4RinEU

Reliable models for deep renovation

D2.1

WP2

Geo-clusters and Building Archetypes

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Foreword

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

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

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

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

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

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

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

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

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Executive Summary

4RinEU project deliverable 2.1 contains the description of the methodology which brought to the definition of a structured repository of simulation results. The outputs come from the application of the renovation packages, further analysed in Project Deliverable 3.3, to the different geo-clusters and building archetypes defined hereby.
The subdivision in geo-clusters has been defined dividing Europe into six areas (keeping the division based on National boundaries), according to the features of the residential building stock, the average building performances provided by the law and climatic conditions. In relation to 4RinEU project, each geo-cluster includes either a demo case or an early adopter (EA) building where the renovation packages will be integrated respectively with a real implementation (demos) or a feasibility study.

In order to populate the repository, four building types have been identified in each geo-cluster. These building archetypes are the most frequent and representative for the geo-clusters. Pieces of information on them have been extracted from the Tabula data tool available online.

The performances of the 4RinEU deep renovation packages are evaluated using a set of Key Performance Indicators (KPIs), set as the outputs of the parametric study.

The evaluated thematic areas considered within the project are energy, comfort, environment, economic issues and building site management (these last two thematic areas are implemented in the repository of results used by Project Deliverable D4.2, concerning the Cost-effective rating tool).

The deep renovation packages were adapted to each geo-cluster and their performances were tested by means of dynamic annual thermal simulations performed with hourly time-step using Trnsys (TRNSYS Various contributors, 2017).
The different combinations between renovation packages have been studied performing a parametric analysis in JEplus tool per each of the 4 building geometries in the 6 climatic areas.
In the table here below, the summary of the possible combination modelled in the parametric analysis is shown; only parameter referring to the possible renovation packages are shown since the existing condition of the building has been simulated apart.
In general, 289 simulations have been done per each geo-cluster and building archetype, for a total of 6936 simulations.

PARAMETER	Involved controls/technologies	COMBINATIONS
RETROFIT CONDITION	Shading control, infiltration control, traditional heating system efficiency, cooling system operability	1

TRADITIONAL HEATING SYSTEM	Heating performed by a traditional system	2
HEAT PUMP HEATING SYSTEM	Heating performed by a heat pump	
NO MECHANICAL VENTILATION	No mechanical ventilation is used	3
DECENTRALIZED VENTILATION MACHINE	Mechanical ventilation provided by a decentralized system	
CENTRALIZED VENTILATION MACHINE	Mechanical ventilation provided by a centralized system	
PV INTEGRATED	PV panels presence within the building	2
CEILING FAN & COOLING SYSTEM	Ceiling fan presence within the building (different working combinations)	3
RETROFIT WALL TYPOLOGY	Two different layouts of the prefabricated panel performing the renovation of the envelope	2
WINDOW TYPOLOGY	Two different new window typologies to be installed	2
SHADING SYSTEM	Presence of a shading system	2
TOT =288 + 1 (existing case)		

The repository of results comes from the parametric simulation work providing results in the KPIs thematic area for the four building typologies in the six geo-clusters.

The repository consists of four Excel files (one per each building typology: Apartment Block, Multi-Family House, Single Family House, Terraced House).

Each row of the file corresponds to one simulation. 1734 simulations are collected per each building type (289 simulations per each geo-cluster).

The repository of results is stored on Zenodo.com (DOI: 10.5281/zenodo.4475691) and it allows the comparison between different renovation scenarios being the starting point for a preliminary analysis in the design phase.

1 European Geo-cluster Division

In order to provide a European framework for the parametric analysis of the renovation package performances, Europe has been divided into six geo-clusters, according to the features of the residential building stock (share of single and multi-family houses), the average building performances provided by the law (in terms of U-value for the envelope) and climatic conditions. National boundaries have been used since they influence technical constraints and legislative requirements in case of renovation (Figure *1*). In relation with 4RinEU project, each geo-cluster includes either a demo case or an early adopter (EA) building where the renovation packages will be integrated respectively with a real implementation (demos) or a feasibility study:

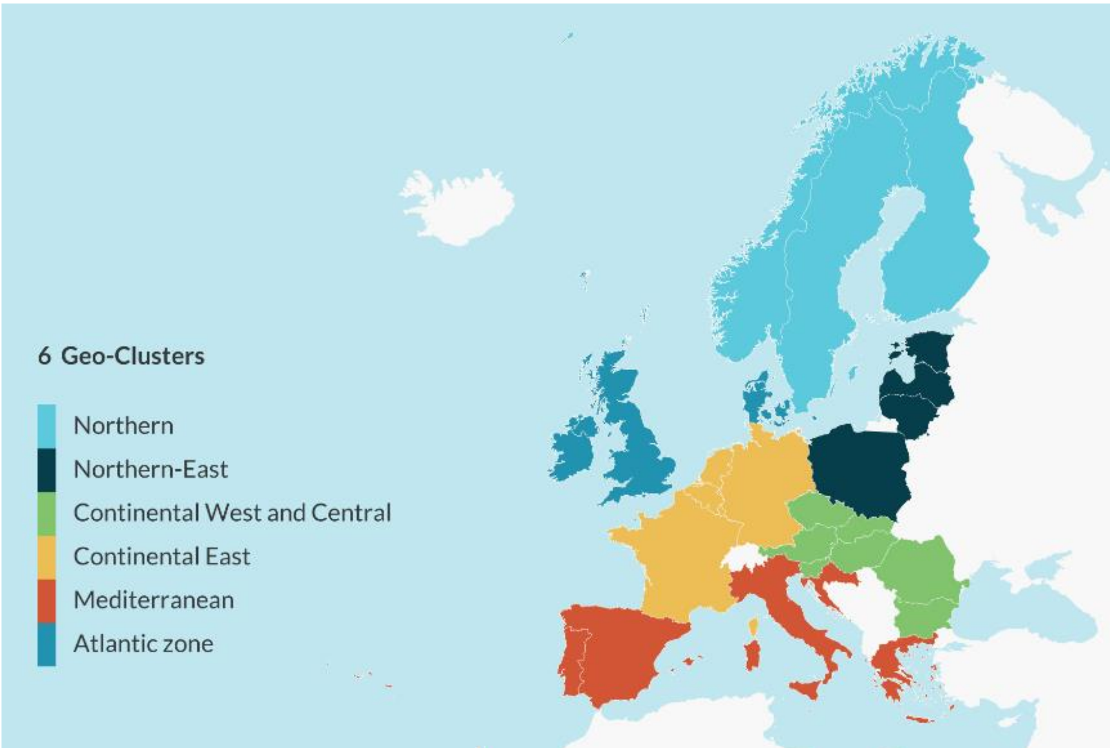


Figure 1. 4RinEU Geo-cluster division

- **Geo-cluster 1:** Northern EU. Northern Europe countries with cold climate and prevalence of single-family houses. Within the cluster, the 4RinEU renovation approach will be implemented in Demo-Case 1, which is a small multi-family house in Norway.

- **Geo-cluster 2:** Northern-East. Countries with cold climate, large amount of multi-family houses built between 1960 and 1990, with prefabricated concrete panels that present low energy performance. 4RinEU will develop specific renovation packages for this kind of constructions to be implemented in an early adopter building in Poland.

- **Geo-cluster 3:** Continental West and Central. This cluster includes central and West Europe. The building stock in the cluster is mainly composed of single-family houses and there is no prevailing construction period, thus, the stock presents different construction features (masonry, concrete or prefabricated structure) and 4RinEU renovation approach will be applied to Demo-Case 2 in the Netherlands.

- **Geo-cluster4:** Continental East. Continental climate, main building typology is single-family with a significant amount of multi-family houses built after the 2nd World War with prefabricated concrete structure.

- **Geo-cluster 5:** Mediterranean. This cluster includes Mediterranean countries with warmer climate where the building stock is split almost equally in single and multi-family houses built in different construction periods mainly with masonry or concrete structures. 4RinEU will implement the solutions in Demo-Case 3, a multi-family house in Spain.

- **Geo-cluster 6:** Atlantic zone. Focused on the UK area, with cold oceanic climate and single-family houses as main building type. 4RinEU will be implemented in an early adopter building in the UK.

2 Description of the selected KPIs

The performances of the 4RinEU deep renovation packages are evaluated using a set of Key Performance Indicators (KPIs), set as the outputs of the parametric study.

The evaluated thematic areas considered within the project are:

- **Energy**: indicators dealing with the energy consumptions of the building and with the energy produced with Renewable Energy Sources (RES). In particular, both energy demand, energy consumption and primary energy consumption have been considered for all the energy-consuming technologies within the building or integrated into the renovation packages.

- **Comfort** and Indoor Air Quality (IAQ): indicators dealing with users' comfort and indoor air quality.

- **Environment**: evaluation of the environmental impact of the building after the renovation

- **Economic issues**: evaluation of the NPV of the renovation calculated along 25 years from the intervention; moreover, the investment cost and energy cost for the renovation.

- **Building site management**: indications on the renovation time due on building site.

In the following Table 1, the detailed list of evaluated KPIs are listed.

Topic and KPI name	Explanation
Energy	
Total heating demand	Yearly net energy demand for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Total cooling demand	Yearly net energy demand for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Heating demand per m^2	Yearly net energy demand for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Cooling demand per m^2	Yearly net energy demand for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Heating consumption [kWh/y]	Yearly final energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Heating consumption [kWh/m2/y]	Yearly final energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Primary energy heating [kWh/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Primary energy heating [kWh/m2/y]	Yearly primary energy consumption for heating as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
Cooling consumption [kWh/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes"
Cooling consumption [kWh/m^2/y]	Yearly final energy consumption for cooling as calculated considering the boundaries set in Annex A of Deliverable 2.1 "Geo-clusters and Building Archetypes" and normalised according to the heated building surface
DHW demand kWh/year	Yearly energy demand for Domestic Hot Water production
Ventilation consumption [kWh/y]	Final Energy consumption for mechanical ventilation
Ceiling fan consumption [kWh/y]	Final energy consumption for the operation of the comfort ceiling fans

PV power produced [kW/y]	Yearly energy produced by the photovoltaic system (if installed during renovation)
Environment	
CO_2 emissions heating [kg/y]	Yearly CO_2 emissions for heating
CO_2 emissions cooling [kg/y]	Yearly CO_2 emissions for cooling
Comfort & IAQ	
CAT_1_PPM [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the CO_2 concentration calculated in a sample room - number of hours in optimal indoor air quality conditions
CAT_2_PPM [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the CO_2 concentration calculated in a sample room - number of hours in acceptable indoor air quality conditions
CAT_I_Adpt [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the indoor temperature and relative humidity conditions in summer period calculated in a sample room - number of hours in optimal thermal comfort conditions (evaluated in cooling period)
CAT_II_Adpt [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the indoor temperature and relative humidity conditions in summer period calculated in a sample room – number of hours in acceptable thermal comfort conditions (evaluated in cooling period)
pmv_zone2_CatI [hours/year] (OPTIMAL)	Number of hours in comfort category I (EN ISO 15251) according to the Predicted Mean Vote of the occupants during winter period calculated in a sample room – number of hours in optimal thermal comfort conditions (evaluated in heating period)
pmv_zone2_CatII [hours/year] (ACCEPTABLE)	Number of hours in comfort category II (EN ISO 15251) according to the Predicted Mean Vote of the occupants during winter period calculated in a sample room – number of hours in acceptable thermal comfort conditions (evaluated in heating period)
Economic issues	
Total investment cost [€]	Investment costs related to technology and/or installation works and materials on building site – more details in Appendix B of Deliverable 4.2
Total investment cost, factor [€]	Investment costs related to technology and/or installation works and materials on building site; adjusted using a country-specific proportional cost factor – more details in Appendix B of Deliverable 4.2
Approximated LCC 50 years [€]	Life Cycle Cost of the building calculated for 50 years after renovation considering investment cost for the interventions, energy supply during operation and maintenance – more details in Appendix B of Deliverable 4.2
Approximated LCC 50 years, factor [€]	Life Cycle Cost of the building calculated for 50 years after renovation considering investment cost for the interventions, energy supply during operation and maintenance; adjusted using a country-specific

	proportional cost factor – more details in Appendix B of Deliverable 4.2
Building site management	
Time on building site [hours]	Number of hours needed for the installation of 4RinEU renovation packages - installation/mounting works – more details in Appendix B of Deliverable 4.2

Table 1 Evaluated KPIs

A special remark should be done concerning the time reduction on building site due to the prefabricated renovation approach.

In fact, the use of prefabrication allows to manufacture off-site the modules, reducing possible mistakes and failure, while increasing productivity and safety during construction.

The remaining works to be performed on-site will consist of the installation of modules and the wires connection to electricity, depending on the technologies installed during prefabrication. Furthermore, some additional finishes between the existing structure and the new elements must be performed.

Moreover, the prefabrication approach allows for a lean construction management methodology, where different actors have clear responsibilities, avoiding delays and mistakes throughout the process.

Time on building site can be further reduced if BIM approach is implemented during the construction. In the Table 2, some of the most important actions along the prefabrication process which may foster on-site time reduction are listed:

Actions shifted during the industrial process
Fixing, positioning and levelling of the insulation panel, mechanical fixing of the insulation panel, Installation of new windows and new windowsills, Installation of the decentralized ventilation machines, Installation of the new boiler for heating and DHW, Installation of the heating distribution system, installation of PV system and solar thermal collectors
Actions not necessary with 4RinEU
Installation of corner pieces, Application of the primer coat, a base mortar over the insulation panel and reinforcing mesh, application of the finishing coat
Actions improved through Lean Management of the building site
Preparation of the building site; removal of the facade cladding, removal of existing windows, removal of existing windows sills
Further actions needed for the installation of 4RinEU packages
Preparation of the façade, anchoring system installation, crane installation of the façade; Connection of integrated systems (HVAC + PV + ST)

Table 2 Actions possibly fostering on-site time reduction

3 Definition of building archetypes in the geo-clusters

For each geo-cluster, we selected four representative building archetypes in the respective reference country. The source for this selection was the national building typologies developed as part of the Tabula project, which is available via the combined Episcope and Tabula website (http://episcope.eu/building-typology/country/). Within Tabula, a number of residential building typologies have been developed. For each country, a summary of the results can be found on the respective country page. An overview of the corresponding national building typology is given by a "Building Type Matrix". Within this table, particular example buildings are defined, representing different building sizes and construction periods. All 4RinEU archetypes are selected among these example buildings. Technical data for the archetypes have been extracted from the Tabula data tool, which is available at http://webtool.building-typology.eu/#bm.

We selected the archetypes mainly according to statistical relevance in the respective country, but secondarily also according to the assumed need for renovation and suitability for refurbishment with prefabricated façade elements (the letter means, examples for historic buildings should not be selected). Our main source for this assessment was the basic statistics on the frequencies of building types and supply system types, available on the respective Tabula country page. Furthermore, we verified the information by using statistics from the INSPIRE project and the EU Building Observatory database, as well as additional evidence within Tabula country reports.

For **Norway**, it was adequate to choose three different construction periods (the numbers of dwelling units are quite evenly distributed). Single-family homes are predominant in Norway. We opted anyhow for a semi-detached type as a reference for the time up to 1955. This type is according to Norwegian rules listed as a terraced house. In reality, however, the type resembles more a SFH than a TH. In addition, the semi-detached one is more typical for the early period than the SFH type listed in the Tabula matrix. For apartment buildings, we selected an archetype from 1956-1970, even though before 1956 more apartments were built. There are many different construction types in the earlier decades, so that it would be difficult to define one typical archetype for this long period. Moreover, many of these older construction types have façades where insulation could not be added easily, or they already have been renovated. There is a bigger potential for façade renovation of apartment buildings from the 1960s (and 70s), in particular when it comes to prefabricated elements. All up, we chose three small houses and one apartment block (large MFH).

Geo-cluster 1	Reference Country	Norway
	Reference City	Oslo
	4RinEU Code	**G1_NO_SFH_02**
	Tabula_Code:	NO.N.SFH.02.Gen
	Building Size Class:	SFH
	Construction Period:	1956 - 1970
	Reference Floor Area:	228 m^2
	4RinEU Code	**G1_NO_SFH_03**
	Tabula_Code:	NO.N.SFH.03.Gen
	Building Size Class:	SFH
	Construction Period:	1971 - 1980
	Reference Floor Area:	152 m^2
	4RinEU Code	**G1_NO_TH_01**
	Tabula_Code:	NO.N.TH.01.Gen
	Building Size Class:	TH
	Construction Period:	Before 1955
	Reference Floor Area:	216 m^2
	4RinEU Code	**G1_NO_AB_02**
	Tabula_Code:	NO.N.AB.02.Gen
	Building Size Class:	AB
	Construction Period:	1956 - 1970
	Reference Floor Area:	1526 m^2

Table 3 Info typical building Geo-cluster 1

In **Poland**, both single-family and multi-family houses are important, with a higher number of dwellings in SFH, but higher total living space in MFH. Therefore, it could be suggested two SFH. Nevertheless, since there is a big potential for renovating newer panel constructions, we dropped one of the SFH archetypes in favour of a large apartment building, in addition to one small MFH and one large MFH archetype, representing the most important construction periods.

Geo-cluster 2	Reference Country	Poland
	Reference City	Warsaw
	4RinEU Code	**G2_PL_SFH_01**
	Tabula_Code:	PL.N.SFH.01.Gen
	Building Size Class:	SFH
	Construction Period:	...1945
	Reference Floor Area:	71 m^2

	4RinEU Code	G2_PL_SFH_02
	Tabula_Code:	PL.N.SFH.02.Gen
	Building Size Class:	SFH
	Construction Period:	1946...1966
	Reference Floor Area:	98 m2
	4RinEU Code	G2_PL_MFH_02
	Tabula_Code:	PL.N.MFH.02.Gen
	Building Size Class:	MFH
	Construction Period:	1946...1966
	Reference Floor Area:	1963 m2
	4RinEU Code	G2_PL_AB_03
	Tabula_Code:	PL.N.AB.03.Gen
	Building Size Class:	AB
	Construction Period:	1967...1985
	Reference Floor Area:	4246 m2

Table 4 Info typical building Geo-cluster 2

In the **Netherlands**, terraced houses are most important (mid-and end-row is counted as one archetype), but there is also a significant share of older detached houses and apartment blocks. Therefore, we included also an archetype for apartment blocks. However, due to the low suitability for renovation with prefabricated elements, we omitted the single-family home in favour of an additional terraced house archetype. When it comes to TH, one could discuss if older periods are more important than 1965-1974. Still, there were too many different construction types in the decades before 1965 and especially before 1946, so that it would be difficult to define one typical archetype for this long period. For this reason, we discarded an older TH type. Incidentally, nearly all Dutch Tabula example buildings have brick façades, which therefore also determines the choice of archetypes. Nevertheless, in the Netherlands, it is not uncommon to insulate brick façades on the outside (see also challenge description in the UK section), although it is most common to insulate the typical cavity wall construction by filling the cavity. External and internal insulation is mainly used when a thermal bridge in the cavity occurs, or in case the cavity is smaller than 50 mm.

Geo-cluster 3	**Reference Country**	The Netherlands
	Reference City	Amsterdam
	4RinEU Code	G3_NL_SFH_01
	Tabula_Code:	NL.N.SFO.01.Gen

	Building Size Class:	SFH
	Construction Period:	... 1964
	Reference Floor Area:	196 m²
	4RinEU Code	G3_NL_AB_01
	Tabula_Code:	NL.N.AB.01.Por1945
	Building Size Class:	AB
	Construction Period:	... 1964
	Reference Floor Area:	4219 m2
	4RinEU Code	G3_NL_TH_02
	Tabula_Code:	NL.N.TH.02.Gen
	Building Size Class:	TH
	Construction Period:	1965 ... 1974
	Reference Floor Area:	117 m2
	4RinEU Code	G3_NL_TH_03
	Tabula_Code:	NL.N.TH.03.Gen
	Building Size Class:	TH
	Construction Period:	1975 ... 1991
	Reference Floor Area:	117 m2

Table 5 Info typical building Geo-cluster 3

In the **United Kingdom**, terraced houses (including semi-detached) are totally dominating (all Tabula examples are from England). We selected three TH archetypes from their three main construction periods. In addition, we chose one newer MFH archetype (which would be more suitable for external façade insulation than MFH archetypes from former construction periods). Although multi-family houses represent only 20 % of the stock, their share is higher than that of single-family homes.

In the case of Great Britain, there are limited options to select archetypes: All UK archetypes in the Tabula data tool have (completely or partly) brick façades. There are no other options to choose from. This simply reflects the British (English) building tradition. Brick façades are a challenge, but in practice, a significant part of the "historic" façades could be insulated externally. In a Tabula background report, BRE lists up challenges and constraints, but external façade renovation is considered in all cases, except archetypes with cavity walls.

Geo-cluster 4	**Reference Country**	UK
	Reference City	London

	4RinEU Code	G4_UK_TH_01
	Tabula_Code:	GB.ENG.TH.01.Gen
	Building Size Class:	TH
	Construction Period:	...1918
	Reference Floor Area:	105 m²
	4RinEU Code	G4_UK_TH_02
	Tabula_Code:	GB.ENG.TH.02.Gen
	Building Size Class:	TH
	Construction Period:	1919...1944
	Reference Floor Area:	93 m²
	4RinEU Code	G4_UK_TH_03
	Tabula_Code:	GB.ENG.TH.03.Gen
	Building Size Class:	TH
	Construction Period:	1945...1964
	Reference Floor Area:	88 m²
	4RinEU Code	G4_UK_MFH_01
	Tabula_Code:	GB.ENG.MFH.01.Gen
	Building Size Class:	MFH
	Construction Period:	...1918
	Reference Floor Area:	425 m²

Table 6 Info typical building Geo-cluster 4

In **Hungary**, single-family homes are dominating, but unfortunately, the statistics are more detailed according to different dwelling sizes than according to building periods. Most dominating are SFH above 80 m² built in the long period from 1945 to 1979, but only one suitable archetype is registered in the Tabula webtool. Therefore, we selected also one smaller SFH from this period, in addition to the suitable larger one. The other chosen types are an example for a large industrialised "panel" building and an example for an "ordinary" MFH, both from the same period (which is the most relevant for MFH) and well suited for renovation with prefabricated elements.

Geo-cluster 5	Reference Country	Hungary
	Reference City	Budapest
	4RinEU Code	G2_PL_SFH_01
	Tabula_Code:	HU.N.SFH.02.Gen
	Building Size Class:	SFH
	Construction Period:	1945...1979

	Reference Floor Area:	116 m²
	4RinEU Code	G5_HU_SSFH_02
	Tabula_Code:	HU.N.SFH.02.Bel80
	Building Size Class:	SFH
	Construction Period:	1945...1979
	Reference Floor Area:	59 m²
	4RinEU Code	G5_HU_AB_02
	Tabula_Code:	HU.N.AB.02.Ind
	Building Size Class:	AB
	Construction Period:	1945...1979
	Reference Floor Area:	2390 m²
	4RinEU Code	G5_HU_MFH_01
	Tabula_Code:	HU.N.MFH.02.Gen
	Building Size Class:	MFH
	Construction Period:	1945-1979
	Reference Floor Area:	838 m²

Table 7 Info typical building Geo-cluster 5

In **Spain**, the building period from 1971 to 1980 has the biggest share. Building types are statistically divided into single-unit houses and multi-unit houses (two or more dwellings). Dwellings in multi-unit houses make up more than two-thirds of the whole residential stock, and even more in the 1960s and 1970s building periods. We selected archetypes for both single-family, multi-family and apartment blocks from the 1960-79 period (the Tabula building type matrix does not distinguish the 1960s and 1970s). In addition, we chose one older MFH archetype, suitable for prefabricated element renovation.

Geo-cluster 6	**Reference Country**	Spain
	Reference City	Barcelona
	4RinEU Code	**G6_ES_MFH_01**
	Tabula_Code:	ES.ME.MFH.03.Gen
	Building Size Class:	AB
	Construction Period:	1937...1959
	Reference Floor Area:	1394 m²
	4RinEU Code	**G6_ES_MFH_02**

	Tabula_Code:	ES.ME.MFH.04.Gen
	Building Size Class:	MFH
	Construction Period:	1960…1979
	Reference Floor Area:	1267 m²
	4RinEU Code	**G6_ES_SFH_01**
	Tabula_Code:	ES.ME.SFH.04.Gen
	Building Size Class:	SFH
	Construction Period:	1960…1979
	Reference Floor Area:	171 m²
	4RinEU Code	**G6_ES_AB_01**
	Tabula_Code:	ES.ME.AB.04.Gen
	Building Size Class:	AB
	Construction Period:	1960…1979
	Reference Floor Area:	1942 m²

Table 8 Info typical building Geo-cluster 6

4 Repository of buildings and 4RinEU deep renovation packages

The aim of the simulation activity is to assess the effectiveness of 4RinEU renovation packages on the selected KPIs on a sample of buildings that are representative of a significant part of the EU building stock.

The outputs of the simulations compose the so-called “Repository”, a comprehensive database including all the information and data dealing with the modelling and with the performance evaluation of the 4RinEU renovation packages.

This section describes the structure of the “Repository” that has been populated with the results of the simulation campaign of the building archetypes, early adopters and demo cases.

In particular, it is structured as follows:

Section 1 - Existing building features: it includes all the characteristics adopted for simulating the baseline performance scenario of the buildings (archetypes, early adopters and demo cases)

Section 2 – Renovation packages: it reports the technologies adopted for the renovation packages for each geo-clusters. It is the base for defining the parametric simulations to evaluate the performances of the building archetypes.

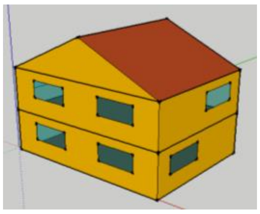
Section 3 – Simulation activity: it describes how the simulation and parametric analysis providing results for the repository have been performed.

Section 4 – KPIs: it reports the KPIs representing the performances of each renovation package.

It is important to underline that the boundary conditions described here below are general and adopted for the overall EU, with some adaptations at country level according to the availability of information. For the specific simulations to be carried out for the demo cases, specific data provided by the building owners and deduced during the auditing phase will be applied. In case of lack of specific information concerning the boundaries of the demo cases, it would be possible to adopt the values as reported in this document.

4.1 Section 1- Existing building features

All 4RinEU archetypes for building the repository have been selected among the example buildings. However, in order to keep the number of models manageable, four main geometries have been identified and used for the simulation in each geo-cluster (Table 9).

Geo-cluster Geometry	Building characteristics
	Archetype: TERRACED HOUSE (TH) Reference floor area: 88 m^2 Floor Height: 2.8 m
	Archetype: SINGLE FAMILIY HOUSE (SFH) Reference Floor Area: 228 m2 Floor Height: 2.5 m

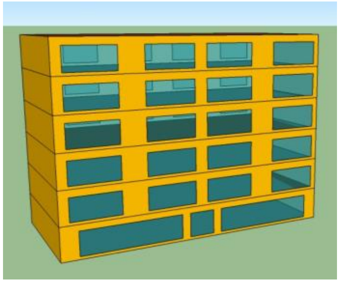
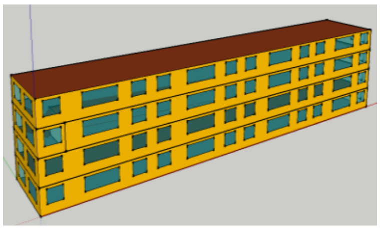
	Archetype: APARTMENT BLOCK (AB) Reference Floor Area: 1330 m2 Floor Height: 2.6 m
	Archetype: MULTIFAMILY HOUSE (MFH) Reference Floor Area: 3456 m2 Floor Height: 2.8 m

Table 9 Simulated geo-cluster geometries

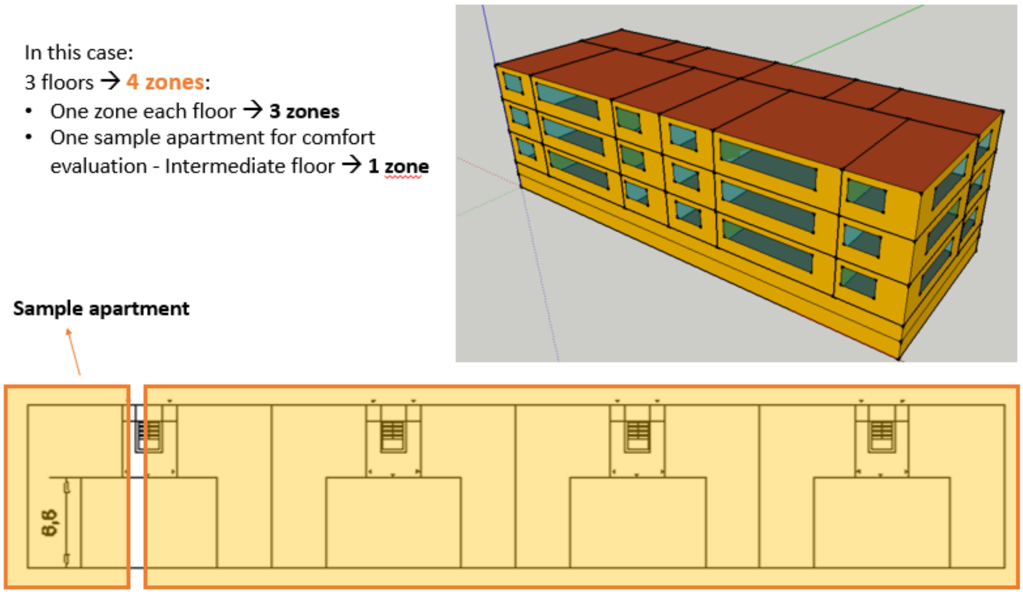
Although the geometries were identical in each geo-cluster (e.g. windows number and dimensions), the envelope's characteristics have been varied according to the typical features of each geo-cluster.
Technical data for the archetypes have been extracted from the Tabula data tool. Therefore, the existing building's envelope characteristics (i.e. wall, roof, window glazing and window frame) have been defined for each geo-cluster.

4.2 Section 2- Renovation packages

This section describes the steps for evaluating the performances of the renovation packages. At first, the main boundaries and modelling assumptions are presented, then the technologies included in the renovation packages (RPs) and the simulation for assessing the impact on the project KPIs. In this research, several deep renovation technologies were combined into different possible renovation packages that were likely to be energy effective in the European context.
In the following section, the main boundary conditions and simulation approach for modelling different renovation packages in Trnsys are presented.

4.2.1 Zoning

In order to simplify the computational effort, we decided to define one zone for each floor and to select one sample apartment for evaluating the comfort parameters.



4.2.2 Infiltration control

The infiltration values of the zones have been calculated in accordance with an empirical method suggested by the ASHRAE K_1, K_2 and K_3 (ASHRAE, 1989) model. Therefore, it has been possible to evaluate the air changes per hour (ACH) in the thermal zones at each time-step of the simulation (Equation 1).

$$ACH_{INF} = K_1 + K_2 * (T_{zone} - T_{out}) + K_3 * V_w \qquad (1)$$

Where K_1, K_2, K_1 are coefficients, T_{zone} is the temperature of the thermal zone in [°C], T_{out} is the temperature of the outdoor ambient in [°C] and V_w is the wind velocity in [m/s]. ASHRAE indicates different values of the K coefficients (Table 10) depending on the air tightness quality of the building envelope. In this study, loose quality has been assigned to the existing case, while tight quality to the retrofitted condition.

Construction Quality	K_1	K_2	K_3	Description
Loose	**0.1**	**0.023**	**0.070**	**Evidence of poor construction on older buildings where joints have separated**
Medium	0.1	0.017	0.049	Building constructed using conventional construction procedures
Tight	**0.1**	**0.011**	**0.034**	**New building in which special precautions have**

				been taken to prevent infiltrations

Table 10 K coefficients values for infiltration calculation

4.2.3 Natural ventilation

In this model, the proposed strategy links the window openings to the hour of the day, zone occupancy and the indoor and outdoor temperature. The opening from 7:00 to 21:00 occurs with ambient temperature between 18°C and 28°C and if the indoor temperature is out of the range 20.5°C and 26°C. During the night (22:00 to 6:00) only if the outdoor temperature is between 20.5°C and 25°C. Natural ventilation is designed to provide 2 ACH.

4.2.4 Heating system – existing condition

The heating system has been modelled in a simplified way, by assigning an efficiency to the building sub-systems. In the case of existing building, where the system is supposed to have low performances, low-efficiency values have been assigned to the emission (0.9), regulation (0.94), distribution (0.97) and generation (0.82) of the heating system. On the other hand, these efficiencies have been increased in the retrofit case. All the adopted values have been taken from the UNI113000-2 2008.
The chosen set point for the heating system was 20°C.
Moreover, in order to estimate the power capacity of the heating system to be installed, a preliminary steady state calculation has been performed for each geo-cluster, taking into account transmission and ventilation losses. In this way, the maximum power for the heating system has been designed.

4.2.5 Internal gains

The occupancy, appliances and lighting profiles were generated using a stochastic model (Widèn & Wäckelgard, 2010). 20 typical occupancy and use profiles (absent / present_active / present_inactive) are proposed and have been randomly selected for representing the modelled zones (Pernetti, Prada, & Baggio, 2013) (Pernetti, Prada, & Baggio, 2014).
Table 11 reports other parameters needed in order to calculate the gains to be assigned at the internal zones. They have been taken from literature or technical documents (e.g. EN 16798 for people, electric equipment and light density in residential areas).

Parameter	Value	Unit
People density	0.04	[pers/m^2]
Electric equipment power density	3	[W/m^2]
Light power density	3.2	[W/m^2]
Convective fraction of sensible heat gains from persons	0.42	-

Convective fraction of sensible heat gains from electric equipment	0.73	-
Convective fraction of sensible heat gains from lighting	0.60	-
Sensible heat gains form persons	252	[kJ/h]
Latent heat gains form persons	0.08	[kg/h]

Table 11 Internal gains parameters

Here below, the renovation packages modelling is presented. The focus is on the use of a prefabricated timber framed multifunctional façade. These prefabricated modules are designed to be anchored to the existing building envelope and represent the new "skin" integrating functions (i.e. building services and components) and able to strongly increase the lifetime of the building.

The different combinations of the prefabricated façade with the different integrated components and services represent the renovation packages.

In particular, the following variants integrated into the façade have been considered:

- Timber prefabricated element: two types of façade module for retrofit have been considered; they are both composed of a timber frame and cellulose fibre insulation in different thicknesses, ensuring two different values of thermal transmittance.
- Window: two typologies of windows have been used, namely a double low emission glazing and a triple glazing, combined with a high performances frame.
- Ventilation: decentralized (façade integrated ventilation with heat recovery) or centralized ventilation machines (balanced AHU with heat recovery) have been considered in the study, considering that the former can be completely integrated into the prefabricated façade and the latter can partly be integrated (e.g. the ventilation ducts)
- BiPV: photovoltaics panels
- Advanced shading system: an automated external shading system

Moreover, we analysed also three further technologies, not strictly related to the prefabricated façade, but studied by 4RinEU within the renovation packages:

- Cooling system
- Heat pump
- Ceiling fan

4.2.6 Shading control

A shading control system is present both in the existing and in the retrofitted configuration. The main difference is that, while in the existing condition the control is based only on the external incident radiation, in the retrofitted condition the shading system is also activated depending on the indoor and outdoor temperatures.

Shading on windows has been assumed to be activated considering a shading factor of 80% if three conditions are met:

- Global vertical irradiation on the façade element greater than 140 W/m^2
- Room temperature greater than 24 °C (shades removed if < 23 °C)
- 24 hour moving average ambient temperature (previous 24h) greater than 12 °C
-

4.2.7 Traditional heating system – retrofit condition

In the case of retrofit building condition, a condensing boiler has been chosen as a traditional heating system; it has been selected in order to have high performances, therefore high-efficiency values have been assigned to the emission (95%), regulation (99%), distribution (99%) and generation (97%) of the heating system.

4.2.8 Heat pump

In the retrofit condition, the condensing boiler was replaced with a heat pump. A coefficient of performance (COP) of 3 has been chosen for the component as this is a typical value of current systems.

4.2.9 Cooling system

A cooling system with unlimited capacity has been included in the retrofit scenario of the models. Working hours have been set from 8:00 to 16:00 with setback set point during the night. According to the ASHRAE 55 adaptive model, considering the 80 per cent acceptability upper limits, the set point for cooling is variable and depending on the weakly mean outdoor temperature (Tm). The set point is calculated as follows:

$$T_{max(80\%)} = 21.3°C + 0.31*T_m \quad (2)$$

4.2.10 Balanced AHU with heat recovery (Centralized mechanical ventilation)

A possibility for the retrofitted scenario is to have a centralized mechanical ventilation system.
Considering the example of the multi-family house, one machine managing 600 [m^3/h], consuming 140 W, per each floor has been provided. This accounts for 0.25 [ACH] per zone. This system enables also a heat recovery between inlet and outlet air with an efficiency of 0.81.
These values have been taken from a commercial centralized ventilation unit. Two possibilities for infiltration control have been set. On the one hand, no infiltration have been supposed, due to the effect of over-pressure in indoor rooms because of mechanical ventilation. In this condition, in order to ensure the right amount of indoor ACH, a doubled airflow from mechanical ventilation machine has been considered. In the second option, the infiltration rate is taken into account without considering the over pressure effect induced by mechanical ventilation machine.

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

In order to have a mechanical ventilation system in the retrofit, another option is the use of a decentralized system. These machines consume up to 20 [W] and can provide 42 [m^3/h] of airflow with 0.7 heat recovery. When this technology has been used, the chosen ACH per apartment was 0.23 [ACH].
These values have been taken from a commercial decentralized ventilation unit.

4.2.12 PV panels (roof & façade integrated)

PV panels placement for renovated cases has been optimized for each geo-cluster and different building geometries. The optimization has been performed with a Eurac internally developed tool, namely 'Early Reno' (Lovati, Adami, & Moser, 2018). It considers the yearly irradiation, with hourly time-step, on an available set of panels, and suggests as an output the configuration with the best positioning in order to have the highest net present value (NPV) within a defined period. The available positions of the PV panels were given on the roof and on the south façade. The chosen module dimension has been 1.44 m^2 with a peak power of 255 W.

4.2.13 Ceiling fan

Another possible improvement applicable to the retrofitted scenario was smart ceiling fans. Considering that the aim of the ceiling fan is to create an air movement able to lower the perceived temperature by the occupants, and hence reducing the energy demand for space cooling, this was simulated with the method proposed by (Babich, Cook, Loveday, Rawal, & Shukla, 2017). Therefore, in order to account for this effect, in case of ceiling fans operations at 0.9 [m/s], the cooling set point has been increased by +1.8°C.

4.3 Section 3 - Simulation activity

The deep RPs were adapted to each geo-cluster and their performances were tested by means of dynamic thermal simulations.
Annual simulations have been performed with hourly time-step using Trnsys (TRNSYS Various contributors, 2017). The parametric simulation has been performed with JEplus tool (Zhang, 2012).
The different combinations between renovation packages have been studied performing a parametric analysis per each of the 4 building geometries in the 6 climatic areas. The software used has been JEplus. This tool is able to read specific strings referring to the parameters to be changed within the *.dck and *.b17 execution files of Trnsys. Then, it assigns to these parameters the corresponding values given by the user in a "job list". Each raw of this file corresponds to a simulation and it contains the values of each of the parameters to be specified.
In Table 12, the summary of the possible combination modelled in the parametric analysis is shown; only parameter referring to the possible renovation packages are shown since the existing condition of the building has been simulated apart.

In general, for each building archetype (4), in each geo-cluster (6), 289 simulations have been done, providing results for all the Key Performance Indicators.
Hence, the main repository is composed of 6936 simulations. Furthermore, other simulations have been performed for specific contexts as explained in the Project Deliverable 4.4.

PARAMETER	Involved controls/technologies	COMBINATIONS
RETROFIT CONDITION	Shading control, infiltration control, traditional heating system efficiency, cooling system operability	1
TRADITIONAL HEATING SYSTEM	Heating performed by a traditional system	2
HEAT PUMP HEATING SYSTEM	Heating performed by an heat pump	
NO MECHANICAL VENTILATION	No mechanical ventilation is used	3
DECENTRALIZED VENTILATION MACHINE (Façade integrated ventilation with Heat Recovery)	Mechanical ventilation provided by a decentralized system	
CENTRALIZED VENTILATION MACHINE (Balanced AHU with heat recovery)	Mechanical ventilation provided by a centralized system	
PV INTEGRATED	PV panels presence within the building	2
CEILING FAN & COOLING SYSTEM	Ceiling fan presence within the building (different working combinations)	3
RETROFIT WALL TYPOLOGY	Two different layouts of the prefabricated panel performing the renovation of the envelope	2
WINDOW TYPOLOGY	Two different new window typologies to be installed	2
SHADING SYSTEM	Presence of a shading system	2
TOT =288 + 1 (existing case)		

Table 12 Parameter list

4.4 Section 4 - KPIs

The performances of the deep renovation packages are evaluated using a set of Key Performance Indicators (KPIs), set as the outputs of the parametric study. The evaluated thematic areas considered within the project are:

- Energy: indicators dealing with the energy consumptions of the building and with the energy produced with Renewable Energy Sources (RES). In particular, both energy demand, energy consumption and primary energy consumption have been considered for all the energy-consuming technologies within the building or integrated into the renovation packages.
- Comfort and Indoor Air Quality (IAQ): indicators dealing with users' comfort and indoor air quality.
- Environment: evaluation of the environmental impact of the building after the renovation
- Economic issues: evaluation of the NPV of the renovation calculated along 25 years from the intervention; moreover, the investment cost and energy cost for the renovation.
- Building site management: indications on the whole renovation time, differentiating between production of the element and complete intervention.

In this paper, the chosen KPIs are limited to those presented in Table 13:

Energy	
Net Energy demand for heating	[kWh] - [kWh/m2]
Final Energy Demand (considering the efficiency of each subsystem of the heating plant)	[kWh] - [kWh/m2]
Net Energy demand for cooling	[kWh] - [kWh/m2]
Final Energy demand for cooling (considering the efficiency of each sub-system of the cooling plant)	[kWh] - [kWh/m2]
Net Energy demand for DHW production	[kWh] - [kWh/m2]
Final Energy demand for DHW production	[kWh] - [kWh/m2]
Energy demand for ventilation (due to ceiling fans operation and mechanical ventilation)	[kWh] - [kWh/m2]
Energy produced via PV system	[kWh] - [kWh/m2]
Electricity self-consumption	[kWh] - [kWh/m2]
Energy produced via ST systems	[kWh] - [kWh/m2]
ST energy balance	[kWh] - [kWh/m2]
Global Building Energy demand	[kWh] - [kWh/m2]
Environment	
CO_2 Emissions for Heating & Cooling	kg CO_2/year
Comfort & IAQ	

IAQ n°hours categories – Adaptive comfort model (EN15251:2007) (to be used during cooling season)	[h]
IAQ n°hours categories – PMV model (EN15251:2007) (to be used during heating season)	[h]
Overheating Degree Hours (>28)	[°C]
Severe Overheating Degree Hours (>29)	[°C]
CO_2 concentration CAT I, C_out[1] + 350 ppm (EN15251:2007)	[h]
CO_2 concentration CAT II, C_out[1] + 500 ppm (EN15251:2007)	[h]
CO_2 concentration CAT III, C_out[1] + 800 ppm (EN15251:2007)	[h]
CO_2 concentration CAT IV, C_out[1] + >800 ppm (EN15251:2007)	[h]

Table 13 Simulation Outputs

[1] *C_out is the outdoor level of CO_2 and has been taken equal to 400 ppm in all performed simulations*

The results of the simulations are organized in a database containing, for each building, the job list and the assessed KPIs. The added value of the database is the possibility to prioritize the RP according to the category of interest (comfort/energy/environment).
The following section reports some exemplary charts summarizing the results referring to the multifamily archetype in the Netherlands (Continental Central geo-cluster) and showing relations between different KPIs.
In some graphs, different groups of results are highlighted in order to recognize easily the effects of the application of different technologies and simulation settings.
Figure 2 shows some results related to the analyzed building at the non-renovated (existing) condition. Energy demand, energy consumption and primary energy factor conversion are indicated for the heating system of the building, considering a natural gas-fueled traditional boiler. Moreover, one highlighted output is referring to the CO_2 emissions in order to provide the needed heating.

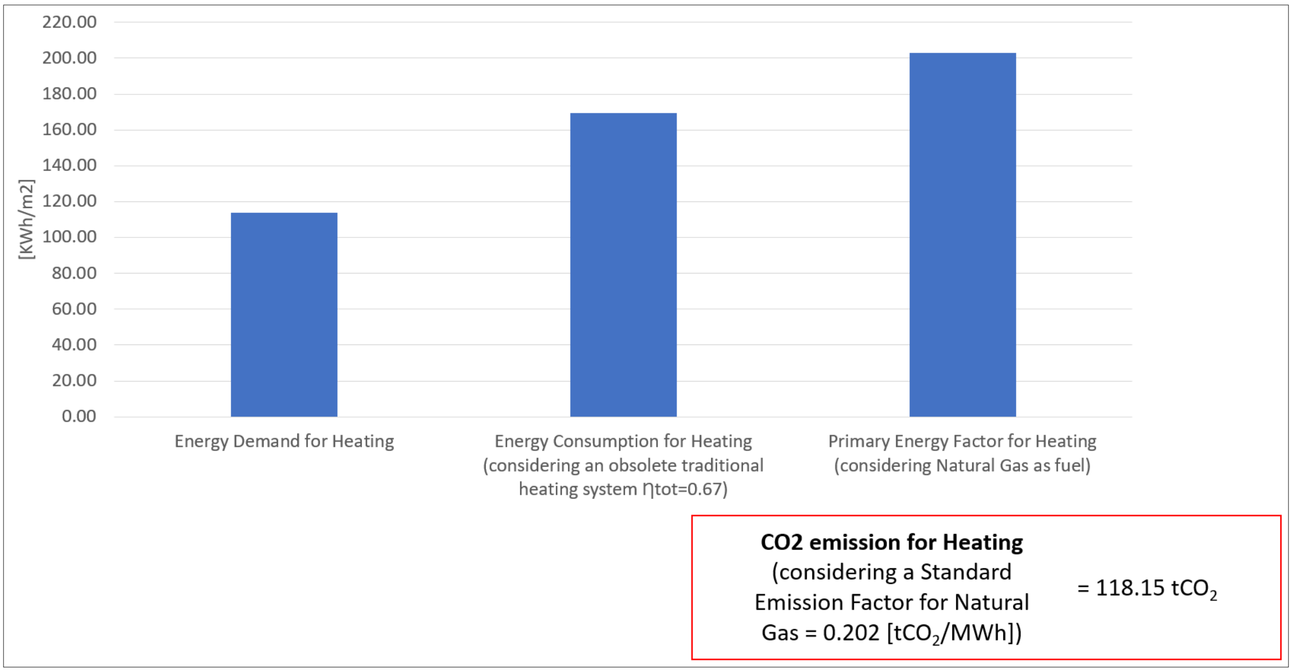


Figure 2 Energy use in the EXISTING condition of the building

Table 14 is summarizing the main parameter list of a preliminary set of simulation performed in order to investigate the effects of some basic renovations intervention on the existing building.
In this set of simulation, not all the parameter described in Table 14 have been taken into account, but only a roof and floor renovation, a variation in the air tightness of the building, the presence of shadings and night cooling.

SIMULATION ID	WALL TYPOLOGY	WINDOW TIPOLOGY	ROOF TIPOLOGY	FLOOR TIPOLOGY	HIGH TIGHTNESS	SHADING PRESENCE	NIGHT COOLING
0	existing wall	existing window	existing roof	existing floor	NO	NO	NO
1	existing wall	existing window	existing roof	existing floor	NO	NO	YES
2	existing wall	existing window	existing roof	existing floor	NO	YES	NO
3	existing wall	existing window	existing roof	existing floor	NO	YES	YES
4	existing wall	existing window	existing roof	existing floor	YES	NO	NO
5	existing wall	existing window	existing roof	existing floor	YES	NO	YES
6	existing wall	existing window	existing roof	existing floor	YES	YES	NO
7	existing wall	existing window	existing roof	existing floor	YES	YES	YES

8	existing wall	existing window	existing roof	retrofit floor	NO	NO	NO
9	existing wall	existing window	existing roof	retrofit floor	NO	NO	YES
10	existing wall	existing window	existing roof	retrofit floor	NO	YES	NO
11	existing wall	existing window	existing roof	retrofit floor	NO	YES	YES
12	existing wall	existing window	existing roof	retrofit floor	YES	NO	NO
13	existing wall	existing window	existing roof	retrofit floor	YES	NO	YES
14	existing wall	existing window	existing roof	retrofit floor	YES	YES	NO
15	existing wall	existing window	existing roof	retrofit floor	YES	YES	YES
16	existing wall	existing window	retrofit roof	existing floor	NO	NO	NO
17	existing wall	existing window	retrofit roof	existing floor	NO	NO	YES
18	existing wall	existing window	retrofit roof	existing floor	NO	YES	NO
19	existing wall	existing window	retrofit roof	existing floor	NO	YES	YES
20	existing wall	existing window	retrofit roof	existing floor	YES	NO	NO
21	existing wall	existing window	retrofit roof	existing floor	YES	NO	YES
22	existing wall	existing window	retrofit roof	existing floor	YES	YES	NO
23	existing wall	existing window	retrofit roof	existing floor	YES	YES	YES
24	existing wall	existing window	retrofit roof	retrofit floor	NO	NO	NO
25	existing wall	existing window	retrofit roof	retrofit floor	NO	NO	YES
26	existing wall	existing window	retrofit roof	retrofit floor	NO	YES	NO
27	existing wall	existing window	retrofit roof	retrofit floor	NO	YES	YES
28	existing wall	existing window	retrofit roof	retrofit floor	YES	NO	NO
29	existing wall	existing window	retrofit roof	retrofit floor	YES	NO	YES

30	existing wall	existing window	retrofit roof	retrofit floor	YES	YES	NO
31	existing wall	existing window	retrofit roof	retrofit floor	YES	YES	YES

Table 14 Simulation ID and their set parameters for the preliminary parametrization considering the basic steps for renovations

Here below, Figure 3 presents the net heating demand referring to the simulation set in Table 14.

It is evident that renovating both roof and floor reduces quite a lot the net heating demand of a building. Moreover, a remarkable influence is due to the airtightness of the envelope. Of course, since shading systems reduce the solar gains, conditions without shadings need less heating energy.

On the other hand, as highlighted in Figure 4 and Figure 5, the absence of the shading system can cause unpleasant overheating phenomena.

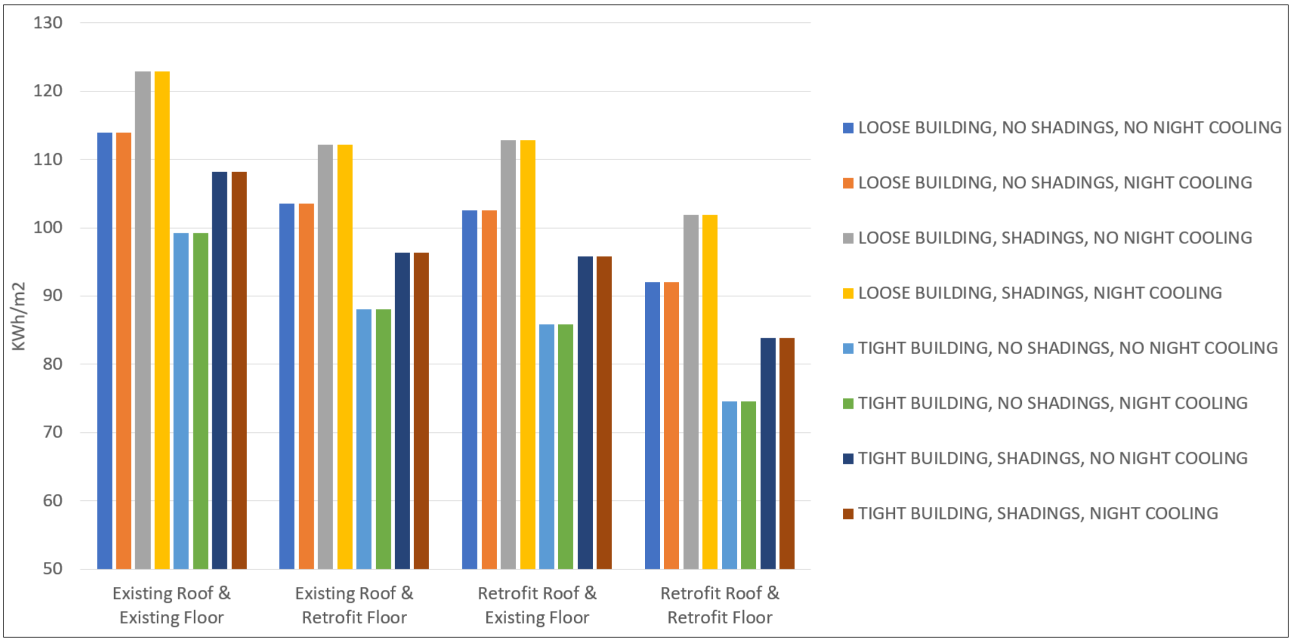


Figure 3 Net heating demand for BASIC RENOVATION conditions

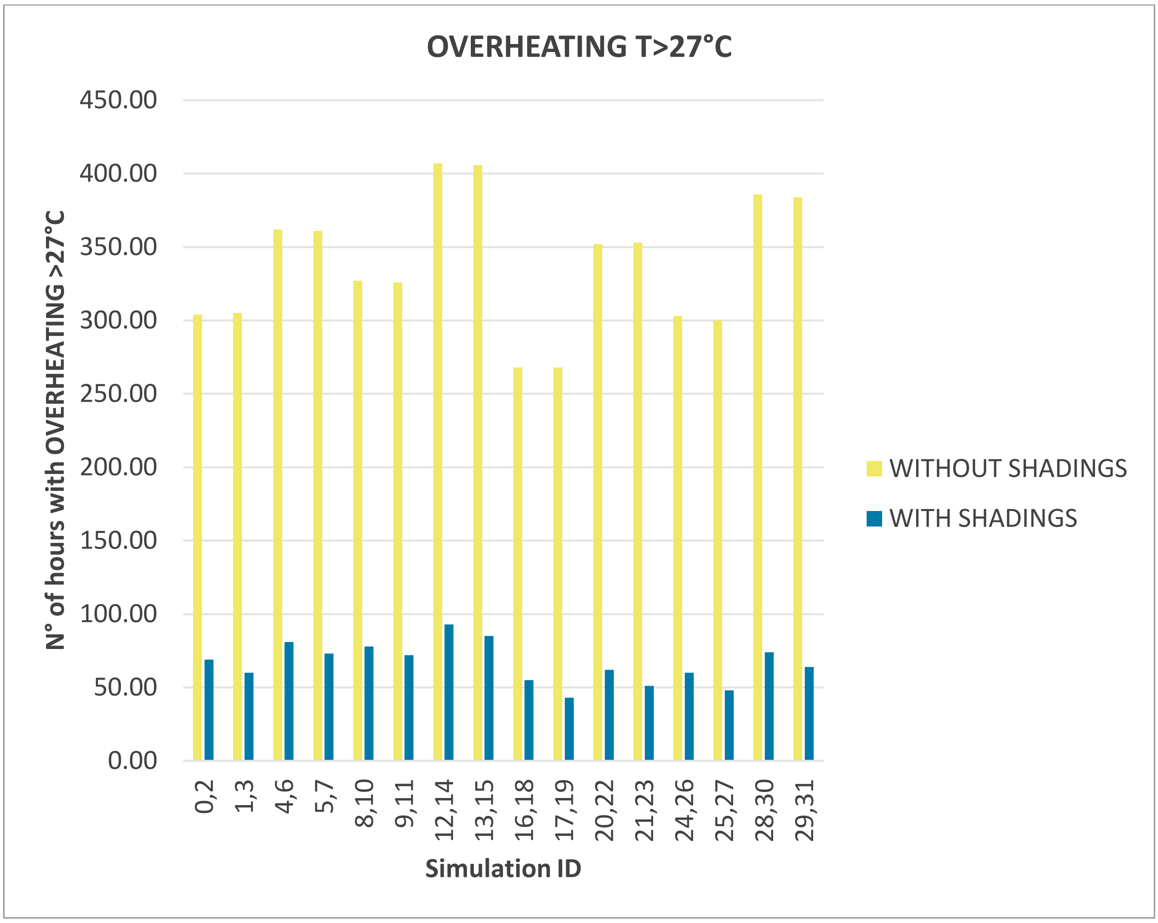


Figure 4 Overheating with temperature >27°C in the BASIC RENOVATION conditions

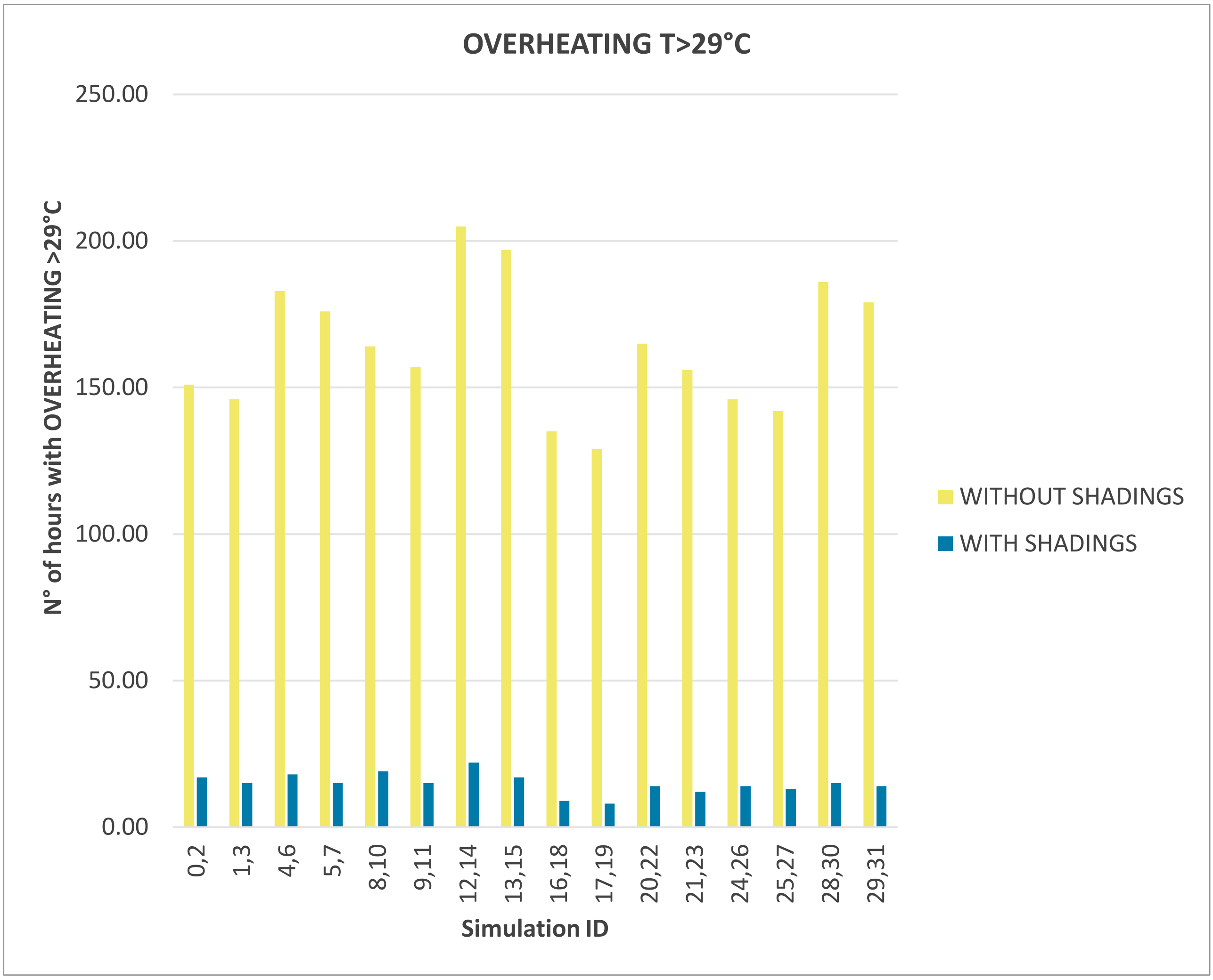


Figure 5 Overheating with temperature >29°C in the BASIC RENOVATION conditions

Figure 6, based on the complete set of simulations, presents the effects of the opaque and transparent envelope on the heating and cooling demand of the modelled building. Since both combinations of opaque and transparent envelope typologies are very well-performing, the difference in energy demands is not very remarkable. On the other hand, a sensible influence, especially on heating demand, is given by the presence or absence of a mechanical ventilation system with heat recovery. This technology is able to reduce the needed heating power while ensuring a better thermal comfort of the indoor environment (as shown by the number of hours in the first and second categories of the adaptive comfort model and PMV comfort model).

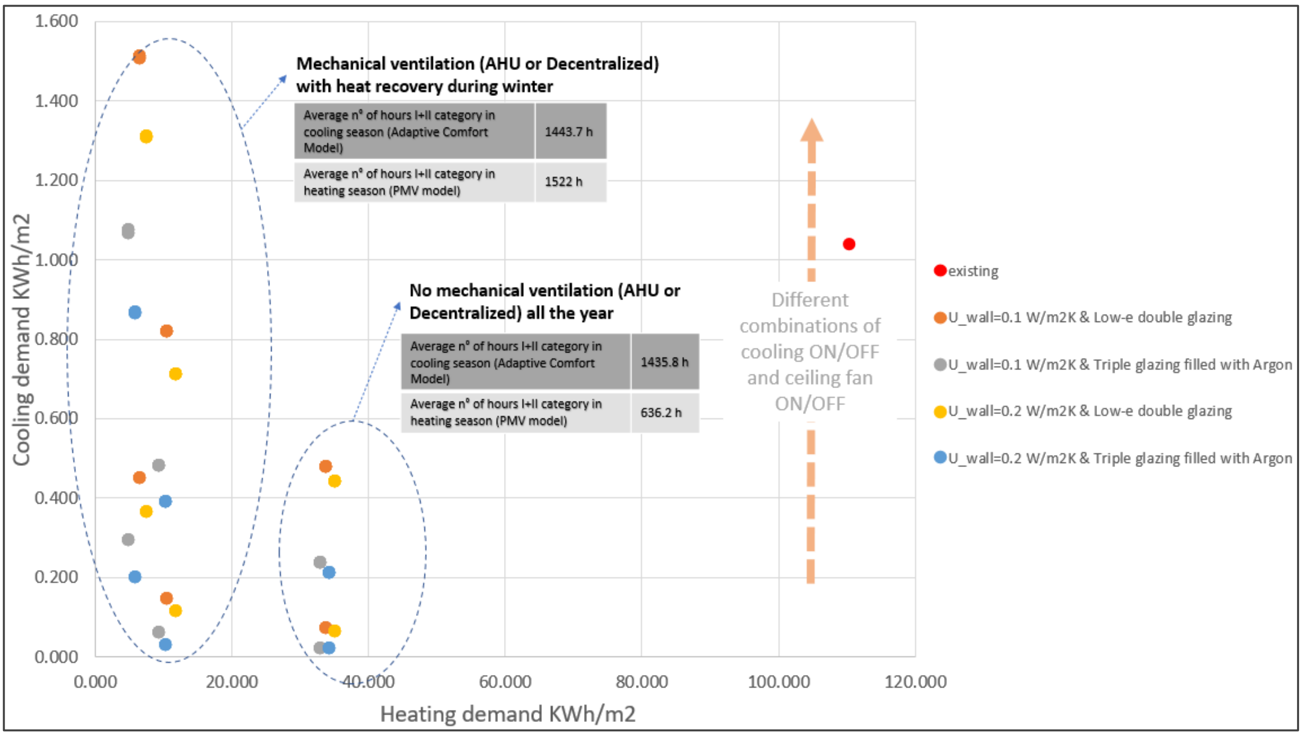


Figure 6 Heating & cooling demand in the complete set of simulations; colours of the indicators refer to opaque and transparent envelope typologies combinations

Figure 7 shows the number of occupied hours with the first or second category of CO_2 ppm (according to the EN15251) in all the simulations (averaged values) in case of mechanical ventilation presence. It is clear that mechanical ventilation can increase a lot the comfort of occupants, both with respect to the existing case (where no mechanical ventilation is occurring but the infiltration rate is higher) and to retrofit condition with no mechanical ventilation (where not enough air change rate is provided to the rooms and the building envelope is very tight).

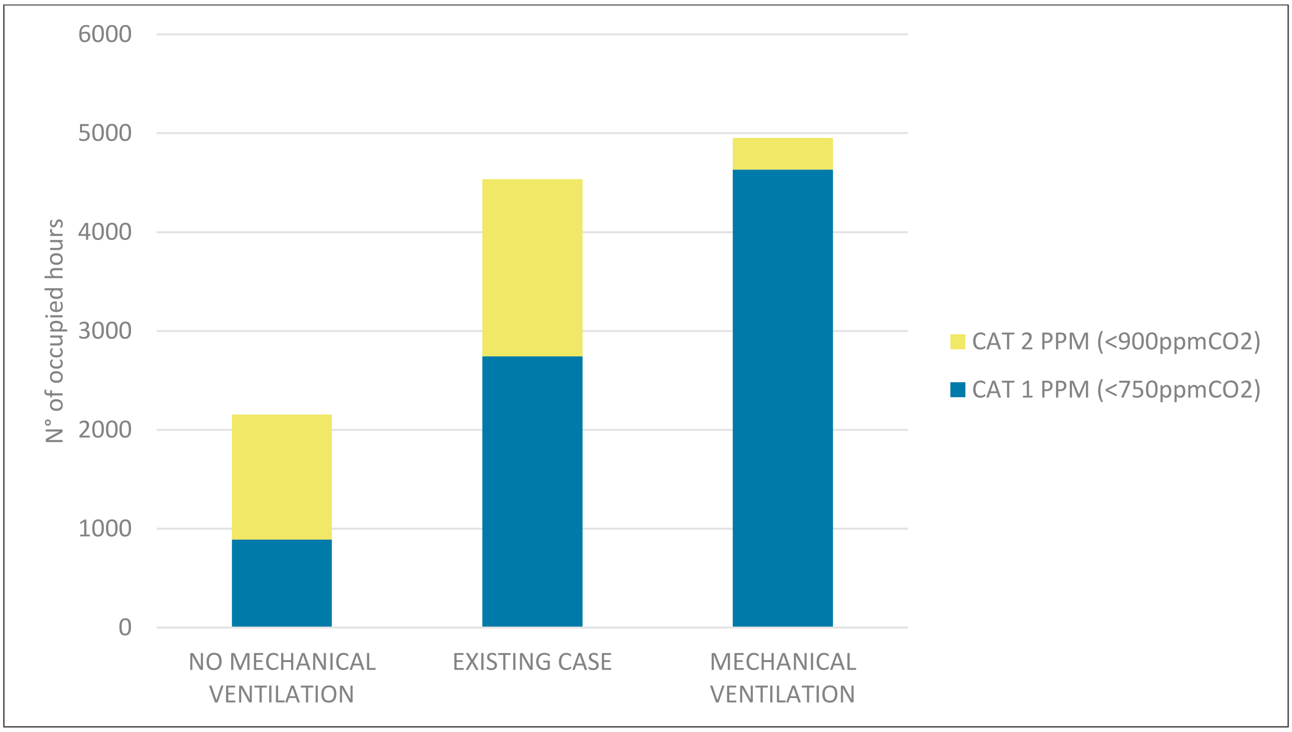


Figure 7 Number of occupied hours in CO_2 ppm categories for Indoor Air Quality Evaluation (EN15251) in the complete set of simulations

Figure 8 and Figure 9 show the effect on energy consumptions and tons of CO_2 emissions given by the use of a traditional system or a heat pump. Of course, this system, if the boundary conditions are favourable, ensures a great potential for energy and emissions savings.

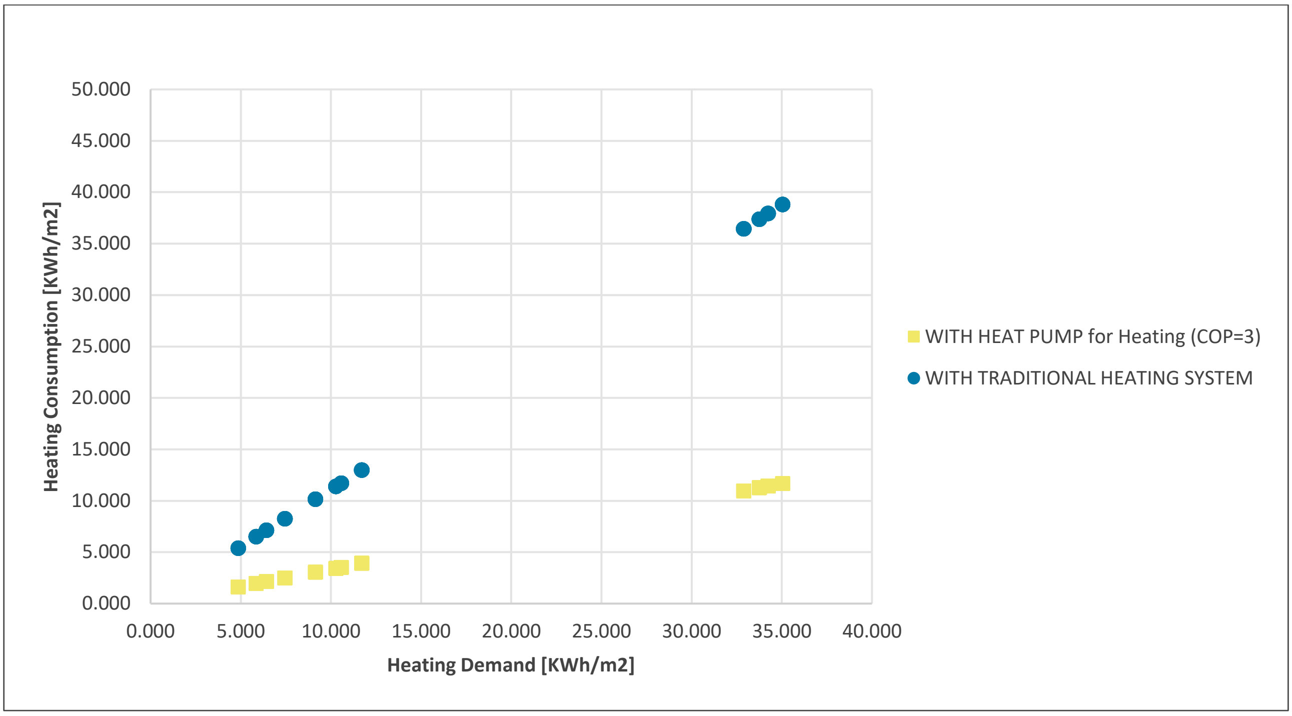


Figure 8 Heating demand & Heating consumption with/without heat pump

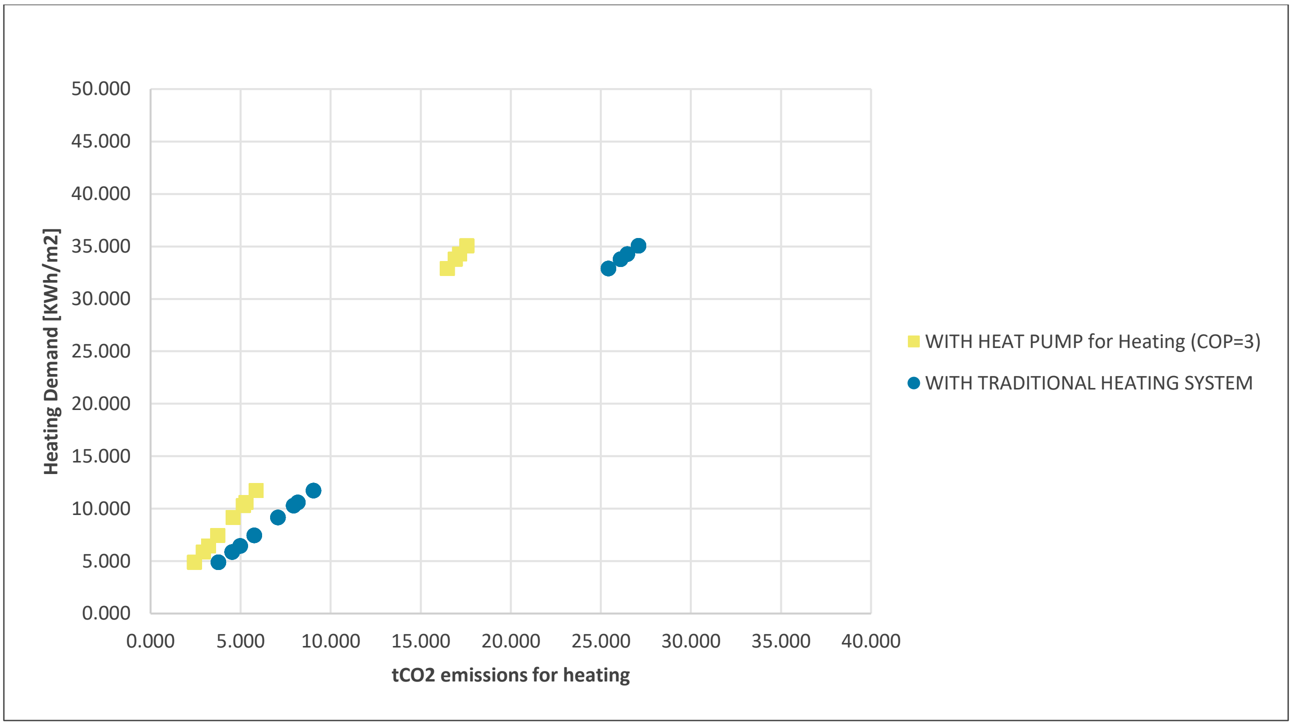


Figure 9 tons of CO_2 emissions for heating & Heating Demand with/without heat pump

This general overview of the results could be the starting point for a more detailed analysis in the design phase. Hence, using a filtering process on all the possibilities based on a priority criterion, the best configuration could be defined; by using the filtering process within the repository it is possible to define the possible energy savings to be achieved respect to non-renovated condition, as well as between different scenarios.

5 Repository Description

The repository of results coming from the parametric simulation work provides results in the KPIs thematic area for the four building typologies in the six geo-clusters.
The repository consists of four Excel files (one per each building typology: Apartment Block, Multi-Family House, Single Family House, Terraced House).
Each row of the file corresponds to one simulation. 1734 simulations are collected per each building type (289 simulations per each geo-cluster).
The first raw (header) shows the parameters considered in the specific simulation (Table 15).

Parameter name	Notes
ID	Identification number of the simulation
BUILDING GEOMETRY	Reference building geometry
GEO_CLUSTER	Reference Geo-Cluster
PRE/POST RETROFIT	Pre-retrofit (existing condition) or post retrofit
HEATING SYSTEM TYPE	Traditional heating system (Gas condensing boiler)
MECHANICAL VENTILATION PRESENCE	-
BIPV PRESENCE	-
SMART CEILING FAN PRESENCE	-
WALL TYPOLOGY	Different Prefabricated Façades Insulations have been used in simulations. The ending part of this parameter name refers to the thermal transmittance U-value of the overall wall after renovation (Existing wall + Prefab. Façade)
WINDOW TYPOLOGY	Different windows have been modelled in the simulations: triple glazing or low-e double glazing windows.
COOLING SYSTEM PRESENCE	-
ROOF TYPOLOGY	-
FLOOR TYPOLOGY	-
SHADING SYSTEM PRESENCE	-
GROUNDFLOOR TYPOLOGY	-

Table 15 Header Parameter Name in the Repository

Table 16 shows the KPIs header used in the repository, referring to those described in Table 1.

Parameter name	Notes
CAT_1_PPM	Number of hours in Category 1 for CO_2 ppm (EN15251:2007)
severe _27	Number of hours with indoor severe overheating >27°C
severe_29	Number of hours with indoor severe overheating >29°C
CAT_IV_OH_Adpt	IAQ n°hours category 4 Over Heating – Adaptive comfort model (EN15251:2007) (to be used during cooling season)
CAT_IV_OC_Adpt	IAQ n°hours category 4 Over Cooling – Adaptive comfort model (EN15251:2007) (to be used during cooling season)
heat_dem_ALL_kWh	Heating demand of the whole building in kWh
cool_dem_ALL_kWh	Cooling demand of the whole building in kWh
heat_dem_ALL_kWhm2	Heating demand of the whole building in kWh/m2
cool_dem_ALL_kWhm2	Cooling demand of the whole building in kWh/m2
heat_con_ALL_kWh	Heating consumption of the whole building in kWh
heat_con_ALL_kWhm2	Heating consumption of the whole building in kWh/m2
cool_con_ALL_kWh	Cooling consumption of the whole building in kWh
cool_con_ALL_kWhm2	Cooling consumption of the whole building in kWh/m2
PEF_Cool_ALL_kWh_m2	Primary Energy Factor for cooling system of the whole building in kWh/m2
lgt_cons_ALL_kWh	Light consumption of the whole building in kWh
vent_cons_ALL_kWh	Ventilation consumption of the whole building in kWh
tot_PV_Power_kW	Power production from PV panels in kW

tot_PV_area_install	Total PV area installed
fan_cons_ALL_kWh	Smart ceiling fan consumption of the whole building in kWh
heating_CO_2_emission	CO_2 emission due to heating system in kgCO_2/year
cooling_CO_2_emission	CO_2 emission due to cooling system in kgCO_2/year
kg H/C CO_2 emission	Total CO_2 emission due to cooling and heating systems in kgCO_2/year
CAT_2_PPM	Number of hours in Category 2 for CO_2 ppm (EN15251:2007)
PEF_Heat_ALL_kWh	Primary Energy Factor for heating system of the whole building in kWh
PEF_Heat_ALL_kWh_m2	Primary Energy Factor for heating system of the whole building in kWh/m2
CAT_I_Adpt	IAQ n°hours category 1 – Adaptive comfort model (EN15251:2007) (to be used during cooling season)
CAT_II_Adpt	IAQ n°hours category 2 – Adaptive comfort model (EN15251:2007) (to be used during cooling season)
CAT_III_Adpt	IAQ n°hours category 3 – Adaptive comfort model (EN15251:2007) (to be used during cooling season)
OHdegree	Over Heating degree respect to category 4 of Adaptive comfort model
OCdegree	Over Cooling degree respect to category 4 of Adaptive comfort model
pmv_CatI	IAQ n°hours category 1 – PMV model (EN15251:2007) (to be used during heating season)
pmv_CatII	IAQ n°hours category 2 – PMV model (EN15251:2007) (to be used during heating season)
pmv_CatIII	IAQ n°hours category 3 – PMV model (EN15251:2007) (to be used during heating season)
pmv_CatIV	IAQ n°hours category 4 – PMV model (EN15251:2007) (to be used during heating season)
Decent. Machines	Number of façade integrated machines to be installed in the building to reach proper ACH

Centralized Machine	Number of AHU machines to be installed in the building to reach proper ACH
DHW consumptions kWh	Domestic Hot Water consumptions for the whole building in kWh

Table 16 Header KPIs used in the Repository

In order to be used, the user should select filters on the parameter header row depending on his preferences. In this way, only a group of simulations and related results can be isolated for further preliminary analyses.
The repository is accessible with free access and it is stored on Zenodo.com (DOI: 10.5281/zenodo.4475691).

6 Conclusions

The analysis performed thanks to the parametric model allow us to have a wide view of the effects provided by the proposed renovation approach.
The benefits provided by the studied technology, as well as by the components integrated into it, are evident and can be verified both in terms of energy needs and comforts. This is of course a good achievement and a confirmation of the potential of this retrofit intervention.
The parametric approach is also fundamental in order to give the possibility to compare different renovation scenarios and to choose the most appropriate one depending on several needs.
This general overview of the results could be the starting point for a more detailed analysis in the design phase. Hence, using a filtering process on all the possibilities based on a priority criterion, the best configuration could be defined.
It is easily replicable and can represent an effective support for the designers in the definition of the most suitable RP according to the boundaries and to the specific building.