4RinEU

Reliable models for deep renovation

D4.4

WP4

Replication potential

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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.

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

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Disclaimer

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Executive Summary

This deliverable contains the information needed in order to evaluate the replication potential of 4RinEU renovation methodology in different contexts, in particular referring to Demo owners building stocks.

We provided an overview of the main constraints related to the application of different 4RinEU developed technologies, taking into account their applicability depending on building features. Constraints such as building geometry, building structural characteristics, sun exposure, architectural design of the building and surrounding areas have been considered as the main possible limiting factor for technologies application such as the timber prefabricated façade, the presence of PV/ST modules or the use of integrated mechanical ventilation.

A level of severity (from 1 to 3) of each constraint is provided, suggesting that main criticalities are due to National legislation and structural characteristic of the existing building related to the possibility to hold new envelope's weight.

After having presented the above-mentioned constraints, results coming from 4RinEU D3.3 have been analysed, highlighting the best performing renovation packages in each geocluster. A cross-check between the best performing package depending on a specific KPI in each context and main constraints identified in the building stock will provide the base information for assessing the replication potential at district level.

In addition to results coming from D3.3, a new set of simulations has been performed after analysing specific building stock more in detail. In particular, from the discussions with the Irish early adopter (Atlantic geocluster) within the 4RinEU task 7.6 and from the AHC's Spanish (Mediterranean geocluster) data available at district level, remarkable construction schemes have been recognized within the respective building stocks and new scenarios have been defined to assess the replication potential of 4RinEU interventions in those specific contexts.

In the Irish building stock a predominance of low-raise edifices with adjacent buildings on the two lateral sides has been identified.

Moreover, strong limitations in those building are related to the application of the prefabricated façade in the front side, due to cultural heritage conservation issues. Therefore, to better represent the building typology suggested during the discussion with the early-adopter team, the new typology has been then modelled as a 3-story-height building where East and West orientation have been considered adiabatic, in order to recreate the adjacency condition.

Concerning the Spanish context, most of the buildings managed by the Agència de l'Habitatge de Catalunya consist on multifamily houses where, usually, lateral

sides are adjacent to other buildings. Therefore, this typology has been modelled in further simulations.

Finally, other information coming from Demo owners have been gathered, providing an assessment of the share of the key constraints in their respective building stock within reference countries. Both Woonzorg and AHC managed buildings consist mainly of multifamily apartment blocks, very similar to respective demo cases, where a uniform construction pattern occurs. These data confirmed a huge replication potential of 4RinEU approach in those contexts, to be quantified in terms of energy, CO_2 emissions and investments compared to the actual condition in the Deliverable 5.4.

1 Introduction

The purpose of this deliverable is to present the methodology for identifying the replication potential of 4RinEU technologies and renovation packages in the European building stock.

It starts with the identification of the building features and the possible technical and regulatory constraints that can affect the implementation and the operation of the 4RinEU deep renovation packages.

A summary of best performing packages in different geo-cluster from D3.3 is then presented and new simulation sets are organized, providing outcome in specific contexts, taking into account specific constraints.

Following this collection of results, the work is focused on the assessment of the building stock in the reference countries of 4RinEU geo-clusters in order to determine how the identified constraints are widespread among the existing constructions.

2 Identification of the main constraints for 4RinEU renovation approach

In order to assess the potential renovation rate with 4rinEU renovation package according to the building stock and the financing schemes available, the main architectural and urban features that can affect their installation have been identified.

The main technologies defining 4RinEU renovation packages considered in this assessment are:

- Prefabricated multi-functional timber-frame façade
- Ceiling fan
- Balanced AHU with heat recovery (Centralized mechanical ventilation)
- Façade integrated ventilation with heat recovery (Decentralized mechanical ventilation)
- Photovoltaics
- Solar thermal system

For each technology some constraints have been identified, that can totally or partially compromise its use. These constraints affect the use of a specific technology in specific contexts and can be associated with an impact on the performance of the building after renovation. Therefore, a level of severity has been assigned to the main renovation technologies. Hence, this represents the influence of the constraint on the 4RinEU technology defining renovation packages. To assess the severity level of these constraints (SL), a value from a minimum of 1 (low level of severity) to a maximum of 3 (high level of severity), has been assigned them.

Furthermore, in order to understand if these renovation packages are applicable to the building stock, some possible questions have been identified.

2.1 Analysis of the main identified constraints

The constraints mentioned in the previous sections can be associated to an impact on the performance of the building after renovation, according to the assigned level of severity that represent the influence of the constraint on the 4RinEU renovation package:

- Level 1: corresponds to a slight performance decrease
- Level 2: brings to a significant performance decrease
- Level 3: compromises the installation

2.1.1 Prefabricated multi-functional timber-frame façade:

- Distances among buildings required by law (e.g. provided for by Italian law): (SL 3)
    - in city centre area for conservative renovation works and for possible refurbishment, the distances among buildings cannot be less than those between existing buildings.
    - New buildings situated in other areas: it is prescribed, in all cases, the absolute minimum distance of 10 m between glazed areas and between front façade.
    - in developing areas of the city: the distance between the windowed façade is equal in front to the height of the tallest building. The rule also applies when only one façade has windows. The minimum distances among buildings, whose roads between the buildings are intended for vehicular traffic, must correspond to the width of the roadway plus:
      - 5 meters per side, for roads less than 7 meters wide;
      - 7.50 meters per side, for roads between 7 meters and 15 meters wide;
      - 10 meters per side, for roads wider than 15 meters wide.
- Occupation of public area: if the building is placed close to the sidewalk or roadway, the prefabricated multifunctional timber-frame façade will occupy public area; (SL 3)
- Irregular facade (for instance: façades with too many corners or curved façade): difficulty in modulating the façade; (SL 2)
- Pitched roof: difficulty in modulating the façade; (SL 1)
- Presence of balconies: difficulty in modulating the façade; (SL 1)
- Old buildings, whose structural frame is unable to withstand the addition of the façade; (SL 3)
- Buildings with light supporting structure, whose structural frame is unable to withstand the addition of the façade; (SL 3)
- Roads too narrow: difficulty in carrying the facades and for trucks to drive/turn around corners; (SL 2)

- Buildings too tall: one of the advantages to install the multifunctional timber-frame façade is the possibility to avoid the use of scaffolding. If the building were too tall, scaffolding would be required, more vehicles should be used, therefore more costs. (SL 1)
- Protected buildings: It is not possible to foresee changes on the façade unless allowed by the Superintendence of Cultural Heritage; (SL 2)
- If there were too high percentage of glazed area, the presence of multifunctional timber-frame façade could cause overheating due to its high insulation capacity. (SL 1)

2.1.2 Installation of ceiling fans:

- Reduced height of the rooms: the installation of the ceiling fan is more complicated if the height of the room is less than 2.50 m. (SL 3)

2.1.3 Balanced AHU with heat recovery (Centralized mechanical ventilation)

- Reduced height of the rooms: if the ducts do not have to cross the multifunctional timber-frame façade, the creation of a false ceiling is needed; (SL 3)
- If there are more apartments in the building, there may be a risk of mutual influence between the apartments that could be caused by excessive pressure differences; (SL 2)
- If there are already machines (fans) for mechanical ventilation, these will not be replaced; (SL 1)
- Pipelines (ducts) need to be clean/check steadily; (SL 1)
- More invasive procedure than that for the installation of decentralized mechanical ventilation; (SL 2)
- More expensive than the decentralized ventilation system. (SL 2)

2.1.4 Facade integrated ventilation with heat recovery (Decentralized mechanical ventilation)

- Narrow windows opening: if the machine must be installed in the window it needs enough space to allocate it; (SL 3)
- Constant maintenance and control: it is important to consider which kind of users the project is aimed at (for instance, this type of installation may be not recommended for elderly users). (SL 2)

2.1.5 <u>Photovoltaic system</u>

- Lower angle of the sun (northern Countries situation): It may be not recommended to install PVs on the roof; (SL 2)

- Building too close or shading surroundings: due to the shading caused by the proximity of the buildings it is not advisable to install the photovoltaic on the façade; (SL 3)
- Mainly vertical building development: the roof surface to insert the PVs is too small compared to the needs of the users (for instance: skyscraper); (SL 3)
- Occupation of public area. if the building is placed close to the sidewalk or roadway and the photovoltaic protrudes, it will occupy public area; (SL 3)
- Electricity production only for common condominium appliances (for instance for the lift): Italian legislation; (SL 2)
- Historic buildings: It is not possible to install PV on the façade. It is possible only on the roof in the manner prescribed by Italian legislation. Italian legislation; (SL 1)
- Landscape authorization required: some buildings need it. (SL 2)

2.1.6 Solar thermal system

This technology is subject to some condition of the photovoltaic. More constraint can relate to the thermal contact of the absorber or the pipes with the wooden parts of the building. This can be the case if the absorber is attached with metal hooks, which are screwed into wood and hold the header pipe. The wood will be heated over a longer period and can decay, which means a loss of stability for the building. (SL 1)

Source: Christoph Cappela, Wolfgang Streicherb, Florian Lichtblauc, Christoph Maurera. 2013. "Barriers to the Market Penetration of Façade-Integrated Solar Thermal Systems". *SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry September 23-25, 2013, Freiburg, Germany*

2.2 Check list to collect the existing constraints

The following Table 1 reports a checklist with the main questions to be addressed concerning the application of the 4RinEU technologies. This instrument can be useful in the design phase of the renovation to assess the renovation potential of a specific building in its context.

Questions	Affected technologies
How much is the distance between buildings?	Prefabricated multifunctional timber-frame façade
	Photovoltaics
	Solar thermal system

Questions	Affected technologies
Is the building placed close to the sidewalk or roadway?	Prefabricated multifunctional timber-frame façade
	Photovoltaics
	Solar thermal system
Does the building present a regular or irregular façade? Report the presence of corners, balconies, curved façade.	Prefabricated multifunctional timber-frame façade
	Photovoltaics
	Solar thermal system
Does the building present a pitched roof?	Prefabricated multifunctional timber-frame façade
How old is the building? Which type of constructive/load bearing capacity the system has?	Prefabricated multifunctional timber-frame façade
Does the urban layout present any issue for access the building?	Prefabricated multifunctional timber-frame façade
How many floors the building present? Report the type of housing and the connection to ground: terraced house, single family house, apartment block, multifamily house, other.	Prefabricated multifunctional timber-frame façade
Is it a protected building?	Prefabricated multifunctional timber-frame façade
	Photovoltaics
	Solar thermal system
Which is the percentage of glazed area in relation to the whole façade?	Prefabricated multifunctional timber-frame façade
How high is the room? Is it more than 2.50m?	Ceiling fan
How many apartments are in the building?	Centralized mechanical ventilation
Does a centralized mechanical ventilation system already exist? Is there available space for AHU, or is it possible to make	Centralized mechanical ventilation

Questions	Affected technologies
prefabricated technical room?	
Is it possible to lead a constant check/clean of the centralized mechanical ventilation ducts?	Centralized mechanical ventilation
What is the size of the windows?	Decentralized mechanical ventilation
Is it possible to lead a constant maintenance of the decentralized mechanical ventilation by the tenants?	Decentralized mechanical ventilation
Does the building have a mainly vertical development?	Photovoltaics
	Solar thermal system
Is the building surrounded by other buildings that could cause shadows on it?	Photovoltaics
	Solar thermal system
Is it an historic building or in any case a building that requires the landscape authorization to allow for its intervention?	Photovoltaics
	Solar thermal system

Table 1 Main issues to be taken into account for different renovation technologies

The checklist represents a useful support when approaching to a 4RinEU deep renovation on an existing building, since it allows to quickly identify the building features that can affect the installation of 4RinEU technologies, in order to support the decision-making process and to choose the proper renovation package.

The list can also be adopted as a preliminary check before using the Cost-Effective Rating tool as developed within Task 4.2, since it allows to exclude unappropriated renovation packages for a certain context.

3 Best performing renovation packages in different contexts

In this chapter, starting from the results of the deliverable D3.3, for each of the four building typologies in the six geo-clusters, the best performing renovation package has been identified.

Instead of evaluating the best configuration in relation to all the KPIs available, for each of the five thematic areas, just one KPI has been chosen, being the most representative and influent for the area itself. Therefore:

- For ENERGY thematic area, the yearly sum for heating and cooling demand savings respect to the non-renovated condition is the selected KPI;
- For COMFORT and IAQ, the percentage of occupied hours in category 1 following the evaluation of the Adaptive Comfort Model, hence referring to the cooling period, is the selected KPI;
- For ENVIRONMENT thematic area, the yearly CO_2 emission due to heating and cooling systems is the selected KPI;
- For ECONOMIC ISSUE, the estimated Net Present Value after 50 years from the intervention is the selected KPI;
- For BUILDING SITE MANAGEMENT, the estimated number of hours needed for the renovation works on the building site is the selected KPI.

In the Table 2 cells, number from 1 to 6 can be found, identifying the renovation package providing the best results for each above mentioned KPI. Numbers refer to a specific package as it follows:

IDENTIFICATION n.	RENOVATION PACKAGE
1	Prefabricated façade
2 (or 3)	Prefabricated façade + Decentralized ventilation (+ BiPV panels)
4	Prefabricated façade + Centralized ventilation + BiPV panels
5	Prefabricated façade + Decentralized ventilation + BiPV panels + Smart Ceiling Fan

6	Prefabricated façade + Smart Ceiling Fan

Table 2 Identification number for the renovation package

In the following tables(Table 3, Table 4, Table 5, Table 6, Table 7, Table 8), the identification number of the best performing renovation package is reported for the five thematic areas KPIs, while between brackets ( ), the absolute value for that specific KPI is shown.

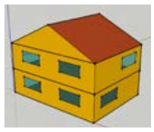
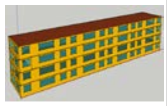
	GEOCLUSTER CONTINENTAL - CENTRAL				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considered**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	6 (-73.1%)	4 (-90.86%)	4 (-95.36%)	5 (-76.3%3)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	2 (97%)	6 (92%)	2 (96.6%)	1 (94.39%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	6 (0.4)	4 (0.66)	4 (2.47)	2 (2.08)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (66786)	1 (86328)	1 (853375)	1 (411275)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 3 Best performing packages in Continental - Central Geo-cluster

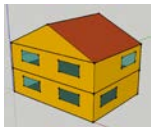
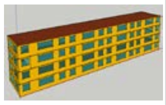
	GEOCLUSTER MEDITERRANEAN				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considered**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	5 (-81%)	4 (-92%)	5 (-99%)	5 (-87%)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	6 (90.7%)	4 (99.37%)	6 (99.8%)	6 (79.8%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	6 (0.27)	4 (0.32)	4 (~0)	2 (0.13)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (55727)	1 (72153)	1 (712630)	1 (343166)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 4 Best performing packages in Mediterranean Geo-cluster

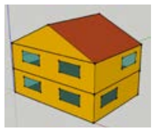
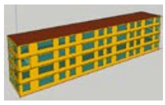
	**GEOCLUSTER NORTHERN**				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considered**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	5 (-44.6%)	4 (-87%)	4 (-92%)	5 (-68.5%)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	1 (91.8%)	4 (90.3%)	1 (87%)	1 (37.8%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	5 (0.53)	4 (0.89)	4 (4.58)	2 (2.23)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (130919)	1 (169226)	1 (1672824)	1 (806200)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 5 Best performing packages in Northern Geo-cluster

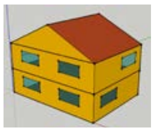
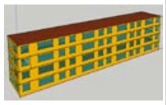
	GEOCLUSTER NORTH-EAST				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considere d**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	5 (-72.7%)	4 (-90%)	4 (-96.85%)	5 (-73.7%)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	1 (92%)	4 (99%)	1 (99%)	1 (42%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	5 (0.5)	4 (1.06)	4 (2.94)	2 (1.95)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (53437)	1 (69073)	1 (682804)	1 (329070)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 6 Best performing packages in North-east Geo-cluster

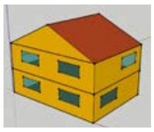
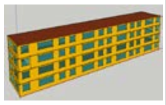
	GEOCLUSTER EAST				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considered**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	5 (-73.5%)	4 (-91.84%)	5 (-95.97%)	5 (-76.63%)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	6 (81%)	4 (99%)	1 (85%)	6 (12%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	2 (0.37)	4 (0.63)	4 (1.92)	2 (1.17)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (43362)	1 (56050)	1 (554069)	1 (267027)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 7 Best performing packages in East Geo-cluster

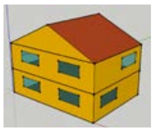
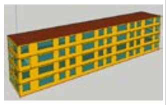
	GEOCLUSTER ATLANTIC				
					
	Tot Area	**88 m2**	**228 m2**	**3456 m2**	**1330 m2**
Thematic Area	**KPI considered**	**Best renovation package for the specific KPI**			
ENERGY	Energy demand (H+C) saving respect to non-renovated	5 (-80.4%)	4 (-91.8%)	4 (-99%)	5 (-86.7%)
COMFORT AND IAQ (check Table 3 of Deliverable 3.3 for more explanation on these KPIs)	CAT_I_Adpt (evaluated in cooling period)	1 (96%)	6 (89%)	1 (100%)	1 (35%)
ENVIRONMENT	Yearly CO_2 emissions due to Heating + Cooling [tCO_2 year]	5 (0.22)	4 (0.58)	4 (0.49)	2 (0.49)
ECONOMIC ISSUES	Net Present Value (50 years) [€]	1 (64490)	1 (83360)	1 (824027)	1 (397131)
BUILDING SITE MANAGEMENT	Duration of the building site [n. of hours]	6 (44)	6 (55)	6 (562)	6 (272)

Table 8 Best performing packages in Atlantic Geo-cluster

4 Performance assessment of renovation packages considering specific constraints

After having developed the simulation campaign based on building archetypes in task 2.1, the building stock in different geo-clusters has been analyzed and some specificities have arisen.
In particular, from the discussions with the Irish early adopter (Atlantic geo-cluster) within the task 7.6 and from the AHC's Spanish (Mediterranean geo-cluster) data available at district level, remarkable construction schemes have been recognized within the respective building stocks and new scenarios have been defined to assess the replication potential of 4RinEU interventions in those specific contexts.

In order to quantitatively assess the impact on the 4RinEU KPIs of the identified constraints, a new set of simulations has been performed, considering two additional building typologies:

- Terraced house (from T2.1) – with 2 adiabatic walls in Atlantic geo-cluster
- Multi-family house (from T2.1) – with 2 adiabatic walls in Mediterranean geo-cluster

4.1 Ireland (Atlantic geo-cluster)

For the Irish early-adopter study, a new building type have been modelled in addition to the four geometries proposed in the T2.1. In the analyzed building stock, in fact, a predominance of low-raise edifices with adjacent buildings on the two lateral sides has been identified.
Moreover, strong limitations in those buildings are related to the application of the prefabricated façade in the front side, due to cultural heritage conservation issues. Therefore, to better represent the building typology suggested during the discussion with the early-adopter team, the new typology has been then modelled as a 3-story-height building where East and West orientation have been considered adiabatic, in order to recreate the adjacency condition.
In Table 9, the building geometry and principal characteristics used for performing the additional simulation set for the Irish early-adopter building stock's typical building are presented.
Concerning the thermal transmittance of the envelope, the same values used for the Project Deliverable 2.1 simulations for the "Atlantic" Single Family House geo-cluster have been applied, as well as the renovation packages resulting from the

combinations of the technologies summarized in Figure 1. (*For more details on technology description and renovation packages, please see Deliverable 2.1 and 3.3)*

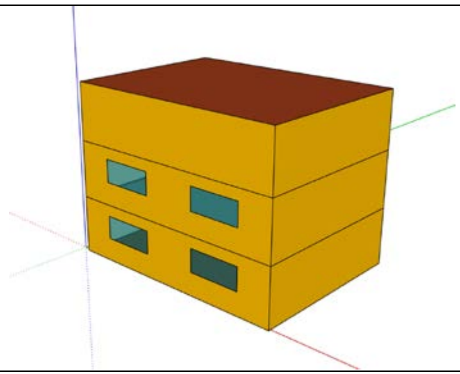
	N° Floors= 3 Area per Floor= 75 m² Building Height= 7.5 m Building Width= 7.5 m Building Length= 10 m EXISTING WALL U-value = 1.62 W/m²K (E/W sides: ADIABATIC)

Table 9 Irish building characteristics for additional simulation

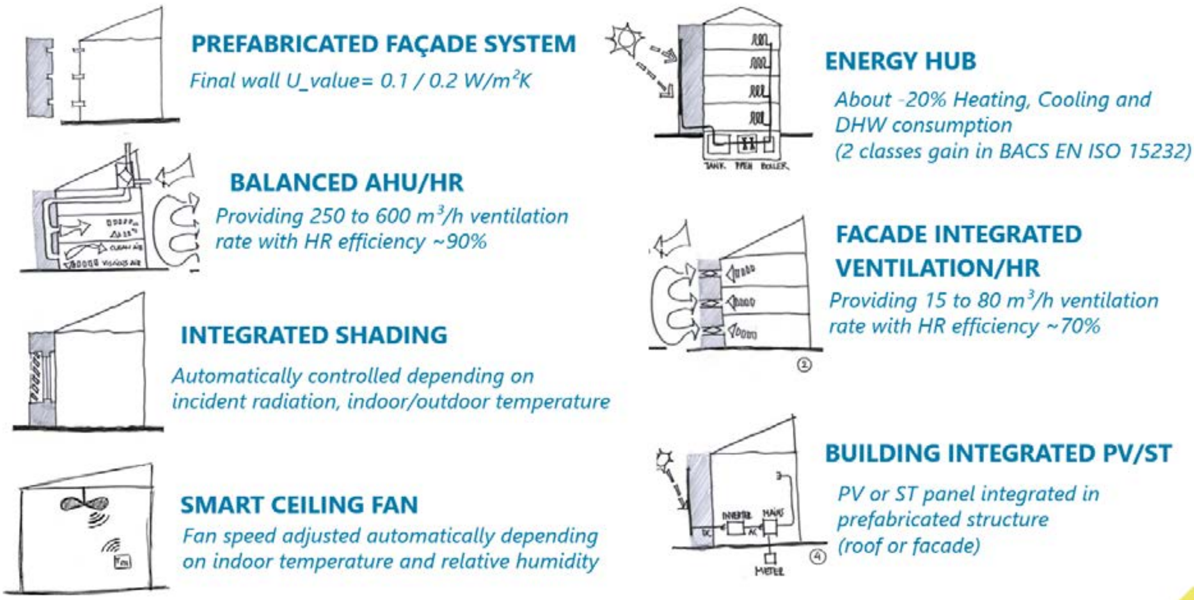


Figure 1 Summary of 4RinEU related technologies composing the renovation packages to be applied to the existing building

As in the primary set of simulation described in the D2.1, all the retrofit conditions which have been simulated, include also:

- The improvement of heating system efficiency,
- The presence of a cooling system (in case it is needed)
- The retrofit of windows (two possibilities are available: 1.24 W/m^{2}K or 0.61 W/m^{2}K glazing thermal transmittance)
- The reduction of infiltration rate, assuming to have an airtight building after the retrofit
- The roof and ground floor retrofit, assuming an improved insulation level.

Considering the limitations related to the application of the prefabricated façade system due to cultural heritage conservation arisen in the Irish context, different

combination for the application of prefabricated multifunctional modules have been considered in the new set of simulation for this specific case. In Table 10, the possible combinations for north and south façade layout are presented, both ensuring a final thermal transmittance of the wall of 0.1 W/m^{2}K or 0.2 W/m^{2}K.
A set of simulations has also been run where prefabricated façade have not been applied; nevertheless, other technologies have been considered with the standard parametric approach in those simulations.

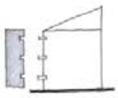
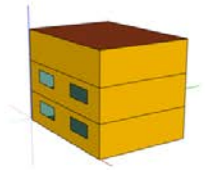
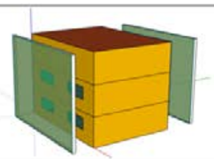
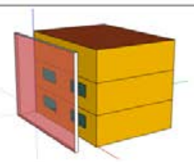
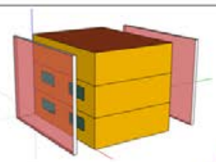
PREFABRICATED FAÇADE SYSTEM 		NORTH FACADE		
		EXISTING WALL	U Value= 0.1 W/m^{2}K	U Value= 0.2W/m^{2}K
SOUTH FACADE	EXISTING WALL			
	U Value= 0.1 W/m^{2}K			
	U Value= 0.2W/m^{2}K			

Table 10 North and South placement of Prefabricated Facade System, as modelled in this new set of simulations

4.1.1 Performance Results

In this chapter, some results related to the new set of simulations related to Irish early-adopter specific context are presented.
In Figure 2, the effects of adding or not the prefabricated façade (final thermal transmittance of the wall indicated with U01 for 0.1 W/m^{2}K or U02 for 0.2 W/m^{2}K) on available sides of the building is shown in relation to the annual heating demand per square meter. The retrofit configuration where the prefabricated façade is placed neither in the north nor south sides is also presented. In this case the reduction in heating demand (-45% respect to non-renovated condition) is provided by other useful retrofit interventions such as windows substitution and use of mechanical ventilation with heat recovery.

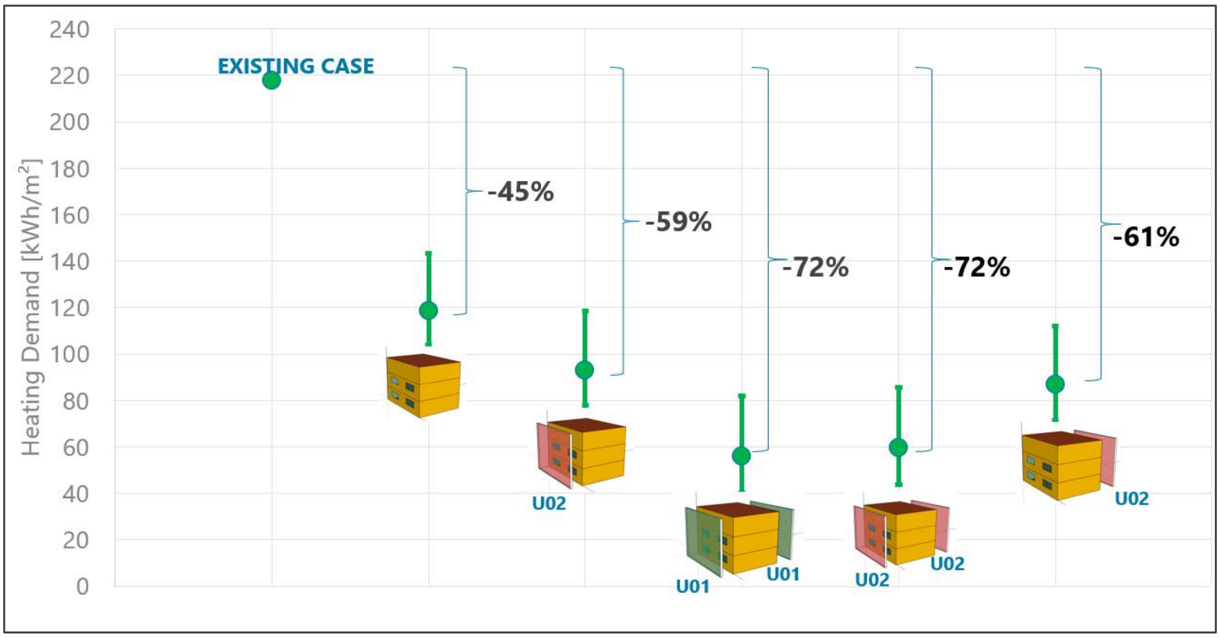


Figure 2 Heating Demand percentage reduction respect to non-renovated condition, depending on the use of prefabricated facade on South and/or North sides

In Figure 3 it is evident how relevant the use of a mechanical ventilation with heat recovery is in such a climatic zone. Percentages shows, in each group of cases with different application of prefabricated facades, the average reduction in heating demand of cases with heat recovery ventilation system respect to cases without.

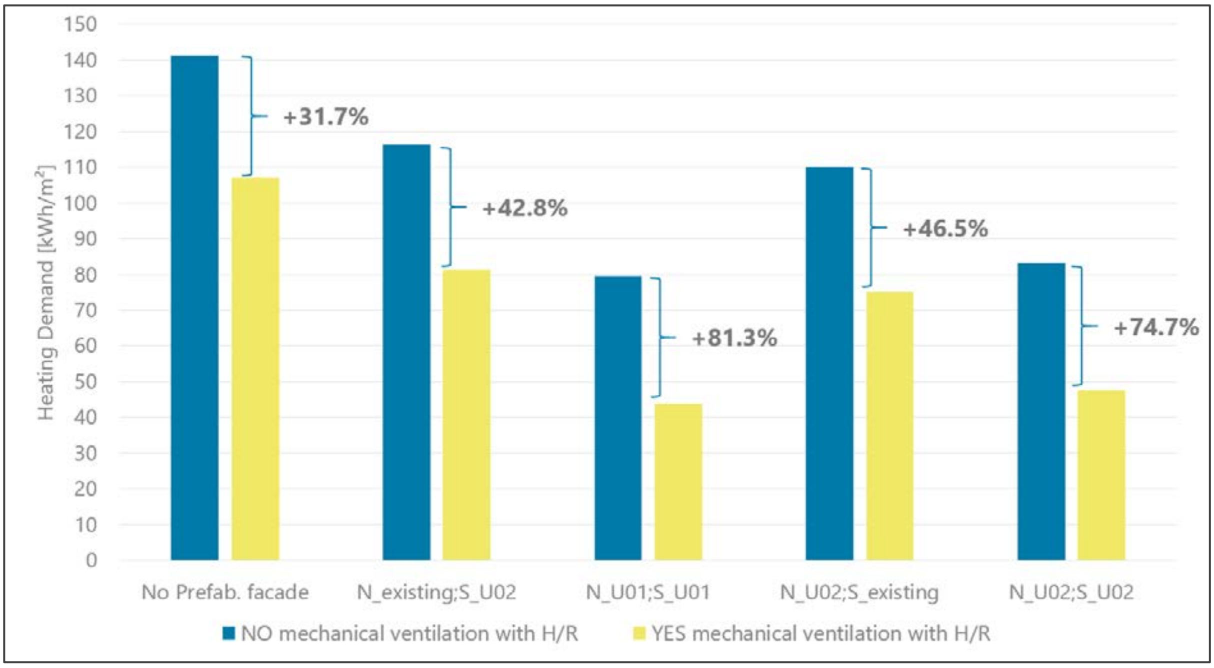


Figure 3 Heating demand variation due to the use of mechanical ventilation with heat recovery ("N" and "S" stand for North and South façade)

Figure 4 presents the advantages of adding to the windows an automated external shading system.

This graph presents average values of heating demand referring to the retrofit condition of this new set of simulations. In the graph it is possible to notice that the presence of automated shading system is causing an increase of the heating demand just for a +2.4% respect to not having the shadings. This is a very small amount and it must be taken into account that the effect provided by the shading system for sure overcome that. In fact, this technology is crucial to reduce glare and visual discomfort for the occupants. Moreover, in the cooling season, it can help reducing the cooling system operations.

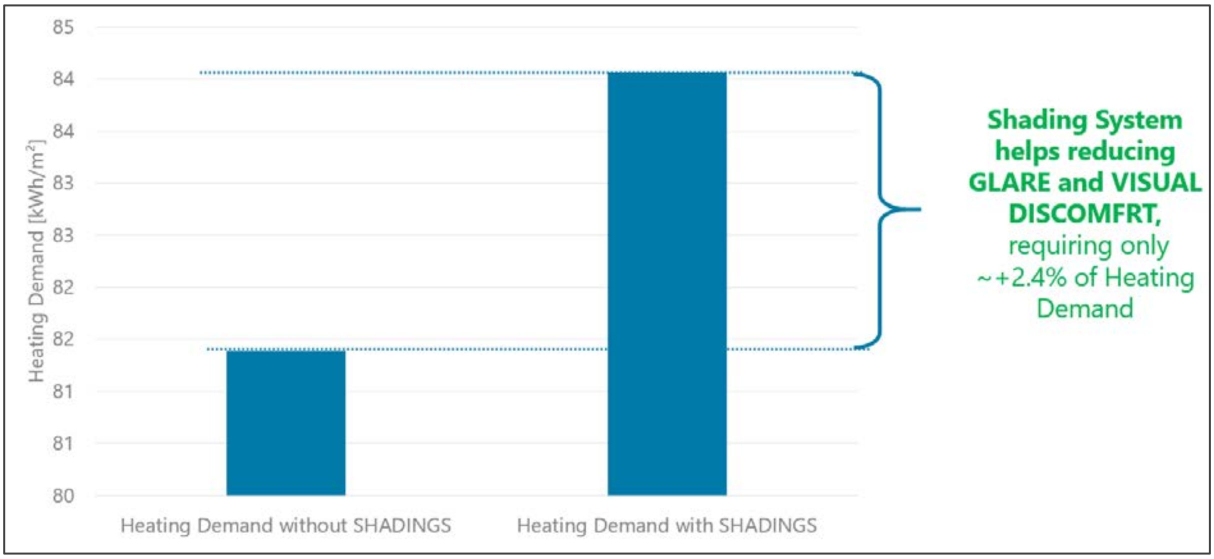


Figure 4 Average effect (on the whole set of simulations on renovated cases) of having an automated shading system

Actually, in the specific modelled conditions, internal temperature of the building never raised above 26 degrees during the cooling season due to the relatively low outdoor temperature (Figure 5). Therefore, it has been noticed that in none of the simulated scenario the cooling system was necessary to cool down the indoor ambient, as well as the use of smart ceiling fan. This may be reasonable in such a climatic zone and it has also been confirmed during the discussion with the Irish early-adopter team.

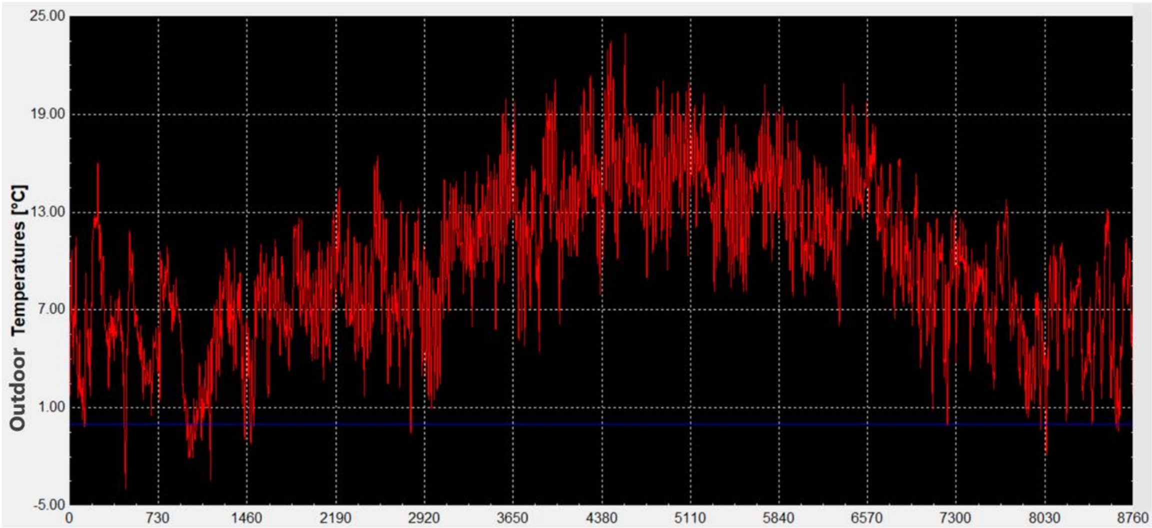


Figure 5 Yearly outdoor temperature from Irish weather file

Figure 6 shows the effects on the yearly heating consumption per square meter due to the use of a heat pump as heating system. It is evident that the heating consumption can be soundly reduced adopting this technology.

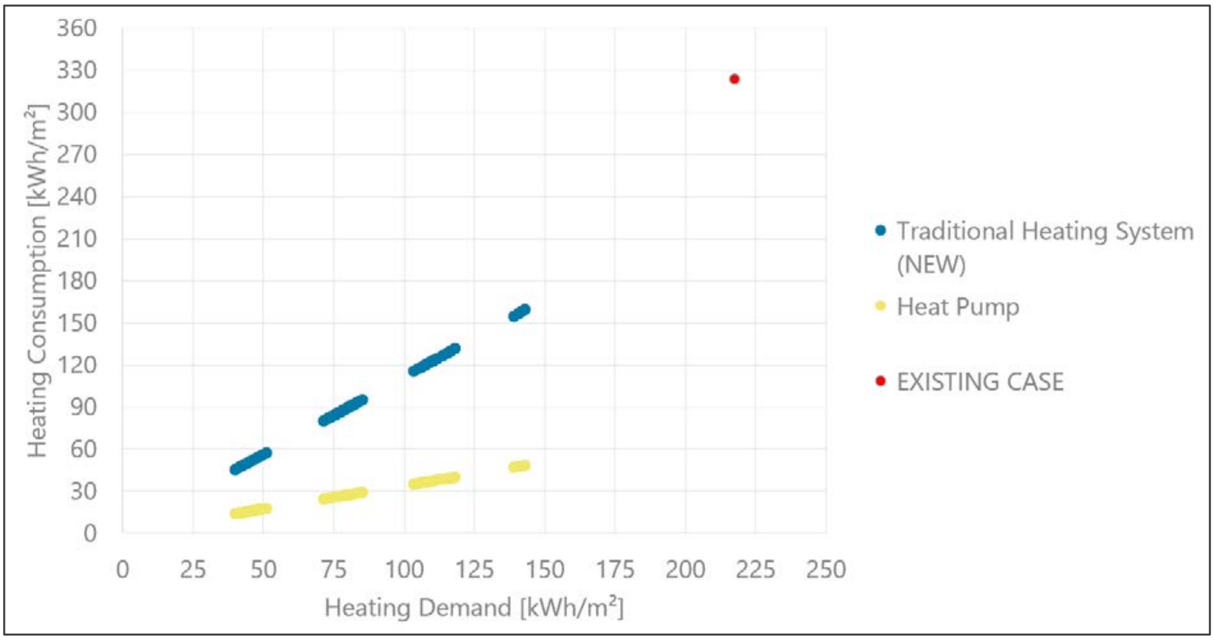


Figure 6 Heating consumptions due to the use of a heat pump

In Figure 8, an evaluation on the users' comfort conditions in the heating season is presented. Here, the percentage reduction of occupied hours in category 4 according to the Predicted Mean Vote (PMV) model is shown.
Category 4, following this comfort model, is reached when the PMV value is below -0.7 or above 0.7 (ranges, related to Percentage of Persons Dissatisfied PPD, are indicated in Figure 7)
Looking at Figure 8, it is evident that retrofit condition have a great potential in the enhancemnt of heating season comfort conditions, especially if supported by the use of the mechanical ventilation with heat recovery.

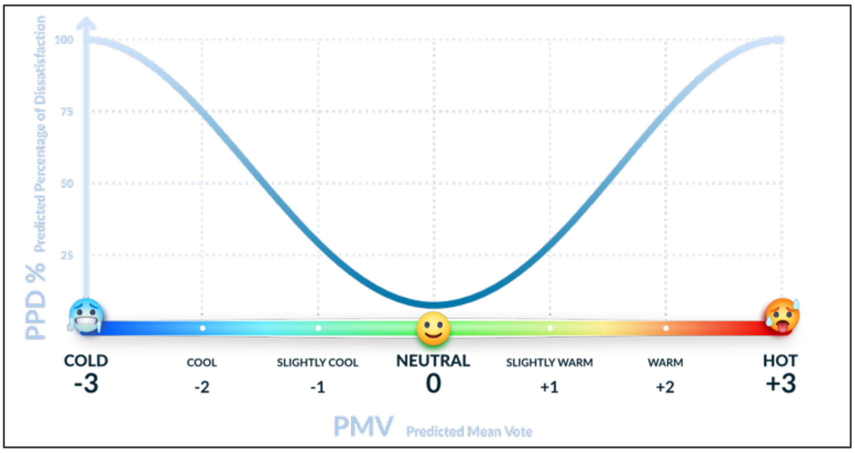


Figure 7 PMV values (x-axis) related to PPD (y-axis)

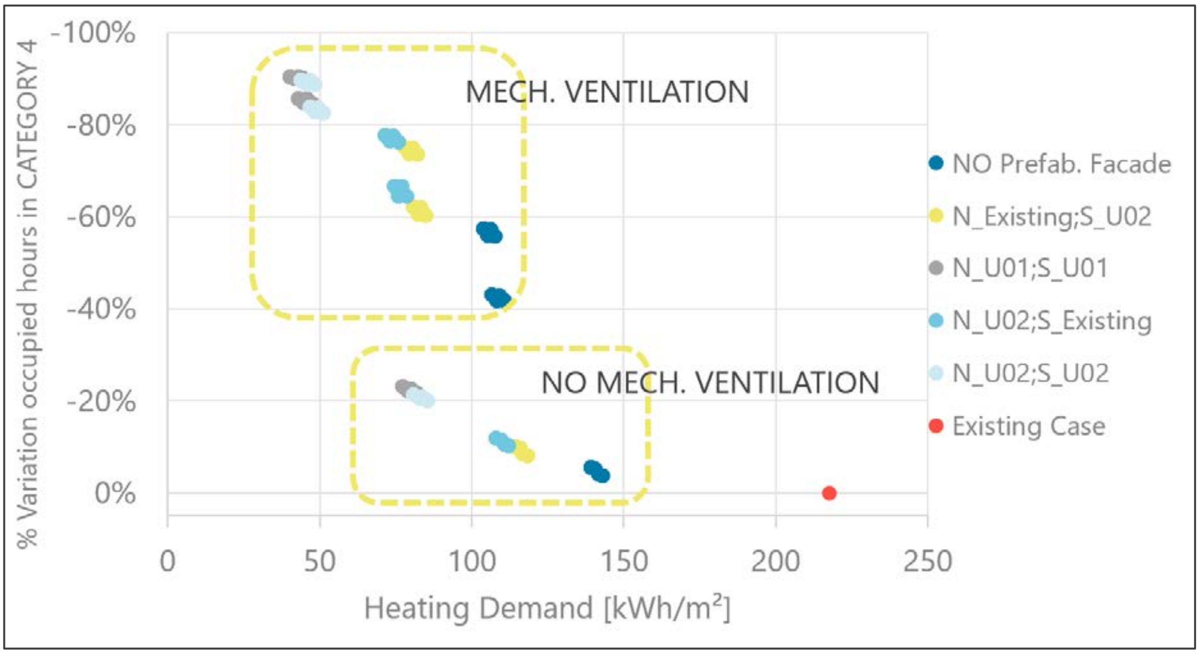


Figure 8 Variation in yearly occupied hours in CATEGORY 4 for PMV comfort model, depending on the use of mechanical ventilation with heat recovery and facade typologies ("N" and "S" stand for North and South sides)

4.1.2 Preliminary costs and installation time on building site

Following the same approach for assessing preliminary costs of the renovation and time needed on building site for the proposed retrofit intervention as explained in the ANNEX B of Deliverable 4.2, investment costs, net present value calculated for 50 years lifetime and time needed on building site have been calculated. Actually, considering the specific context discussed with the Irish early adopter team, prefabricated façade is mainly supposed to be placed just in the rear side of the building, since the front side cannot be affected by external components due to heritage conservation issues.

Therefore, preliminary investment costs for the renovation presented here below refer only to the application of the prefabricated façade on one side of the building, consisting of 75m^2 of façade area (northern or southern side would have the same effect in terms of costs and installation time on building site).

Looking at the values shown in Table 11 it must be considered that, although in the table are mentioned only the main 4RinEU related technologies, several other improvements are taken into account in the renovation action (e.g. improved efficiency of heating system, roof and ground floor insulation). Moreover, values presented are given in ranges since the use of specific technologies may include different options whose costs have not been split. It must be considered that the large difference in the investment costs is mainly related to the distance between the construction site and building site; this parameter has been take into account in the cost analysis, hence transportation costs for prefabricated modules is strongly affecting the total expenditures for renovation. Cost ranges here below refer to the main renovation packages related to the 4RinEU intervention. For further details on the included options please have a look at Deliverable 3.3 and Annex B of Deliverable 4.2.

Main technologies included in the renovation package	**Investment Costs [€]**	**Time needed for renovation on building site [h]**
Prefabricated façade	28,358 ÷ 208,804	17 ÷ 38
Prefabricated façade + Building Integrated PV	29,231 ÷ 209,717	18 ÷39
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan	30,742 ÷ 210,799	17 ÷39
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan + Mechanical Ventilation	32,856 ÷213,444	19 ÷ 40 (for centralized ventilation) or 63 (for decentralized ventilation)

Table 11 Ranges of investment costs and renovation time on building site needed for specific Irish context

4.2 Spain (Mediterranean geo-cluster)

After the evaluation of the Spanish building stock provided by the demo owner, a specific building typology have been identified. In fact, most of the buildings managed by the Agència de l'Habitatge de Catalunya consist on multifamily houses where, usually, lateral sides are adjacent to other buildings. Therefore, a new simulation set has been performed in order to assess the performances of such a construction typology.

Therefore, applying same conditions described in Deliverable 2.1 for building models, the Multi Family geometry (Table 12) has been tested in the Mediterranean geo-cluster, setting the adiabatic condition to the lateral sides of the construction.

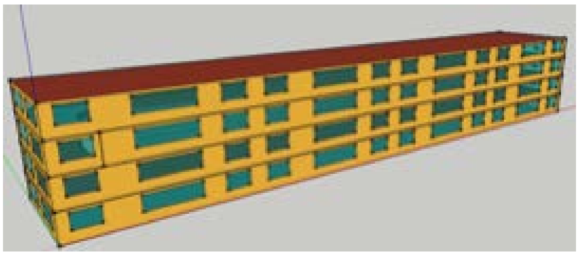
	N° Floors= 4 Area per Floor= 864 m² Building Height= 12 m Building Width= 12 m Building Length= 72 m ❖ *E/W sides: ADIABATIC*

Table 12 Additional Spanish contest simulation set: building description

4.2.1 Performance Results

Results for this set of simulations are summarized here below, reporting in the graphs the outcome form the main evaluated KPIs.

In Figure 9, heating demand and cooling demand of each simulated condition are shown.

The color of the marker gives information on the envelope’s final thermal transmittance (U075 stays for 0.75 kWh/m^2, while U029 for 0.29 kWh/m^2) and on the glazing typology of the retrofit windows.

The existing condition, which is not displayed in the chart to keep x-axis shorter for graphical reasons, requires almost 57 kWh/m^2 for the heating demand and about 1 kWh/m^2 for cooling.

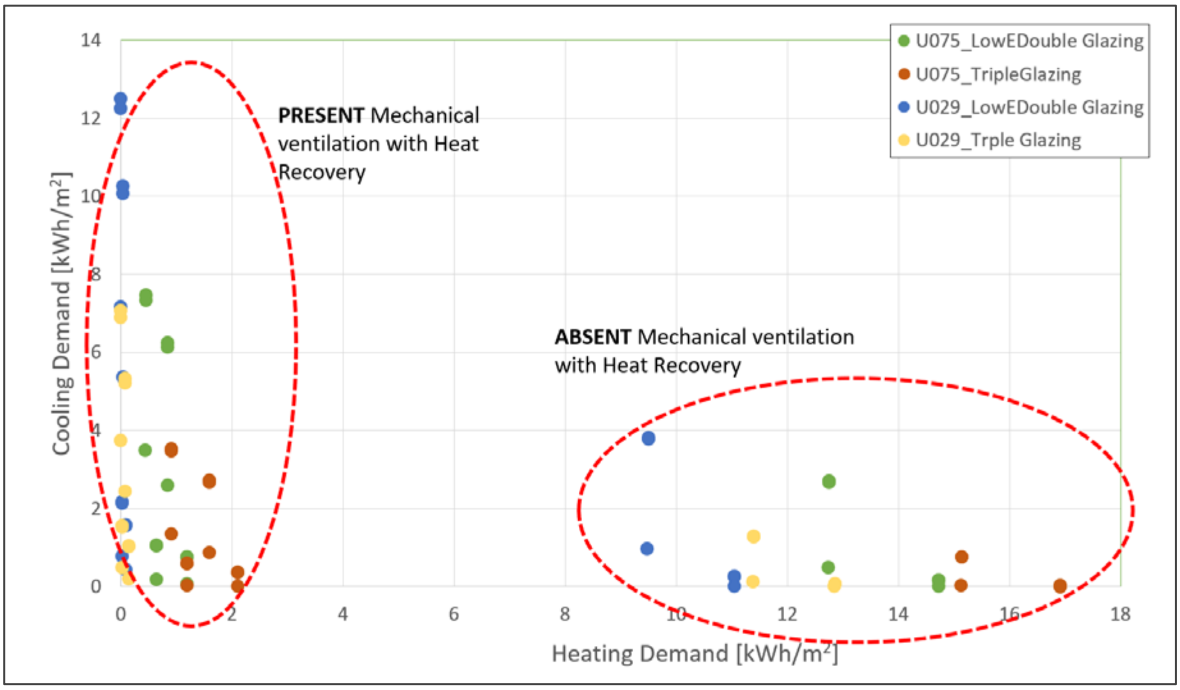


Figure 9 Heating and cooling demand. Renovation packages using the mechanical ventilation machine with heat recovery are marked, as well as thermal transmittance and glazing type of each specific case.

Figure 10 shows the effect of having smart ceiling fan technology and shading system in the renovation package.

Of course, in the resulting simulation set, higher values for cooling demand are related to cases where the envelope of the building has been retrofitted but no other technologies (in particular shading system and smart ceiling fan) have been adopted. Improving envelope thermal transmittance and increasing building airtightness without reducing solar gains and ensuring the proper ventilation causes cooling demand to increase and bad indoor comfort conditions.

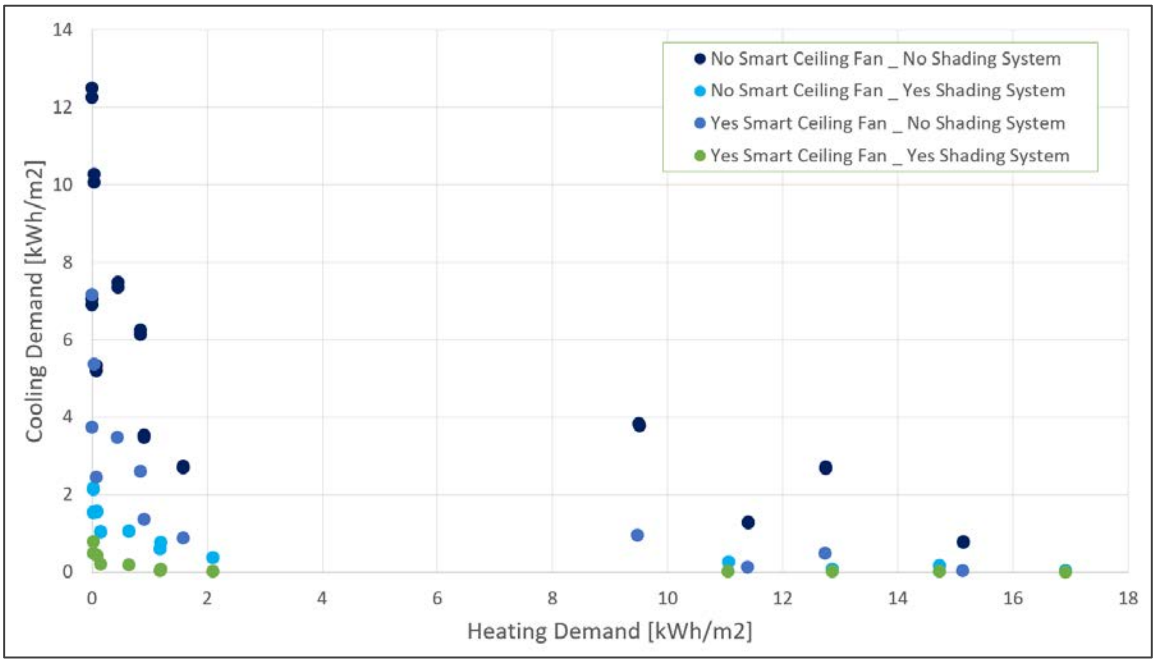


Figure 10 Heating and cooling demand with Smart Ceiling Fan and Shading system presence highlighted with colored marker.

Figure 11 present indoor comfort conditions during cooling (on the x-axis) and heating (on the y-axis) period showing respectively the evaluated KPIs. Red dashed lines on the graph indicate simulations taking into account the use of shading system (mainly affecting the cooling period) and mechanical ventilation with heat recovery (mainly affecting the heating period).

Higher comfort conditions during occupied hours during the year occur when both technologies are equipped in the renovation package.

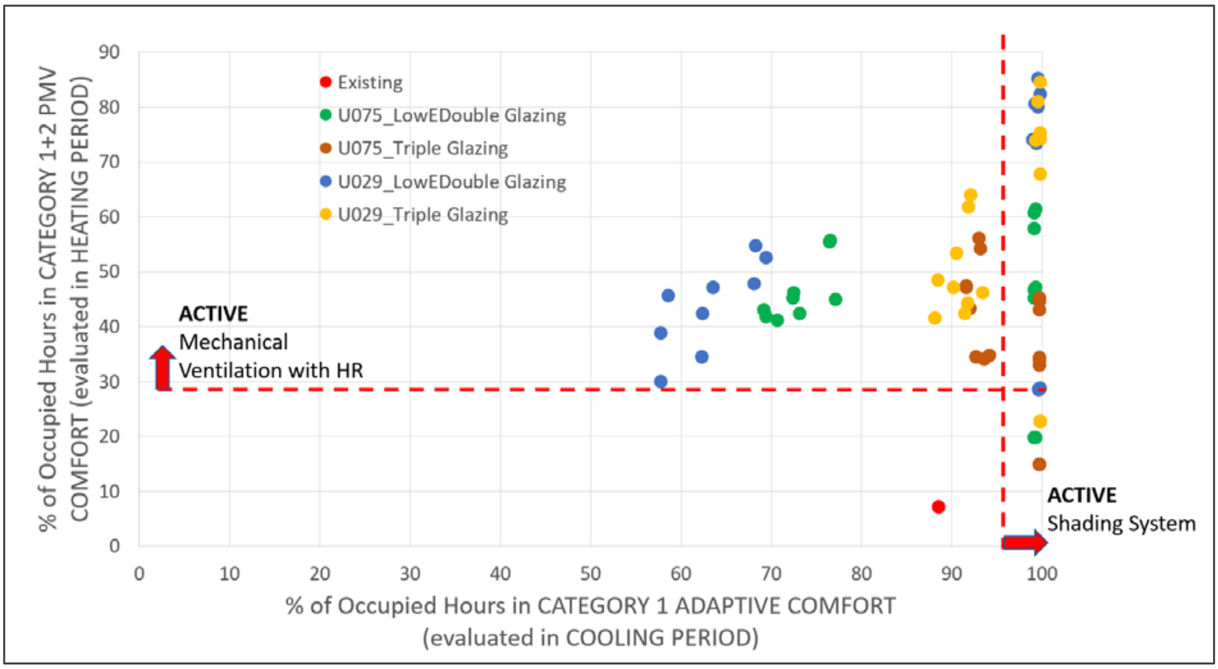


Figure 11 Comfort conditions during heating and cooling season. On the graph the use of specific technologies is highlighted, while colored marks indicate the thermal transmittance of the envelope and glazing type.

4.2.2 Preliminary costs and installation time on building site

In Table 13 (prefabricated façade applied on 1 side) and Table 14 (prefabricated façade applied on 2 sides) investment costs and times for the renovation needed on building site are summarized referring to the main renovation packages developed within the project.

Main technologies included in the renovation package	Investment Costs [€]	Time needed for renovation on building site [h]
Prefabricated façade	517,562 ÷ 851,771	1,374 ÷ 1,857
Prefabricated façade + Building Integrated PV	543,709 ÷ 877,918	1,408 ÷ 1,891
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan	596,554 ÷ 915754	1,408 ÷ 1,891
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan + Mechanical Ventilation	659,821 ÷ 994,917	1,443 ÷ 2,678

Table 13 Investment costs and time on building site in case only one facade is prefabricated

Main technologies included in the renovation package	Investment Costs [€]	Time needed for renovation on building site [h]
Prefabricated façade	563,546 ÷ 991,431	484 ÷ 1,045
Prefabricated façade + Building Integrated PV	585,957 ÷ 1,013,843	513 ÷ 1,074
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan	638,802 ÷ 1,051,680	513 ÷ 1,074
Prefabricated façade + Building Integrated PV + Smart Ceiling Fan + Mechanical Ventilation	693,032 ÷ 1,119,533	543 ÷ 1,748

Table 14 Investment costs and time on building site in case two facade are prefabricated

4.3 Further constraints in specific contexts

Together with the above-mentioned constraints, emerged after deeply analyzing specific building stocks, some further general limitations arose looking at general European contest.
The main constraint is related to the most impacting 4RinEU technology, namely the prefabricated multifunctional timber façade.
In fact, analyzing the available building stocks shared from the partners within the project, it is clear that the existing building envelope may not be adequate for the application of the prefabricated modules. This can be due mainly to two reasons: on the one hand, the structural characteristics of the existing building may not be sufficiently good for supporting the new anchored envelope; in this case, having a detailed documentation of the existing building, as well as performing a disruptive investigation during the pre-design phase may help in evaluating the feasibility on the use of the prefabricated façade for retrofit. On the other hand, the architectonical layout of one of the existing façades may represent a limitation for the use of the prefabricated modules for retrofit. In fact, as mentioned in Table 1, the presence of balconies, ledges, cavities and curved surfaces can represent hard difficulties to overcome with timber prefabricated elements.
All the above-mentioned criticalities can affect one or more side of the building.
Therefore, the prefabricated multifunctional timber façade approach may be integrated with a standard renovation approach, depending on the specific context. In this case, energy and comfort performances can be kept similar, although robustness and longevity of the intervention are reduced, thus affecting costs during building lifetime.

Another technology developed within 4RinEU Project, applicable to indoor of renovated apartments, is the Smart Ceiling Fan. Concerning its application, the main constraints is related to the available distance between floor and ceiling of the rooms. European regulation in this matter requires a distance between the floor and the device's fans of minimum 2.30 meters. As confirmed by the analysis of the building stock in different geo-clusters, applying the Smart Ceiling Fan technology satisfying that constraint may be problematic.

5 Identification of the constraints in the building stock

This section aims to provide an assessment of the share of the key constraints in the building stock of reference countries.

In particular, the analysis focuses on the Mediterranean and on the Continental geo-cluster, where more detailed data were available from the building stocks of Agència de l'Habitatge de Catalunya AHC (Spain) and WOONZORG (The Netherlands).

5.1 AHC Building Stock

AHC manages approximately 20,365 apartments with an average surface of 60 m2 (total surface managed: about 1.2 million of m2). These apartments are mostly grouped in apartment blocks or multifamily houses, both dedicated to residential sector.

- Regarding the building characteristics of the whole building stock managed by AHC, approximately 80% of the buildings are isolated blocks, while the remaining 20% have adjacent constructions (on 2 or 3 sides).

- Just 5,042 apartments have Solar Thermal Systems for DHW. This means the 24,75% of the global number of apartments managed by AHC.

- Just 24 apartments have Photovoltaic panels. This means 0,18% of the global number of apartments managed by AHC.

- Most of the apartments have normally 2.5m distance between floor and ceiling, eventually reduced to 2.4 in case the false ceiling is used.

- Within the total managed buildings, AHC can provide more details on 13,924 apartments (distributed in 688 residential blocks) regarding the year of construction. Those apartments built after 1979 and those built after 2006 (Table 15), have thermic requirement for their envelop, specified in the respective regulations.

Year of Construction	Apartments	Building regulations
Between 2006/2010	4,382	CTE 2006

Between 2005/1980	6,568	Regulation NBE-CT-79
Between 1979/1970	949	-
Between 1969/1960	357	-
Between 1959/1950	205	-
Between 1949/1930	180	-
Unknown	1,283	-

Table 15 Year of construction classification of AHC managed buildings

Furthermore, in Table 16, the renovation plan performed from 2015 to 2020 is reported.

YEAR	ACTIONS IMPLEMENTED	Nº BUILDINGS	FLOOR SURF. RENOVATED	TOTAL FLOOR SURF. RENOVATED
2019	*"Envelops renovation"*	*17 Blocks (540apt + some stores)*	54,500 m^2	**55,700 m^2**
	"Envelop Renovation & façade Insulation"	*1 block (12apt. + some stores)*	1,200 m^2	
2018	*"Facilities & common stairs renovation + façade repairs"*	*4 Blocks (36apt)*	2,474 m^2	**2,474 m^2**
2017	"Structural repairs"	*5 blocks (42apt.)*	3,000 m^2	**89,549 m^2**
	"Envelop Renovation, Structural repairs & façade Insulation"	*20 blocks (868apt)*	69,203 m^2	
	"Injection of façade insulation"	*2 blocks (120 apt.)*	11,820 m^2	
	"Facades renovation and ground floor insulation"	*2 blocks (69apt.)*	5,526 m^2	
2016	*"Envelop Renovation & Injection of Façade Insulation"*	*3 blocks (180 apt. + some stores)*	17,730 m^2	**22,800 m^2**
	"Facade Renovation & Ground floor Insulation"	*2 blocks (38 apt.)*	*2,660 m^2*	
	"Foundations repair"	*2 blocks (24 apt.)*	*2,410 m^2*	

2015	*"Structural Interventions"*	*5 blocks (148 apt +some stores)*	*14,680* m^2	**33,291.5 m^2**
	"Facade Renovation & Ground floor Insulation"	*5 blocks (100 apt)*	*5,821* m^2	
	"Injection of façade insulation"	*2 blocks (100apt)*	*11,820* m^2	
	"Deep energy renovation" European Project RELS	*1block (21apt)*	*970.48* m^2	

Table 16 Renovation works by AHC - last 5 years

5.1.1 Lleida building stock

Moreover, AHC provided a building stock detailed repository based on 36 buildings situated in the city of Lleida, which year of construction goes from 1998 to 2009.
In Figure 12, Figure 13, Figure 14 and Figure 15 the data on Lleida specific context are reported.

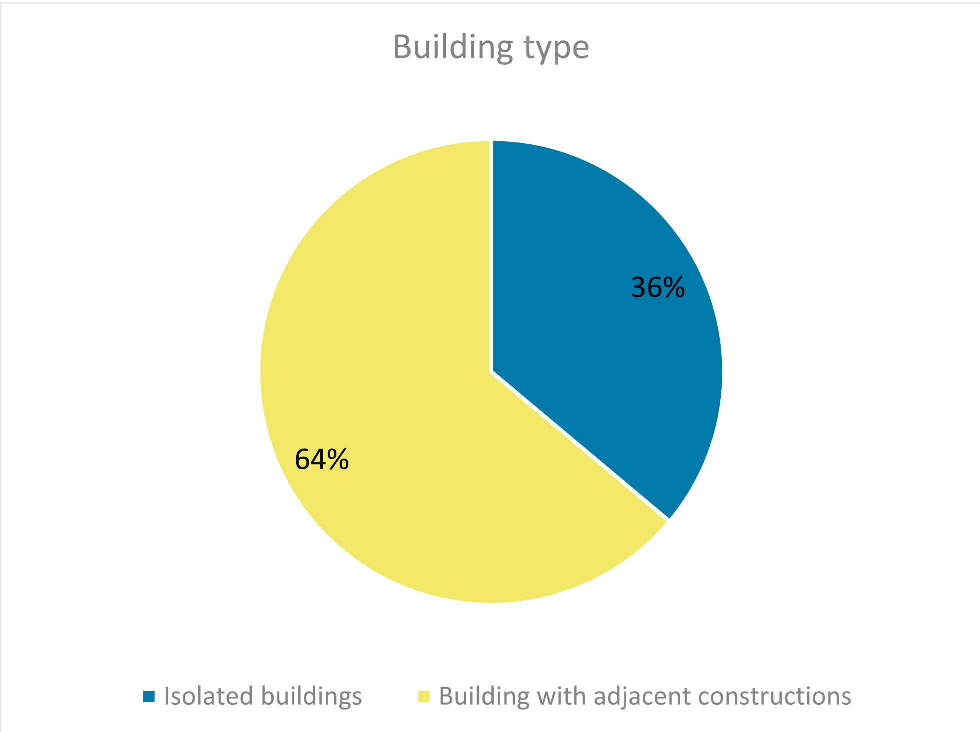


Figure 12 Building type AHC building stock in Lleida

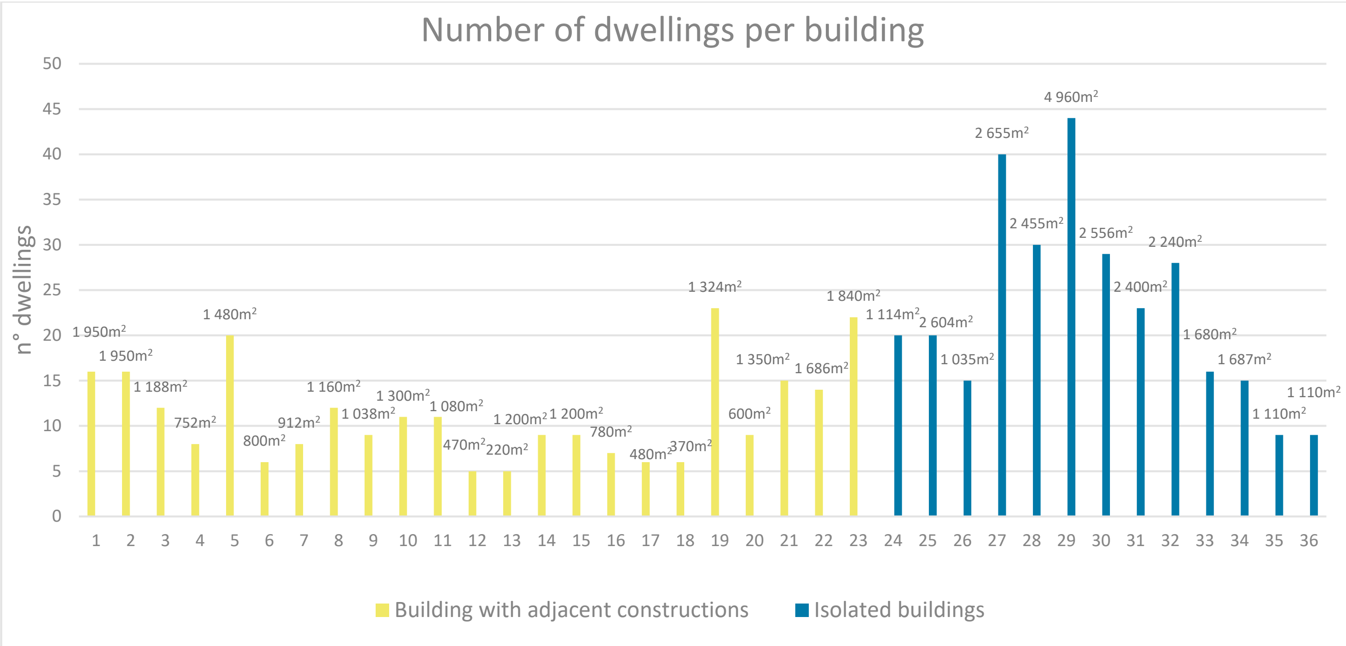


Figure 13 Number of dwellings per building (on each column, representing one building, total dwellings' area is reported)

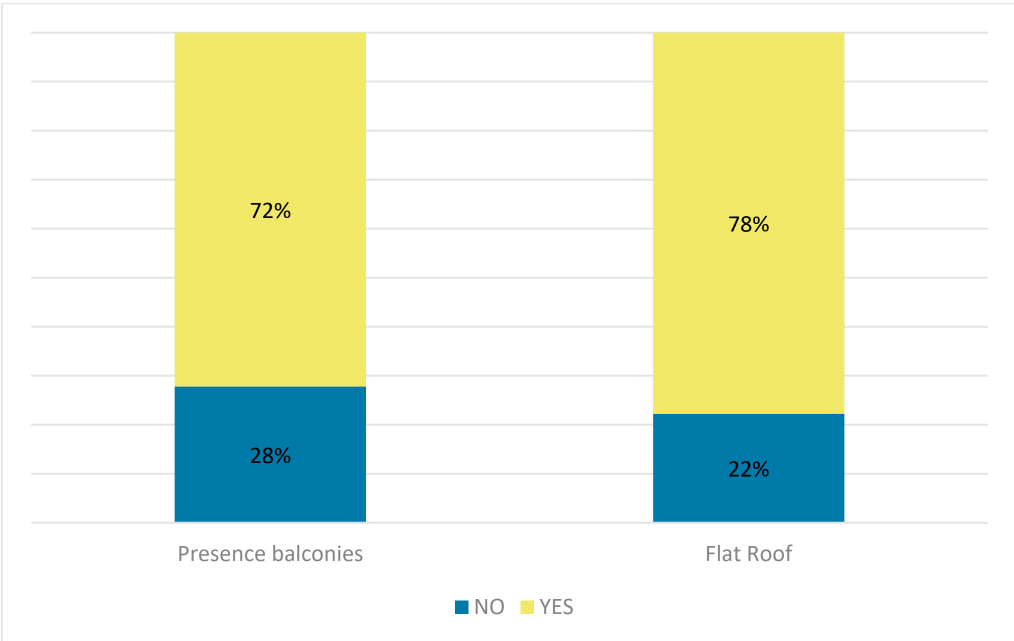


Figure 14 Specific characteristic of buildings in Lleida building stock - Presence of balconies and presence of flat roof

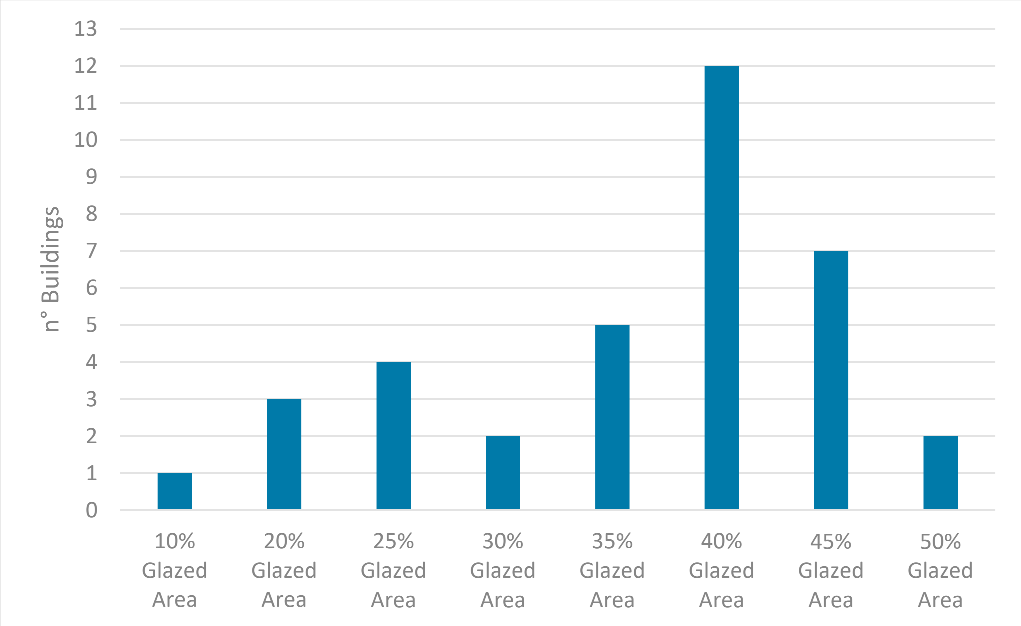


Figure 15 Glazed area percentages in different buildings

5.2 WOONZORG Building Stock

Woonzorg managed buildings accounts to almost 641 units, for a total of approximately 28705 dwellings. These buildings' construction year is estimated from 1900 to 2017 and average apartment area is 65 m2. Table 17 shows the number of buildings within the building stock in different ranges of construction years. Table 18 also presents the number of building in National energy labels categories.

Construction year	N° Buildings	N° Dwellings	Typical building of that period (these buildings have been taken from Woonzorg building stock)
Before 1950	5	171	

From 1950 to 1970	20	688	
From 1970 to 1990	335	17,446	
From 1990 to 2000	158	6,268	
From 2000 to 2017	121	4,131	

Table 17 Woonzorg's building stock construction years

	Dutch Energy Labels in Buildings						
Construction period	**a**	**b**	**c**	**d**	**e**	**f**	**g**
Before 1950	19	3	19	33	28	25	44
From 1950 to 1970	26	43	261	75	106	128	28
From 1970 to 1990	1150	2537	4804	5453	2012	745	325
From 1990 to 2000	1588	1816	2047	681	123	3	1
From 2000 to 2017	3105	805	177	31	1	0	0

TOTAL	5888	5204	7308	6273	2270	901	398

Table 18 Number of buildings of Woonzorg building stock subdivided per energy labels and construction period

For existing residential buildings, following the National Agreement, the Label after renovation should be at minimum "b".

The buildings managed by Woonzorg are approximately 95% building block typology with outer balconies, similar to the Dutch demo case "Marienheuvel".
Two main undercategories can be identified in this building stock:

- With the corridors in the middle, apartments on both sites (same as the 4RinEU demo case)
- With (open) corridors on one side of the building and apartments on the other side.

Roofs are mainly flat while pitched typology is more rare. Estimated percentages are presented in Figure 16.

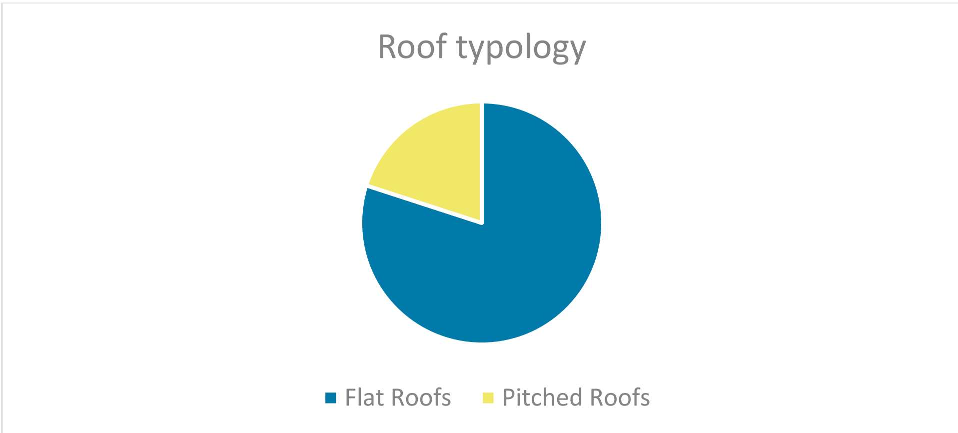


Figure 16 Percentages flat and pitched roofs

6 Renovation potential estimation

After analysing the different building stocks provided by AHC and Woonzorg, an estimation on the renovation potential has been performed. This outcome combined with results on different KPIs related thematic areas coming from this deliverable and Deliverable 3.3, will provide a quantitative evaluation on the renovation potential in such contexts (4RinEU Deliverable 5.5)
In the following tables, percentages on total building stock where 4RinEU renovation packages can be potentially applicable are reported.

6.1 AHC Building Stock Renovation Potential

Concerning AHC's building stock, information from the most general and bigger pool of buildings available from AHC have been considered. In particular, from the 20365 total apartments managed by the Agència (grouped approximately in 1000 buildings), a selection of 688 buildings have been taken into account. This selection consists of Social apartments in Public Residential building blocks, whose construction years is from 1930 up to 2010. Hence, being these buildings completely managed by AHC, they represent the most appropriate typology to undergo deep renovation.

Therefore, the replication potential evaluation will focus on **688 buildings (~69% of AHC total building stock**); taking into account building stock differentiations described in Chapter 5.1 related to AHC total building stock context:

- the *80% (550 buildings)* of them will be considered as isolated multifamily houses, where timber prefabricated façade can be applied on 4 sides,
- while the remaining *20% (138 buildings)* will be considered as adjacent to other constructions, with prefabricated timber façade applied only on two (main) sides.

Since no specific diffused obstacles for the use of **active technologies within prefabricated façade** have been identified in AHC building stock, their application will be investigated indistinctively, as well as the **use of smart ceiling fan** inside apartments. In fact, although in the demo building of the 4RinEU Project the use of ceiling fan was not possible due to low floor-to-ceiling height, it is plausible that the smart ceiling fans will be adapted to similar indoor spaces heights after future technology developments (having a floor-to-ceiling distance <2.6m is a very common situation around Europe).

6.2 WOONZORG Building Stock Renovation Potential

Woonzorg building stock consists of approximately 641 buildings (corresponding to almost 28,705 apartments) almost totally identifiable with the multifamily house archetype defined in 4RinEU. **The 67% of the buildings (427)** are categorized with energy label b or less. Therefore, the renovation potential will be analysed specifically on these buildings in project Deliverable 5.5.

As for the AHC building stock, since no specific obstacles for the application of certain 4RinEU renovation packages have been identified in a generalized way, the application of the main renovation packages will be taken into account without further distinctions.

Hence, different renovation potential scenarios will be provided.

7 Conclusions

In this deliverable, after having identified the main constraints and building features possibly affecting 4RinEU renovation approach, a selection of the best performing renovation packages from D3.3 have been defined, taking into account the main KPIs in different thematic areas.

Moreover, further simulations have been performed to identify the performances due to 4RinEU renovation in specific contexts, depending on specific geocluster's building stock constraints.

Finally, a more detailed analysis of AHC and Woonzorg building stocks have been presented.

This information, combined to the assessment of the performances in those specific contexts, coming both from additional simulations and D3.3 results, will provide the outcome for the renovation potential quantification, in terms of energy, CO_2 emissions and investments reduction compared to the actual condition of the building stock. This analysis will be part of Deliverable 5.5.