production and energy use will have separate monitoring systems after the end of the 4RinEU project period. The sensible data handler dashboard will not be developed in time for implementation. Post monitoring data will be available to the system, and valuable for prototyping and feedback from Norway LDWG.

2.8 Renovation concepts: evaluation of KPIs

KPIs are defined for 5 different areas in the 4RinEU project, presented in the following subsections. Values are based on simulations performed for the Oslo demo case by SINTEF using the computer program SIMIEN if no other specification is given. SIMIEN is also used to document energy efficiency with respect to building regulations.

2.8.1 Area 1: Energy

The KPIs for Area 1 Energy are listed in Table 18 along with design values for before and after renovation. Different normalization schemes are applied, such as normalization per square meter, HDD or CDD corrections, etc.

Table 18. Energy-related KPIs - before and after evaluation used with calibrated values

KPI		Unit	Before	After
1.1	Net Energy demand for heating[1)]	[kWh] [kWh/m^2]	49193 153.7	14745 46
1.2	Delivered energy for heating[4)]	[kWh] [kWh/m^2]	49193 153.7	14803 46.2

1.3	Net Energy demand for cooling	[kWh] [kWh/m²]	Not relevant	
1.4	Delivered energy for cooling	kWh] [kWh/m²]	Not relevant	
1.5	Net Energy demand for DHW production	[kWh] [kWh/m²]	9536 29.8	9536 29.8
1.6	Delivered energy for DHW production	[kWh] [kWh/m²]	17338 54.2	17338 54.2
1.7	Net Energy demand for ventilation[2)]	[kWh] [kWh/m²]	0	4630 11.7
1.8	Electricity produced via PV system	[kWh] [kWh/m²] [kWh/m² PV surface]	0	2959 7.5 107.2
1.9	Electricity self-consumption	[kWh] [kWh/m²]	0	2959 7.5
1.10	Energy produced via ST systems	[kWh] [kWh/m²] [kWh/m² ST surface]	Not relevant	
1.11	ST energy balance	[kWh] [kWh/m²] [kWh/m² ST surface]	Not relevant	
1.12	Global Building Final Energy demand[3)]	[kWh] [kWh/m²]	76235 236.8	43927 136.3

[1)] *Includes direct electric energy demand for space heating and energy demand for ventilation heating*
[2)] *Includes only electricity for the ventilation fans. The heating of air is included in KPI 1.1.*
[3)] *Final energy demand: delivered energy to the whole building subtracted the self-consumed PV produced electricity (KPI 1.9)*
[4)] Includes *the loss of 12 % in the heating coil*

The results of the simulation campaign show that the Oslo demo case reaches the target of a 60 % reduction in delivered energy. With respect to energy demand, the target value of the 60 % reduction is reached.

Table 19. Energy performances - comparisons between different models, approaches reported in delivered energy

Energy performance	Before renovation	After renovation
Calculated energy performance (standard model)	184.4	107.2
Calculated energy performance (calibrated model) Calibrated values for DHW	236.8	143.8
Monitored energy performance	247	N/A

2.8.2 Area 2: Comfort

The main indoor environment problem in the Oslo demo case was draft from air inlet openings, not room temperature. Especially in winter times, inlet openings will be closed, in some cases also of more personal reasons. Thermal bridges may also contribute to the draft problem.

Haugerudsenteret 17-19 has large living room windows in each apartment facing South. Only a few apartments had external solar shading before renovation. However, many of the tenants have inside curtains, reported as often more closed than normal caused by privacy demand. Solar shading controlled by the tenants' curtains is an uncertain factor in the numerical model regarding comfort levels. The expected outcome of the changes before and after the renovation of the operative temperatures is minor, but positive. The simulations are done without external shading, and with internal light curtains. External integrated solar shading in prefabricated elements is not a preferred solution by Boligbygg.

BSim - Building Simulation program was used to assess a single apartment (which is representative of all apartments in the dwelling) thermal comfort and CO_2 concentration level throughout a year. More information about BSim can be found here: https://sbi.dk/bsim/Pages/BSim_Building_Simulation.aspx. The exact same input values for simulations in SIMIEN, subsection 2.6.2 (standard model with a heating setpoint of 21/19 °C of 16/8 hours) were used for the comfort simulations in BSim. The outdoor concentration of 400 ppm was used.

Zone occupancy and time can be seen in Table 20. One person is considered present 24 hours and generates 12,24 l/s CO_2 at 1 met. The window g-value has been considered to 0,7 before renovation and 0,3 after renovation.

Table 20. Overview of simulated zones

Zone	Time present
1	07:00-23:00
2	23:00-07:00
3	10 minutes at 08:00, 12:00, 16:00 and 20:00
4	Not present

The figure below shows the simplifications from the original floor plan to the zone model geometry in BSim.

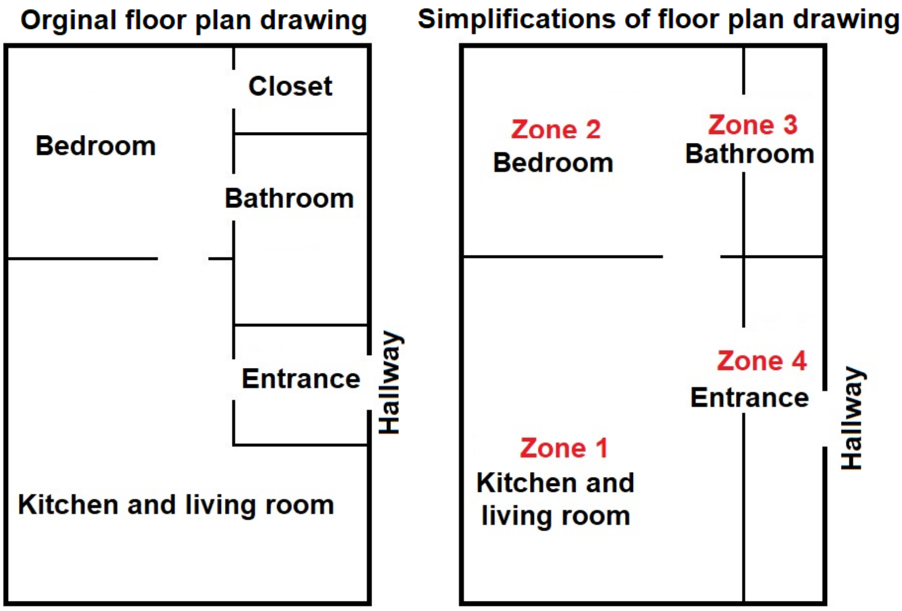


Figure 20. Zone simplifications done in the numerical simulation program BSim

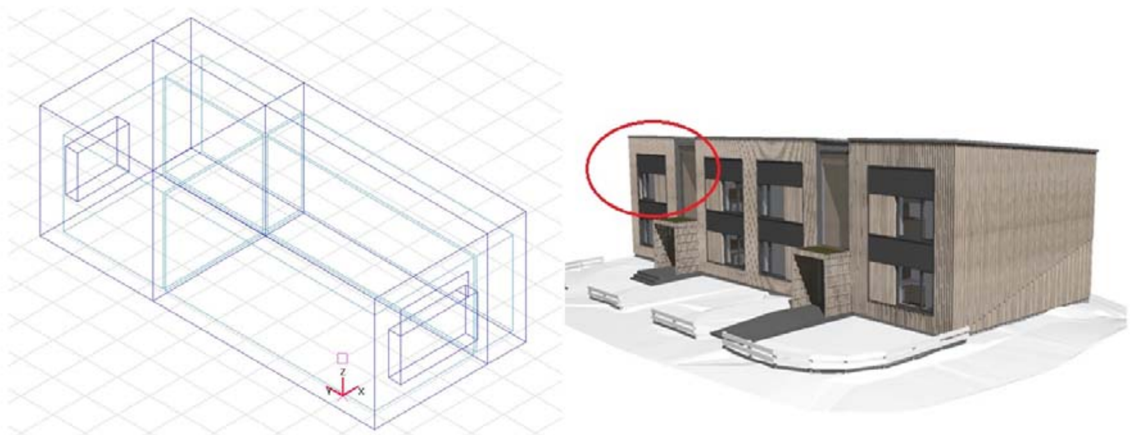


Figure 21. A single apartment at Haugerud Center modelled in BSim (left) and the chosen apartment to model can be seen on the right.

Figure 22 shows the yearly operative temperature, and CO_2 concentration described with 25th and 75th percentile whisker boxplots with minimum and maximum values. The median is described as a straight line within the boxplots.

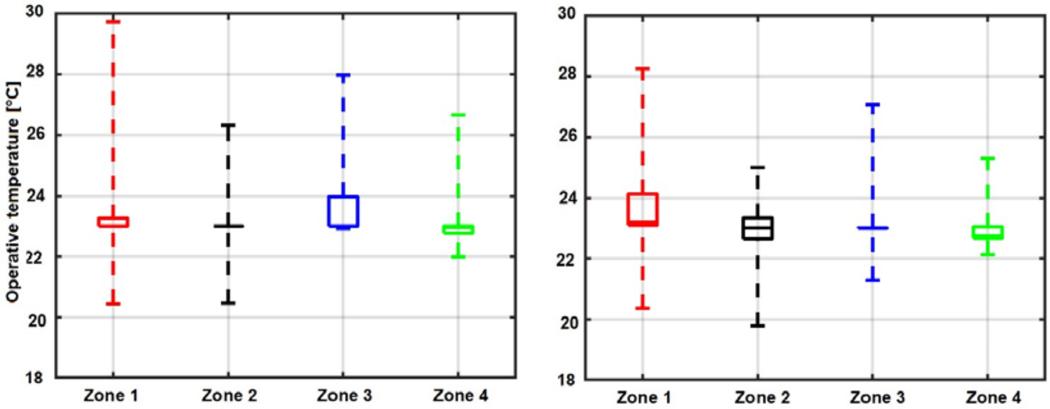


Figure 22. Operative temperature before (left) and after renovation (right). Zone 1 kitchen and living room, zone 2 bedroom, zone 3 bathroom, and zone 4 entrance

As seen in Figure 22, the median operative temperature in the dwellings before and after the renovation is close to 23 °C in each zone. The maximum operative temperature has decreased by nearly 2 °C in each zone after renovation. This may be due to the new building properties, mainly the new windows with a lower g-value, U-values on the walls, and the roof contributing to keeping a cooler climate indoor.

In accordance with the KPI's, the operative temperature is kept between 19-26 °C approximately 90 % of the time, and the remaining time above 26 °C before renovation. However, after renovation, the operative temperature is around 95 % of the time within the chosen comfort level (19-26 °C), as seen in Table 21. The remaining time is also above 26 °C. Based on the simulation inputs and parameters in this study, the operative temperature will exceed 26 °C to some extent, both before and after renovation. These high temperatures occur in July and August on warm summer days.

Table 21. Hours between 19-26 °C and above 26 °C before and after renovation. One-year simulation in BSim

Zone	Hours between 19-26 °C Before renovation	Hours above 26 °C Before renovation	Hours between 19-26 °C After renovation	Hours above 26 °C After renovation
1	8275	485	8417	342
2	8758	2	8760	0
3	8643	117	8757	3
4	8746	14	0	0

Based on these numbers, the thermal situation is improving, but still too high in the living room. However, the real situation is probably better caused by the explained use of curtains.

The local draft situation will be solved by balanced ventilation. This effect is not visible without more detailed simulation programs.

In Figure 23, the CO_2 concentration has nearly halved after renovation in zone 2 and 3, and this is due to a higher and more controlled air change rate per hour after the mechanical ventilation has been installed. Nevertheless, the median is almost the same both before and after renovation, but the maximum values do not increase to the same CO_2 concentration levels as before renovation with the considered inputs and parameters for this simulation campaign. Smoking tenants have not been considered in the CO_2 concentration calculations.

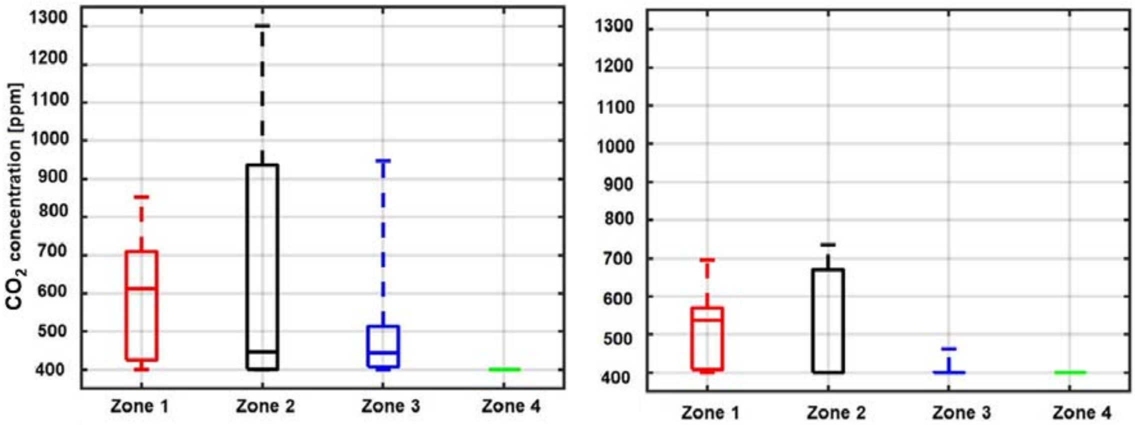


Figure 23. CO2 concentration before (left) and after renovation (right. Zone 1 kitchen and living room, zone 2 bedroom, zone 3 bathroom and zone 4 entrance

2.8.3 Area 3: Environment

The CO_2 emissions are estimated from the energy consumption based on the building (KPI 1.2) multiplied with a factor accounting for the CO_2 emissions related to electric power production.

Norway has a much higher fraction of renewables in the energy mix than the 28 EU countries. 98 % of Norway's power production is from renewable sources, with hydroelectric power as the main contributor (96 %) and about 2 % from wind power (https://www.nve.no/energiforsyning/varedeklarasjon/nasjonal-varedeklarasjon-2018/). This is translated in the Norwegian Standard NS 3720, which presents two scenarios for Life cycle assessment of buildings using both a Norwegian power mix and the European (EU28 + NO). CO_2 emission rates are presented below for the two mix scenarios. Both numbers are calculated based on a scenario for the time span of 2015–2075.

Table 22. CO2 emissions power mix in Norway

Power mix	C0₂ emission rate
Norwegian (NO, 96% renewable)	18 g CO_2-eq/kWh
European (EU28)	136 g CO_2-eq/kWh

The European mix represents today's situation without any extra measures to increase the fraction of renewable sources through warrantees or similar. The Norwegian mix represents a future situation where most energy sources are renewable.

The KPI is calculated from the total delivered energy (electricity) to the building, subtracted the energy delivered by local RES (BIPV panels).

Table 23. CO2 emissions before and after renovation

KPI		Unit	Before	After
3.1	CO_2 emissions	[kg-CO_2/year] EU28 [kg-CO_2/year] NO	11499 1522	6987 925

2.8.4 Area 4: Renovation costs

Cost reduction

Boligbygg's motivation, budget and decision on deep renovation of the building by use of prefabricated elements was already in place when the project started. Calculation of NPV of investments was not demanded by Boligbygg. However, cost efficient solutions have been in focus.

Low tenant disturbance and short on-site construction time have been emphasized. For traditional renovation projects, tenants need to move out for part or the whole period. Alternative accommodation is often costly. Use of prefabricated elements implicate only short visits for adjustments of new windows and air inlet diffusors. The goal is to have all tenants at home throughout the construction period.

Short on-site construction time and prefabrication also allow for light rig and minimized waste handling. The elements will be installed by crane, and costs can be saved for scaffolding.

The producer was part of the design team. This represents an extra cost at early stage but supplied the design team with valuable knowledge, makes more effective and smooth the production phase, and reduces failures and un-predicted issues in the implementation phase. Co-design reduce time needed for first design and avoid re-design. Use of BIM all through the process will also secure good tolerances and identify problems at an early stage. It is emphasized that the design should be optimized for efficient production. Standard sized beams, ductwork and other components are chosen to exclude costly extra operations. The renovation package is adapted version of existing solutions rather than completely new. The idea of prefabricated technical room/shaft is one cost and time-saving result of the good co-design.

Installation costs are also foreseen to be cost efficient. The producer is also responsible for the installation. This secure transfer of understanding of the solution to construction site, eliminates costs for knowledge transfer on installation procedure and safety, and minimize the installation problems, time and costs.

Annual energy cost is found from the delivered energy to the building and multiplied with an energy cost of 1 NOK / kWh. Conversion rate is 1 € = 9 NOK, or 1 NOK = 0,11 €.

Table 24. Investment assessment – Area 4

KPI		Unit	Before	After
4.1	The net present value of the energy renovation – LCC (50 y)	[€] [€/m2]	Not available	
4.2	The investment cost for the renovation (Production, transport, installation (incl. PV), and external work)	[€] [€/m2]	732950 1850	

4.3	Annual energy cost before/after renovation	[€] [€/m2]	9300 26.4	5948 15.0

2.8.5 Area 5: Renovation process

The renovation process is planned to be carried out within 2018. This includes the major part of the Technical design stage and Production stage (both off-site and on-site production). The planned progress is presented in section 2.10 in this report, and the duration of each activity is read out from the Gantt diagram and planned progress.

Table 25. Renovation time – Area 5

KPI		Unit	Design values
5.1	Renovation time incl. off-site production	[days]	16 w – 80 workdays
5.2	Renovation time, on-site construction	[days]	7 w – 35 workdays

The estimated completion time for on-site works is seven weeks, and the installation of the elements only two weeks. Including time for off-site production of elements, the time is 16 weeks. Estimates from the Norwegian carpenter's association indicate that the renovation, using a traditional approach, would require 12 – 16 weeks of work. All weeks would be on site.

A reduction in the on-site renovation time from 12 – 16 weeks to 7 weeks corresponds to a 42 – 56 % reduction in renovation time corresponds well to the overall target of reduction of renovation time with a factor 2 (50 %).

2.8.6 Final decision of the renovation package

The main problem for the Oslo demo case deep renovation was to identify an element producer capable and willingly to develop advanced prefabricated elements with integrated building services. Once the right company was identified, the decision process was quite compact and straight forward.

Final renovation package included new foundations, prefabricated elements with integrated PV, windows and extra insulation on the south façade, prefabricated elements with integrated ventilation ducts for supply air, windows and extra insulation on north façade. Plane elements with extra insulation on east and west façade and prefabricated plane elements with extra insulation on roof. Installation of balanced ventilation and prefabricated technical rooms/shafts on north façade.

2.9 Tender procedure

2.9.1 Public procurements in Norway

Public procurement in Norway is regulated by the «Public Procurement Act» and «Public Procurement Regulations». The Public Procurement Regulations is divided into three parts: part I to III. Part I applies to all public procurements, part II to those exceeding the national threshold value and part III to those exceeding EU/EEA threshold values (see table below).

Table 26. Public procurement regulation parts in Norway

Regulations	Announcement	Threshold values
Part III	EEA area and nationally	> NOK 51 million for procurement relating to building and construction work and > NOK 2 million for services
Part II	Nationally	< NOK 51 million for procurement relating to building and construction work and < NOK 2 million for services
Part I	-	< NOK 1,1 million

Details of public procurements pertaining to medium size (part II) procurements are published nationally on www.doffin.no. Likewise, large procurements (part III) will additionally be published in the EEA area on www.ted.europa.eu.

2.9.2 Regulations for construction projects (Building application)

The Norwegian Planning and Building Act (2008) regulates how construction projects should be carried out. The main purpose of the act is to define and divide responsibilities between different roles in a construction project and to impose national building regulations through the regulation on building matter (SAK) and the technical requirements for buildings (TEK). The main roles and their responsibilities are shown in the table below.

Table 27. Main roles within Norwegian Planning and Building Act

Role	Building matter responsibilities	Building project responsibilities
Owner	• Overall on-site HES responsibility	• Contract (at least) the responsible applicant, design team and contractor • Promote own requirements to the project team
Responsible applicant **(SØK)**	• Divide all relevant responsibilities in the building matter • Complete and file the application itself	• Coordinate the different actors in the project
Responsible design team consultant(s) **(PRO)**	• Design the building to fulfil all requirements imposed by the municipalities, i.e., national and local regulations and plans	• Design the building to fulfil any additional requirements imposed by the owner
Responsible contractor **(UTF)**	• Constructing the building according to the design • File plans and reports for waste handling	

Depending on the complexity of the building, competence requirements are imposed on the different roles above. These requirements apply to all the formal roles (responsible applicant, design team, and contractor), and are formulated as a requirement of both formal education and documented experience.

One professional or company may have several roles. Examples are:

- The architect can be both the responsible applicant (SØK) and hold responsibility for certain parts of the design (PRO).
- A contractor will often in turn-key contracts hold responsibility for design (PRO) and construction (UTF)

The design team consists of several different professionals holding responsibility for different parts of the project, such as construction safety, fire safety, energy use, ventilation, etc. These are often referred to as "RIB", "RIE", "RIBr" etc., where the first two letters refer to "Consultant engineer" and the last letter(s) to the type of responsibility. Similarly, the architect is often denoted "ARK".

The design of the building and flow of requirements and information is shown in Figure 24 below.

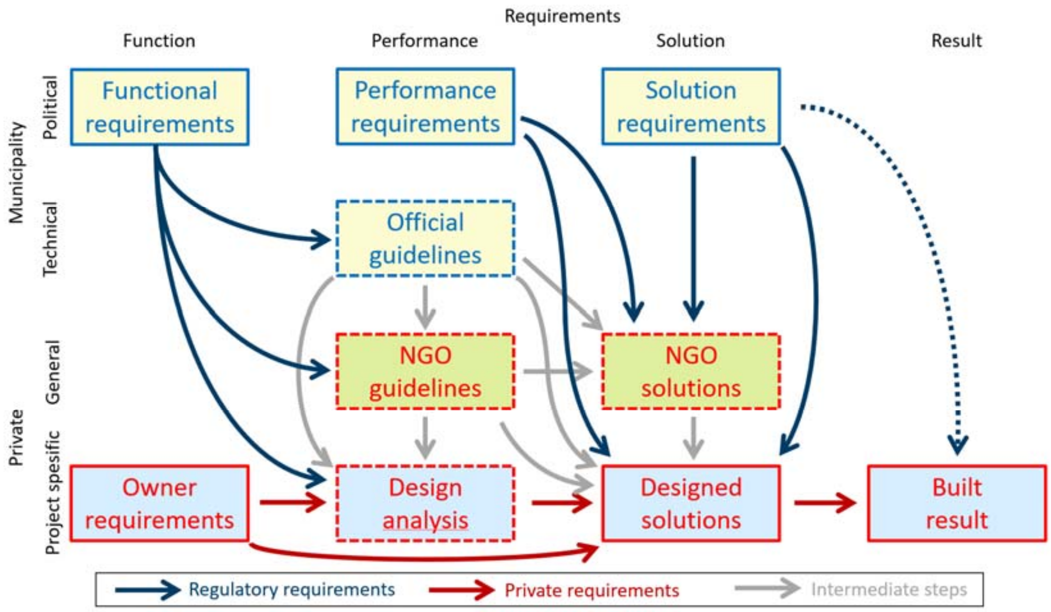


Figure 24. Flow of requirements and information in the design process. Dashed boxes are not mandatory stages of the design process

Municipalities impose on national and local levels, both functional requirements, performance requirements, and solution requirements. Examples are:

- **The functional requirement** in TEK17 § 13-4 (1):
  The indoor thermal climate in rooms intended for continuous occupancy shall be regulated in a manner that promotes health and satisfactory comfort when the rooms are used as intended.
- **Performance requirement** in TEK17 § 13-2 (1):
  Dwelling units shall have ventilation that ensures an average supply of fresh air at a minimum rate of 1,2 m^3 per hour per m^2 of floor space when the dwelling unit is occupied.
- **Solution requirement** in TEK17 § 13-4 (2):

In rooms for continuous occupancy, it must be possible to open at least one external window or door.

Guidelines on how to fulfil the requirements are either given as official guidelines issued by different government bodies or as guidelines issued by different NGO's. The article collection "Byggforskserien" is an example of the latter. Then, the design team chooses a design based on guidelines and/or further analysis and come up with the building design. The contractor erects the built result.

TEK17: 2017. Regulations on technical requirements for construction works ("Byggteknisk forskrift - TEK17"). edited by Ministry of Local Government and Modernisation.

2.9.3 Tender procedure and design team

Boligbygg's procurement in the 4RinEU project has a total budget below the EU threshold value and is governed by part II of the Public Procurement Regulation. This enables Boligbygg to use a "negotiating procedure" in the tender process. A negotiating procedure means that Boligbygg is both allowed to talk to the bidders and manufacturers during the tender process and to discuss their bid.

Using this negotiating procedure, Boligbygg does not have to adhere to a minimum time limit or deadline for the procurement. Although sufficient time should be given to the bidders, this makes the tender process itself efficient, and in this case, the time-consuming part of the process was the complexity of the building project, not the legal issues related to the building matter or the procurement itself.

A map of the different roles of the construction projects is shown in the figure below.

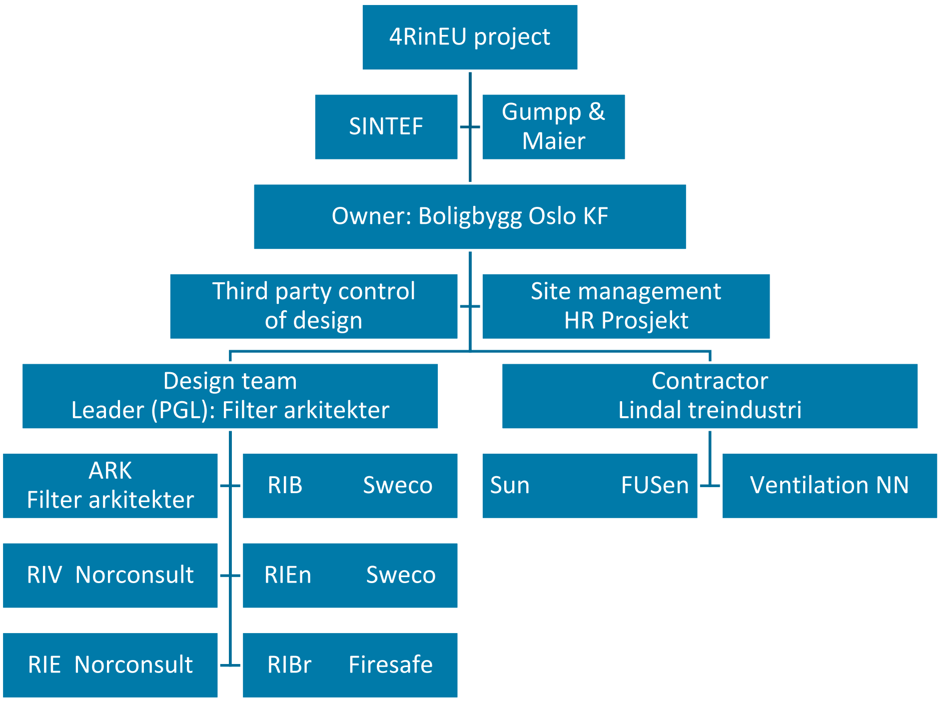


Figure 25. Design team overview

In this project, Lindal plays a special part in the sense that they play the role of both a part of the design team, the element manufacturer and the contractor responsible for the onsite assembly of the elements. Usually, manufacturers work under the EU Construction Product Regulative (CPR) and produce construction products according to relevant product standards and systems for declaration of performance and conformity.

Here, the product did not exist at the beginning of the project, and because of this, Lindal's participation in the design process is crucial for the success of the renovation project. The choice of using prefabricated elements, as opposed to traditional on-site construction, pertains to the Concept design and the Developed design stage of the RIBA Plan of Work, depending on the complexity of the project (RIBA 2013).

Normally, when façade elements are used, only adaptation of the elements to project specific dimensions etc. are necessary, and element manufacturers are not involved until the late Developed design, Technical design or Construction stage depending on the need for adaptations.

Here, however, "normal" elements needed to be majorly modified and "new" elements developed incorporating building services, PV solar panels, etc. The possibilities for modification have possibly a great impact on the technical design, and, hence, the manufacturer's know-how on these possibilities for modification, constraints of their production line, and on-site accountability are crucial to the project.

2.10 Gantt of the renovation activities

Below is a detailed Gantt diagram of the planned renovation project. The stages are connected to the RIBA Plan of Work nomenclature except for the off-site production (RIBA 2013). This will normally be a part of the Construction stage but is taken out to distinguish between off-site and on-site construction.

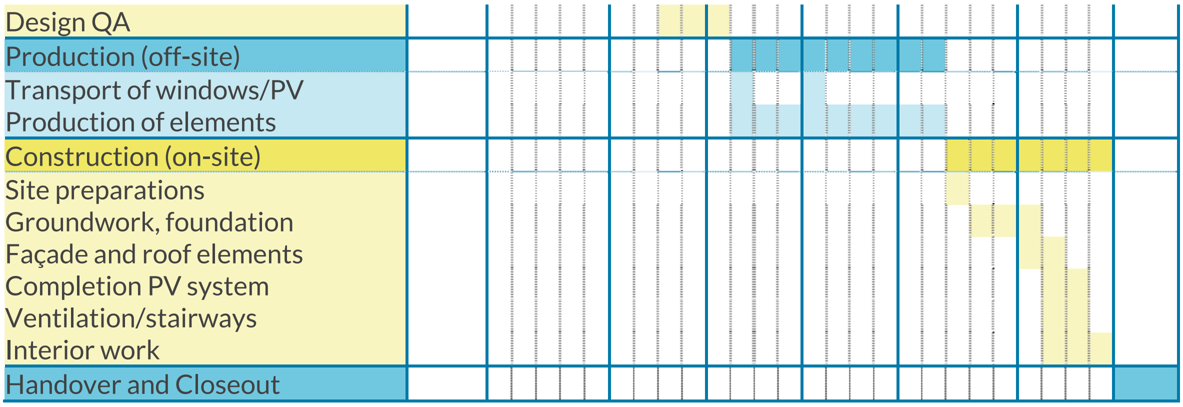
Boligbygg had decided to renovate the building before the 4RinEU project started. When the opportunity to join the project came, the plans were adjusted to 4RinEU deep renovation targets.

The concept design of the building was performed in 2017. The tender process was carried out during the concept and developed design stages. During these stages, the design team was chosen, and Lindal as the manufacturer was included in the process.

The decision regarding the use of PV RES and the technical design of the façade and roof elements did not start until the project itself started.

Table 28. Preliminary Gantt Chart of the activity

Activity	2017	Jan	Feb	March	Apr	May	June	July
Building application/approval								
Concept/developed design								
Technical Design								
PV								
Walls and roofs								
Energy and ventilation								



2.11 References

Ministry of Local Government and Labour. 1969. Building Regulations of August 1 1969. edited by Ministry of Local Government and Labour: Ministry of Local Government and Modernisation.

Planning and Building Act. 2008. Act of 27 June 2008 No. 71 relating to Planning and the Processing of Building Applications (the Planning and Building Act - "pbl."). edited by Norwegian Building Authority: Ministry of Local Government and Modernisation.

RIBA, Royal Institue of British Architects. 2013. RIBA Plan of Work 2013. Overview. London: Royal Institute of British Architects.

TEK17. 2017. Regulations on technical requirements for construction works ("Byggteknisk forskrift - TEK17"). edited by Ministry of Local Government and Modernisation.

3 Spanish Demo Case: Bellpuig

This demo case is a multi-family building, owned by a public authority and destinated to social housing. The dwellings are rented by people in risk of social exclusion.
The building owner is INCASOL, the Catalan Institute of Land, while the manager is AHC, who is in charge of the maintenance issues, both ordinary and extraordinary interventions. Therefore, the internal design team of AHC deals with the definition of the renovation concepts for the building. AHC is also in charge of the management of tenants, also faced within 4RinEU.

3.1 Key features of the building

The building was constructed in 2006 and it is placed in a rectangular plot with a slope of 10% in the sense of the street. The building is divided in two blocks in a row due to the terrain's topography, but it has a unique entrance in the east facade (street facade). Each block has three floors and a horizontal roof. They share the basement (a half-underground floor used as a garage) and, also, the common stairs that connect different common corridors placed in the west-facade, and built as open spaces. There is a total number of 15 dwellings, all are west-east orientated, with cross ventilation.

The blocks have a pillar frame concrete structure and its envelope presents quite a low-quality insulation and several thermal bridges. The façades are composed by a single brick wall (15cm), insulated in the inside with mineral wool (4cm), then an internal gap and a plasterboard wall. The openings represent around 30% of the main façade and have double-glazing windows with aluminium frames and rolling shutters.

Figure 26. East façade (street access) and West façade (common corridors) of Bellpuig demo case

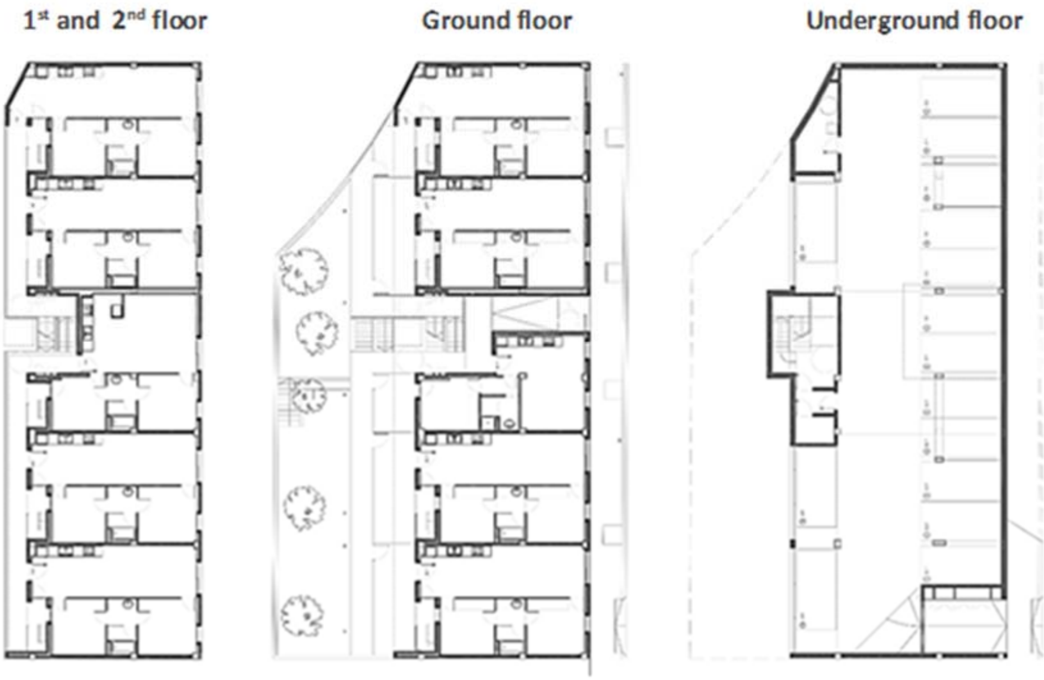


Figure 27. Floor plans of Bellpuig demo case.

Regarding HVAC: The apartments were designed to be heated with electric radiators, although, currently, 45% of the tenants use butane heating, due to the high cost of the electric energy. There is no air conditioning, but they have natural ventilation for the main rooms. There is also an extractor fan in the kitchen (but not in the bathrooms). There is no mechanical ventilation either centralized or decentralized.

Concerning DHW: the system was built with individual boilers inside the apartments to produce DHW with the support of collective solar thermal panels (placed on the roof).

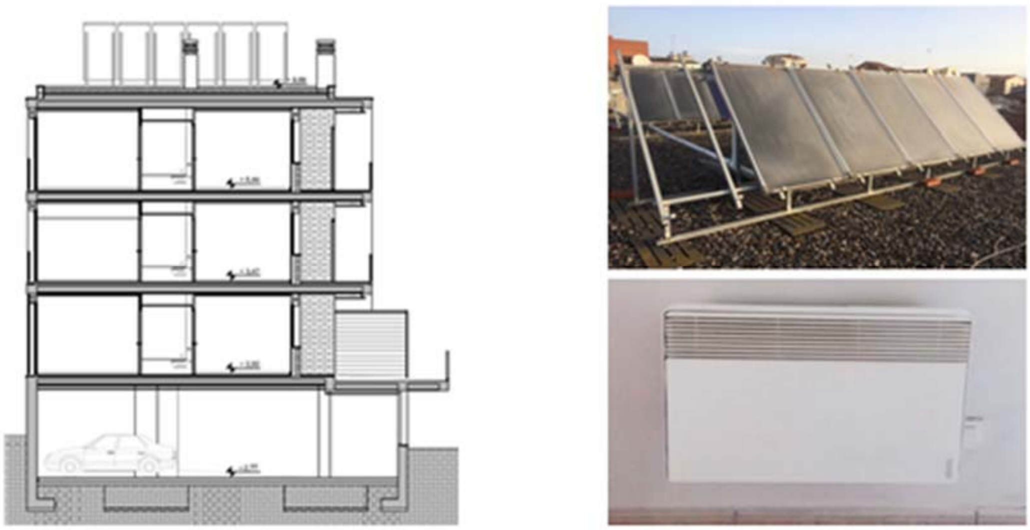


Figure 28. Vertical section of Bellpuig democase / Solar thermal roof panels (DHW) / electric radiators (HVAC)

Although the building is quite new, it presents high primary energy consumption. In fact, it was built during the Spanish housing bubble with poor standards and low-quality solutions. Several thermal bridges can be distinguished in the external envelope.

3.2 Drivers of the renovation

On one hand this section describes the general drivers that lead the owner/manager to renovate, as there are common issues affecting several properties in the building stock managed by AHC and, moreover, in the residential stock in the whole Spain.

On the other hand, it reports the specific needs and problems identified in the selected demo case.

General drivers

- Overall CO_2 reduction target of the Catalan Government. Since AHC is a public institution, it has to contribute actively and to have an exemplary role. Specifically, in two objectives identified in the ECREE[3]; the energy efficiency of the residential building stock and the decarbonisation of the energy used in those buildings.
- Social responsibility of AHC: To improve indoor comfort. Many of our tenants suffer from fuel poverty, this means they cannot pay the energy invoices. To increase energy-efficiency in social housing will also generate co-benefits for the users, as the reduction of their energy invoice costs or the increase of comfort. It can even reduce health problems.
- Economic benefits for AHC: To achieve a lower maintenance cost by improving the building with solutions that take into account cost-effectiveness.
- To activate the regional market and increase its capabilities by introducing innovative technologies and approaches for renovation.
- High replication potential of the technologies in other buildings of the residential stock that AHC manages, but also in other buildings from all over Catalonia

Building specific drivers

- To improve the current low-quality construction. Although it has been built in 2006, the building's envelope presents quite a low-quality insulation and several thermal bridges (it was designed with the energy law of 1987)
- To minimize the discomfort of the continental climate of the Bellpuig region: The temperatures in winter and summer in this region, make necessary to use heating from October to May, while on the other hand there are two months of hard summer conditions.
- To reduce the high energy invoices of the building. This building uses electricity from the public grid as the unique energy source, even for heating and cooking, this involves high energy invoices for the tenants. In some cases, the cost has been so unaffordable for users that they have moved to other residential buildings. AHC

[3] ECREE_ Catalan Estrategy of Energy Renovation in Buildings (February 2014)

has reduced the apartment's rent, in order to compensate the high energy invoice and avoid empty flats.

- To reduce unsustainable or unhealthy habits of tenants. In this residential building, some tenants use alternative energy systems in irregular conditions (ex. Butane for cooking or heating). They might stop this practice if AHC reduces the electricity demand of the building and introduces free photovoltaic energy.

3.3 Key issues to consider for a successful renovation

This section describes the specific needs highlighted within the LDWG by the demo owner for a successful planning of the building renovation.

- To include and motivate the tenants in the process (provide them visible benefits)
- To calculate the theoretical consumption before and after renovation, in order to demonstrate the benefits of the project – economic and also comfort issues.
- Retrofitting works with the tenants living inside. So, it is important to reduce disturbance to minimum possible.
- Minimize Maintenance costs.
- Maximize the passive retrofitting actions (by acting in the overall building skin, which includes both facades and the roof), and see what it fits related to the HVAC and RES solutions.
- To explain the aims of the renovation to the technical Dpt. of the municipality and obtain its approval for the retrofitting actions.
- To use cost-efficient solutions.

3.4 Target of the renovation

3.4.1 Minimum requirements provided by law and local regulations

This section reports the minimum requirements* of the renovation to be fulfilled as reported by the law owners.

- Minimum envelope requirements of the National Regulations**:

Table 29. Minimum envelope requirements

Building element*	Current situation	Ordinary energy renovation**	Minimum requirements for new buildings**	4RinEU targets
East Facade	0.64	0.66	0.60	0.37 (G. Floor) 0.16 (1st-2nd Floor)
West Facade	0.64	0.66	0.60	0.64
Side-facade	1.22	-	0.85	1.22
Roof	0.53	0.38	0.40	0.37
Ground Floor	0.64	0.49	0.40	0.64

Glazing	-	-		-
Average U-value	3.82-4.13	2.90***	2.70	1.43 (just in the renovated façade)
G-value glazing	0.75	-	-	0.63
Ventilation	0.80ren/h	-	-	0.63ren/h
Air tightness	50m3/hm2	-	27m3/hm2	27m3/hm2

*The building is placed in climatic zone D3, so the values exposed are the requirements that the National regulation stablishes in this specific zone.
**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.

- ***Energy target***

The Multiregional Operative Programme for Spain ERDF 2014-20 has as one of its main priorities to support the transition towards a low carbon economy through: energy efficiency in enterprises, houses and public infrastructure; the production, distribution and use of renewable energy; the multimodal sustainable urban mobility; research and innovation in low carbon technologies.

In particular, regarding building renovation, some indicators are:
- Improve energy performance in houses

It is planned to achieve **33.313 Households** with improved energy consumption classification.
- Reduce consumption in public buildings

It is planned to decrease **623.734.246 kWh/year** of annual primary energy consumption of public buildings.

- ***Fire safety requirements that can affect 4RinEU renovation approach***

Regarding the fire safety of the prefabricated multifunctional timber façade there is no specific requirements to take into account, as it is not a public use building, nor a high-rise building.

Spanish regulation just establishes that for facades with less than 18m height, the minimum class of reaction to fire of the materials used in the ventilated rooms up to a height of 3.5m is Euroclase B-s3, d2. This restriction is applied when the lower start of the façade is accessible to public from the outside, and also has to be accomplished in the upper part of the facade if the roof is accessible. The rest of the facade has no specific fire safety demand.

For the determination of the maximum actions in structures exposed to fire, the nominal temperature-time curves are used. These curves are defined in the norm EN 1363-1 and 2 in Eurocode 1.

- ***Structural safety***

For each timber element, the following checks have to be carried out, in accordance with the corresponding articles of the CTE-SE-M.

- Parallel fibre traction: Article 6.1.2.

- Compression parallel to the fibre: Article 6.1.4
- Flexion: Article 6.1.6
- Cutting: Article 6.1.8
- Torsion: Article 6.1.9
- Combined traction and flexion: Article 6.2.2
- Combined compression and flexion: Article 6.2.3

It has also been necessary to accomplish EAE2011 (Structural Steel Instructions) to guarantee the structural safety of the anchoring system, and EHE-08 (Structural Concrete Instructions) to assure that the existing concrete structure will correctly support the Prefabricated Multifunctional façade.

- ***Other targets***

The Multiregional Operative Programme for Spain ERDF 2014-20 also establishes:
- GHG reduction
  The estimated annual decrease of GHG is 3.739.227 Tonnes of CO2eq
- Housing Renovation in urban areas
  Planned: 1.601 Housing units

3.4.2 Targets of 4RinEU project

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

The high primary energy use of this building is mainly due to the heating system, based in Joule effect (with electricity source) or in catalytic combustion of low performance (with GLP). The 4RinEU renovation will directly contribute to reduce the primary energy use, by improving the envelops insulation, reducing the air infiltrations and increasing the use of renewal energy generated in the building (through the improved ST system and the new PV system).

The primary energy needs before and after renovation have been obtained through an energy simulation presented later. Anyway, some very preliminary evaluation on apartment consumptions showed at the initial state a value of approximately 220 kWh/m2, while after the renovation a reduction in primary energy to approximately 135kWh/m2. This means a reduction of approximately 40%. The simulation considered 2 different energy sources for the initial state: electricity and GLP. While after the renovation, was considered just electricity -as AHC expects that the energy savings will allow tenants to stop use GLP.

- **Cost reduction of at least 15%**

compared with a typical renovation (i.e. a renovation that meets current minimum requirements of existing building regulations) 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.

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

This comparison takes into account the time spent on the prefabrication phase and during the site works. In both cases -4RinEU and typical renovation-, it has been assumed a similar set of actions to implement upgraded insulation in east façade and the roof, new windows in east façade (just 1st and 2nd floor), a balanced ventilation system, etc. In the case of using standard methods, an estimation about the time need, based on previous experiences of AHC renovations can only be done.

3.4.3 Expectations of the owners (wish list)

- The proposal has to be financially viable. INCASOL (owner) and AHC (manager) have funds for the renovation works, but these are limited, and it is necessary to clarify the order of magnitude of the investments.
- Focused in indoor comfort conditions (moisture, IAQ, temperature) improvement directly related with healthy conditions.
- Improve the deficiencies of the building envelope to reduce energy demand, and consequently the energy invoices.
- AHC does not want to become D.S.O., renewable energy self-consumption can be considered (PV or ST) but it is necessary to maintain electric meters decentralized, so each tenant is responsible of its own energy invoice.
- Possibility to install Ventilation system with Heat Recovery: Avoid moisture problems and improve indoor air quality. The ventilation system can be centralized or individual.
- To encourage the common and individual use of photovoltaic self-consumption systems, this make sense after the approval of Royal Decree 244/2019,
- To reduce works time and disturbance to the tenants.

3.5 Specific constraints

- AHC will supply Photovoltaic panels and will renovate the Solar panels for the Domestic Hot Water system. However, no changes will be done in the electric heating system existing in the dwellings as it implies a too large investment.
- The technical proposal must be resistant and provide the protection of valuable items, since this is a residential block with a high rotation of tenants (with very different profiles).
- Any technical solution in timber must considerate the strong contrast of temperatures in Lleida, and the requirements of the Spanish Building Code
- Any envelope solution must take into account the urban regulations. In Bellpuig municipality, it is restricted to increase the façade thickness, especially in ground-floor level.

3.6 Building performances before renovation

3.6.1 Location

The building is located in La Vall street, number 09 in the town of Bellpuig (in Lleida province). It is a rural environment, in the limits of the urban area. It is 115 km far from Barcelona city.

Figure 29. Location of Bellpuig demo case.

The building is East-oriented on the street façade and West in the inner façade.

Figure 30. Satellite view of Bellpuig demo case.

3.6.2 Weather conditions

When assessing the baseline energy consumption and the energy reduction potential of solutions sets, the Typical Meteorological Year (TMY) is used. It derives from the interpolation of historical data series and that can be extracted from the Meteonorm database.

The weather data for the location of Bellpuig are shown here below.

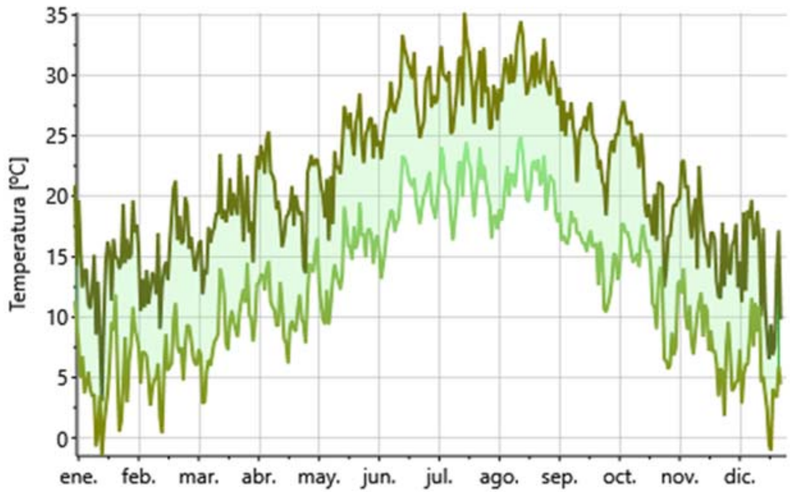


Figure 31. Air temperature distributions of the TMY weather files

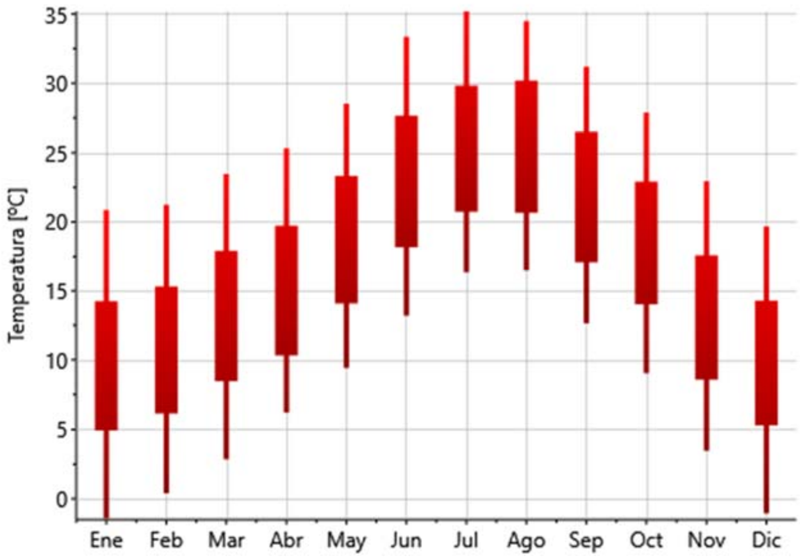


Figure 32. Average monthly air temperatures distributions of the TMY weather files.

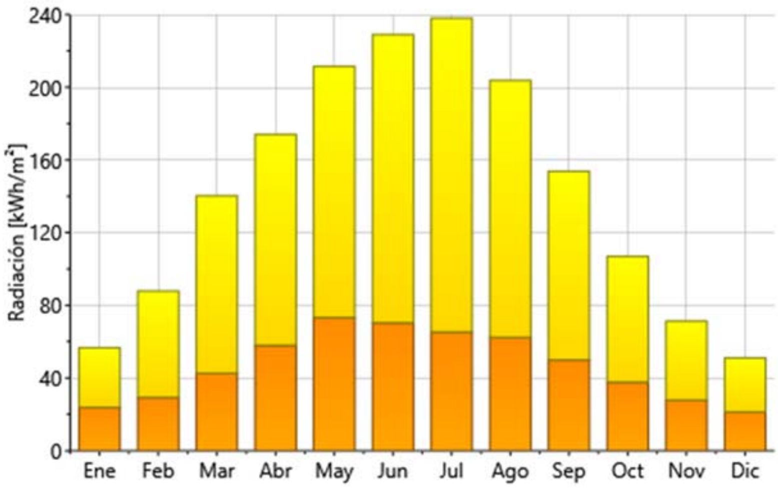


Figure 33. Global horizontal radiation distributions of the TMY weather files.

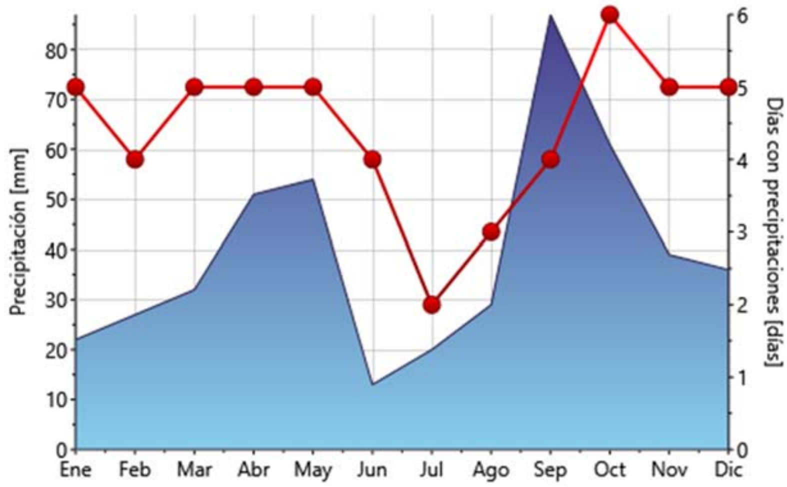


Figure 34. Precipitation distributions of the TMY weather files.

Bellpuig

Radiación | Temperatura | Precipitación | Duración de la insolación
Radiación global diaria | Temperatura diaria | Tabla de datos

	Gh kWh/m²	Dh kWh/m²	Bn kWh/m²	Ta °C	Td °C	FF m/s
Enero	57	24	93	9,2	2,7	3
Febrero	88	29	135	10,4	3,3	3,3
Marzo	140	43	184	12,9	5,1	3,4
Abril	174	58	192	15,2	7,2	3,5
Mayo	211	73	212	18,7	10,8	3,1
Junio	229	70	237	23,3	14,3	2,9
Julio	238	65	261	25,3	16,2	3,1
Agosto	204	62	221	25,4	16,1	3
Setiembre	154	50	184	22	14,4	2,9
Octubre	107	38	143	18,2	11,8	2,7
Noviembre	71	28	115	12,8	5,8	3
Diciembre	51	21	90	9,4	3,2	3
Año	1721	561	2066	16,9	9,2	3,1

Figure 35. Summary of weather parameters for the TMY weather files

When comparing the results of the simulations with the monitored data for the calibration, the Actual Meteorological Year (AMY) is used.
In the case of Bellpuig, the data come from the city of Lleida, through AEMET services (the Spanish Weather Agency). Data from Bellpuig was not possible to obtain in the corresponding timeframe due to the pilot case change.
The calibration period is one year, from November 2016 until October 2017. Available data includes temperature, humidity, global radiation, wind direction and speed.

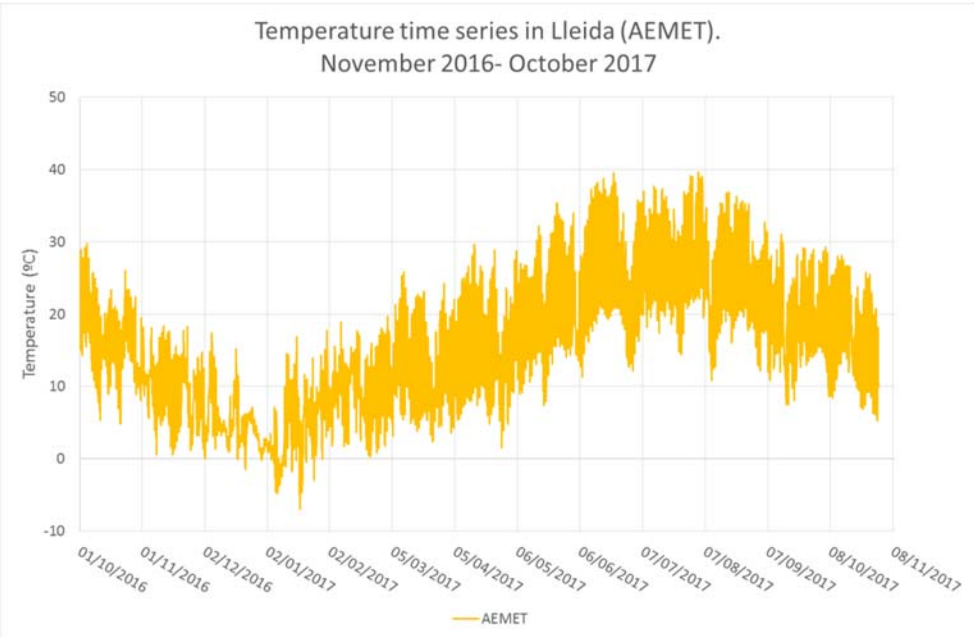


Figure 36. Air temperature distributions of the AMY weather files

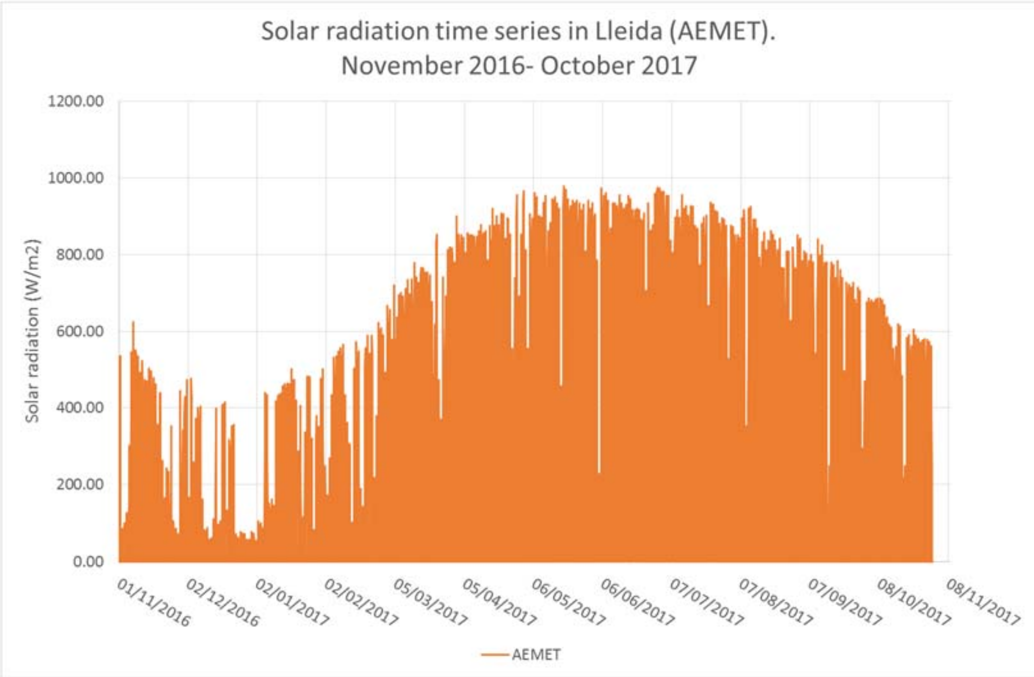


Figure 37. Global horizontal radiation distributions of the AMY weather file

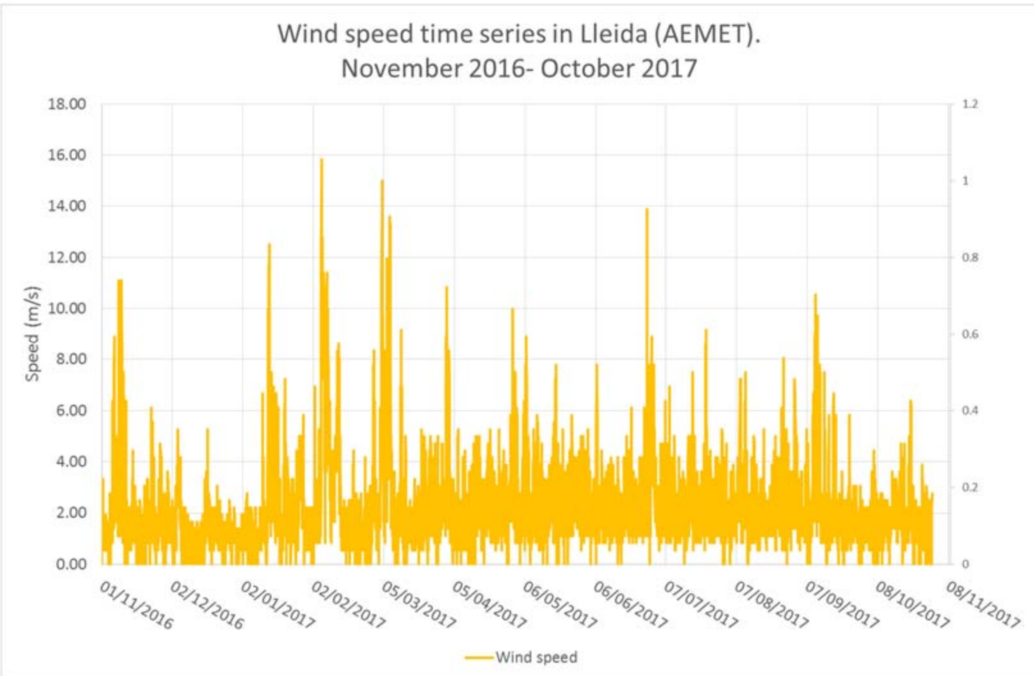


Figure 38. Wind speed distributions of the AMY weather files

3.6.3 Zoning

Here the description of the reference model follows, which refers to the actual state of the building.

The simulations have been done using Trnsys software.
For each floor, modulization has been carried out for the two dwelling typologies, one is in contact with the central scale and the other one is not.

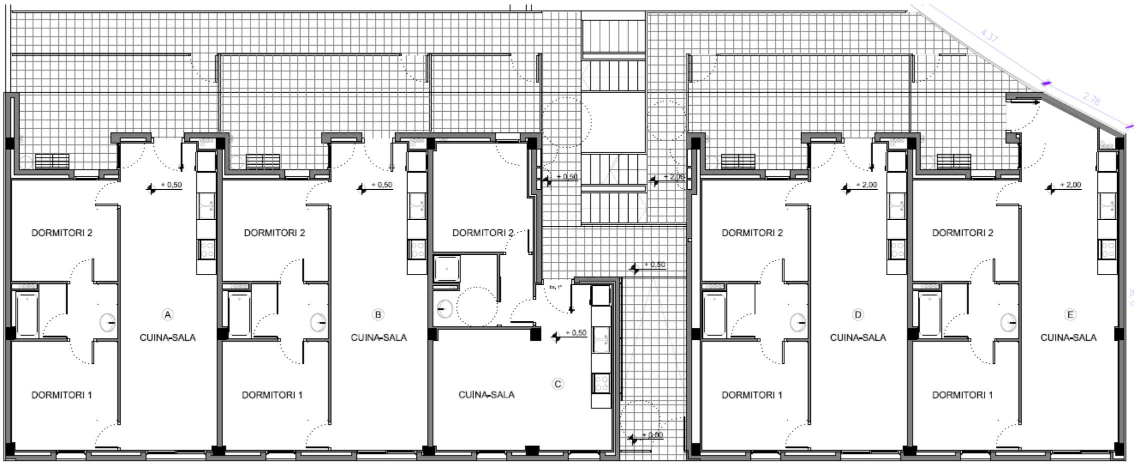


Figure 39. Floor planar view

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 1^{st} and 2^{nd} 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.

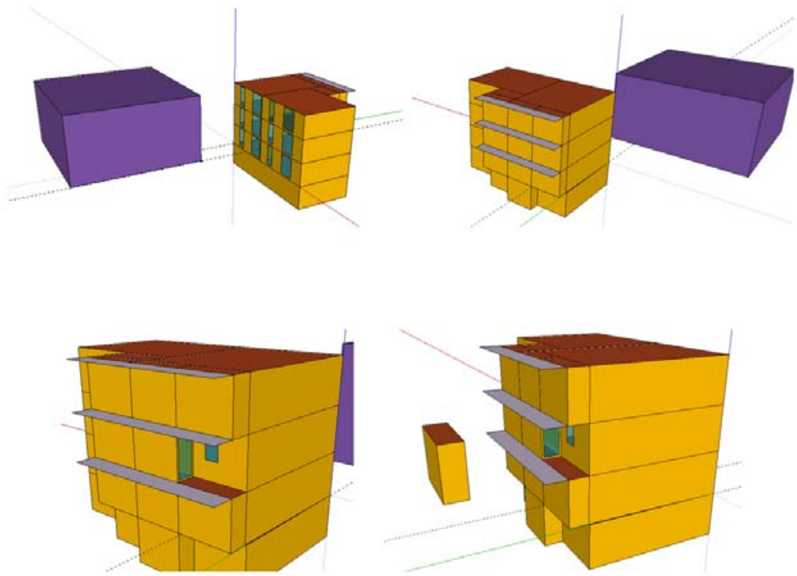


Figure 40. Building geometry within the model

3.6.4 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 30. 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%.

3.6.5 Heating and cooling setpoints

No temperature setpoints are applied.

3.6.6 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

3.6.7 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, as shown in the following graph.

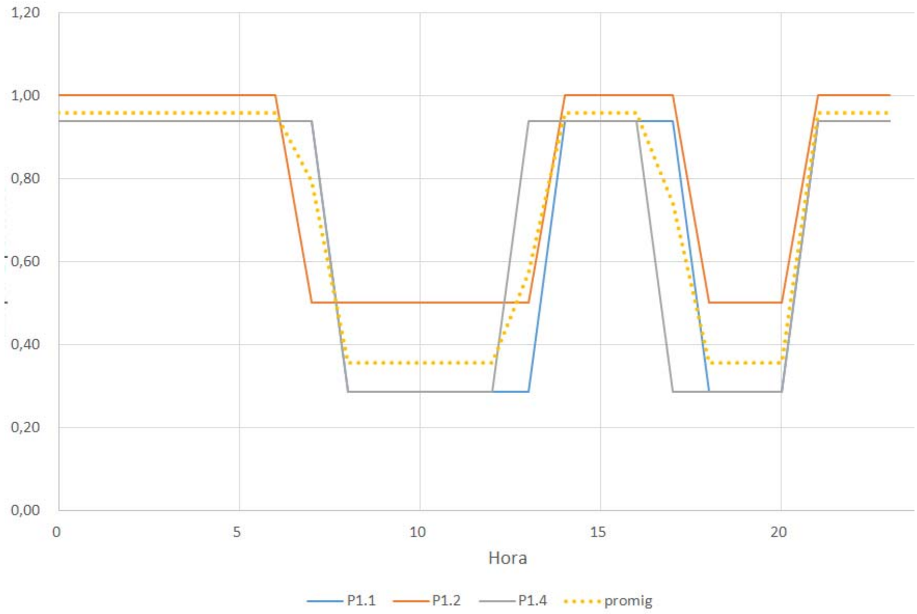


Figure 41. Occupancy profile used in the simulations

According to EN ISO 7730 standard, the internal gains are considered as a total heat flux of 120 W/person (sensible (65 W/person) and latent gains (55 W/person)).

3.6.8 Lighting and appliances

The dwellings have also been studied to make an inventory of the lighting devices and appliances. The following table includes the appliances inventory for the different dwellings.

Table 31. Appliances inventory for the different dwellings - Part 1/2

Door	Date of inventory	N°of Persons	Light Inventory	Fridge	Washing Machine	Oven	Cook top	TV + DVD	PC or Laptop	Hot water equipment	Heating equipment	Microwave oven	Other
BX-1													
BX-2	25/04/2018	-	CFL bulb 11W: 1 unit Halogen : 2 units Incandescent: 2 units	Edesa - Practica - Combi Fridge	Nikkei Nk LB65E09	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently 3 butane gas cookers	32" ancient plasma TV	–	Electric boiler (with ST system)	–	Yes	Bread oven with butane + Cooker Hood
BX-3	25/04/2018	–	Led: 5 units CFL bulb 11W: 1 unit	Freezer + Big Fridge (Balay)	Siemens IQ300	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently 2 butane gas cookers	32" plasma TV + 22" plasma TV	–	Electric boiler (with ST system). Problems with the individual boiler for DHW (maybe because of calcium o the electric resistence)	–	No	Electric wheelchair +Cooker Hood
BX-4	30/05/2018	1 Adult	CFL bulb 11W: 1 unit Halogen 42W : 4 units	Combi fridge (Candy no frost Antiga)	No	Electric - CATA	Original 4 electric cookers / Currently 2 butane gas cookers	43" Samsung TV	No	Electric boiler (with ST system)	1 butane heater	Yes	No
BX-5	25/04/2018	1 Adult	CFL bulb : 7 units Fluorescent 36W : 2 units Fluorescent 18W: 3 units Led: 1 unit	Ancient Combi Fridge (Beko)	Telefunken 14TLK1005 5kg (A+)	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently 3 butane gas cookers	28" Plasma TV	–	Electric boiler (with ST system) Problems with the individual boiler for DHW (maybe because of calcium o the electric resistence)	-	Yes	Cooker Hood
1-1	26/06/2018	1 Adult + 2 childs (during weekend : 2 adults+2 childs)	Bathroom: 1 CFL bulb Bedroom 1 : 1 CFL bulb Bedroom 2: 1 CFL bulb Sallon: 1 CFL bulb / 1 LEDs lamp	Combi fridge (Candy no frost Antiga)	Balay	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently 4 butane gas cookers	32"Plasma LG TV	No	Electric boiler (with ST system)	5 electric radiators (they don't use). 1 butane heater	No	Wi-fi // They spent 1 butane bottle /month for cooking + 2butane bottles/year for heating)
1-2	15/05/2018	1 Adult + 1 child	Bathroom: 1 Bedrooms: 2 Sallon: 2 Laudry-room: 1	Ancient Combi Fridge (LG)	Zanussi Progress (ZWG) 6Kg	Teka HC490 ME (Class A)	Original 4 electric cookers	Ancient TV (Triniton Sony) + Ancient TV	No	Electric boiler (with ST system)'Problems with the individual boiler for DHW (maybe because of calcium o the electric resistence)	5 electric radiators (1000W)	No	Cooker Hood

Table 32. Appliances inventory for the different dwellings - Part 2/2

Door	Date of inventory	N°of Persons	Light Inventory	Fridge	Washing Machine	Oven	Cook top	TV + DVD	PC or Laptop	Hot water equipment	Heating equipment	Microwave oven	Other
1-3	15/05/2018	2 Adults or 3 Adults	Bathroom: 1 Bedroom A: 3 Bedroom B: 1 Sallon: 4 Laudry-room: 1	Freezer (Daewoo)+ Big Fridge (Bluesky)	Indesit 7kg (A+)	Teka HC490 ME (Class A)	Original 4 electric cookers/ Currently 4 gas cookers	Plasma TV (Philips) + Plasma TV (Samsung)	Yes (ancient laptop 14 years)	Electric boiler (with ST system)	2 oil radiators	Yes (Bluesky)	Dishwasher Teka MDW600 (A+A) + Fan + Cooker Hood + Home Sound System
1-4													
1-5	25/04/2018	1 Adult	CFL : 4 units Led: 1 unit	Ancient Combi Fridge Zanussi	Home HLF105APW-13 (A+)	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently 4 butane gas cookers	Ancient TV	1 laptop	Electric boiler (with ST system). Problems with the individual boiler for DHW (maybe because of calcium o the electric resistence)	4 eletric radiators 1000W (not using them) / 1 butane heater	Ancient Microwave (mechanical controller)	Radio + Wi-fi + Blender + Cooker Hood
2-1	25/04/2018	2 Adults	CFL: 5 units Fluorescents 18W: 1 unit Fluorescent 36 W: 1 unit	Ancient Fridge Lieber	Whirlpoll AWO/D 6723	Teka HC490 ME (Class A)	Original 4 electric cookers / Currently butane gas cookers	TV: 32" TV Grundig	1 Laptop 1 PC	Electric boiler (with ST system)	4 eletric radiators 1000W (not using them) / 1 butane heater	Silver Crest normal Microwave (800W)/	Cooker Hood + Play
2-2													
2-3	09/06/2018	2 Adults + 1 kid	Halogen: 5 units CFL: 1 Unit	Ancient Fridge Combi (Indesit)	Ballay	2 ovens: Teka HC490 ME (Class A) // Itinet	Original 4 electric cookers	TV: TV LG	No	Electric boiler (with ST system)	5 electric radiators (1000W) + Butane Heater: (1 butane bottle/week during winter)	Yes	
2-4	25/04/2018	2 Adults + 1 kid // People at home just in the afternoon	Incandescent: 5 units Halogen: 1 unit	Bluesky Freezer (small) + big old freezer	No	Electric - CATA	4 induction cookers (Teka)	3 TV: '50" TV // TV // TV	No	Electric boiler (with ST system)	5 electric radiators (1000W)	No	Cooker Hood + DVD + Iron
2-5													

3.6.9 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.

3.6.10 Use scenarios

In order to set the use scenarios, different dwellings have been analysed, using the following available data:

1. Dwellings inventories – to know the energetic devices of the dwellings
2. Electric invoices – to know the order of magnitude of the electric consumptions
3. One-year electric hourly data – coming from the energy company (aggregated data)
4. Meteorological data for a whole year – from the official Spanish meteorological organization

The process followed to set the scenarios was this one:

- To define the occupation and operation hypothesis (user profiles, HVAC profiles, electrical devices profiles, etc.).
- To check if the simulation results obtained are in the same order of magnitude of the final electrical consumptions obtained from the bills

In the table below, it is shown with a cross when data is available. Dwellings P1.1 and P2.1 have been selected as “average cases”.

Table 33. Data availability for different dwellings

CANDIDATES FLOORS		CONSUMP.	INVENTORY	PICTURES INVENTORY	OCCUPANTS	CLEAN TERMO	INFILTRATIONS
BX1							
BX2		X	X				
BX3		X	X				
BX4			X		1	30/5/18	
BX5			X	X	1	30/5/19	
P1.1		X	X		1.5Ad.+2nen		
P1.2		X	X	X	1adul.+1nen		X
P1.3		X	X	X	2adul.+3nen		
P1.4							
P1.5			X	X	1		
P2.1			X	X	2		X
P2.2							
P2.3		X	X		2adul.+1nen		
P2.4			X		2adul.+1nen		
P2.5							

Selected
One aof the two

Only for boundary conditions

Selected
One aof the two

Further information for some dwellings is summarized in the table here below.

Table 34. Yearly consumptions for some dwellings

Apartment	Consumption including HVAC			Consumption without HVAC		
	kWh per year	Area (m2)	Watts/m2	kWh per year	Area (m2)	Watts/m2
P1.1	3354.23	54.68	7	2053.79	54.68	4
P1.2	3518.89	52.73	8	2184.39	52.73	5
P1.4	5915.15	52.73	13	2489.04	52.73	5

The created use profile is an average that considers:

- HVAC profile: difference between winter consumption and summer consumption
- Electricity consumption profile: yearly profile without including HVAC
- Occupancy profile: the dwelling is occupied as long as a little consumption is monitored

3.6.11 Model calibration

The model that includes the real conditions scenario (not the “standard comfort” scenario that should be expected if comfort conditions were obtained during regulations occupancy profiles) cannot be calibrated following ASHRAE protocol because of inconsistency of data. Not enough parameters are monitored and it makes no sense to adjust in a very precise way the model. However, considering the available data, a selection process of representative dwellings and further analysis to calibrate the model have been important to have as reliable data as possible to undertake the energy savings assessment. Here below the results of the model, referring to heating demand per analysed apartment.

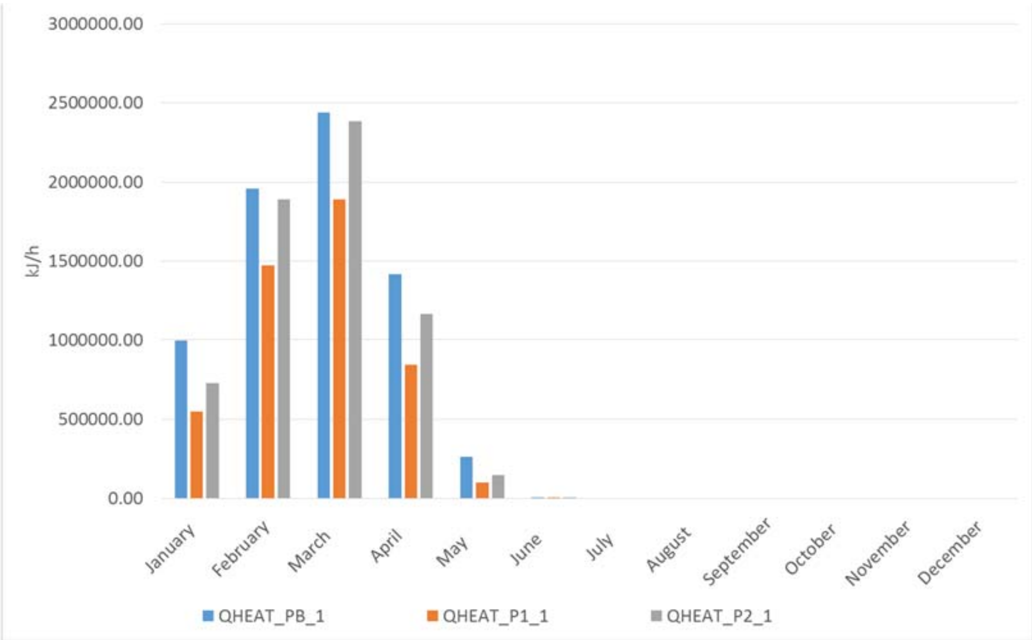


Figure 42. Heating demand per apartment

3.6.12 Baseline model outcomes

Here below the outcomes for the BASELINE scenario in two different situations are reported: real conditions (including lack of comfort) and hypothetical conditions (standard comfort).

Results. BASELINE scenario in REAL conditions

Table 35. Real conditions BASELINE simulation results

QHEAT_TOT	[kWh/m^2]	32,61
QCOOL_TOT	[kWh/m^2]	0,00
QLAT_TOT	[kWh/m^2]	0,00
QUA_TOT	[kWh/m^2]	-80,26
QGCONV_TOT	[kWh/m^2]	-4,75
QSOLTR_TOT	[kWh/m^2]	33,55
QINF_TOT	[kWh/m^2]	-26,71
QVENT_TOT	[kWh/m^2]	0,00
TAIR_TOT	[ºC]	24,94
PMV_TOT	Average	0,68
PPD_TOT	Average	34,42
TMR_TOT	[ºC]	24,93
TOP_TOT	[ºC]	24,94
OVER_TOT	[h]	3.314,05
UNDER_TOT	[h]	771,50
Occupancy hours	[h]	6.440,00
Balance	[kWh/m^2]	-45,56

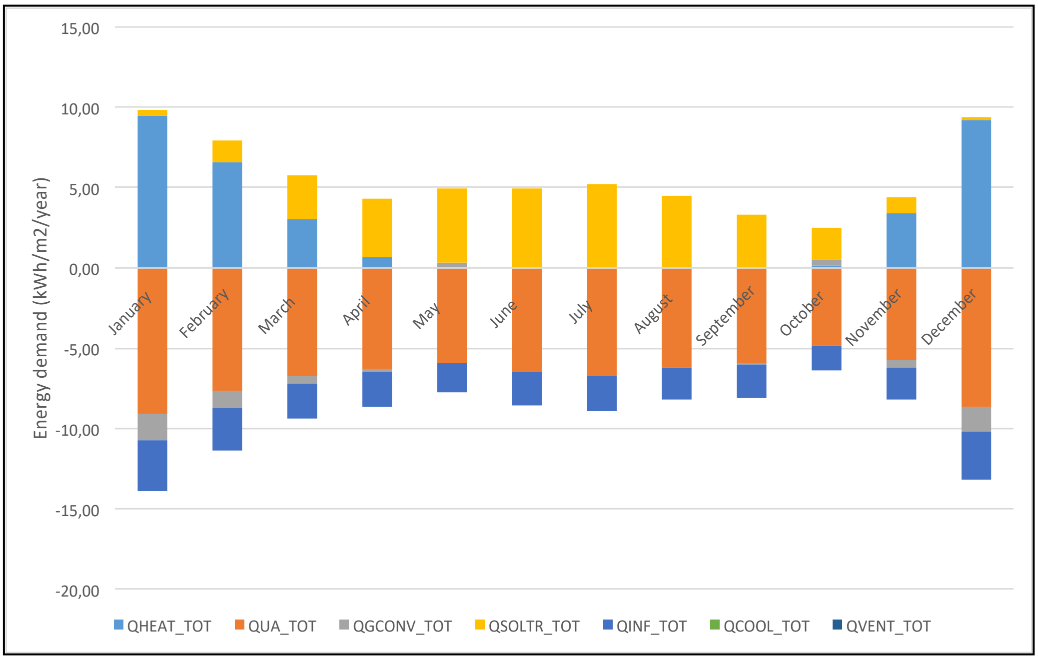


Figure 43. Real condition BASELINE energy balance

Results in the table and previous graph show the low energy demand (33 kWh/m2/y of heating demand and zero cooling demand) and lack of comfort conditions (771 hours of underheating and 3314 hours of overheating).

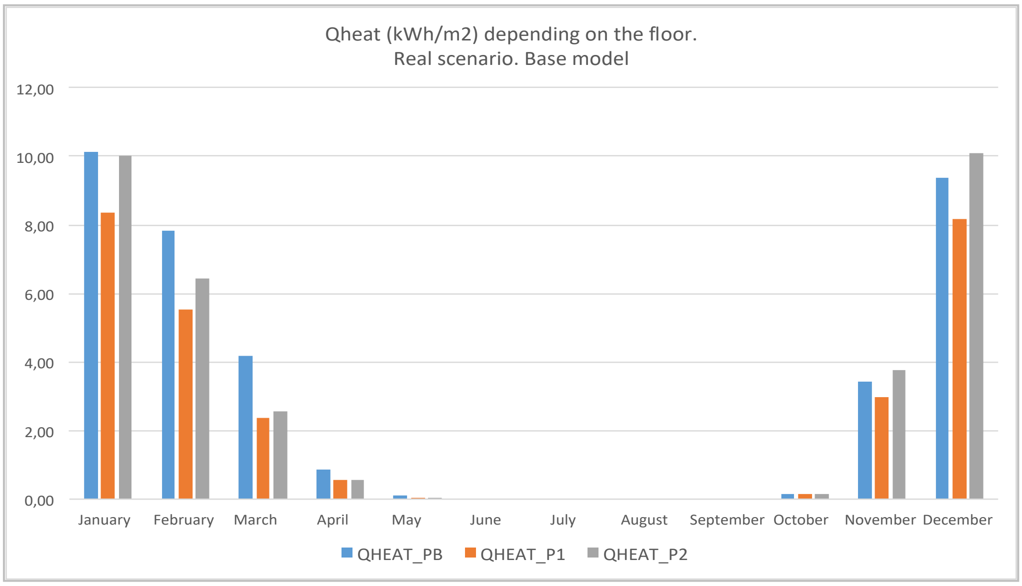


Figure 44. Real condition BASELINE Heating demand per floor

In the following graph the comfort in the real condition scenario is assessed. It is clearly shown the deviation from the ideal values (0 for PMV and 0% for PPD), and mostly important in summer conditions (central area in the graph).

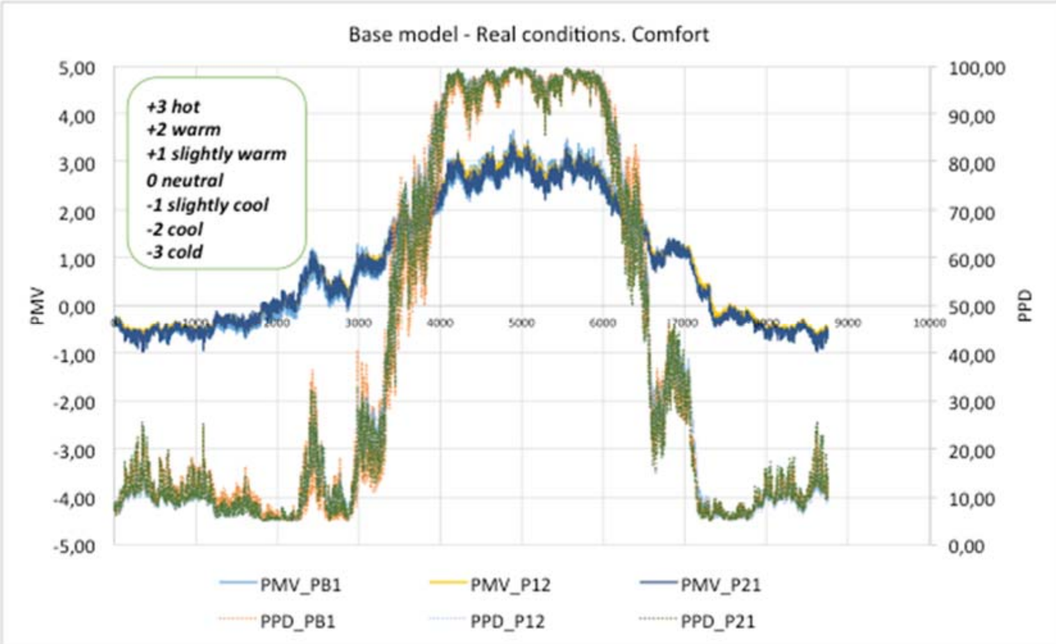


Figure 45. Real conditions BASELINE Comfort evaluation results

Results. BASELINE scenario in <u>THEORETICAL</u> conditions

The following graphs and text are presenting the results of the energy analysis for the baseline scenario under theoretical conditions (standard comfort).

As it is reported in the following table, the heating demand results much more important than the cooling demand (54 versus 18 kWh/m^2/y). Also, it can be checked that thermal comfort measured as PMV is at the ideal value of 0.

Table 36. Theoretical conditions BASELINE simulation results

QHEAT_TOT	[kWh/m²]	53,61
QCOOL_TOT	[kWh/m²]	-17,71
QLAT_TOT	[kWh/m²]	0,00
QUA_TOT	[kWh/m²]	-47,32
QGCONV_TOT	[kWh/m²]	-11,65
QSOLTR_TOT	[kWh/m²]	36,27
QINF_TOT	[kWh/m²]	-16,06
QVENT_TOT	[kWh/m²]	-21,98
TAIR_TOT	[ºC]	21,54
PMV_TOT	Average	0,01
PPD_TOT	Average	20,00
TMR_TOT	[ºC]	21,66
TOP_TOT	[ºC]	21,60
OVER_TOT	[h]	583,19
UNDER_TOT	[h]	1.603,05
Occupancy hours	[h]	6.440,00
Balance	[kWh/m²]	-24,84

In the following graph, it can be observed the solar gains (in yellow), mainly important in summer season, the heating and cooling demands (soft blue and green respectively) and the thermal losses through the envelope (in orange).

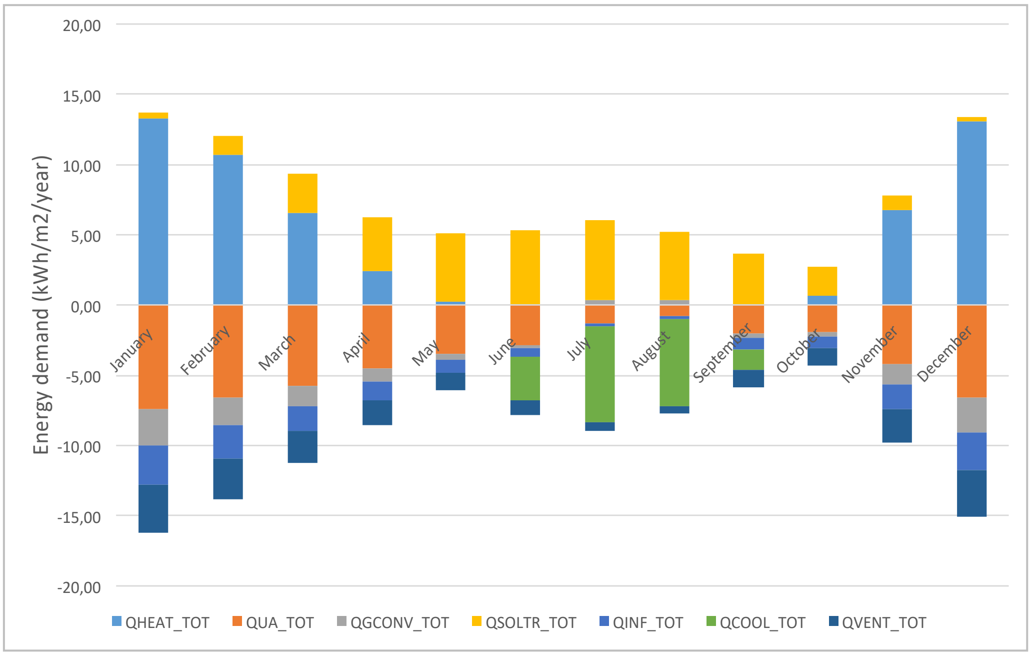


Figure 46. Theoretical condition BASELINE energy balance

In the following graph, the heating demand for three different dwellings is shown. Differences among them are not very important.

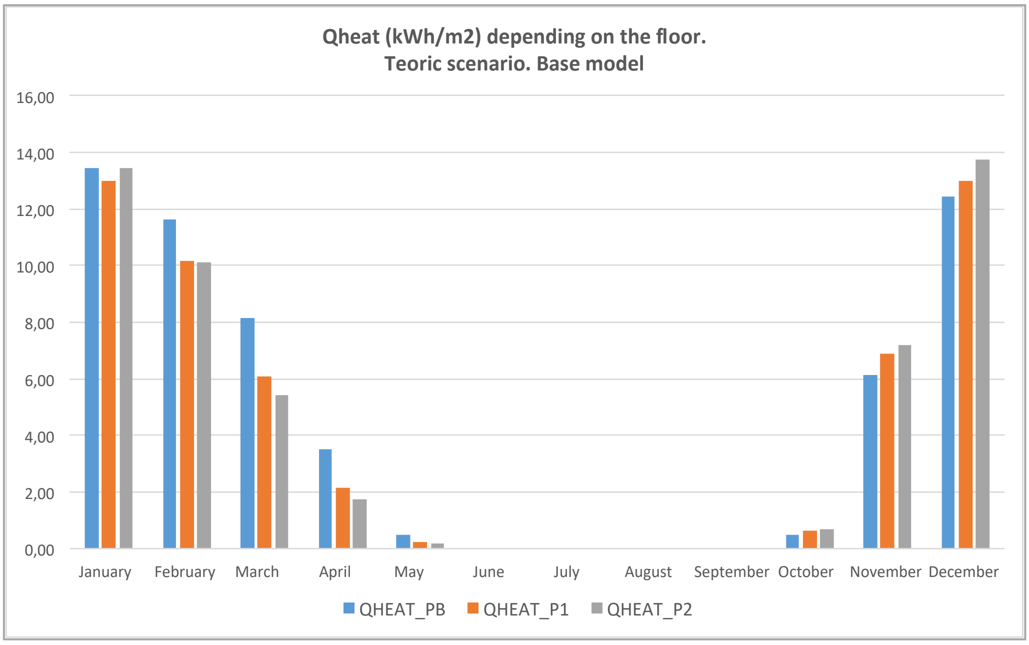


Figure 47. Theoretical condition BASELINE Heating demand per floor

Differently from the stated just above for the heating demand, when it applies to the cooling demand, the upper floor is clearly in much more need for cooling due to much more envelope surface that is exposed (roof).

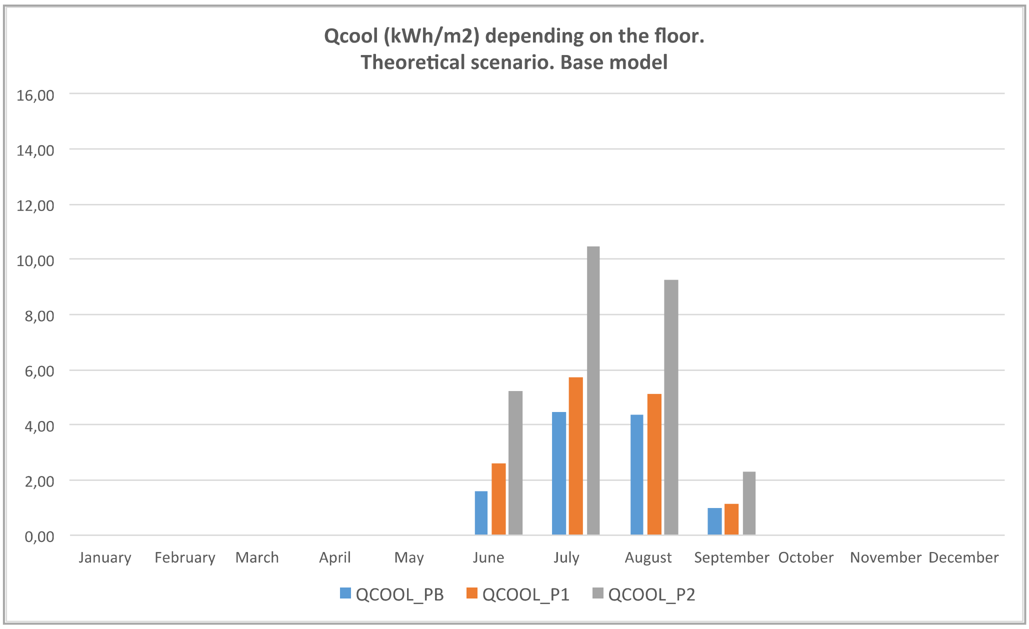


Figure 48. Theoretical conditions BASELINE Cooling demand per floor

Comfort assessment: the comfort in this scenario is close to the optimal because energy demands are covering the need of comfort. Comparing to the real conditions scenario, the values are much more favourable in this case.

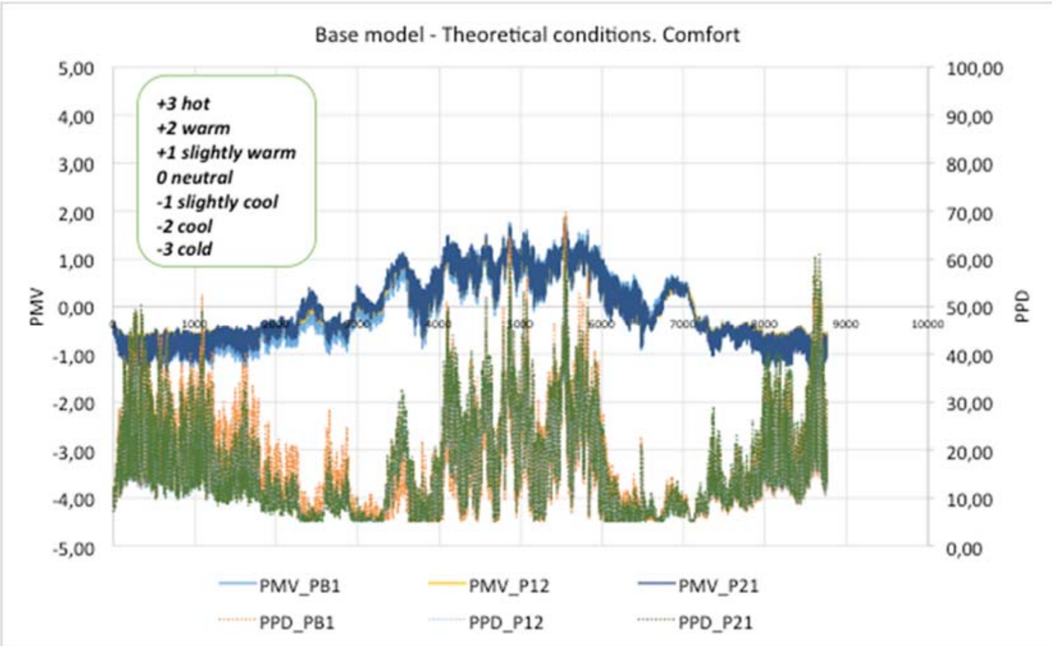


Figure 49. Theoretical conditions BASELINE Comfort evaluation results

3.7 Renovation concepts

A general overview of the applied renovation concepts is presented here below and further explained in the chapter.

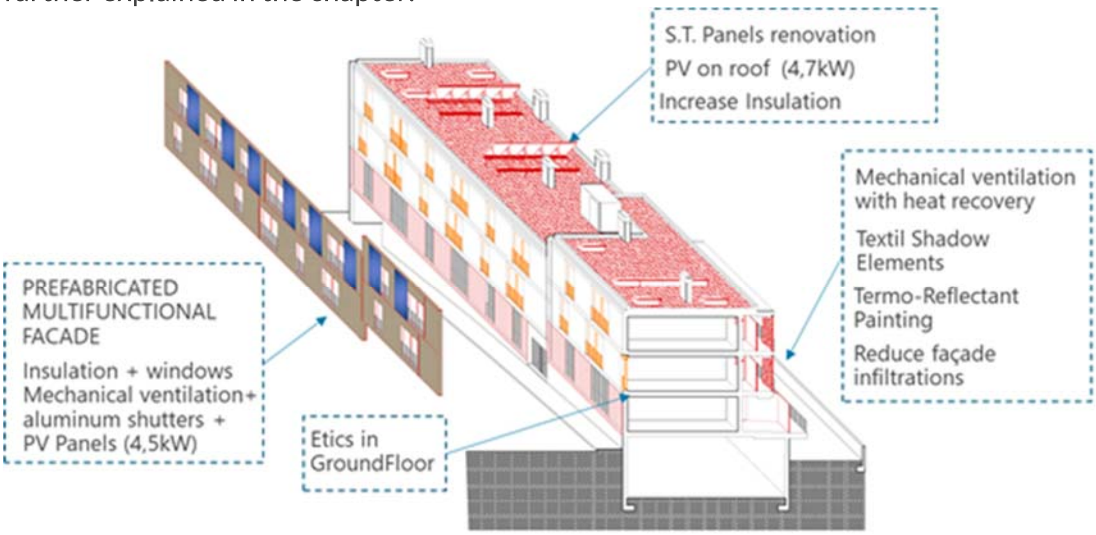


Figure 50. Isometric view of existing Bellpuig demo case and planned intervention.

3.7.1 Prefabricated Multifunctional facade

This section reports decision-making process for the development of the prefabricated multifunctional façade (collaboration with G&M and the local supplier). In particular, it presents the technical details, the integration strategies and the adopted solutions for the demo.

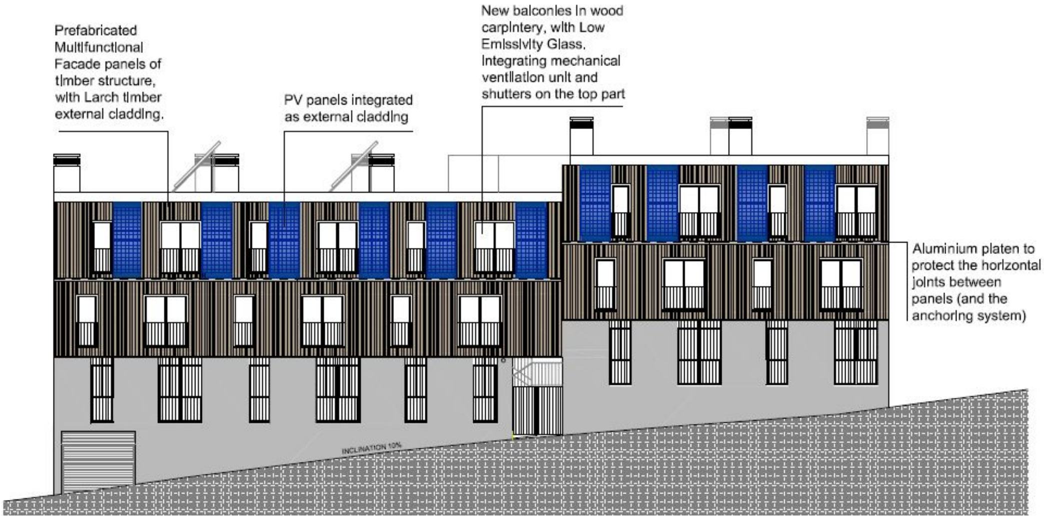


Figure 51. Prefabricated Multifuntional Façade in Spanish Democase

AHC gives priority to passive solutions as normally require less maintenance and are more effective for the type of tenants that Agency has.

In the Spanish demo-case, the main façade (East oriented) appears to be the most suitable one for implementing the add-on Prefabricated Multifunctional Façade (PMF). The main reasons to do so are the following ones:

- (1) accessibility to install the prefabricated panels
- (2) a flatten surface that allow using big panels with less joints
- (3) No balconies that represent discontinuities in the implementation of the façade.
- (4) the orientation that allows the use of Solar energy
- (5) the opacity of the façade (where balconies/window represent less than 40% of the global surface).

Even though, the Prefabricated Multifunctional Façade cannot be installed in the Ground floor level due to urban regulations. The Bellpuig municipality does not allow solutions that increase the thickness of the existing façade in the ground-floor more than 5cm, and the add-on prefabricated panels have a minimum thickness of 25cm.

In its composition the prefabricated facade includes three main layers: (1) the insulation – (2) the air chamber – (3) the external cladding. To cover the global surface of the 1st and 2nd floor facades it is foreseen to use 8 independent panels, with a maximum height of 3.20cm -to be easily transported – and a length between 5,50m-11m.

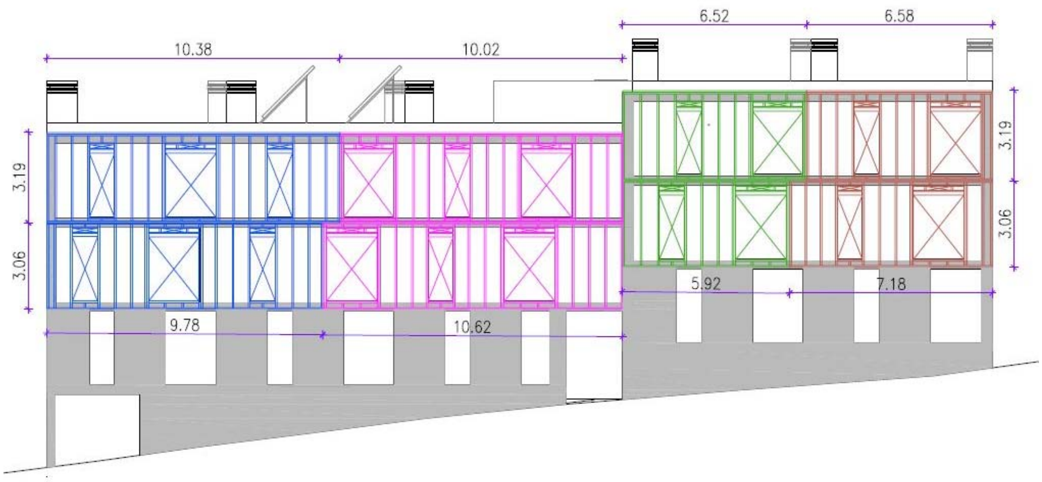


Figure 52. Structure of the Panels that compose the Prefabricated Multifuntional Façade

The anchoring system transmit the panels weight from the bottom part of each panel to the edge of the slab. The top part of the panels, although are not transmitting weight, are also fixed to the slabs' edge to avoid tipping over.

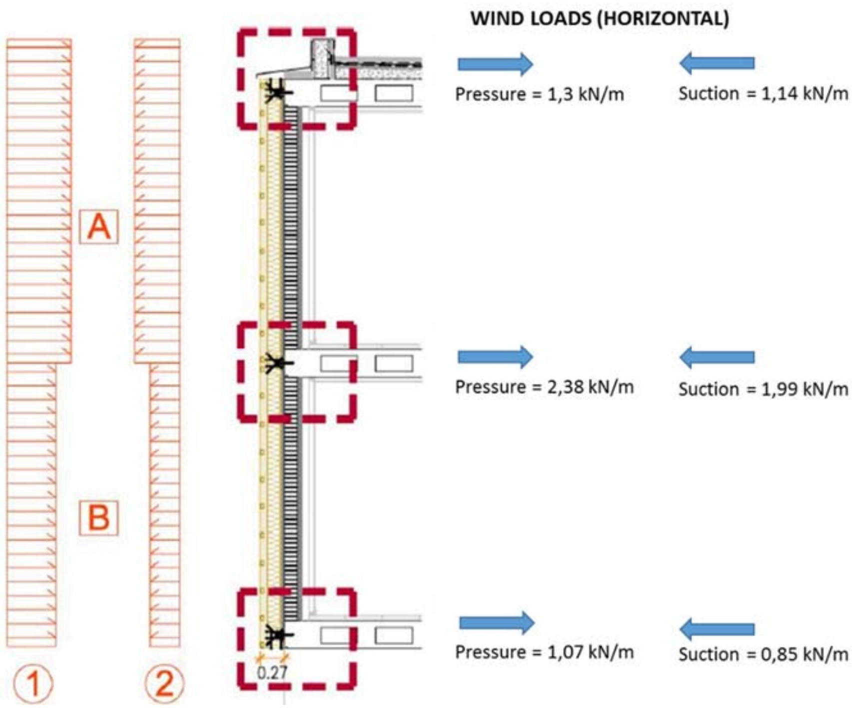


Figure 53. wind loads in the anchoring system of the Prefabricated Multifunctional façade (PMF).

Regarding West façade, no insulation solution is applied after considering several options. The external alternatives - including the PMF- were not possible, because they would have narrowed the common corridors that already have the minimum dimensions accepted by the Spanish building regulation. Moreover, the complex

geometry of the façade and its discontinuity in each level (due to the slab of the common corridor) advice against the PMF solution. Internal solutions or intermediate solutions (air chamber) were also difficult to introduce as it would have been necessary to dismount several devices in the inside of the renovated apartments (kitchen, heater…). The measures were not enough cost-efficient, and it would have caused several inconvenient to the tenants.
Concerning the side-façades no actions is previewed either, as in the future they should be protect by the blocks to be built in the besides plots.

The existing building utilities are compatible with the integration of PV panels and mechanical ventilation units in the Prefabricated Multifunctional façade. The PV are used as external cladding in those parts of the East façade that are more sun radiated. These panels complement a new PV system that is previewed on the roof.

On the other hand, the ventilation units, are hidden in the interior of the PMF, on the top part of the new balconies. To have enough room for the machines. The existing roller-shutters of the openings are replaced by folding-shutters.

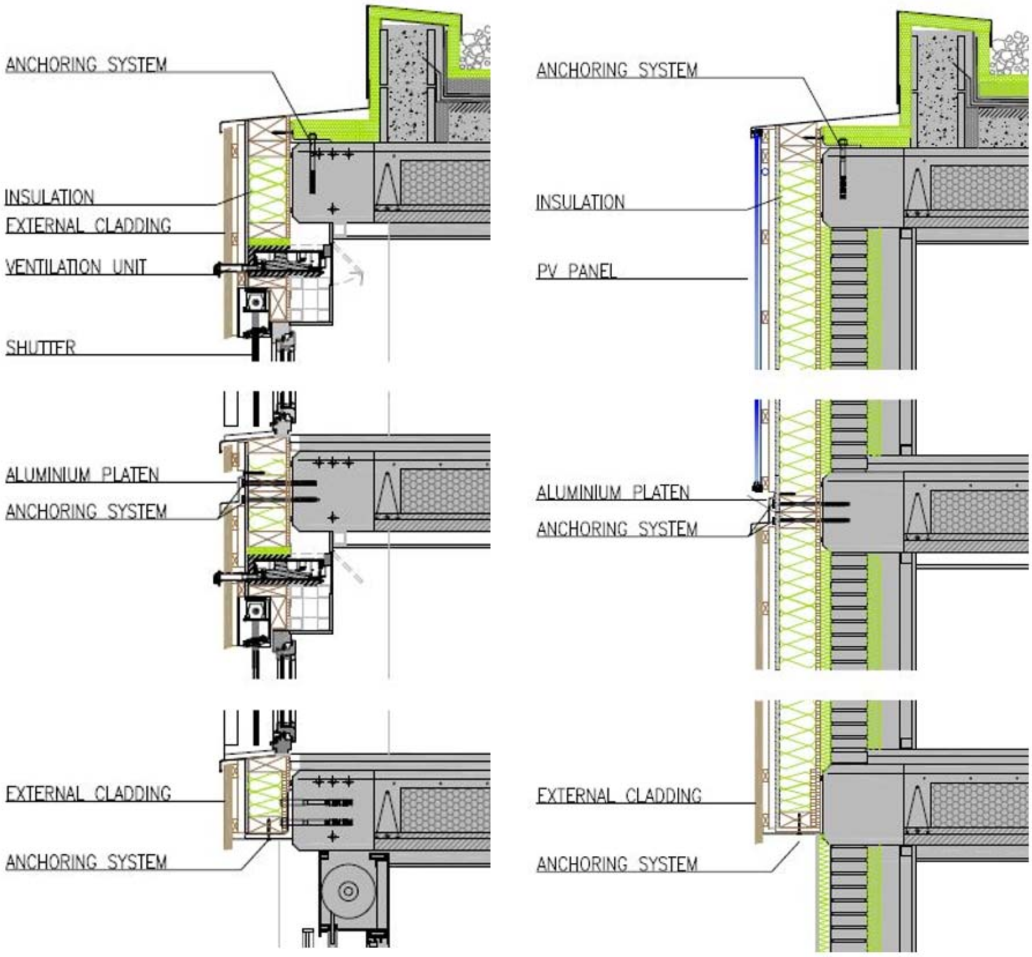


Figure 54. Section Details of the Prefabricated Multi-functional Façade in Spanish demo-case

3.7.2 Other envelope renovation actions

It is also necessary to upgrade the building's roof insulation in order to achieve adequate energy savings. This involves dismantling the existing solar thermal panels of the roof (that will be replaced by new ones) and remove the grave (that will be clean and put back).
In parallel, to protect west façade from sun radiation it is previewed to install mobile textile elements (curtains) in the common corridor and to cover with thermo-reflective paint the metallic surfaces that close the laundry areas.
To reduce the air infiltration on west façade, the projects propose to increase the tightness the entrance doors, of the glass doors (in the laundry areas) and of the windows by using weather-strip.
Other renovation actions to implement in the external common areas of are the insulation of the ceiling in the open entrance hall of the building, and the replacement of some damaged areas of the false ceiling in the common corridor.

3.7.3 HVAC system renovation

The existing 10 solar thermal panels of the roof, model Solarhart M, have more than 10 years, and it produces less than 50% of the consumed DHW. To improve the efficiency of the system the old panels will be replaced by 10 new panels type Baxi Mediterraneo 250 or similar. This will increase the solar capture surface from 18m^2 to 24m^2, and improve the system's performance in order to cover up to 66% of the DHW consumed.

4.7.5 Integration of the Plug&Play Energy Hub

The P&P Energy Hub advantages cannot be appreciated in this building, due to the installation system based on individual boilers and tanks for DHW, for this reason it has been discarded in this renovation.

4.7.6 RES exploitations: results from EarlyReno evaluations

EarlyReno was used to distinguish those parts of the East façade that are more sun radiated, therefore more suitable to add on them the PV panels as external cladding.

3.8 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.

3.8.1 Area 1: Energy

In the following table the energy performance of the existing building and the foreseen values of the renovated buildings are reported. The first row includes the standard assessment, considering comfort standards. 89% reduction of energy consumption is expected when considering PV production (37% when not including it).

As for the scenario where no comfort conditions are considered (closer to the real situation), the energy demand is reduced by 47%.

Table 37. Energy performances before & after renovation

Energy performance	Before renovation	After renovation
Calculated energy performance (standard approach – theoretical values)	47.55 kWh/m2/year (HVAC uses)	29.93 kWh/m2/year (HVAC uses without PV) 5.2 kWh/m2/year (HVAC uses with PV)
Calculated energy performance (calibrated model)	32.61 kWh/m2/year (heating and cooling demands)	17.18 kWh/m2/year (heating and cooling demands)

3.8.2 Area 2: Comfort

In this section the results of the renovation packages in terms of comfort conditions should be reported.
Data is given for the calculations under theoretical conditions in first place, and secondly under real conditions.

Theoretical conditions:

- Predicted Mean Vote (PMV): it remains almost neutral in both cases, being 0.01 for the baseline and 0.07 for the selected renovation package.
- Predictive Percentage of Dissatisfied (PPD): it is improved from 20 (baseline) up to 13.82 (selected renovation package).
- Overheating hours (T>26°C): it is improved from 583 hours (baseline) up to 443 hours (selected renovation package).
- Underheating hours (T<18°C): it is improved from 1603 hours (baselined) to 1558 hours (selected renovation package).

Real conditions:

- Predicted Mean Vote (PMV): it is slightly improved, from 0.68 (baseline) to 0.64 (selected renovation package).
- Predictive Percentage of Dissatisfied (PPD): it is improved from 34 (baseline) up to 31 (selected renovation package).
- Overheating hours (T>26°C): it is not improved, but slightly increased from 3314 hours (baseline) up to 3589 hours (selected renovation package).
- Underheating hours (T<18°C): it is substantially improved from 771 hours (baseline) to 554 hours (selected renovation package).

3.8.3 Area 3: Environment

Optimal RES configuration and CO_2 emission – comparison between before and after renovation.

See energy label in section “Energy performance evaluation”.

3.8.4 Area 4: Renovation costs

First of all, it is important to remark that standard renovations currently implemented by AHC are difficult to compare with 4RinEU solution from the cost perspective. The conventional actions do not achieve the results of 4RinEU technologies, from the energy efficient point of view.

For this demo, we have limited the comparison to the Prefabricated Multifunctional solution installed in the East façade. As a conventional solution we had consider an ETICS and new balconies, but without PV or ventilation units. The table below show the indicators related to the costs of the renovations. The prices are just estimations done before the renovation, not the real final costs.

The 4RinEU solution of the Prefabricated Multifunctional façade had a higher cost/sqm than a conventional AHC solution in the works phase. It also increases the maintenance cost, due to the new mechanical ventilation and PV systems integrated in the 4RinEU Façade.

Table 38. Estimated costs of the renovations

Indicators	**PMF façade (4RinEU solution)**		**ETICS + Windows (Standard solution)**
Cost of prefabrication	135460 €	**217740 € (1008 €/m2)**	
Cost of installation PMF	82280 €		**106150 € (505.5€/m2)**
Increase of Maintenance cost (PV system + ventilation units)*	**900 €/year**		**0 €/year**
Façade PV production	3750 kWh /year		0 kWh /year
Expected energy Savings (East façade + roof insulation) **	47% (20455 kWh /year)		25% (10880 kWh /year)
Expected cost energy savings/year (including East façade renovation + roof insulated)***	**7500 €/year** (0.31€/kWh**** x 24205 kWh/year)		**3373 €/year** (0.31€/ kWh **** x 10880 kWh/year)

*Considering 0€/year as a baseline for envelope maintenance, the use of PMF brings along higher maintenance costs due to added services. Nevertheless, with the PMF, due to its higher quality, a longer life span is expected. ETICS should undergo strong degradation after about 25/30 years, while PMF can last almost double the time with minor aesthetical maintenance.

**These indicators have considered just the solutions implemented in 210m^2 of East Façade (as it is the part renovated with 4RinEU solution).

***These indicators take into account the effects of renovating East façade and increasing the roof insulation, as it was not available the isolated value for just the East façade. (insulation roof cost =19.915,39 €). Other renovation actions to implement; as improving ST panels, PV on the roof, reduce irradiation in West façade, were not in this cost analyses as they are not 4RinEU solutions.

****The kWh cost has been estimated using the electric energy invoices of the tenants in 2018.

The table shows that, in this state, the 4RinEU solution appears to have a higher cost/sqm than a conventional solution. Nevertheless, this conventional solution, would not achieve the same Primary Energy savings, and would neither generate the same self-renewal energy production level (as there is not enough roof to install the façade PVs). This means that 4RinEU solution, will have a higher cost savings related to the energy invoices. Therefore, in this analysis we have to take into account the Life Cycle Cost.

In addition, in this moment, the conventional solution is taking advantage of being a well-extended practice, applied in economy of scale. While the 4RinEU technology involves the manufacturing of a first prototype. An economy of scale applied to the PMF facade might reduce its sqm/cost. This global perspective shows that 4RinEU solution could, in the future, achieve the target of 15% cost reduction compared with standard procedures.

3.8.5 Area 5: Renovation process

In this section, the renovation processes of the 4RinEU renovation should be evaluated in terms of duration and construction site impact.
The PMF façade, is composed by 8 prefabricated panels of different dimensions, with a maximum height of 3.20m and maximum length of 10.40m. To use big panels, allow to reduce joints in facades. Nevertheless, the system of transport, imposed size restrictions to the panels, to guarantee the access to the plot.

Before prefabricating the modules, is necessary to carry out an accurate measurement of the existing façade to be sure that the panels will fix correctly during the installation. The modules will be completed on the manufacturer site, and carried finished, except for the ventilation units (that are placed on site) and some pieces of the external cladding (that will cover the joints).

In parallel to the prefabrication phase, there are some works on-site to be done. It is previewed to clean the façade surface and to dismantle some external façade elements. To anchor the panels, it will be installed a scaffolding, of 3 levels, that will be dismantled in phases following the steps of the anchoring procedure.

Each panel will be elevated with a crane and placed in its exact position and anchored. The panels have to be self-supporting to have enough rigidity to be hanging from the crane. At the same time, in the interior of the apartments the existing balconies frame will be removed, as the panels will integrate the new balconies. This action has to be well coordinated to minimize the discomfort of the tenants.

Once the panels are anchored, then is necessary to proceed finishing the internal part of the openings, as after removing the frames, it might be necessary to paint the walls, install pavement, place the ventilation units and other minor actions, as do the electrical connection of the prefabricated façade with the apartment.

Table 39. Time estimations - comparison of 4RinEU & standard approach

Indicators	PMF façade 4RinEU solution	ETICS + Replace Standard solution
Number of days for Works on site	77days	110 days
Number of days of the Global renovation.	99 days	110 days
Number of days in which the tenants should go away from their homes	0 days	0 days
Construction site impact	Reduce: - waste, - energy & water consumption. - noise and air pollution. - Insecurity	

First estimations show that the Prefabricated Multifunctional façade can reduce 30% the time spent in on-site works during the renovation. In addition, the 4RinEU solution minimize the negative environmental and social impacts of a standard refurbishment, by moving outside part of the renovation activities (introducing a high level of prefabrication in the solution).

3.8.6 Final decision of the renovation package

Final renovation package is the one described as Scenario 2 in the following table.

Table 40. Renovation scenarios

DIFFERENT PASSIVE/(ACTIVE) SOLUTIONS
OPTION A (Scenario 1)
Prefabricated façade at East façade (1st and 2nd floor) including windows replacement and internal manual screens
Integrated mechanical ventilation
Roof insulation improvement
Sealing improvement
Canopies at West façades (1st and 2nd floor)
Reflective painting for external finishing of the utility room
Smart ceiling fans
PV in East façade and roof
OPTION B (Scenario 2) - SELECTED
Prefabricated façade at East façade (1st and 2nd floor) including windows replacement and internal manual screens
Integrated mechanical ventilation
Roof insulation improvement
Sealing improvement
Canopies at West façades (1st and 2nd floor)
Reflective painting for external finishing of the utility room
Smart ceiling fans

First floor insulation improvement
PV in East façade and roof
OPTION C (Scenario 3)
Prefabricated façade at East façade (1st and 2nd floor) including windows replacement and internal manual screens
Integrated mechanical ventilation
Roof insulation improvement
Sealing improvement
Canopies at West façades (1st and 2nd floor)
Reflective painting for external finishing of the utility room
Smart ceiling fans
Windows replacement for East Façade ground floor
PV in East façade and roof

3.9 Evaluation of the performances of the proposed renovation packages

The tree renovation scenarios presented in 3.8.6 have been analysed, in addition to two additional renovation variants of scenario 2, namely 2b and 2c, presented in Table 41 (only for AHC internal information), and the baseline. 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 understood 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).

The following table resumes the measures considered in each one of the simulated scenarios.

Table 41. Measures in the studied renovation scenarios

	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 ETICS (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

3.9.1 Energy performance evaluation

- Results: RENOVATION SCENARIOS IN THEORETICAL CONDITIONS

Once all the baseline and renovation scenarios were analysed and run, the energy results are summarized in the following table for the case of theoretical conditions. Heating demand is reduced between 36% and 38%, while cooling demand is reduced between 38% and 44%, depending on the scenario. Comfort is also improved.

Table 42. Energy results from Trnsys for each of the renovation scenarios under theoretical conditions (values)

		THEORETICAL CONDITIONS						
		Base case	Scenario 1		Scenario 2		Scenario 3	
			Value	%	Value	%	Value	%
QHEAT_TOT	[kWh/m²]	53,61	34,50	35,6%	33,61	37,3%	33,18	38,1%
QCOOL_TOT	[kWh/m²]	-17,71	-10,95	38,2%	-11,27	36,3%	-9,90	44,1%
QLAT_TOT	[kWh/m²]	0,00	0,00	--	0,00	--	0,00	--
QUA_TOT	[kWh/m²]	-47,32	-43,32	8,5%	-41,95	11,3%	-39,05	17,5%
QGCONV_TOT	[kWh/m²]	-11,65	7,28	162,5%	7,28	162,5%	7,28	162,5%
QSOLTR_TOT	[kWh/m²]	36,27	10,11	72,1%	10,07	72,2%	8,37	76,9%
QINF_TOT	[kWh/m²]	-16,06	-8,46	47,3%	-8,53	46,9%	-8,41	47,6%
QVENT_TOT	[kWh/m²]	-21,98	-22,76	-3,5%	-22,95	-4,4%	-22,17	-0,8%
TAIR_TOT	[ºC]	21,54	21,69	-0,7%	21,73	-0,9%	21,66	-0,5%
PMV_TOT	Average	0,01	-0,08	988,8%	-0,07	904,3%	-0,08	1007,9%
PPD_TOT	Average	20,00	13,88	30,6%	13,82	30,9%	13,55	32,3%
TMR_TOT	[ºC]	21,66	21,71	-0,2%	21,77	-0,5%	21,68	-0,1%
TOP_TOT	[ºC]	21,60	21,70	-0,5%	21,75	-0,7%	21,67	-0,3%
OVER_TOT	[h]	583,19	422,97	27,5%	442,82	24,1%	443,79	23,9%
UNDER_TOT	[h]	1.603,05	1.571,82	1,9%	1.558,22	2,8%	1.588,23	0,9%
Occupancy hours	[h]	6.440,00	6.440,00	--	6.440,00	--	6.440,00	--
Balance	[kWh/m²]	-24,84	-33,59	-35,2%	-33,74	-35,8%	-30,69	-23,5%

The following graph helps visualizing the reduction.

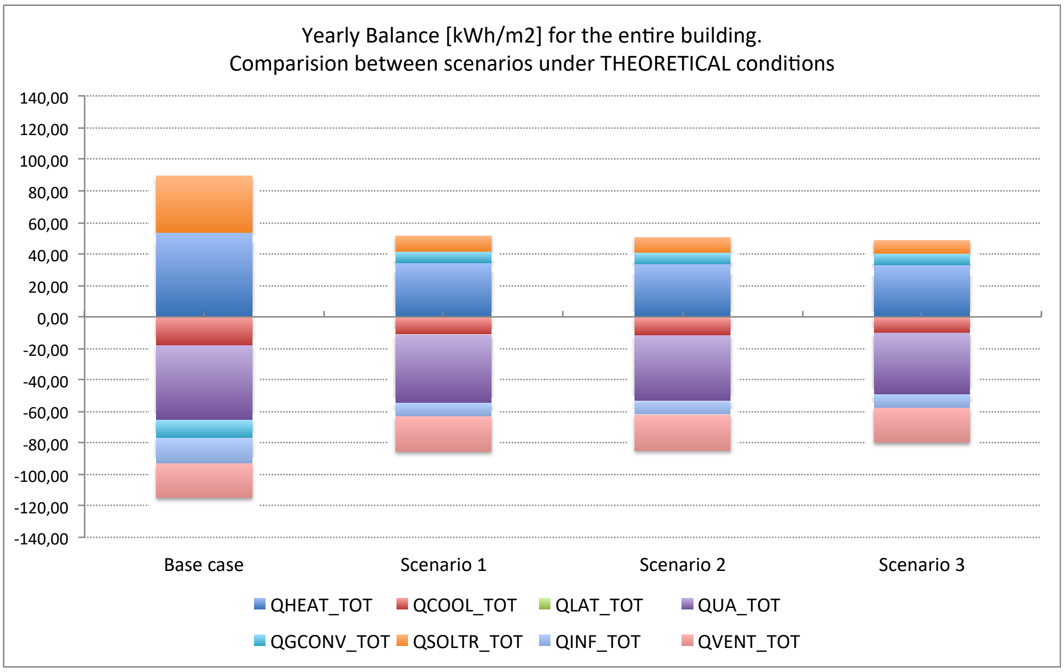


Figure 55. Energy results from Trnsys for each of the renovation scenarios under theoretical conditions (graph)

- 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 43. 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%

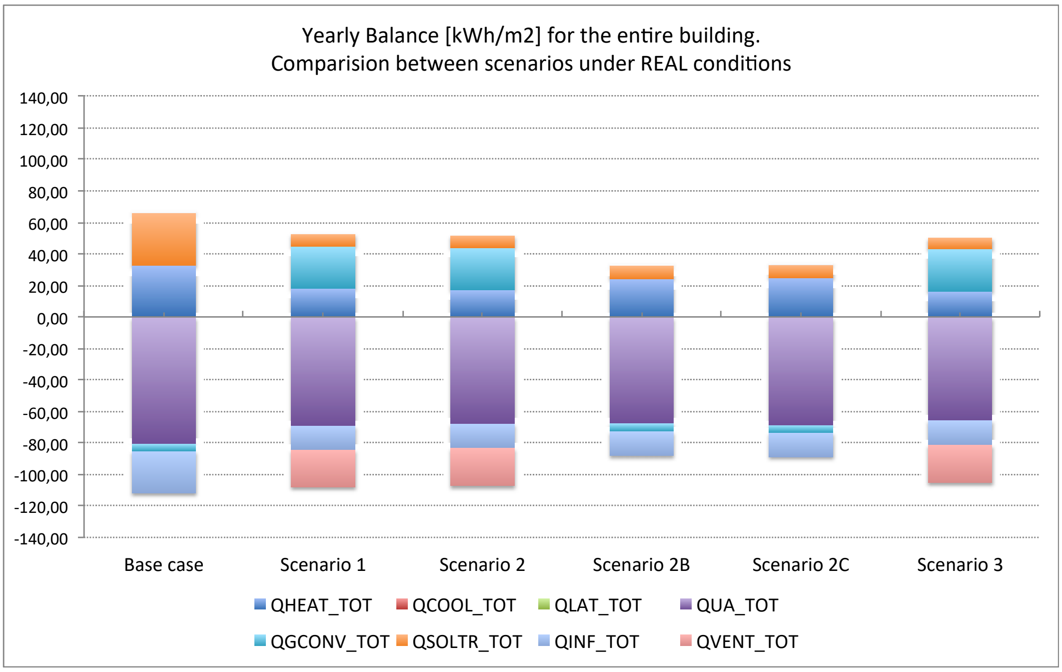


Figure 56. Energy results from Trnsys for each of the renovation scenarios under real conditions (graphs)

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).

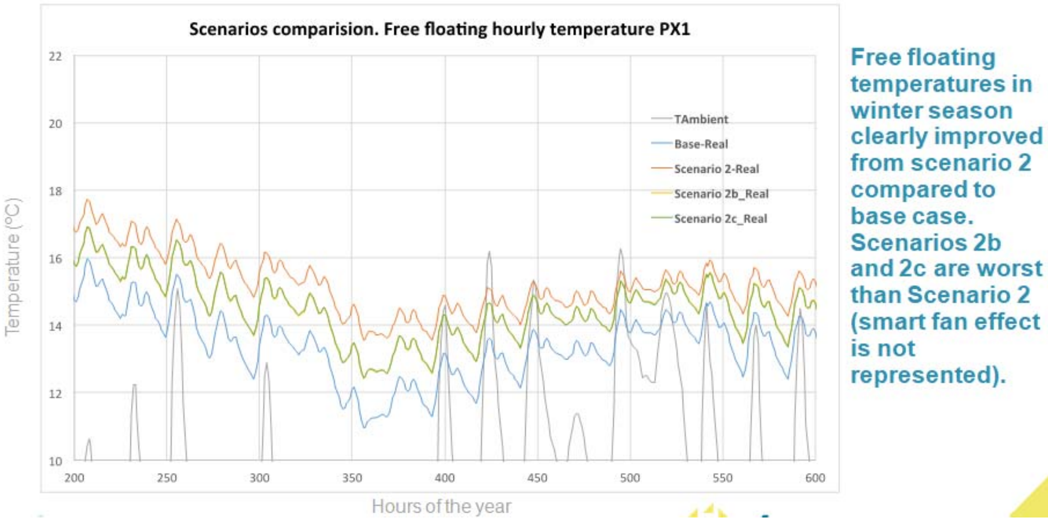


Figure 57. Free floating temperatures for each renovation scenario

- 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 an average of 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 amount 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 44. 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%.

- Energy label

For the current situation, according to the Spanish Energy Performance Certification procedures, the energy label is E in emissions and E in primary energy (see below).

Table 45. Emission label for the current situation

INDICADOR GLOBAL		INDICADORES PARCIALES			
< 8.4 A 8.4-13.6 B 13.6-21.1 C 21.1-32.4 D 32.4-66.3 E 66.3-79.6 F ≥ 79.6 G	46.2 E	CALEFACCIÓN		ACS	
		Emisiones calefacción [kgCO2/m² año] 38.65	E	Emisiones ACS [kgCO2/m² año] 6.39	G
		REFRIGERACIÓN		ILUMINACIÓN	
Emisiones globales [kgCO2/m² año]		Emisiones refrigeración [kgCO2/m² año] 1.17	A	Emisiones iluminación [kgCO2/m² año] -	-

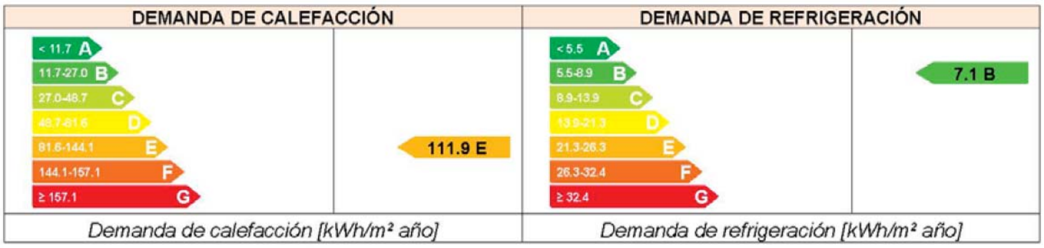
La calificación global del edificio se expresa en términos de dióxido de carbono liberado a la atmósfera como consecuencia del consumo energético del mismo.

	kgCO2/m² año	kgCO2/año
Emisiones CO2 por consumo eléctrico	27.93	21479.06
Emisiones CO2 por otros combustibles	18.28	14053.81

Table 46. Energy label for the current situation

INDICADOR GLOBAL		INDICADORES PARCIALES			
< 37.1 A 37.1-60.1 B 60.1-93.2 C 93.2-143.3 D 143.3-298.1 E 298.1-336.8 F ≥ 336.8 G	251.3 E	CALEFACCIÓN		ACS	
		Energía primaria calefacción [kWh/m²año]	E	Energía primaria ACS [kWh/m² año]	G
		206.70		37.70	
		REFRIGERACIÓN		ILUMINACIÓN	
Consumo global de energía primaria no renovable [kWh/m² año]		Energía primaria refrigeración [kWh/m² año]	B	Energía primaria iluminación [kWh/m²año]	-
		6.90		-	

Per uses, heating demand obtains E and cooling demand B.



3.9.2 Economical evaluation

Further information on the economical evaluation are reported in chapter dealing with renovation concepts in Area 4: Renovation cost.

3.9.3 EarlyReno – RES integration

Using the EarlyReno software, developed within the project, an economic and energy assessment considering PV installation has been done.
For the economic assessment, the optimal scenario is to install 9 kW_{peak} of PV modules, which are expected to generate almost 36 k€ after 25 years.

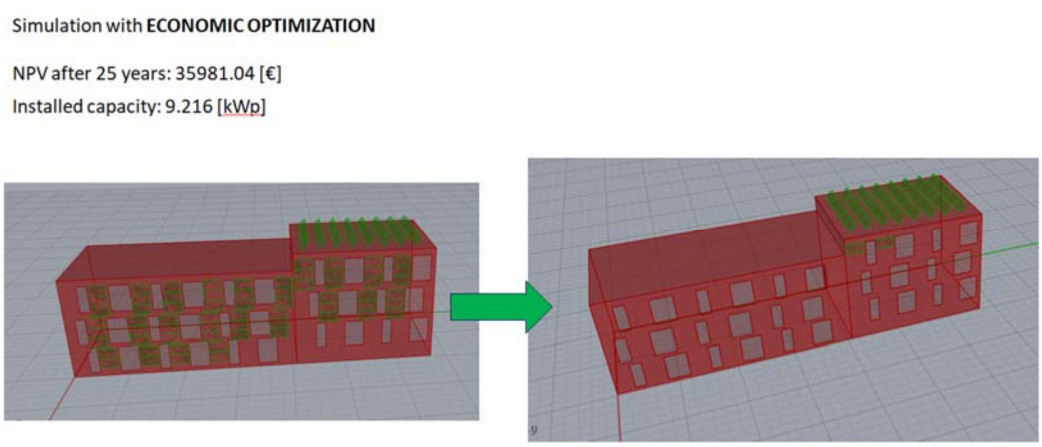


Figure 58. Preliminary results from EarlyReno simulation – economic optimization

The energy assessment finds the optimal in installing 16 kW_{peak} of PV modules. However, the economic output is less interesting (31 k€ after 25 years).

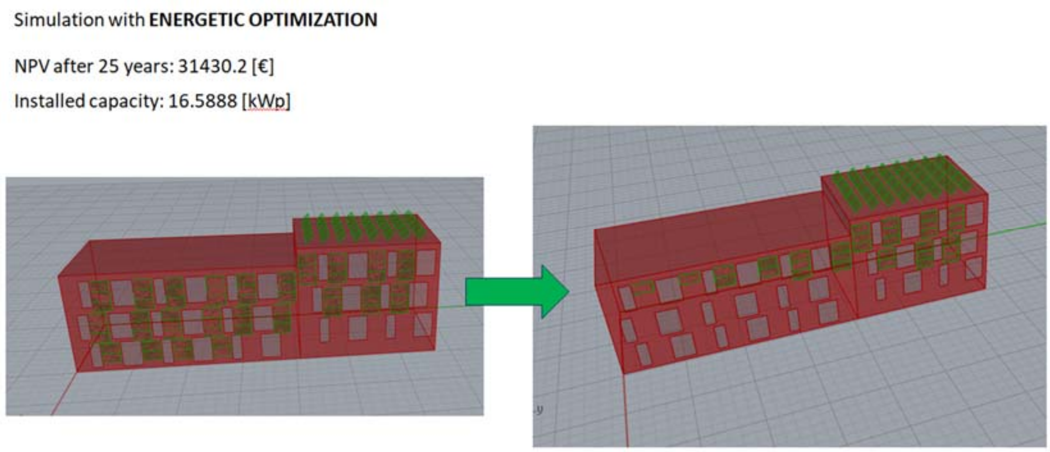


Figure 59. Preliminary results from EarlyReno simulation – energetic optimization

3.9.4 Results of the participative design approach

Concerning tenants, there has been an important change of profile, due to the economic crisis. Before 2012, most of them were young people, who were living in our apartments temporally (a few years). As their economic situation improved, they use to leave our dwellings to enter in the conventional rent market. Therefore, the type of social housing that AHC have are small apartments (for just 1/2 users+ a young child).

Due to the crisis, now, another user profile has increased: families from evictions. Those users are normally older and may have children of different ages (or they take care of older relatives). These family units, more numerous, they can have several difficulties to find stable work, due to their age, and they stay in the social housing for longer periods. However, these flats were not intended to be permanent homes and they are too small to accommodate these types of families.

Tenants can come also from other groups that have always been at risk of social exclusion (battered women or Roma families). Current users of AHC's flats require a follow up. The AHC does not do social services (it is a responsibility of other entities), but it does financial and coexistence supervision.

Before the current emergency situation, the access to social housing was done following economic criteria. Our users had a varied profile. However, during the last 2 years, the apartments are directly awarded to population at risk (through the "Mesa d'Emergència"). This means that in our dwellings there coexist a high concentration of disadvantaged and conflictive population.

3.10 Tender procedure

AHC is a public organism that follows Public Contract Spanish Law 9/2017, 8th November, related to the European directives 2014/23/UE and 2014/24/UE, 26th February of 2014. This Spanish law defines different types of tender procedures depending on the nature of the contract (works or supply and services) and its cost estimation.

Table 47. Tender types in Spanish regulation

Types of Tender	**OPEN Simplified Abbreviated**	**OPEN Simplified**	**OPEN no SARHA****	**OPEN SARHA**
Supply and Services	VEC* ≤ 35.000 €	VEC ≤ 100.000 €	VEC < 221.000€	VEC ≥ 221.000€
Construction Works	VEC ≤ 80.000 €	VEC ≤ 2.000.000€	VEC < 5.548.000€	VEC ≥ 5.548.000€

*VEC : the contract estimation cost including extensions and modification but not including TAX.
**SARHA: Subjected to harmonized regulation

In the case of the Bellpuig building renovation, the construction works are all included in a unique tender, to simplify the procedure and to avoid conflicts of responsibility between different subcontracted companies during the works. Therefore the global estimation cost for the works to be subcontracted amounted up to 350.000€. The tender procedure to apply is the **Open Simplified Works Tender**. The documents needed to start the procedure are the following ones:

1. The "*Needs to start a recruitment*" *Report (specifies and justifies the raisons for opening the tender procurement)*
2. The Technical Specification document (specifies the technical and economic conditions of the contract).
3. The Technical Renovation Project (includes all the documents need to the execution of works: plans, technical report, estimation cost, works chronogram, Health & Security Plan…)

Once the Open Simplified Tender documents are prepared, the administrative procedure to approve the documents, open the tender to public and select the final subcontracted company takes 7 months. This procedure is divided in 5 steps:

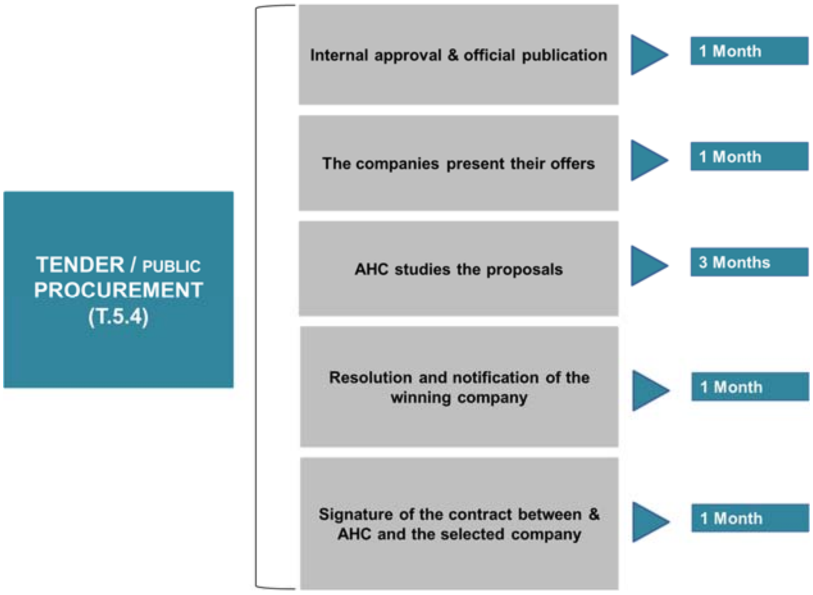


Figure 60. Tender procedure

Details of public procurements are published nationally, on the Catalan's Government platform for Public Tender Procurement (*https://contractaciopublica.gencat.cat*).

3.11 Gantt of the renovation activities

Here below a preliminary Gantt chart of the renovation process.

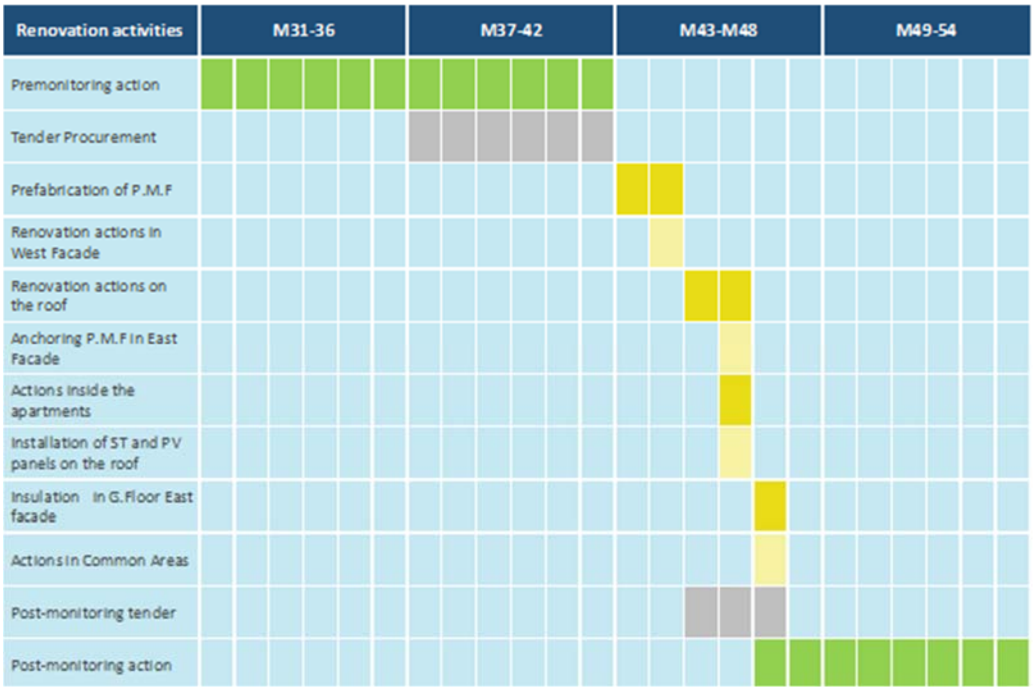


Figure 61. Gantt chart Spanish demo

4 Dutch Demo Case: Mariënheuvel, Soest

The building owner is Woonzorg, a social housing company developing and managing residences especially for elderly people.

The residential building which is the demo case, Mariënheuvel 79 apartments, is one of two residential buildings (in total 151 apartments) to be renovated and is located on a site in Soest consisting of three buildings; the other residential building is Mariënhorst with 72 apartments; the third is a care-centre, Mariënburg. The latter will be demolished and replaced by a new building. The two residential buildings consist of four floors and will be renovated to current Dutch standards. The insulation of the roof construction will be changed and improved to a level close to 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 and the corridors will be enlarged and refurbished. Bicycle storage rooms will be added. On top of this renovation, the 4RinEU project will be applied on 15 of the 79 dwellings, mainly existing of mounting prefab façades on the exterior side of the existing façades.

4.1 Key features of the building

The two blocks of residential buildings Mariënhorst and Mariënheuvel are built in 1980, when standards in terms of insulations were low in comparison with today. In fact, the Netherlands had just begun to use insulation in the cavity walls. The windows with wooden frames were equipped by the first generation of double glazing. Concrete elements such as balconies and consoles were connected with the concrete floors with thermal bridges. The building has central collective condensing gas boilers recently renovated for the heating supply and central separate boilers with storage for DHW production. The building presents natural ventilation supply and mechanical exhaust ventilation with vertical duct distribution.

All together the building and system characteristics of the blocks don't respond to nowadays demands.

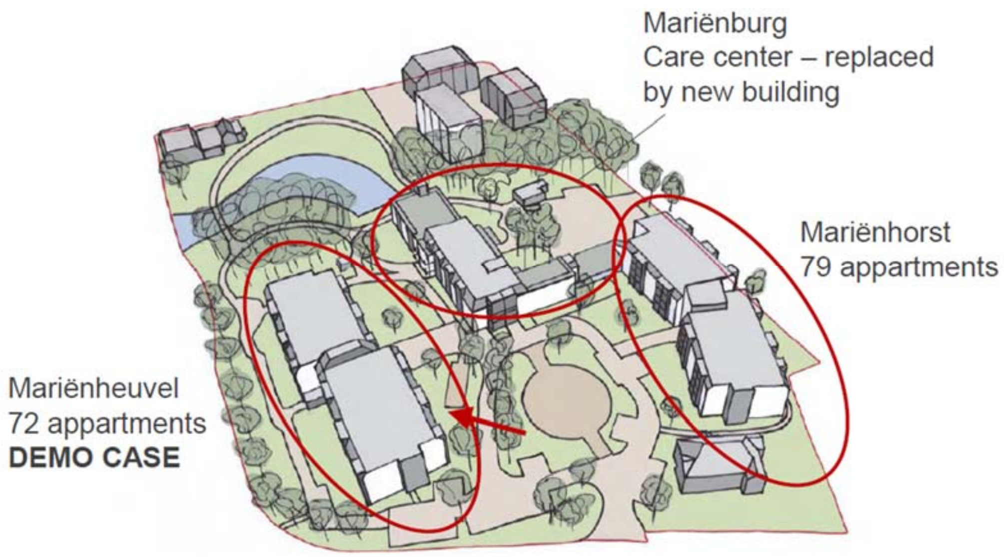


Figure 62. overview of the complete site of Mariënheuvel, Mariënburg and Mariënhorst

Figure 63. Typical architecture Mariënheuvel

4.2 Drivers of the renovation

This section reports both the main drivers that led Woonzorg to the renovation of the specific building adopted as demo case within 4RinEU and the specific needs of the demo.

General drivers

- Woonzorg is the owner of several buildings on the same plot. Woonzorg owns stock throughout The Netherlands. Therefore, there is a high replication potential locally and nationally.
- Woonzorg can compare this deep renovation with the standard renovation of existing building stock of 30 – 40 years old.
- Woonzorg wants to explore the impact of deep renovation beyond 'Energy Label B', which is the typical target of energy renovation projects.

Building specific drivers

- To adapt the building according to the needs of the users that are getting older with more deficit (e.g. dementia) and the soft care is not enough.

- To solve functional and safety problems: move from balconies to terrace (as garden above ground), add storage for (electric) bicycles
- To reduce energy consumption. Current insulation values of the building are too low.
- To improve the building aesthetic. The whole site does need modernization to be ready for extended exploitation.
- To improve indoor comfort, both thermal and indoor air quality.

4.3 Key issues to consider for a successful renovation

This section describes the key issues highlighted within the LDWG by the demo owner that have to be considered for planning a successful renovation of the building.

- To exploit the ventilation potential (for indoor air quality and to ensure the summer comfort – night cooling) → strategic the application of EarlyReno.
- To define an optimal control & operation of the HVAC system (At the moment the schedule is fixed)
- To reduce disturbance for the users during the interventions as much as possible: the renovation works have to be developed with the tenants living inside.
- To work actively for involving the end-users → awareness and responsibility for reducing the energy consumption (as highlighted by the Municipality of Soest)

4.4 Target of the renovation

4.4.1 Minimum requirements provided by law and local regulations

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

Figure 64. Logo of Dutch building energy label

In the Netherlands energy performance of the building stock is determined in Energy Labels. 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 regular 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 48. 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 [m2K/W]	Rc = 1.3 [m2K/W]	Rc=1.3 [m2K/W]	Rc = 6.5 [m2K/W]
Roof	Rc = 0.35 [m2K/W]	Rc = 3.5 [m2K/W]	Rc=2.0 [m2K/W]	Rc = 6 [m2K/W]
Ground Floor	Rc = 0.15 [m2K/W]	Rc = 2.5 [m2K/W]	Rc=2.5 [m2K/W]	Rc = 3.5 [m2K/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	mechanical	-	decentral
Air tightness	-	-	-	Qv max 0,25
Energy Label	D	B	B	A or A+

Dutch building regulations require different standards depending of 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 building. Also for existing buildings minimum insulation values apply for different situations.

Table 49. 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	2.20

panels in window frames		2.2	2.20
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 50. 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
	[m2K/W]	[W/m2K]	[W/m2K]
roof	6.0		0.16
facade	4.5		0.21
glazing		2.2	2.20
panels in 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 51. 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
panels in window frames		2.2	2.20
floor	1.3		0.68

Source: Bouwbesluit, artikel 5.6 lid 1	

Table 52. 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
panels in 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.

The Dutch team: 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 53. 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
	[m2K/W]	[W/m2K]	[W/m2K]
roof	0.4		2.04
facade	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/m2**
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. In order to meet this by using the minimum insulation values for existing buildings, combined with mechanical exhaust ventilation and a new condensing gas boiler, it is enough to achieve energy label B.

In the case of Marienheuvel, the standard roof insulation at the level of new construction 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/m2. Given that the real energy performance of the existing building is just above 100 kWh/m2, 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 54. Standard insulation values and calculated net heat demand for space heating in for the standard renovation of Mariënheuvel

Standard renovation Marienheuvel			
			for international comparison
	Rc value	U value	U value
	[m2K/W]	[W/m2K]	[W/m2K]
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/m2**
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 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 55. 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 56. Comparison of U values, ventilation system and net heat demand for the existing situation, minimum requirements, standard renovation and demo renovation

Renovation Marienheuvel				
	EXIST	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 including frames	3.00	2.20	1.80	1.00
Opaque panels in window frames*	2.20	2.20	0.60	0.17
floor	3.13	0.37	0.27	0.27
ventilation	extract	extract	extract	decentralised
Net heat demand	kWh/m2		kWh/m2	kWh/m2
PHPP	125		67	20
UNIEC	132		70	19
Monitored	108			

* In Dutch building practice it is common to have window frames filled either with glazing or opaque panel, usually with poor thermal insulation quality. In the retrofit condition of the demo, these panels will be substituted reaching good insulation level.

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

Table 57. Comparison of the Energy Labels for the existing situation, standard and demo renovation. Calculation refers to a reference room with 51 m^2 area.

Energy performance		exist	standard	4RinEU
Specific energy performance	MJ/m2	1161	782	508

Characteristic energy use	MJ	59199	39857	25906
Allowed characteristic energy use	MJ	24394	24394	24394
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 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.

4.4.2 Targets of 4RinEU project

- **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 58. 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					
		existing	standard	4RinEU	
Yearly primary energy use per function					

Space heating		MJ	29938	15828	4132	- 86%
Auxiliary energy		MJ	3823	3733	3658	-4%
Domestic Hot Water		MJ	12470	12470	12470	0%
Auxiliary energy		MJ	2063	2063	2063	0%
Cooling		MJ	0	0	0	
Auxiliary energy		MJ	0	0	0	
Summer Comfort		MJ	1163	702	781	- 33%
Fans		MJ	7392	2710	452	- 94%
Lighting		MJ				
	TOTAL	**MJ**	**56849**	**37506**	**23556**	**- 59%**

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

- **Cost reduction of at least 15%** compared with a typical renovation.

  The costs have been compared between a standard renovation and the 4RinEU renovation package. The project Marienheuvel was primarily developed as a standard renovation, therefore in the table below, both the costs for the demo renovation as standard and deep retrofit 4RinEU approaches, are reported. In red, the results of the evaluation are highlighted: 27649€ for the standard renovation and an added 25761€ for 4RinEU package.

  Nevertheless, these costs may be misleading. In fact, they are not really comparable since they refer to different renovation approaches providing different benefits. The standard renovation approach reported here is only considering an improvement of thermal insulation and a slight improvement of comfort condition, while the 4RinEU approach's cost here estimated is accounting for much higher energy performances of the building and a strongly improvement of the indoor climate and comfort condition. In conclusion, a reliable cost and time comparison between renovation approaches would occur only if equal intervention qualities and performances are taken into account.

Table 59. 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 60. 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 61. 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 62. 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 Table 62 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.

- **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 the prefabricated façade costs one day per apartment, and small finishing works may remain afterwards.

Nevertheless, as specified for the costs' comparison, also in this case the comparison may be misleading. In fact, time comparison of the intervention between different approaches is reliable only in case the renovations provide the same benefits.

In conclusion, considering a deep retrofit as outcome of the renovation, the 4RinEU approach requires probably less time on building site compared to a standard renovation approach, thanks to the prefabrication process.

4.4.3 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.

4.5 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 realisation of the renovations.

4.6 Renovation concepts

<u>**Brief history of the Dutch demo project in 4RinEU**</u>

- Demo proposed by housing association Portaal
- Demo withdrawn by Portaal during contract negotiations
- Replacement project proposed: Marienburg, Soest, owned by Woonzorg Nederland
- After the renovation design process, it was concluded that this building could not meet the programme with too many structural alterations.
- Finally, Marienheuvel was selected to demonstrate the 4RinEU technologies, as applicable to this building.

- In 2020 execution of demonstration project Marienheuvel

Decision to demolish and rebuild Marienburg

- Since the spatial requirements for a care and living centre did not match with the structure and spaces in Marienburg, the interventions were so costly, that Woonzorg Nederland decided to invest slightly more, and aimed to have a totally new building for the services needed in Marienburg.
- A design for new construction of Marienburg has been elaborated
- The demo part of 4RinEU moved to the residential apartment blocks Marienheuvel and Marienhorst, both located at the same site in Soest.

Standard renovation Marienheuvel and Marienhorst

Marienheuvel and Marienhorst will undergo a standard energy renovation, resulting in energy label B, in total 136 apartments. Other 15 apartments in Marienheuvel will undergo 4RinEU renovation.

4.6.1 Deep renovation 15 apartments Marienheuvel

15 apartments of Marienheuvel will apply 4RinEU technologies to demonstrate the feasibility of more advanced energy strategies

The 15 apartments in the South East wing of Marienheuvel will have new prefabricated facades with three additionally integrated technologies: shading, ventilation with heat recovery and summer night ventilation.

- 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 (styles polarized firing) 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)

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

- 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).

- 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 (Qv10 max. 0.25).

- 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 fires 38 x approx. 160 mm with cellulose
    - vapor-proofing film according to the manufacturer's advice
    - Multiplex WBP 12 mm, three-layered factory-painted

- 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.

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

- Integrated elements
    - In order to use the Climarads technology, the required facilities for installation have been included in 15 frames in accordance with Movair's patented system.

    - 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. They allow for:
        - air supply and exhaust with heat recovery
        - bypass ventilation for summer night ventilation
        - pre-heating ventilation air in the combination of the radiator and the ventilation device.

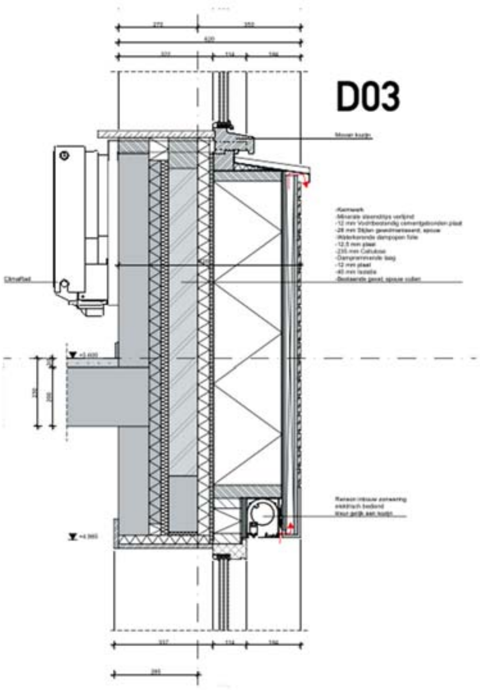


Figure 65. Windowsill and integrated shadings details

4.6.2 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. Also entrances are being renewed and all facades will be painted to improve the aesthetical quality.

4.6.3 HVAC system renovation

The heating and hot water system in the project have not been changed, due to a previous modernization. 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 decentral 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.

4.6.4 Integration of the Energy Hub

- Key issue is that Marienheuvel and Marienhorst have a communal heating and hot water system, which is vertically organised. I.e. 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.

4.6.5 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 North East 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.

4.6.6 Integration of the sensible data handler

The integration of the sensible data handler is being considered as part of the monitoring programme, which is under elaboration at the time of writing of this report.

4.7 Building performances analysis

4.7.1 Building description

The residential building 'Mariënheuvel' is located in Soest, The Netherlands. This is a village in the geographical middle of the country

The number of apartments of the regular renovation is 151 divided in two blocks. The block concerned, Mariënheuvel, consists of 79 apartments. 15 of them are involved in the 4RinEU project.

Common area's in the building are the entrance, the corridors, the bicycle storage room.

Woonzorg Nederland, a not-for-profit independent private organisation (not a public body) is the owner of the building.

4.7.2 Location

Figure 66. Location of Mariënheuvel in Soest, The Netherlands

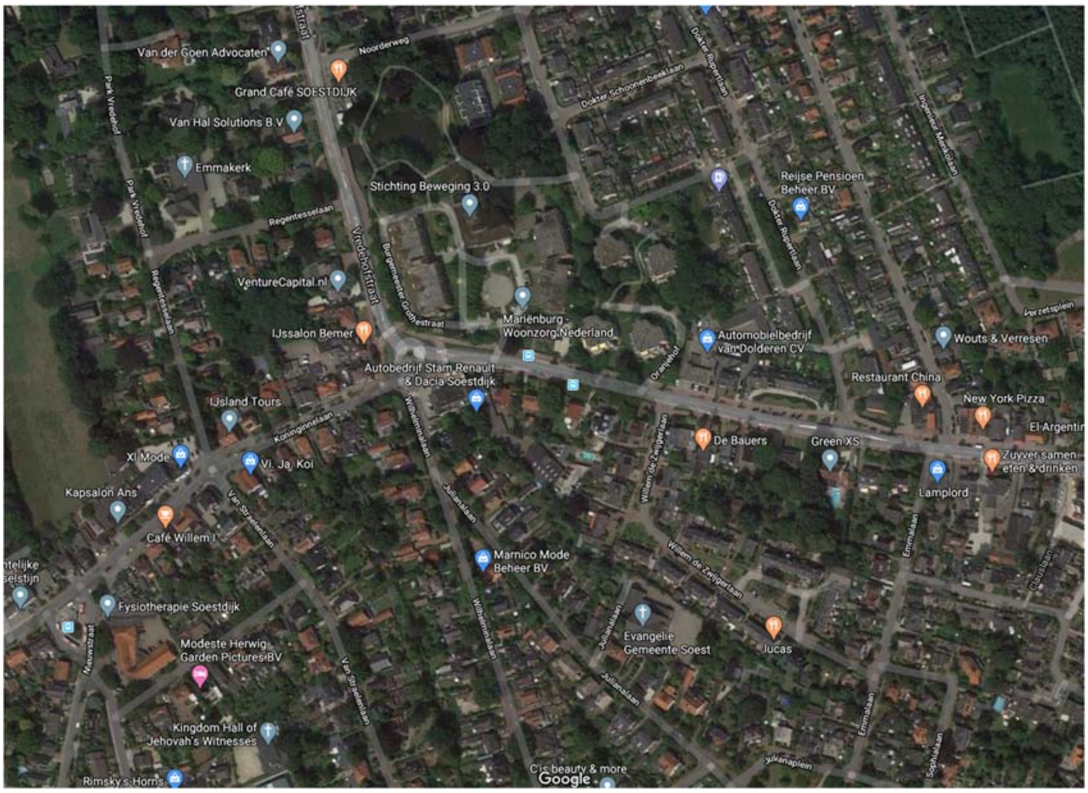


Figure 67. Satellite view of location of Mariënheuvel in Soest, The Netherlands

The location is in the middle of the urban tissue of the village of Soest (46.000 inhabitants), near the village centre. There is public transport on walking distance and a shopping centre with supermarket nearby.

4.7.3 Weather conditions

The Dutch national energy simulation tools for new and existing building use a specific climate file which is documented in NEN5060. This climate file has warmer summers and milder winters than previous versions, in anticipation on climate changes.

The chosen weather file in PHPP is De Bilt, the location of the KNMI, the National Meteorological Institute which is on less than 15 km distance from the project Marienheuvel in Soest.

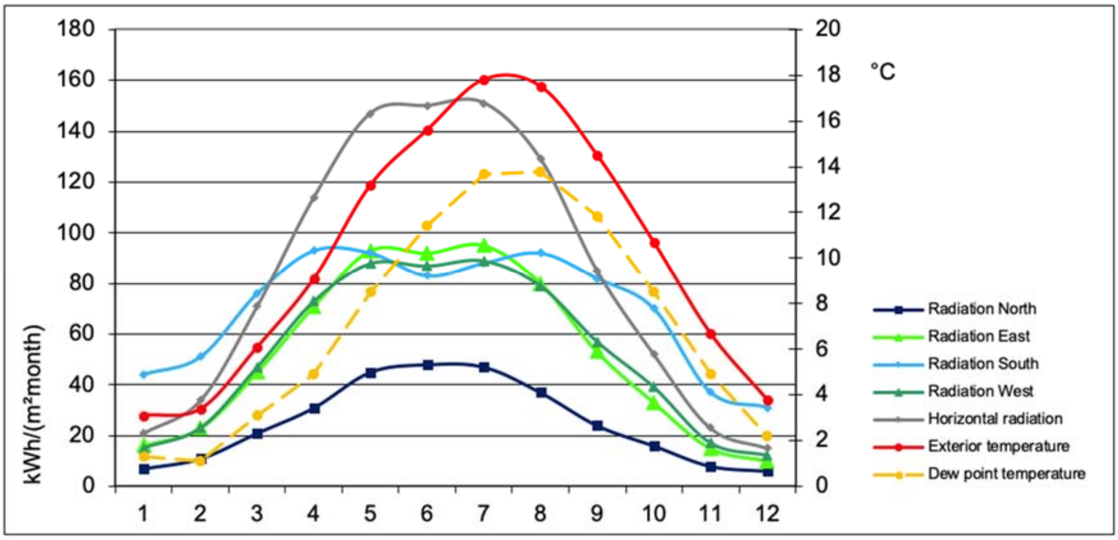


Figure 68. Graphical representation of climate conditions weather station De Bilt, as defined in PHPP9.

4.7.4 Building Model

Here follows the description of the reference model, which refers to the actual state of the building. The demo part involves 15 apartments.

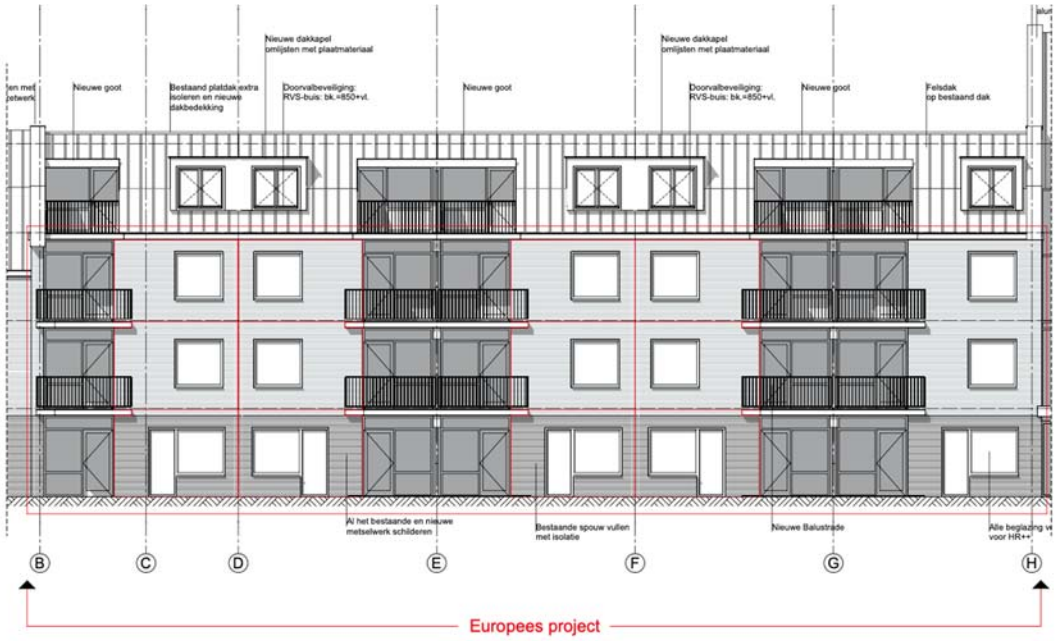


Figure 69. North East elevation of the 4RinEU demo façade renovation in Mariënheuvel, Soest

- Zoning

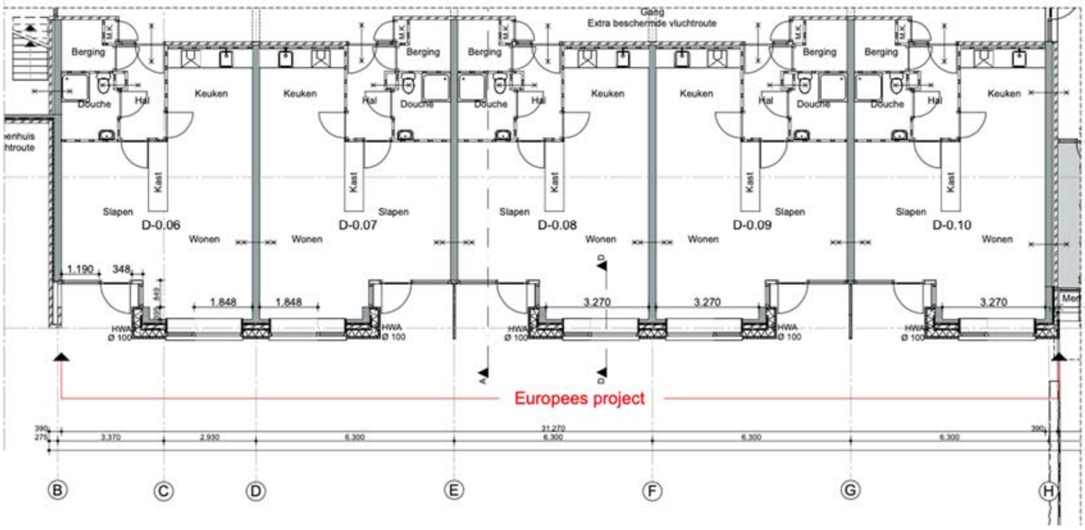


Figure 70. North East floor plan of the 4RinEU demo façade renovation in Mariënheuvel, Soest

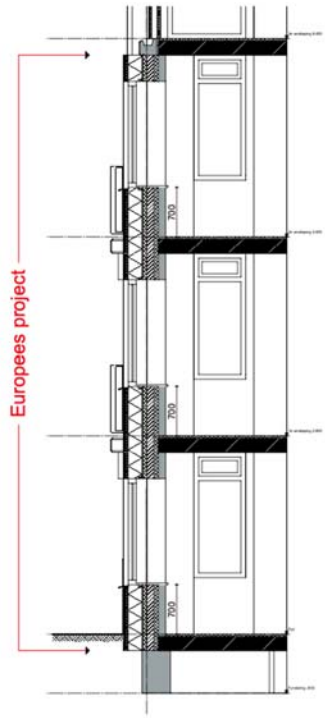


Figure 71. Schematic cross section of 4RinEU demo façade renovation in front of the existing cavity wall construction

The Local Design Team has modelled the project by defining a virtual average apartment with 51 m^2 of area, which has an average size roof, average size ground floor, average size end facades and its real front elevations.

Brief description of the main envelope features of the reference room used for setting the model is presented here below:

Table 63. Area definition of an average 4RinEu demonstration apartment. Each apartment has a virtual percentage of the exterior envelope in this simulation. The façade is defined in three parts

Area input																
Area no.	Building assembly description	To group No.	Assigned to group	Quan-tity	x (	a [m]	x	b [m]	+	User deter-mined [m²]	-	User sub-traction [m²]	-	Subtraction window areas [m²]	) =	Area [m²]
	Projected building footprint	0	Projected building footprint	1	x (		x		+		-		)		=	0,0
	Treated floor area	1	Treated floor area	1	x (		x		+	51,00	-		)		=	51,0
	Exterior door	7	Exterior door		x (		x		+		-		) -		=	
1	Living room facade	8	External wall - Ambient	1	x (	3,75	x	2,80	+		-		) -	2,3	=	8,3
2	Balcony facade	8	External wall - Ambient	1	x (	1,50	x	2,80	+		-		) -	1,9	=	2,3
3	Bedroom facade	8	External wall - Ambient	1	x (	2,55	x	2,80	+		-		) -	5,7	=	1,4
4	External facade	8	External wall - Ambient	0,2	x (	7,00	x	2,80	+		-		) -	0,0	=	3,9
5	Roof	10	Roof/Ceiling - Ambient	0,25	x (		x		+	60,00	-		) -	0,0	=	15,0
6	Ground floor	11	Floor slab / Basement ceiling	0,25	x (		x		+	60,00	-		) -	0,0	=	15,0

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

Living room façade

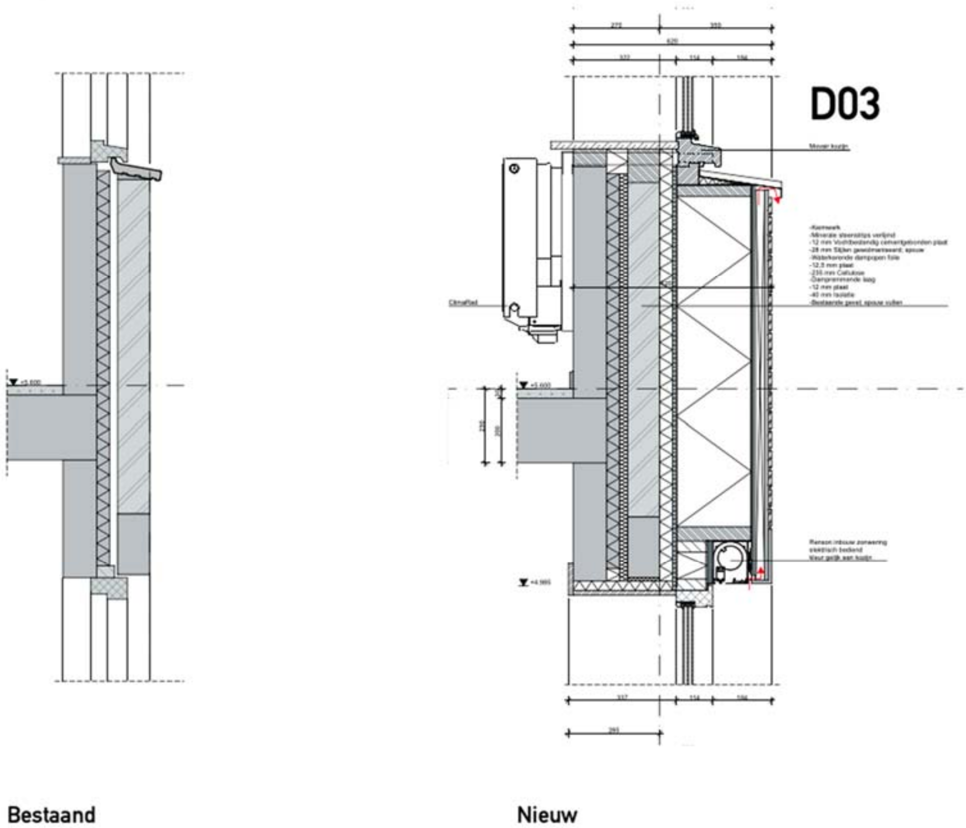


Figure 72. Cross section existing and 4RinEU demo façade in front of the existing cavity wall

Balcony façade

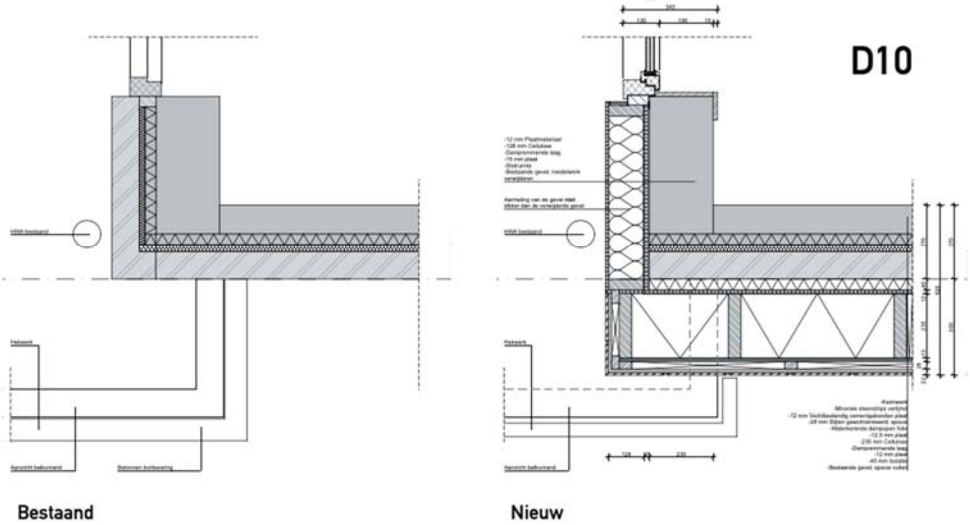


Figure 73. Horizontal cross section of the new prefabricated façade in front of the cavity wall and around the balcony. Due to the position of the rainwater sewage, the thickness of the prefab façade has been adjusted at the side of the balcony

Bedroom façade

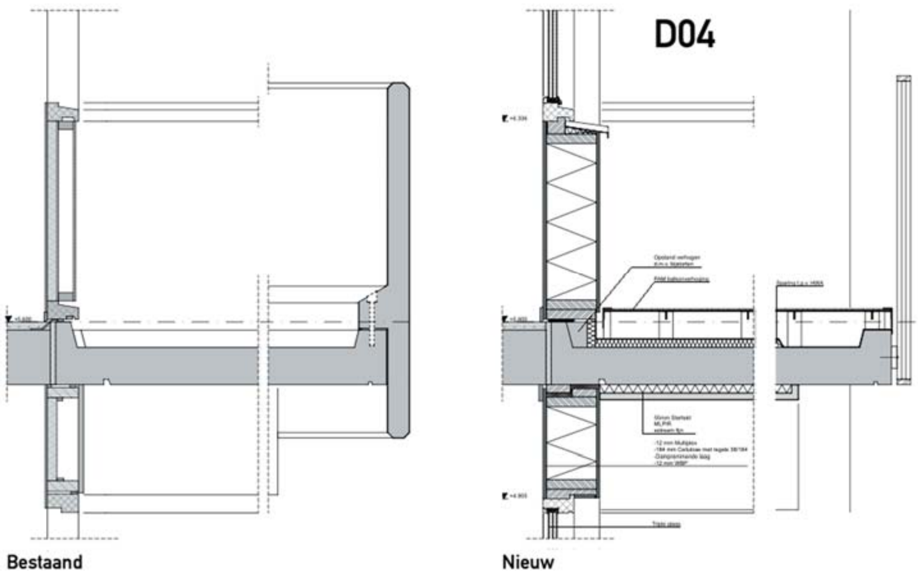


Figure 74. Cross section of the existing window frame façade between the bedroom and the balcony. The opaque insulation is much better than normally required. Also, the thermal bridge impact of the balcony has been reduced by adding insulation on top and under the balcony slap. A new balcony floor eases the step between the bedroom and the balcony

- Building envelope

Specifications before

Table 64. U value calculation of the current cavity wall construction in Mariënheuvel, Soest

Assembly no.	Building assembly description	Interior insulation?
01ud	Facade	

Heat transmission resistance [m²K/W]

Orientation of building element	2-Wall	interior R_{si}	0,13
Adjacent to	1-Outdoor air	exterior R_{se}	0,04

Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	2,000					100
cavity wall	0,167					60
brickwork	1,000					100
				0,679		

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			26,0

U-value supplement: W/(m²K)

U-value: 1,472 W/(m²K)

Table 65. Thermal properties of the current glazed surfaces in Mariënheuvel, Soest

Window ID	Surfaces	U_g [W/m²K]	U_f [W/m²K]	g-value
EXT_WD	Exterior window	2.9	2.5	0.7

Specification standard

Table 66. U value calculation of the standard cavity wall insulated construction in Mariënheuvel, Soest

04ud	External wall	

Heat transmission resistance [m²K/W]

Orientation of building element	2-Wall	interior R_{si}	0,13
Adjacent to	1-Outdoor air	exterior R_{se}	0,04

Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	2,000					100
cavity wall insulation	0,035					60
brickwork	1,000					100
				N.A.		
				2,034		

Percentage of sec. 1	Percentage of sec. 2	Percentage of sec. 3	Total
100%			26,0

U-value supplement: W/(m²K)

U-value: 0,492 W/(m²K)

Table 67. Thermal properties of the glazed surfaces after standard renovation in Mariënheuvel, Soest

Window ID	Surfaces	U_g [W/m²K]	U_f [W/m²K]	g-value
EXT_WD	Exterior window	1.3	2.5	0.6

Specifications 4RinEU demo

Table 68. U value calculation of the 4RinEU demo façade in front of the living room in Mariënheuvel, Soest

01ud	Facade					
		Heat transmission resistance [m²K/W]				
Orientation of building element:	2-Wall	interior R_{si}:	0,13			
Adjacent to:	1-Outdoor air	exterior R_{se}:	0,04			

Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	2,000					100
cavity wall insulation	0,035					60
brickwork	1,000					100
cavity wall insulation	0,035					40
OSB	0,130					15
cellulose	0,038					230
OSB	0,130					15
insulation	0,320			9,586		40
	Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
	100%					60,0
U-value supplement:		W/(m²K)		U-value:	0,104	W/(m²K)

Table 69. U value calculation of the 4RinEU demo façade facing the balcony in Mariënheuvel, Soest

02ud	Insprong					
		Heat transmission resistance [m²K/W]				
Orientation of building element:	2-Wall	interior R_{si}:	0,13			
Adjacent to:	1-Outdoor air	exterior R_{se}:	0,04			

Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]	Thickness [mm]
Concrete	2,000					200
cavity	0,035					40
OSB	0,130					15
cellulose	0,038					130
OSB	0,130					15
				5,065		
	Percentage of sec. 1		Percentage of sec. 2		Percentage of sec. 3	Total
	100%					40,0
U-value supplement:		W/(m²K)		U-value:	0,197	W/(m²K)

Table 70. U value calculation of the 4RinEU demo façade between the bedroom and balcony in Mariënheuvel, Soest

03ud	Timber frame | Window frame						
			Heat transmission resistance [m²K/W]				
Orientation of building element	2-Wall	interior R_{si}:	0,13				
Adjacent to	1-Outdoor air	exterior R_{se}:	0,04				
Area section 1	λ [W/(mK)]	Area section 2 (optional)	λ [W/(mK)]	Area section 3 (optional)	λ [W/(mK)]		Thickness [mm]
OSB	0,130						15
cellulose	0,038						200
OSB	0,130						15
				5,664			
Percentage of sec. 1	100%	Percentage of sec. 2		Percentage of sec. 3		Total	23,0
U-value supplement		W/(m²K)		U-value:	0,177	W/(m²K)	

Table 71. Thermal properties of the glazed surfaces after the 4RinEU demo renovation in Mariënheuvel, Soest

Window ID	Surfaces	U_g [W/m²K]	U_f [W/m²K]	g-value
EXT_WD	Exterior window	0.6	1.3	0.54

- Heating and cooling setpoints

Default assumptions of PHPP9 and UNIEC have been used in the simulations.

- Infiltration and ventilation

Infiltration and ventilation are simulated as follows

Standard renovation

Table 72. Infiltration parameters of standard renovation Mariënheuvel, Soest

Marienheuvel - standard renovation / Climate: De Bilt / TFA: 51 m² / Heating: 67 kWh/(m²a) / Freq. overheating: 4 % / PER: 191,2 kWh/(m²a)

Treated floor area A_{TFA}	m²	51		('Areas' worksheet)
Room height h	m	2,50	2,50	
Volume of ventilated space (A_{TFA}*h) = V_V	m³	128		(Worksheet 'Annual heating')

Ventilation type

Please select: 2-Extract air unit

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for wind protection class	Several side exposed	One side exposed
No protection	0,10	0,03
Moderate protection	0,07	0,02
High protection	0,04	0,01
Coefficient f	15	20

			For annual demand:	For heating load:		
Wind protection coefficient, e			0,07	0,18		
Wind protection coefficient, f			15	15	Net air volume for press. test	V_{n50}
Air change rate at press. test	n_{50}	1/h	5,00	5,00	130	m³

			For annual demand:	For heating load:
Excess extract air		1/h	0,63	0,63
Infiltration air change rate	$n_{V,Rest}$	1/h	0,080	0,375

Table 73. Ventilation parameters of standard renovation Mariënheuvel, Soest

Dimensioning of ventilation system with only one ventilation unit

Occupancy	m²/P	35				
Number of occupants	P	1,5				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	44				
Extract air rooms		Kitchen	Bathroom	Bathroom (shower only)	WC	
Quantity		2	1			
Extract air requirement per room	m³/h	60	40	20	20	
Total extract air requirement	m³/h	160				

Design air flow rate (maximum): m³/h 160 — Recommended: 160 m³/h

Average air change rate calculation

Type of operation	Daily operation times h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
maximum		1,00	160	1,25
Standard	**2,0**	**0,77**	123	0,97
Basic ventilation	**13,0**	**0,54**	86	0,68
Minimum	**9,0**	**0,40**	64	0,50
	Average value	0,51	Average air flow rate (m³/h): **81**	Average air change rate (1/h): **0,63**

Demo renovation

Table 74. Infiltration parameters of 4RinEU demo renovation Mariënheuvel, Soest

Marienheuvel / Climate: De Bilt / TFA: 51 m² / Heating: 19,6 kWh/(m²a) / Freq. overheating: 1 % / PER: 109,3 kWh/(m²a)

Treated floor area A_{TFA}	m²	51		('Areas' worksheet)
Room height h	m	2,50	2,50	
Volume of ventilated space (A_{TFA}*h) = V_V	m³	128		(Worksheet 'Annual heating')

Ventilation type

Please select: 1-Balanced PH ventilation with HR

Infiltration air change rate

Wind protection coefficients e and f		
Coefficient e for wind protection class	Several side exposed	One side exposed
No protection	0,10	0,03
Moderate protection	0,07	0,02
High protection	0,04	0,01
Coefficient f	15	20

			For annual demand:	For heating load:		
Wind protection coefficient, e			0,07	0,18		
Wind protection coefficient, f			15	15	Net air volume for press. test	V_{n50}
Air change rate at press. test	n_{50}	1/h	1,00	1,00	130	m³

			For annual demand:	For heating load:
Excess extract air		1/h	0,00	0,00
Infiltration air change rate	$n_{V,Rest}$	1/h	0,071	0,179

Table 75. Ventilation parameters of 4RinEU demo renovation Mariënheuvel, Soest

Dimensioning of ventilation system with only one ventilation unit

Occupancy	m²/P	35				
Number of occupants	P	1,5				
Supply air per person	m³/(P*h)	30				
Supply air requirement	m³/h	44				
Extract air rooms		Kitchen	Bathroom	Bathroom (shower only)	WC	
Quantity		1	1			
Extract air requirement per room	m³/h	60	40	20	20	
Total extract air requirement	m³/h	100				

Design air flow rate (maximum) m³/h 100 Recommended: 100 m³/h

Average air change rate calculation

Type of operation	Daily operation times h/d	Factors referenced to maximum	Air flow rate m³/h	Air change rate 1/h
maximum		1,00	100	0,78
Standard	2,0	0,77	77	0,60
Basic ventilation	13,0	0,54	54	0,42
Minimum	9,0	0,40	40	0,31
Average value		0,51	Average air flow rate (m³/h): 51	Average air change rate (1/h): 0,40

- Occupancy

Occupancy has followed the PHPP assumption, resulting in 2.1 W/m2 as internal gains in general.

- Lighting and appliances

Lighting and appliances are included in the total 2.1 W/m2.

- HVAC system

The heating and hot water system in the project have not been changed, due to a previous modernization. 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.

Simulations have focused on the ventilation of the apartments. The comparison has been made between mechanical extract ventilation, balanced ventilation with heat recovery and decentralized room ventilation with heat recovery.
The decentral room ventilation system has been modelled under the assumption that there is partial unbalance in the system, due to the combination of balanced ventilation and extract ventilation. A modest 50% heat recovery has been assumed in the PHPP calculation.
In the UNIEC simulation results of declared performances have been used.

4.7.5 Model calibration

The models used by the LDWG have not been calibrated. However, it is commonly understood that real energy performance in existing buildings is lower than simulated on the basis of simulations based on constant temperatures at comfort levels. Therefore, it is important to compare monitored figures before with monitored figures after renovation.

4.7.6 Baseline model outcomes

Table 76. Comparison of U values, ventilation system and net heat demand for the existing situation, minimum requirements, standard renovation and demo renovation

Renovation Marienheuvel				
	EXISTING	REQUIRED	STANDARD	4RinEU
	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	extract	extract	extract	decentralised
Net heat demand	kWh/m2		kWh/m2	kWh/m2
PHPP	125		67	20
UNIEC	132		70	19
Monitored	108			

Pre-retrofit Condition

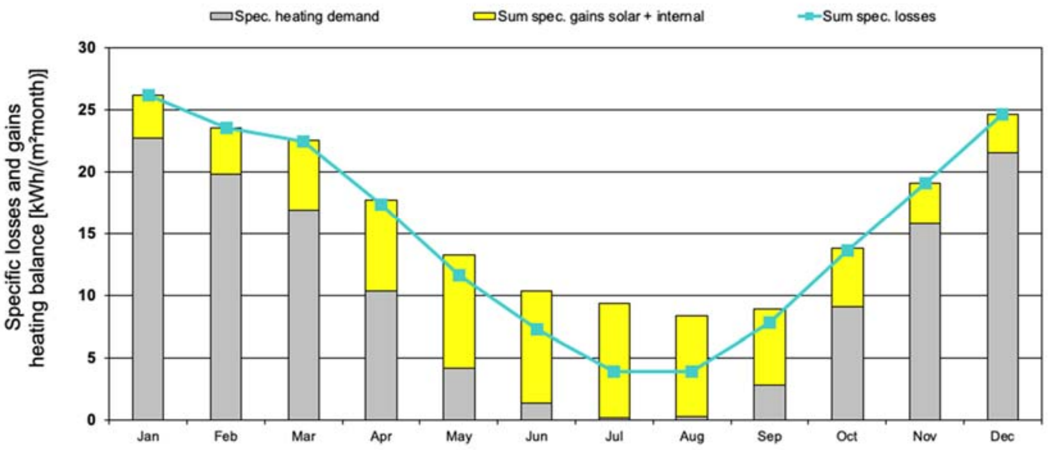


Figure 75. PHPP9 monthly energy demand existing situation Mariënheuvel, Soest

Standard Renovation

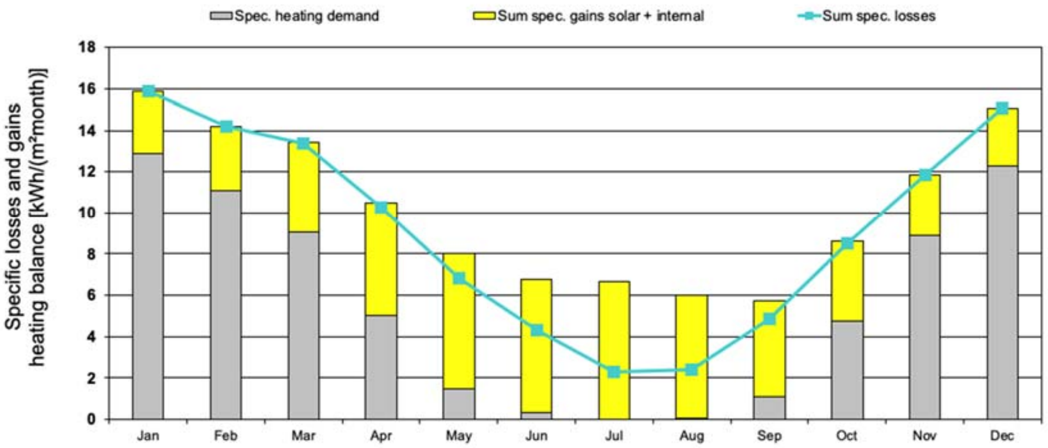


Figure 76. PHPP9 monthly energy demand standard renovation Mariënheuvel, Soest

4RinEU Renovation

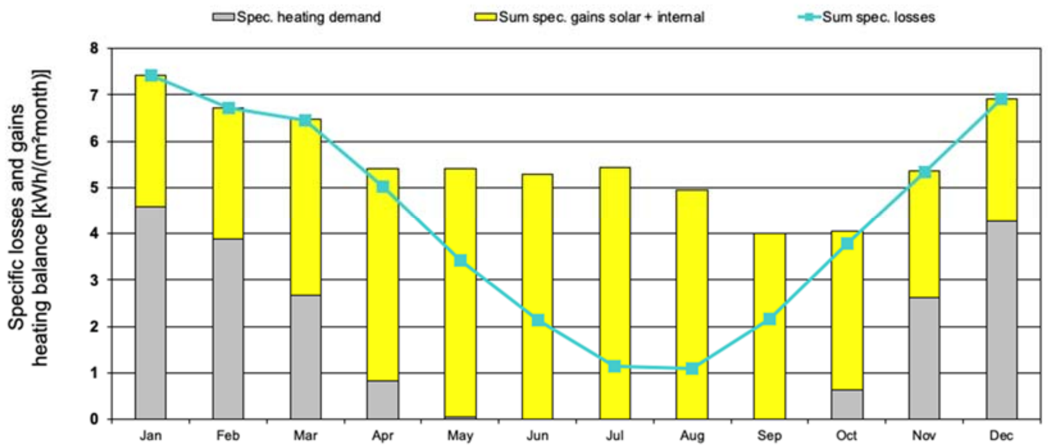


Figure 77. PHPP9 monthly energy demand 4RinEU demo renovation Mariënheuvel, Soest

4.8 Renovation concepts: evaluation of KPIs

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

4.8.1 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 77. 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 78. 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			

4.8.2 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 has 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.

- Since in the standard renovation the tenants are still able to manage manually the ventilation, provided by ventilation grilles in the windows, there is still the risk for high draught and that heating system may not be able to provide enough heat to overcome them

- 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.

4.8.3 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 79. 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.

4.8.4 Area 4: Renovation costs

- Cost connected to prefabrication

Table 80. cost analysis of prefabricated façade per m2

	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		

The comparison has been made against the total façade area. Windows and frames have also been analysed against its own area. Most striking figure 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 in 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 tenant to stay at home. Again, it is worthy to mention the same issue arisen for time and cost comparison between different approaches. The comparison cannot be done between standard and prefab multifunctional façade if they provide different retrofit effects. The costs reported in that table below are not considering for instance the added value in building site duration and the longer durability of the prefabricated façade. The thermal insulation part, made by ETICS in a standard insulation, is less durable respect to the more compact prefabricated façade. In an exhaustive comparison, this should be taken into account.
In the last line of the table, a simple payback time has been calculated considering both the difference between standard and 4RinEU retrofit approaches with the pre-retrofit condition, and the difference between the 4RinEU and standard approaches.

To access the payback time, assumptions on expected expanses and savings have been used.

Table 81. 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

4.8.5 Area 5: Renovation process

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 sequential steps, which cannot be done within one day per apartment.

Because of the choice for a wet façade cladding system (plaster and fake brickwork) the time needed for this method has been spent in the prefabrication process and not on site. Shifting time from the site to the factory reduces the impact of a renovation for tenants.

4.8.6 Final decision of the renovation package

The final package has been decided in close cooperation between the locally involved partners and the 4RinEU partners.

4.9 Tender procedure

The Dutch legislation and the policy of Woonzorg have been followed. According to the Dutch legislation not-for-profit housing companies are not obliged to use a tender procedure for housing developments. The adopted policy considered that, although tendering is preferred, it is not obliged. For the external consultant and the prefab façade supplier any tender has been done. The main contractor has been selected by a tender procedure.

- External consultant for design

In the Marienheuvel project the architect agNOVA was selected for several reasons. Woonzorg wanted an architect who was well known with sustainability, and agNOVA was one of the partners in a consortium known as "De verduurzamers" (english: The Sustainers). Other members are Trecodome, Heijmans and a company responsible for maintenance.
Other reason was that agNOVA is well known with buildings in the care sector, Woonzorg develops and manages residences, care homes and nursing homes for frail elderly people. Third reason was that agNOVA showed some attractive examples of realised works, where they showed to be capable to design with 'value for money', which means they are very good at design for affordable housing which still looks nice and during the process they are capable of cutting costs if demanded so.

- Supply of the façade elements

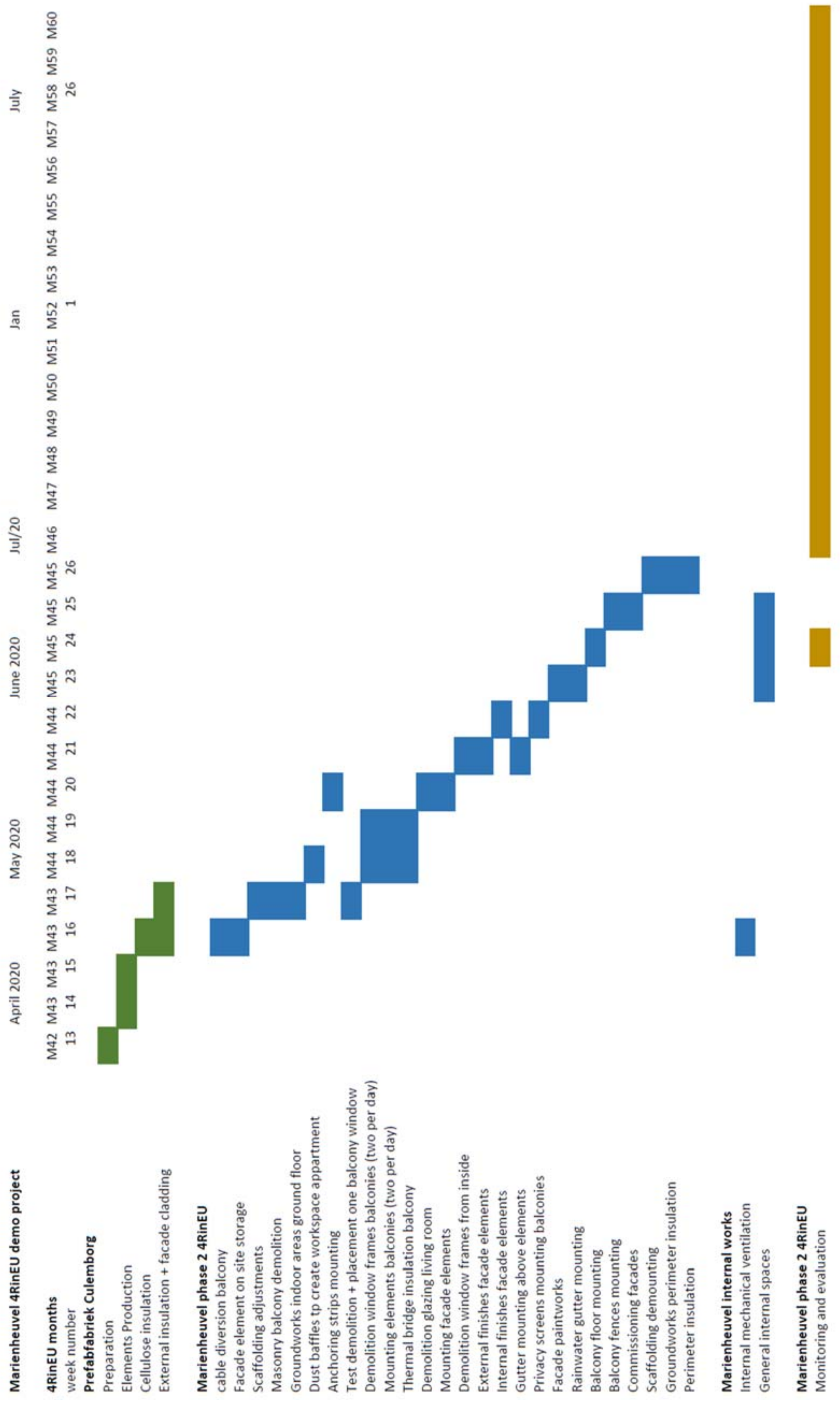
In the 4RinEU project the idea was initially that Gumpp & Maier (G&M), German project partners, could supply the prefabricated elements for the demo case façade. However, this gave complications, such as a budget shift.
In cooperation with the 4RinEU programme leader it has been decided to select a Dutch manufacturer to supply the prefabricated façade elements. The role of G&M was to do the consulting, since this company was already very experienced with Timber elements of high thermal insulation grade and with appliance of sustainable and ecological materials. One of the advantages of this solution was that in this way their knowledge could be disseminated.
Trecodome, partner in the 4RinEU project, proposed Timmerfabriek Culemborg as timber manufacturer. In previous projects with high standards on sustainability, they had already proven to be a solid and reliable partner. They are capable to provide us with façade elements with the specifications and quality demands formulated by G&M. After meetings with both the programme leader as well as with G&M it has been decided to invite them into the project.

- Main contractor

Heilijgers is the main contractor for the total project of Marienburg, Marienheuvel and Marienhorst. Heilijgershas been selected in a tender among four main contractors. The project has been elaborated in detail together with Heilijgers.

4.10 Gantt of the renovation activities

A preliminary Gantt of the activity is reported here below.


Marienheuvel 4RinEU demo project
April 2020
May 2020
June 2020
Jul/20
Jan
July
4RinEU months
M42 M43 M43 M43 M43 M43 M44 M44 M44 M44 M44 M45 M45 M45 M45 M46 M47 M48 M49 M50 M51 M52 M53 M54 M55 M56 M57 M58 M59 M60
week number
13 14 15 16 17 18 19 20 21 22 23 24 25 26 1 26
Prefabfabriek Culemborg
Preparation
Elements Production
Cellulose insulation
External insulation + facade cladding
Marienheuvel phase 2 4RinEU
cable diversion balcony
Facade element on site storage
Scaffolding adjustments
Masonry balcony demolition
Groundworks indoor areas ground floor
Dust baffles tp create workspace appartment
Anchoring strips mounting
Test demolition + placement one balcony window
Demolition window frames balconies (two per day)
Mounting elements balconies (two per day)
Thermal bridge insulation balcony
Demolition glazing living room
Mounting facade elements
Demolition window frames from inside
External finishes facade elements
Internal finishes facade elements
Gutter mounting above elements
Privacy screens mounting balconies
Facade paintworks
Rainwater gutter mounting
Balcony floor mounting
Balcony fences mounting
Commissioning facades
Scaffolding demounting
Groundworks perimeter insulation
Perimeter insulation
Marienheuvel internal works
Internal mechanical ventilation
General internal spaces
Marienheuvel phase 2 4RinEU
Monitoring and evaluation

5 Italian Demo Case: Pinerolo

A new demo case has been introduced within the project during around month 42. This demo was necessary in order to test the plug & play technology developed within 4RinEU. Despite being traditionally called Plug & Play Energy Hub within the 4RinEU project, trademarks for the technology have been registered using different commercial names. A R&D contract between Eurac Research and Thermics S.r.l., the industrial partner manufacturing the products, allowed to protect the commercialization of the technology under the names NRGate Box™ and NRGate Hydronics™. In the following, the name NRGate Box™ will be used as synonym of Plug & Play Energy Hub.
The building owner is TECNOZENITH srl, an Italian company based in Saluzzo, dealing with several aspects of the building sector such as energy efficiency refurbishment and design, managing and maintenance of HVAC systems.
The demo building, along with the 4RinEU retrofit measures concerning the installation of the NRGate boxes, has undergone a deep renovation process thanks to another H2020 project (BuildHEAT).

5.1 Building status before renovation

5.1.1 BUILDING DESCRIPTION

The building is a multifamily house with 13 dwellings. Apartments have from one to three rooms, with different sizes between 35 m² and of 60 m². The building, of only two floors, develops in length, with 6 apartments on the ground floor and 7 apartments on the first floor.
Condominium is located in Via Tabona 5, in the city of Pinerolo (Italy), close to the historic centre, next to a creek. It was born as a residence for holidays, but now it hosts different type of tenants. The accesses for the apartments on the ground floors is located directly on the façade, while dwellings on the first floor face a corridor accessible via a common internal staircase.
Building has had a sort of first renovation in the last years, with the replacement of the external doors and windows of the dwellings and the substitution of the gas boilers for heating and DHW purpose with condensation ones.

Figure 78. Pinerolo Demo Case – External views 1

Figure 79. Pinerolo Demo Case – External views 2

An attic is present, under the two-pitched roof, completely empty before the renovation project, with a thin fiberglass insulation layer resting on the ground.

Figure 80. Pinerolo Demo Case – Space under roof

Figure 81. Pinerolo Demo Case - Internal view dwellings

In the renovation done in the past years, there was an installation of a photovoltaic system of 8 kW of peak power.
The building has a single POD (point of delivery) for electricity: energy meters for each dwelling and common services are present, to allocate consumption correctly.

Figure 82. Pinerolo Demo Case – Existing PV system on the roof

5.1.2 BUILDING CONSTRUCTION

- Reinforced concrete structure with non-bearing brick walls
- External walls consisting with no insulation: an air gap between two layers of bricks is present
- Gable roof with wooden slats and joints and concrete tiles
- Double-pane glass windows with thermal break (dwellings), single pane windows, with aluminium frame on the staircase and common corridor.

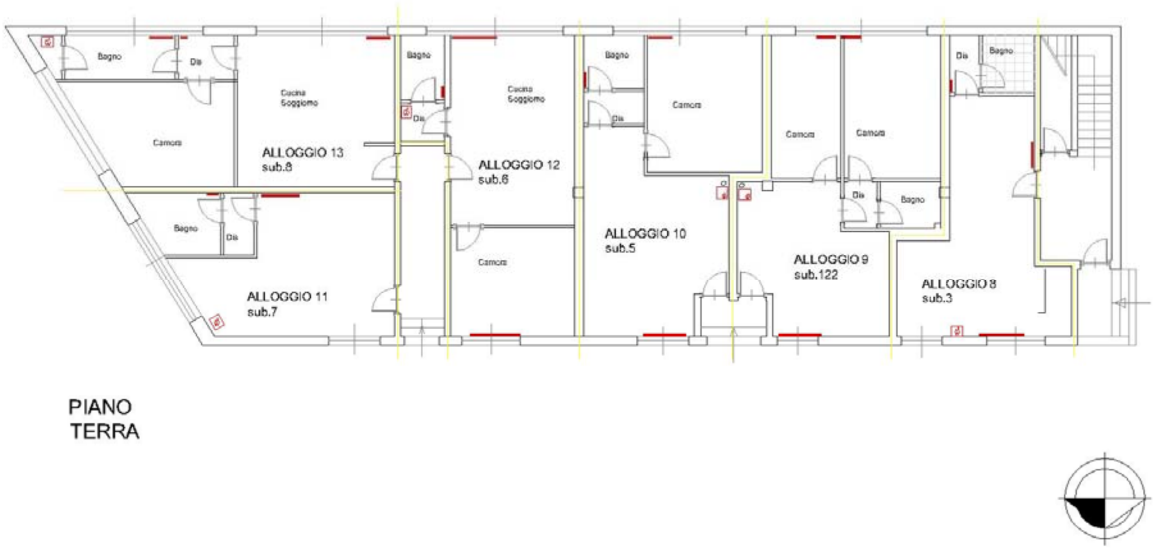


Figure 83. Ground floor planimetry

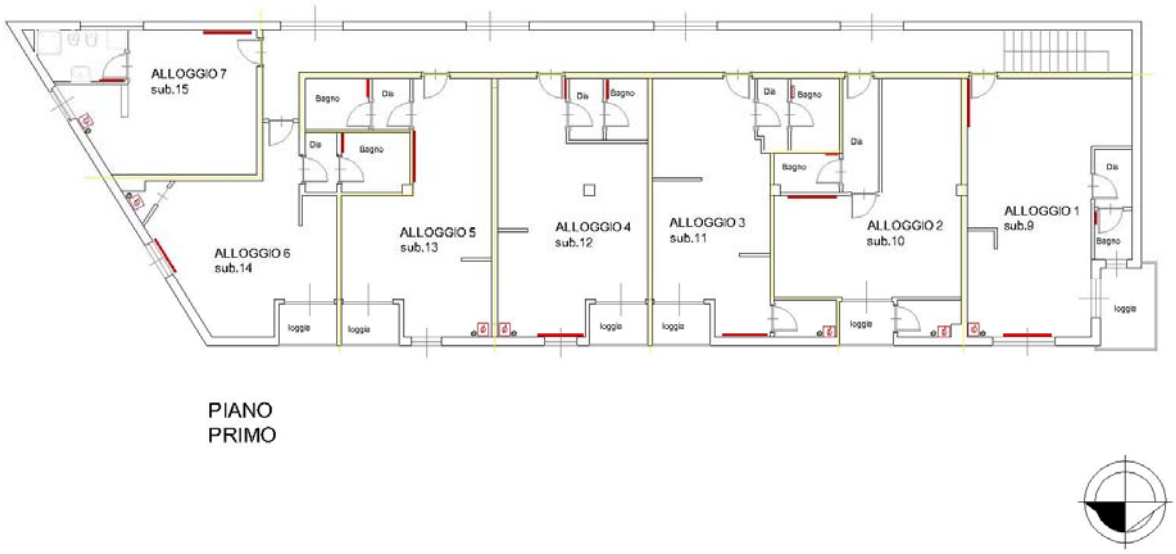


Figure 84. First floor planimetry

5.1.3 BUILDING SERVICES

- Independent heating system for every dwelling with a gas condensing boiler
- Heating terminals represented by water radiators placed mostly under windows
- DHW production by using the same gas boilers located in each apartment
- No air conditioning system is present
- No ventilation system is present
- Photovoltaic system installed on the roof of 8 kW power peak

5.2 Building Renovation performed under another H2020 project

This demo case has recently undergone a renovation process thanks to a European H2020 project, namely BuildHEAT (www.buildheat.eu/). 4RinEU has taken the advantages of the previous renovation and contributed to enhance the performance of the building, testing the NRGate Box™ technology. The planned interventions for Pinerolo case study building in BuildHEAT project are summarized here below:

- Renovation of the building envelope
- Installation of a new ventilation system for every apartment
- Installation of a new heating and cooling system, with the heating system working in parallel with the existent one during winter

- Installation of a new system for domestic hot water production in series with the gas boiler
- Renovation of the insulation on the horizontal parts

5.2.1 Renovation of the building envelope

The renovation of the building envelope includes several types of interventions:

- Installation of a ventilated façade on all the external vertical walls, with insulation composed by glass wool layers of different thickness. Inside the ventilated façade, pipes and ducts for the new HVAC and DHW systems pass;

Figure 85. Insulation layer behind ventilated facade

Figure 86. Ventilated facade mounting

- Laying of EPS insulation layer in the gap under the ground floor;
- Laying of a fiberglass insulation on the attic floor, replacing the existent one

5.2.2 Building services

Renovation of the systems includes modification on the existent heating and DHW production systems and the installation of a new ventilation and cooling system.

In particular, a new ventilation system is created, in order to keep a good air quality inside the apartments and to avoid moisture excess. This system foresees ducts for fresh air supply placed in the main room of each apartments, while the extraction of the exhaust air occurs from the bathroom. Round ducts for this scope are applied on the existent façade and they are covered by the two layers of the ventilated façade insulation, remaining hidden from view, for aesthetical reasons.
In winter season, the existent heating system, with gas boiler and water radiators as terminals remains in operation, but a new fan coil for every room is installed on ceilings, to provide heating generated with a new heat pump that will be placed, later, on the roof, to use energy production from photovoltaic for heating and cooling purpose.
The new machine that will be installed will be able to produce also cooling water during summer, in order to include also cooling to the systems of the building.
Sanitary water from the aqueduct to be warm up generating domestic hot water will pass in a future heat exchanger on the roof, before entering in the boiler: the new machine can provide also the heat to heat up sanitary water. Boiler will only intervene during summer and in severe conditions during winter.
All the pipes and electrical wires connecting boilers and fan coils to the attic, passes inside the ventilated façade.

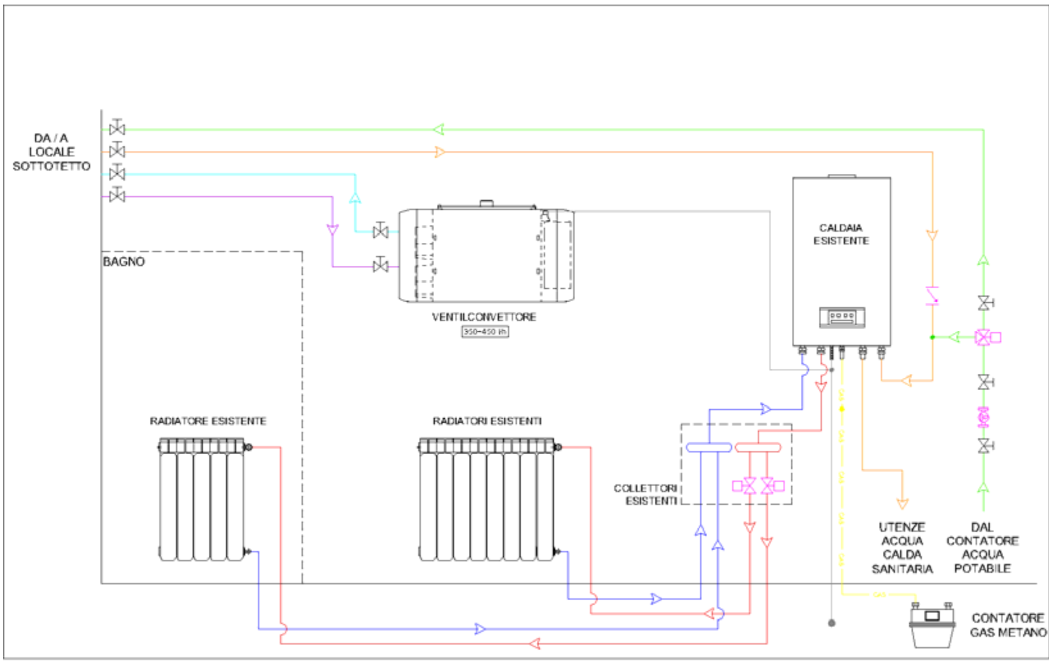


Figure 87. Improved HVAC/DHW system scheme

5.3 Pre-retrofit building consumption evaluation

Following the prescriptions given by the UNI CEI EN 16247 and the UNI CEI 11428, a baseline for energy consumption of the building has been calculated. The estimation, accounting for 2815 degree-day during the year, considers 51.4 MWh/year (~113 kWh/m^2year) for total heating consumptions.
Winter DHW baseline consumption (beginning of October to end of April) is estimated as 9.6 MWh/year (~ 21 kWh/m^2*year) with 200 m^3/year of water used.

Summer DHW baseline consumption (beginning of May to end of September) is 4.8 MWh/year (~ 10 kWh/m^{2}*year and about 500 Nm^{3} of gas) using about 110 m^{3}/year in that period.
Finally, 5.7 MWh/year (600Nm3/year of natural gas) are due to cooking consumptions.

5.4 4RinEU retrofit intervention

The 4RinEU renovation concept tested in this demo is based on the idea of reducing fossil fuel consumptions, increasing the efficiency of the HVAC and DHW production and delivery.
The project foresees the installation of an invertible heat-pump connected to the existing condensing boilers, passing through the NRGate Box™ hydronic modules.
The heat pump will be placed over the rooftop, while the 13 hydronics modules (one for each dwelling) will be located under the roof, in a currently non-used space.
All the duct connections between the hubs and the components with the apartments will pass through the cavity in the ventilated façade.

5.4.1 Heat pump

The preliminary concept is to install the Duran (previously called Hydra-2) air-to-water inverter heat pump with 2 pipes, provided by Thermics, partner of 4RinEU project. This unit can come in the 2-pipes or 4-pipes version. The 4-pipe version allows to manage separately the domestic hot water circuit and the space heating and cooling circuit, allowing a very effective production of hot water during the warm season because the heat rejected by the heat pump thermodynamic cycle is used to heat up the water instead of being released in the environment. Like its sister, the 2-pipes version can be operated in inverse mode which allows the machine to work as a chiller instead of a heater. Currently it is foreseen in the demo case the 2-pipes version of the machine to be employed, as the gas boilers in the apartments will not be removed. The heat pump will be directly connected to a 500 liters thermal energy storage, like shown in Figure 90. The need of inserting a regulating valve to control the supply temperature (not shown in the figure) downstream the water storage is debatable: it would allow to fine-regulate the temperature in the fan-coils but it is not seen as strictly needed.

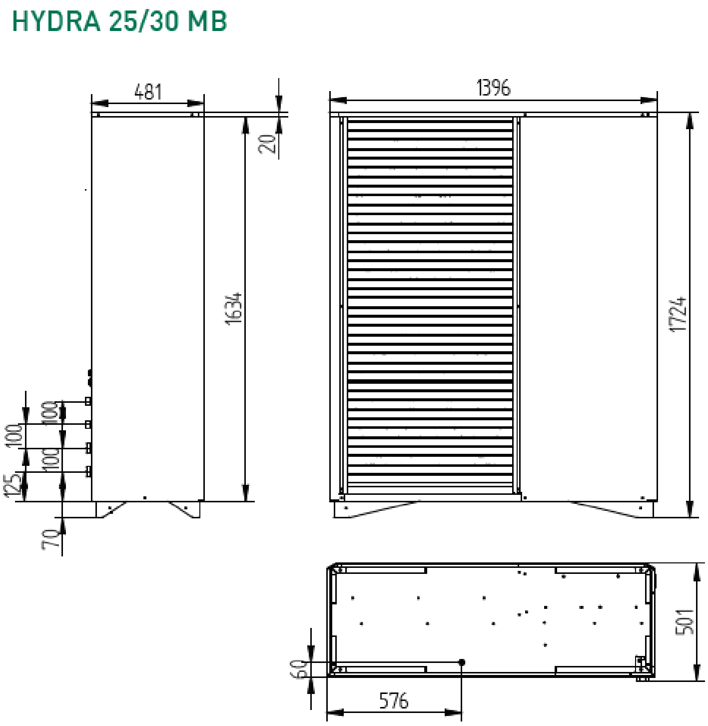


Figure 88. Heat pump dimensions

5.4.2 The DHW & SH NRGate Box™ module

The hydronic module deployed in the demo case is part of a family of products marketed under the name NRGate Box™ and NRGate Hydronics™. The specific NRGate Box™ module employed in the demo is the DHW & SH model. It is a hydraulic module controlled by an integrated digital controller providing the following functionalities:

- The unit supplies heat energy for space heating and for instantaneous domestic hot water preparation when connected to a hot water source;
- The unit can guarantee a high precision of the outlet temperature of the supplied DHW water;
- The units and digital controller of the unit is designed to minimize energy consumption, in particular, the module allows water to be distributed in the primary circuit at lower temperatures than usual (50 – 55 °C);
- Finally, the unit provides a certificated accounting of thermal energy consumed by the final user, discriminating between domestic hot water and space heating.

In order to provide the DHW and SH the module is equipped with a stainless-steel plate heat exchanger and connects to three circuits (drinkable water, heat supply primary, heat supply secondary). For this reason, this NRGate Box™ module is also called the 6-pipes module.

Although this module has been designed with only instantaneous DHW preparation and space heating in mind, the design proved flexible enough to be used in this demo case in a configuration where space cooling was also needed. In fact, as will be described below, this NRGate Box™ module will be used as a Heating and Cooling module with the ability, in the cold season, to completely cover or assist the production of DHW of the gas boiler, therefore reducing the boilers gas consumption through the year.
Here below, the main characteristics of the NRGate Box™ DHW & SH are reported:

Table 82. Main characteristics of the Hydronic Unit to be used

	PPEH DHW – H/C
Maximum pressure	6 bar
Working Temperature	2 – 95 °C
Maximum headloss at primary circuit at 1700 l/h	103,1 KPa
Maximum headloss at secondary circuit at 20 l/min	30 KPa
System connections	1" G
DHW connections	3/4" G
Maximum flow	3,0 m^3/h
Power Supply	230 V – 50Hz – 1 Ph
Maximum Power input	96 W
Dimensions	648,5 x 502 x 189 mm
Circulation pump	Electronically controlled
Plate exchanger	Stainless Steel with Copper brazing
Energy meter Minimum flow rate	0,015 m^3/h
Energy meter Maximum flow rate	3,0 m^3/h

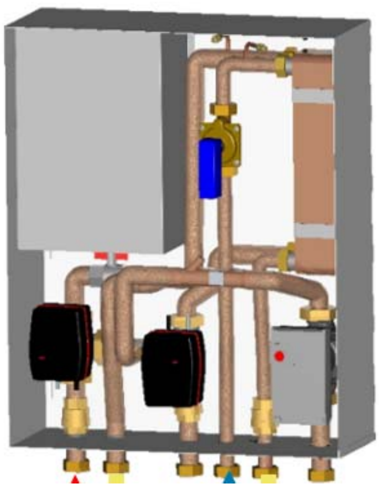


Figure 89. Energy Hub design

5.4.3 Preliminary connection scheme

The preliminary idea is to connect the reversible heat pump (placed above the rooftop) with a 0.5 m^3 water thermal energy storage (in a technical room below the roof); the NRGate Box™ DHW+SH hydronic modules (also placed in the technical

room below the roof) will be connected in parallel to this water tank and to the fan coils and radiators in bathrooms. Moreover, each NRGate module will be connected in series to the existing boilers in the apartments, which is kept as heating recovery system in case of low efficiencies of the heat pump. Thanks to these connections and a proper managing of the valves in the circuit, also the cooling operation should be guaranteed during summer period, since the heat pump will work in cooling mode and the 6 pipes NRGate module will directly provide cooled water to fan coils, while the heating boilers will be in charge of providing DHW.
In Figure 90 and Figure 91, a preliminary scheme for connection between the components is shown:

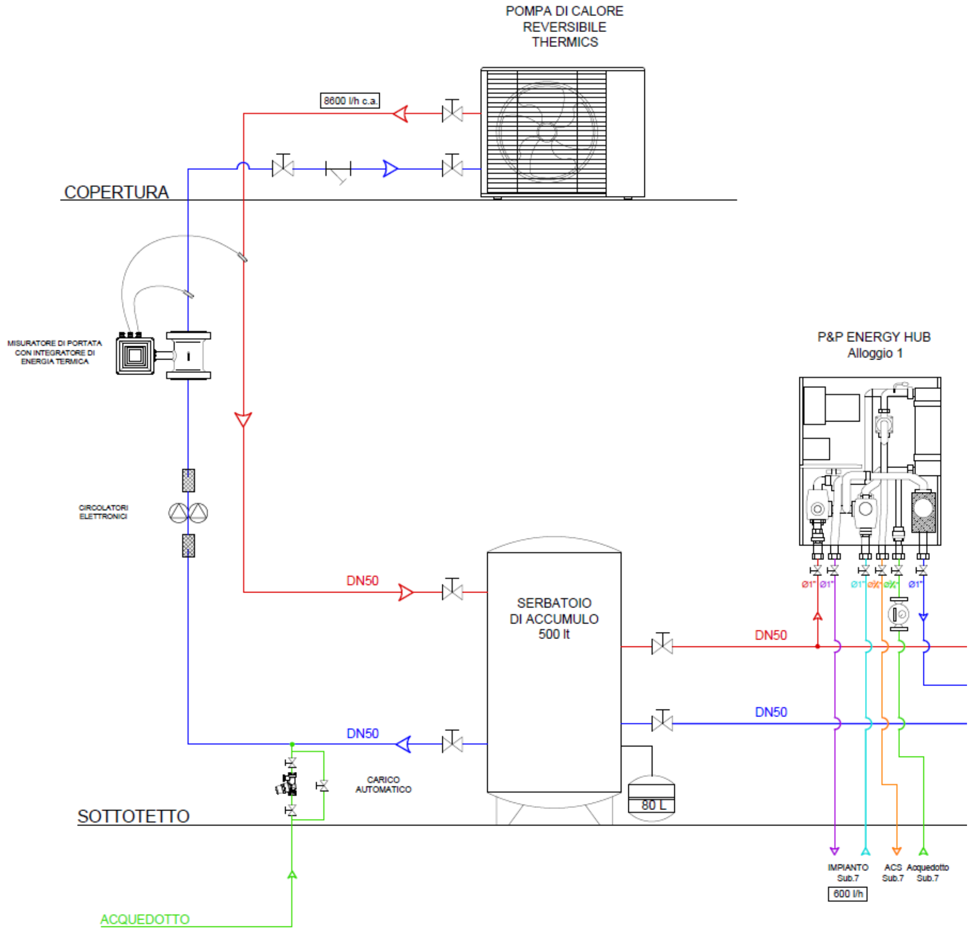


Figure 90. Preliminary circuit scheme - Heat pump and Energy Hub connections

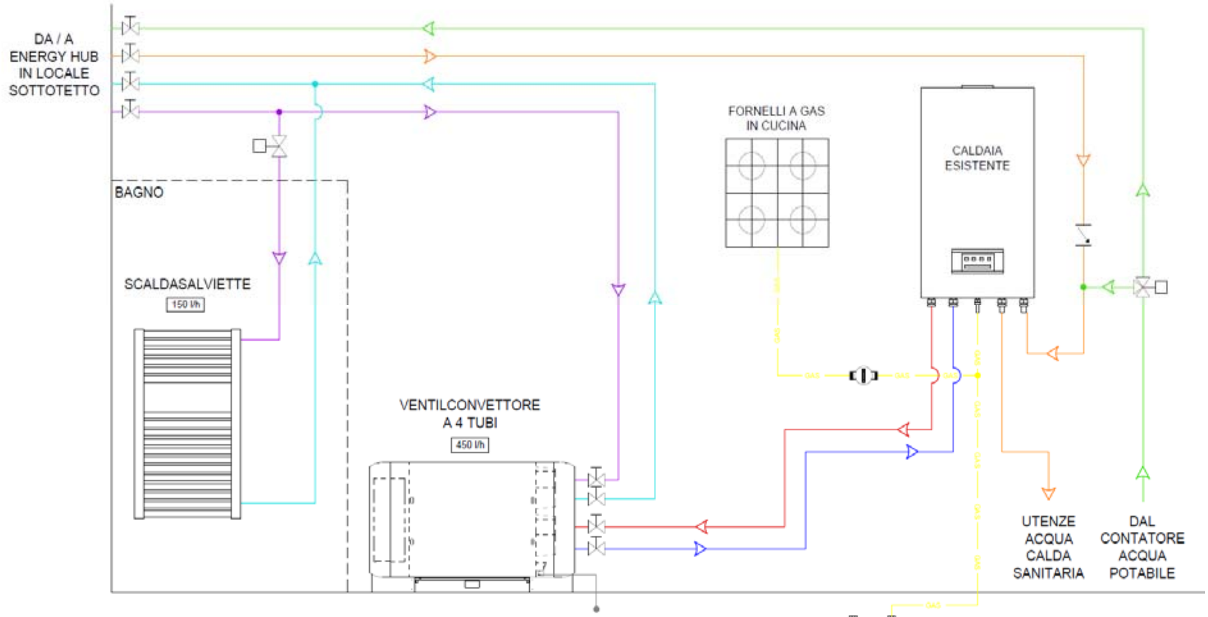


Figure 91. Preliminary circuit scheme - Energy Hub connections, appliances and existing boilers connection

5.5 Expected energetic improvements

Thanks to the integration of the energy hubs coupled with the heat pump and other passive measures aiming to the increase of the thermal performances of the building envelope, a reduction for heating consumptions from 51.4 MWh_{th}/year to 18.1 MWh_{th}/year is expected. Moreover, at least the 90% of this 18.1 MWh_{th}/year will be provided by renewable energies (PV system).
As far as the winter DHW consumptions (9.6 MWh/year with 200 m^3/year of water) are concerned, after the renovation, 3.7 MWh/year will be produced using the PV system combined with the heat pump. The remaining 5.9 MWh/year will still be produced by heating boiler.

5.6 Timeline of the renovation process

Table 83. Preliminary Gantt chart

	M41	M42 (March 2020)	M43 (April 2020)	M44 (May 2020)	M45 (June 2020)	→	M54
Definitive design of the system							
EH and Heat Pump Production phase							
Delivery of EH and Heat							

Pump to Tecnozenith							
Installation works							
Monitoring system definition & installation							
Monitored data acquisition							