

Technical report on the reference conditions for modelling

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The contents of this report do not necessarily reflect the viewpoints or policies of the International Energy Agency (IEA) or its member countries, the IEA Solar Heating and Cooling Technology Collaboration Programme (SHC TCP) members or the participating researchers.

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1 Introduction

The main objective of SubTask B is to analyse and select optimized control strategies to manage the interaction between solar and cooling machine and to investigate demand/response strategies to optimise the interaction with smart grids. The latter objective is developed in the Deliverable B2, while the first is presented in the Deliverable B5. Reference buildings, energy plant layouts and control strategies used for assessing the performance of innovative systems are described in B1, B3 and B4 respectively.

The aim of this report is therefore to provide information on the boundary conditions and construction typologies that have been used to simulate heating and cooling demands of residential buildings.

Two approaches are presented in this document. The first adopts reference buildings: the simulation models have been benchmarked (calibrated) against the energy statistics for each of the seven climate regions based on the aggregated data for the whole residential building stock in that climate region.

The second method refers to the last three cases and uses specific buildings, actually designed or monitored by project partners, which location, wall construction, windows, HVAC systems are well characterised.

The reference buildings of the first approach include a Single Family House (SFH) and a Multi Family House (MFH) located in seven different European climates. The second example is a wooden Single Family House located in south Italy, therefore in a humid and warm climate. The third case is another SFH, but located in Austria, so in a Continental climate. Finally, the fourth example is a MFH located in Austria with three floors and four dwellings per floor.

2 Model of Single Family House and Multi Family House reference building from iNSPiRe project

Within the iNSPiRe project, two reference residential building typologies were individuated after an extensive European building stock analysis [1].

The reference buildings' models are based on the representative building models in terms of building construction type and geometry. However, the construction has been modified so that the heat transmission coefficients - U-values - are those average values for the seven climates and six periods of construction defined in the project iNSPiRe.

The definition of the zones used as well as the overall geometry are given in section 2.1.

Boundary conditions for the simulations (infiltrations and/or natural ventilation, shadings and occupancy profiles) are defined as in section 2.2 and 2.3. Simulations have been carried out in TRNSYS 17.

2.1 Models of Reference Buildings

The study grouped the existing European building stock by construction periods and climates. In particular, the individuated construction periods refer to: pre 1945, between 1945-1970, 1970-1980, 1980-1990, 1990-2000, post 2000. Details and examples reported in the following, refer to the buildings of the 1945-1970 construction period.

Regarding the climates, more details are reported in section 2.2.3, while information on the analysed typologies, Single Family House (SFH) and small Multi Family Houses (sMFH) are presented here in the following.

2.1.1 Residential building – Single Family House - SFH

The SFH model has a fixed geometry for all the climates and periods of construction. It has been defined following the common characteristics for a European SFH. The building model is composed of two storeys with a total of 100 m² of living area ($S/V = 0.90$, 2 thermal zones are simulated); no balcony has been considered, only an overhang due to the roof has been modelled. The glazing ratio changes according to the façade orientation: on the south side it amounts to 20%, on the north side 10% and on the east and west side 12%.

Main geometrical features are reported in Table 1. Models for semi-detached and row houses have also been created by defining the wall in between dwellings as an adiabatic one.

2.1.2 Residential building – small Multi Family House - s-MFH

The second reference building typology represents multi-family houses with a small size base area ($S/V = 0.61$ to 0.46 assuming number of floors from 3 to 7, see Table 2). This reference building has two dwellings per floor and an individual staircase located inside the building envelope. The dwelling size is 50 m² and the number of floors varies from 3 to 7.

The building model includes two zones per dwelling, one per orientation, plus the staircase zone. Three floors have been simulated, and for buildings with more than 3 floors the behaviour of all intermediate floors is assumed to be the same as the mid-floor.

A glazing ratio of 20% in the north and south facades has been defined according to the most common s-MFHs.

Table 1 – SFH main geometrical features

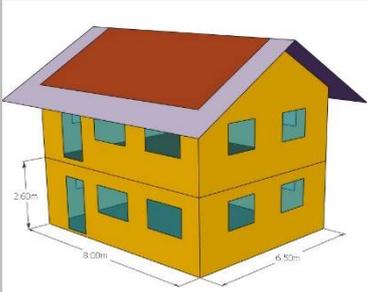
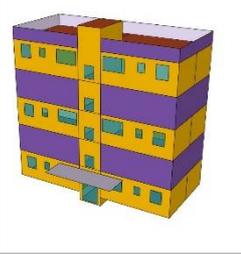
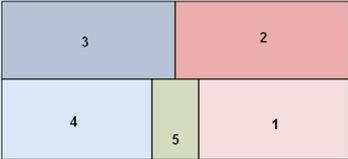
SFH	
Sketch and picture	 
Number of floors	2
Living area per floor	50 m ²
Ceiling/floor height	2.7 / 3.0 m
Building width /depth	6.5 / 8.0 m
Roof type and materials	Tilted (30°) saddle roof
Glazing ratio	North = 10%, South = 20%, East and West = 12%

Table 2 – s-MFH main geometrical features

s-MFH	
Sketch and picture	 
Zones / floor	
Number of floors	3 to 7
Living area per dwelling	50 m ²
Number of dwellings per floor	2
Ceiling/floor height	2.7 / 3.0 m
Building width / depth	16.3 / 7.6 m
Roof type and materials	Flat concrete roof
Glazing ratio	20 % on the North and South facade

2.2 Boundary conditions

2.2.1 Heating and cooling

In order to assess the heating and cooling demands of the buildings before renovation and benchmark the simulation results with statistic data, ideal heating and cooling were applied. The set point for heating varied from 18 °C to 24 °C, while the cooling set point varied from 20 °C to 26 °C, both with a 2 °C step. When

varying the cooling set point, the heating set point has been kept at 18 °C, and the cooling set point was kept at 26 °C when the heating set point was varied.

During simulations with the HVAC; heating set point is fixed at 20°C and cooling set point at 25°C.

Table 3 – Summary of heating and cooling for residential buildings

HEATING AND COOLING	Default	Min	Max	Step	Unit
Heating					
Set temperature	18	18	24	2	[°C]
Heating Power	Infinite / ideal				[W]
Humidification	OFF				
Cooling					
Set temperature	26	20	26	2	[°C]
Cooling Power	Infinite / ideal				[W]
Dehumidification	ON for relative humidity > 50%				

2.2.2 Ground coupling

The ground coupling has been modelled applying indications from ISO/DID 13370 standard [5] on thermal losses through the ground. A non-ventilated air gap of 1.5 m below the ground floor of MFHs has been considered in order to consider slab-on-ground houses and buildings with cellars. For each climate, a ground profile temperature has been therefore calculated and used as external file. The SFH has been supposed to do not have a cellar.

2.2.3 Climates

The simulation climates have been taken from Meteonorm data, with statistical data for the period 1986-2005 for global radiation and 2000-2009 for temperature, humidity, precipitation and wind speed.

The climates were chosen to have a representative number of degree days for the climate region that they represent. Figure 1 and Figure 2 show maps of the heating and cooling degree days respectively, with the locations of the climates used in the simulations shown as rings. It is clear from these that the heating and cooling degree days show different trends for the different climate regions. From France across to Poland, the lines of equal heating degree days are nearly north-south whereas they are more or less east-west for cooling degree days.

Table 4 reports the classification of the European countries into seven reference climates. The first column reports the reference city weather conditions used for the related climatic zone, belonging to the country coloured in red.

Table 4 - Locations for simulation and related climatic zones

LOCATION	Climatic zone	Countries within climatic zone
Madrid	Southern Dry	Portugal, Spain
Rome	Mediterranean	Cyprus, Greece, Italy , Malta
Lyon	South-Continental	Bulgaria, France , Slovenia
London	Oceanic	Belgium, Ireland, Netherlands, UK
Stuttgart	Continental	Austria, Czech Republic, Germany , Hungary, Luxembourg, Romania, Slovakia
Gdansk	North-Continental	Denmark, Lithuania, Poland
Stockholm	Nordic	Estonia, Finland, Latvia, Sweden

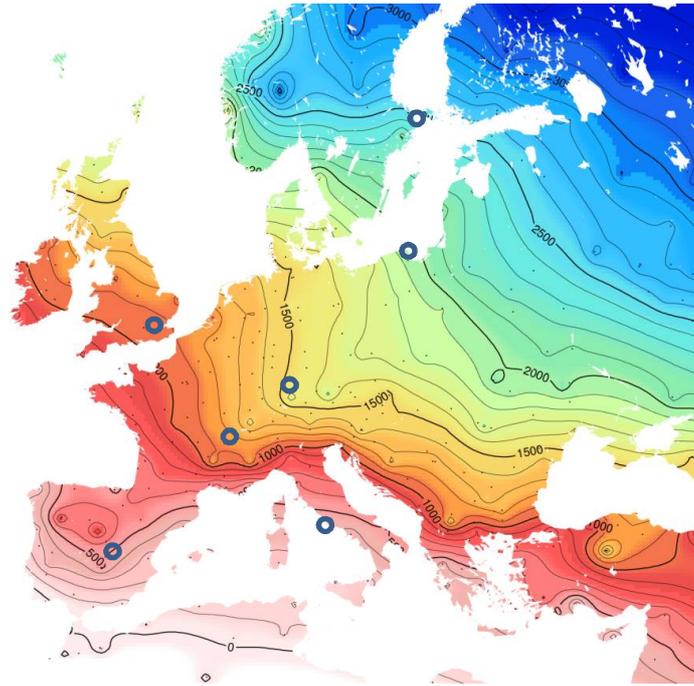


Figure 1 – Heating degree day base 12 in Europe (Source: zafh.net, based on Meteonorm Data).

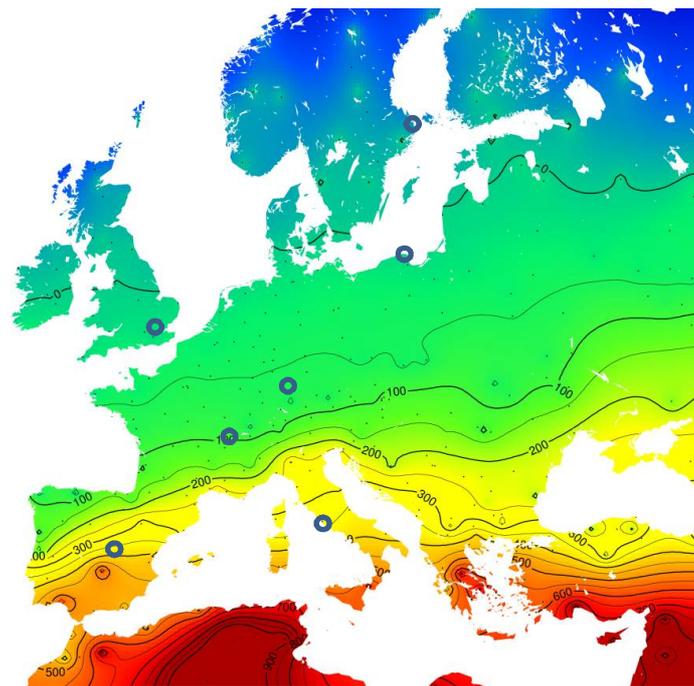


Figure 2 – Cooling degree day base 21 in Europe (Source: zafh.net, based on Meteonorm Data).

2.2.4 Internal gains

Internal gains are divided into occupational gains and gains from electrical appliances. No separate gains from lighting are defined. For single family houses, profiles from Task 44 [2] were applied while the value of the gain derives from statistics (see [1]).

The profiles for multi-family houses were generated for a number of inhabitants of the building using a stochastic model developed by researchers at Uppsala University [2]. The procedure is used for generating profiles of occupancy, appliances and lighting and DHW load. One profile per apartment is created in a way

that the loads are not contemporaneous and have a day-to-day variation over the whole year, whereas the Task 44 profile is a repeated 24 hour cycle. Both these and the Task 44 profiles have a 1 hour resolution.

Table 5 – Summary of internal gains for residential buildings

INTERNAL GAINS		Unit
Occupancy		
Schedule	see Figure 3 and Figure 5	
Activity level (ISO 7730)	Seated, very light writing	
Sensible heat	65	[W]
Latent heat	55	[W]
Appliances		
Schedule	see Figure 4 and Figure 6	
Sensible heat	10	[W/m ²]

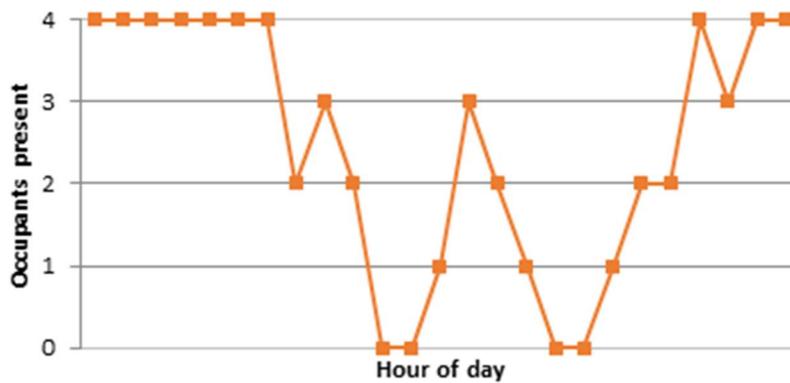


Figure 3 – Task 44 presence profile for single family house with four occupants [2]

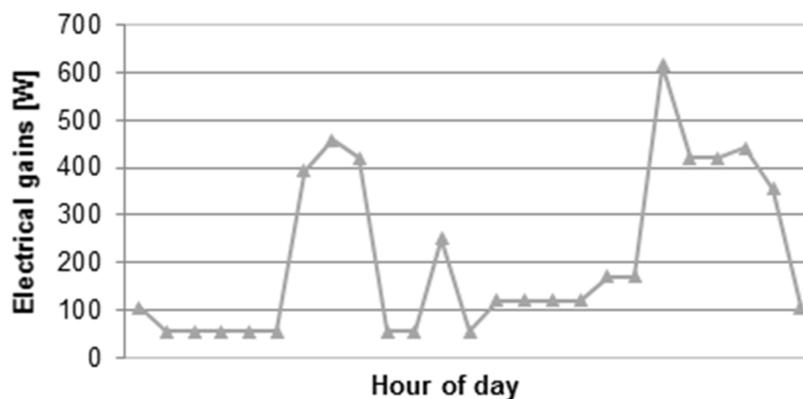


Figure 4 – Task 44 profile for internal electrical gains in a single family house of 140 m² with four occupants [2].

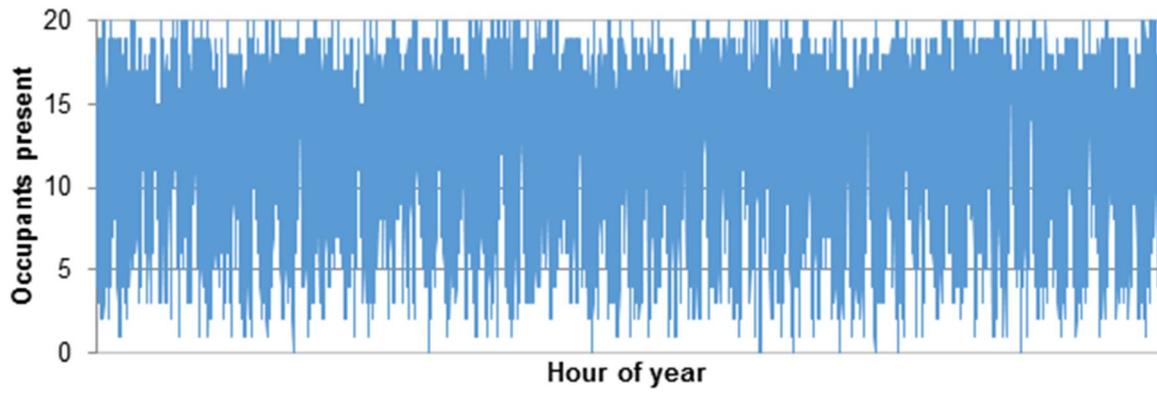


Figure 5 – Stochastically generated presence profile for a multi-family house with 20 occupants [2]

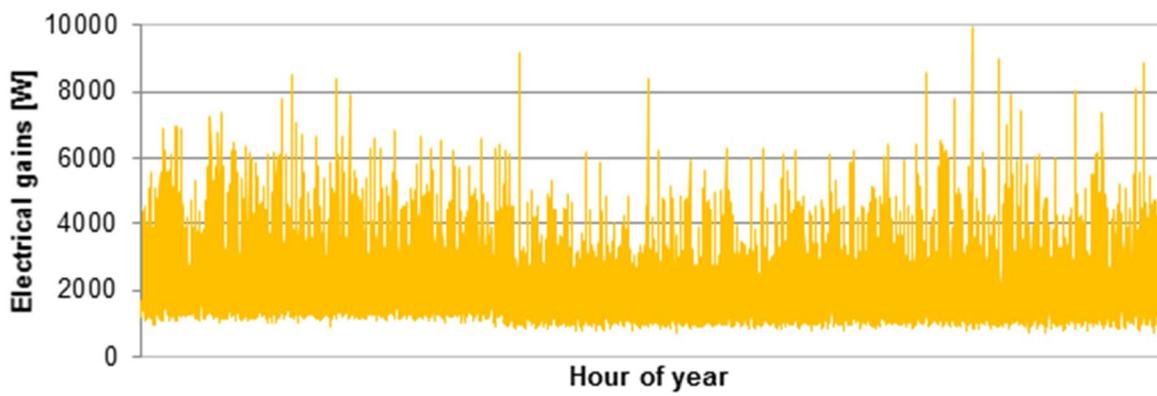


Figure 6 – Stochastically generated internal gains profile for a multi-family house with 20 occupants [2]

2.3 Envelope features

Starting from the existing buildings of different construction periods, envelope renovation solutions are chosen for achieving 4 levels of heating demand: 15, 25, 45, 700 kWh/(m²y). For each of the studied cases, an additional insulation layer, windows quality and mechanical ventilation system with heat recovery (MVHR), has been chosen.

2.3.1 Opaque elements

The tables in this section show averaged U-value through the external surfaces, the added insulation thickness for each energy level, the presence of MVHR with the correspondent efficiency and the reached heating demand. The average U-value is weighted by the surface area. As already mentioned, the results here reported refer to the building construction period between 1945-1970. For more details, please refer to [3].

For the renovation, the insulation layer is an EPS (expand polystyrene) with a conductivity of 0.039 W/(mK).

Table 6 - Summary of averaged u-values, insulation thickness, presence of MVHR and heating demand by climate region and energy level - SFH

		Average U-value [W/m ² K]	Insulation wall / roof [cm]	Insulation Ground / Perimeter [cm]	MVHR efficiency [-]	Heating demand [kWh/m ² y]
Southern Dry	MAD_Existing	2.02	-	-	-	248
	MAD_15	0.29	10/20	10/0	0.85	12
	MAD_25	0.32	9/19	8.9/0	0.85	29
	MAD_45	0.42	6/16	6.3/0	0.00	51
	MAD_70	0.58	10/20	0/0	0.00	76
Mediterranean	ROM_Existing	1.77	-	-	-	171
	ROM_15	0.34	8/18	7.3/0	0.85	16
	ROM_25	0.54	6/6	2.9/0	0.85	27
	ROM_45	0.61	12/18	0/0	0.00	49
	ROM_70	0.90	4/4	0/0	0.00	69
Southern Continental	LYO_Existing	2.21	-	-	-	306
	LYO_15	0.19	22/32	10/10	0.85	11
	LYO_25	0.26	13/23	10/0	0.85	22
	LYO_45	0.27	12/22	8.7/0	0.00	49
	LYO_70	0.41	7/17	6.7/0	0.00	71
Oceanic	LON_Existing	1.80	-	-	-	321
	LON_15	0.15	34/44	10/10	0.85	11
	LON_25	0.22	17/27	10/0	0.85	22
	LON_45	0.25	13/23	10/0	0.00	42
	LON_70	0.31	9/19	9.1/0	0.00	73
Continental	STU_Existing	1.37	-	-	-	285
	STU_15	0.13	40/50	10/10	0.85	26
	STU_25	0.17	24/34	10/10	0.85	34
	STU_45	0.18	21/31	10/10	0.00	55
	STU_70	0.18	23/33	10/0	0.00	67
Northern Continental	GDA_Existing	1.24	-	-	-	327
	GDA_15	0.13	40/50	10/10	0.85	23
	GDA_25	0.13	40/50	10/10	0.85	25
	GDA_45	0.24	12/22	10/10	0.85	45

	GDA_70	0.25	11	10/10	0.00	72
Nordic	STO_Existing	0.48	-	-	-	174
	STO_15	0.10	40	10/10	0.85	21
	STO_25	0.10	40	10/10	0.85	23
	STO_45	0.24	8	5/5	0.85	50
	STO_70	0.24	8	5/5	0.00	74

Table 7 - Summary of residential u-values by country and climate region. Floors and Roofs. Weighted averages over total floor area

		Average U-value [W/m²K]	Insulation wall / roof [cm]	MVHR [-]	Heating demand [kWh/m²y]
Southern Dry	MAD_Existing	2.01	-	-	145
	MAD_15	0.71	6/6	0.85	15
	MAD_25	0.97	3/3	0.85	31
	MAD_45	1.14	2/2	0.00	56
	MAD_70	1.42	1/1	0.00	74
Mediterranean	ROM_Existing	1.70	-	-	86
	ROM_15	0.87	3/3	0.85	15
	ROM_25	1.02	2/2	0.85	22
	ROM_45	1.50	0/5	0.00	51
	ROM_70	1.69	0/0	0.00	66
Southern Continental	LYO_Existing	2.25	-	-	179
	LYO_15	0.62	7/7	0.85	14
	LYO_25	0.83	4/4	0.85	29
	LYO_45	0.83	4/4	0.00	53
	LYO_70	1.14	2/2	0.00	75
Oceanic	LON_Existing	1.81	-	-	169
	LON_15	0.57	7/7	0.85	15
	LON_25	0.76	4/4	0.85	31
	LON_45	0.76	4/4	0.00	57
	LON_70	1.03	2/2	0.00	80
Continental	STU_Existing	1.36	-	-	154
	STU_15	0.46	9/9	0.85	16
	STU_25	0.61	5/5	0.85	30
	STU_45	0.49	8/8	0.00	49
	STU_70	0.75	3/3	0.00	74
Northern Continental	GDA_Existing	1.29	-	-	191
	GDA_15	0.38	13/13	0.85	24
	GDA_25	0.47	8/8	0.85	28
	GDA_45	0.37	14/14	0.00	52
	GDA_70	0.59	5/5	0.00	83
Nordic	STO_Existing	0.50	-	-	95
	STO_15	0.30	6/6	0.85	18
	STO_25	0.34	4/4	0.85	24
	STO_45	0.24	10/10	0.00	50

2.3.2 Windows

The used windows for the after renovation cases are double-pane or triple-pane, depending on the climate and energy level. The main characteristics are reported in Table 8.

Table 8 – Windows characteristics

Windows	Good (3)	Medium (2)	Poor – Existing (1)
Number of panes	3	2	1
g / [-]	0.584	0.622	0.755
Ug / [W/(m² K)]	0.59	1.40	2.83
Uf / [W/(m² K)]	2.87	3.34	4.20

In Table 9, the windows typologies (double pane – 2, or triple pane – 3) adopted per energy level and building typology in each country are summarized. In particular for the SFH, the triple glazed windows are installed in the four energy levels for the climates of Nordic and Northern Continental, in the 3 most efficient energy levels for Continental and Oceanic, in the most efficient energy level in Southern Dry climate and all double pane windows for the Mediterranean case.

Due to the lower S/V ratio of the sMFH, in this case the triple-pane windows are only used for the most efficient energy levels in the climates of Nordic, Northern Continental, Oceanic, Continental and Southern Continental, while in the other energy levels and climates the double-pane window is used.

Table 9 – Windows quality adopted in SFH and sMFH

Energy Level	SFH				sMFH			
	15	25	45	70	15	25	45	70
Nordic	3	3	3	3	3	3	2	2
Northern Continental	3	3	3	3	3	3	2	2
Continental	3	3	3	2	3	3	2	2
Oceanic	3	3	3	2	3	3	2	2
Southern Continental	3	3	2	2	3	3	2	2
Southern Dry	3	2	2	2	2	2	2	2
Mediterranean	2	2	2	2	2	2	2	2

2.3.3 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 levels of infiltration rate have been defined by experience depending on the Climate and on the building energy level. Infiltration rate is based on calculation from the “Ventilation” sheet in the PHPP tool [4].

Natural ventilation due to the windows opening is assumed to be 0.4 vol/h. Same ratio is used for the mechanical ventilation; efficiency for the MVHR system is assumed to be 0.85 Table 7.

Table 10 – Infiltration rate [vol/h] based on calculation from “Ventilation” sheet in the PHPP tool [4]

Energy Level	SFH				sMFH			
	15	25	45	70	15	25	45	70
Stockholm	0.042	0.07	0.07	0.006	0.042	0.07	0.07	0.006
Gdansk	0.042	0.07	0.07	0.006	0.042	0.07	0.07	0.006
Stuttgart	0.042	0.07	0.006	0.006	0.042	0.07	0.07	0.006
London	0.042	0.07	0.006	0.006	0.042	0.07	0.07	0.006
Lyon	0.042	0.07	0.006	0.006	0.042	0.07	0.07	0.006
Madrid	0.042	0.07	0.006	0.006	0.042	0.07	0.07	0.006
Roma	0.042	0.07	0.006	0.006	0.042	0.07	0.07	0.006

2.3.4 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.

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.

3 Model of a Wooden Single Family House (WRB)

The reference building is an existing Wooden Residential Building (WRB) in Sicily. It is a class A+ single house, having bearing structures in XLAM wood panels and thermal insulation in wood fibre and mineral wood. The building is a single residential storey. Total surface and volume of the building are 130 m² and 728 m³. The building model is developed in TRNBuild as a unique thermal zone.

Table 11-WRB main features.

WRB	
Picture	
Number of floors	1
Living area per floor	130 m ²
Ceiling/floor height	3.0 m
Building width /depth	16.5 / 8.0 m
Roof type and materials	Tilted (30°) saddle roof
Glazing ratio	25 %

3.1 Boundary conditions for WRB

3.1.1 Heating and cooling

In order to assess the heating and cooling demands of the building before renovation, ideal heating and cooling were applied. The set point for heating was 20°C, while the cooling set point was 26 °C. The model does not foresee any shading device.

Table 12 – Summary of heating and cooling for residential and office buildings

HEATING AND COOLING	Value	Unit
Heating		
Set temperature	20	[°C]
Heating Power	Infinite / ideal	[W]
Humidification	Off	
Cooling		
Set temperature	26	[°C]
Cooling Power	Infinite / ideal	[W]
Dehumidification	On	

3.1.2 Ground coupling

The ground coupling has been modelled considering a non-ventilated air gap below the floor. Moreover, the temperature of the soil has been calculated by means of type 77 and used as input.

3.1.3 Climates

The simulation climates have been taken from Meteonorm data included in TRNSYS.

The climates were chosen to have a representative number of degree days for the climate region that they represent. In Figure 7, a map with the cities considered in the analysis is reported.

Table 13 - Locations for simulation and related climatic zones

LOCATION	Climatic zone	Countries within climatic zone
Almeria, Barcelona	Southern Dry	Portugal, Spain
Athens, Larnaca, Luca, Messina	Mediterranean	Greece, Cyprus, Malta, Italy
Marseille	Southern Continental	Bulgaria, France, Slovenia
Freiburg, Stuttgart	Continental	Austria, Czech Republic, Germany, Hungary, Luxembourg, Romania, Slovakia



Figure 7: map of the cities considered.

3.1.4 Internal gains

Internal gains are divided into occupational gains, gains from electrical appliances and gains for lightning. Each of these can be described by some periodic profiles.

Table 14 – Summary of internal gains for residential buildings

INTERNAL GAINS	Unit	
Occupancy		
Schedule	see Figure 8	
Activity level (ISO 7730)	Seated at rest	
Sensible heat	60	[W]
Latent heat	40	[W]
Appliances		
Schedule	see Erreur ! Source du renvoi introuvable.	
Type	230 W PC with colour monitor	[W]
Lightning		
Schedule	see Erreur ! Source du renvoi introuvable.	
Total heat gain	10	[W/m ²]

The occupation profile and the schedule used for the lightning are shown in Figure 8 and Figure 9, respectively.

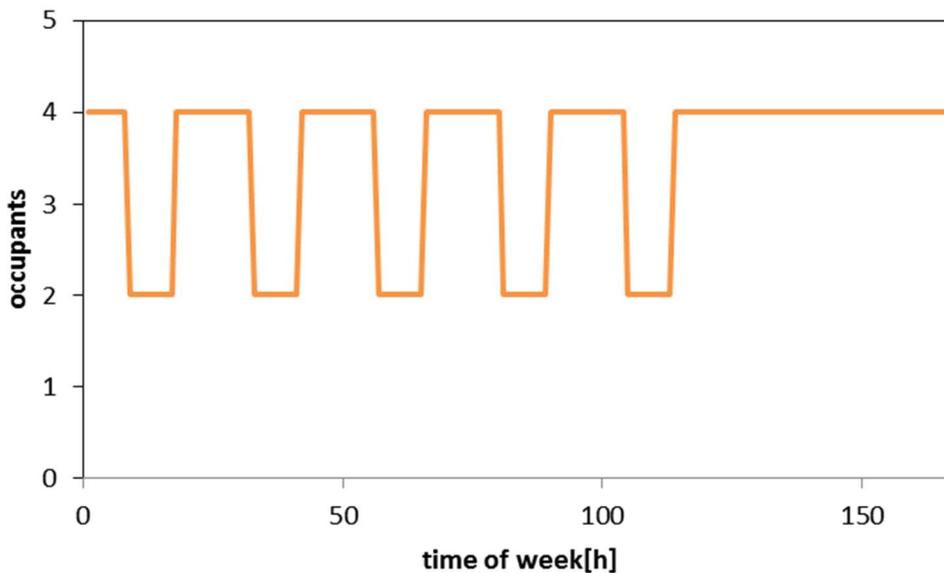


Figure 8: occupation profile used in the analysis.

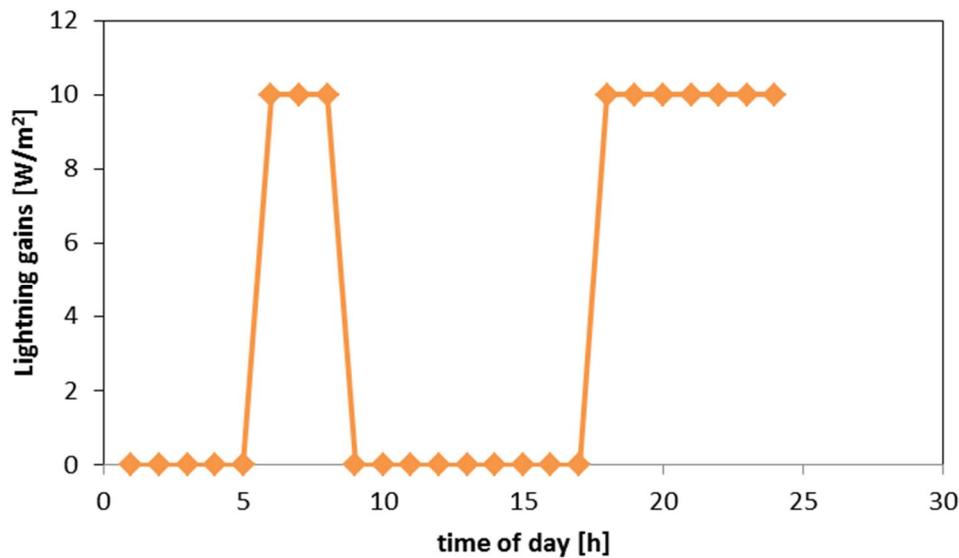


Figure 9: lightning profile used in the analysis.

3.2 Envelope features

3.2.1 External surfaces

According to the actual structure of the building, 4 different types of walls were defined: external walls, roof, ceiling and glass wall. The characteristics of the layer composing the walls and the overall U-value of each wall are reported in **Erreur ! Source du renvoi introuvable.**

Table 15- Features of the envelope of the wooden building.

Wall type	Layer	Thickness	Conductivity	Capacity	Density	U-value
		m	W/mK	kJ/kgK	kg/m ³	
External wall	Plaster	0.015	0.84	1.01	1400	0.288
	Wood wool panel	0.025	0.09	1.55	400	
	Wooden fibre	0.080	0.04	2.7	150	
	XLAM panel	0.071	0.09	1.55	400	
	Air gap		0.26	1	1	
	Drywall	0.013	0.28	1.1	1150	
Glass wall	Window glass	0.060	1.27	0.75	2500	2.94
	Air gap		0.26	1	1	
	Window glass	0.060	1.27	0.75	2500	
Roof	Air gap					0.194
	Wooden fibre	0.080	0.04	2.7	150	
	Wood panel	0.030	0.01	1.6	550	
	Air gap		0.26	1	1	
Floor	Wood floor	0.020	0.01	1.6	550	0.142
	Lime	0.040	0.09	1.4	450	
	Wooden fibre	0.040	0.04	2.7	150	
	Wood panel	0.040	0.01	1.6	550	
	Air gap		0.26	1	1	

The characteristics of the windows are instead reported in Table 16.

Table 16- characteristics of the windows.

Windows	U-value	g-value	c-value frame
	W/m2K	%	W/m2K
	1.43	0.605	2.27

3.2.2 Infiltration and mechanical ventilation

Constant infiltration equal to 0.3 h^{-1} has been considered, that accounts for infiltration and windows opening. There is not a mechanical ventilation system.

4 Model of a Single Family House - TheBat building

4.1 Model of the TheBat-building

The model of the building is based on the SFH45 that was created for use in Task 44-B. It is composed of two storeys with a total of 140 m² of living area split equally between them. Both storeys were modelled as separate zones, additionally a separate zone was created to represent the attic area which is not used as living space. No balcony or roof overhang were considered. The building also does not include a basement level. Main geometrical features are reported in Table 17 as well as Table 18.

Table 17 – SFH based on Task 44

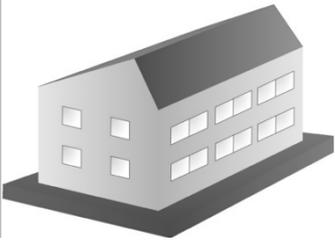
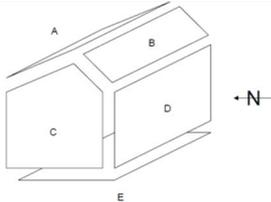
SFH	
Sketch and picture	
Number of floors	2
Living area per floor	70 m ²
Ceiling/floor height	2.8 / 2.8 m
Roof type and materials	saddle roof with inclinations of 20° and 45°
Glazing ratio	11%

Table 18 – inside areas of the model building

	A	B	C	D	E
					
Orientation	Roof 20° North	Roof 45° South	Wall East/West	Wall North/South	Floor Ground
Inside (net) area [m²]	54.6	26.4	45.7	56.0	70.0
glazing area [m²]	-	-	4.0	3.0(N) 12.0 (S)	-

Boundary conditions for the simulations (infiltrations and/or natural ventilation, shadings and occupancy profiles) are defined as in section 4.3.3 and 4.3.4. Simulations have been carried out in TRNSYS 17.

4.2 Boundary conditions for the TheBat building

4.2.1 Heating and cooling

For heating purposes, the building is equipped with floor heating as TABS in both floors (as can be seen in Figure 10). The energy to the TABS is supplied via a heat pump in conjunction with a Thermal Energy Storage. Several cases were considered, with the setpoint for air temperature being varied from 21 °C to 26 °C in steps of 1°C. Cooling of the building outside of the heating period was not considered for this case.

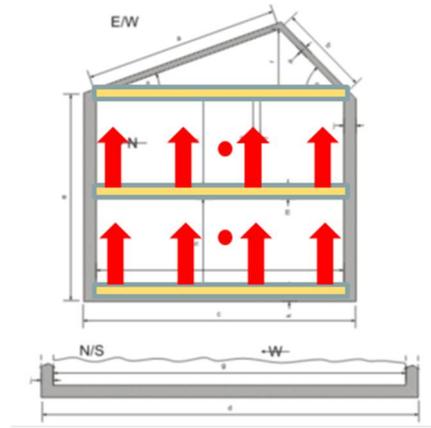


Figure 10 - TABS placed in the building

HEATING	Default	Min	Max	Step	Unit
Heating					
Set temperature	20.5-21.5	21	26	1	[°C]
Heating Power		3000	10000		[W]
Humidification	Off				

4.2.2 Ground coupling

The ground coupling has been modelled based on Task 44 using Kasuda undisturbed ground temperature model – Type 77.

4.2.3 Climate

Simulations were conducted with reference climate data for the university area of Innsbruck. The climate data has been taken from Meteonorm, with statistical data for the period 1986-2005 for global radiation and 2000-2009 for temperature, humidity, precipitation and wind speed.

4.2.4 Internal gains

Internal gains are divided in occupational gains and gains from electrical appliances. Gains from lighting are included in gains from electrical appliances and are not separately defined. The profiles are based on those created for Task 44. All gains are based on periodic profiles which are repeated in a 24 h cycle. All profiles have a resolution of 1 h. No variations in terms of weekly or seasonal periods were considered.

Gains caused by the inhabitants are divided in convective and radiative gains. The latent heat is included as a humidity mass flow. The specific values can be found in Table 19 with the related daily profile displayed in Figure 8.

Table 19 - Internal gains caused by inhabitants

	Area per resident [m ² /P]	Heat gains		Humidity gains
		radiative [W/m ²]	convective [W/m ²]	[g/h.m ²]
RES45	35	1,14	0,57	1,65

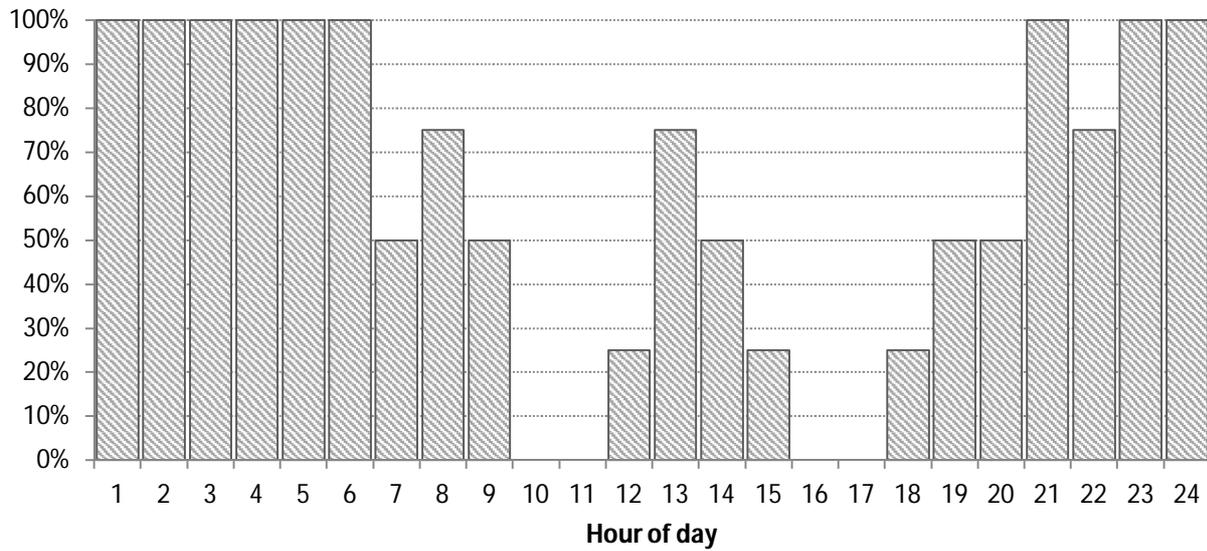


Figure 11 – daily profile for occupancy

The gains from electric applications are considered purely convective heat gains. The specific values can be found in Table 20 with the related daily profile displayed in Figure 12.

Table 20 - Internal gains caused by electrical appliances

	Heat gains [W/m ²]
RES45 (140m ²)	4,39

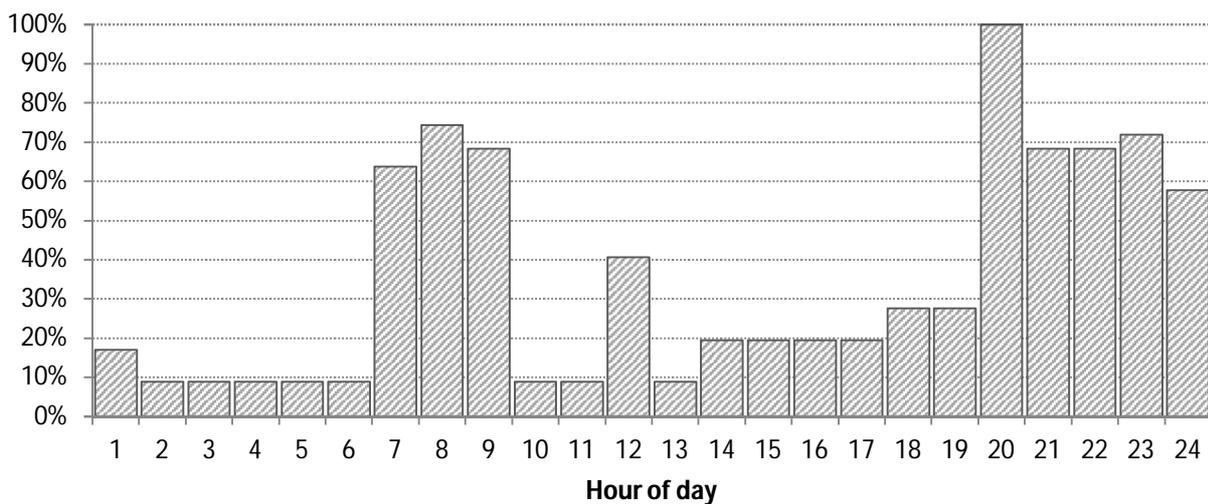


Figure 12 – daily profile for electrical appliances

4.3 Envelope features

4.3.1 Opaque elements

The construction of the external opaque elements is described in Table 21.

During simulations, the layer „Brick“ of the exterior wall section was exchanged for a massless layer with a resistance of 0.1 hm²K/kJ.

Table 21 - Construction of opaque building elements (external layer)

Assembly	layer	Layer thickness	Conductivity	Capacity	Density	U-Value construction
			\square	cp	\square	
internal -> external		[m]	[W/mK]	kJ/kgK	[kg/m ³]	[W/m ² K]
Exterior Wall	Plaster	0.015	0.600	1.00	1200	0.286
	Brick	0.210	0.700	1.00	1380	
	EPS	0.120	0.040	0.70	17	
Roof ceiling	Plaster	0.003	0.700	1.00	1800	0.197
	Gypsum board	0.025	0.211	1.00	900	
	Plywood	0.015	0.081	2.50	300	
	Rockwool	0.160	0.036	1.03	60	
Ground Floor	Plywood	0.015	0.081	2.50	300	0.174
	Wood	0.015	0.150	2.50	600	
	Plaster	0.120	1.400	1.00	2000	
	Sound Insulation	0.040	0.040	1.50	80	
	Concrete	0.180	1.330	1.08	2000	
	XPS	0.160	0.037	1.45	38	

In addition to the external opaque elements, two opaque elements are used inside the building. Their construction can be found in Table 22. The Interior ceiling represents the layer between the two floors as well as between the second floor and the attic. Both floors include an additional area of 52 m² of internal walls each.

Table 22 - Construction of opaque building elements (interior)

Assembly	layer	Layer thickness	Conductivity	Capacity	Density	U-Value construction
			\square	cp	\square	
beneath -> above		[m]	[W/mK]	kJ/kgK	[kg/m ³]	[W/m ² K]
Interior ceiling	Concrete	0.180	1.330	1.08	2400	0.690
	Sound Insulation	0.040	0.040	1.50	80	
	Plaster	0.120	1.400	1.00	2000	
	Wood	0.015	0.150	2.50	600	
Wall Interior	Clinker	0.200	0.231	0.92	650	0.964

4.3.2 Windows

A reference window was chosen for all windows in the exterior surface. The relevant values are as follows:

Table 23 – Windows characteristics for TheBat Building

Characteristic	Unit	Value
U-Value	W/m ² K	1.1
g-Value	%/100	0.609
area frame	%/100	0.15
c-value	kJ/(hm ² K)	6.48
Solar absorptance	-	0.6
Emissivity	-	0.9

4.3.3 Ventilation and Infiltration

The required ventilation rate of the building is achieved as a combination between infiltration and window ventilation during the nighttime, therefore no heat exchange is considered.

The infiltration rate through the building hull was defined with a fixed value of 0.4 1/h.

Window ventilation is calculated for three windows each floor ($W/H = 0.94/1.24$ m) with an inclination of 10° .

The window ventilation is active if all the following conditions are met:

- time between 21:00 and 08:00
- 24 h mean ambient temperature above 12°C
- Temperature difference between ambient and room temperature exceeds 2 K (deactivated if below 1 K)
- Room temperature above 24°C (deactivated if it sinks below 20°C)

4.3.4 Shading elements and strategies

The shading of the building is designed as a purely active system. The building features no permanent shading elements through roof overhang or balcony. All active elements feature a shading factor of 0.25. This means that in case of shading 75% of the solar irradiation is blocked by the active elements.

The shading system is activated if all the following control conditions are met:

- Air Temperature in the building exceeds 23.8°C (shades removed if it falls below 22.8°C)
- Global horizontal radiation exceeds 300 W/m^2 (shades removed if it falls below 200 W/m^2)

5 Model of a Reference Multi Family House from the Project HVACviaFaçade

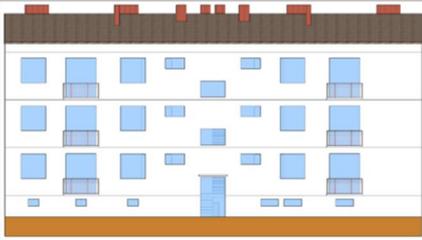
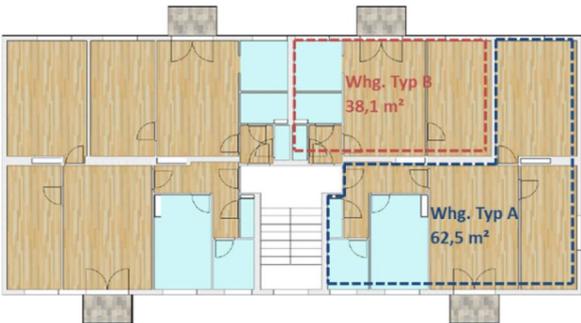
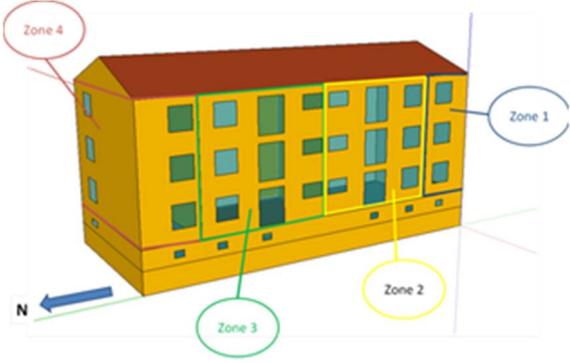
The following reference building was defined for an Austrian national project on refurbishment with prefabricated façade elements with integrated building service systems. More details on the reference buildings can be found in German language in [6].

5.1 Building Model

This reference building typology represents a multi-family house with three floors (see Table 24) and is based on a real building from the 1960s. The building has three floors and four dwellings per floor. The staircase is located eastward inside the building envelope. The dwelling sizes are 38.1 m² and 62.5 m² respectively.

The building model (TRNBUILD) includes four zones for the whole building; every zone includes three stacked dwellings with the same ground plot. The staircase zone is not conditioned. In addition, there are zones for the basement and attic which are also not conditioned.

Table 24 – MFH (HVACviaFaçade) main geometrical features

MFH - HVACviaFaçade	
Sketch and picture	
	
Zones	
	
4 zones (3 stacked dwellings with the same ground plot)	
Number of floors	3
Living area per dwelling	50.3 m ² (average)
Number of dwellings per floor	4
Ceiling/floor height	2.6 m
Building width / depth	23.4 / 10.5 m
S/V	0.47
Roof type and materials	Top-floor ceiling: concrete with insulation Roof: tiles (slope: 20°)

Glazing ratio	21 %
Location:	Graz (AT) - Weather data file METEONORM

5.2 Boundary Conditions

Two thermal standards (energy levels) are defined for the refurbishment: approximately 30 kWh/(m²_{GFAA}) and 15 kWh/(m²_{GFAA}) of space heating demand. For simplification, these will be labelled 'EL. 30' and 'EL. 15' respectively.

5.2.1 Occupancy

The occupancy of the building was modelled for all thermal zones according to Figure 13. The shown weekly profile was derived from [7]. In this project the presence of occupants in several multi-family building was evaluated using questionnaires.

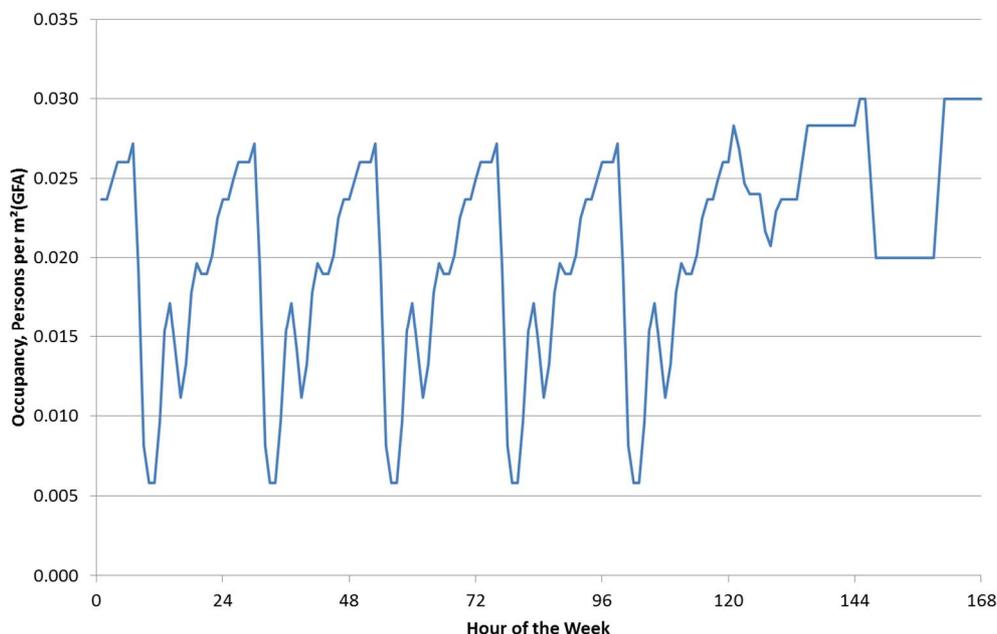


Figure 13: Occupancy of reference building in persons per square meter of gross floor area (GFA)

5.2.2 Ventilation and infiltration

In refurbishment standard **EL.15**, a controlled mechanical ventilation system is assumed using an air change rate of 30 m³/(hr and person). Therefore, the air change rate depends on the current occupancy level. For the zones that are not conditioned (stair case, attic, basement) a constant air change rate of 0.1 h⁻¹ was assumed.

The reference building with **EL.30** is assumed to use an exhaust air ventilation system with controlled air inlets in the window frames with a constant air change rate of 0.35 h⁻¹; the non-conditioned zones are ventilated with 0.1 h⁻¹.

5.2.3 Internal Gains

The internal gains due to the occupants are coupled with the occupancy profile and amount to 90 W per person. For lighting and other technical equipment, constant internal gains of 71 W and internal gains depending on the occupancy of 140 W (for maximum occupancy) were defined.

5.2.4 Summary of Boundary Conditions

Table 25 - parameters for simulation of heating demand of the MFH

	EL15	EL30
Room temperature	20°C Night setback 17°C (0.00 – 5.00)	
Air change:	Occupied zones: 30 m ³ /(h person) dependent on occupancy zones attic, basement, staircase: const. 0.1 h ⁻¹	Occupied zones: const. 0.35 h ⁻¹ zones attic, basement, staircase: const. 0.1 h ⁻¹
Infiltration:	Included in the window ventilation	
Occupancy:	2.5 people/dwelling → 30 people, with weekly occupancy profile	
Internal gains from people:	90 W per person dependent on occupancy (66% radiative, 33% convective)	
Internal gains from lighting and technical equipment:	per dwelling: 140 W dependent on occupancy und 71 W const.	
Windows	South: 5.9 m ² , east: 49.1 m ² , west: 54 m ²	
Shading of windows:	70% ON if global irradiation on the facade > 140 W/m ² OFF if global irradiation on the facade < 120 W/m ²	

5.2.5 Domestic Hot Water Consumption

The following numbers were used for DHW consumption:

- Occupancy: 2.5 people/dwelling → 30 people in the building
- DHW-consumption: 30 l/day*person at 60°C → 900 l/day at 60°C or approx. 1300 l/day at 45°C respectively
- Average temperature of cold water: 12°C

The daily distribution was defined based on long-term measurements and experiences from apartment houses [6].

This sums up to an annual energy demand of 18.4 kWh/a for DHW-preparation.

5.3 Insulations Levels

The insulation of the exterior building elements of the reference buildings are summarized in Table 26.

Table 26 – Insulation levels of reference buildings

	EL 15	EL 30
Top-floor ceiling	36 cm	28 cm
Ground floor to basement	16 cm	16 cm
Exterior walls (prefabricated façade elements)	24 cm	18 cm
Windows U Value	0.85 W/(m ² K)	0.95 W/(m ² K)

5.4 Resulting Energy Demand

The assumptions described above lead to an energy demand for space heating and domestic hot water as shown in Table 27 below.

Table 27 - Energy demand reference building

	EL.15	EL.30	
Space heating demand	9.7	19.9	<i>MWh/a</i>

Domestic Hot Water Demand	18.4	18.4	<i>MWh/a</i>
Total	28.0	38.2	<i>MWh/a</i>
Specific values:			
Space heating demand	14.1	29.0	<i>kWh/(a m²_{GFA})</i>
Domestic Hot Water Demand	26.7	26.7	<i>kWh/a m²_{GFA}</i>
Total	40.8	55.7	<i>kWh/(a m²_{GFA})</i>

5.5 Average Dwelling

Annual simulations (building and heating system directly interfaced in TRNSYS STUDIO) have been carried out for central heat supply systems as well as for de-centralized systems (for a single dwelling). In case of de-centralized heat supply the dwelling is modelled with the same specific heating demand as the whole building, in order to allow the comparability of central and de-centralized systems.

In a real building, the individual dwelling would have different heating demand depending on the position of the dwelling within the building as well as the orientation of the dwelling.

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