D6.3a - Performance of the Studied Systemic Renovation Packages - Method

Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

iNSPiRe

Project Title: Development of Systemic Packages for Deep Energy Renovation of Residential and Tertiary Buildings including Envelope and Systems

Project Acronym: iNSPiRe

Deliverable Title:

D6.3a Performance of Studied Systemic Renovation Packages – Methods

Dissemination Level: PU

Lead beneficiary: EURAC

Roberto Fedrizzi, EURAC

Chiara Dipasquale, EURAC

Alessandro Bellini, EURAC

Marcus Gustafsson, SERC

Chris Bales, SERC

Fabian Ochs, UIBK

Georgios Demerzentzis, UIBK

Romain Nouvel, ZAFH

Mariela Cotrado, ZAFH

Date: 30 September 2015

This document has been produced in the context of the iNSPiRe Project.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 314461. All information in this document is provided "as is" and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability. For the avoidance of all doubts, the European Commission has no liability in respect of this document, which is merely representing the authors view.

Table of Contents

1 Executive Summary

One of the primary objectives of the iNSPiRe project was to develop a tool that predicts the energy and cost saving impacts of various systemic retrofit interventions. This tool is now available for all those involved in the renovation of older buildings (from consulting offices, moving through construction companies and to decision makers) to use as a means of selecting which retrofit package will deliver the greatest costs savings and most improved energy efficiencies.

To this purpose, we have produced three databases that provide valuable information about the energy performance of a variety of buildings in different climates, based on different energy requirements. These are the results of a three stage process:

1. Collection of energy use data (statistics) for the whole of EU 27, the structuring of a building stock database and the definition of reference buildings that represent the most typical buildings of the building stock. Data for six different age categories were derived, including typical construction information and insulation standards for these periods. Seven climatic regions were also defined to cover the EU 27. The structured data are available in the Building Stock Statistics database.
2. Derivation of a complete and consistent database of heating and cooling demands in residential and office buildings covering the whole of the EU 27 based on the simulation of the defined reference buildings in seven climatic regions. The simulations were calibrated against the energy use statistics, and are thus consistent with these, but offer the full range of heating and cooling demands for all climates and building types for six different age categories. The results are available in the Reference Building Simulation database.
3. Definition of a range of retrofit measures for the reference buildings including climatic shell, HVAC system and heating/cooling distribution. The matrix of these measures was then simulated for all building types for the seven different climatic regions to provide data for the third database, the Systemic Renovation Packages database.

1.1 Building Stock Statistics database

This is based on figures available in the reviewed literature. The database shows publicly available literature for each EU country's energy use.

In this database, Europe has been divided into seven climate regions, grouped together based on heating requirements, known as Heating Degree Days (HDD), which varies from about 500 to 2500. Each climate region contains one of the seven most populated countries in Europe (Italy, Spain, France, Germany, UK, Poland and Sweden) and these countries are home to 80 per cent of Europe's total population (See reports D2.1a and b for more information).

The database also shows each country's population, its total available floor space and floor space being heated and/or cooled.

This is a simple look-up table – a tool devised to compare existing data. So, it hows you the average energy used and consumed for heating, cooling, domestic hot water and lighting in

the selected country or climatic region of Europe for both residential and office buildings. In addition to energy uses, the literature references actually used (because believed reliable), as well as standard deviation of the used data points is reported for statistical purposes.

1.2 Reference Buildings Simulations database

This is based on data generated from simulations of iNSPiRe's selected reference buildings, representing the large majority of the EU building stock. These data can be used to complement the gaps in the Building Stock Statistics but also to prove the reliability/consistency (or not) of the data in available literature.

As with the Building Stock Statistics database, this database also divides Europe into seven climate regions, but country specific data are not reported since this would have required an unjustified simulation effort. Data are provided per climatic region, having used the most populated country as representative of the entire region's climate. In particular, Rome, Madrid, Lyon, Stuttgart, London, Gdansk and Stockholm have been used as exemplary climates.

The building typologies in this database reflect the diversity of iNSPiRe's reference buildings, so includes a variety of buildings, from single family homes to large multi-family homes, as well as several types of office buildings. All building are also categorized by age into the following periods: those built before 1945, between 1945 and 1970, 1970-1980, 1980-1990, 1990-2000 and those built after 2000 (see report D2.1c for more details).

In this database information is provided in terms of:

- What the share of the total building stock is for your selected climatic region, your selected building type, or age.
- The energy demand and consumption for heating or cooling of your selection.
- How much primary energy is consumed and CO_2 is produced in providing this heating or cooling requirement.

The database gives a complete and consistent overview of heating and cooling demands in residential and office buildings covering the whole of the EU, as the results have been calibrated against the data from the building stock statistics database. However, the, approach of matching the simulation results with the energy statistics by varying the set temperature, resulted in several inconsistencies being found and suitable adaptations were chosen. These inconsistencies would need to be further investigated in order to find their causes. It is a far more detailed and comprehensive approach than has been previously applied, and the derived results are believed to be more reliable than those previously published for the whole of EU. The approach itself, ensures that the simulation results are consistent with the energy statistics.

The methodology developed has a number of uncertainties, from both a statistical and simulation perspective. However, it has provided further information about the energy demands for building typology, age at regional and European level.

The results suggest that lower set point temperatures in winter are often used in practice, at least in the residential sector, compared to those used in simulation studies. The identified set temperature exceeds 20 °C only for the Nordic climate. This seems to indicate that not all the living area is equally warmed up 24 hours a day. Literature shows that a better building standard is correlated with higher indoor temperature, and thus real energy savings when improving the insulation level of residential buildings is likely to be somewhat lower than expected. However, comfort would be significantly improved. Heating demand in office buildings in Europe is quite uniform.

The method gives consistent results in term of cooling demand estimation for both residential and office sectors, where few statistical data are available. Therefore, it could be used to complement energy statistics where data is missing. While 24 – 25 °C seems to be accepted in residential buildings (with exception to the Oceanic climate, where around 22 °C was identified), lower temperatures are required in offices (20 – 23 °C), with the exception of Continental and Southern continental regions (about 25 °C). The cooled floor area reported in the literature was shown to be relevant only in the most southern countries.

1.3 Systemic Renovation Packages database

The focus of this report is on the vast amount of data of energy performance that iNSPiRe has generated for a variety of retrofit technologies applied to iNSPiRe's selected reference buildings. This informs on how given retrofit packages impact on the specific reference building. A clear understanding of the needs and effects of decisions taken during retrofit design is highlighted in this database.

As in the previous cases, data are provided per climatic region, represented by the climates of Rome, Madrid, Lyon, Stuttgart, London, Gdansk and Stockholm.

In addition to climate, building type and age of construction, one can select a number of retrofit parameters, such as:

- Wished heating demand after retrofit, which determines the insulation and new windows quality
- Type of heating & cooling generation system
- Set temperatures imposed to the indoor air
- Type and temperatures of the heating & cooling distribution systems
- Size and position of the solar thermal collectors and PV panels.

Again, the solutions are predetermined through simulations. However, some results are calculated based on the energy performance and on the values provided in the input worksheet. In particular, LCA and economic data are calculated in this way.

2 Methodology

An extensive simulation work has been carried out, following the methodology shown in Figure 1.

The first step consisted in defining the envelope renovation solutions in terms of new windows and insulation thickness added on top of the existing one in order to reach a specific energy efficiency of the building in terms of heating demand.

Although the mechanical ventilation system is not properly to be considered as an envelope renovation solution, its occurrence in the renovation packages has been defined together with the measures in terms of windows and insulation solutions, since they strongly affect each other with respect to the effect on the heating demand.

Once these solutions are defined, the cooling demand derives consequently: the envelope renovation packages entail for all climates considered external shading systems that limit the cooling demand during the cooling season (from late spring to autumn).

Secondly, a reference H&C configuration has been defined, from which other H&C configuration variants can easily be derived. These have been modelled in the simulation environment TRNSYS 17, using a modular sub-decks method. Thousands of cases have been simulated for different locations, building energy levels and sizing parameters, using the parametric tool TrnEdit. A sizing tool was developed in excel with the purpose of setting the system features (components sizes and set points) depending on the different loads and variants.

Simulation output files have been automatically processed and relevant information data has been imported into the database, by means of a Visual Basic macro. Finally, the results have been represented in comprehensive charts elaborated with Matlab scripts.

This procedure is detailed in the following sections.

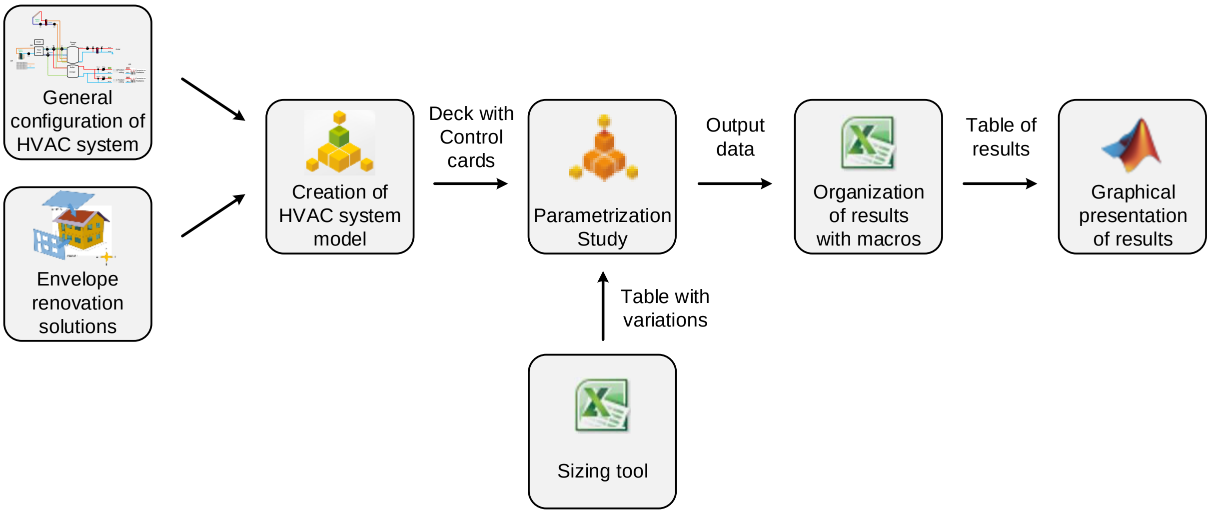


Figure 1 –Methodology used for the simulation and analysis of the systemic energy renovation variants

2.1 Systemic approach

2.1.1 Renovation approach to the envelopes

As already mentioned, the renovation packages elaborated use the reference buildings defined in the report D2.1c as exemplary reference existing constructions. For each climate (7 cases), age of construction (6 cases) and building typology (5 cases – 3 residential and 2 offices), the insulation standard is improved by substituting windows with more effective ones, and by adding insulation onto the external walls and roof. In some of the cases (northern countries and buildings with high S/V ratio), it has been necessary to also insulate between cellar and the ground floor, as well as all along the construction perimeter (defined as the external walls partially or fully underground).

Four target heating demand levels were defined for: 15, 25, 45, 70 kWh/m^{2}y for residential buildings and 25 and 45 kWh/m^{2}y for offices. The insulation levels required to meet these demands were then derived using iNSPiRe auditing tool, the validated PHPP software from the Passive House Institute. The good practices suggested by the Passive House Institute to thermally insulate buildings have been also used to define thermal bridges, infiltrations and needed mechanical ventilation units' flows and efficiencies.

With respect to the reduction of the cooling loads, external shading devices were defined for both the residential and office buildings: manual for the residential buildings, automatic for the offices. This is not only significant for southern countries but also for the most northern: by improving the thermal insulation along with the retrofit process, the transmittance losses are lowered also in summer with the result that the heat accumulated during daytime is only partially released during nights. This results in cooling demands that increase compared with the initial condition before renovation, unless proper shading and night ventilation strategies are operated.

The entire set of boundary conditions and solutions that were defined is reported in Annex I to this document. The cross sections of the walls and roofs for all the buildings, climates and sought heating demands are reported in Annex II.

RESIDENTIAL BUILDINGS: having in mind the mentioned approach, 4 renovation levels have been defined for the residential buildings in terms of heating demand: 15, 25, 45, 70 kWh/m^{2}y. For each climate-age-type of building combination the heating demand was obtained by adding thermal insulation in steps of 2 centimetres, once window quality and mechanical ventilation unit presence was decided. For this reason, the renovation levels cannot be reached exactly, even though a very good approximation is obtained. As the heat recovery and window selection has a large impact, in some cases the required extra insulation thickness is smaller for a lower heating demand than for a higher, due to the fact that the renovation for the lower heating demand has heat recovery while the case with higher heating demand does not.

Maximum insulation thicknesses of 40 cm onto the external walls, 50 cm on the roof, and 10 cm onto perimeter and cellar floor have been used with respect to the coldest climates.

OFFICE BUILDINGS: due to the lack of information on the construction of the external walls of office buildings as a function of the age of construction, it was decided to take into consideration two main construction typologies and two S/V ratio buildings (0.54 for OFF1 and 0.46 for OFF2 with three storeys, 0.41 and 0.34 respectively for offices with seven storeys). The first construction typology accounted for in this analysis is a self-bearing external wall made of bricks (period 1 and 3, see D2.1c) and the second is a curtain wall hanging onto a concrete structure (period 4, see D2.1c). In the first case, the suggested envelope renovation approach is similar to the one used for the renovation of residential buildings: new windows + insulation of façade and roof. This means that for the period 1 and 3 cases, the envelope standard is adapted to give the desired heating demand for each climate resulting in different insulation thicknesses in each climate. For period 4 all climates have exactly the same construction for the façade. In the latter, a brand new curtain façade module is installed with enhanced effectiveness. In all renovated offices we considered mechanical ventilation heat recovery.

2.1.2 Renovation approach to the Heating & Cooling generation and distribution systems

A reference H&C configuration structure has been defined, composed of a generation system, a distribution system, a storage for DHW, a buffer storage for heating and cooling distribution and solar thermal and photovoltaic systems. This reference structure is the basis for the simulation of different configurations for SFH, MFH and offices, by varying components sizes and control set points.

Four generation units have been considered: air to water heat pumps (AWHP), ground source heat pumps (GWHP), biomass and gas boilers (GAS, BIO, see Figure 2). Combinations with solar thermal and PV panels' fields have been elaborated consequently to define suitable Generation Renovation Packages. Solar thermal and PV solutions are not exclusive in our Packages.

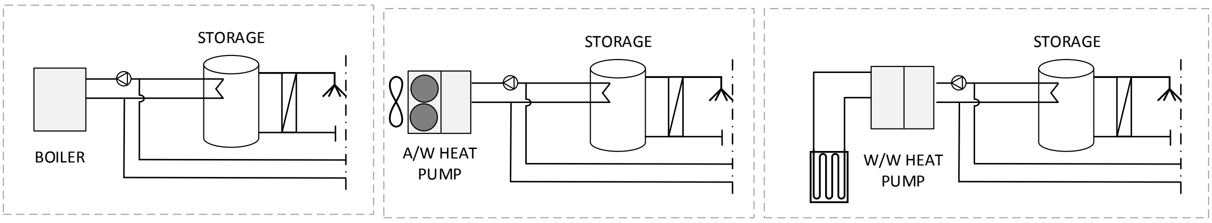


Figure 2 – Generation unit solutions

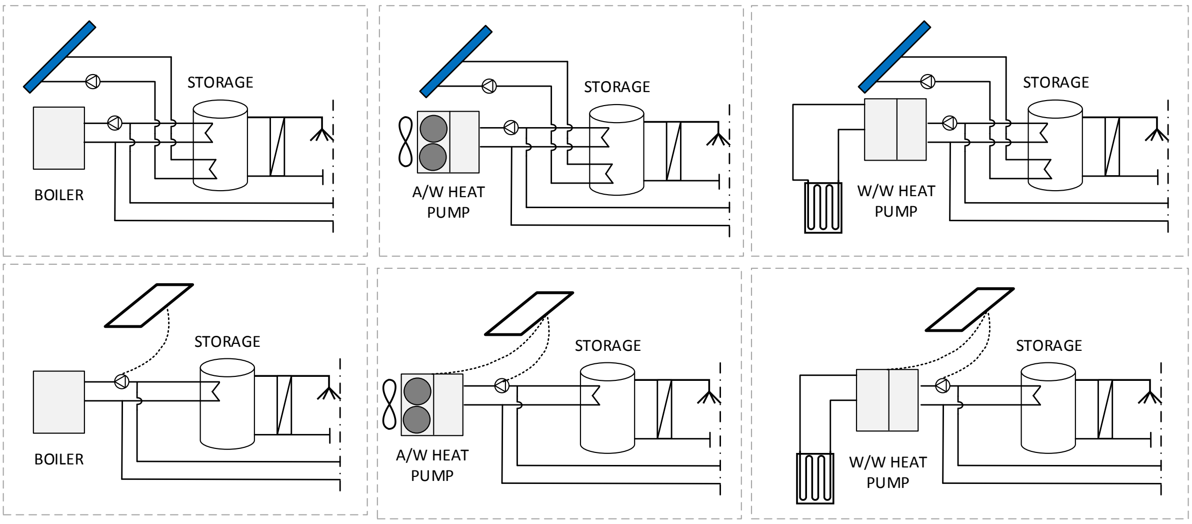


Figure 3 – Generation renovation packages with solar thermal field (above) and PV panels (below)

The solar thermal field supplies renewable energy into a thermal storage tank in parallel with the main generation unit; depending on the size of the field, the solar energy is used only for DHW preparation (smaller fields compared to the load) or for both heating and DWH preparation (larger fields).

The PV field is used for both driving the generation/distribution systems – namely generation units, pumps, valves and backup heater – and covering the building's electric appliances. In order to compare the effectiveness of the solar thermal solutions with the PV ones, the PV electricity used to drive the H&C system is treated separately from the one used for the appliances. The excess PV electricity is considered fed into the grid.

With respect to the distribution system, we considered the possible use of radiant ceilings, fan coils and radiators. In the latter case, a split unit is foreseen in addition to the mentioned generation units as the unique source of cooling.

Figure 4 shows the configuration of the reference H&C system used for all the simulations in TRNSYS. The PV field is not represented for the sake of simplicity; again to better clarify the concept, the DHW thermal storage is represented here separately from the solar thermal storage: in single family homes, the two are integrated into one single volume, the solar storage being located at the bottom part of the combi-storage.

In multifamily buildings' retrofit, it is usually hard finding the needed space for a large combi-storage; therefore, it is often necessary to separate different functionalities in multiple storages.

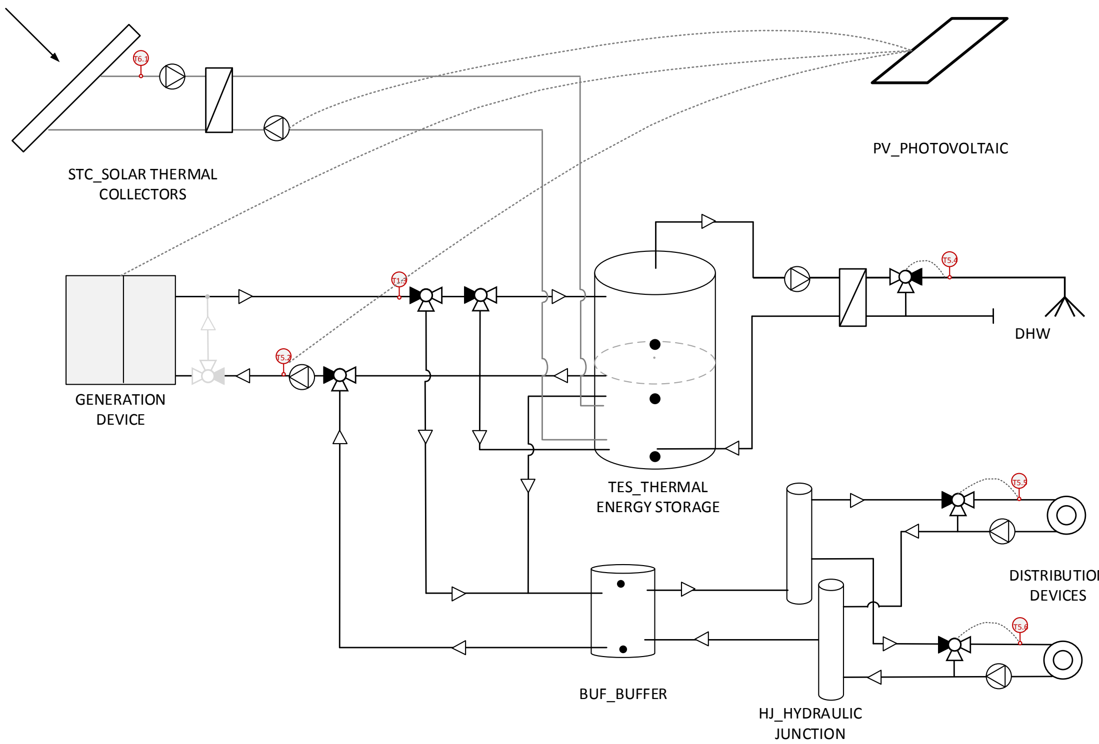


Figure 4 – Reference H&C system used to simulated different Generation and Distribution Renovation Packages

In any case, the solar storage can be considered as placed in series to the DWH tank and the solar thermal field. In the Packages where no solar thermal field is considered, the solar thermal storage volume is set to zero.

The generation unit delivers heat and cold to the distribution system, through a small buffer tank: in case of heat pumps, this limits the number of on-off cycles and in winter it can be used for AWHP de-icing by reversing the cycle. The size of the buffer tank strongly depends on the generation technology.

"Solar heating" can be provided to the building by drawing warm water from the solar storage tank when a specific set temperature is exceeded.

A pump + mixing valve unit delivers heat and cold to each thermal zone (floor or dwelling depending on the building) with the needed set temperature and mass flow.

For the different simulations run in iNSPiRe, system models with different buildings located in different climates and using a combination of centralized/decentralized heating systems and energy distribution systems are required (see Figure 5). Since many parts of the reference configuration of the system need to be changed to build new configurations, a method for modelling complex systems within TRNSYS was used, called the sub-decks method.

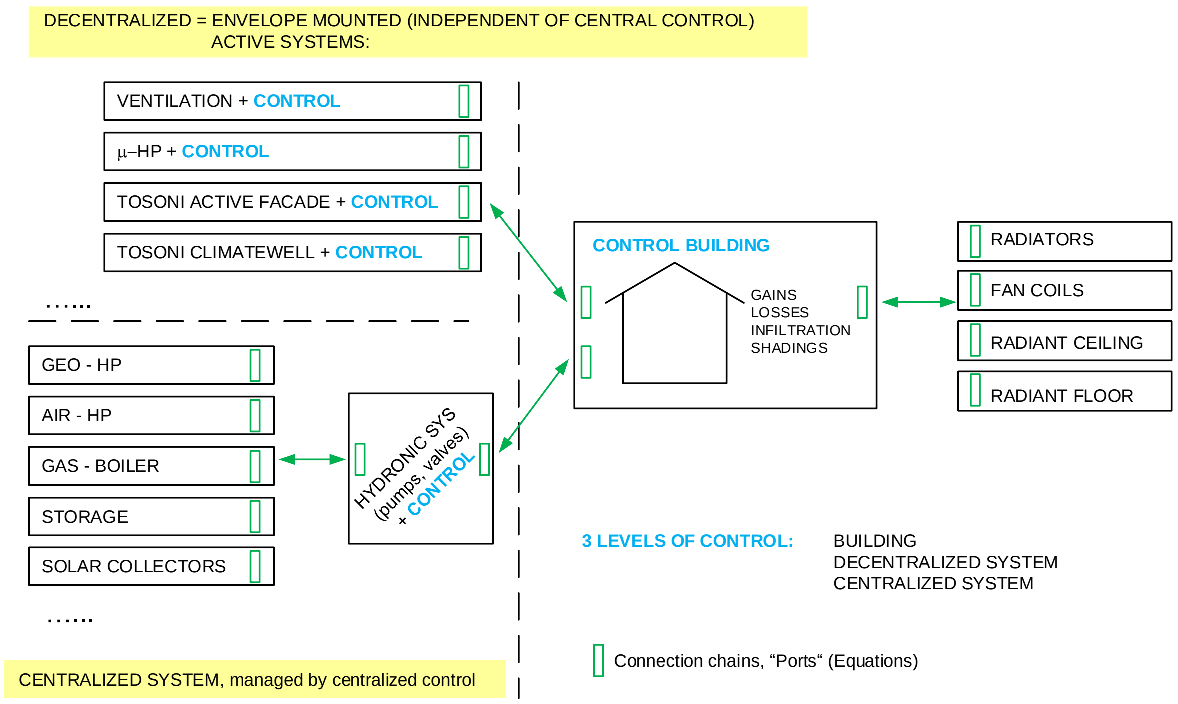


Figure 5 –Sketch including different options for the HVAC models using sub-deck- method (source EURAC)

The sub-decks method, developed in the Kassel University (Kuethe, 2008), models in a modular way the HVAC configuration using subsystems (sub-decks) interconnected by interfaces. This makes it possible to replace each subsystem without modifying the connections with other subsystems.

Figure 6 compares two ways to connect types (systems) in the simulation environment TRNSYS. In the usual case (left side), the number of links needed are equal the number of connections required among types. The sub-decks method (right side) consists in dividing the entire system into subsystems, interfacing each other with a pair of standard input/output blocks. The latter contain the input/output temperatures and mass flows to each component of the H&C system. In this way only few connections need to be interchanged time after time, facilitating in this way the process of building complex systems into TRNSYS and improving the quality control of the simulation environment, and therefore the reliability of the results. An exemplary case of a system divided into sub-decks is shown in Figure 7.

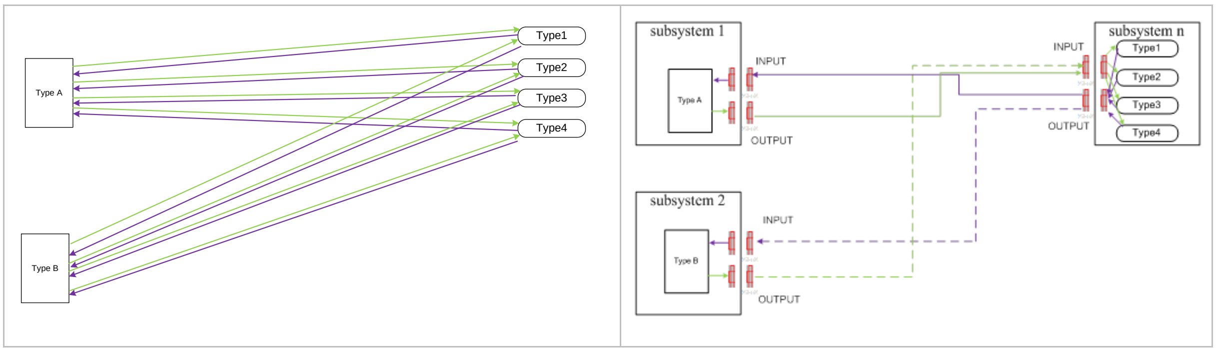


Figure 6 – Usual way (left) and sub-decks method (right) to connect types in Trnsys

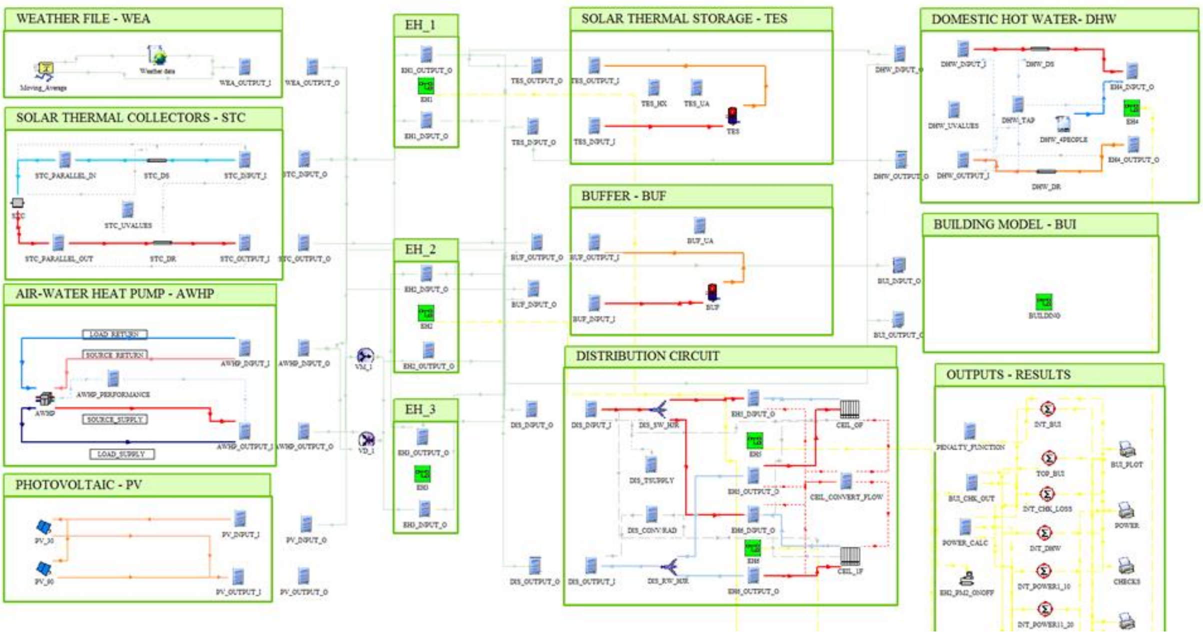


Figure 7 – Example of a system using the sub-decks method

2.2 Sizing tool

While the selection of the renovation measures and sizing of the insulation layers have been performed by means of PHPP, we decided to size the components and to define the control strategies of the H&C systems by means of what we called a Sizing Tool.

This sizing tool has been developed as an excel table, based on reference sizing methods and project partners' expert knowledge. Its outputs are directly used for the parametric study that produces the results that are loaded into the Renovation Packages Database.

2.2.1 Space heating, cooling and DHW loads

For residential buildings, simulations in TRNSYS (again validated through PHPP) have determined space heating and cooling maximum loads (kW/m^2y). In order to consider realistic maximum load for sizing components, peak loads averaged over a duration of 1 hours have been taken into consideration.

For office buildings, maximum heating and cooling loads were also determined through simulations in TRNSYS, but the peak loads were taken as average over a duration of 2 hours rather than 1 hour.

The space heating and cooling loads have been obtained through an "ideal" heating and cooling model that exactly maintain the indoor air temperature at the imposed set. A model with 30% radiant and 70% convective heating contributions has been used as a reference, representing typical radiators. As we will show, this has a significant effect on the demands (kWh/m^2y) that are obtained by simulating real distribution systems.

For the calculation of the DHW loads and the related required storage volume for residential buildings (SFH and MFH), the standard UNI 9182 has been used, assuming typical parameters listed in the Table 1. We have disregarded the DHW demand in office buildings for two reasons:

1. DHW demand in office buildings is irrelevant compared to heating and cooling ones
2. Covering such small demand with a centralised system is meaningless since the thermal losses through the pipelines are significantly larger than the demand itself.

Table 1 - Parameters considered for the calculation of the DHW maximum load, for SFH and MFH buildings (10 dwellings as an example)

	SFH	MFH
Dwelling number	1	10
Simultaneity factor 1 (Dwelling number)	1.15	0.47
Simultaneity factor 2 (Rooms factor)	1.2	1.1
Dwelling area [m^2]	100	60
Persons per dwelling	4	3
Total peak flow shower [L/h]	745	2792
shower duration [min]	4	4
Daily peak load duration [h]	0.27	0.20
Storage heat-up time [h]	1.07	1.60
DHW preparation temperature [°C]	40	40

Cold tap water temperature [°C]	10	10
Water temperature in storage [°C]	45	45
DHW storage volume [L]	136	425
Maximum heat load [kW]	5.2	10.8
Daily consumption [L/day/pers]	50	40
Yearly consumption [kWh/m².yr]	25	25

2.2.2 Energy generation units

Generation units' thermal capacity is sized based on the largest of the loads calculated as mentioned above.

In most residential cases, the largest load is the DHW one, since here we are considering high energy efficiency levels both for heating and for cooling. Only in some cases (70 kWh/m^{2}y heating demand) the conditioning loads prevail.

Again, not always heating demand is higher than cooling: in the northern countries and with respect to the best energy efficiency standards (15 kWh/m^{2}y heating demand), the low-rise path of the sun during spring and fall generates significant cooling loads. Nevertheless, in the residential sector, we decided to size the generation units based on the heating loads only, for two reasons:

1. In this way all the systems are easily comparable
2. During spring and fall when outside air temperature is moderate in northern countries, the cooling loads can be easily covered through natural ventilation (opening windows). This free cooling was, however, not modelled.
3. Therefore, even if the cooling loads are theoretically the highest, in practice they would be lower due to free cooling with extra ventilation, e.g. at nights.

With respect to offices, on the contrary, the generation units have been sized compared to either heating or cooling loads, depending on building type and climate.

<u>AIR TO WATER HEAT PUMP</u>: the thermal capacity of an AWHP is strongly dependent on the load's and source's temperatures. This said, this component has been sized to cover the maximum heating load with an outside air temperature of -5 °C. Below this, a back-up electric heater is switched on.

The heat pump model used is a stationary model based on a performance map (See section 4 for performance maps of generation units). The data used to build the table are taken from the datasheet of an average heat pump with constant speed compressor. Since data are provided at standard rating conditions, a correction factor (1.65) for the size is used to increase both rated thermal capacity and electric consumption to nominal design conditions, being sure that performance at -5 °C are still sufficient to cover the maximum thermal load. The same factor is used for all climates.

GROUND SOURCE HEAT PUMP: to size the geothermal vertical heat exchanger of ground-source heat pump, average soil properties corresponding to "normal rocky underground" have been assumed for the 7 locations. Following the method and assumption of the norm VDI 4640-2, boreholes length has been calculated as a function of the heat loads to be covered.

The size of the HP is selected accordingly. A correction (1.2) is used also here as a safety factor, accounting that ground temperature ranges around 0 °C in wintertime, therefore temperature at evaporator can drop some degree below this level.

GAS AND BIOMASS BOILERS: condensing gas boiler efficiency is considered dependent on inlet water temperature, while pellet boiler efficiency is considered a constant. Only the case of condensing boiler has been simulated; the pellet boiler consumption are calculated in post process. The efficiency also slightly depends on the partial load ratio (PLR). Correlation between efficiency and inlet temperature and PLR have been retrieved by datasheets.

SPLIT UNITS: For modelling split units, we used the TRNSYS Type 916 "Model for Air Cooled Compression Chillers V0.9" developed by B.Nienborg Frauhofer ISE - directly inspired from the norm DIN V 18599-7.

The numerical model gives the set cooling capacity whenever the split unit is on. A nominal EER of 4.5 (at 33 °C ambient temperatures and 26 °C room temperature) is defined according to common modern split units. A minimum split unit size of 2.5 kW has been chosen as minimum installed cooling capacity (minimum capacity available on the market) per zone.

The split unit model accounts for humidity and thus reduces humidity in the zone; this is reflected in the energy use due to the latent share.

2.2.3 Solar systems

For the installation of the solar thermal and photovoltaic systems, two main variants are considered, as illustrated in the Figure 8:

- On the best-oriented roof (SW orientation, since the buildings are oriented 45°)
- On the SW façade

With respect to residential buildings, because of the windows and chimneys, the surfaces cannot be completely covered with photovoltaic (PV) modules / solar thermal (ST) collectors. We assume therefore that only 60% of the facade and 80% of the roof surface can be covered.

With respect to the offices, we considered that solar thermal collectors are not economic justified due to both low space heating and DHW loads. Therefore, we did not include this technology in the office Renovation Packages. On the opposite, we considered the possible use of PV panels both installed onto the façade and on the roof.

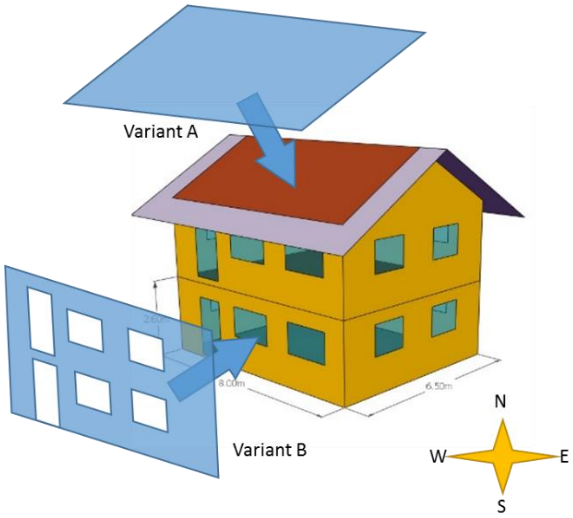


Figure 8 – The two solar systems orientation variants

PHOTOVOLTAIC MODULES: the manufacturing data of an average mono-crystalline PV module have been considered for the parameterization and sizing of the PV panels, with an active area of 1.31 m^2 per panel. Beside the inclination variants, different number of PV panels have been studied. For residential buildings the variants are:

SFH

- 1 series of 6 panels (total active area: 7.8 m^2 - around 1 kWp)
- 2 series of 6 panels (total active area: 15.6 m^2- around 2 kWp)
- 3 series of 6 panels (total active area: 23.4 m^2- around 3 kWp)

MFH – 5 floors

- 3 series of 6 panels (total active area: 23.6 m^2 - around 3 kWp)
- 4 series of 6 panels (total active area: 31.4 m^2 - around 4 kWp)
- 5 series of 6 panels (total active area: 39.6 m^2 - around 5 kWp)

For offices, a different approach was used, considering fixed percentages of façade and/or roof are covered with PV panels (see Table 2 and Table 3).

Table 2 – PV areas considered for offices façades with brick bearing walls (Period 1, see also Deliverable 2.1c) and with curtain walls (Period 2)

Period	Floors	Office cells per floor	Available area, m²	PV area, m²		
				30%	60%	90%
1	3	6	85.1	25.5 (3 kWp)	51 (7 kWp)	76.5 (10 kWp)
		12	170.1	51 (7 kWp)	102.1 (14 kWp)	153.1 (20 kWp)
	5	6	141.8	42.5 (6 kWp)	85.1 (11 kWp)	127.6 (17 kWp)
		12	283.5	85.1 (11 kWp)	170.1 (23 kWp)	255.2 (34 kWp)
	7	6	198.5	59.5 (8 kWp)	119.1 (16 kWp)	178.6 (24 kWp)
		12	396.9	119.1 (16 kWp)	238.1 (32 kWp)	357.2 (48 kWp)
3	3	6	48.6	14.6 (2 kWp)	29.2 (4 kWp)	43.7 (6 kWp)
		12	97.2	29.2 (4 kWp)	58.3 (8 kWp)	87.5 (12 kWp)
	5	6	81.0	24.3 (3 kWp)	48.6 (6 kWp)	72.9 (10 kWp)
		12	162.0	48.6 (6 kWp)	97.2 (13 kWp)	145.8 (19 kWp)
	7	6	113.4	34 (5 kWp)	68 (9 kWp)	102.1 (14 kWp)
		12	226.8	68 (9 kWp)	136.1 (18 kWp)	204.1 (27 kWp)

Table 3 - PV areas considered for offices roofs

Office cells per floor	Available area, m²	PV area, m²		
		25%	35%	50%
6	162	40.5 (5 kWp)	56.7 (8 kWp)	81 (11 kWp)
12	324	81 (11 kWp)	113.4 (15 kWp)	162 (22 kWp)

<u>SOLAR THERMAL COLLECTORS</u>**:** the manufacturing data of an average solar thermal collector (eta$_0$ = 0.82, a_1 = 3.8) with an active area of 2.3 m^2 have been considered for the parameterization and sizing of the solar thermal field. Beside the inclination variants, different number and configuration of solar thermal collectors have been studied:

SFH

- 1 series of 2 collectors (total active area: 4.6 m² - only DHW preparation)
- 1 series of 4 collectors (total active area: 9.2 m² - DHW preparation and space heating)
- 2 series of 3 collectors (total active area: 13.8 m² - DHW preparation and space heating)

MFH

- 2 series of 4 collectors (total active area: 18.4 m² - only DHW preparation)
- 3 series of 4 collectors (total active area: 27.6 m² - DHW preparation and space heating)
- 4 series of 4 collectors (total active area: 36.8 m² - DHW preparation and space heating)

2.2.4 Thermal storages

The sizing of the thermal energy storage is based on both the requirements related to the DHW load (chapter 2.2.1) and to the volume needed to store solar thermal energy.

In case solar thermal collectors are not installed, a minimum storage volume is considered as per calculations in chapter 2.2.1. In case solar thermal collectors are actually installed, the maximum volume is selected among the DHW and the solar thermal tank size, the latter being defined as:

- 50 l/m² (litres of the storage tank per surface of the collectors' area)
- 100 l/m²

We selected this range based on the usual practice for solar thermal systems.

2.2.5 Pipes

In the models elaborated, pipes are included in the solar and DHW circuits only. The diameters of each pipe are designed in a way that the water speed never exceeds 1 m/s. The insulation thickness is equal to the diameter for DHW pipelines and to 2 diameters for solar circuit pipes

2.2.6 Buffer tank

For the air source heat pump, the buffer tank is sized to guarantee the minimum energy required for a de-icing cycle by inverting the compression cycle. This phase is required to avoid the HP performance decreasing due to ice formations on the surface of the evaporator. The buffer tank is sized in order to store the required energy from the HP for the de-icing procedure. The sizing is based on this balance:

$$E_{HP_{DI}} = E_{Buffer}$$

Where the left term is the energy required by the evaporator of the HP at nominal conditions for the de-icing, while the right term is the energy that the buffer can store,

$$E_{HP_{DI}} = P_{HP_{ev}} * time_{DI}$$

The right term can be written also as the evaporator power (*PH_{Pev}*) for the de-icing duration: a $time_{DI} = 30'$ has been considered in this study, as this is a timeframe not affecting the indoor comfort (the heat pump does not deliver heating to the building during de-icing), therefore many units adopting cycle inversion for de-icing purposes operate in this way. Consequently, the buffer energy stored during the de-icing is:

$$E_{Buffer} = V_{buffer} * \rho_{water} * c_{p_{water}} * (t_{max} - t_{min})$$

Where t_{max} is the set point temperature held in the buffer, supplying the distribution system, and $t_{min} = 15°C$, is the minimum temperature acceptable in the buffer.

The buffer tank volume so designed is also useful to reduce the on-off cycles of the heat pump which thermal capacity is most of the times oversized compared to the space heating and cooling thermal loads. Thus, the buffer tank is used also for systems with ground source heat pump.

2.2.7 Energy distribution systems

For the parameterisation and sizing of the different energy distribution systems, manufacturing data and self-made measurements have been considered for a range of units:

RADIANT CEILINGS: the performance and properties of TRIPAN radiant ceilings has been considered for sizing this component. Their nominal capacity is around 140 W/m^2 in heating mode and about 100 W/m^2 in cooling mode (both at $\Delta\theta$ of 10 °C).

Their capacity has been evaluated with the equation provided by lab tests as a function of the temperature difference between the average temperature of the panel and the room temperature. With an inlet temperature in the panel of 35 °C and a flow rate per panel of 50 kg/hr, the radiant panel capacity is around 140 W/m^2, while with a temperature of 30 °C the capacity decrease to 93 W/m^2. In the cooling conditions the panel capacity is around 87 W/m^2 because of a smaller ($\Delta\theta$) between the average panel temperature and the ambient. Radiant panels do not dehumidify the air.

The number of radiant panels per zone is consequently calculated in order to cover the building/dwelling peak power.

As reported already, space heating thermal power has been used for sizing purposes in case residential applications are considered (since this is normal praxis), while cooling is most often the largest thermal load in offices. In this way, in some residential cases, the cooling demand cannot be covered guaranteeing full comfort with respect to all outdoor conditions. The implications of specific design choices are further discussed in this document. This strategy also applies to fan coils.

FAN COILS: the manufacturing data of the vertical 2-tubes fan coil has been considered for the sizing and parameterization of the fan coils model. The fan coil model we refer to is a Carrier 42FA01. Based on the manufacturer data, the performance of this fan coil has been evaluated as a function of the inlet mass flow rate (water side) and the temperature difference between the inlet water and air. Depending on the operating temperatures, the fan coil can cause dehumidification of the air. The sizing procedure used is as follows:

1. A water mass flow rate of 150 kg/h is defined for each fan coil used
2. As many units are used as the number of the building's rooms. i.e., in case of a SFH, 3 units per floor are considered, while for MFHs, 5 per dwelling.
3. The total space heating capacity of the units is matched to the building/dwelling peak power by varying the fan coils airflow rate, once the inlet water temperature is decided (35 or 45 °C in the cases considered). The airflow rate of each unit is checked to avoid unreasonable solutions.

This approach is particularly useful since the electric consumption of the fan coils is computed on their airflow rate (45 W_{el} / kW_{th}). In this way, a link is established between building's space heating/cooling standard and electricity consumed to cover thermal loads.

RADIATORS: the model "DeLonghi Plantella NT mod. 21" has been selected for the radiator (0.9 meter height, 85 mm width). The performance of this radiator is implemented using the standard logarithmic method. The procedure is as follows:

1. The water mass flow rate is decided based on the model's performance at specific inlet water temperatures (35 or 45 °C in the cases considered), in order to install a temperature difference between inlet and outlet of 5 °C.
2. As many units are used as the number of the building's rooms. i.e., in case of a SFH, 3 units per floor are considered, while for MFHs, 5 per dwelling.
3. The total space heating capacity of the units is matched to the building/dwelling peak power by varying the length of the units. The length of each unit is checked to avoid unreasonable (too long) solutions.

The n-exponent is provided by the manufacturer (n=1.33), while characteristics of radiative and convective fractions come from manuals (Recknagel 2012). The convective part of the emitted heat is supposed to be the 65% of the total, while the radiative is the 35%.

2.2.8 Management strategies and set points

The operation management can be divided into two parts, one related to the generation side while the second to the distribution. Every working mode regulates the on-off of the system components, the modulation of pumps and valves and determines the system priorities.

SOLAR CIRCUIT – GENERATION. This circuit is managed thanks to the temperature sensors between the bottom of the main storage and the outlet of the solar collector field (on-off DT = 7/3 °C). Furthermore, there are two safety controls to limit steam formation in the storage and stagnation effects in the solar field. The energy collected by the solar panels is stored in the lower part of the tank.

GENERATION CIRCUIT – GENERATION. The management of this circuit does not vary with the different system configurations (AWHP, GWHP or Boiler). This circuit feeds the upper part of the tank for the DHW preparation and provides heated or cooled water to the buffer tank for the space H&C. The priority is the DHW preparation.

In the study, different tank volumes are considered starting from the minimum volume used to cover DHW preparation (see 2.2.1) to a maximum of 100 l/m² of solar collectors. Changing the volume, the position of the circuits' inlets and outlets varies as well. In the third column of Table 4, the relative position of inlets and outlets is shown, when the storage is used for DHW preparation only. The forth column, instead, shows the relative inlet and outlet positions according to the storage height, varying with solar collectors area considered. For SFHs, the minimum volume amounts to 200 litres, while for MFHs this is 450 litres. In

Table 5, the set points and hysteresis values for the DHW preparation and space heating and cooling are listed.

Table 4 Inlets-Outlets positions of the thermal storage and buffer storage

DHW-storage				
Name	In/out	Relative height (from the bottom)	Relative height (from the bottom)	Description (Figure 9)
		DHW only	DHW + solar	
TES_DP1	In	0	0	Inlet DHW
	Out	1	1	Outlet DHW
TES_DP2	In	0.9	0.9	Inlet Back-up circuit
	Out	0.2	(STOR-SOL)*0.2+SOL	Outlet Back-up circuit
TES_DP3	In	-	0.1	Inlet Solar heating
	Out	-	0.8*SOL[1]	Outlet Solar heating
TES_DP4	In	-	0.8*SOL[1]	Inlet Solar circuit
	Out	-	0.1	Outlet Solar circuit
BUF_DP1	In	0.1	0.1	Inlet distribution system
	Out	0.9	0.9	Outlet distribution system
BUF_DP2	In	0.9	0.9	Inlet from Back-up circuit
	Out	0.1	0.1	Outlet to Back-up circuit
(1) SOL = height of volume heated by solar energy on the bottom part of the storage tank				
(2) STOR-SOL = height of the minimum volume for DHW on top of the storage tank				

Table 5 – Set point temperatures and hysteresis values for the DHW preparation and space heating / cooling

	Sensor	Positions	Temp. [°C]	Hysteresis [°C]	Description
Buffer storage	SENS1	0.8	Distribution system set point (1)	-3/+3	Sensor for distribution supply temperature
Thermal storage	SENS2	(STOR-SOL)*0.2+SOL	45	0/+5	Sensor used for DHW preparation control
Thermal storage	SENS3	0.8*SOL	Distribution system set point	-3/+3	Sensor used for solar heating control
Thermal storage	SENS4	0.1	Outlet Temp solar coll. (2)	+2/+7	Sensor used for solar circuit control

(1) Radiant ceilings summer: 15 °C — Radiant ceilings winter: 30 or 35 °C
Fan coils summer: 7 °C — Fan coils winter: 35 or 45 °C
Radiators summer: - — Radiators winter: 35 or 45 °C
(2) solar collectors' temperature

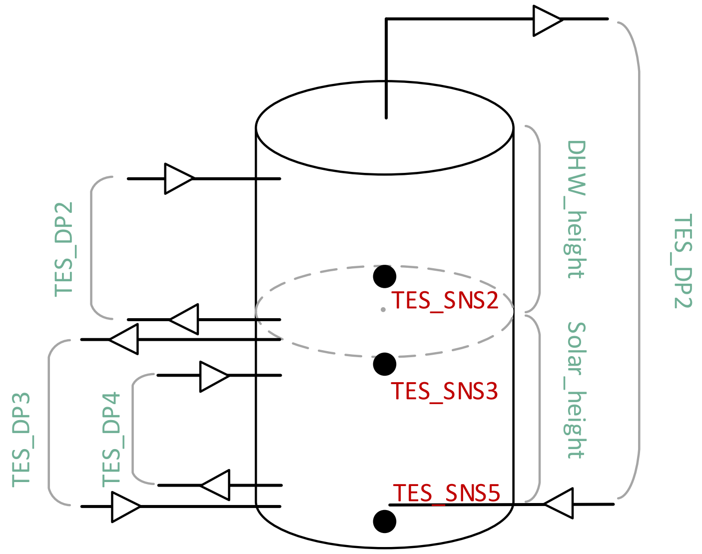


Figure 9 - Double ports and sensors position in the storage tank

SOLAR SPACE HEATING – GENERATION. The solar space heating mode allows to feed the buffer tank with solar energy stored in the lower part of the thermal storage tank. The outlet from the thermal storage tank is located appropriately in order to avoid that water heated for DHW in the top part of the tank is used for the space heating.

To this aim, inlet and outlet for the solar heating (double port DP4) are below the outlet for the DHW preparation (DP2). When the sensor SENS3 measures a temperature at least equal to the DHW set temperature, the solar heating mode is activated.

BACKUP – GENERATION. Only in those cases where the units used for heating distribution cannot provide also cooling (radiators) or the generation is a boiler, a split unit is installed. The management of this device is performed with the convective temperature of the zone. The set point of the convective temperature is 25 (0/-0.5 °C).

DHW PREPARATION – DISTRIBUTION. The circuit of DHW for the SFH is activated when the user request for it. For MFHs, this circuit is activated also for recirculation to keep the entire circuit warm enough, avoiding users' temporary discomfort. No DHW distribution is foreseen for the offices.

HEATING AND COOLING – DISTRIBUTION. The request of each thermal zone simulated (see D2.1c) is done using the sensible temperature with a hysteresis of ±0.5 °C. The set point of the sensible temperature are 19.5+0.5 °C for the winter and 25 - 0.5 °C for the summer.

2.3 Parametric study

The parametric analysis has been performed using the software TRNEDIT that allows to run multiple TRNSYS simulations, based on a common TRNSYS model (DECK file) and a table of varying parameters (based on the Sizing Tool outcomes).

For each of the construction ages (1945-1970, 1970-1980, 1980-1990, 1990-2000) and the building types (SFH, sMFH, lMFH, OFFICE) we simulated the following variants.

Table 6 - Parametric variants for the simulation work

Parametric variables	Number	Values
Location	7	Stockholm; Gdansk; Stuttgart; London; Lyon; Rome; Madrid
Building heating demand levels	Residential 4	15, 25, 45, 70 kWh/m^{2}y
	Office 2	25; 45 kWh/m^{2}y
Heating and Cooling system	4	AWHP, GWHP, Gas boiler, Pellet boiler
Radiant ceiling supply temperature	Winter 2	30,35 °C
	Summer 1	15 °C
Fan coils supply temperature	Winter 2	35, 45 °C
	Summer 1	7 °C

Radiators supply temperature	Winter 2	35, 45 °C
	Summer 1	Split unit
Solar thermal collectors inclination	2	30°, 90°
Specific tank volume	2	50, 100 l/m²
Photovoltaic modules inclination	2	30°, 90°

The entire set of simulations leads to more than 500'000 records in the database. To report all the generated information in a document is impractical and meaningless, since a number of similar solutions would need comment.

For this reason, here only a reduced set of solution is reported: in particular, with respect to the residential sector, only the reference buildings built within the first age (1945-1970) are accounted for. These buildings need Envelope Renovation solutions that are extreme with respect to the ones required for the other ages, therefore representing conservative results from both the technical and the economic point of view.

With respect to the offices, two ages are considered (1945-1970 and 1980-1990) since they require very different renovation approaches.

2.4 Systemic Renovation Packages database

This database contains a vast amount of data of energy performance that iNSPiRe has generated for a variety of retrofit technologies applied to iNSPiRe's selected reference buildings. This informs on how specific retrofit packages impact on the specific reference building.

The solutions are predetermined through simulations as reported above, while some results are calculated based on the energy performance and on the values provided in the input worksheet. In particular, LCA and economic data are calculated in this way.

Data are provided per climatic region, represented by the climates of Rome, Madrid, Lyon, Stuttgart, London, Gdansk and Stockholm. In addition to climate, building type and age of construction, one can select a number of retrofit parameters:

- Building typology and age of construction selected as a starting point of the retrofit
- Wished heating demand after retrofit, which together with summer and winter set temperatures, determines the insulation and new windows quality
- Type of heating & cooling generation system including size and position of solar thermal and/or PV fields
- Type and temperatures of the heating & cooling distribution systems into the building.

The database is built as a sequence of records each one reporting on a specific simulation's results. In the following sections, we describe the groups of data that can be examined and the Key Performance Indicators (KPIs) used to analyse the Renovation Packages.

2.4.1 Reference buildings features and envelope renovation packages

The first part of the database reports on the dimensions of the building both in terms of opaque and glazed surfaces. With respect to the opaque portion, insulation thicknesses are stated, while type of new windows is specified for windows. Finally, infiltration levels and mechanical ventilation air flows are reported.

2.4.2 Heating and cooling system features

In addition to type and thermal capacity of the generation unit considered, this section of the database reports on the thermal storages and buffer tank volumes, pipes diameters and insulation thicknesses and pumps volume flows.

The dimensions and thermal capacity of the distribution terminals are also stated in this section. Surface area and specific capacity (W/m^2) is used for the 3 solutions (radiant ceilings, radiators and fan coils). This kind of specification is clear for radiant ceilings, and can be linked to the frontal area of radiators and fan coils, once the radiator type and brand is selected, as we did. On the contrary, this is not a common way to report on the performance of fan coils.

2.4.3 Buildings heating and cooling used: Demand vs. Used Energy

In chapter 2.2.1 we stated that space heating and cooling loads have been obtained through an “ideal” heating and cooling model that exactly maintain the indoor air temperature at the imposed set. A model with 30% radiant and 70% convective heating contributions has been used as a reference, representing typical radiators.

While energy uses reported in this section are calculated with this method for the reference buildings, this is not true for the renovated buildings.

In the latter cases, an H&C system has been simulated, with indoor set temperatures varying within a hysteresis of 0.5 °C and with different proportions of radiative vs. convective contributions depending on the heating/cooling distribution system utilised.

Since set temperatures are always imposed on indoor air convective temperature - instead of the operative temperature -, this has an effect on the energy uses for heating and for cooling. Distribution systems with a higher contribution of the radiative component (radiant ceilings) need more energy to reach the same levels of indoor air convective temperature due to higher transmission losses caused by higher wall surface temperatures. On the other hand, they allow for higher comfort levels.

As such, we will refer to energy demand with respect to reference buildings before renovation, while we will talk about “used energy” in case of the renovated buildings. In particular:

- Heating and cooling demands are shown for the reference buildings before retrofit
- Heating, cooling and DHW used energy for the renovated buildings

2.4.4 Performance indicators for heating and cooling generation units

The performance of the H&C generation units are reported in terms of:

SCOP: The COP is defined as the ratio of the heat output of the heat pump unit to the effective electricity input to the unit for a stationary operating condition. In this case, the ratio is calculated based on the average seasonal values both thermal and electric.

$$SCOP_{DHW} = Q_{DHW}/E_{DHW}$$

$$SCOP_{SH} = Q_{SH}/E_{SH}$$

$$SCOP_{tot} = (Q_{DHW} + Q_{SH})/(E_{DHW} + E_{SH})$$

SEER: The EER is defined as the ratio of the cold output of the reversible heat pump unit to the effective electricity input to the unit for a stationary operating condition. In this case, the ratio is calculated based on the average seasonal values both thermal and electric.

$$SEER_{SC} = Q_{SC}/E_{SC}$$

THERMAL EFFICIENCY: in case boilers are considered, the thermal efficiency is the ratio of the heat output to the building to the energy entailed in the fuel consumed, expressed by the Higher Calorific Value (HCV).

$$\eta_{DHW} = Q_{DHW}/HCV_{DHW}$$

$$\eta_{SH} = Q_{SH}/HCV_{SH}$$

$$\eta_{tot} = (Q_{DHW} + Q_{SH})/(HCV_{DHW} + HCV_{SH})$$

For non-condensing boilers, like biomass ones, this value ranges between 0.8 and 0.85. For condensing boilers this value ranges between 0.9 and 0.95, while for gas driven sorption heat pumps values up to 1.2 can be reached.

The boundaries for the assessment of the above energy fluxes are set just around the unit, meaning that we consider the electricity needed to run the HP compressor, backup electric heater and fan (the latter in case of AWHP), while the electricity used to drive any pumps is not accounted for.

2.4.5 Performance indicators for heating and cooling (generation and distribution) systems

The above performance figures can be used also when moving the study from the single unit to the entire generation and distribution system.

In this case, the electricity consumption figures also account for the energy used by all the pumps, valves and control unit (a constant 20 W consumption 24/7 is accounted for, in order to consider this contribution), as well as the electricity used by the mechanical ventilation (0.4 Wh/m³ of fresh air exchanged).

In this case, SCOP and SEER are referred to as SPF: SEASONAL PERFORMANCE FACTOR.

In addition to the SPF and thermal efficiencies, the database reports also on systems':

FINAL ENERGY USE: for electricity driven systems, the FE equals the electricity used to drive the HVAC systems, while for gas or biomass driven ones, the FE equals the HCV of the used fuel by its mass consumption.

PRIMARY ENERGY USE: In order to compare systems and technologies in terms of their environmental impact, the use of the Primary energy concept is recommended in this report. The PE use gives information on the consumption of non-renewable energy sources for the provision of useful energy output of the system. Note that this does not account for the production, distribution, installation and end-of-life disposal of the HVAC system itself. It is a figure which considers the depletion of limited energy resources contained in e.g. fossil fuels.

For the calculation of this figure, the CED_{NRE} – Cumulative Energy Demand (CED), non-renewable – is used: it quantifies the non-renewable primary energy used to provide the final energy, including the energy used for construction of the electric grid and power plants. This indicator accounts for the primary energy from fossil, nuclear and primary forest resources (i.e. original forests that are destroyed and replaced by farmland) defined in terms of primary energy to final energy - kWh_{PE}/kWh_{FE}.

$$PE = FE * CED_{NRE}$$

Since the provenance of the electrical energy at the plug varies widely from country to country due to their power generation and import mixes, it is important to define reference values for comparison purposes. For the electric energy, the corresponding European electricity supply mix (ENTSO-E – European Network of Transmission System Operators for Electricity) on low voltage level for these two indicators was chosen (Task 44, Deliverable B1).

The primary energy factor is for non-renewable energy and the value used is a European average for the year 2012. As such it is larger than the relevant values for certain individual countries and it will decrease with time as a consequence of the expected increasing RES penetration in the electricity market.

For all other energy carriers, the values for each country are nearly identical and are taken from the Ecoinvent database (Ecoinvent (2013)) that contains a large number of processes for production of goods and provision of services with a focus on European production chains (see Table 7).

Table 7 - CED_{NRE} for different energy carriers (Malenkovic I., 2012)

Energy carrier	CED_{NRE} [kWh_{PE}/kWh_{FE}]
Electricity	2.878
Gas	1.194
Oil	1.271
Wood	
logs	0.030
pellets	0.187
chips	0.035

PRIMARY ENERGY RATIO: the same calculation approach used for the SPF definition can be used for the calculation of the PER. In this case, the PE is used instead of the FE at the denominator. This allows to compute a performance figure that comprehends all the different energy uses that cannot be summed up as is.

$$PER_{DHW} = Q_{DHW} / PE_{DHW}$$

$$PER_{SH} = Q_{SH} / PE_{SH}$$

$$PER_{SC} = Q_{SC} / PE_{SC}$$

$$PER_{tot} = (Q_{DHW} + Q_{SH} + Q_{SC}) / (PE_{DHW} + PE_{SH} + PE_{SC})$$

SOLAR FRACTION, AEROTHERMAL/GEOTHERMAL FRACTION AND RENEWABLE ENERGY FRACTION: solar fraction is defined as the percentage of DHW and/or heating demand that is covered by solar thermal energy.

$$SF_{DHW} = Q_{ST,DHW} / Q_{DHW}$$

$$SF_{SH} = Q_{ST,SH} / Q_{SH}$$

$$SF_{tot} = (Q_{ST,DHW} + Q_{ST,SH}) / (Q_{DHW} + Q_{SH})$$

Where $Q_{ST,DHW}$ is the net solar thermal energy employed, detracted of thermal losses along the pipelines and the thermal storage. The computation of this figure poses a challenge, since all the solar thermal energy is conveyed to the solar storage tank, and then used both for DHW preparation and for space heating; therefore, there is no formal way to split the total renewable energy into the two contributions. As an approximation, the contribution of the solar thermal energy to the different loads has been considered as proportional to the power delivered during the DHW and solar space heating delivery.

The same strategy is used to calculate the net amount of aerothermal (respectively geothermal) energy harvested by the heat pump that contributes to cover the heating and DHW loads.

$$AF_{DHW} = {Q_{\mathrm{A},DHW}}/{Q_{DHW}}$$

$$AF_{SH} = {Q_{\mathrm{A},SH}}/{Q_{SH}}$$

$$AF_{tot} = {(Q_{\mathrm{A},DHW} + Q_{\mathrm{A},SH})}/{(Q_{DHW} + Q_{SH})}$$

Finally, the renewable energy fraction is calculated as the total amount of loads to the total renewable energy (solar thermal, aerothermal and geothermal) that contributes to cover such loads. For sake of simplicity, the renewables contribution to the grid electricity used is disregarded. As a main consequence, renewable energy sources do not contribute to cover cooling loads.

$$RENF_{DHW} = {Q_{\mathrm{REN},DHW}}/{Q_{DHW}}$$

$$RENF_{SH} = {Q_{\mathrm{REN},SH}}/{Q_{SH}}$$

$$RENF_{tot} = {(Q_{\mathrm{REN},DHW} + Q_{\mathrm{REN},SH})}/{(Q_{DHW} + Q_{SH})}$$

PENALISED FE AND SPF: we have defined penalty calculations to make sure that the same thermal comfort is achieved by all systems (based on using the convective temperature). The following conditions result in penalties being calculated for the system: $T_{DHW} < 40°C, T_{SH} < 19.5°C, T_{SC} > 25.0°C$).

To fairly compare different HVAC systems though, we must acknowledge that some of them do not perform as wished and we must penalise their operation. To do that, we calculate the penalised FE and SPF: whenever the investigated system is not able to fulfil the user demand for the room temperature and DHW supply temperature, an additional energy demand, the penalty, is calculated and interpreted as an auxiliary energy demand of the heating system. The electric energy required is calculated accounting for an ideal electric system with COP (or EER) equal to average computed for the system (Haller M. Y., 2014). For more information refer to task 26 book "Solar heating systems for houses" (Weiss W., 2003).

If the temperature of the room is lower than the set point, the penalty is defined as the product of $(UA)_{building}$ (building heat loss rate) and the difference between required set temperature and actual indoor air temperature.

The penalty function is calculated for every time step and then integrated on a yearly basis. In the following, the two equations used for the heating and cooling penalties are reported:

$$Q_{PEN_{SH}} = UA_{BUI} * MAX\left(0, MAX(0, T_{set_H} - T_{zone}) + \left(MAX(0, T_{set_H} - T_{zone}) + 1\right)^{X_{SH}} - 1\right)$$

$$Q_{PEN_{SC}} = UA_{BUI} * MAX(0, \left(MAX(0, T_{zone} - T_{set_C}) + 1\right)^{X_{SC}} - 1)$$

Where

$UA_{BUI} = 30.1 + Q_{HEAT_{ave}} * 2.13$ is the building heat loss rate related to the energy level

x_{SH} is the (punishment factor) introduced by the exponent: 2 (arbitrarily)

T_{set_H} heating lower temperature limit is 19.5 °C (20.5 °C for offices)

T_{set_C} cooling upper temperature limit is 25.0 °C

The calculation of the penalty for the DHW simply calculates the missing energy to reach the set point temperature. The "punishment factor" is defined (again arbitrarily) as 1.5:

$$Q_{PEN_{DHW}} = 1.5 * \dot{m}_{DHW} * C_{p,WATER} * MAX(0, T_{set_{DHW}} - T_{DHW})$$

Although, the penalisation functions are purely subjective, as already stated, they allow to objectively comparing systems that guarantee comfort conditions, to those that do not.

These three electric energies are added to the system Final Energy, and shown in the $FE_{penalised}$. The penalised SPF ($SPF_{penalised}$) is calculated using the $FE_{penalised}$.

UTILITY ENERGY BILL: as for the PE figure, the total energy bill is another method to aggregate the contributions of the different energy sources to covering the building's energy uses:

$$UEB = (E_{DHW} + E_{SH} + E_{SC}) \cdot Cost_E + (HCV_{DHW} + HCV_{SH} + HCV_{SC}) \cdot Cost_{fuel}$$

All the above mentioned figures are calculated for:

- Space cooling loads only
- Space heating loads only
- DHW loads only
- Space heating and DHW loads
- Space heating, cooling and DHW loads
- Space heating, cooling and DHW loads + ventilation electricity consumption

This approach allows to highlight the weight of the different loads' contributions to the total energy consumption of the building related to the HVAC system.

2.4.6 Performance indicators for solar thermal field

SOLAR THERMAL SYSTEM EFFICIENCY: the efficiency of the solar thermal system is defined as the ratio of the obtained useful heat divided by the irradiation (see e.g. VDI 6002-1 (2004)) on the collector plane. Depending on how the useful heat is defined and where it is measured, stagnation periods, pipe losses, actual weather conditions and interdependency to the conventional heating system may be taken into account (Task 44, Deliverable B1).

In this report, the useful energy delivered to the solar thermal energy storage is considered, accounting for all the irradiation incident on the collector plane when the solar pump is running or during stagnation periods. Thus, the solar thermal system efficiency can be defined as:

$$\eta_{ST} = {Q_{ST,store}}/{I_{coll}}$$

GROSS SOLAR YIELD: using the net solar energy delivered to the storage tank, we calculated the solar field GSY:

$$GSY_{ST} = {Q_{ST,store}}/{Area_{coll}}$$

In addition, stagnation periods are accounted for.

2.4.7 Performance indicators for photovoltaic field

The FE and PE figures described account for the PV electricity produced and instantaneously consumed by the H&C system: the PV electricity is subtracted by the electricity consumption if it is produced when H&C system operates. In many cases, this is a small fraction of the total PV production. Therefore, a dedicated section of the database shows the total PV electricity consumption, how much of this electricity is self-consumed and how much is fed into the grid. Note that the self-consumption is based on a time step of 1 hour (consumption as well as PV electricity production). The energy bill accounts only for the electricity taken from the grid. Incentives and renewable based funding in general are disregarded as they differ by country.

The computation of the PE utilization accounts only for the PV electricity used by the HVAC systems. It is easy to recalculate the total PE consumption by subtracting the specific amount of PV electricity, dependent on the boundary considered (the entire building or the grid as a whole).

2.4.8 LCA study

In this chapter we do not go in details into the performance figures used for the LCA study since that is largely treated in report D6.1.

2.4.9 Performance indicators for economic analysis

This section presents the economic analysis of the systemic Renovation Packages in terms of total costs of ownership (investment + running) over a 30 years period. The latter have been adopted to permit a direct comparison with the LCA study, and to provide a spendable figure that final users and customers can easily understand.

Besides clear advantages from the environmental and technical point of view, investment costs are a bottleneck for a widespread diffusion of systemic Renovation Packages. Thus, we must "uncover" the best solutions from both the technical and economic point of view.

INVESTMENT COSTS: The up-front cost a customer pays when adopting a systemic Renovation Package is defined as the total cost of ownership TCO [€/m^2] calculated according to the Net Present Value (NPV) method, which takes into account all costs during the period of analysis and in particular:

- initial investment costs I_0;
- replacement costs C_r.
- operation linked payments (maintenance costs, insurance, taxes) C_m;
- consumption linked payments (final energy costs) C_{fe};

The advantage of adopting this approach is that the cost-effectiveness of a given system is not defined in relative terms with respect to a reference system, on the contrary, it is evaluated in terms of specific energy price that has been paid by a final user during the life time of the building itself.

For sake of simplicity, the calculation approach adopted here assumes that the investment costs and replacement costs can be born with own budget. Whenever this condition does not occur, these costs are funded through a bank loan, and the interest rates must be accounted for, together with inflation rates. For the same reasons, incentive schemes are disregarded.

In order to compare two investments representing two different energy system variants, a common economic timeframe must be defined. We decided to use a timeframe of 30 years since passive and active solutions are entailed in the Renovation Packages.

The Renovation Package lifespan τ is in general shorter than the calculation period N (Figure 10). An estimation of τ is not easy to derive and most of the times it can be based only on personal experience. Annex IV reports on the assumptions adopted. In the database published, the user is free to input such value for each of the subsystems individuated.

When a system completes its lifespan, a replacement occurs. From an economic perspective, this reflects in a series n of replacements each of them resulting in a replacement cost C_r. Since replacement costs occur at different times than the initial investment cost, inflation interest i has to be considered as follows:

$$C_{r,0}^{(1)} = I_0 \cdot (1+i)^{0\cdot\tau} \text{ , the initial investment}$$

$$C_{r,0}^{(2)} = I_0 \cdot (1+i)^{1\cdot\tau} \text{ , if } 1\cdot\tau < N$$

...

$$C_{r,0}^{(n)} = I_0 \cdot (1+i)^{n\cdot\tau} \text{ , if } n\cdot\tau < N$$

The total replacement cost $C_{r,0,N}$ is the sum of the single replacement costs that have been faced during the period N:

$$C_{r,0,N} = \sum_{j=0}^{n} C_{r,0}^{(j)} = I_0 \frac{1-(1+i)^{\tau\cdot n}}{1-(1+i)^{\tau}}$$

During the lifespan τ, it is assumed that the system has a linear depreciation of the investment cost I_0 or the replacement cost C_r. At the end of the economic analysis period N, a positive residual value RV might occur. The actualized residual value RV_0 of a system can be calculated as follows:

$$RV_0 = \frac{RV}{(1+i)^N} = I_0(1+i)^{\tau\cdot n-1}\left(1-\frac{\tau\cdot n-30}{\tau}\right)$$

Hence, the net total replacement cost $C_{r,N}$ is the difference between the replacement cost $C_{r,0,N}$ and the actualized residual value RV_0 of the system.

$$C_{r,N} = C_{r,0,N} - RV_0$$

Since little information from comparable subjects is available, the definition of maintenance cost C_m is also not an easy task. For sake of simplicity, a benchmark yearly cost is here established as a percentage c_m of the initial system investment cost, in the range of 1-3%/year.

$$C_{m,N} = \sum_{j=1}^{N} C_m \cdot (1+i)^j$$

The yearly energy related cost C_{fe} can be calculated on the basis of the cost of the final energy annualised by means of the rate of change of the energy costs with time:

$$C_{fe,N} = \sum_{j=1}^{N} C_{fe} \cdot (1+i_e)^j$$

Once the initial investment cost I_0, the total final energy cost $C_{fe,N}$, the maintenance cost $C_{m,N}$ and the net replacement cost $C_{r,N}$ related to the economic analysis period N have been computed, the total cost of ownership TCO can be easily calculated as:

$$TCO = I_0 + C_{fe,N} + C_{m,N} + C_{r,N}$$

In the database, the TCO is also reported in terms of annual cost (€/y) and annual costs per unit surface of living area (€/m^2/y), over 30 years.

In addition, simple investment costs and annualised investment costs, are reported a basic way to compare initial ("entrance") costs to be born for the renovation process.

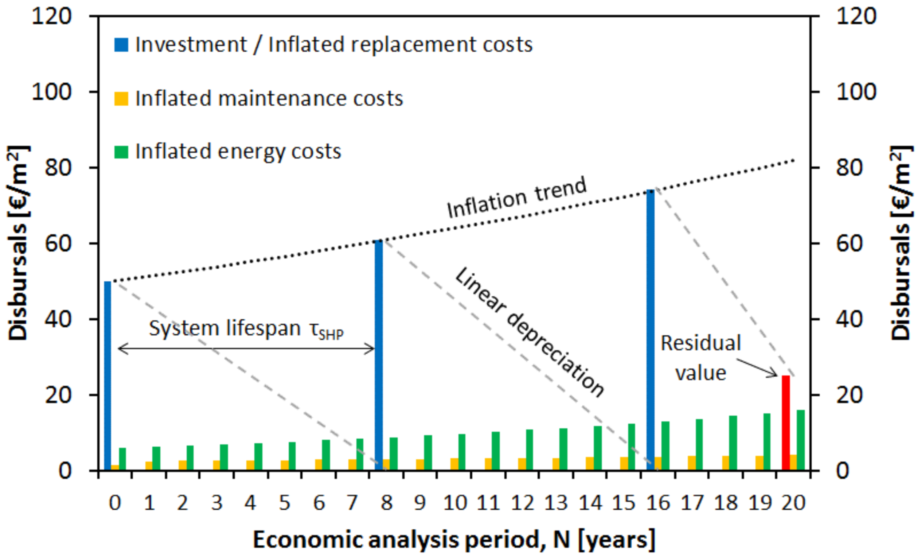


Figure 10 - Graphical representation of the periodicity of disbursals and interest related costs during an economic analysis period.

3 Annex I – Reference buildings boundary conditions

3.1 Buildings' orientation

One orientation has been fixed for all the cases, at **45°** (towards East).

3.2 Internal gains

Internal gains are divided into occupational and electric (appliances + lighting).

3.2.1 Residential Buildings:

Occupancy loads:

For the occupancy, the sensible and latent heat follows the norm ISO 7730 where an activity of seated, very light writing is considered. Consequently, the sensible heat per person is 65 W, with a convective part of the 40%, and latent heat amounts to 55 W (which corresponds to a value of latent production 0.059 kg/h/person).

Table 8 – Buildings' occupancy

BUILDING TYPOLOGY	PERSONS per dwelling
	[-]
SFH	4
MFH	3

For the SFH, a daily occupancy profile is used (Dott R. et al, 2013) while in the MFHs a yearly stochastic profile generated with the method developed by Widén at the University of Uppsala (Widén J. et al, 2010) is used. According to the dwelling area and number or people per dwelling, the average internal gain due to persons amounts to 1.18 W/m² for SFHs, 2.36 W/m² for s-MFHs and 1.8 W/m² for l-MFHs.

Electric loads:

Internal gains due to appliances are calculated taking into account the lighting and also the losses due to hot water of washing machine and dishwasher, dryer, cooking, cold water (e.g. Toilet water heated to room temperature), evaporation (towels, plants). It has been evaluated a value of 2100 kWh/dwelling/year due to electrical loads. From existing to renovated case, it has been assumed that the appliances consumption does not change, while the lighting is reduced by a half due to improved technologies' used (LED luminaires). The average value of internal gains along the year for the three building typologies is reported in the following table.

As for the occupancy, the appliances have been considered with a daily profile for the SFHs and with a stochastic profile for the MFHs.

Table 9 – Buildings' electric loads

BUILDING TYPOLOGY	AREA	GAIN
	[m²]	[W/m²]
SFH	97	2.4
s-MFH	50	4.8
l-MFH	65	3.7

DHW loads:

According to the statistics, the DHW demand has been considered with a value of 21 kWh/m²a (Birchall S. et al., 2014). For the simulation, the DHW profiles have been generated using a stochastic generator software (Widén J. et al., 2010) both for SFH (one single profile) and for s-MFH (multiple profiles).

A tap water temperature oscillating between 8 and 12 °C along the year with a sinusoidal behaviour has been considered for all climates.

3.2.2 Office Buildings:

Occupancy loads:

In the offices, internal gains are divided into three main categories: occupancy, appliances and lighting gains. The level of occupancy is estimated to be 9 m²/pers. The presence of people in the office varies during the day according to schedules defined in Table 10.

Table 10 – Schedule profile during working days

From	Until	People & lighting	Electric appliances
00:00	07:30	0	0
07:30	08:30	0	1
08:30	12:30	1	1
12:30	13:30	0	1
13:30	17:30	1	1
17:30	00:00	0	0

According to typical office activity level, a total internal gain of 115 W/pers is considered. This value takes into account sensible (65 W) and latent gains (0.059 kg/h/person). Sensible gains are further divided into convective (60%) and radiative (40%) contributions.

The presence of occupants during the working days has been defined according to an hourly schedule (see Table 10) while during the weekend the occupancy is set to zero. Holidays are taken also into account by setting 1+1 weeks off during the summer (mid-August holiday) and winter (Christmas) time.

Electric loads:

The gains due to appliances is calculated based on the common presence computer, monitors, printers, etc. With respect to the reference case where common equipment were used, for the target buildings, low energy consumption appliances are considered. The total internal gains due to these amounts to 7 W/m². During working hours, these internal gains are assumed to be continuously on.

Lighting loads:

In the offices, the lighting load is one of the main cause of internal gains. While for the existing building a common value of lighting load is 25 W/m², for the renovated cases this value is strongly reduced up to 10-15 W/m². In the simulations a value of 11,6 W/m² is used.

4 Annex II – Generation units' Performance

This Annex summarizes the performance figures for all generation units. Data are obtained from manufacturers' datasheets.

4.1 Air to Water heat pump

Figure 11 shows how COP varies according to ambient temperature and temperature at the condenser, while *Figure 12* shows EER trends in relation to external air temperature and temperature at the evaporator.

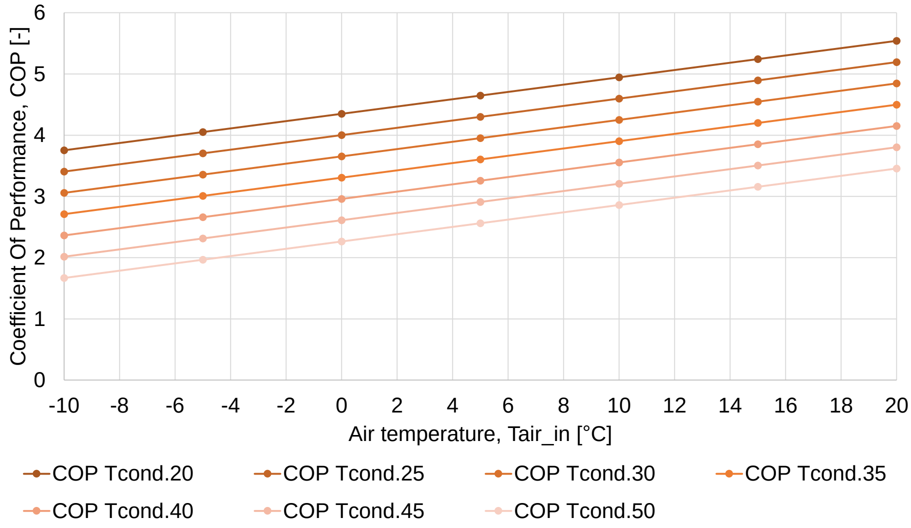


Figure 11 - Coefficient Of Performance for an Air to Water Heat Pump in winter mode as a function of the ambient air and the inlet water temperature at the condensing side

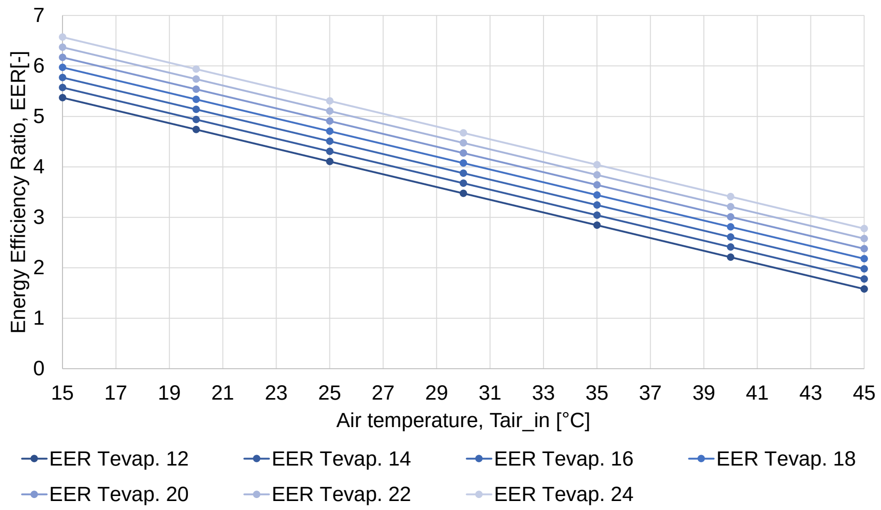


Figure 12 - Energy Efficiency Ratio for the Air to Water Heat Pump in cooling mode as a function of the ambient air and the inlet water temperature at evaporator side

4.2 Ground Source heat pump

Figure 13 shows the COP variation with the evaporator and condensing temperature changing, whereas Figure 14 draws the EER trends depending, again, on the evaporator and condensing temperatures.

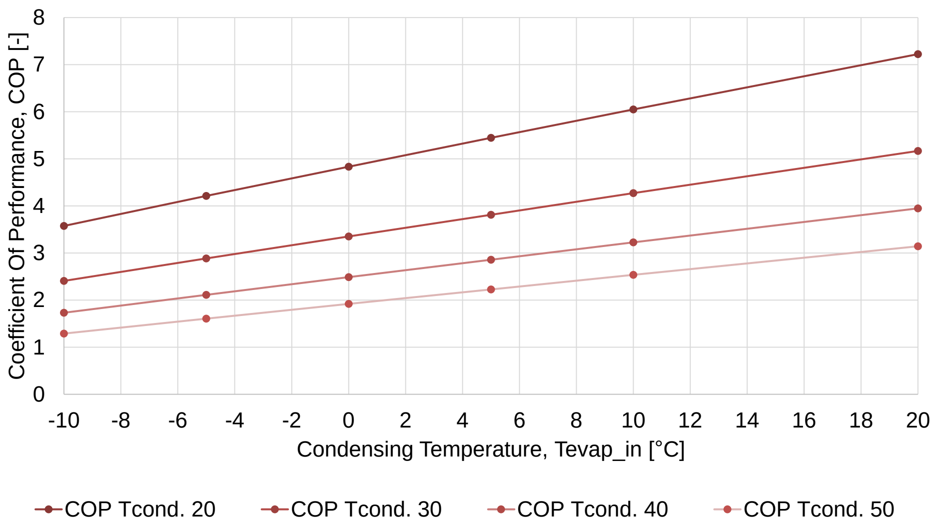


Figure 13 - Coefficient of Performance for Water to Water Heat Pump in winter mode as a function of the ambient air and the inlet water temperature at condensing side.

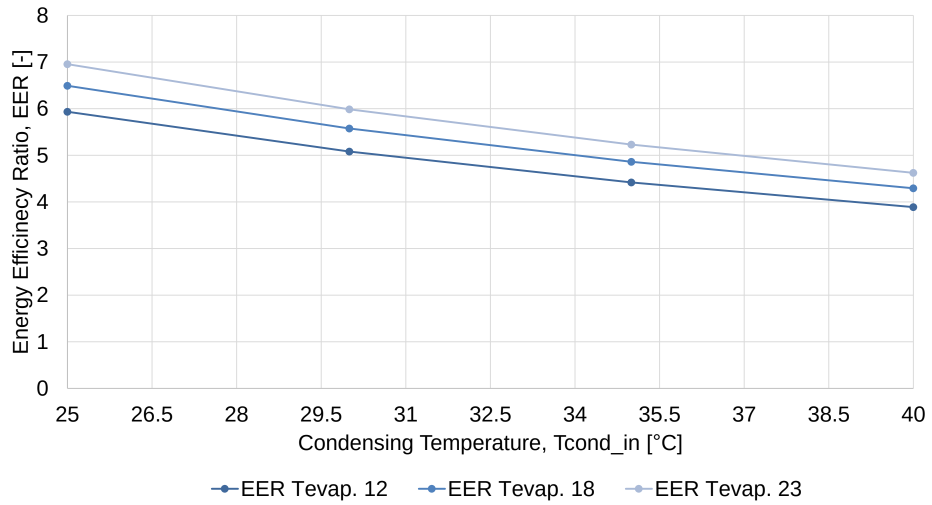


Figure 14 - Energy Efficiency Ratio *for the Water to Water Heat Pump in cooling mode as a function of the water temperature at condensing and evaporator sides.*

4.3 Biomass and Gas boiler

The thermal efficiency of the condensing gas boilers simulated is a function of the return water temperature as shown in Figure 15. The thermal efficiency of biomass boilers is taken as constant.

The thermal efficiency of the boilers considered only slightly depends on the Part Load Ratio: 2% at the minimum load compared the one at rated load.

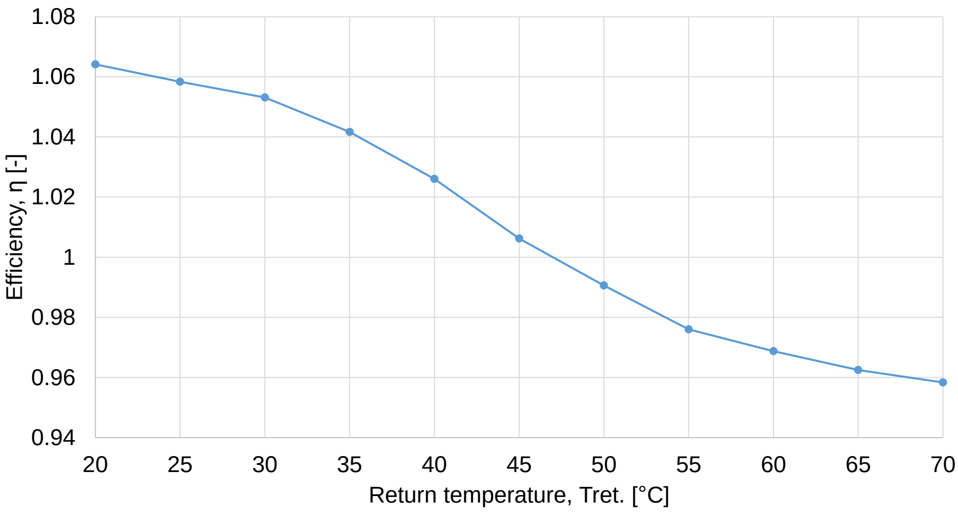


Figure 15 – Efficiency of the condensing boiler as a function of the return temperature of the water.

4.4 PV panels

The PV production has been calculated using crystalline panels which main characteristics are reported in the following table.

Table 11 – Main characteristics of the PV panels

	UNIT	VALUE
Nominal power	[Wp]	220
Electric efficiency (at rated conditions)	%	13
Voltage at maximum-power point	[V]	36
Current at maximum-power point	[A]	4,58
Voltage at open circuit	[V]	43,8
Current at short circuit	[A]	5,18

4.5 Solar thermal collectors

For the study, solar collectors, which main characteristics are reported in the following table, are used:

Table 12 - Main characteristics of the ST collectors

	UNIT	VALUE
Collector surface	[m²]	2.3
Efficiency	[%]	82,4
Coefficient of heat loss – k1	[W/(m²K)]	3,792
Coefficient of heat loss – k2	[W/(m²K)]	0,021

The mass flow rate for the solar thermal field has been calculated considering a value of 50 kg/h per $m^2$of panel; actually it consists of 115 kg/hm^2 for each series of collectors.

4.6 Split Unit

The design EER of the Split unit (air to air heat pump) is 4.5, as a common value of split units on the market. The EER is function of the ambient temperature and the standard conditions are referred to 31°C ambient (see Figure 16).

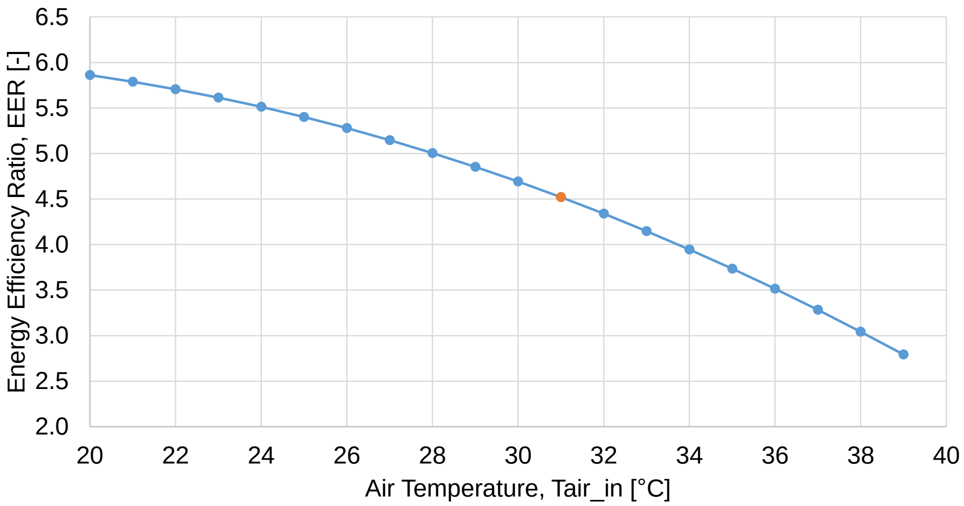


Figure 16 - Energy Efficiency Ratio *for the Air to Air Heat Pump in cooling mode as a function of the ambient air temperature.*

5 Annex III – Envelope Renovation Packages

This chapter presents the details of simulated renovation packages. The chapter is sub divided in four sections where each one shows the different aspects considered in the renovation phase: envelope, windows, shadings, infiltration and mechanical ventilation. For the sake of simplicity, every subchapter is subdivided in the categories SFH MFH and OFF.

5.1 Infiltrations and Mechanical ventilation

Infiltration rate is strongly connected to the building airtightness and occupants' behaviour and it varies during the year. For the sake of simplicity, a fixed value through the day and the year is defined. Different values of infiltration rate have been defined by experience depending on the Climate and on the building energy level.

5.1.1 Single Family Houses

The infiltration rate for the SFHs are presented in the following tables:

Table 13 - Infiltration rate n50 [1/h]

	Level of heating demand [kWh/m²y]			
	15	**25**	**45**	**70**
Stockholm	0.6	1	1	1.5
Gdansk	0.6	1	1	1.5
Stuttgart	0.6	1	1.5	1.5
London	0.6	1	1.5	1.5
Lyon	0.6	1	1.5	1.5
Madrid	0.6	1	1.5	1.5
Rome	0.6	1	1.5	1.5

Table 14 - Infiltration + mechanical ventilation rate [1/h] based on calculation of "Ventilation" sheet in PHPP

	Level of heating demand [kWh/m²y]			
	15	**25**	**45**	**70**
Stockholm	0.042	0.07	0.07	0.006
Gdansk	0.042	0.07	0.07	0.006
Stuttgart	0.042	0.07	0.006	0.006
London	0.042	0.07	0.006	0.006
Lyon	0.042	0.07	0.006	0.006
Madrid	0.042	0.07	0.006	0.006
Rome	0.042	0.07	0.006	0.006

Mechanical ventilation in SFHs has been considered for all the buildings with an air rate of **0.40 1/h**. A heat recovery with exhaust air has been considered for the buildings in all the climates in the first two energy levels (15 and 25 kWh/m² y) and for Nordic and Northern Continental climates for the third energy level too.

Where foreseen, a constant efficiency of the heat recovery has been fixed at **0.85** (see Table 15).

The effective air rate for mechanical ventilation is calculated as follows:

$$n_{mech\_eff} = n_{mech} * (1 - \eta_{PHI})$$

Where

n_{mech_eff} is the effective air rate for mechanical ventilation

n_{mech} is the total ventilation rate

η_{PHI} is the heat recovery efficiency

The heat recovery efficiency according to Passive House Institute is defined as follows:

$$\eta_{PHI} = \frac{(\theta_{ext} - \theta_{exh}) + \frac{P_{el\_vent}}{\dot{m} \cdot c_p}}{(\theta_{ext} - \theta_{amb})}$$

Table 15 Efficiency of heat recovery [η_{PHI}]

	Level of heating demand [kWh/²y]			
	15	**25**	**45**	**70**
Stockholm	0.85	0.85	0.85	0.0
Gdansk	0.85	0.85	0.85	0.0
Stuttgart	0.85	0.85	0.0	0.0
London	0.85	0.85	0.0	0.0
Lyon	0.85	0.85	0.0	0.0
Madrid	0.85	0.85	0.0	0.0
Rome	0.85	0.85	0.0	0.0

5.1.2 Multifamily houses

For MFHs the assumptions are slightly different and summarized in the following tables:

Table 16 - Infiltration rate n50 [1/h]

	Level of heating demand [kWh/m²y]			
	15	**25**	**45**	**70**
Stockholm	0.6	1	1	1.5
Gdansk	0.6	1	1	1.5
Stuttgart	0.6	1	1	1.5
London	0.6	1	1	1.5
Lyon	0.6	1	1	1.5
Madrid	0.6	1	1	1.5
Rome	0.6	1	1	1.5

Table 17 - Infiltration and mechanical ventilation rate [1/h] based on calculation of "Ventilation" sheet in PHPP

	Level of heating demand [kWh/m²y]			
	15	**25**	**45**	**70**
Stockholm	0.042	0.07	0.07	0.006
Gdansk	0.042	0.07	0.07	0.006
Stuttgart	0.042	0.07	0.07	0.006
London	0.042	0.07	0.07	0.006
Lyon	0.042	0.07	0.07	0.006
Madrid	0.042	0.07	0.07	0.006
Rome	0.042	0.07	0.07	0.006

Mechanical ventilation for the MFH works as for the SFH but the heat recovery is present only for the lower energy level (15kWh/m²a and 25 kWh/m²a) included the hottest climates (Mediterranean and Southern Dry). The efficiency of heat recovery is again 85%.

Table 18 Efficiency of heat recovery MFH [η_{PHI}]

	Level of heating demand [kWh/²y]			
	15	**25**	**45**	**70**
Stockholm	0.85	0.85	0.0	0.0
Gdansk	0.85	0.85	0.0	0.0
Stuttgart	0.85	0.85	0.0	0.0
London	0.85	0.85	0.0	0.0
Lyon	0.85	0.85	0.0	0.0
Madrid	0.85	0.85	0.0	0.0
Rome	0.85	0.85	0.0	0.0

5.1.3 Offices

With respect to the offices, it has been foreseen the mechanical ventilation with heat recovery for every climatic zone. The efficiency of the heat recovery system is 0.85. The heat recovery unit was bypassed when the average convective temperature in the office was higher than the outdoor temperature, and during the “summer” season (indoor temperature > 23 °C). Mechanical ventilation was considered with an air change rate of 40 l/h per person, or 1.48 1/h. The presence of mechanical ventilation follows the schedule for presence of people in the office, with one additional hour before and one hour after the office hours, as shown in Table 10. For infiltration, a fixed value of 0.07 1/h through the day and the year was defined for the renovated buildings.

5.2 Envelope

5.2.1 Residential buildings

For the renovated cases, an insulation layer is added to the external surfaces (external walls, floors and roofs) in order to reach the 4 energy levels (15, 25, 45, 70 kWh/m²y).

The insulation layer is an EPS (expanse polystyrene) with good thermal properties summarized here below:

Table 19 – insulation layer thermal features

Conductivity	λ	0.039	W/(mK)
Capacity	cp	1.25	kJ/(kgK)
Density	ρ	30	kg/(m³)

The following tables summarize all the insulation thickness for SFHs and sMFHs. For the SFHs it has been chosen to apply the insulation on the vertical surfaces (wall) on the roof and on the cellar (a SFH with cellar is always considered). In the numerical model, the cellar is not implemented, but the effect of the transmission losses through it is accounted for as a thermal bridge with the ground floor. The perimeter insulation in the table has been used to reduce this thermal bridge effect. The insulation has been considered only with respect to external walls and roof for the MFHs, while it is not considered between cellar and ground.

Table 20 – Insulation thicknesses for SFHs

Climate	Energy Level	Wall [cm]	Roof [cm]	Ground [cm]	Perimeter
Stockholm	15	40.0	50.0	10.0	10.0
	25	40.0	50.0	10.0	10.0
	45	8.0	15.0	5.0	5.0
	70	8.0	15.0	5.0	5.0
Gdansk	15	40.0	50.0	10.0	10.0

	25	40.0	50.0	10.0	10.0
	45	12.4	22.4	10.0	10.0
	70	11.3	21.3	10.0	10.0
Stuttgart	15	40.0	50.0	10.0	10.0
	25	24.0	34.0	10.0	10.0
	45	21.4	31.4	10.0	10.0
	70	22.8	32.8	10.0	-
London	15	34.4	44.4	10.0	10.0
	25	16.5	26.5	10.0	-
	45	12.9	22.9	10.0	-
	70	9.1	19.1	9.1	-
Lyon	15	21.5	31.5	10.0	10.0
	25	12.8	22.8	10.0	-
	45	12.0	22.0	8.7	-
	70	6.5	16.5	6.5	-
Madrid	15	10.0	20.0	10.0	-
	25	8.9	18.9	8.9	-
	45	6.3	16.3	6.3	-
	70	10.1	20.1	-	-
Rome	15	8.0	18.0	7.3	-
	25	6.0	6.0	2.9	-
	45	12.0	18.0	-	-
	70	4.0	4.0	-	-

Table 21– Insulation thicknesses for s-MFHs

Climate	Energy Level	Wall [cm]	Roof [cm]	Ground [cm]	Perimeter
Stockholm	15	6.0	6.0	-	-
	25	4.0	4.0	-	-
	45	10.0	10.0	-	-
	70	0.0	0.0	-	-
Gdansk	15	13.0	13.0	-	-
	25	8.0	8.0	-	-

	45	14.0	14.0	-	-
	70	5.0	5.0	-	-
Stuttgart	15	9.0	9.0	-	-
	25	5.0	5.0	-	-
	45	8.0	8.0	-	-
	70	3.0	3.0	-	-
London	15	7.0	7.0	-	-
	25	4.0	4.0	-	-
	45	4.0	4.0	-	-
	70	2.0	2.0	-	-
Lyon	15	7.0	7.0	-	-
	25	4.0	4.0	-	-
	45	4.0	4.0	-	-
	70	2.0	2.0	-	-
Madrid	15	6.0	6.0	-	-
	25	3.0	3.0	-	-
	45	2.0	2.0	-	-
	70	1.0	1.0	-	-
Rome	15	3.0	3.0	-	-
	25	2.0	2.0	-	-
	45	0.0	5.0	-	-
	70	0.0	0.0	-	-

5.2.2 Offices

For the offices the same insulation material used for residential has been applied. Table 22 shows the insulation thickness and windows needed to reach the different energy levels. The tables refer to the two offices typologies, small (6 cells per floor) and large (12 cells per floor).

Table 22 – Insulation thicknesses and windows for offices

Climate	Period	Cells	Insulation, mm		U_{window}, W/m²K		Heating demand, kWh/m²y	Cooling demand, kWh/m²y
			Facade	Roof	Glass	Frame		
Stockholm	I	6	22	22	0.59	2.87	24.8	9.9
		12	130	130	1.40	3.34	25.5	9.9
	I	6	44	44	1.40	7.73	43.5	7.9
		12	24	24	1.40	7.73	44.8	7.6
	III	6	100	0	1.16	3.03	54.1	8.3

		12	100	0	1.16	3.03	41.4	8.0
Gdansk	I	6	55	65	0.59	2.87	24.6	7.7
		12	150	150	1.40	3.34	24.9	7.7
	I	6	65	70	1.40	7.73	44.2	5.6
		12	27	27	1.40	7.73	43.9	5.0
	III	6	100	0	1.16	3.03	53.9	6.9
		12	100	0	1.16	3.03	40.0	6.7
Stuttgart	I	6	40	50	0.59	2.87	23.8	11.7
		12	80	80	1.40	3.34	24.1	11.7
	I	6	33	43	1.40	7.73	45.2	9.7
		12	15	22	1.40	7.73	43.6	8.9
	III	6	100	0	1.16	3.03	39.7	11.0
		12	100	0	1.16	3.03	30.6	10.6
London	I	6	80	80	1.40	3.34	24.2	6.2
		12	40	50	1.40	3.34	23.8	6.2
	I	6	22	22	1.40	7.73	43.8	4.4
		12	10	10	1.40	7.73	44.5	3.8
	III	6	100	0	1.16	3.03	29.5	6.4
		12	100	0	1.16	3.03	17.7	6.5
Lyon	I	6	70	70	1.40	3.34	23.6	20.7
		12	35	45	1.40	3.34	23.7	20.7
	I	6	18	18	1.40	7.73	44.5	19.3
		12	12	0	1.40	7.73	44.8	19.0
	III	6	100	0	1.16	3.03	28.5	21.4
		12	100	0	1.16	3.03	19.3	20.4
Madrid	I	6	35	40	1.40	3.34	24.0	29.2
		12	20	20	1.40	3.34	24.4	29.2
	I	6	12	0	1.40	7.73	44.3	29.9
		12	0	15	1.40	7.73	44.6	26.1
	III	6	100	0	1.16	3.03	18.0	31.8
		12	100	0	1.16	3.03	15.0	30.0
Rome	I	6	0	35	1.40	3.34	26.4	26.7
		12	10	10	1.40	3.34	24.0	26.7
	I	6	0	0	1.40	7.73	33.0	27.5
		12	0	0	1.40	7.73	35.9	30.5
	III	6	100	0	1.16	3.03	18.1	32.8
		12	100	0	1.16	3.03	11.7	31.5

Offices of the period 1980-1990 are modelled with a curtain wall element.

The external façade is a transparent assembly of 8+8/16/10 glazing filled with Argon gas. The internal side is a safety glass made by two panes of 8 mm each, while the external side is a 10 mm pane with a single low-e coating. The optical characteristics are typical of commercial products.

For a better understanding of Table 23, it should be pointed out that:

- the symbols τ, ρ and ε are referred to the trasmissivity, the reflectivity and the emissivity characteristics of the glass;
- the subscripts "sol" and "vis" are linked to the solar infrared and the visible portion of the spectral irradiance;

- the subscript numbers “1” and “2” are referred to the characteristics of the front and back side.

The u-value and g-value of the glazing assembly amount to 1.17 W/(m^{2}K) and to 0.448, respectively. The façade frame ratio has been fixed to 17.5%, whereas the u-value of the frame amounts to 1.5 W/(m^{2}K).

Table 23- Optical characteristics of reference office facade.

Optical characteristics	SGG Vision-Lite, 8 mm Saint Gobain	SGG Planistar, 10 mm Saint Gobain
τ_{sol}	0.743	0.381
$\rho_{sol,1}$	0.085	0.435
$\rho_{sol,2}$	0.073	0.266
τ_{vis}	0.904	0.771
$\rho_{vis,1}$	0.044	0.062
$\rho_{vis,2}$	0.048	0.068
ε_1	0.868	0.037
ε_2	0.837	0.837

5.3 Windows

Four levels of windows have been identified: good (3), medium + (2.5), medium (2) and poor (1). The *poor* window is supposed to be referred to the existing cases; the 2 and 3 are used for the refurbishment of offices from the I period, while window 2.5 is used for the offices of III period. Characteristics of the windows are reported in Table 24. By experience, a typology of window has been assigned to the different buildings depending on the climate and energy level (see Table 25).

Table 24 – U-values for windows

Windows	Good (3)	Medium+ (2.5)	Medium (2)	Poor - Existing (1)
TRNSYS ID	13007	14003	2304	1002
Number of panes	3	3	2	2
g / [-]	0.584	0.373	0.622	0.755
Ug / [W/(m^2 K)]	0.59	1.16	1.40	2.83
Uf / [W/(m^2 K)]	2.87	3.03	3.34	4.20
Uf_{TRNSYS} /[kJ/(h m^2 K)]	10.34	10.91	27.82	52.87

$) linear thermal transmittance included in the frame U_f

[!]) U-value in TRNSYS without convective and radiative coefficients

*) 20 % frame ratio

5.3.1 Residential buildings

Table 25 and

Table 26 show the windows level for each building energy level and climate.

Table 25 - Windows quality (3 good, 2 medium, 1 poor) - SFH

	Level of heating demand [kWh/m²y]			
	15	**25**	**45**	**70**
Stockholm	3	3	3	3
Gdansk	3	3	3	3
Stuttgart	3	3	3	2
London	3	3	3	2
Lyon	3	3	2	2
Madrid	3	2	2	2
Rome	2	2	2	2

Table 26 - Windows quality (3 good, 2 medium, 1 poor) – s-MFH

	15	**25**	**45**	**70**
Stockholm	3	3	2	2
Gdansk	3	3	2	2
Stuttgart	3	3	2	2
London	3	3	2	2
Lyon	3	3	2	2
Madrid	2	2	2	2
Rome	2	2	2	2

5.3.2 Offices

For the offices of the period 1945-1970 the quality of the window is the same of those used for residential buildings, while for the period 1980-1990 the window "2.5" was used in the curtain wall (see Table 24).

Table 27 - Windows quality (3 good, 2 medium, 1 poor) – offices

	Energy level		
	25	**45**	**III period**
Stockholm	3	2	2.5
Gdansk	3	2	2.5

Stuttgart	3	2	2.5
London	2	2	2.5
Lyon	2	2	2.5
Madrid	2	2	2.5
Rome	2	2	2.5

5.4 Shading elements and strategies

Shading devices have a strong influence in cooling demands. The position (internal or external), the shading factor, and the strategy of shading determine a high or low cooling demand both for warm and cold climates. Here it is presented the strategy adopted for residential buildings and offices.

5.4.1 Residential buildings

In Southern Europe, external shading is commonly used both for single and multi-family houses, while buildings in Northern and Central Europe rarely are equipped with external shading. Despite that, for residential renovated buildings external shading is assumed for all the climates because of the not negligible solar gains contribution. The shadings of the reveals are not considered in this study.

A common shading factor of 0.3 has been used for all the locations that means when activated: total solar irradiation is 70% blocked when the shadings are activated. The shading system is activated when the following conditions are all verified for both SFH and MFH:

- Beam irradiation incident on the façade greater than 100 W/m² (shadings removed if irradiation < 50 W/m²)
- Room temperature greater than 24 °C (shades removed if < 23 °C)

The beam irradiation is used as a parameter assuming that users close the manual external shadings, when the sun is directly entering the windows on the specific façade.

5.4.2 Offices

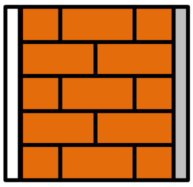
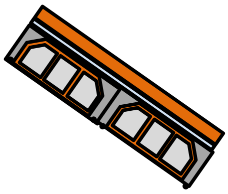
The strategies adopted for the offices is the same as the one used for residential buildings. Here however, the global radiation is used as a parameter to which the same threshold is applied. Here it is assumed that an automatic system actuates the shading devices by measuring the global irradiation on the specific façade.

5.5 Walls' constructions

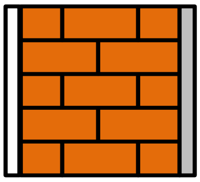
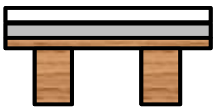
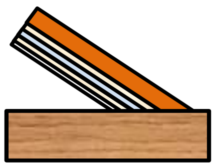
In this section there is the overview of the wall construction for all the residential buildings and offices for two periods: 1945-1970 and 1980-1990.

iNSPiRe
Systemic energy renovation of buildings

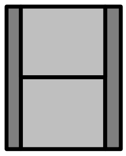
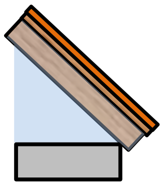
5.5.1 Walls' sections Single Family Houses - SFH - 1945-1970 - Mediterranean

	SFH_ROM_1945-1970				
	Material	*λ [W/mK]*	*l [m]*	*r [m²K/W]*	
EXTERNAL WALL	*Internal resist of surface*			*0.13*	
	Gypsum plaster	0.35	0.020	0.000	
	Block massive 10	0.87	0.300	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00	0.000	0.000	
	-	1.00	0.000	0.000	
	External resist of surface			*0.04*	
	Total U-value [W/m²K]		0.34	***1.59***	
FLOORS (SFH: CELLAR)	*Resistance int surface*			*0.17*	
	Ceramics	1.20	0.030	0.000	
	Concrete slab	1.13	0.140	0.000	
	Gypsum plaster	0.35	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.17*	
	Total U-value [W/m²K]		0.185	***1.88***	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			*0.10*	
	Tile	1.00	0.040	0.000	
	Perpendicular Air layer 10-2	1.00	0.030	0.130	
	Hollow block 3	1.30	0.220	0.000	
	-	1.00	0.000	0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.29	***2.09***	

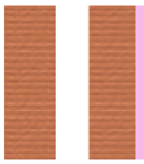
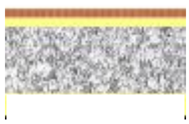
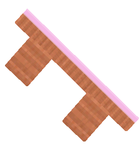
Southern Dry

	SFH_MAD_1945-1970				
	Material	*λ [W/mK]*	*l [m]*	*r [m²K/W]*	
EXTERNAL WALL	*Resistance int surface*			*0.13*	
	Gypsum plaster	0.35	0.015	0.000	
	Block massive 11	0.99	0.240	0.000	
	Gypsum plaster	0.35	0.015	0.000	
	-	1.00	0.000	0.000	
	-	1.00	0.000	0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.27	***2.01***	
FLOORS (SFH: CELLAR)	*Resistance int surface*			*0.17*	
	Ceramics	1.20	0.020	0.000	
	Lime mortar	0.87	0.010	0.000	
	Spruce/Pine	0.13	0.010	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.17*	
	Total U-value [W/m²K]		0.04	***2.25***	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			*0.10*	
	Gypsum plaster	0.35	0.015	0.000	
	Spruce/Pine	0.13	0.020	0.000	
	Horizontal Air layer 10-50	1.00	0.060	0.169	
	Spruce/Pine	0.13	0.010	0.000	
	Tile	1.00	0.030	0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.135	***1.63***	

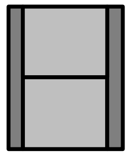
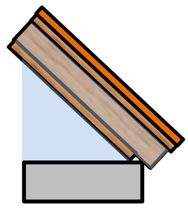
Southern Continental

	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
	SFH_LYO_1945-1970				
EXTERNAL WALL	*Resistance int surface*			0.13	
	Lime mortar	0.87	0.015	0.000	
	Hollow block 3	1.30	0.300	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.33	**2.30**	
FLOORS (SFH: CELLAR)	*Resistance int surface*			0.17	
	Linoleum	0.17	0.015	0.000	
	Lw concrete 11	1.60	0.050	0.000	
	Sand gravel	0.70	0.030	0.000	
	Common concrete	2.10	0.120	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.215	**1.79**	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			0.10	
	-	1.00		0.000	
	Spruce/Pine	0.13	0.030	0.000	
	Roofdeck	0.14	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.045	**2.10**	

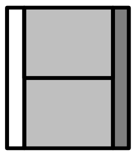
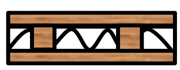
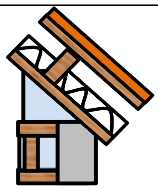
Oceanic

	Material	λ [W/mK]	l [m]	r [m²K/W]	
	SFH_LON_1945-1970				
EXTERNAL WALL	*Resistance int surface*			0.13	
	Gypsum plaster	0.35	0.015	0.000	
	Hollow block 3K 8	0.90	0.060	0.000	
	Perpendicular Air layer 10-20	1.00	0.030	0.130	
	Hollow block 3K 8	0.90	0.120	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.225	**1.84**	
FLOORS (SFH: CELLAR)	*Resistance int surface*			0.17	
	Linoleum	0.17	0.020	0.000	
	Wooden wool 1	0.09	0.010	0.000	
	Common concrete	2.10	0.150	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.18	**1.57**	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			0.10	
	Spruce/Pine	0.13	0.000	0.000	
	Spruce/Pine	0.13	0.045	0.000	
	Tile	1.00	0.030	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.075	**1.94**	

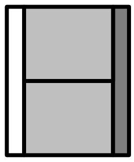
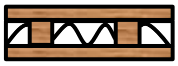
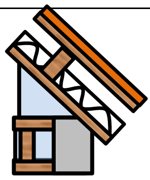
Continental

	Material	λ [W/mK]	l [m]	r [m^2K/W]	Drawing
	SFH_STU_1945-1970				
EXTERNAL WALL	Resistance int surface			0.13	
	Lime mortar	0.87	0.015	0.000	
	Hollow block 3K 5	0.55	0.300	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00	0.000	0.000	
	-	1.00	0.000	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m^2K]		0.33	**1.33**	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Timberfloor	0.14	0.020	0.000	
	Lw concrete 10	1.30	0.050	0.000	
	Sand gravel	0.70	0.070	0.000	
	Concrete slab	1.13	0.120	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m^2K]		0.26	**1.37**	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.020	0.000	
	Horizontal Air layer 10-500	1.00	0.160	0.169	
	Spruce/Pine	0.13	0.020	0.000	
	Roofdeck	0.14	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m^2K]		0.21	**1.46**	

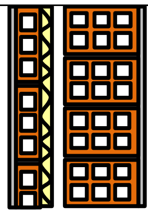
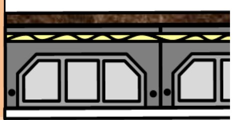
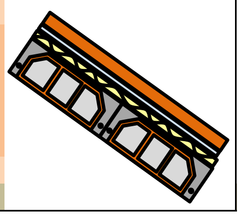
Northern Continental

	Material	λ [W/mK]	l [m]	r [m^2K/W]	Drawing
	SFH_GDA_1945-1970				
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Hollow block 2-4K 5	0.44	0.240	0.000	
	Cement mortar	1.40	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m^2K]		0.272	**1.31**	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Spruce/Pine	0.13	0.020	0.000	
	Wooden wool 2	0.15	0.015	0.000	
	Spruce/Pine	0.13	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m^2K]		0.055	**1.34**	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.025	0.000	
	Mineral wool 050	0.05	0.040	0.000	
	Spruce/Pine	0.13		0.000	
	Tile	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m^2K]		0.065	**0.88**	

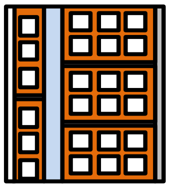
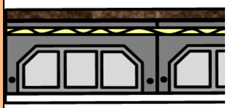
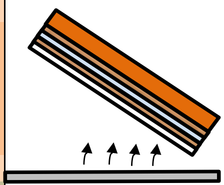
Nordic

	SFH_GDA_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	**Drawing**
EXTERNAL WALL	*Resistance int surface*			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Hollow block 2-4K 5	0.44	0.240	0.000	
	Cement mortar	1.40	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.272	**1.31**	
FLOORS (SFH: CELLAR)	*Resistance int surface*			0.17	
	Spruce/Pine	0.13	0.020	0.000	
	Wooden wool 2	0.15	0.015	0.000	
	Spruce/Pine	0.13	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.055	**1.34**	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			0.10	
	Spruce/Pine	0.13	0.025	0.000	
	Mineral wool 050	0.05	0.040	0.000	
	Spruce/Pine	0.13		0.000	
	Tile	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.065	**0.88**	

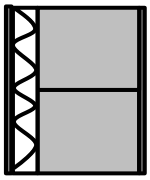
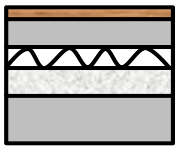
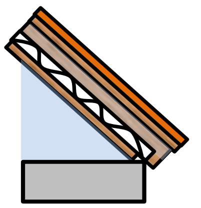
1980-1990 - Mediterranean

	SFH_ROM_1980-1990				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	*Resistance int surface*			0.13	
	Hollow block 3	1.30	0.080	0.000	
	Insulation	0.04	0.020	0.000	
	Perpendicular Air layer 10-20	1.00	0.030	0.130	
	Hollow block 2	1.30	0.120	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	**0.99**	
FLOORS (SFH: CELLAR)	*Resistance int surface*			0.17	
	Ceramics	1.20	0.020	0.000	
	Cement mortar	1.40	0.020	0.000	
	Insulation	0.04	0.008	0.000	
	Hollow block 3	1.30	0.100	0.000	
	Gypsum plaster	0.35	0.015	0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.163	**1.45**	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			0.10	
	Hollow block 2-4K 5	0.44	0.125	0.000	
	Concrete slab	1.13	0.030	0.000	
	Insulation	0.04	0.008	0.000	
	Perpendicular Air layer 10-20	1.00	0.030	0.130	
	Tile	1.00	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.223	**1.23**	

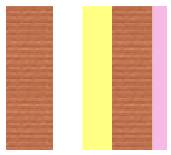
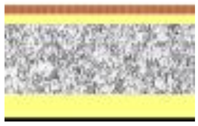
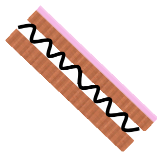
Southern Dry

	SFH_MAD_1980-1990				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 3K 6	0.64	0.080	0.000	
	Perpendicular Air layer 10	1.00	0.030	0.130	
	Hollow block 3K 8	0.90	0.120	0.000	
	Cement mortar	1.40	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.28	**1.57**	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Ceramics	1.20	0.020	0.000	
	Common concrete	2.10	0.050	0.000	
	Insulation	0.04	0.015	0.000	
	Hollow block 3	1.30	0.160	0.000	
	Gypsum plaster	0.35	0.015	0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.26	**1.09**	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.015	0.000	
	Spruce/Pine	0.13	0.030	0.000	
	Horizontal Air layer 10-50	1.00	0.040	0.169	
	Spruce/Pine	0.13	0.020	0.000	
	Tile	1.00	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.135	**1.31**	

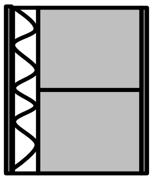
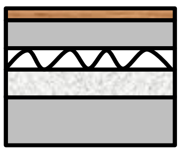
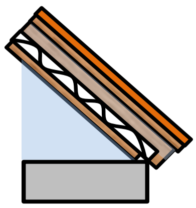
Southern Continental

	SFH_LYO_1980-1990				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	**Drawing**
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Hollow block 3K 8	0.90	0.240	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.3	**0.73**	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.050	0.000	
	Polystyrene 040	0.04	0.030	0.000	
	Sand gravel	0.70	0.050	0.000	
	Common concrete	2.10	0.200	0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.345	**0.71**	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.020	0.000	
	Mineral wool 040	0.04	0.040	0.000	
	Spruce/Pine	0.13	0.000	0.000	
	Roofdeck	0.14	0.000	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.06	**0.76**	

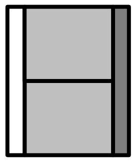
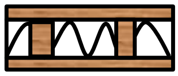
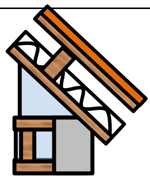
Oceanic

	SFH_LON_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 3K 8	0.90	0.080	0.000	
	Perpendicular Air layer 10-20	1.00	0.050	0.130	
	Mineral wool 040	0.04	0.030	0.000	
	Hollow block 3K 8	0.90	0.120	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.3	0.74	
FLOORS (SFH: CELLAR)	Internal resist of surface			0.17	
	Linoleum	0.17	0.020	0.000	
	Wooden wool 2	0.15	0.010	0.000	
	Common concrete	2.10	0.080	0.000	
	Mineral wool 040	0.04	0.015	0.000	
	-	1.00		0.000	
	External resist of surface			0.17	
	Total U-value [W/m²K]		0.125	1.05	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.015	0.000	
	Mineral wool 040	0.04	0.050	0.000	
	Spruce/Pine	0.13	0.015	0.000	
	Tile	1.00	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.1	0.60	

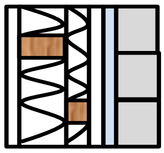
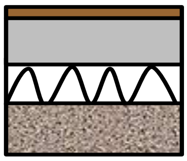
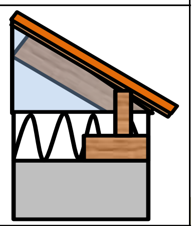
Continental

	SFH_STU_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Hollow block 3K 5	0.55	0.230	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.29	0.66	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.070	0.000	
	Polystyrene 040	0.04	0.030	0.000	
	Sand gravel	0.70	0.050	0.000	
	Concrete slab	1.13	0.180	0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.345	0.67	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.020	0.000	
	Mineral wool 040	0.04	0.080	0.000	
	Spruce/Pine	0.13	0.000	0.000	
	Roofdeck	0.14	0.000	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.1	0.43	

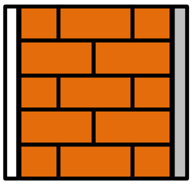
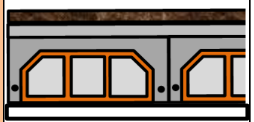
Northern Continental

	SFH_GDA_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Hollow block 2-4K 1	0.29	0.250	0.000	
	Cement mortar	1.40	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.282	**0.92**	
FLOORS (SFH: CELLAR)	Resistance int surface			0.17	
	Spruce/Pine	0.13	0.025	0.000	
	Wooden wool 2	0.15	0.040	0.000	
	Spruce/Pine	0.13	0.030	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.17	
	Total U-value [W/m²K]		0.095	**0.97**	
ROOFS (SFH: INSULATION IN ROOF)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.025	0.000	
	Mineral wool 050	0.05	0.060	0.000	
	Spruce/Pine	0.13		0.000	
	Tile	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.085	**0.65**	

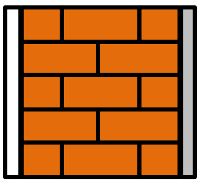
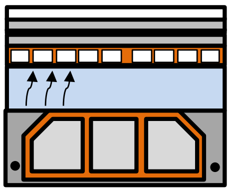
Nordic

	s-MFH_STO_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Mineral wool 035	0.04	0.100	0.000	
	Gypsum plaster	0.35	0.012	0.000	
	Perpendicular Air layer 10-2	1.00		0.130	
	Limestone 7	1.30		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.124	**0.32**	
FLOORS (MFH: SLAB-ON-GRADE)				0.17	
	Linoleum	0.17	0.003	0.000	
	Concrete slab	1.13	0.100	0.000	
	Mineral wool 035	0.04	0.100	0.000	
	Sand gravel	0.70		0.000	
	-	1.00		0.000	
				0.00	
	Total U-value [W/m²K]		0.203	**0.33**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.220	0.000	
	Mineral wool 035	0.04	0.110	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.33	**0.30**	

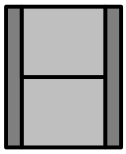
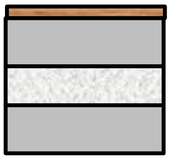
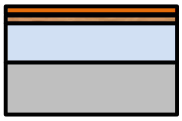
5.5.2 Walls' sections Single Family Houses – s-MFH - 1945-1970 - Mediterranean

	s-MFH_ROM_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Block massive 11	0.99	0.340	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.38	**1.59**	
FLOORS (SFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.040	0.000	
	Lime mortar	0.87	0.100	0.000	
	Concrete slab	1.13	0.250	0.000	
	Sand gravel	0.70		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.39	**1.85**	
ROOFS (SFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.015	0.000	
	Hollow block 2-4K 8	0.73	0.140	0.000	
	Concrete slab	1.13	0.030	0.000	
	Ceramics	1.20	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.205	**2.09**	

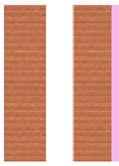
Southern Dry

	s-MFH_MAD_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Block massive 7	0.54	0.115	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.155	**2.01**	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.020	0.000	
	Cement mortar	1.40	0.020	0.000	
	Concrete slab	1.13	0.250	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface				
	Total U-value [W/m²K]		0.29	**2.37**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 2-4K 6	0.49	0.140	0.000	
	Concrete slab	1.13	0.040	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.2	**1.73**	

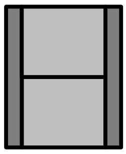
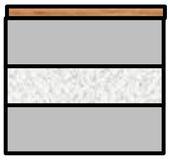
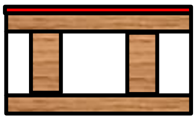
Southern Continental

	s-MFH_LYO_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	**Drawing**
EXTERNAL WALL	Resistance int surface			0.13	
	Lime mortar	0.87	0.015	0.000	
	Hollow block 3	1.30	0.300	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.33	**2.30**	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Linoleum	0.17	0.015	0.000	
	Lw concrete 6	0.70	0.050	0.000	
	Sand gravel	0.70	0.050	0.000	
	Concrete slab	1.13	0.170	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.285	**1.81**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.080	0.000	
	Horizontal Air layer 10-50(	1.00	0.150	0.169	
	Spruce/Pine	0.13	0.010	0.000	
	Roofdeck	0.14	0.000	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.24	**2.07**	

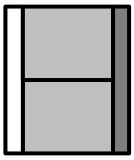
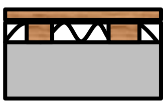
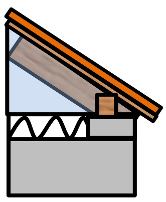
Oceanic

	s-MFH_LON_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.015	0.000	
	Hollow block 3K 8	0.90	0.060	0.000	
	Perpendicular Air layer 10-	1.00	0.030	0.130	
	Hollow block 3K 8	0.90	0.120	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.225	**1.84**	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Linoleum	0.17	0.015	0.000	
	Common concrete	2.10	0.200	0.000	
	Sand gravel	0.70	0.200	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.415	**1.56**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.015	0.000	
	Concrete slab	1.13	0.275	0.000	
	Bitumen	0.17	0.005	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.295	**1.94**	

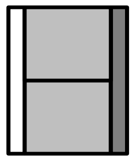
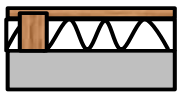
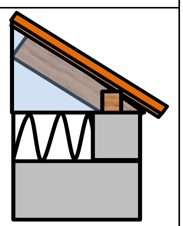
Continental

	s-MFH_STU_1945-1970				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Lime mortar	0.87	0.015	0.000	
	Hollow block 3K 5	0.55	0.300	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.33	1.33	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.020	0.000	
	Lw concrete 5	0.62	0.100	0.000	
	Sand gravel	0.70	0.100	0.000	
	Common concrete	2.10	0.240	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.46	1.37	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.020	0.000	
	Horizontal Air layer 10-50	1.00	0.160	0.169	
	Spruce/Pine	0.13	0.020	0.000	
	Roofdeck	0.14	0.002	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.202	1.45	

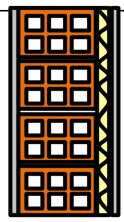
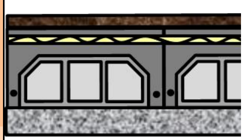
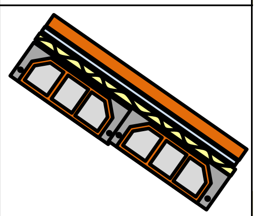
Northern Continental

	s-MFH_GDA_1945-1970				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Hollow block 2-4K 5	0.44	0.240	0.000	
	Cement mortar	1.40	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.272	1.31	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Spruce/Pine	0.13	0.025	0.000	
	Wooden wool 2	0.15	0.050	0.000	
	Concrete slab	1.13	0.080	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.155	1.31	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.150	0.000	
	Mineral wool 050	0.05	0.040	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.19	0.93	

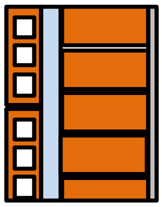
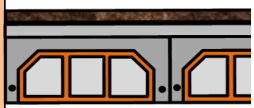
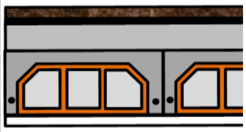
Nordic

	s-MFH_STO_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	**Drawing**
EXTERNAL WALL	*Resistance int surface*			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Lw concrete w natural pum	0.15	0.250	0.000	
	Cement mortar	1.40	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.282	**0.53**	
FLOORS (MFH: SLAB-ON-GRADE)	*Resistance int surface*			0.17	
	Linoleum	0.17	0.003	0.000	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 040	0.04	0.080	0.000	
	Concrete slab	1.13	0.160	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.293	**0.41**	
ROOFS (MFH: INSULATION IN CEILING)	*Resistance int surface*			0.10	
	Common concrete	2.10	0.140	0.000	
	Mineral wool 035	0.04	0.070	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.21	**0.45**	

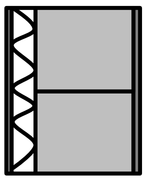
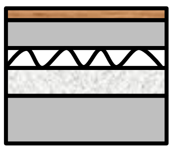
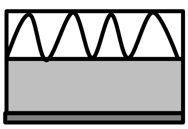
1980-1990 - Mediterranean

	s-MFH_ROM_1980-1990				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	*Resistance int surface*			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 2-4K 4	0.39	0.120	0.000	
	Polystyrene 025	0.03	0.010	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.17	**1.01**	
FLOORS (SFH: SLAB-ON-GRADE)	*Resistance int surface*			0.17	
	Ceramics	1.20	0.030	0.000	
	Concrete slab	1.13	0.010	0.000	
	Insulation	0.04	0.014	0.000	
	Hollow block 2-4K 8	0.73	0.080	0.000	
	Sand gravel	0.70	0.000	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.134	**1.51**	
ROOFS (SFH: INSULATION IN ROOF)	*Resistance int surface*			0.10	
	Hollow block 2-4K 5	0.44	0.160	0.000	
	Concrete slab	1.13	0.060	0.000	
	Insulation	0.04	0.010	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.23	**1.24**	

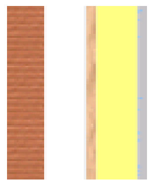
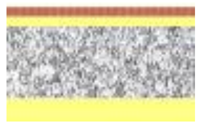
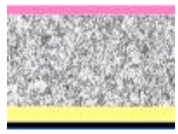
Southern Dry

	s-MFH_MAD_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 3K 6	0.64	0.080	0.000	
	Perpendicular Air layer 10-	1.00	0.030	0.130	
	Hollow block 3K 8	0.90	0.120	0.000	
	Cement mortar	1.40	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.28	1.57	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.040	0.000	
	Lime cement mortar	0.87	0.040	0.000	
	Concrete block	0.51	0.080	0.000	
	Hollow block 2-4K 6	0.49	0.250	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.41	1.09	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Concrete block	0.51	0.200	0.000	
	Cement mortar	1.40	0.060	0.000	
	Bitumen	0.17	0.005	0.000	
	Ceramics	1.20	0.040	0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.325	1.32	

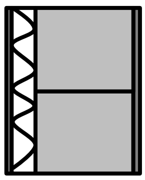
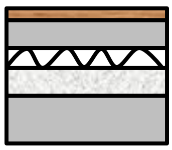
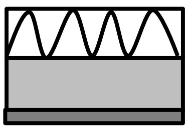
Southern Continental

	s-MFH_LYO_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Hollow block 3K 8	0.90	0.240	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.3	0.73	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.050	0.000	
	Polystyrene 040	0.04	0.030	0.000	
	Sand gravel	0.70	0.050	0.000	
	Concrete slab	1.13	0.200	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.345	0.75	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Lime cement mortar	0.87	0.015	0.000	
	Concrete slab	1.13	0.250	0.000	
	Mineral wool 040	0.04	0.035	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.3	0.75	

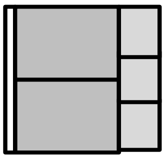
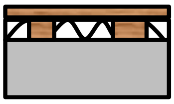
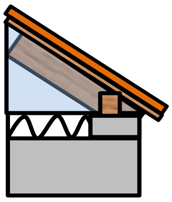
Oceanic

	s-MFH_LON_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.013	0.000	
	Mineral wool 040	0.04	0.030	0.000	
	Plywood	0.15	0.012	0.000	
	Perpendicular Air layer 20	1.00	0.050	0.169	
	Hollow block 2-4K 8	0.73	0.075	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.18	**0.75**	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Linoleum	0.17	0.020	0.000	
	Wooden wool 1	0.09	0.010	0.000	
	Common concrete	2.10	0.152	0.000	
	Mineral wool 040	0.04	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.202	**1.02**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.010	0.000	
	Common concrete	2.10	0.120	0.000	
	Mineral wool 040	0.04	0.050	0.000	
	Bitumen	0.17	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.19	**0.61**	

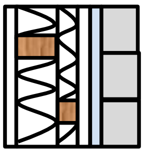
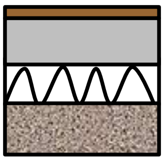
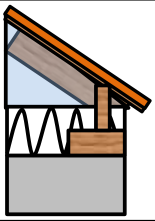
Continental

	s-MFH_STU_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Hollow block 3K 5	0.55	0.230	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.29	**0.66**	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.070	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Sand gravel	0.70	0.050	0.000	
	Common concrete	2.10	0.180	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.35	**0.73**	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Lime cement mortar	0.87	0.015	0.000	
	Concrete slab	1.13	0.250	0.000	
	Mineral wool 040	0.04	0.080	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.345	**0.40**	

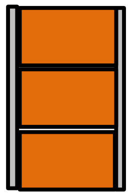
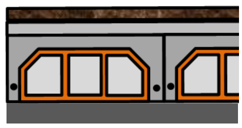
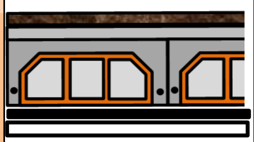
Northern Continental

	s-MFH_GDA_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Hollow block 2-4K 1	0.29	0.200	0.000	
	Block massive 1	0.29	0.070	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.282	0.88	
FLOORS (MFH: SLAB-ON-GRADE)	Resistance int surface			0.17	
	Spruce/Pine	0.13	0.025	0.000	
	Wooden wool 2	0.15	0.070	0.000	
	Concrete slab	1.13	0.160	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.255	1.03	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.150	0.000	
	Mineral wool 050	0.05	0.060	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.21	0.68	

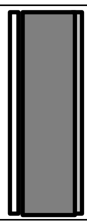
Nordic

	s-MFH_STO_1980-1990				
	Material	λ [W/mK]	l [m]	r [m²K/W]	Drawing
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.012	0.000	
	Mineral wool 035	0.04	0.100	0.000	
	Gypsum plaster	0.35	0.012	0.000	
	Perpendicular Air layer 10-2	1.00		0.130	
	Limestone 7	1.30		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.124	0.32	
FLOORS (MFH: SLAB-ON-GRADE)				0.17	
	Linoleum	0.17	0.003	0.000	
	Concrete slab	1.13	0.100	0.000	
	Mineral wool 035	0.04	0.100	0.000	
	Sand gravel	0.70		0.000	
	-	1.00		0.000	
				0.00	
	Total U-value [W/m²K]		0.203	0.33	
ROOFS (MFH: INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.220	0.000	
	Mineral wool 035	0.04	0.110	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.10	
	Total U-value [W/m²K]		0.33	0.30	

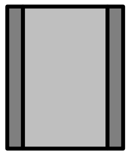
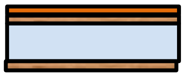
5.5.3 Walls' sections Offices – OFF - 1945-1970 - Mediterranean

	Office_ROM_1945-1970				
	Material	**λ** [W/mK]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Block massive 10	0.87	0.240	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.28	**1.78**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.020	0.000	
	Common concrete	2.10	0.100	0.000	
	Hollow block 2K 8	0.90	0.180	0.000	
	Concrete slab	1.13	0.100	0.000	
	Pumice gravel	0.19	0.150	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.55	**0.76**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.015	0.000	
	Hollow block 2-4K 8	0.73	0.160	0.000	
	Concrete slab	1.13	0.030	0.000	
	Bitumen	0.17	0.005	0.000	
	Ceramics	1.20	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.24	**2.07**	

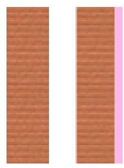
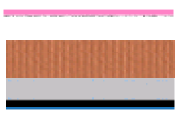
Southern Dry

	Office_MAD_1945-1970				
	Material	**λ** [W/m]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Lw concrete 10	1.30	0.230	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	**2.17**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Horizontal Air layer 10-500	1.00	0.100	0.169	
	Roofdeck	0.14	0.030	0.000	
	Bitumen	0.17	0.005	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.155	**1.64**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Horizontal Air layer 10-500	1.00	0.100	0.169	
	Roofdeck	0.14	0.030	0.000	
	Bitumen	0.17	0.005	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.155	**1.64**	

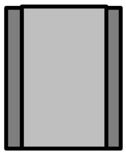
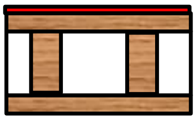
Southern Continental

	Office_LYO_1945-1970				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Lime mortar	0.87	0.015	0.000	
	Lw concrete 9	1.00	0.280	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.31	2.06	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Linoleum	0.17	0.015	0.000	
	Lw concrete 9	1.00	0.070	0.000	
	Sand gravel	0.70	0.100	0.000	
	Concrete slab	1.13	0.150	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.335	1.66	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.015	0.000	
	Horizontal Air layer 10-50(	1.00	0.100	0.169	
	Spruce/Pine	0.13	0.015	0.000	
	Roofdeck	0.14	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.14	1.64	

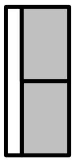
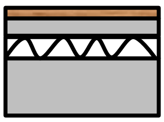
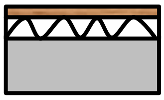
Oceanic

	Office_LON_1945-1970				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.010	0.000	
	Hollow block 2-4K 8	0.73	0.090	0.000	
	Perpendicular Air layer 10	1.00	0.050	0.130	
	Hollow block 2-4K 8	0.73	0.090	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.24	1.74	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.020	0.000	
	Lw concrete 4	0.55	0.150	0.000	
	Sand gravel	0.70	0.080	0.000	
	Concrete slab	1.13	0.080	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.33	1.55	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Horizontal Air layer 10-50(	1.00	0.200	0.169	
	Beech/Oak	0.20	0.020	0.000	
	Common concrete	2.10	0.100	0.000	
	Poured asphalt st.	0.90	0.010	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.35	1.80	

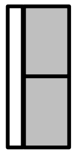
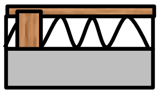
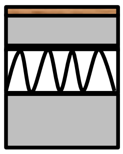
Continental

	Office_STU_1945-1970				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Lime mortar	0.87	0.015	0.000	
	Hollow block 3K 5	0.55	0.270	0.000	
	Lime cement mortar	0.87	0.015	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.3	**1.44**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.030	0.000	
	Lw concrete 7	0.79	0.080	0.000	
	Sand gravel	0.70	0.070	0.000	
	Concrete slab	1.13	0.200	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.38	**1.31**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Spruce/Pine	0.13	0.030	0.000	
	Horizontal Air layer 10-500	1.00	0.160	0.169	
	Spruce/Pine	0.13	0.030	0.000	
	Roofdeck	0.14	0.030	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.25	**1.02**	

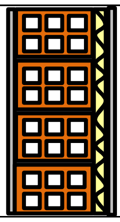
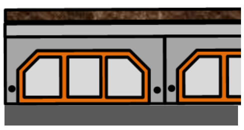
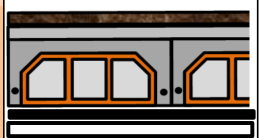
Northern Continental

	Office_GDA_1945-1970				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Lw concrete with swell clay 5	0.30	0.200	0.000	
	Cement mortar	1.40	0.010	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.21	**1.19**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.025	0.000	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 050	0.05	0.025	0.000	
	Common concrete	2.10	0.050	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.15	**1.07**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 040	0.04	0.045	0.000	
	Roofdeck	0.14	0.005	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.1	**0.74**	

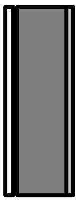
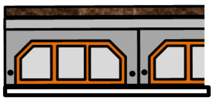
Nordic

	Office_STO_1945-1970				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	*Resistance int surface*			0.13	
	Lw concrete w natural pumice 1	0.15	0.250	0.000	
	Cement mortar	1.40	0.010	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.26	**0.54**	
FLOORS (SLAB-ON-GRADE)	*Resistance int surface*			0.17	
	Linoleum	0.17	0.003	0.000	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 040	0.04	0.080	0.000	
	Concrete slab	1.13	0.160	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.293	**0.41**	
ROOFS (INSULATION IN CEILING)	*Resistance int surface*			0.17	
	Linoleum	0.17	0.003	0.000	
	Common concrete	2.10	0.016	0.000	
	Mineral wool 035	0.04	0.080	0.000	
	Common concrete	2.10	0.050	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.149	**0.40**	

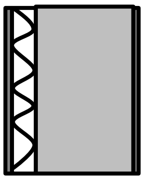
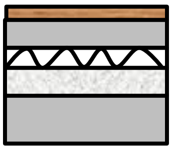
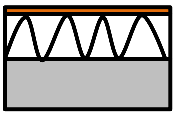
1980-1990 - Mediterranean

	Office_ROM_1980-1990				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	*Resistance int surface*			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Hollow block 2-4K 4	0.39	0.220	0.000	
	Polystyrene 025	0.03	0.010	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	**0.80**	
FLOORS (SLAB-ON-GRADE)	*Resistance int surface*			0.17	
	Ceramics	1.20	0.020	0.000	
	Common concrete	2.10	0.100	0.000	
	Hollow block 2K 6	0.64	0.180	0.000	
	Concrete slab	1.13	0.100	0.000	
	Pumice gravel	0.19	0.200	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.6	**0.60**	
ROOFS (INSULATION IN CEILING)	*Resistance int surface*			0.10	
	Gypsum plaster	0.35	0.015	0.000	
	Hollow block 2-4K 6	0.49	0.160	0.000	
	Concrete slab	1.13	0.030	0.000	
	Bitumen	0.17	0.005	0.000	
	Ceramics	1.20	0.030	0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.24	**1.69**	

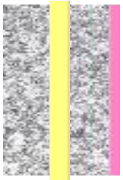
Southern Dry

	Office_MAD_1980-1990				
	Material	**λ** [W/m]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.020	0.000	
	Lw concrete 7	0.79	0.230	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	**1.74**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Ceramics	1.20	0.030	0.000	
	Lw concrete w natural pu	0.15	0.060	0.000	
	Hollow block 2K 1	0.29	0.160	0.000	
	Gypsum plaster	0.35	0.020	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	**0.80**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Lw concrete 3	0.49	0.100	0.000	
	Roofdeck	0.14	0.040	0.000	
	Bitumen	0.17	0.005	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.165	**1.39**	

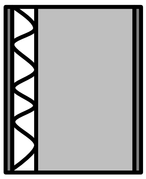
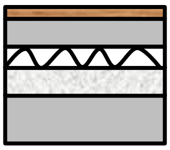
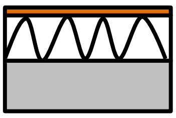
Southern Continental

	Office_LYO_1980-1990				
	Material	**λ** [W/m]	**l** [m]	**r** [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Lw concrete 11	1.60	0.250	0.000	
	Polystyrene 040	0.04	0.020	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.295	**1.15**	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.050	0.000	
	Polystyrene 040	0.04	0.020	0.000	
	Sand gravel	0.70	0.050	0.000	
	Concrete slab	1.13	0.200	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.335	**0.93**	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Lime cement mortar	0.87	0.015	0.000	
	Concrete slab	1.13	0.250	0.000	
	Mineral wool 040	0.04	0.030	0.000	
	Bitumenroof	0.17	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.305	**0.83**	

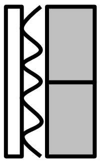
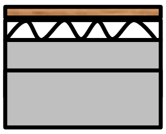
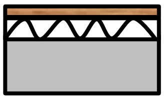
Oceanic

	Office_LON_1980-1990				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Gypsum plaster	0.35	0.010	0.000	
	Lw concrete 1	0.39	0.190	0.000	
	Polystyrene 040	0.04	0.020	0.000	
	Cement mortar	1.40	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.23	0.83	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Lw concrete 11	1.60	0.100	0.000	
	Polystyrene 040	0.04	0.020	0.000	
	Sand gravel	0.70	0.100	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.22	1.12	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Gypsum plaster	0.35	0.020	0.000	
	Clinker 1	0.81	0.200	0.000	
	Polystyrene 040	0.04	0.040	0.000	
	Bitumen	0.17	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.27	0.65	

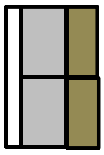
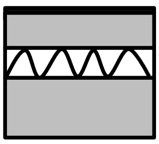
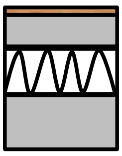
Continental

	Office_STU_1980-1990				
	Material	λ [W/m]	l [m]	r [m²K/W]	
EXTERNAL WALL	Resistance int surface			0.13	
	Lime cement mortar	0.87	0.015	0.000	
	Lw concrete 11	1.60	0.230	0.000	
	Polystyrene 040	0.04	0.035	0.000	
	Lime cement mortar	0.87	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.29	0.80	
FLOORS (SLAB-ON-GRADE)	Resistance int surface			0.17	
	Timberfloor	0.14	0.015	0.000	
	Lw concrete 11	1.60	0.070	0.000	
	Polystyrene 040	0.04	0.055	0.000	
	Sand gravel	0.70	0.050	0.000	
	Concrete slab	1.13	0.180	0.000	
	Resistance ext surface			0.00	
	Total U-value [W/m²K]		0.37	0.51	
ROOFS (INSULATION IN CEILING)	Resistance int surface			0.10	
	Lime cement mortar	0.87	0.015	0.000	
	Concrete slab	1.13	0.250	0.000	
	Mineral wool 040	0.04	0.060	0.000	
	Bitumenroof	0.17	0.010	0.000	
	-	1.00		0.000	
	Resistance ext surface			0.04	
	Total U-value [W/m²K]		0.335	0.50	

Northern Continental

	Office_GDA_1980-1990				
	Material	***λ*** *[W/m]*	***l*** *[m]*	***r*** *[m²K/W]*	
EXTERNAL WALL	*Resistance int surface*			*0.13*	
	Lw concrete with swell clay 5	0.30	0.230	0.000	
	Mineral wool 035	0.04	0.015	0.000	
	Block massive 11	0.99	0.200	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.445	***0.64***	
FLOORS (SLAB-ON-GRADE)	*Resistance int surface*			*0.17*	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 035	0.04	0.025	0.000	
	Sand gravel	0.70	0.100	0.000	
	Concrete slab	1.13	0.100	0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.00*	
	Total U-value [W/m²K]		0.275	***0.89***	
ROOFS (INSULATION IN CEILING)	*Resistance int surface*			*0.10*	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 035	0.04	0.075	0.000	
	Roofdeck	0.14	0.005	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.13	***0.44***	

Nordic

	Office_STO_1980-1990				
	Material	***λ*** *[W/m]*	***l*** *[m]*	***r*** *[m²K/W]*	
EXTERNAL WALL	*Resistance int surface*			*0.13*	
	Lw concrete w natural pumice 1	0.15	0.200	0.000	
	Mineral wool 035	0.04	0.020	0.000	
	Block m swell clay 1	0.20	0.150	0.000	
	-	1.00		0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.04*	
	Total U-value [W/m²K]		0.37	***0.36***	
FLOORS (SLAB-ON-GRADE)	*Resistance int surface*			*0.17*	
	Linoleum	0.17	0.003	0.000	
	Common concrete	2.10	0.050	0.000	
	Mineral wool 035	0.04	0.110	0.000	
	Concrete slab	1.13	0.160	0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.00*	
	Total U-value [W/m²K]		0.323	***0.29***	
ROOFS (INSULATION IN CEILING)	*Resistance int surface*			*0.17*	
	Linoleum	0.17	0.003	0.000	
	Common concrete	2.10	0.016	0.000	
	Mineral wool 035	0.04	0.110	0.000	
	Common concrete	2.10	0.050	0.000	
	-	1.00		0.000	
	Resistance ext surface			*0.00*	
	Total U-value [W/m²K]		0.179	***0.31***	

6 Annex IV - Economic parameters

Envelope parameters			
Facade insulation type	EPS		
Facade insulation investment cost		1.7	€/m²/cm
Facade insulation installation cost	200%	34	€/m²
Facade insulation maintenance cost	0.0%	0	€/m²/y
Facade insulation Lifespan		30	y
Roof insulation type	EPS		
Roof insulation investment cost		1.7	€/m²/cm
Roof insulation installation cost	200%	34	€/m²
Roof insulation maintenance cost	0.0%	0	€/m²/y
Roof insulation Lifespan		30	y
Cellar insulation type	EPS		
Cellar insulation investment cost		1.7	€/m²/cm
Cellar insulation installation cost	200%	34	€/m²
Cellar insulation maintenance cost	0.0%	0	€/m²/y
Cellar insulation Lifespan		30	y
Perimeter insulation type	EPS		
Perimeter insulation investment cost		1.7	€/m²/cm
Perimeter insulation installation cost (including the trench)	500%	85	€/m²
Perimeter insulation maintenance cost	0.0%	0	€/m²/y
Perimeter insulationLifespan		30	y
Windows frame material	PVC		
Windows investment cost		150	€/m²
Windows installation cost	400%	600	€/m²
Windows maintenance cost	0.5%	3.75	€/m²/y
Windows Lifespan		25	y
H&C system parameters			
A/W Heat Pump material	-		
A/W Heat Pump investment cost		600	€/kW
A/W Heat Pump installation cost	20%	120	€/kW
A/W Heat Pump maintenance cost	1.5%	10.8	€/kW/y
A/W Heat Pump Lifespan		15	y
B/W Heat Pump material	-		
B/W Heat Pump investment cost		600	€/kW
B/W Heat Pump installation cost (including boreholes)	400%	2400	€/kW
B/W Heat Pump maintenance cost (including boreholes)	0.5%	15	€/kW/y
B/W Heat Pump Lifespan		15	y
Gas bolier material	-		
Gas bolier investment cost		150	€/kW
Gas bolier installation cost	20%	30	€/kW
Gas bolier maintenance cost	1.5%	2.7	€/kW/y
Gas bolier Lifespan		12	y

Wood chips bolier material	-		
Wood chips bolier investment cost		800	€/kW
Wood chips bolier installation cost	20%	160	€/kW
Wood chips bolier maintenance cost	1.5%	14.4	€/kW/y
Wood chips bolier Lifespan		15	y
Split unit material	-		
Split unit investment cost		350	€/kW
Split unit installation cost	20%	70	€/kW
Split unit maintenance cost	3.0%	12.6	€/kW/y
Split unit Lifespan		12	y
iNSPiRe micro Heat Pump material	-		
iNSPiRe micro Heat Pump investment cost		6000	€/kW
iNSPiRe micro Heat Pumpinstallation cost	20%	1200	€/kW
iNSPiRe micro Heat Pump maintenance cost	1.5%	108	€/kW/y
iNSPiRe micro Heat Pump Lifespan		15	y
Solar thermal system material	-		
Solar thermal system investment cost (including TES and pumps)		500	€/m^2
Solar thermal system installation cost	20%	100	€/m^2
Solar thermal system maintenance cost	1.5%	9	€/m^2/y
Solar thermal system Lifespan		25	y
Solar PV system material	-		
Solar PV system investment cost		1900	€/kW
Solar PV system installation cost	20%	380	€/kW
Solar PV system maintenance cost	1.5%	34.2	€/kW/y
Solar PV system Lifespan		20	y
Pumps material	iron		
Pumps investment cost		0.08	€/l/h
Pumps installation cost	300%	0.24	€/l/h
Pumps maintenance cost	1.5%	0.0048	€/l/h / y
Pumps Lifespan		15	y
Solar pipes (stainless steel) insulation type	elastomer		
Solar pipes investment cost		0.9	€/m/mm
Solar pipes installation cost	20%	0.18	€/m/mm
Solar pipes maintenance cost	0.0%	0	€/m/mm/y
Solar insulation investment cost		0.7	€/m/mm
Solar insulation installation cost	20%	0.14	€/m/mm
Solar insulation maintenance cost	0.0%	0	€/m/mm/y
Solar pipes Lifespan		30	y
H&C pipes (copper) insulation type	elastomer		
H&C pipes investment cost		0.8	€/m/mm
H&C pipes installation cost	20%	0.16	€/m/mm
H&C pipes maintenance cost	0.0%	0	€/m/mm/y
H&C insulation investment cost		0.7	€/m/mm
H&C insulation installation cost	20%	0.14	€/m/mm
H&C insulation maintenance cost	0.0%	0	€/m/mm/y
H&C pipes Lifespan		30	y

Ventilation system material	-		
Ventilation system type	local		
Ventilation system investment cost (surface of living area)		28	€/m^3/h
Ventilation system installation cost	20%	5.6	€/m^3/h
Ventilation system maintenance cost	1.5%	0.50	€/m^3/h / y
Ventilation system Lifespan		15	y
Radiant ceilings material	-		
Radiant ceilings investment cost		30	€/m^2
Radiant ceilings installation cost	200%	60	€/m^2
Radiant ceilings maintenance cost	0.0%	0	€/m^2/y
Radiant ceilings Lifespan		30	y
Radiators material	-		
Radiators investment cost		120	€/m^2
Radiators installation cost	200%	240	€/m^2
Radiators maintenance cost	0.0%	0	€/m^2/y
Radiators Lifespan		30	y
Fan coils material	-		
Fan coils investment cost		200	€/m^2
Fan coils installation cost	300%	600	€/m^2
Fan coils maintenance cost	5.0%	40	€/m^2/y
Fan coils Lifespan		15	y
Luminaires material	-		
n. luminaires (surface of living area)		0.6	-/m^2
Luminaires investment cost (each one)		12	€/-
Luminaires installation cost	100%	12	€/-
Luminaires maintenance cost	0.0%	0	€/y
Luminaires Lifespan		10	y
Economic parameters			
Gas cost		0.10	€/kWh$_{FE}$
Electricity cost		0.20	€/kWh$_{FE}$
Wood chips cost		0.06	€/kWh$_{FE}$
inflation growth rate		1.0%	-
energy costs growth rate		2.0%	-

7 Literature references

4. VDI 2067 Part 1. Economic efficiency of buildings installations. Fundamentals and calculation. Verein Deutscher Ingenieure, 2000.
5. VDI 6025. Economy calculation systems for capital goods and plants. Verein Deutscher Ingenieure, 1996.
6. Commission delegated regulation (EU) No. 244/2012. Supplementing Directive 3010/31/EU of the European Parliament and of Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and buildings elements.
7. Miara M., Günther D., Kramer T., Oltersdorf T., Wapler J., 2011. Wärmepumpen Effizienz. Messtechnische Untersuchung von Wärmepumpenanlagen zur Analyse und Bewertung der Effizienz im realen Betrieb. Fraunhofer ISE, Freiburg, Germany.
8. Malenkovic I, Eicher S., Bony J. Definition of main system boundaries and performance figures for reporting on SHP systems- A technical report of Subtask B- Deliverable B1.1. IEA SHC Task 44, HPP Annex 38, 2012
9. Haller M.Y., System Simulation Reports for the IEA SHC Task 44 HPP Annex 38. A technical report of subtask C. Report C3, IEA Solar Heating & Cooling Programme, 2014
10. Weiss W., Solar heating systems for houses. A design book for solar combisystems, James & James, IEA Solar Heating & Cooling Programme, London 2003: p. 137-141
11. Passiv Haus Institute – The independent institute for outstanding energy efficiency in buildings. www.passiv.de
12. Dott R., Haller M. Y., Ruschenburg J., Ochs F., Bony J., The reference framework for system simulations of the IEA SHC Task 44 / HPP Annex 38. Part B: Building and space heat load. A technical report of subtask C. Report C1 part B, IEA Solar Heating & Cooling Programme, 2013.
13. Widén, J. and E. Wäckelgård, A high-resolution stochastic model of domestic activity patterns and electricity demand. Applied Energy, 2010. 87: p. 1880-1892
14. Birchall S., Wallis I., Churcher D., Pezzutto S., Fedrizzi R., Causse E., D2.1a Survay on the energy needs and architectural features of the EU building stock, iNSPiRe EU FP7 Project 2014, www.inspirefp7.eu 2014