TRI-HP PROJECT | Trigeneration systems based on heat pumps with natural refrigerants and multiple renewable sources

Energy demands for multi-family buildings in different climatic zones

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EXECUTIVE SUMMARY

This document covers the definition of reference multi-family buildings and the calculation of the corresponding energy demands to be used in the simulation framework developed in Task 1.3.

The study targets two distinct scenarios: space heating (SH) dominated and space cooling (SC) dominated climates, corresponding to Northern/Central and Southern Europe, respectively. As a base for the energy demand calculations, two particular buildings representative of each zone were defined as reference cases. All the parameters, such as dwelling floor surface, insulation, etc. were set considering average values, resulting in the typical kind of construction that can be found in each zone. Additional parameters, such as number of occupants, use of appliances, etc. were also particularized so that the energy consumption is also representative of each case.

Both reference cases were modelled using different simulation software. Then, several scenarios were tested in order to calculate the corresponding energy demands in various conditions. Mainly, new low-energy buildings (low space heating/cooling SH/SC demand with a significant share of domestic hot water DHW) and older SH/SC dominant buildings were simulated. The aim was to obtain different sets of conditions to further analyze the performance of the systems developed in the project when implemented in different kinds of buildings. In order to do that, relevant parameters, such as U-values or infiltration rate, were modified in the models to representative values. Reference values according to local regulations were considered when doing so.

Additionally, different climatic zones were analyzed for each of the cases, so as to broaden the scope of performance and applicability studies that will be undertaken in other tasks (mainly within WP 7). For instance, the dual-source system, which is intended for Southern Europe, i.e. typically cooling dominant climates, will also need to provide heat (e.g. for the case of Madrid). For the purpose of providing the necessary data to assess such cases, the Southern European reference building was simulated also in a climate in which heating demand is significant: Bilbao.

Apart from the heating and cooling demand, domestic hot water (DHW) and electric demands were calculated in order to simulate the complete system with the whole energy demand. Occupant behavior was taken into account in the calculation process.

Consequently, the whole energy demand of different reference buildings was obtained for various climates. All the combinations result in energy data representative of a significant number of European buildings. This reference data will be used as an input for the design of the systems developed within the project as well as for the extrapolation to various conditions, maximizing the impact of the project.

Finally, the preliminary design conditions were defined for each heat pump concept. These reference design points were defined taking into account the characteristics of each concept as well as nominal conditions derived from applicable standards.

List of acronyms

ACPH	air changes per hour
Bsk	semi-arid (steppe) climate
Cfa	Humid subtropical climate
Cfb	Oceanic climate without dry season and warm summers
Csa	Hot-summer Mediterranean climate
Dfa	Hot-summer humid continental climate
Dfb	Humid continental climate without dry season and warm summers
Dfc	Regular subarctic without dry season
DHW	Domestic hot water
ET	Polar climate/permanent ice and snow
HP	Heat pump
MFB	multi-family building
nZEB	near zero energy building
SC	Space cooling
SH	Space heating
TUD	Time Use Data
U-value	thermal transmittance

1. INTRODUCTION

The main objective of WP1 is to set the framework for the TRI-HP project. The progress obtained in this work package is fundamental, as it defines the boundary conditions that will later be used to design and assess the systems developed in the project. Task 1.1 represents the first steps within this goal.

Reference energy demands (including SH, SC, DHW and electricity demand) are the basis for the system simulations of Task 1.3. These simulations will then be used as a tool for the design, assessment and scaling/extrapolation of the two systems developed in the project (solar ice-slurry and dual-source heat pumps system). In order to ensure a wide approach that allows for a thorough study of the new concepts, different reference-cases are defined.

The work undertaken along this task is clearly divided in two groups, corresponding to two distinct regions: Central and Northern Europe, and Southern Europe. The methodology that was followed for both cases is equivalent, but each of them has clearly distinguishable particularities, being that the reason for the separate treatment.

The first step for the energy demand calculation was to set the climates used for the simulations. Then, a typical reference building was defined for each case and all the relevant parameters defined considering case-dependent particularities. Finally, energy demands were calculated by means of energy simulation software.

2. CLIMATE DEFINITION

As stated above, there is a clear distinction between the climates of the two reference regions. The main difference is found in the annual average temperature: northern climates are colder and thus the space heating demand is clearly dominant over cooling needs. Southern climates are typically characterized by the exact opposite.
In this section, two particular climates are selected as a base for the energy demand calculations corresponding to each of the reference regions. Additionally, other climates are proposed for extrapolation purposes, in order to assess the performance of the systems in different regions and ensure the applicability throughout Europe.

The climate selection is based on Köppen classification [1], as it is one of the most well-known climate classification systems:

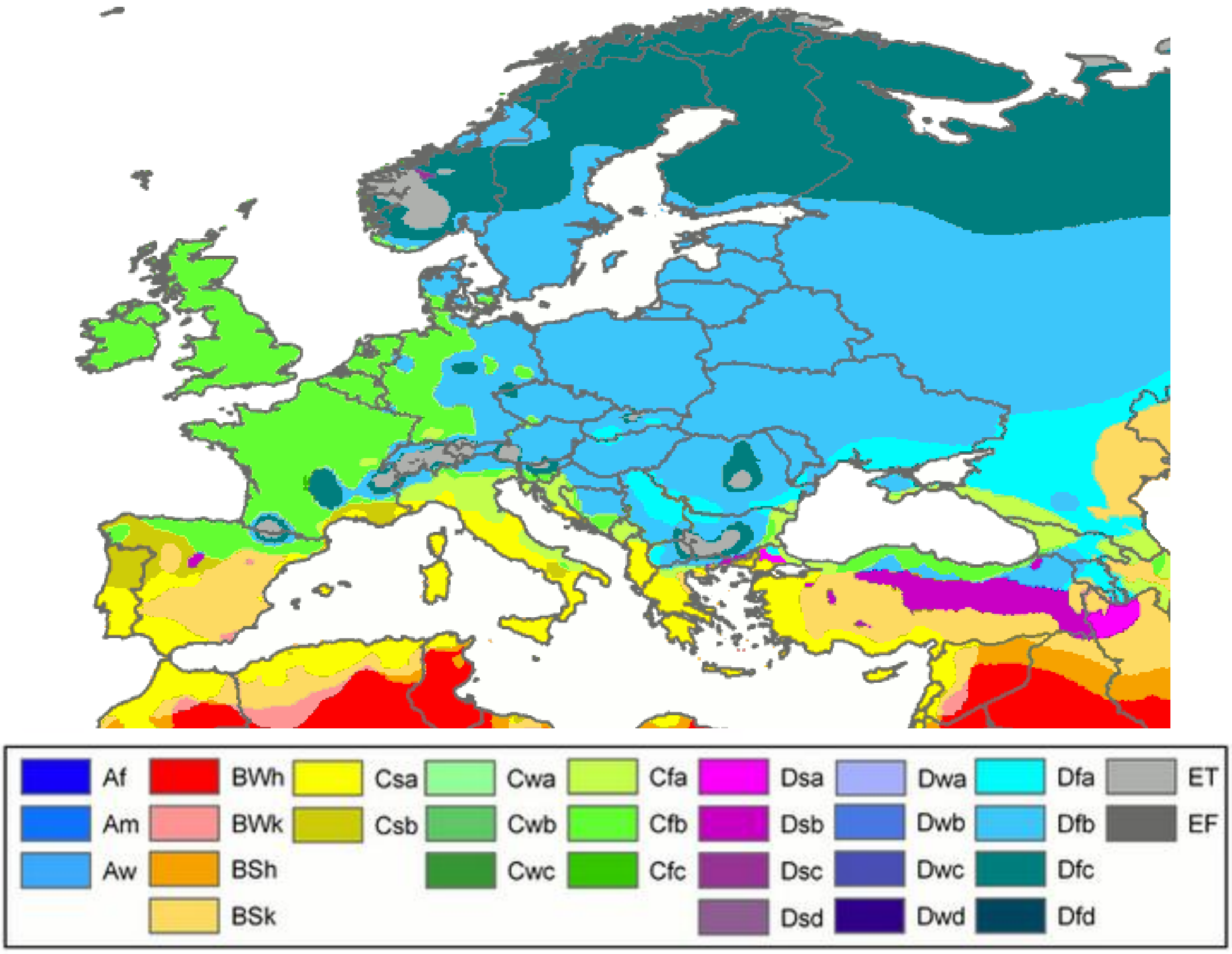

Figure 1. European climate zones according to Köppen classification [1]

2.1 CENTRAL AND NORTHERN EUROPEAN CLIMATES

In Central and Northern European climates, the demand for heating during the winter months is typically significantly higher than the cooling demand in summer. However, there are considerable differences among different types of climates as well as among the building types. Most of Central and Northern Europe is covered by the categories Cfb, Dfb, Dfc and ET as can be seen in Figure 3, Figure 4, Figure 5 and Figure 7 with the only exception being the areas close to the Danube river in the south east that fall into the category Dfa. Regions classified as Cfa are most of France, the Benelux Union, western Germany, the British Islands, Ireland as well as the south of Denmark. The category Dfb spans most eastern Germany, most of the eastern European countries, the northern part of Denmark, the southern part of Sweden as well as parts of both Norway and

Finland. Finally, regions that are classified as Dfc are in the Alps, in some low mountain ranges like the Ore mountains or the Massif Central as well as in Scandinavia.

Switzerland is a country with various different climatic conditions. Since it is located at the Alpine main ridge there are regions on the south side of the Alps with mild winters as well as on the north side with colder climatic conditions. Therefore, according to the Köppen classification, locations in Switzerland representative for large parts of Europe in terms of temperatures and humidity can be chosen for the project.

The most densely populated area of Switzerland is located in the Swiss Plateau that reaches from Geneva in the west to St. Gallen in the East and contains all of the country's major cities. A recent recalculation of the Köppen classification with 1-km resolution that is shown in Figure 2 revealed that while most parts of the Swiss Plateau are classified as Dfb (Humid continental climate without dry season and warm summers) some areas close to lakes and rivers fall into the Cfb category (Temperate oceanic climate without dry season and warm summers) [2]. Areas in the Alps between 1450 and 2100 Meters are classified as Dfc (Regular subarctic without dry season) and mountain regions above 2100 meters fall into the ET (Polar climate/permanent ice and snow) category. The valleys south of the Alps exhibit warmer climatic conditions and are mainly classified in the oceanic climate group Cfb. Some areas are having the humid subtropical climate Cfa.

As the main reference for the Central and Northern European climate the city of Zurich is chosen since it lies at the intersection of the two most dominant climatic conditions Cfb and Dfb. For extrapolation, the city of Bern is chosen to represent a typical Dfb climate, the city of Davos is chosen to represent a typical Dfc climate and the city of Locarno is chosen to represent the climatic conditions of southern Switzerland as well as northern Italy at the intersection of Cfb and Cfa. With these cities, all climatic conditions of Switzerland are represented except the very sparsely populated ET area.

A limitation of this approach is that the Köppen classification does not consider both the yearly sum and the annual distribution of solar irradiance. This becomes most evident when comparing e.g. the Swiss Plateau with the south of Scandinavia. Both are classified as Dfb according to Köppen but show large differences in the availability of solar resources. In order to account for this, additional locations will be used for extrapolation. Warsaw will be studied as an example of a more pronounced continental. Oslo will be used to investigate the effects of high latitude solar irradiation. In addition, Vienna, Prague, Kopenhagen and Riga will be added to study the effect of latitude on solar gains during the heating period in more detail. A summary of all covered climate categories with the respective locations including the cases defined for Southern Europe in section 2.2 can be found in Table 1.

Table 1 Main Köppen classifications of Europe with the respective locations chosen for the project (Bold: reference cities, Normal: cities used for extrapolation)

Köppen classification		City	Latitude
Cfa	Humid subtropical	Venice	45.43°
		Locarno (Cfa/Cfb)	46.17°
Cfb	Oceanic with warm summers	**Bilbao**	43.26°
		Zürich (Cfb/Dfb)	47.37°
Csa	Hot-summer Mediterranean	**Tarragona**	41.12°
Bsk	Cold semi-arid	Madrid	40.42°
Dfb	Humid continental	Bern	46.95°
		Vienna	48.21°
		Prague	50.09°
		Warsaw	52.23°
		Kopenhagen	55.68°
		Riga	56.95°
		Oslo	59.91°
Dfc	Regular subarctic	**Davos**	46.80°

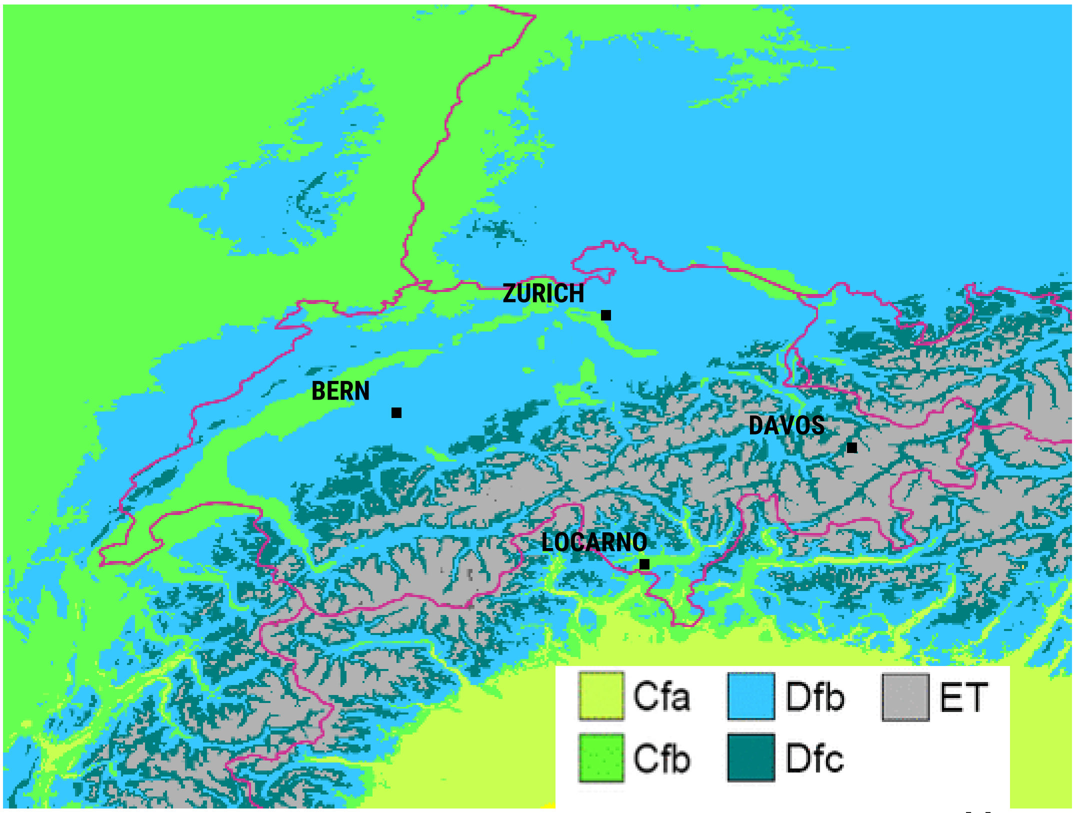

Figure 2. Detailed view on Swiss climate zones according to Köppen classification [2]

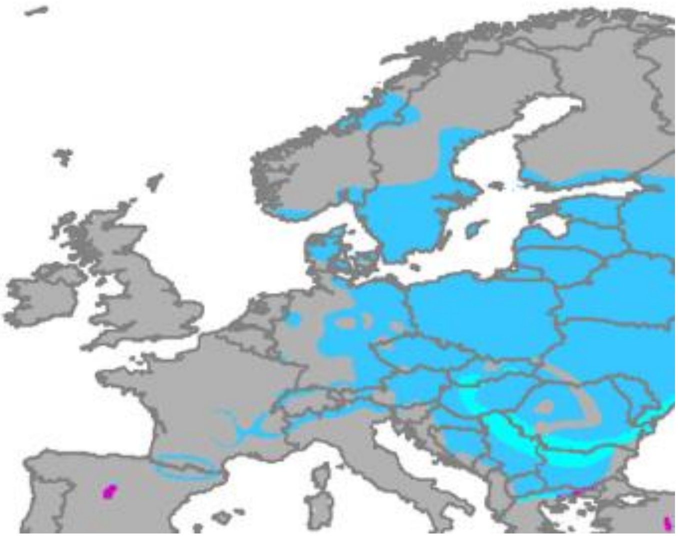
Figure 3. European Dfb climate zone, according to Köppen classification

Figure 4. European Dfc climate zone, according to Köppen classification

2.2 SOUTHERN EUROPEAN CLIMATES

In Southern European climates the cooling demand is typically dominant over heating needs. However, there are also locations in which winters are cold enough for the heating demand to become relevant, for example, Madrid.

Spain is a good example of land with various climate conditions (as it can be observed in **Figure 1**), including regions with cold winters in spite of being at the southernmost part of Europe. In fact, the northern part of Spain is in the same climate zone as the United Kingdom or the Netherlands, as shown in **Figure 5**. This climate zone, named Cfb, is the temperate oceanic climate and is characterized by relatively cool summers, with an average temperature below 22 ºC in the warmest month. Therefore, the cooling needs are typically low. During winter, however, temperature does not drop to extreme values. In fact, the lack of extreme temperatures throughout the year is a characteristic of this kind of climate. Within this climate zone, Bilbao is selected as the reference location for the heating dominant region in Southern Europe.

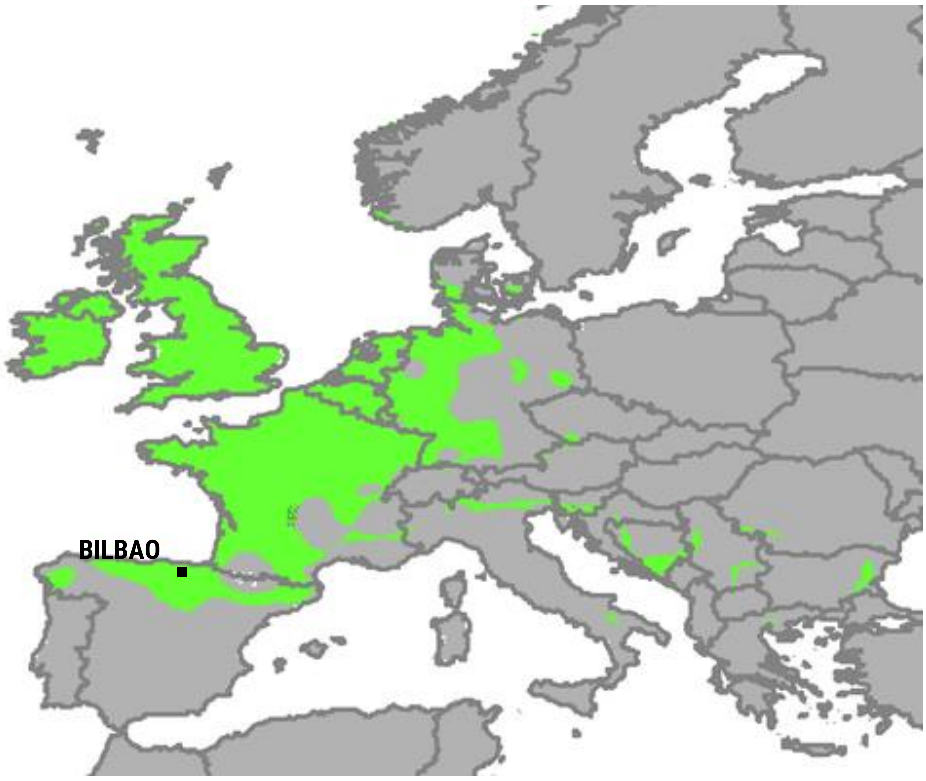

Figure 5. European Cfb climate zone, according to Köppen classification

Regarding the typical cooling dominant climate, Tarragona is defined as the reference location, belonging to hot-summer Mediterranean climate (Csa), as shown in **Figure 6**. This climate is characterized by hot and dry summers, with an average temperature above 22 ºC during its warmest month. It is considered the typical Mediterranean climate, covering an important area, including cities such as Rome or Athens.

Figure 6. European Csa climate zone, according to Köppen classification

Both proposed climates, in combination, cover a vast extension of European land, and thus are suitable as a base for the system simulations, as this implies that the performance of the system will be tested for an important part of the potential market.

Regarding extrapolation, some more extreme climates are proposed, in order to assess the possible application in alternative zones. Such is the case of humid subtropical climate, particularly hot and humid (Cfa in Köppen classification, see **Figure 7**); and cold semi-arid climate, characterized by big temperature swings (BSk in Köppen classification, see **Figure 8**). Venice and Madrid, respectively, are proposed as representative reference locations for each of the climate zones.

Figure 7. European Cfa climate zone, according to Köppen classification

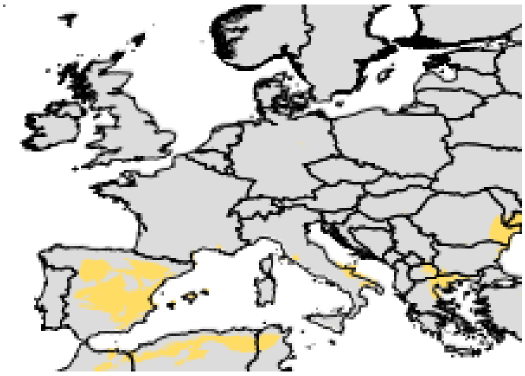

Figure 8. European BSk climate zone, according to Köppen classification

3. REFERENCE BUILDINGS AND HYPOTHESIS FOR DEMAND CALCULATION

As a base for the energy simulations, a reference multi-family building was selected for each zone (Central and Northern Europe; Southern Europe). Both buildings are representative of their regions, as they have characteristic particularities derived from local factors, such as climate, country specific, laws, etc.

A common feature is that both are new low-energy buildings, meaning that their high-performance constructive elements lead to low heating/cooling demands. As a result, they are referred as “DHW dominant buildings” even that depending on the climate, heating demand might still be higher than the DHW demand. In contrast, with the aim of testing the SH/SC dominant scenario, an alternative set of U-values was defined for the constructive elements in order to simulate an equivalent older building.

After the definition of the physical characteristics corresponding to the buildings, additional parameters (such as occupancy, consumption profiles, etc.) were set in order to complete the definition of all the hypothesis required for the calculation of the energy demands.

3.1 REFERENCE BUILDING AND HYPOTHESIS FOR CENTRAL AND NORTHERN EUROPE

The reference building used in the Central and Norther European Climates is an apartment small multi-family building (MFB) with six living units on three floors. The reference building meets the Swiss Minergie-Standard [3], that certifies buildings with an envelope of high energetic quality. The space heating demand of the building in Zurich is 30 kWh per heated surface area and year (30 kWh/(m^{2}year)) and is called MFB30. Therefore, the reference building represents a new building with relatively high DHW demand shares, e.g. around 40 % in Zurich. The building characteristics correspond approximately to the average of a set of 65 apartment buildings in Switzerland that have been analyzed in a recent research project [4]. A detailed documentation of the building can be found in Annex 1. Its main features are:

- 6 dwellings (divided in 2 floors + ground floor)
- Basement with parking and cellar
- 1396.1 m^2 gross floor area
- 1205.0 m^2 heated/cooled floor area
- 150.0 m^2 average dwelling net floor area

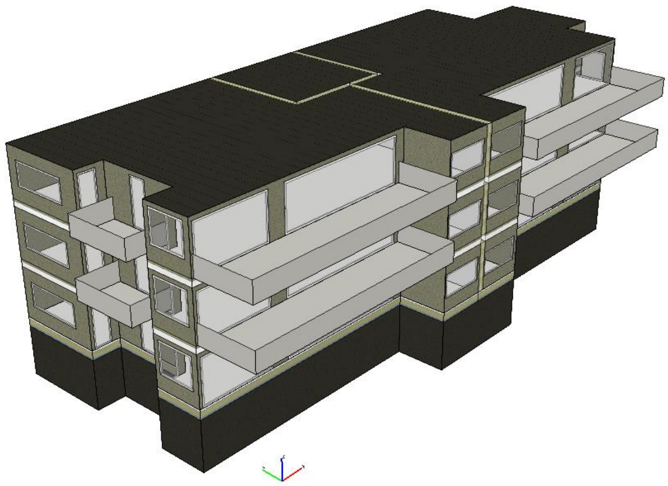

Figure 9. Reference multi-family building for Northern Europe

The U-values of the main constructive elements are:

- **External wall to ambient:** 0.18 W/(m^{2}K)
- **External wall to ground:** 0.39 W/(m^{2}K)
- **Internal wall against not heated rooms:** 0.34 W/(m^{2}K)
- **Internal wall:** 2.57 W/(m^{2}K)
- **Ground floor:** 0.27 W/(m^{2}K)

- **Floor against not heated rooms:** 0.21 W/(m^{2}K)
- **Floor between heated rooms:** 0.66 W/(m^{2}K)
- **Roof ceiling:** 0.19 W/(m^{2}K)

The natural **infiltration** through other parts of the building skin than opened windows is neglected. The **mechanical ventilation** operates non-stop with a heat recovery efficiency of 80 %. If the moving 24 h average ambient temperature is higher than 18 °C, the ventilation system uses a bypass, in which the air from outside is directly transferred into the building without heat recovery.
Natural ventilation due to window openings was derived from monitoring results [4]. In general, it was assumed that one window per apartment is open in the night from spring to autumn. The conditions for opening the windows are:

- Time between 20.00 h to 07.00 h
- Day between 1st of April to 30th of September

In order to achieve significant cooling demands, the additional window opening during night time aimed at passive cooling during summer time that is defined in the reference building in Annex 1 was removed.

Two types of shading where taken into account for the simulation. The fixed shadings due to e.g. balconies and the variable shadings like window blinds. All windows in the buildings are equipped with external blinds. When the blinds are activated, the window g-value is reduced (multiplied by 0.14), and the short-wave shading coefficient is reduced by a factor of 0.19. The U-value is not changed when the blinds are active. The blinds are activated, if following conditions are met:

- Solar irradiation on corresponding façade is over 200 W/m^2
- Wind speed is less than 10 m/s
- The moving average op. room temperature over 48 hours is comfortable

The internal loads caused by occupants and appliances are calculated by using daily reference profiles for weekdays as well as weekends. For each hour, these profiles provide a factor that determines the fraction of the maximum load that is present. The maximum values are 1440 W for occupation and 7649 W for appliances. The daily profiles are given in Figure 10.

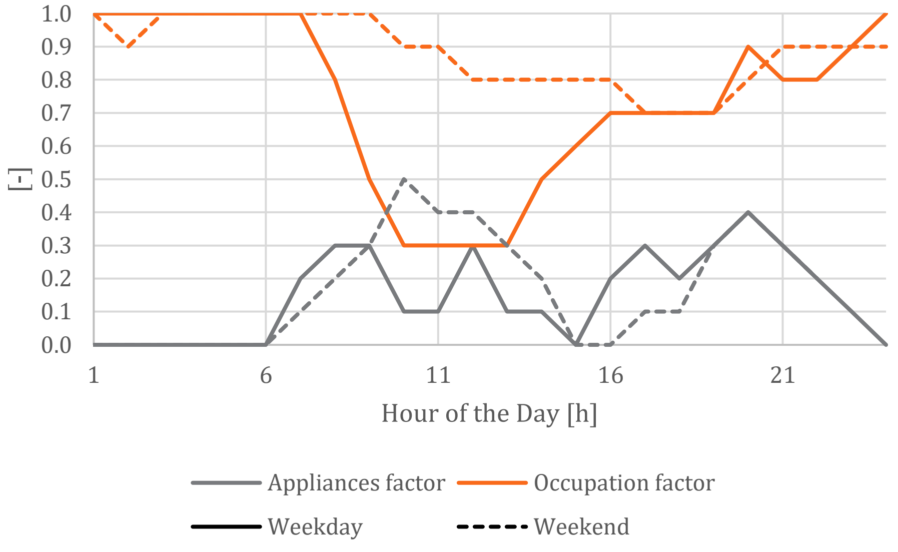

Figure 10. Daily profiles of occupation and appliances

For the energy calculation, the heating room temperature set point is defined as 21 °C. The cooling set point was is defined as 26 °C.

In addition to the reference building with high insulation standards, a second building that represents an old building constructed in the period of 1950-1980 was defined. As a difference of the reference case used for new buildings, the case representing old buildings is not based on real buildings, but on an adaption of the new building to achieve realistic demands of low insulated buildings. The general shape of the older building is the same as in the base case building with only minor changes. In order to take into account the lower insulation standard of the older building the U-values of the envelope have been changed as follows:

- **External wall to ambient:** 0.68 W/(m^2K)
- **External wall to ground:** 3.91 W/(m^2K)
- **Internal wall against not heated rooms:** 3.23 W/(m^2K)
- **Internal wall:** 2.57 W/(m^2K)
- **Ground floor:** 1.14 W/(m^2K)
- **Floor against not heated rooms:** 1.03 W/(m^2K)
- **Floor between heated rooms:** 1.0 W/(m^2K)
- **Roof ceiling:** 0.48 W/(m^2K)

The space heating demand of the old building in Zurich is 90 kWh/(m^2year) and is thus called MFB90. It has a constant **infiltration** of 225.7 l/s. There is no **mechanical ventilation** assumed for the older building. A second opened window was assumed whenever the specified conditions defined above are met.
It is assumed that there are also older electrical devices with higher electricity demand compared to the new building. Therefore, the maximum reference load of appliances is increased to 9277 W.

3.2 REFERENCE BUILDING FOR SOUTHERN EUROPE

The building defined as a reference for Southern Europe has the characteristics of a new nearly Zero Energy Building (nZEB) multi-family building. A real building was taken as a reference for the base case. This building has been newly built in Santurtzi (Spain), and it is a reference in the H2020 AZEB project [5]. Its main features are the following:

- 32 dwellings (divided in 4 floors + ground floor + 1 semi-basement)
- 32 storage rooms in basement -1
- 14 parking spots in basement -2
- 18 parking spots in basement -3
- 2885.5 m^2 gross floor area
- 2397.87 m^2 heated/cooled floor area
- 73.79 m^2 average dwelling net floor area

Figure 11. Reference multi-family building for Southern Europe

The **U-values** of the main constructive elements are the following:

- **Windows:** 1.09 – 1.18 W/(m^2K)
- **Façade:** 0.23 W/(m^2K)
- **Wall to dwelling:** 0.29 W/(m^2K)
- **Wall to stairs:** 0.41 W/(m^2K)
- **Ceiling to dwelling:** 0.62 W/(m^2K)
- **Roof:** 0.23 W/(m^2K)

The selected value for **infiltrations**, considering that the base case is a new low-energy building, is set at 0.05 ACPH (air changes per hour).

The rest of parameters, which are more related to the usage, are set to typical values, meeting the requirements stablished by local regulations (in this case, by the Spanish "Código Técnico de la Edificación", CTE [6]).

Mechanical ventilation is on continuously during the whole year, in order to ensure good indoor air quality, as required by CTE [6]. A heat recovery system is included to increase the efficiency of the building and keep energy demand low.

Natural ventilation is set at 4 ACPH, from 1 h to 8 h, from June to September (inclusive), as defined in the usage profile established by the CTE [6]. It represents the ventilation caused by opening windows during nighttime in the summer.

The aforementioned usage profile also defines the **thermal loads** caused by occupants, appliances and lighting as follows:

Table 2. Usage profile and associated thermal loads

Residential use		24h profile						
		1-7	8	9-15	16-18	19	20-23	24
Occupation – sensible heat (W/m^2)	Weekdays	2.15	0.54	0.54	1.08	1.08	1.08	2,15
	Weekends and holidays	2.15	2.15	2.15	2.15	2.15	2.15	2,15
Occupation – sensible heat (W/m^2)	Weekdays	1.36	0.34	0.34	0.68	0.68	0.68	1,36
	Weekends and holidays	1.36	1.36	1.36	1.36	1.36	1.36	1,36
Lighting (W/m^2)		0.44	1.32	1.32	1.32	2.20	4.40	2.20
Appliances (W/m^2)		0.44	1.32	1.32	1.32	2.20	4.40	2.20

Occupancy is set to 2.7 inhabitants per dwelling, according to reference data from SECH-SPAHOUSEC [7] corresponding to multi-family buildings in Spain.

Regarding heating/cooling systems **temperature setpoints**, the following profiles are defined:

- Heating mode - Winter set points (October to May): 18 ºC during night (24-7) / 21 ºC during day (8-23)
- Cooling mode - Summer set points (June to September): 26.5 ºC (9-24)

The nZEB building described above corresponds to a DHW dominant scenario, since its heating / cooling demands are low due to proper insulation, heat recovery system, etc., as evidenced by the specified values. Based on that scenario, a new set of parameters was defined by modifying some relevant variables in order to reproduce the characteristics of an older building, so as to obtain a SH/SC dominant scenario. The modifications that led to such scenario are the following:

The **U-values** of the main constructive elements were set according to reference data [8] for a building built between 1975 and 1990 (SH/SC dominant scenario):

- **Windows:** 4.20 $W/(m^2K)$
- **Façade:** 1.20 $W/(m^2K)$
- **Floor:** 0.80 $W/(m^2K)$
- **Roof:** 0.80 $W/(m^2K)$

- **Wall between dwellings**: 2.2 W/(m^2K)
- **Wall between dwellings and corridors:** 2.5 W/(m^2K)
- **Floor between dwellings and garages/storage rooms/hall:** 1.3 W/(m^2K)

Likewise, window solar factor was increased to 0.7, which is a realistic value for an older building.

Additionally, **mechanical ventilation** was set to zero, as older buildings did not include such systems.

On the contrary, a combined value for **infiltrations + ventilation** was set to 0.7 ACPH.

4. METHODOLOGY FOR ENERGY DEMAND CALCULATION

In all cases, energy demands were calculated based on all the parameters corresponding to each case, as well as the assumptions and hypothesis defined in the previous section. However, the energy simulation software used was different for each kind of demand.

For the heating and cooling demand of Central and Northern European reference case, the building simulation software IDA ICE v.4.8 was used. The simulations were done with climate data of Zurich, Switzerland and under the assumptions of ideal heaters. A detailed 3D-model of the building that incorporates all the boundary conditions and building characteristics defined above was implemented for the simulation. The use of IDA ICE allows to take into account detailed phenomena of the energy balance in the building such as partial window shading due to balconies or heat bridges in the building structure.

The electricity as well as the hot water consumption profile for the Central and Northern Europe was defined using the software LoadProfileGenerator [9]. The LoadProfileGenerator uses households that consist of archetype users to construct a yearly load profile. The consumption profiles together with the building occupancy are coherent from each other. Due to constraints in the profile import of IDA ICE only a single reference day profile for weekdays as well as weekends could be used.

On the other hand, for the reference case corresponding to Southern Europe, DesignBuilder was used. DesignBuilder is a simulation software aimed principally at building design and assessment. It offers additional functionalities allowing detailed parameter specification (e.g. detailed HVAC design) and comprehensive simulation results.

First, the Southern European reference multi-family building was “drawn” in the core 3-D modeler, as shown in **Figure 12**:

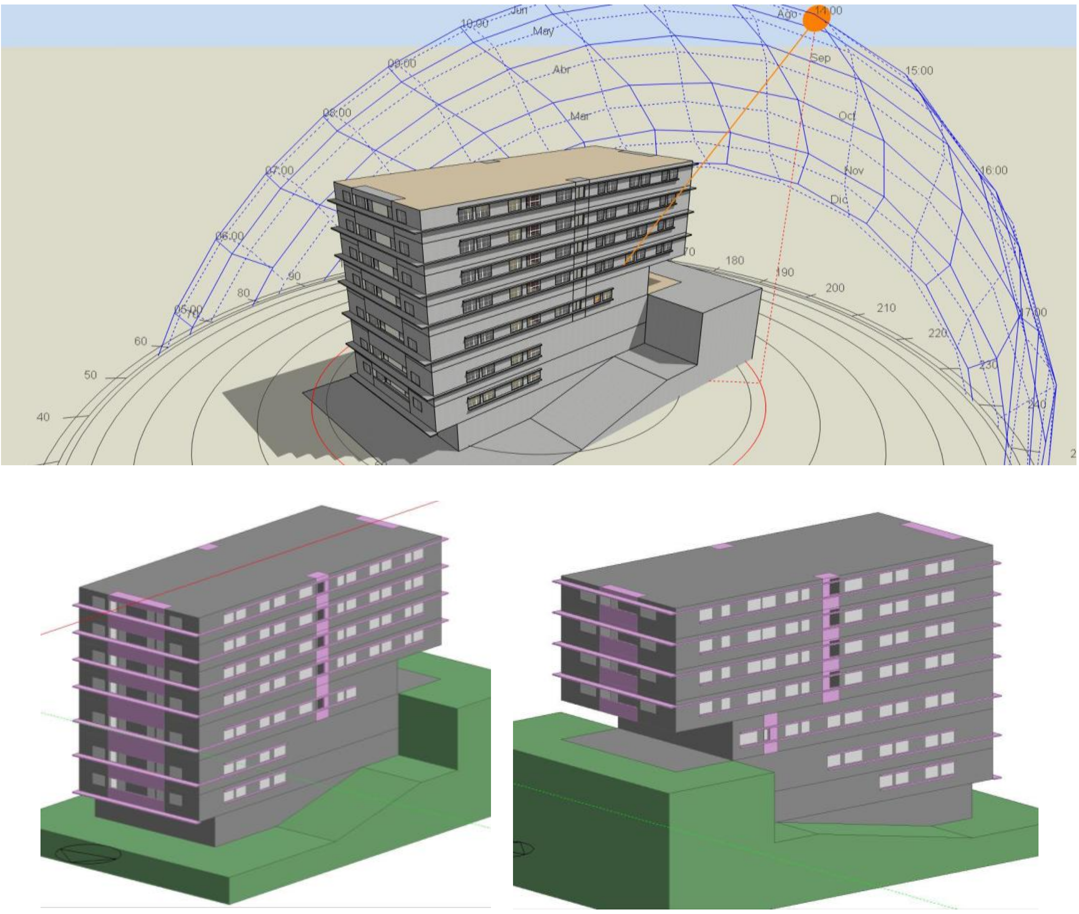

Figure 12. Southern Europe reference case representation in DesignBuilder

At this building modelling stage, all the constructive elements were defined taking into account their U-value, according to the data stated in the previous section.

As the goal with this software is to calculate the space heating and cooling demands. Relevant parameters besides the U-values that need to be defined are:

- Location (and associated parameters such as climate zone)
- Occupancy
- Temperature setpoints for both the heating and cooling systems
- Heating and cooling system working hours
- Appliance usage profile
- Infiltrations
- Mechanical ventilation (and heat recovery efficiency)
- Natural ventilation rate and profile

All the relevant parameters were adjusted accordingly for each simulated case. Those parameters are the inputs for the energy simulations that are carried out by means of EnergyPlus simulation engine. Energy plus is tightly integrated within DesignBuilder (which provides the user interface) and performs all the thermal calculations to obtain the resulting heating and cooling loads.

Several parameters were selected as output for comparison and validation purposes. The outputs of all the simulated cases were compiled in a spreadsheet and analyzed in detail. Once the outputs were validated by comparing them with the ones obtained through other simulation tools (e.g. Herramienta Unificada LIDER- CALENER, "HULC" [10]) heating and cooling demands were selected as the main results. They are shown in the following section 5.

As for the DHW demand calculation, the software DHWCalc v2.0 [11] was used. This program distributes DHW draw-offs throughout the year with statistical means, according to a probability function. Reference conditions for the draw-offs (flow rates, draw-off periods, etc.) and reference conditions for the probability function (daily probabilities for draw-offs etc.), can be set by the user, as well as general profile parameters like time step period and mean daily draw-off volume. The program can be downloaded free of charge at the web page of the University of Kassel.

Finally, electricity demand was estimated by means of a stochastic electricity profile generator developed by IREC. This model relies on two main sources of information, the Spanish Time Use Data (TUD) and the SECH-SPAHOUSEC study [7].

The TUD survey is a harmonized European survey that describes what people are doing during the day. The TUD used to develop the model was carried out in 2009-2010 in Spain by the Spanish Statistical Office. It is made out of 19,295 participants living in total of 9,541 dwellings. Respondents were asked to document their daily activities within 10 minutes intervals.

The SECH-SPAHOUSEC project characterizes the energy consumption of the residential sector in Spain, including detailed information about the equipment stock and the main energy uses.

Based on the TUD, the model stochastically establishes in a 10 minutes interval the number of occupants in each dwelling, as well as the activities undertaken (if any). Each activity has a probability duration (quantified based on literature review) and an associated use of equipment. The availability and the power consumption of each electrical device for a dwelling is based on the information taken from the SECH-SPAHOUSEC study and other sources. **Figure 13** shows the workflow of the electric load generator used.

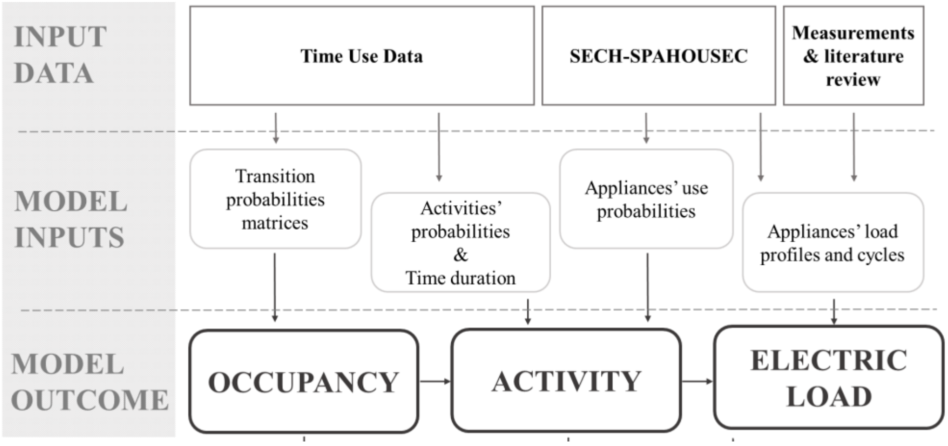

Figure 13. Overview of the stochastic electric load generator. Source: IREC

5. RESULTS. ENERGY DEMANDS

This section collects the energy demand results obtained from the previously described calculation process.

5.1 ENERGY DEMANDS FOR THE CASES DEFINED IN CENTRAL AND NORTHERN EUROPE

For the chosen reference location of Zurich the MFB30 showed a calculated heating demand of 36 270 kWh/year which corresponds to 30.1 kWh/(m^2,year). The detailed monthly heat balance is shown in Figure 14. It can be seen that due to assumed window opening behavior that starts in April the heating demand in April exceeds the one from March. In addition, the defined building showed only a very small cooling demand in summer for Zurich.

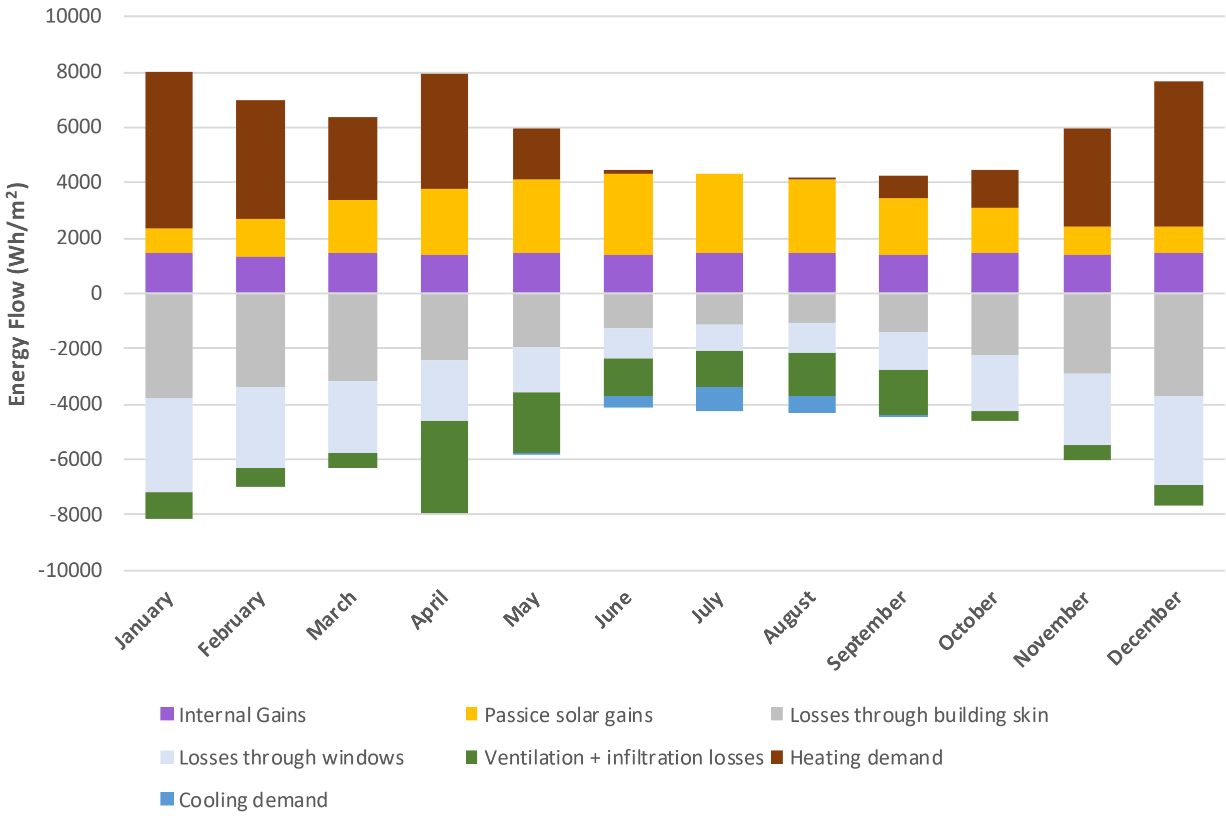

Figure 14. Monthly energy (heat) balance corresponding to the MFB30 defined for Central and Northern Europe in Cfb climate (Zürich)

Monthly energy demands of MFB90 are shown in Figure 15. The older building showed an increased heating demand of 104 594 kWh/year which corresponds to 86.8 kWh/(m^2year). Due to the generally higher heating demand, the effect of the window opening behavior is less pronounced in the old building. Like in the MFB30, the MFB90 has only negligible cooling demands in Zurich.

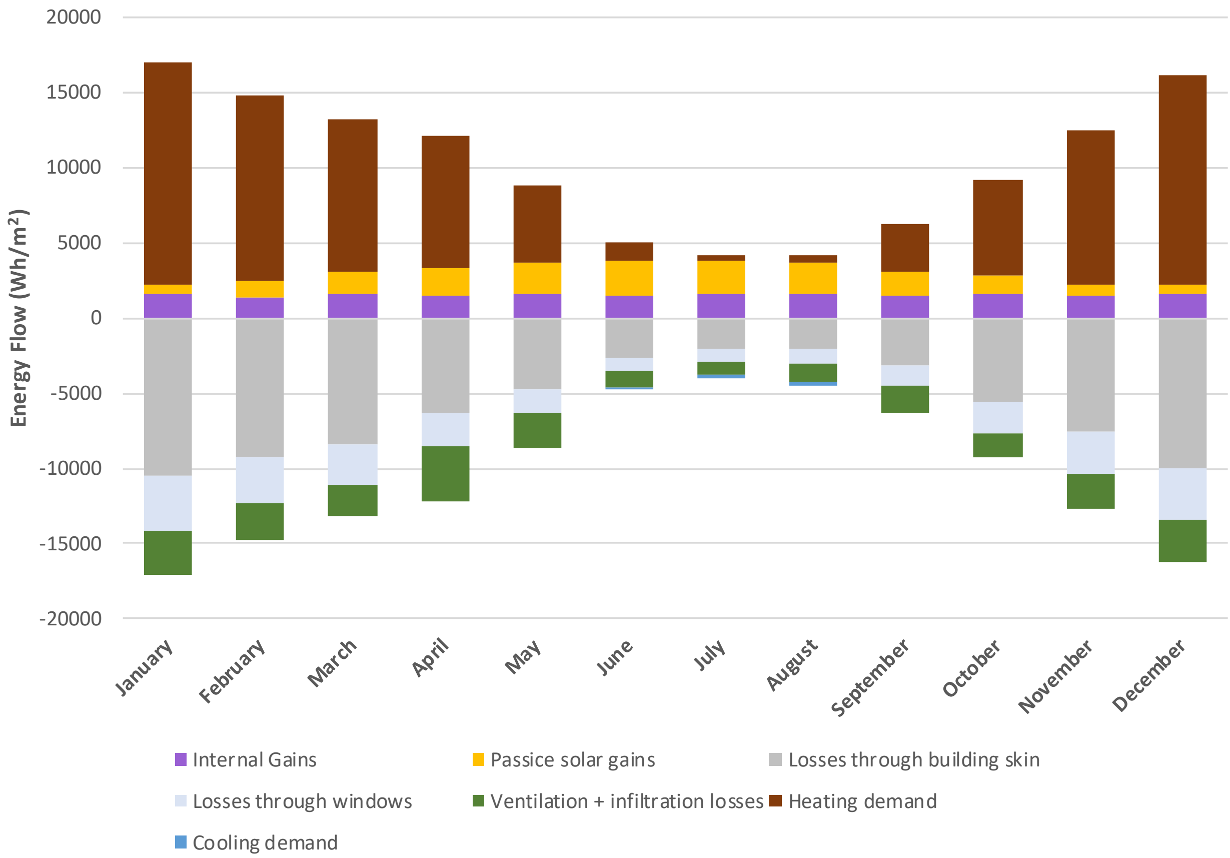

Figure 15. Monthly energy (heat) balance corresponding to the old case multi-family building defined for Central and Northern Europe in Cfb climate (Zürich)

Results for the base case building in the climatic conditions in Locarno are shown in Figure 16. In comparison to Zurich, due to the warmer and more sunny weather in Locarno, the building has a lower heating demand of 16.9 kWh/m^2 and a higher cooling demand of 7.1 kWh/m^2.

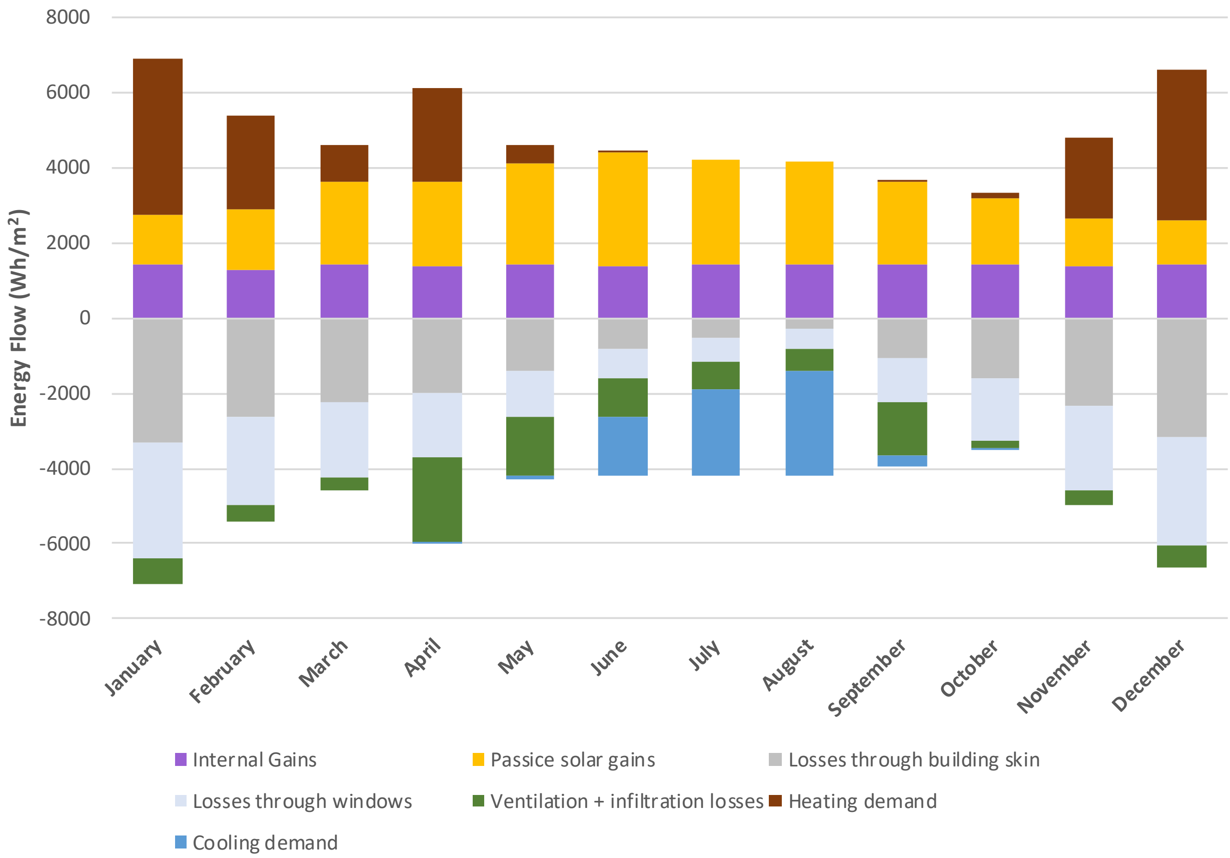

Figure 16. Monthly energy (heat) balance corresponding to the base case multi family building defined for Central and Northern Europe in Cfb/Cfa climate (Locarno)

The reference days for the demand profiles of domestic hot water were chosen such that the resulting yearly average consumption of domestic hot water is close to an average defined in Swiss standards of 45 liters per person and day [15]. Equivalently, the electricity profile is in agreement with a study that analyzed monitoring data and showed an average yearly electricity consumption of 2622 kWh per household for buildings of similar characteristics [12]. The detailed consumption per household can be found in Table 3. Domestic hot water consumption is the same in both the base case building and the old building. The 17 380 kWh heat demand for domestic hot water is 32.5 % of the total heat demand of the MFB30 and 14.3 % of the total heat demand of the MFB90.

Table 3. Domestic hot water and electricity consumption in the base case building using the LoadProfileGenerator. Household profile explained at the end of Annex 1.

Household profile	Number of persons in household	Daily water consumption at 60°C [l/pd]	Electricity consumption of appliances [kWh/year]
CHR33	2	46.0	2278
CHR44	4	47.2	3520
CHR27	4	36	2963
CHS04	2	56.0	1972
CHR55	2	62.3	2397
CHR18	4	39.7	3034
Total	18	287.2 (17380 kWh/y)	16164

5.2 Energy demands for the cases defined in Southern Europe

Within the heating and cooling demand values, there is an evident difference between the new and old building simulation results. For instance, in the case of Cfb climatic zone, represented by Bilbao, even if it is a heating dominant climate, it can be observed that the resulting heating (and cooling) demands are very low, as shown in **Figure 17**. In fact, this is a DHW dominant scenario.

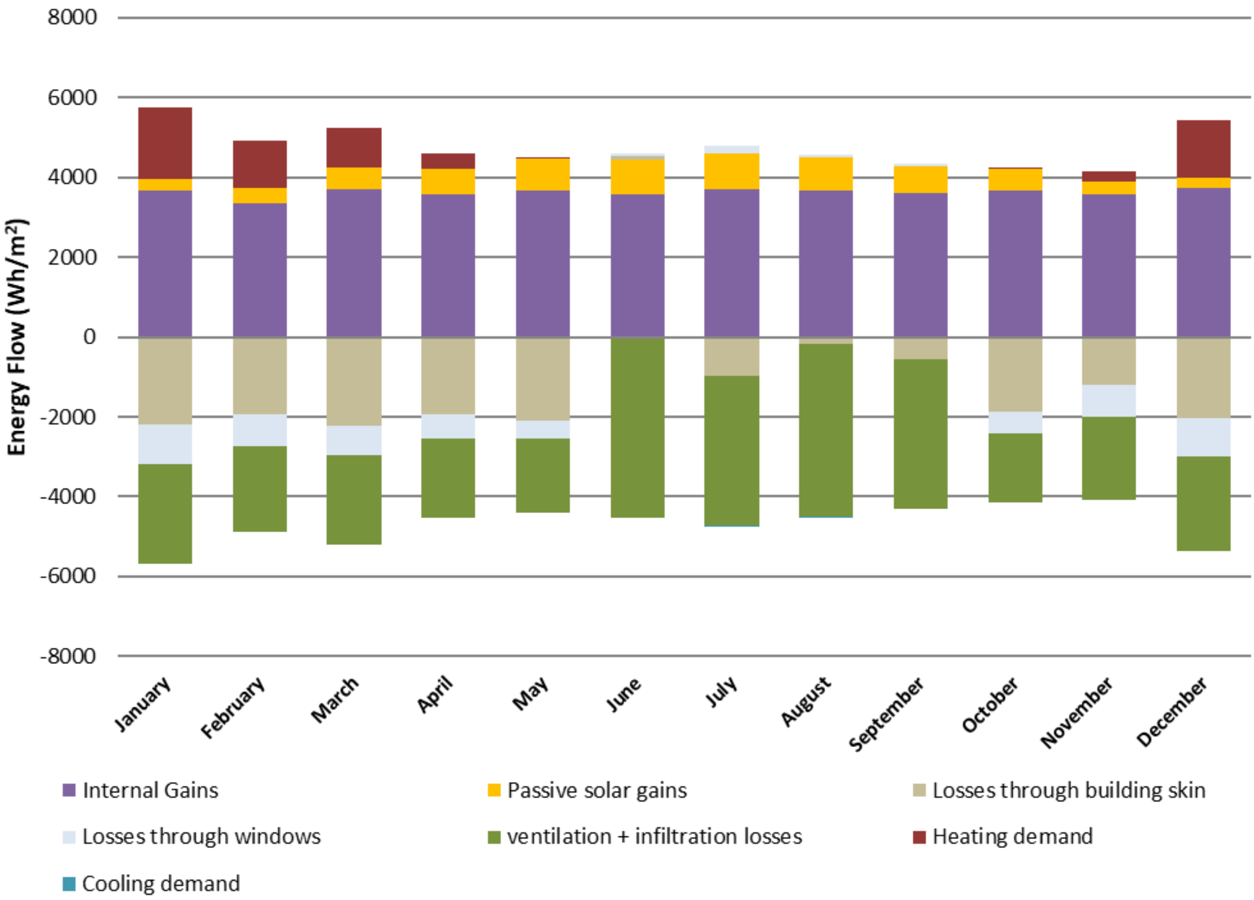

Figure 17. Monthly heating and cooling demand corresponding to a new nZEB building in Cfb climate (Bilbao)

As for the older building, it can be observed (see **Figure 18**) that the heating demand is notably higher compared to the one corresponding to the new nZEB. In this case, the difference between heating and cooling demand is also greater, being the latter negligible. This is a clear example of SH dominant scenario.

The difference is clear when aggregated yearly totals are compared: the new low-energy building reference case has a very low heating demand of 6.02 kWh/m^2 or 14 442.66 kWh, while the older building has a much more considerable heat demand of 59.81 kWh/m^2, equivalent to 143 413 kWh in Bilbao.

Cooling results are almost negligible: 0.029 kWh/m^2 (71.18 kWh) for the new building and 200.6 kWh/m^2 (481 kWh) for the old one. This can be clearly observed in **Figure 17** and **Figure 18**, in which cooling demand is almost unnoticeable.

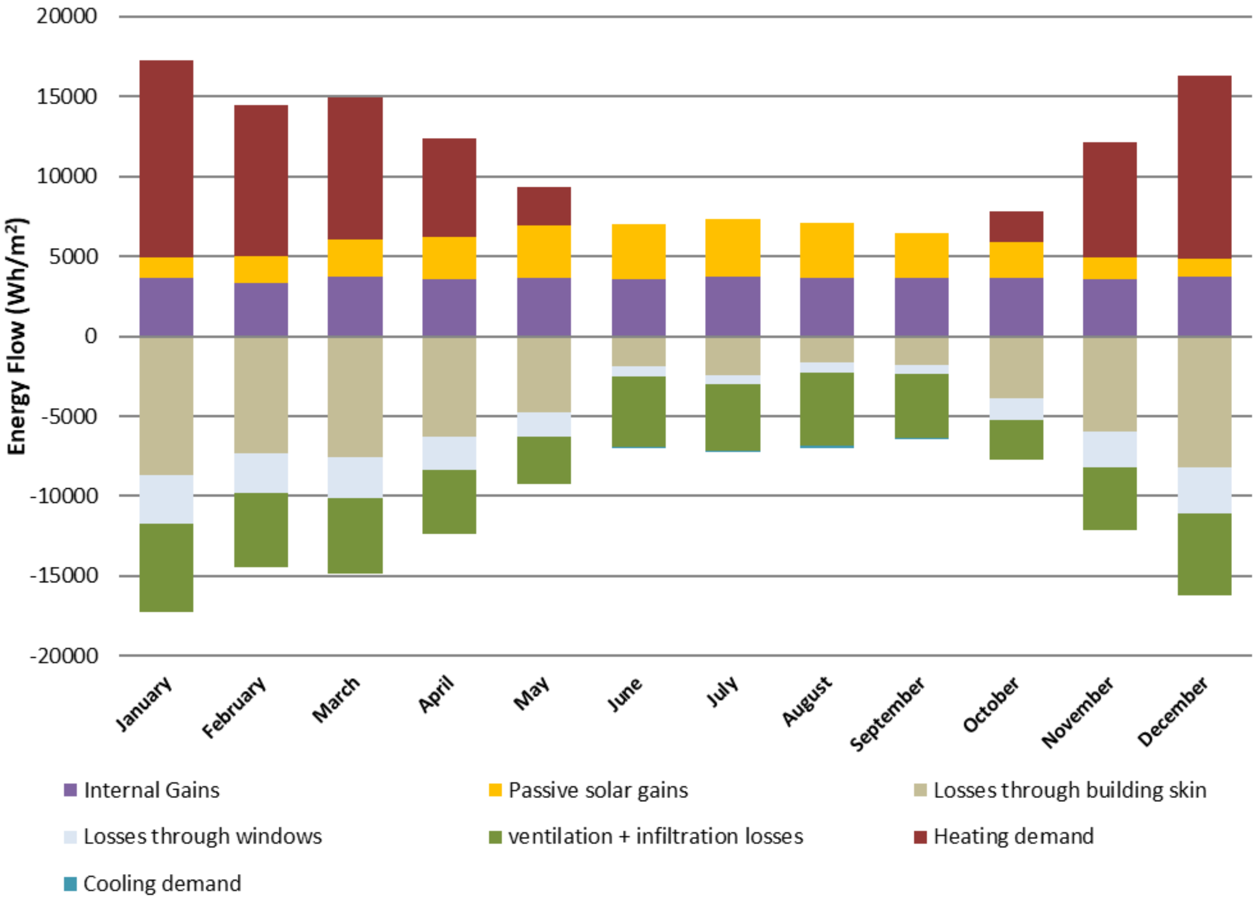

Figure 18. Monthly heating and cooling demand corresponding to an older (1975-1990) building in Cfb climate (Bilbao)

Similarly, the results for Tarragona, as a location representative of hot-summer Mediterranean climate (Csa), are the following:

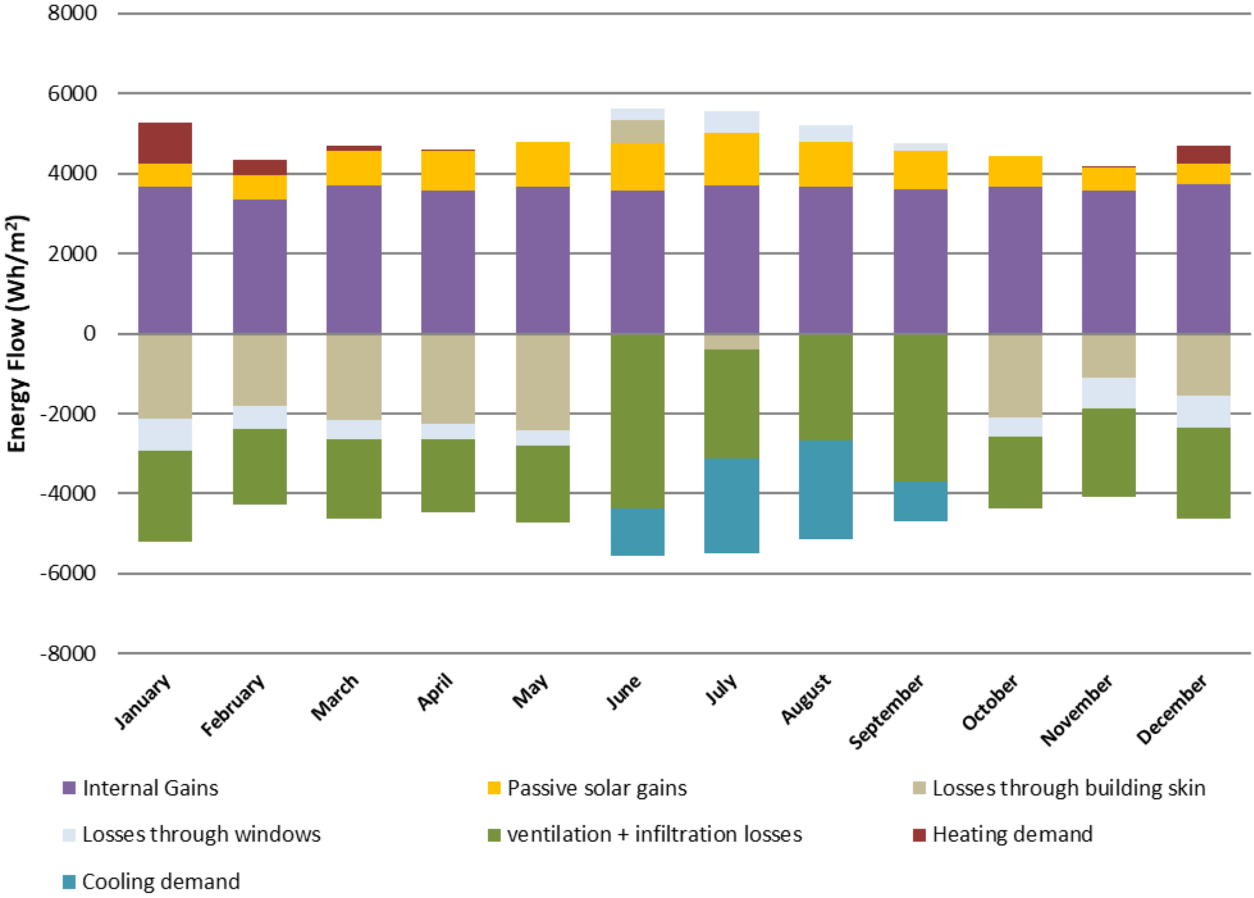

Figure 19. Monthly heating and cooling demand corresponding to a new nZEB building in hot-summer Mediterranean climate (Csa), (Tarragona)

Figure 19 shows clearly the importance of cooling demand, which in the new building is clearly greater than heating demand. This cooling dominance is typical of Southern European warm climates.

As for the older building (see **Figure 20**), even if the absolute cooling demand is higher than in the new low-energy building, it can be seen that, comparatively, the heating demand is even higher. The poor insulation has a big impact in the energy demand during winter and the infiltrations and additional ventilation during summer leads to a relatively not-so-high cooling demand.

In this case, total (annual) heating and cooling demands for the new building are, respectively, 1.96 kWh/m^2 (negligible) and 6.98 kWh/m^2 (comparatively much higher, but not large in absolute terms).
For the old building, heating demand is 33.63 kWh/m^2 (noticeably higher, as explained before) and cooling demand 12.57 kWh/m^2, higher than that in the new building in absolute terms, but lower compared to the heating demand.

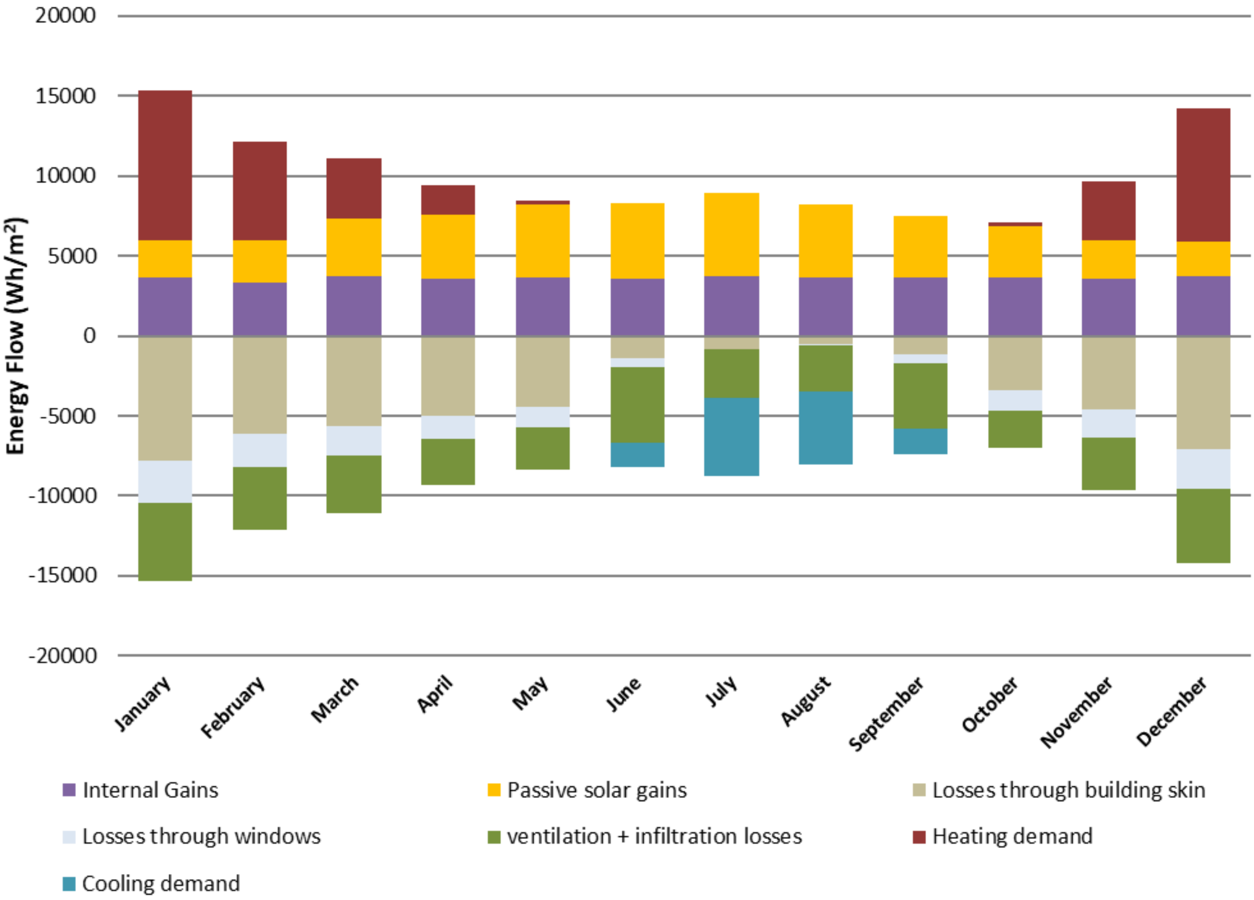

Figure 20. Monthly heating and cooling demand corresponding to an older (1975-1990) building in hot-summer Mediterranean climate (Csa), (Tarragona)

Regarding electricity demand, the electric load generator by IREC yields a global energy consumption for the whole building of 75.48 MWh yearly, which correspond exclusively to domestic appliances and lighting. This is equivalent to a demand of 2 358 kWh/year per flat, which is in line with the reference value of SECH-SPAHOUSEC

[7] for buildings of the same type and climate region (2 251 kWh/year) as well as similar to the demands obtained for Central and Northern Europe (2 694 kWh/year). The stochastic nature of the model describes the instantaneous power demand properly, while maintaining the hourly distribution of the demand in plausible values. **Figure 21** shows the electric demand distribution constructed both for a summer and a winter day.

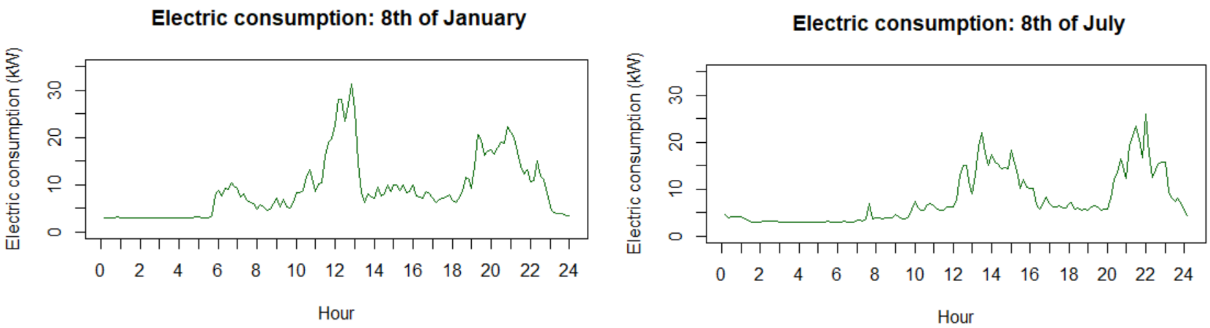

Figure 21. Example electric profile for a winter and summer day

Concerning DHW demand, the resulting load is in accordance with the reference value foreseen at the Spanish regulation (CTE [6]). Besides, the seasonal distribution follows the pattern described in the scientific literature [13], which is relevant due the variations of system performance under varying environmental conditions; **Figure 22** shows the mean daily consumption in monthly basis.

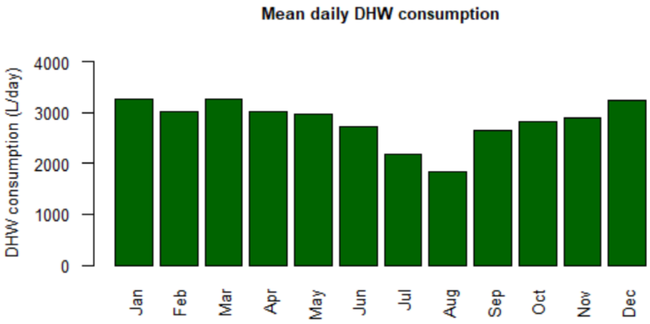

Figure 22. Monthly distribution of DHW consumption

Besides the volume of hot water requested, the temperature of the water network and the consumption temperature of the DHW are relevant parameters when determining the DHW load on energy basis. For the cold water temperature, again, data from the Spanish Building Code (CTE, [6]) for the Bilbao region is used and the consumption temperature is set to 45 ºC. **Table 4** shows the resulting load data in monthly basis.

Table 4. Summary of DHW demand results

	DHW load (Liters)	Cold water temp (ºC)	DHW load (kWh)
January	98110	9	4100.9
February	90503	10	3677.9
March	97974	10	3981.6
April	90790	11	3584.2
May	88925	13	3304.1
June	81462	15	2837.6
July	65365	17	2125.1
August	55449	17	1802.7
September	79834	16	2688.2
October	84583	14	3044.5
November	86594	11	3418.6
December	96931	10	3939.2

The resulting yearly total DHW load value is thus 38 504.6 kWh/year (16.1 kWh/m^{2}year). In order to visualize the relevance of this value within the overall heat generation needs (DHW + SH) a comparison with the SH demand is done in **Table 5**, taking as a reference the Bilbao reference case (Cfb climate zone):

Table 5. DHW vs Space heating (SH) demand

Building Type	DHW demand (kWh/m^{2}year)	SH demand (kWh/m^{2}year)	DHW demand (%)	SH demand (%)
New (nZEB)	16.1	6.0	72.8	27.2
Old (built within 1975-1990)	16.1	59.8	21.2	78.8

The difference is clear: the new low-energy building has a very low space heating demand, and thus the DHW generation is relatively much bigger. Hence, it is a DHW-dominant case.
On the contrary, the older building has the same DHW demand, but a much bigger space heating demand due to poor insulation. Therefore, it is a SH-dominated case.

Another characteristic of the developed DHW load is the stochasticity of the profiles, which allows for a proper characterization of not just of the overall energy demand but also of the instantaneous (peak) loads, which is a fundamental element in the sizing of the system, hence it's characterization as well. **Figure 23** shows the generated DHW profile for two different days, one in winter and another in summer. As can be seen, the results follow a more or less predictable pattern, with higher consumption early in the morning, but with high chopping in the profile due to the uncertain result of the superposition of the consumption of many apartments.

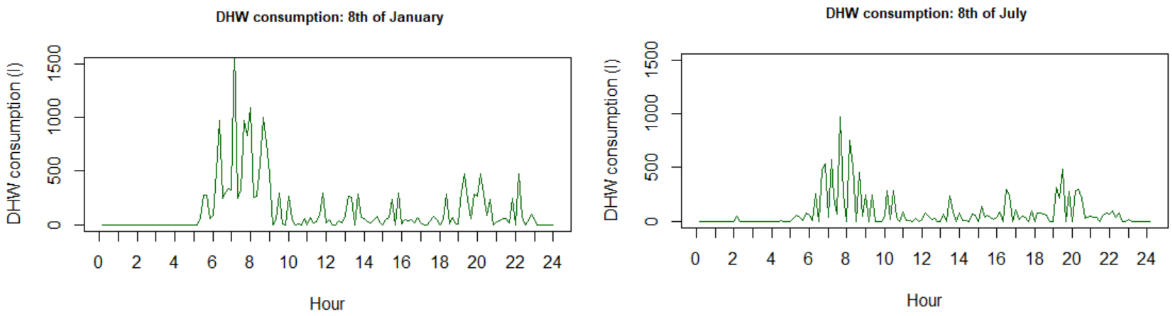

Figure 23. Example of daily profiles of DHW consumption, winter (left) and summer (right)

6. DEFINITION OF DESIGN CONDITIONS FOR THE HEAT PUMPS

In this section a first definition of the design conditions for the heat pumps to be developed in WP5 is presented. Taking into account the particularities in each of the cases (ice-slurry system and dual-source system), the heat source/sink temperatures have been decided. These values have been selected taking into account the nominal conditions at which the heat pumps are tested, according to the Standard EN 14511-2 [14].

Also, the design conditions of the produced hot/cold water have been selected, taking into account the most probable heat distributor system. For the space conditioning, the return and produced water temperatures of the heat distribution system are based on the Standard EN 14511 [14]:

- Low temperature: 30/35 ºC
- Medium temperature: 40/45 ºC
- High temperature: 47/55 ºC
- Very high temperature: 55/65 ºC

And for cooling:

- Low temperature: 23/18 ºC
- Medium temperature: 12/7 ºC

It is expected that for new buildings the hot and/or cold water emitters will be selected taking into account the maximum energy efficiency, e.g. lower hot water temperature generation when in heating mode. In that case, radiant systems will have the lowest temperature, which corresponds to the low temperature mode 30/35 ºC. However, for systems in which heating and cooling has to be delivered, fan coils could be a good option as well, even working at higher temperatures in the case of heating, equivalent to the medium temperature mode (40/45 ºC). Fan coils can as well provide cooling water at 7ºC and deal with latent heat, without the risk of having condensations such as in a cooling radiant system, which depending on the conditions could not be the most appropriate option. On the other hand, high temperature and very high temperature modes, corresponding to medium/high temperature radiators, have been discarded.

Taking into account all this, the most unfavorable conditions among both best possible options (low temperature and medium temperature) have been selected for the generation of hot and cold water temperatures.

In the case of Domestic Hot Water generation, the design temperature is set to 70 ºC aiming to achieve the highest possible temperature, taking into account the heat pump will work with propane and technically it is possible to achieve such temperatures. There are several propane heat pump manufacturers which claim to reach 70 ºC for heating water. This has been identified in the analysis of the State-of-the-art that has been carried out in WP 5. Also, in the scope of Task 1.3, an analysis of DHW generation requirements has been carried out, taking into account important aspects for the hydraulic layouts such as the need of a recirculation loop, or safety aspects related to the prevention of Legionella growth. This information will be included in D1.3.

6.1 ICE-SLURRY HEAT PUMPS

Ice-slurry heat pumps are intended to operate without reversibility in the refrigerant side, i.e. without a 4-way valve. Thus, the condenser/desuperheater (propane) or gas cooler (CO_2) will reject heat to the water loop(s), and this heat could be used (heating/DHW modes) or just rejected to the ambient (cooling mode). The same happens with the evaporator, which cools down the water loop (potentially ice-slurry). Considering this, the reference design temperatures have been considered for the propane-ice and CO_2-ice heat pumps.

<u>PROPANE-ICE HEAT PUMP</u>

A summary of the design reference temperatures for the propane-ice heat pump is shown in **Table 6**. These values have been selected considering the nominal conditions at which the heat pumps are tested, according to the Standard EN 14511-2 [14]. Propane-ice heat pumps are intended for new and refurbished buildings where heating is the main need.

Table 6. Reference design conditions for the propane-ice heat pump.

Heat exchanger	Operation mode	Temperature (ºC) Return to HP / Supply from HP
Evaporator	Heating	0 / -3
	Cooling	12 / 7
Condenser	Heating	40 / 45
	Cooling	35 / 40
Desuperheater	DHW	70

From space conditioning point of view, a medium temperature system selection was considered both for heating and cooling, according to the classification in Standard EN 14511 [14]. Thus, we talk about:

- Return/supply water temperatures at the condenser in heating mode equal to 40/45 ºC.
- Return/supply water temperatures at the evaporator in cooling mode equal to 12/7 ºC.

The heat source design temperatures in heating mode (at the evaporator/supercooler) are the most unfavorable. For ice slurry-based systems, this means that there is an ice-slurry/water mixture in the ice-slurry tank at 0 ºC, and the water is supercooled up to -3 ºC.

The heat sink design temperatures in cooling mode (at the condenser) have been selected as 35/40 ºC (water loop). These temperatures are realistic for locations where heating is the basic need.

In the case of DHW generation, the design temperature is set to 70ºC, which is possible with propane as refrigerant.

CO_2-ICE HEAT PUMP

A summary of the design reference temperatures for the CO_2-ice heat pump is shown in **Table 7**. These values have been selected considering the nominal conditions at which the heat pumps are tested, according to the Standard EN 14511-2 [14]. CO2-ice heat pumps are intended for new buildings where DHW is the main need.

Table 7. Reference design conditions for the CO_2-ice heat pump.

Heat exchanger	Operation mode	Temperature (ºC) Return to HP / Supply from HP
Evaporator	Heating	0 / -3
	Cooling	12 / 7
	Heating	30 / 35
Gas Cooler	Cooling	35 / 40
	DHW	70

From space conditioning point of view, a low temperature system was considered for heating at gas cooler, i.e. return/supply water temperature at the gas cooler in heating mode equal to 30/35 ºC. For the cooling mode, temperatures corresponding to medium temperature system were chosen, i.e. return/supply water temperatures at the evaporator in cooling mode equal to 12/7 ºC. This difference, low temperature system for heating mode, medium temperature system for cooling mode, is justified because cooling is not the main objective of CO_2-ice heat pumps, and the most unfavorable conditions have been selected to be on the safe side.

The heat source design temperatures in heating mode (at the evaporator/supercooler) have been considered as for the propane-ice heat pump, i.e. return/supply temperatures equal to 0/-3 ºC. The same with the heat sink design temperatures in cooling mode (at the gas cooler), with return/supply temperatures equal to 35/40 ºC (water loop). In the case of DHW generation, the design temperature is set to 70 ºC, which is a value relatively easy to achieve with CO_2 transcritical heat pumps.

6.2 DUAL-SOURCE HEAT PUMP

For the dual-source heat pump, reference temperatures for the external heat exchanger have been selected. The two possible sources/sinks have been taken into account (ground and air), for the two working modes (heating or cooling mode).

In the case of ground source, the value of 0/-3 is taken as the most unfavorable condition, from the point of view of the dimensioning of geothermal systems. These need to be sized with the aim not to reach a temperature lower than 0 ºC in the ground in order to avoid permafrost formation, over the expected life span of 25 years of the system. The same design conditions are taken for the heat pump, which correspond as well to the nominal point for testing brine-water systems in Standard EN14511.

In the case of air source, the nominal values of the Standard EN14511 for testing the heat pumps are taken as a reference as well. A more unfavorable condition could have been chosen for air source, but taking into account the dual nature of the heat pump it is considered that when there is a lower air temperature the mode of the heat pump is going to switch to the use of the ground source. For that reason, a milder air temperature is chosen as the design point.

A summary of the design reference temperatures is shown in **Table 8**.

Table 8. Reference design conditions for the dual-source heat pump.

Heat exchanger	Source	Operation mode	Temperature (ºC) Inlet to HP / Outlet from HP
External heat exchanger	Ground	Heating	0 / -3
		Cooling	25 / 30
	Air	Heating	7
		Cooling	35
Space conditioning heat exchanger		Heating	40 / 45
		Cooling	12 / 7
Desuperheater		DHW	70

From space conditioning point of view, a medium temperature system selection was considered both for heating and cooling, according to the classification in Standard EN 14511 [14]. Thus, we talk about:

- Return/supply water temperatures at the condenser in heating mode equal to 40/45 ºC.
- Return/supply water temperatures at the evaporator in cooling mode equal to 12/7 ºC.

In the case of DHW generation, the design temperature is set to 70 ºC, which is possible with propane as refrigerant.

8. CONCLUSIONS

The work carried out in this task led to obtaining a comprehensive set of energy demand data corresponding to average multi-family buildings in different locations and climates. Heating, cooling, domestic hot water and electricity demand were calculated.

Different simulation tools were utilized for the calculation of the different demands, but the obtained results were consistent with the expected values for each case. For example, it was observed that the obtained DHW demand was noticeably higher than the heating/cooling demand for the case of new buildings located in Spain, which is in line with the excellent insulation of low-energy buildings. In Central and Northern Europe, the shares of DHW for low-energy building are significant, but not necessarily dominant.

The energy simulation models allowed to replicate a great variety of conditions, which led to calculated demands representative of an important share of buildings in Europe. These sets of data represent the base for the future simulations of the whole system that will aid the design of the new heat pump concepts proposed within the project. Moreover, inputs are defined also for the extrapolation of the systems to various locations.

Finally, the reference design conditions were defined for each system. Essentially, nominal temperatures were stablished according to the particularities of each concept and complying with regulating standards.

All this work is the basis for future simulations and concept design that will result in the achievement of the project goals.

REFERENCES

[1] Peel, M. C., Finlayson, B. L., and McMahon, T. A.: Updated world map of the Köppen-Geiger climate classification, Hydrol. Earth Syst. Sci., 11, 1633-1644, https://doi.org/10.5194/hess-11-1633-2007, 2007.

[2] Beck, H.E., N.E. Zimmermann, T.R. McVicar, N. Vergopolan, A. Berg, E.F. Wood: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018).

[3] Anwendungshilfe zu den Gebäudestandards Minergie/Minergie-P/Minergie-A, (2019). https://www.minergie.ch/media/190103_anwendungshilfe_minergie_p_a_v2019.1_de.pdf (accessed August 14, 2019).

[4] I. Mojic, M. Luzzatto, M. Haller, M. Lehmann, M. Benz, S. Van Velsen, ImmoGap - Einfluss der Kombination aus Nutzerverhalten und Gebäudetechnik auf den Performance Gap bei Mehrfamilienhäuser, SPF Institut für Solartechnik, HSR Hochschule für Technik Rapperswil, 2018.

[5] AZEB (Affordable Zero Energy Buildings) project, grant agreement No 754174, https://azeb.eu/

[6] Código Técnico de la Edificación (CTE), according to "Ley 8/2013", Ministerio de Fomento, Gobierno de España, 2013

[7] Análisis del consumo energético del sector residencial en España. SECH-SPAHOUSEC Project. IDAE / Ministerio de Industria, Energía y Turismo – Gobierno de España, 2011

[8] Mitigation of CO2 Emissions from the Building Stock - Beyond the EU Directive on the Energy Performance of Buildings, ECOFYS, 2004.

[9] Pflugradt N. Load Profile Generator. Chemnitz: Technical University Chemnitz; 2014.

[10] Herramienta Unificada LIDER-CALENER v 1.0.1564.1124, IDAE / Ministerio de Fomento, Gobierno de España, 2017

[11] DHWcalc: Program to generate domestic hot water profiles with statistical means for user defined conditions, ISES World Congress, Orlando, 2005. Jordan, U. and Vajen, K.

[12] SIA Merkblatt 2024: Standard-Nutzungsbedingungen für die Energie- und Gebäudetechnik", Schweizerischer Ingenieur- und Architektenverein, 2015

[13] A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis, Fuentes, E., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.05.229

[14] EN 14511-2: Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors - Part 2: Test conditions.

[15] SIA 385/2 „Anlagen für Trinkwarmwasser in Gebäuden – Grundlagen und Anforderungen", Schweizerischer Ingenieur- und Architektenverein, 2015.

Annex 1: Central and Northern European reference building description

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FHO Fachhochschule Ostschweiz

Annex 1: Central and Northern European reference building description

Reference Framework for Building and System Simulations:

Multifamily Reference Building

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Abstract

This section describes two different reference multifamily buildings (MFB) for the application in simulation tasks. Both buildings share the same geometry, the main difference is the insulation standard and the ventilation. The buildings are named MFB30 and MFB90 according to their heat load (30 kWh/m^2 and 90 kWh/m^2) for Zurich.

MFB30 represents an actual building which fits the Swiss Minergie-Standard with an envelope with high energetic quality. This building could be used as nearly zero energy building (nZEB) for the most European countries.

MFB90 represents two cases: a non renovated existing building from the year 1980-1990, or an older building (1950-1980) which is renovated.

The goal of this reference building description is to provide a simple basis for the comparison of different HVAC system solutions in Switzerland or countries with a similar building stock. These reference buildings can be implemented in several simulation platforms. The buildings contain six apartments with total four stories. The main building specifications are:

	MFB30	MFB90	
Energy reference area (ERA)	1'205	1'169	m^2
Net floor area (NFA)	1018	1026	m^2
Window ratio to ERA	24.7%	14.3%	
Shape factor	1.3	1.14	
Ventilation	mechanical (η = 80%)	fixed infiltration	

Different inhabitant profiles for the six apartments were defined, in total 18 inhabitants were assumed. The electrical profile corresponds to the internal load profiles and the occupancy of the apartments. There are no profiles for the electrical use of the heating and ventilation system. In addition, a domestic hot water demand was defined which is synchronized with the electrical and occupancy profiles. All profiles are provided as additional text files in one minute time steps.

The heating demand of MFB30 is 36'219 kWh and of MFB90 it is 104'584 kWh for the climate Zurich (SMA) simulated with IDA ICE (v4.8).

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Change log

Version	Date	Change
1.0	15.09.2019	Release
1.1	10.12.2019	Acknowledgment to SFOE added

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1. Introduction

This paper describes two different reference multifamily buildings (MFB) for the application in simulation tasks. Both buildings share the same geometry, the main difference is the insulation standard and the ventilation. Influenced by the IEA SHC Task 44 / HPP Annex 38 [1] the buildings are named MFB (Multi-Family Buildings) 30 and 90 according to their heat load for Zurich (Switzerland).

- MFB30 represents an actual building which fits the Swiss Minergie-Standard [2] with an envelope with high energetic quality. The 30 refers to the annual demand for space heating in kWh per heated energy reference floor area in m^2. Regarding the energy performance of buildings directive (EPBD) of the European Union (EU) the building could be used as nearly zero energy building (nZEB) for the most countries[1].
- MFB90 represents two cases: a non renovated existing building from the year 1980-1990, or an older building (1950-1980) which is renovated. The second case relies on an analysis of renovated MFB in Geneva, which shows that renovated buildings cannot reach the renovation targets in praxis [3].

The goal of this reference building description is to provide a simple basis for the comparison of different HVAC system solutions in Switzerland or countries with a similar building stock. These reference building can be implemented in several simulation platforms. The main difference to the Task44 / HPP Annex 38 reference buildings [1] is that the actual knowledge regarding real user behaviour and the so-called "Energy Performance Gap" for new and renovated buildings has been considered. On the other hand, the heating distribution is not considered in this version, i.e. all results were simulated with ideal heaters. The buildings correspond approximately to the average of all examined objects regarding the building parameters from the SFOE project ImmoGap [4,5]. In the project ImmoGap, 65 apartment buildings in Switzerland were analysed in detail concerning the "Energy Performance Gap".

In Table 9, some parameters of the buildings are introduced. The buildings represent the Swiss building stock well, regarding the amount of floors and apartments [6,7]. The apartment floor areas are relatively large compared to the Swiss average. Especially for the older building (MFB90), the net floor area (NFA) average Swiss buildings is quite smaller. The reason for this is that the inner zones where fixed for both building types for simplicity and only the outer walls were adapted in order to correspond to a non-refurbished older building.

[1] At the time this documentation was written (2019), the energy requirements for nZEB was not finally defined in most countries.

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Table 9: Summary of the main building parameter

	MFB30	MFB90	
Energy reference area (ERA)[2]	1'205	1'169	m^2
Net floor area (NFA)[3]:	1018	1026	m^2
- Apartments	900	900	m^2
- Stairwell	118	126	m^2
- Underground floor (cellar, parking etc.)	378.1	378.1	m^2
Window ratio to ERA	24.7%	14.3%	
Shape factor[4]	1.3	1.14	
Ventilation	mechanical (η = 80%)	fixed infiltration	

The reference buildings are simulated with the standard SIA 2028 [9] climate data for Zurich SMA in Switzerland.

Version changes of the reference buildings are reported in the first section "Change log".

[2] Includes the insulation and walls (definition SIA 380/1 [8])
[3] Does not include internal walls in the apartments (see *Figure 38* and *Figure 39*)
[4] Shape factor = thermal envelope divided by energy reference area

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2. Building geometries

An overview of the building is shown in Figure 24. The orientation is given for the northern hemisphere. The common geometrical structure of the buildings is fixed by inside measures. The different insulation standards of the buildings are then derived by applying different wall thicknesses. Internal walls and floors are only taken into account if they are between different apartments or between the stairwells and the apartments. In the same apartment, internal walls and floors are shown in the drawings but are not simulated. They can be added if there is a need for it. The building has in total eight zones: six apartments, one cellar (underground floor) and one stairwell, which connects all floors. The buildings are not shaded by other buildings or objects like trees, they stand free. In Figure 25 to Figure 27 some dimensions of the buildings are shown.

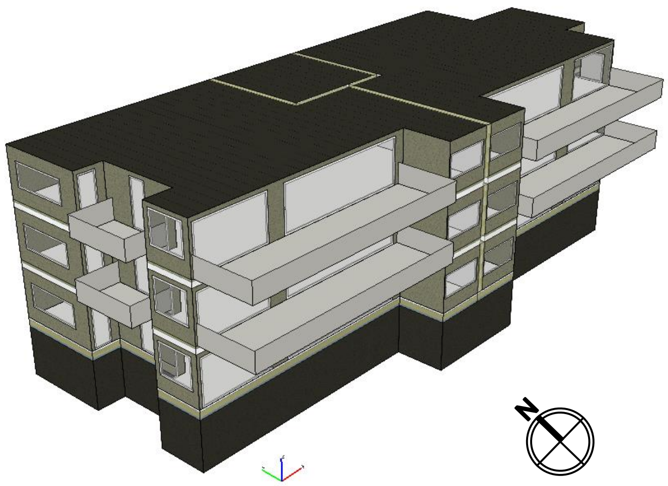

Figure 24: 3D illustration of the reference building MFB30 in IDA ICE.

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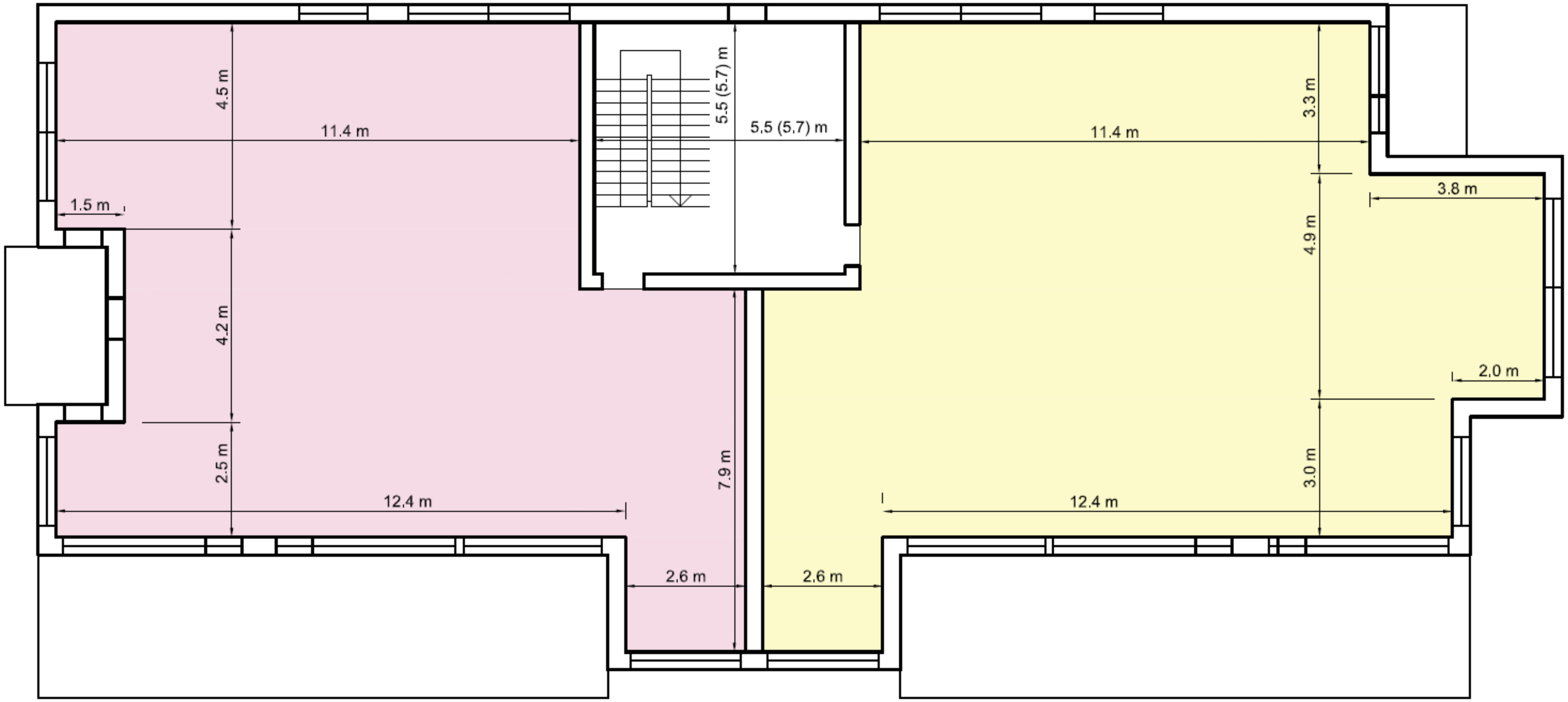

Figure 25: Floor plan of the three stories with apartments. Dimensions in brackets show values for MFB90, which are different to MFB30.

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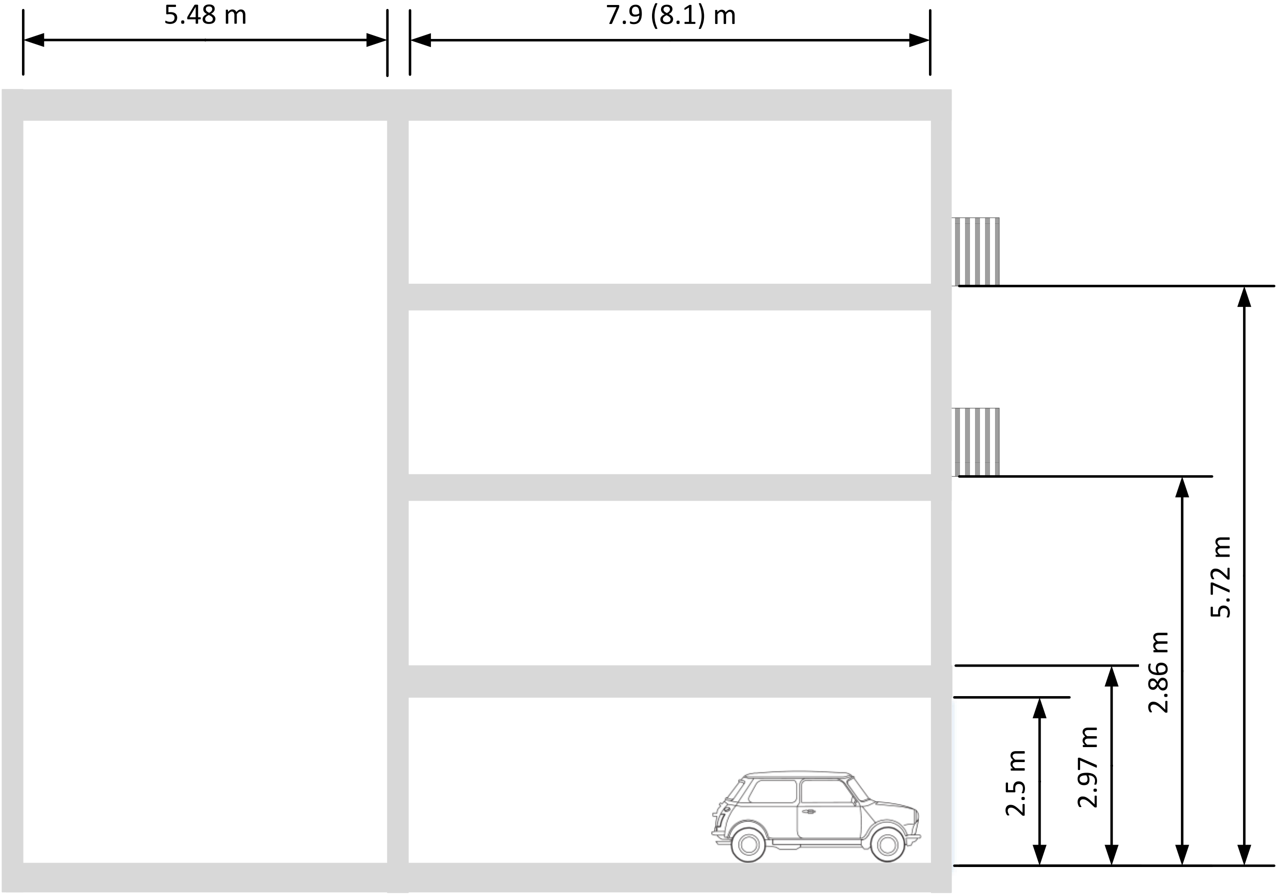

Figure 26: Side view of the building (cut in the middle). Dimensions in brackets show values for MFB90, which are different to MFB30.

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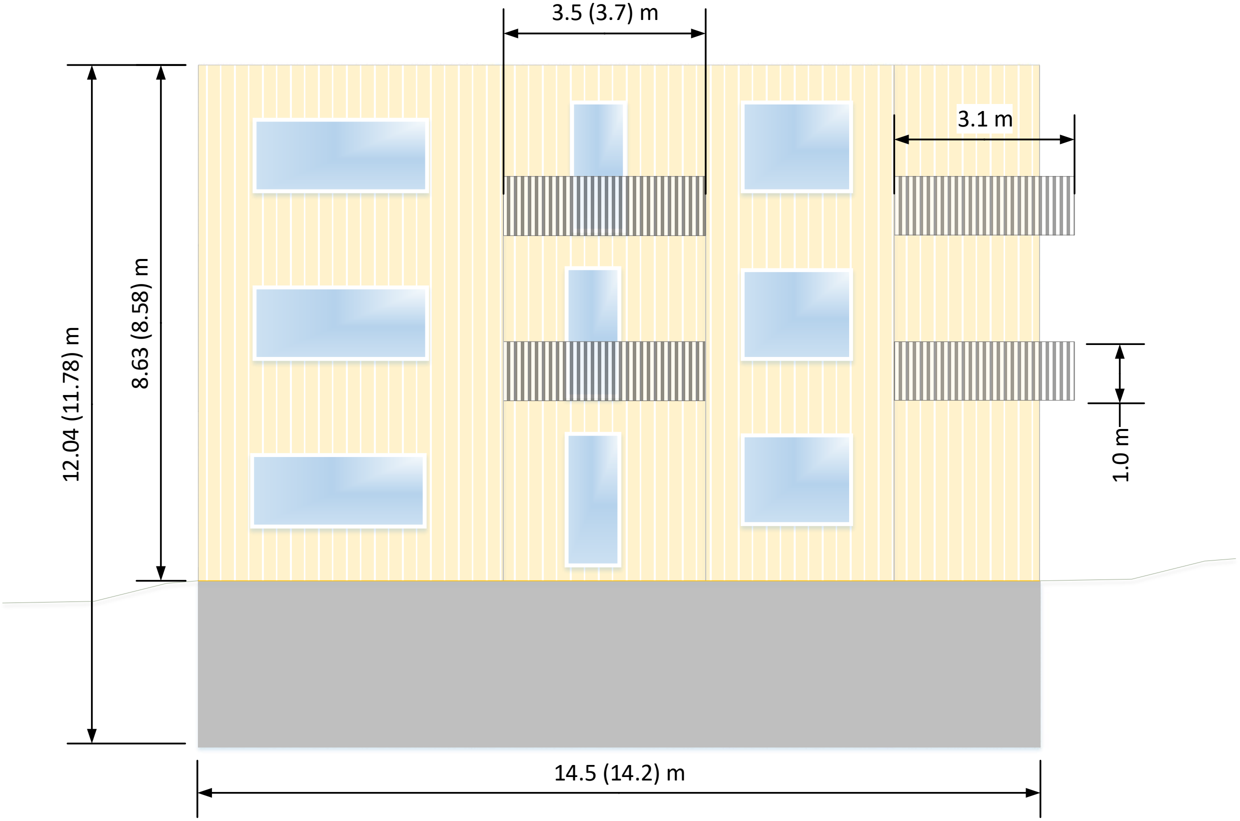

Figure 27: Side view of the building. Dimensions in brackets show values for MFB90, which are different to MFB30.

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2.1 Construction of building elements

The building envelop and construction elements are described in detail in the following sections.

2.1.1 Opaque elements

The opaque elements for both buildings are summarised in Table 10 and described in detail in Table 25 to Table 40. For the U-value calculations, a total heat transfer coefficient of αi = 7.69 W/(m²K) to the inside and α_e = 25 W/(m²K) to the outside (ambient) was used according to ISO 6946:2017 [10]. Doors are not taken into account, i.e. they have the same u-value as the walls.

Table 10: Summary of the opaque elements

	MFB30		***MFB90***	
	U-value	thickness	U-value	thickness
Element	(W/(m²K))	(m)	(W/(m²K))	(m)
External wall to ambient	0.18	0.385	0.68	0.265
External wall to ground	0.39	0.290	3.91	0.210
Internal wall against not heated rooms	0.34	0.32	3.23	0.22
Internal wall	2.57	0.17	2.57	0.17
Ground floor	0.27	0.43	1.14	0.340
Floor against not heated rooms	0.21	0.474	1.03	0.364
Floor between heated rooms	0.66	0.369	1.0	0.355
Roof ceiling	0.19	0.412	0.48	0.364

2.1.2 Thermal bridges

Thermal bridges were taken into account for both buildings. The main parameters are summarized in Table 11. The thermal bridges are calculated according to the "Wärmebrückenkatalog" [11]. In Figure 28, the included thermal bridges are marked with "X" in the check boxes.

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Table 11: Summary of the thermal bridges with Ψ as length related heat transfer coefficient.

	MFB30		***MFB90***	
	length	Ψ	length	Ψ
Type	(m)	(W/(m K))	(m)	(W/(m K))
L1 (1.1 balcony connection)	124.8	0.27	124.5	0.7
L2 (2.2 wall connection to celler)	63	0.21	63.0	0.07
L3	-	-.	-	-
L4	-	-	-	-
L5 (5.1 – 5.3 window connection)	539.9	0.148	466.2	0.115
Total	127.5 W/K		145.1 W/K	

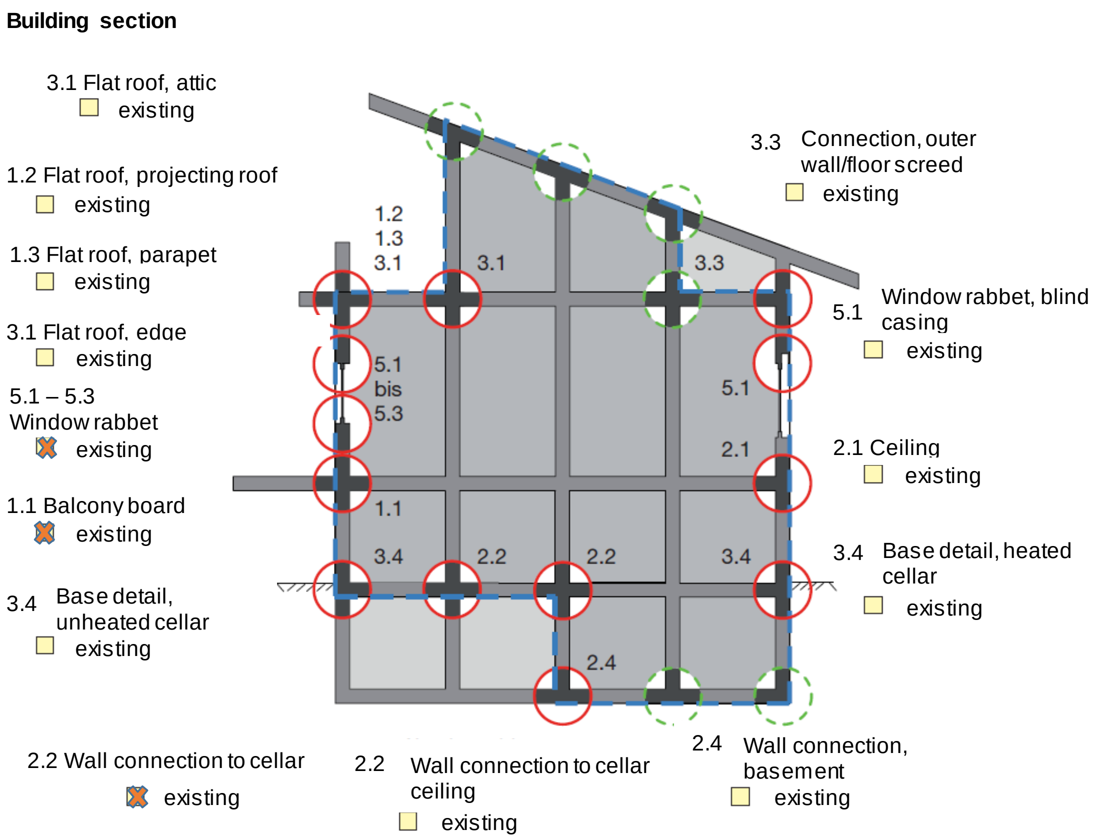

Figure 28: Illustration of the different thermal bridges for a residential building [12].

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2.1.3 Windows

The global window parameters are given in Table 12. Specific window parameters for the MFB30 buildings are given in Table 13 and Table 14, and for the MFB90 the information are given in Table 15 and Table 16. The detailed position of the windows is given in Figure 38 and Figure 39. In addition to the standard U-value for glass (Uglass) provided in Table 12, a U-value including the losses of the window spacer are provided in Table 13 for MFB30 and for MFB90 in Table 15.

Table 12: Global window parameter for MFB30 and MFB90.

	MFB30	MFB90	
U_{frame}	1.3	1.6	$W/(m^2K)$
Tau_e	0.4	0.4	-
G-value	0.45	0.62	-
U_{glass}	0.7	1.5	$W/(m^2K)$

Table 13: Specific window parameter of MFB30

	U_{window} (W/m^2K)	share frame	A_{window} (m^2)	height (m)	width (m)	U_{glass} incl. window spacer $(W/(m^2K))$
W1	0.93	16%	3.6	1.2	3.0	0.86
W2	0.89	13%	6.2	1.6	3.9	0.83
W3	1.00	20%	2.4	1.6	1.5	0.93
W4	0.89	13%	5.6	1.6	3.5	0.83
W5	0.90	14%	5.3	2.3	2.3	0.84
W6	0.85	10%	9.0	2.3	3.9	0.80
W7	0.90	15%	2.9	1.2	2.4	0.83
W8	0.95	12%	6.9	2.3	3.0	0.815
W9	0.89	18%	2.1	2.3	0.9	0.875
W10	0.95	17%	3.1	1.6	1.94	0.88

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Table 14: Window area compared to different reference areas for MFB30

	Window area (m^2)	Glass area (m^2)	Window ratio to energy reference area (-)	Window ratio to facade[5] (-)
North	54.3	45.9	4.5%	17.6%
East	43.8	37.6	3.6%	34.0%
South	173.1	153.6	14.4%	56.2%
West	26.4	22.0	2.2%	20.5%
Total	297.6	259.0	24.7%	34.1%

Table 15: Window parameter of MFB90

	U_{window} (W/(m²K))	share frame	A_{window} (W/(m²K))	height (m)	width (m)	U_{glass} incl. window spacer (W/(m²K))
W1	1.72	16%	3.45	1.15	3.0	1.74
W2	1.78	13%	3.45	1.15	3.0	1.80
W3	1.84	20%	1.2	1.2	1.0	1.90
W4	1.83	13%	2.3	1.15	2.0	1.86
W5	1.8	14%	2.0	2.2	0.9	1.83
W6	1.79	10%	2.0	2.2	0.9	1.81
W7	1.83	15%	1.2	1.2	1.0	1.87
W8	1.74	12%	5.18	1.15	4.5	1.76
W9	1.79	18%	2.07	2.3	0.9	1.83
W10	1.84	17%	2.3	1.15	2.0	1.89
W11	1.71	10%	1.73	1.15	1.5	1.72

[5] Without underground floor

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Table 16: Window area compared to different reference areas for MFB90

	Window area (m^2)	Glass area (m^2)	Window ratio to energy reference area (-)	Window ratio to facade (-)
North	41.0	34.9	3.5%	13.6%
East	23.3	19.9	2.0%	18.7%
South	78.9	69.5	6.8%	26.2%
West	23.5	19.5	2.0%	18.9%
Total	166.6	143.8	14.3%	19.6%

2.2 Ground floor coupling

Ground floor coupling is calculated based on ISO 13370 [13]. The calculated heat resistance of the connecting ground is expressed in two layers; i) a 0.5 m thick layer of the outermost ground layer material and below that ii) a 0.1 m virtual layer with a negligible heat capacity and a heat conductivity calculated to represent the rest of the heat resistance. The virtual ground temperature (T_v) is calculated according to the standard as a weighted average value of the annual and the monthly mean air temperatures (T_{mean}) and the actual air temperature (T_{amb}), including a calculated time lag (see Eq. 1). The used ground parameters are summarized in Table 17.

Eq. 1 $$T_v = T_{mean} \cdot \left(1 - \frac{H_{pe}}{H_g}\right) + \frac{H_{pe}}{H_g} \cdot T_{amb}$$

Table 17: Ground parameters for both buildings.

	Symbol	Value	Unit
Thermal conductivity	λ	2.0	W/(m K)
Density	ρ	2000	kg/m³
Heat capacity	c	1000	J/(kg K)
Thickness	d	1	m
Steady-state ground heat transfer coefficient	H_g	127.9	W/K
External periodic heat transfer coefficient	H_{pe}	50.36	W/K

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3. Loads

3.1 Household profiles

For each apartment a household was defined which is typical for Switzerland. The household profiles include the electricity use, domestic hot water demand and the occupancy. The profiles were generated with the software LoadProfileGenerator V.8. More details of the six households can be found in Table 42 to Table 50.

3.2 Domestic hot water

In Table 18 the domestic hot water (DHW) demand for each household is shown. On the SPF homepage [6] a text file with the DHW demand with a time resolution of one minute is provided. The DHW demand is the same for both buildings.

Table 18: Daily DHW demand at the point of use (tap, shower, etc.) for mixed water temperature of 35 °C and the DHW load including distribution heat losses for each household.

Household label	Number of persons	DHW demand 35 °C (l/(p,day))	DHW load[7] (kWh/year)
CHR33	2	92.1	1'978
CHR44	4	94.3	4'051
CHR27	4	72	3'093
CHS04	2	111.9	2'404
CHR55	2	124.5	2'674
CHR18	4	79.4	3'411
Total	18	91.1	17'611

3.3 Electricity

Detailed electricity profiles for each household are defined, and stored in an extra text file with a time resolution of one minute (www.spf.ch/MFBref). The annual electricity demand of the MFB30 building is 16'164 kWh or 15.9 kWh/m^2(NFA) per net floor area. For MFB90 the annual electricity demand is 22% higher with 19'719 kWh (19.2 kWh/m^2(NFA)). The reason for this difference is that more lighting is needed in older buildings due to the lower window area. The fact that nowadays the electric

[6] www.spf.ch/MFBref
[7] For the cold water temperature the virtual ground temperature (see Eq.1) was used and for the hot water temperature 60 °C was used. This DHW load is only valid for the climate of Zurich (SMA).

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devices are more energy efficient is partially compensated by the fact that more devices are installed in the new buildings. In these electricity profiles, the demand for heating equipment or ventilation system is not included. These profiles have to been considered separately depending on the system efficiency of the components that are simulated. The influence on the heating demand of the buildings is assumed to be small, because these components are usually installed in the unheated cellar.

3.4 Ventilation

The new building standard (MFB30) has a mechanical ventilation with a heat recovery efficiency of 80%. The ventilation rates were designed according the Minergie standard [2], and are summarized for each zone in *Table 19*. If the moving 24 h average ambient temperature is higher than 18 °C, the ventilation system uses a bypass, where the air from outside is directly transferred into the building without heat recovery.

MFB90 has a constant, passive air exchange of 225.7 l/s (0.7 $m^3/(h\ m^2(ERA))$), there is no mechanical ventilation assumed for the older building. The infiltration rate correspondents to the standard SIA 380/1 [8].

For both buildings, a realistic window opening behaviour was assumed that was derived from the project ImmoGap [4] of which a short version was published also in English [5]. In general it was assumed that one window per apartment is open in the night from spring to autumn. The conditions for opening the windows are:

Time between 20.00 to 07.00

Day between 1st of April to 30th of September

In the case of MFB30 the window W4 on the north façade (one window per apartment) was opened by 10% of the window area (0.56 m^2/apartment). For MFB90 the windows W4 (two windows per apartment) on the north façade where opened by 10% of the window area (2 x 0.23 m^2 = 0.46 m^2/apartment).

For the summer case, additional windows are open at night if the following conditions are met:

Time between 21.00 to 07.00

Average temperature of the last 24 hours is above 18 °C (dead band 0.5 K)

Room temperature above 24 °C (dead band 1 K)

Ambient temperature at least 2 K below the actual room temperature (dead band 1 K)

In this case, the following windows are opened by 10% of their window area in all apartments, MFB30: W1, W3, W5, W6, W7, W10 / MFB90: W1, W2, W3, W5, W7, W10, W11

The volume flow rate (m^3/s) for such tilted windows is directly simulated in dynamic simulation tools as IDA ICE or TRNSYS for example. If the flow rate cannot be calculated in the simulation tool, than

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the following equation described in the IEA SHC Task44 / HPP Annex 38 [1] could be used. The calculation method is based on the work of A. Weber [14].

Eq. 2 $\dot{V}(\alpha) = C_d \cdot C_k(\alpha) \cdot \frac{W}{3} \cdot \sqrt{\frac{\Delta T}{T_{amb}} \cdot g \cdot H^3}$

with

Eq. 3 $C_d = 0.0174 \cdot \alpha - 0.0928 \cdot H \cdot W^{-1} + 0.4116$

Eq. 4 $C_k = 2.6 \cdot 10^{-7} \cdot \alpha^3 - 1.19 \cdot 10^{-4} \cdot \alpha^2 + 1.86 \cdot 10^{-2} \cdot \alpha$

α = opening angle of the window

H = height of the window

W = width of the window

T_{amb} = ambient temperature

ΔT = difference of ambient and room temperature

g = acceleration of earth's gravity

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Table 19: Ventilation rates in m^3/h for each zone in the apartment west and east.

	West apartment		East apartment	
	exhaust air	supply air	exhaust air	supply air
Room 1	0	30	0	30
Bath 1	40	0	50	0
Bath 2	30	0	40	0
Room 2	0	30	0	30
Room 3	0	30	0	30
Living room	0	50	0	50
Kitchen	60	0	60	0
Storeroom	10	0	20	0
Room 4	-	-	0	30
Total	140	140	170	170

3.5 Shading

Two types of shading where taken into account for the simulation. The fixed shadings due to e.g. balconies and the variable shadings like window blinds. The fixed shading parameters are summarized in Table 20 and Table 21, they are calculated according to SIA 380/1 [8]. All windows in the buildings are equipped with external blinds. These are activated, if following conditions are met:

Solar irradiation on corresponding façade is over 200 W/m^2

Wind speed is less than 10 m/s

The moving average op. room temperature over 48 hours is comfortable (see Figure 29)

It is not assumed that the shading control is automatic, but rather triggered by user behaviour. When the blinds are activated, the window g-value is reduced by multiplication with the factor 0.14, and the short-wave shading coefficient with a factor of 0.19. The U-value is not changed when the blinds are active.

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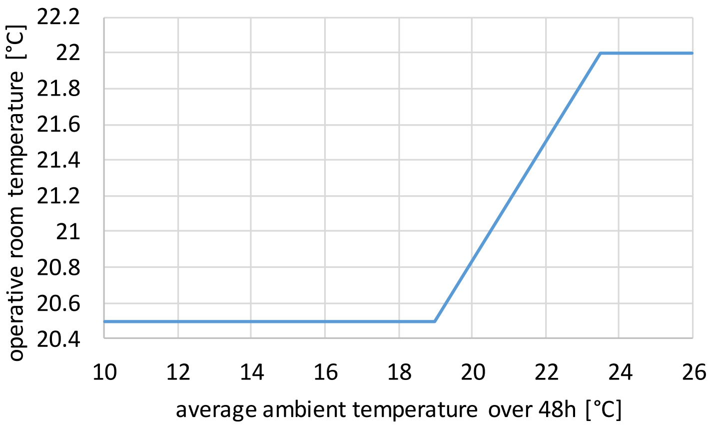

Figure 29: Comfortable operative room temperature depending on the average ambient temperature [15].

These shading parameters are based on findings from the project ImmoGap [4], where it was deduced that the passive solar gains through windows are lower than in the standards [8] described.

*Table 20: Shading factors of **fixed elements** for the specific façade of building MFB30.*

	North	East	South	West
F_{S1} (horizon and other buildings)	1.00	0.98	0.99	0.98
F_{S2} (overhang e.g. balcony)	0.93	0.97	0.47	0.88
F_{S3} (side visor - window)	1.00	0.93	0.95	0.94
F_S ($F_{S1} \cdot F_{S2} \cdot F_{S3}$)	0.93	0.89	0.44	0.82

*Table 21: Shading factors of **fixed elements** for the specific façade of building MFB90.*

	North	East	South	West
F_{S1} (horizon and other buildings)	1.00	1.00	1.00	1.00
F_{S2} (overhang e.g. balcony)	0.90	0.96	0.60	0.86
F_{S3} (side visor - window)	1.00	0.92	0.94	0.94
F_S ($F_{S1} \cdot F_{S2} \cdot F_{S3}$)	0.90	0.88	0.57	0.82

3.6 Internal load profiles

Two types of internal gains are added in the buildings. On the one hand caused by heat released by inhabitants and on the other hand by electric equipment.

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It is assumed that one person emits in average 80 W[8] (1.2 met, body surface 1.8 m^2) sensible heat (according to ISO 7730:2005 with T_{room} = 21 °C). The heat gains by occupants are also depending on the number of persons and their presence. The presence shown in Figure 30 for each apartment represents an average week and weekend day of the year. The detailed presence profile is given in an extra text file with a time resolution of one minute (www.spf.ch/MFBref) which matches with the DHW and electric equipment profile. The heat gains from the electrical equipment depends on the electrical power profile described in 0. In Figure 31, the electricity demand profile for an average week and weekend day is shown. The effective heat gains are calculated by multiplying the profile factor with the maximum heat gain values in Table 22. The internal heat gains in the stairwell and the underground floor (cellar) were neglected.

Table 22: Maximal internal heat gains per apartment when fully occupied (presence = 1) or all electrical devices where used (electricity use = 1).

Household profile	Number of persons	Max. occupant internal heat gains (W)	Max. electrical internal heat gains (W)	Max. electrical internal heat gains (W)
			MFB 30	MFB90
CHR33	2	160	995.4	1214.4
CHR44	4	320	1325.9	1617.6
CHR27	4	320	1683.8	1999.3
CHS04	2	160	1367.7	1668.6
CHR55	2	160	846.3	1032.5
CHR18	4	320	1430.0	1744.6
Total	18	1'440	7649	9277

[8] The sensible heat emission by persons varies depending on the indoor room temperature and the clothing level, which is neglected in this case. These reference buildings are designed with focus on the heating demand. For this reason, a room temperature of 21 °C was assumed for the calculation of heat emission by inhabitants. This leads to higher heat loads in summer compared to more realistic dynamic calculations of person emissions (e.g. IDA ICE simulations).

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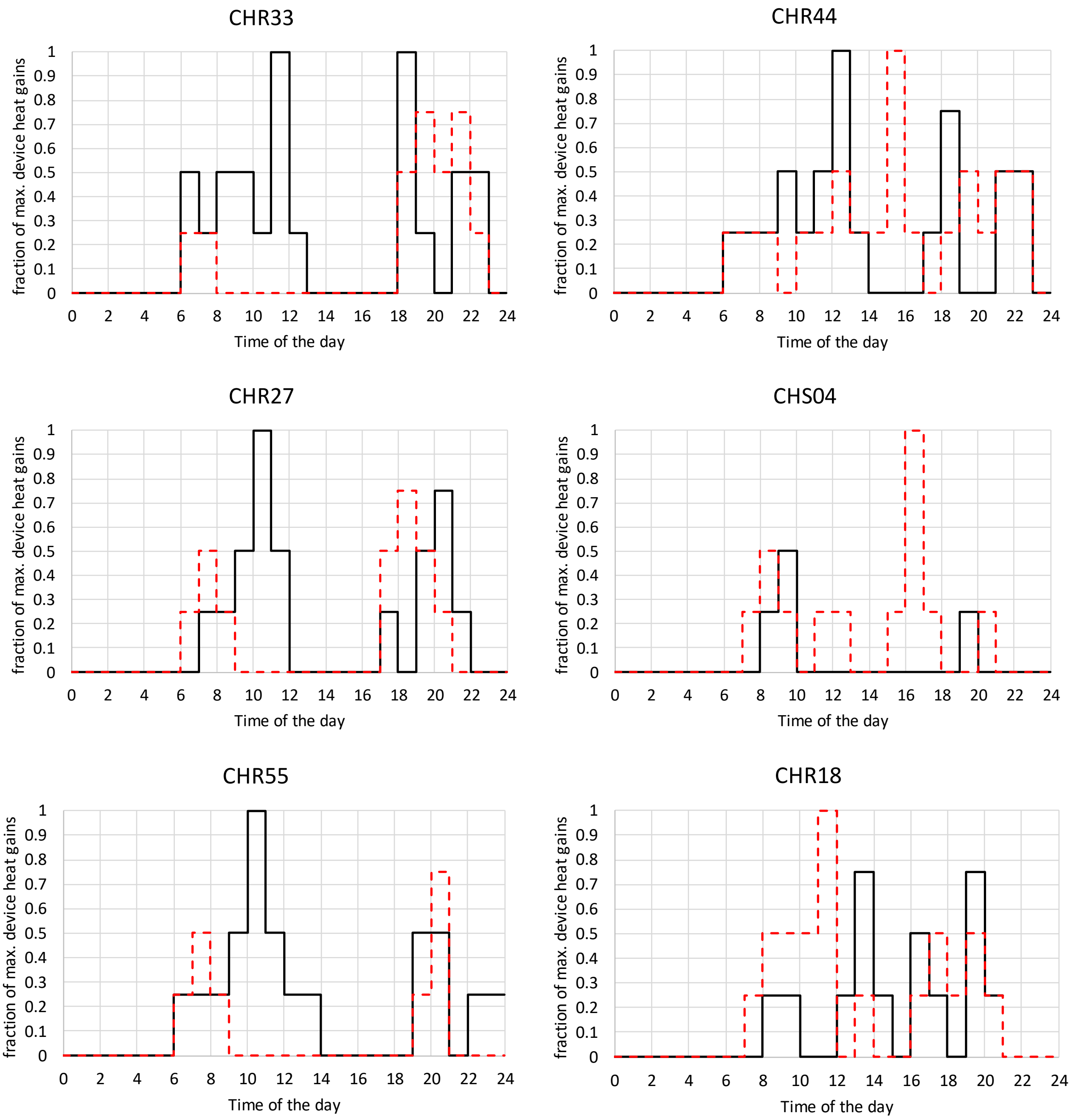

Figure 30: Profiles for the different households regarding the heat gains by electrical devices, in black the weekend (Saturday and Sunday) profile and in red the weekday profile.

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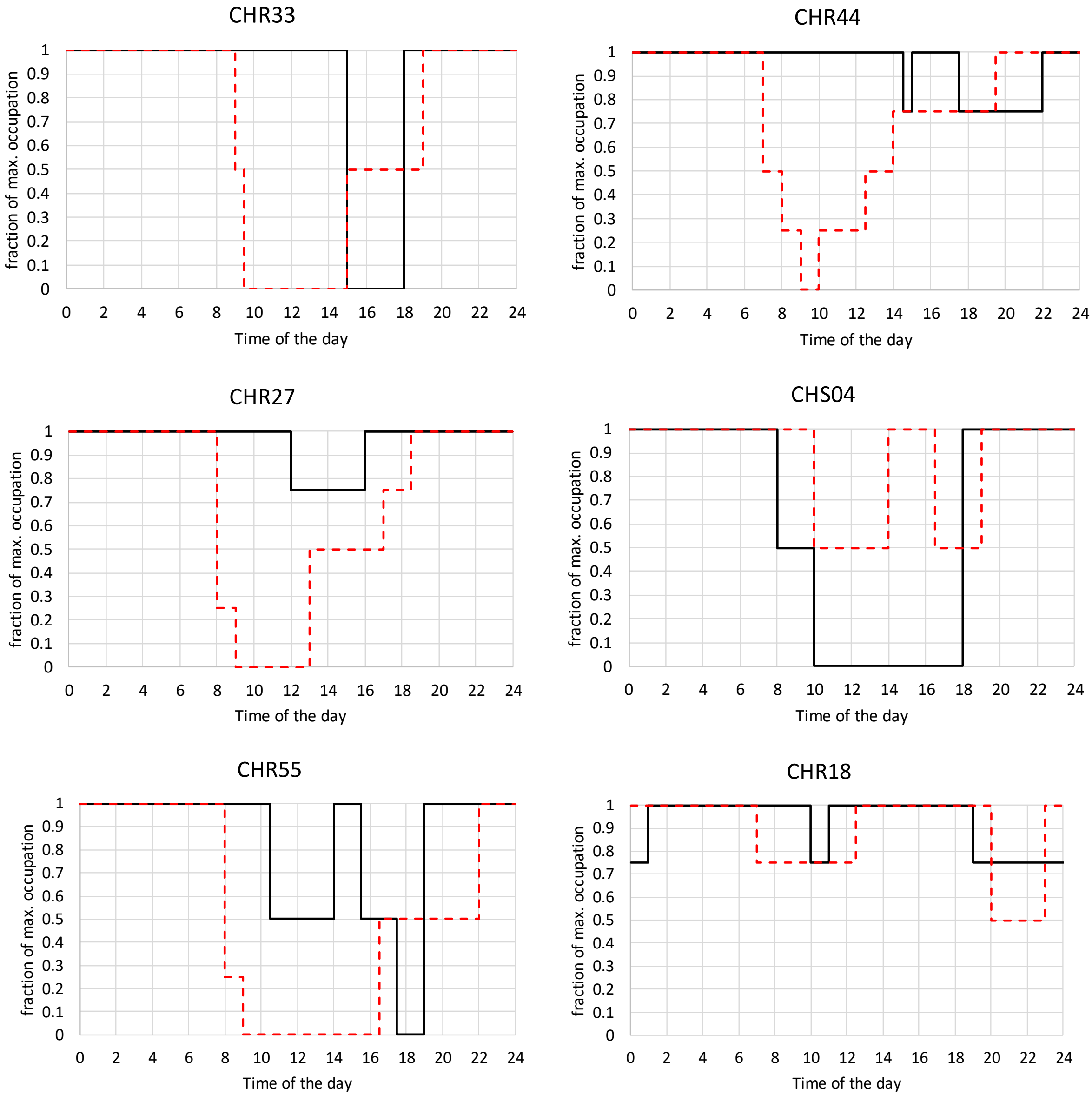

Figure 31: Profiles for the different households regarding the presence of occupants, in black the weekend (Saturday and Sunday) profile and in red the weekday profile.

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4. Simulation results

The following results were simulated with IDA ICE v.4.8 with climate data of Zurich, Switzerland. Ideal heaters were used as heating distribution system, the set point room temperature is 21 °C[9]. The calculated heating demand is 36'219 kWh/year (30.1 kWh/(m^2,year(ERA))) and 104'584 kWh/year (89.5 kWh/(m^2,year(ERA))) for MFB30 and MFB90 respectively.

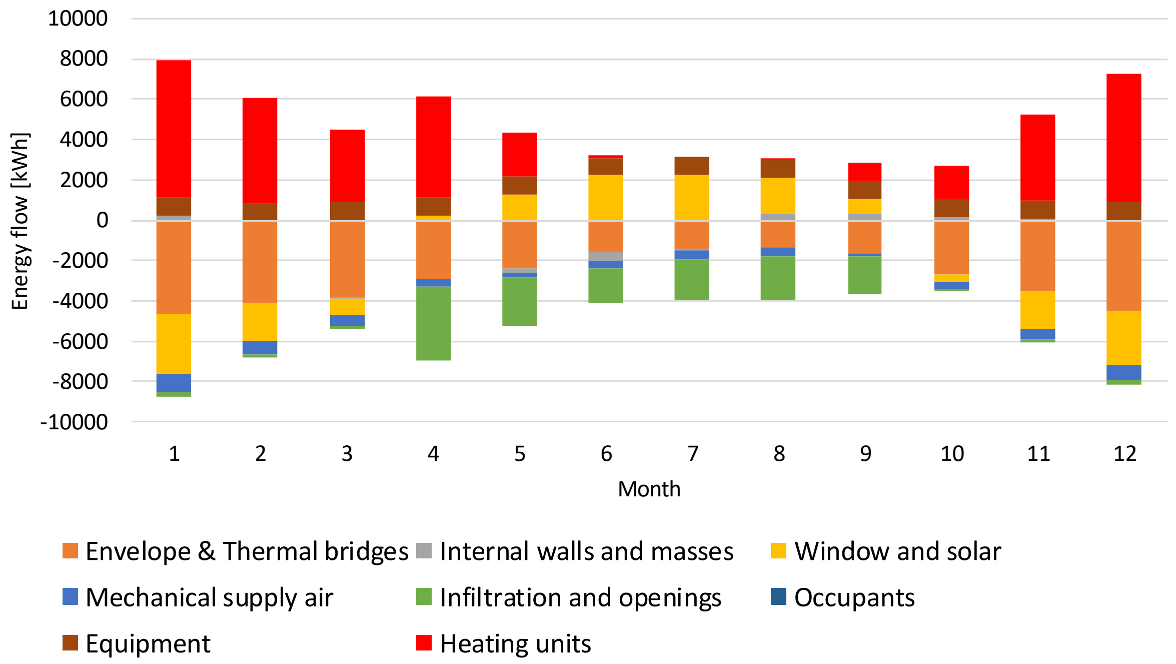

Figure 32: Monthly energy balance of MFB30.

[9] Depending on the goal of a simulation, we would recommend to simulate higher room set point temperatures to get more realistic results. In the project ImmoGap [4] it was found that the average room temperature in winter is more likely 23 °C then 21 °C.

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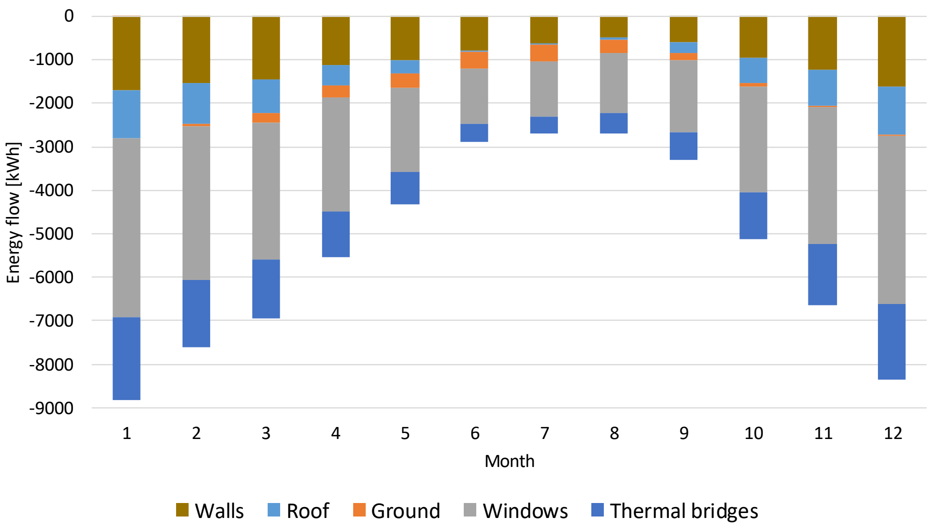

Figure 33: Monthly transmission through the building envelope of MFB30.

Table 23: Monthly and yearly energy balance of MFB30 in kWh.

Month	Envelope & thermal bridges	Internal walls and masses	Window and solar	Mechanical supply air	Infiltration and openings	Occupants	Equipment	Heat supply
1	-4607	199	-3034	-876	-229	0	896	6809
2	-4112	29	-1873	-661	-170	0	810	5213
3	-3800	-88	-856	-500	-127	0	897	3629
4	-2934	8	247	-354	-3682	0	869	5026
5	-2382	-214	1284	-216	-2392	0	896	2181
6	-1602	-425	2230	-330	-1726	0	869	152
7	-1436	-95	2223	-386	-2053	0	897	0
8	-1309	280	1851	-485	-2133	0	896	39
9	-1661	275	798	-166	-1861	0	870	916
10	-2670	132	-433	-317	-88	0	896	1639
11	-3497	113	-1925	-511	-147	0	867	4284
12	-4506	40	-2702	-718	-194	0	899	6332

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Month	Envelope & thermal bridges	Internal walls and masses	Window and solar	Mechanical supply air	Infiltration and openings	Occupants	Equipment	Heat supply
Total	-34514	255	-2189	-5519	-14803	0	10560	36219

In Figure 34 the monthly heating demand of the MFB30 building is shown. As a result of the window opening behaviour the heating demand is higher in April than in March.

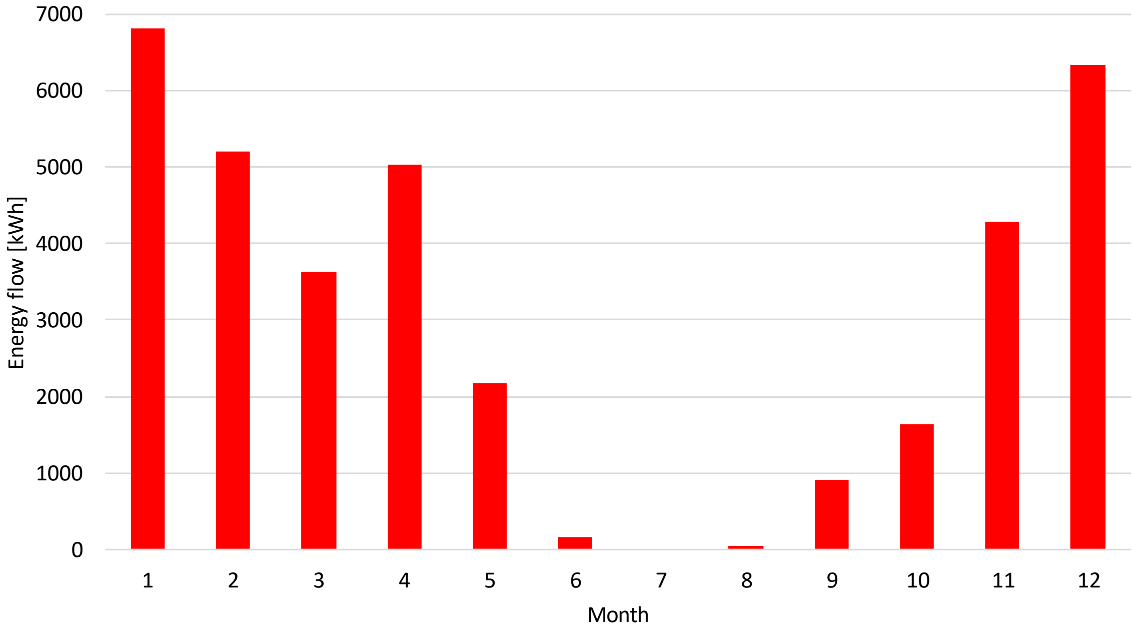

Figure 34: Monthly heat load of MFB30.

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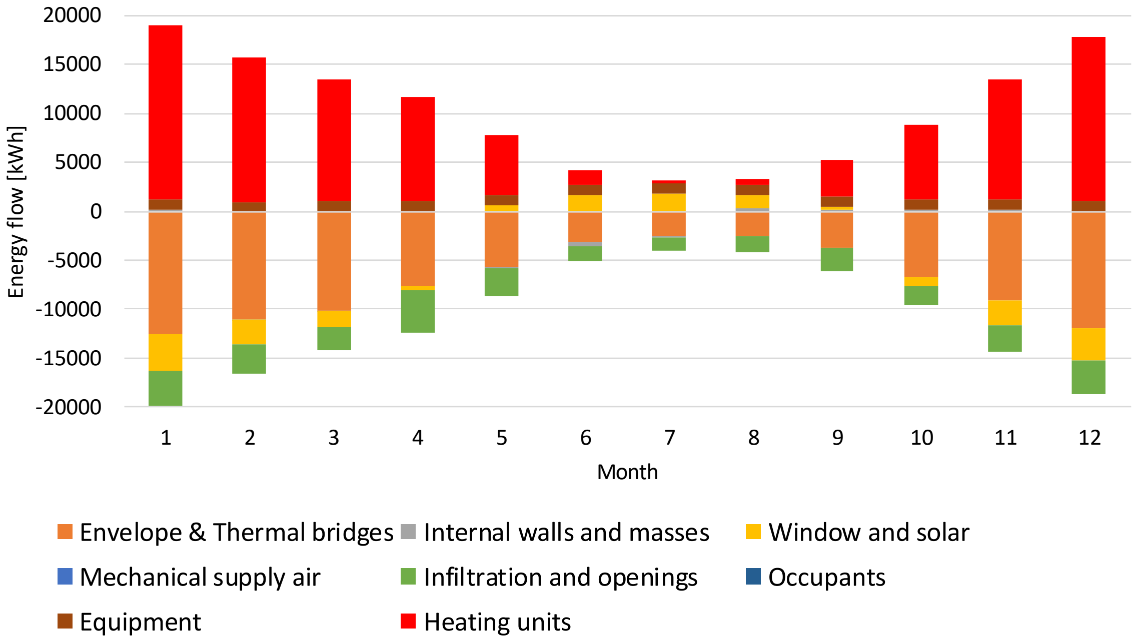

Figure 35: Monthly energy balance of MFB90.

Table 24: Monthly and yearly energy balance of MFB90 in kWh.

Month	Envelope & thermal bridges	Internal walls and masses	Window and solar	Mechanical supply air	Infiltration and openings	Occupants	Equipment	Heat supply
1	-12601	187	-3635	0	-3614	0	1062	17760
2	-11105	-7	-2482	0	-2949	0	961	14820
3	-10098	-92	-1592	0	-2481	0	1064	12355
4	-7563	-44	-481	0	-4381	0	1031	10624
5	-5708	-175	625	0	-2800	0	1062	6157
6	-3192	-399	1692	0	-1442	0	1031	1490
7	-2569	-127	1756	0	-1280	0	1064	310
8	-2540	297	1341	0	-1626	0	1062	619
9	-3755	154	279	0	-2321	0	1033	3784
10	-6670	120	-980	0	-1995	0	1062	7622

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11	-9159	184	-2470	0	-2725	0	1029	12328
12	-12024	59	-3308	0	-3359	0	1067	16715
Total	-86984	155	-9254	0	-30972	0	12528	104584

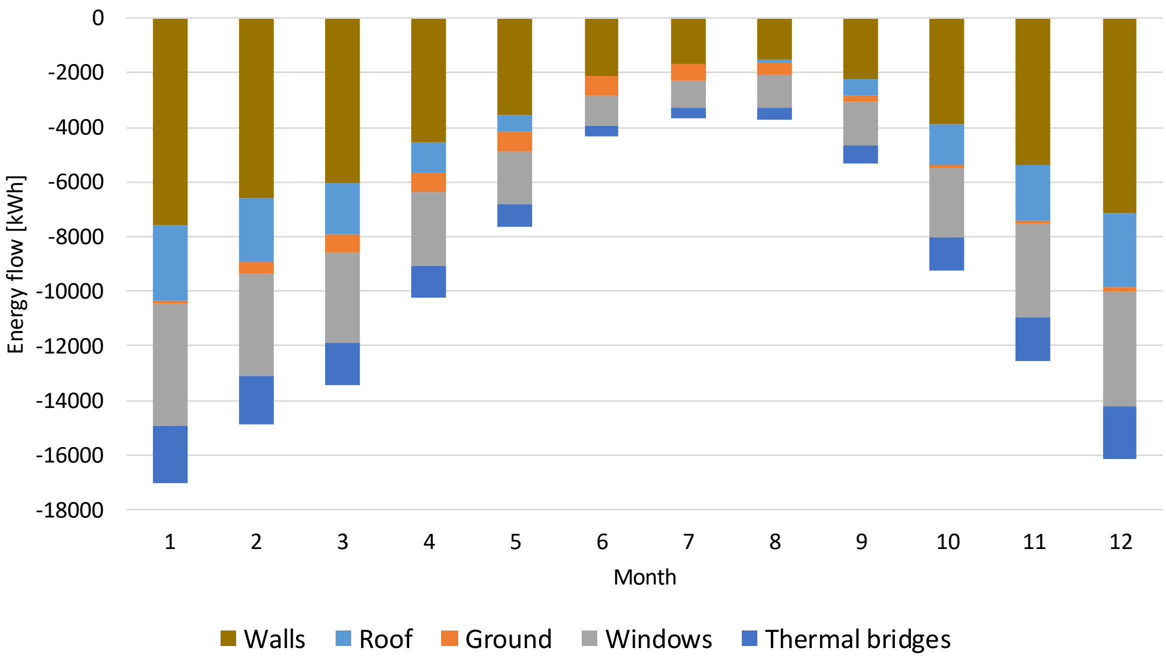

Figure 36: Monthly transmission through the building envelope of MFB90.

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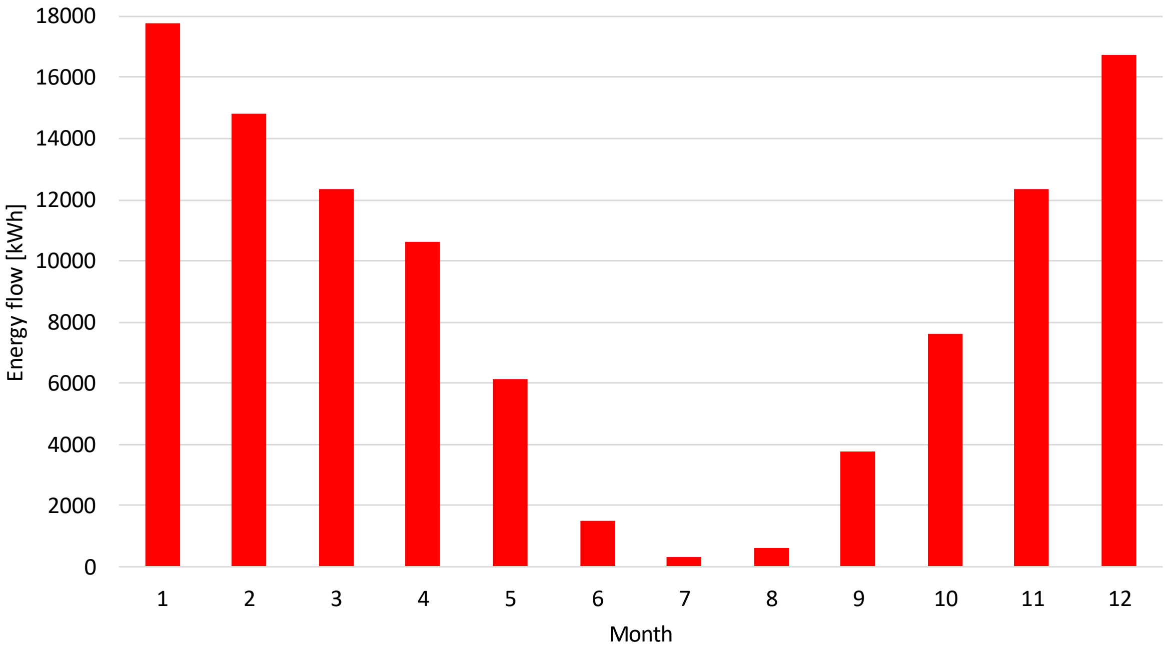

Figure 37: Monthly heat load of MFB90.

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5. Literature

[1] R. Dott, M.Y. Haller, J. Ruschenburg, F. Ochs, J. Bony, The Reference Framework for System Simulations of the IEA SHC Task 44 / HPP Annex 38 - Part B: Buildings and Space Heat Load, (2013). http://www.taskx.iea-shc.org/data/sites/1/publications/T44A38_Rep_C1_B_ReferenceBuildingDescription_Final_Revised_130906.pdf (accessed August 1, 2019).

[2] Anwendungshilfe zu den Gebäudestandards Minergie/Minergie-P/Minergie-A, (2019). https://www.minergie.ch/media/190103_anwendungshilfe_minergie_p_a_v2019.1_de.pdf (accessed August 14, 2019).

[3] J. Khoury, P. Hollmuller, B. Lachal, Energy performance gap in building retrofit: characterization and effect on the energy saving potential, in: BRENET 19. Status-Seminar, Zürich, 2016.

[4] I. Mojic, M. Luzzatto, M. Haller, M. Lehmann, M. Benz, S. Van Velsen, ImmoGap - Einfluss der Kombination aus Nutzerverhalten und Gebäudetechnik auf den Performance Gap bei Mehrfamilienhäuser, SPF Institut für Solartechnik, HSR Hochschule für Technik Rapperswil, 2018.

[5] I. Mojic, M. Lehmann, S. van Velsen, M. Haller, ImmoGap – Analysis of the performance gap of apartment buildings, E3S Web Conf. 111 (2019) 04016. doi:10.1051/e3sconf/201911104016.

[6] Gebäude nach Gebäudekategorie sowie Bauperiode und Geschosszahl, Bundesamt für Statistik, 2018.

[7] Gebäude- und Wohnungsregister (GWR) 2000 - 2014, Statistisches Amt Kanton Zürich, n.d.

[8] SIA 380/1:2009: Thermische Energie im Hochbau, Schweizerischer Ingenieur- und Architektenverein, 2009.

[9] SIA Merkblatt 2028: Klimadaten für Bauphysik, Energie- und Gebäudetechnik, Schweizerischer Ingenieur- und Architektenverein, 2010.

[10] ISO 6946:2017-06: Building components and building elements - Thermal resistance and thermal transmittance - Calculation methods, ISO, Geneva, 2017.

[11] Wärmebrückenkatalog, Bundesamt für Energie BFE, Bern, 2002.

[12] Energienachweis - Checkliste Wärmebrücken, EnFK - Konferenz Kantonaler Energiefachstellen, 2010.

[13] ISO 13370:2007: Thermal performance of buildings - Heat transfer via the ground - Calculation methods, ISO, 2007.

[14] A. Weber, Modell für natürliche Lüftung durch Kippfenster, TRNSYS Usertag, Stuttgart, Germany, 1997.

[15] SIA 180: Wärmeschutz, Feuchteschutz und Raumklima in Gebäuden., (2014).

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6. Symbols

Symbols

H_g	steady-state ground heat transfer coefficient, W/K
H_{pe}	external periodic heat transfer coefficient, W/K
T_v	virtual ground temperature, °C
$\dot{V}$	volume flow rate, m^3/s
α_e	outer surface heat transfer coefficient, W/m^2K
α_i	inner surface heat transfer coefficient, W/m^2K
ΔT	temperature difference, K
ERA	energy reference area, m^2
F	window shading factor
H	height, m
NFA	net floor area, m^2
R	overall resistance, m^2K/W
T	Temperature, °C
U	heat transfer coefficient, W/m^2K
W	width, m
c	specific heat capacity, J/kgK
d	thickness, m
g	gravitation of the earth, 9.81 m/s^2
g	solar energy transmittance of window
met	metabolic rate, -
Ψ	length related heat transfer coefficient, W/mK
α	opening angle of the window, °
λ	thermal conductivity, W/mK
ρ	density, kg/m^3

Subscript

amb	ambient outside air
$frame$	window frame
$glass$	window glass
$mean$	average

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Appendix A Construction Details

A.1 Detailed opaque element parameters

Table 25: Construction: outer wall facing ambient MFB30

	thickness	density	lambda	Cp	R-value
Layer	m	kg/m^3	W/(m K)	J/(kg K)	m^{2}K/W
Interior plaster	0.01	1400	0.7	900	0.014
Armoured concrete	0.2	2400	1.8	1102	0.111
Insulation (Swisspor LAMBDA White)	0.16	16	0.031	1404	5.16
Exterior plaster	0.015	1800	0.87	1101	0.017
U-value			**0.18 W/(m^{2}K)**		

Table 26: Construction: outer wall facing ambient MFB90

	thickness	density	lambda	Cp	R-value
Layer	m	kg/m^3	W/(m K)	J/(kg K)	m^{2}K/W
Interior plaster	0.01	1400	0.7	900	0.014
Armoured concrete	0.2	2400	1.8	1102	0.111
Insulation (Swisspor ROC)	0.045	110	0.039	828	1.026
Exterior plaster	0.01	1800	0.87	1101	0.017
U-value			**0.68 W/(m^{2}K)**		

Table 27: Construction: outer wall facing ground MFB30

	thickness	density	lambda	Cp	R-value
Layer	m	kg/m^3	W/(m K)	J/(kg K)	m^{2}K/W
Interior plaster	0.01	1400	0.7	900	0.014
Armoured concrete	0.2	2400	1.8	1102	0.111
Insulation (XPS 300)	0.08	30	0.035	1400	2.286
U-value			**0.39 W/(m^{2}K)**		

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Table 28: Construction: outer wall facing ground MFB90

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Interior plaster	0.01	1400	0.7	900	0.014
Armoured concrete	0.2	2400	1.8	1102	0.111
U-value			**3.91 W/(m²K)**		

Table 29: Construction: interior wall facing unheated room (stairwell) MFB30

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Interior plaster	0.01	1400	0.7	900	0.014
Insulation (Swisspor EPS15)	0.1	15	0.038	1404	2.63
Armoured concrete	0.2	2400	1.8	1102	0.072
Exterior plaster	0.01	1400	0.7	900	0.014
U-value			**0.34 W/(m²K)**		

Table 30: Construction: interior wall facing unheated room (stairwell) MFB90

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Interior plaster	0.01	1400	0.7	900	0.014
Armoured concrete	0.2	2400	1.8	1102	0.111
Interior plaster	0.01	1400	0.7	900	0.014
U-value			**3.23 W/(m²K)**		

Table 31: Construction: interior wall facing heated room MFB30

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Interior plaster	0.01	1400	0.7	900	0.014

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Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Brick	0.15	1070	0.79	850	0.19
Interior plaster	0.01	1800	0.87	900	0.014
U-value			**2.57 W/(m²K)**		

Table 32: Construction: interior wall facing heated room MFB90

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Interior plaster	0.01	1400	0.7	900	0.014
Brick	0.15	1070	0.79	850	0.19
Interior plaster	0.01	1400	0.7	900	0.014
U-value			**2.57 W/(m²K)**		

Table 33: Construction: floor facing unheated room (basement) MFB30

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Cement screed	0.07	2000	1.4	850	0.05
PE cover foil	0.002	920	0.22	-	0.009
Insulation (EPS 30)	0.02	30	0.033	1404	0.606
Sound insulation (EPS-T)	0.02	13.5	0.039	1404	0.512
PE cover foil	0.002	920	0.22	-	0.009
Armoured concrete	0.25	2400	1.8	1102	0.139
Insulation (Lambda Facade 030)	0.1	18	0.03	1404	3.333
Interior plaster	0.01	1400	0.7	900	0.014
U-value			**0.21 W/(m²K)**		

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Table 34: Construction: floor facing unheated room (basement) MFB90

Layer	thickness m	density kg/m^3	lambda W/(m K)	Cp J/(kg K)	R-value m^{2}K/W
Cement screed	0.07	2000	1.4	850	0.05
PE cover foil	0.002	920	0.22	-	0.009
Insulation (cork)	0.03	175	0.05	1501	0.6
PE cover foil	0.002	920	0.22	-	0.009
Armoured concrete	0.25	2400	1.8	1102	0.139
Interior plaster	0.01	1400	0.7	900	0.014
U-value			**1.03 W/(m^{2}K)**		

Table 35: Construction: floor facing ground MFB30

Layer	thickness m	density kg/m^3	lambda W/(m K)	Cp J/(kg K)	R-value m^{2}K/W
Cement screed	0.06	2000	1.4	850	0.05
Armoured concrete	0.25	2400	1.8	1102	0.139
Insulation (XPS 500)	0.12	34	0.035	1400	3.43
U-value			**0.27 W/(m^{2}K)**		

Table 36: Construction: floor facing ground MFB90

Layer	thickness m	density kg/m^3	lambda W/(m K)	Cp J/(kg K)	R-value m^{2}K/W
Cement screed	0.06	2000	1.4	850	0.05
Insulation (cork)	0.03	175	0.05	1501	0.6
Armoured concrete	0.25	2400	1.8	1102	0.139
U-value			**1.14 W/(m^{2}K)**		

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Table 37: Construction: floor facing heated room (intermediate storey) MFB30

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Floor finish	0.005	1200	0.17	1400	0.03
Cement screed	0.07	2000	1.4	850	0.05
PE-foil	0.002	920	0.22	-	0.009
Insulation (Swisspor EPS30)	0.02	30	0.033	1404	0.606
Sound insulation (EPS-T)	0.02	13.5	0.039	1404	0.512
PE-foil	0.002	920	0.22	-	0.009
Armoured concrete	0.25	2400	1.8	1102	0.139
U-value			**0.66 W/(m²K)**		

Table 38: Construction: floor facing heated room (intermediate storey) MFB90

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Floor finish	0.005	1200	0.17	1400	0.03
Cement screed	0.07	2000	1.4	850	0.05
PE-foil	0.002	920	0.22	-	0.009
Insulation (cork)	0.03	175	0.05	1501	0.6
PE-foil	0.002	920	0.22	-	0.009
Armoured concrete	0.25	2400	1.8	1102	0.139
U-value			**1.0 W/(m²K)**		

Table 39: Construction: roof facing ambient MFB30

Layer	thickness m	density kg/m³	lambda W/(m K)	Cp J/(kg K)	R-value m²K/W
Armoured concrete	0.25	2400	1.8	1102	0.139
Foil (Swisspor BIKUPLAN)	0.0038	1236	0.17	1800	0.022
Insulation (Swisspor PUR)	0.1	30	0.02	1404	5.0

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	thickness	density	lambda	Cp	R-value
Layer	m	kg/m^3	W/(m K)	J/(kg K)	m^2K/W
Foil (Swisspor BIKUPLAN)	0.008	1236	0.17	1800	0.047
Gravel	0.05	2000	2.0	1051	0.025
U-value			**0.19 W/(m²K)**		

Table 40: Construction: roof facing ambient MFB90

	thickness	density	lambda	Cp	R-value
Layer	m	kg/m^3	W/(m K)	J/(kg K)	m^2K/W
Armoured concrete	0.25	2400	1.8	1102	0.139
Insulation (Swisspor XPS)	0.06	35	0.035	1450	1.71
Foil (Bitumen)	0.004	1100	0.23	1000	0.017
Gravel	0.05	2000	2.0	1051	0.025
U-value			**0.48 W/(m²K)**		

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A.2 Window position

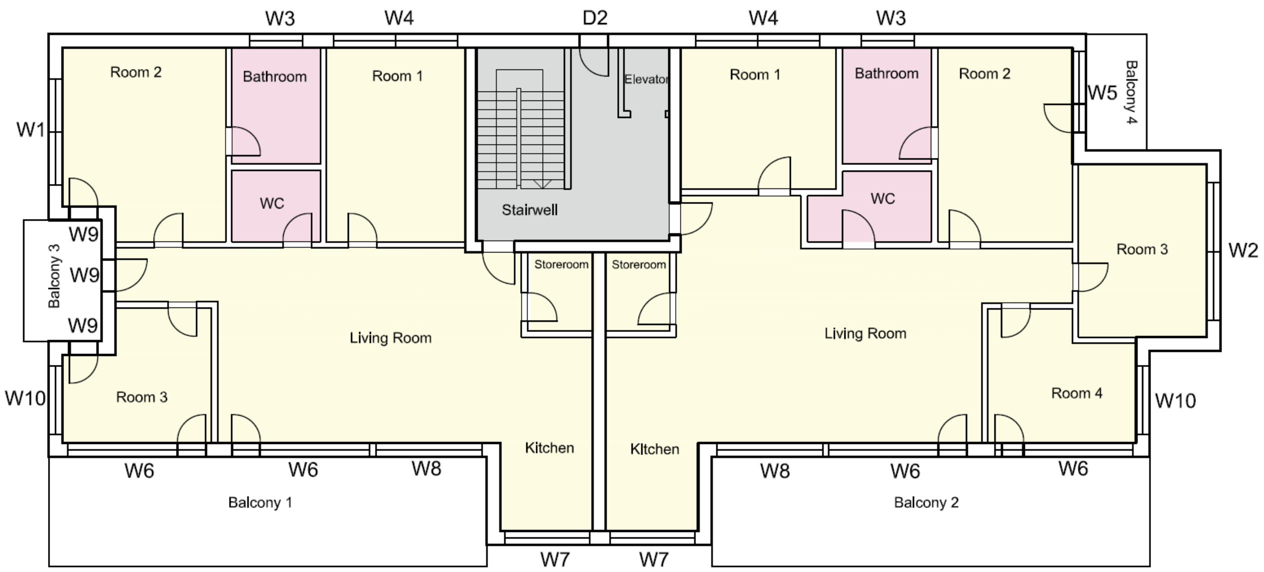
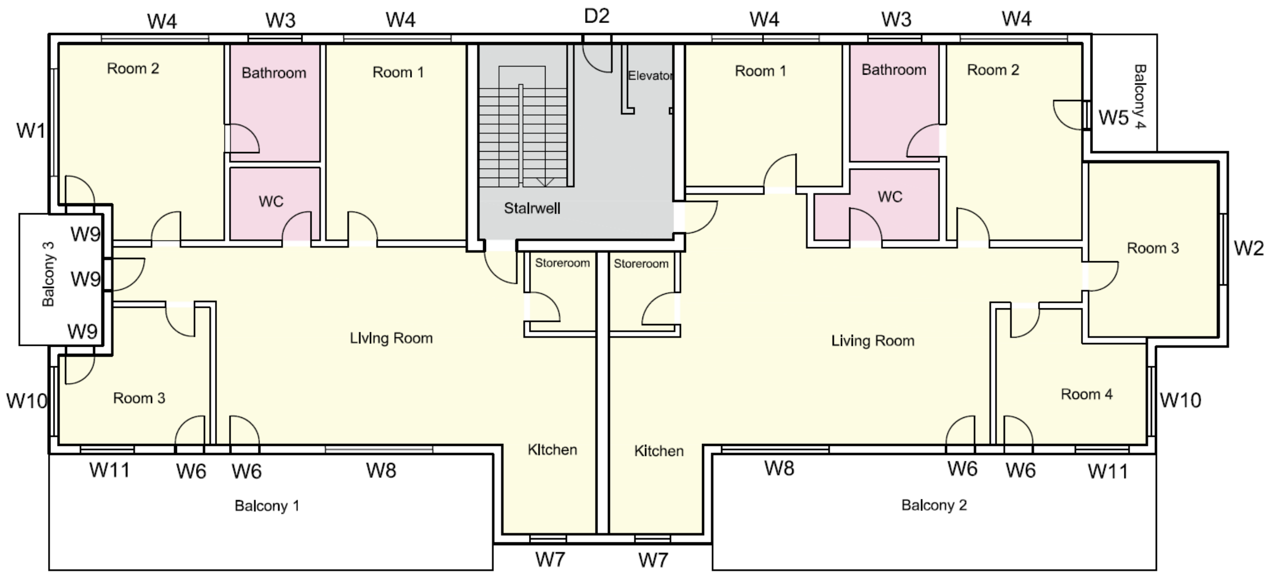


Figure 38: Floor plan for MFB30 with window labelling.



4

Figure 39: Floor plan for MFB90 with window labelling.

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Table 41: Window height measured from corresponding floor (floor to outer frame).

	MFB30 (m)	MFB90 (m)
W1	0.7	1.0
W2	0.7	1.0
W3	0.7	1.0
W4	0.7	1.0
W5	0.0	0.0
W6	0.0	0.0
W7	0.7	0.7
W8	0.0	1.0
W9	0.0	0.0
W10	0.7	1.0
W11	-	1.0

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Appendix B Household profiles

B.1 Description

The following parameter were used in the loadprofilegenerator to generate the household profiles.

CHR33: Couple, both under 30 years and employed

Table 42: CHR33 detailed user profile.

	Florian	Vicky
Age:	28	27
Sex:	male	female
Work:	Office: 9 hours a day from 8 a.m., 5 days a week	Teacher: 9 hours a day, 4.2 days a week
Hobbies:	Home cinema, dancing, laptop and internet	Home cinema, reading, puzzle
Sick at home:	3 days per year	3 days per year
Holydays:	11 days in April (together)	
Apartment:	Ground floor west	

CHR44: Family with two children, father working, mother at home

Table 43: CHR44 detailed user profile parents.

	Barbara	Reiner
Age:	43	45
Sex:	female	male
Work:	Home	Office: 9 hours a day from 8 a.m., 5 days a week
Hobbies:	Music, home cinema, puzzle, coffee at home with friends	Home cinema, puzzle, painting, video games, laptop and internet
Sick at home:	3 days per year	3 days per year
Holydays:	7 days in March (together)	
Apartment:	Ground floor east	

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Table 44: CHR44 detailed user profile children.

	Christopher	Sandy
Age:	16	14
Sex:	male	female
Work:	High School: 6 hours a day, 3.5 days a week	High School: 6 hours a day, 3.3 days a week
Hobbies:	Home cinema, video games, laptop and internet, party	Home cinema, babysitting, laptop and internet
Sick at home:	3 days per year	3 days per year
Holydays:	7 days in March (together)	
Apartment:	Ground floor east	

<u>CHR27: Family with two children, both parents working</u>

Table 45: CHR27 detailed user profile parents.

	Melanie	Emil
Age:	39	43
Sex:	female	male
Work:	Office: 9 hours a day from 8 a.m., 5 days a week	Teacher: 9 hours a day, 4.2 days a week
Hobbies:	Home cinema, puzzle, painting, video games, laptop and internet, music playing	Home cinema, laptop and internet
Sick at home:	3 days per year	3 days per year
Holydays:	20 days in July (together)	
Apartment:	First floor west	

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Table 46: CHR27 detailed user profile children.

	Tobias	Laura
Age:	13	9
Sex:	male	female
Work:	High school: 6 hours a day, 3.3 days a week	School: 6 hours a day, 3.5 days a week
Hobbies:	Home cinema, laptop and internet	Home cinema, playing piano
Sick at home:	3 days per year	4 days per year
Holydays:	20 days in July (together)	
Apartment:	First floor west	

CHS04: Couple, both retired

Table 47: CHS04 detailed user profile.

	August	Margot
Age:	71	68
Sex:	male	female
Work:	Retired	Retired
Hobbies:	Sleeping, volunteering work, home cinema, outgoing (weekends)	Computer, sleeping, sewing, TV, outgoing (weekends)
Sick at home:	5 days per year	7 days per year
Holydays:	6 days in September and 6 days in November (together)	
Apartment:	First floor east	

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CHR55: Couple, both working

Table 48: CHR55 detailed user profile.

	Stephan	Nicole
Age:	45	40
Sex:	male	female
Work:	Office: 11 hours a day from 7 a.m., 5 days a week	Teacher: 9.1 hours a day, 4.2 days a week
Hobbies:	Music, reading, swimming	Home cinema, running, shopping
Sick at home:	5 days per year	8 days per year
Holydays:	10 days in January (together)	
Apartment:	Second floor west	

CHR18: Family with two children, both parents at home

Table 49: CHR18 detailed user profile parents.

	Rachel	Dan
Age:	35	37
Sex:	female	male
Work:	Home office	Home office
Hobbies:	Running, home cinema, sleeping, cocking	Running, Home cinema, sleeping
Sick at home:	2 days per year	2 days per year
Holydays:	7 days in March (together)	
Apartment:	Second floor east	

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Table 50: CHR18 detailed user profile children.

	Simon	Sora
Age:	8	12
Sex:	male	female
Work:	School: 6 hours a day, 3.3 days a week	School: 6 hours a day, 3.5 days a week
Hobbies:	Video games	Video games
Sick at home:	3 days per year	3 days per year
Holydays:	7 days in March (together)	
Apartment:	Second floor east	

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