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Reference Framework for Building and System Simulations:

Multifamily Reference Building

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TRI-HP PROJECT

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Abstract

This paper describes two different reference multifamily buildings (MFH) 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 MFH30 and MFH90 according to their heat load (30 kWh/m^2 and 90 kWh/m^2) for Zurich.

- MFH30 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.
- MFH90 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:

	MFH30	MFH90	
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 MFH30 is 36'219 kWh and of MFH90 it is 104'584 kWh for the climate Zurich (SMA) simulated with IDA ICE (v4.8).

Changelog

Version	Date	Change
1.0	15.09.2019	Release
1.1	05.12.2019	Update of the front page with additional funding information (SFOE added)

Content

1 Introduction

This paper describes two different reference multifamily buildings (MFH) 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 MFH (Multi-Family Buildings) 30 and 90 according to their heat load for Zurich (Switzerland).

- MFH30 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].
- MFH90 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 MFH 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 1 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 (MFH90), 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.

Table 1: Summary of the main building parameter

	MFH30	MFH90	
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 "Changelog".

[2] Includes the insulation and walls (definition SIA 380/1 [8])
[3] Does not include internal walls in the apartments (see Figure 15 and Figure 16)
[4] Shape factor = thermal envelope divided by energy reference area

2 Building geometries

An overview of the building is shown in Figure 1. 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 2 to Figure 4 some dimensions of the buildings are shown.

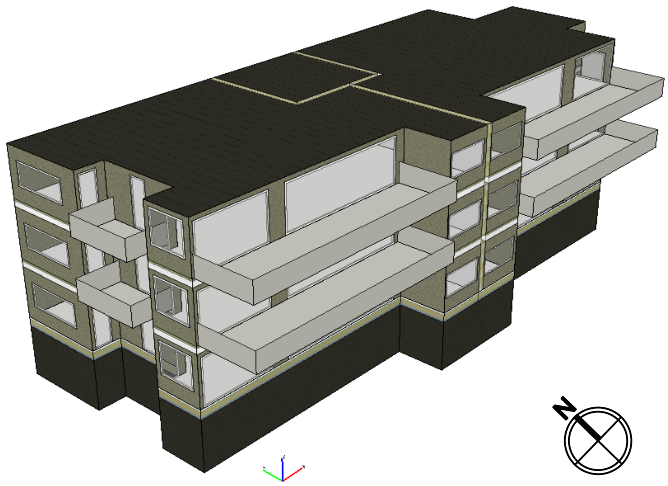

Figure 1: 3D illustration of the reference building MFH30 in IDA ICE.

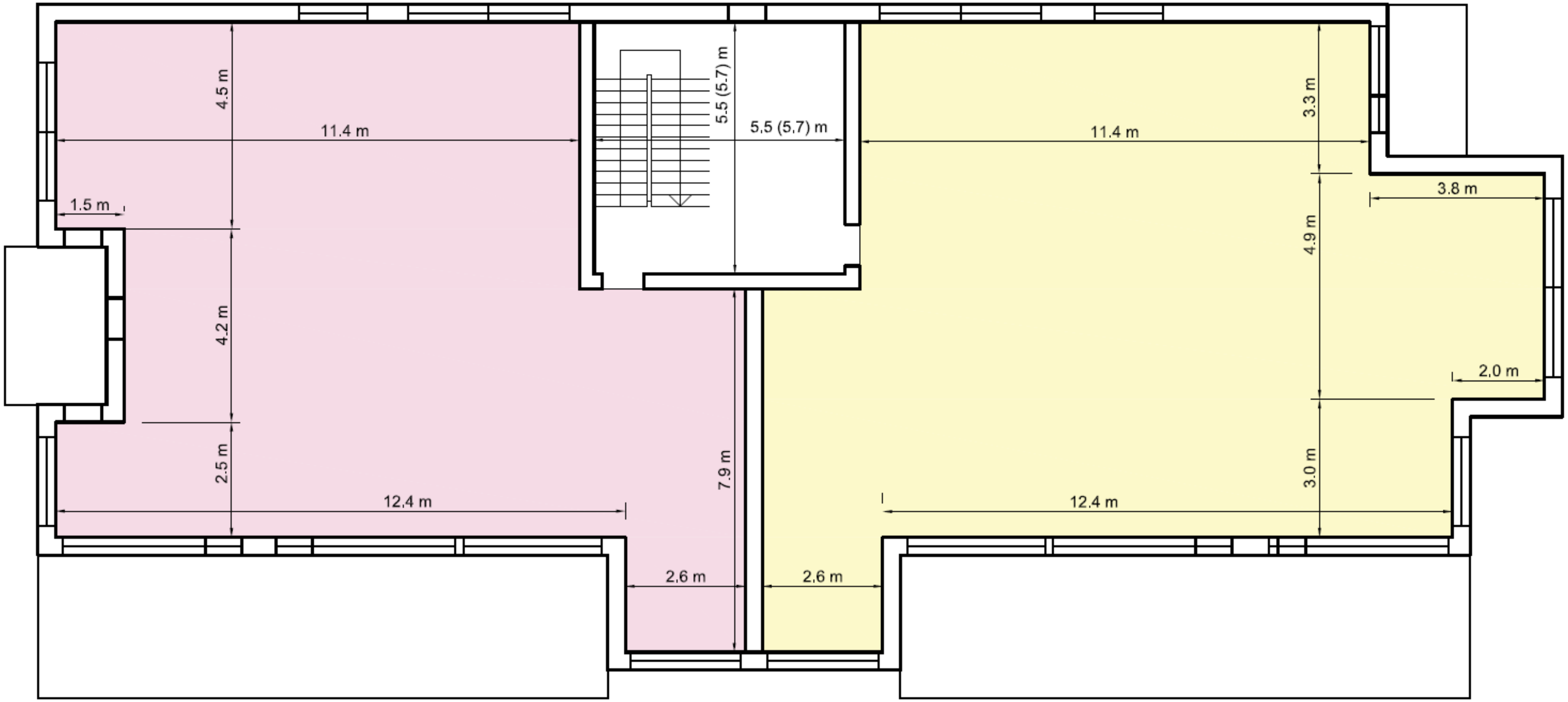

Figure 2: Floor plan of the three stories with apartments. Dimensions in brackets show values for MFH90, which are different to MFH30.

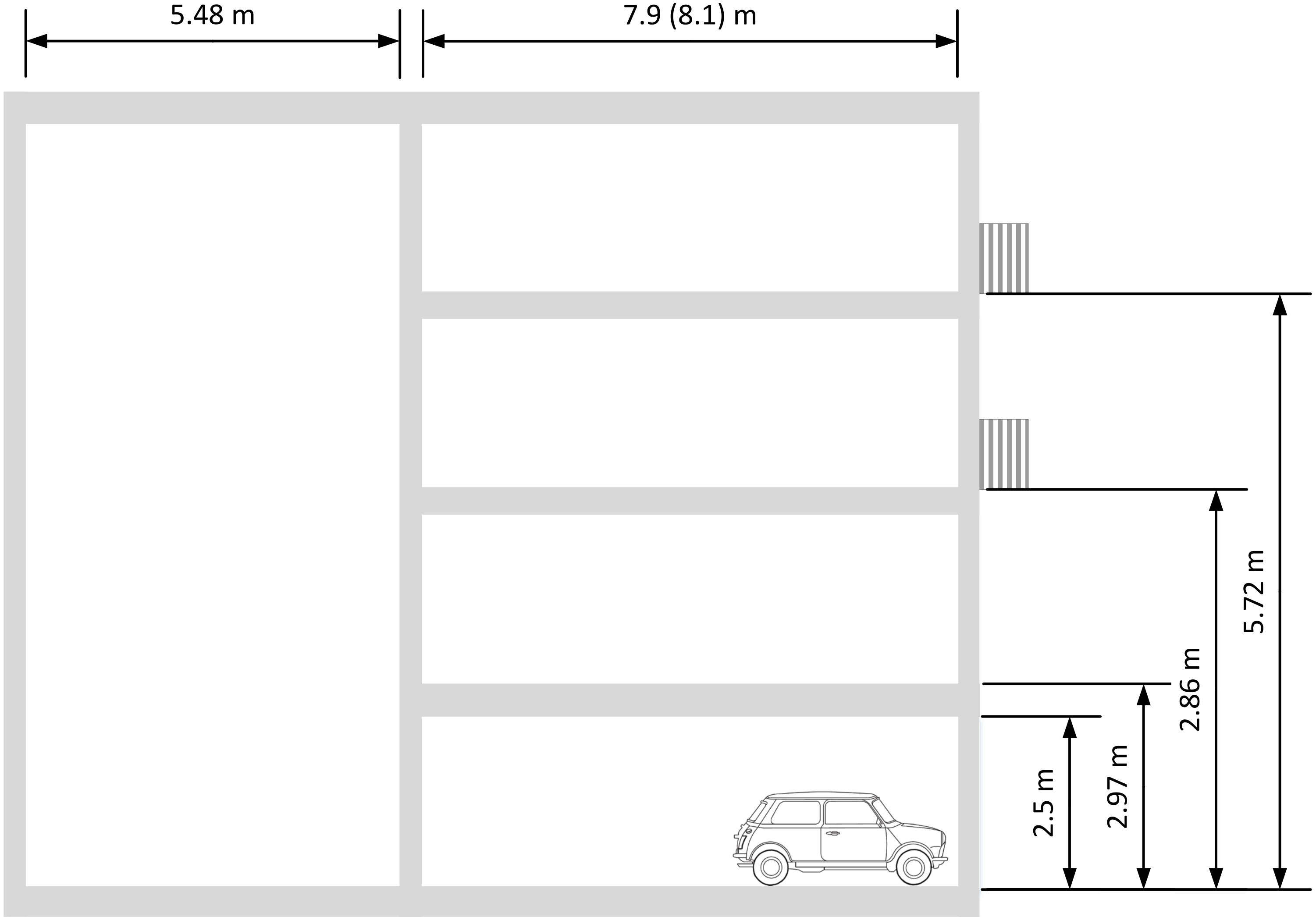

Figure 3: Side view of the building (cut in the middle). Dimensions in brackets show values for MFH90, which are different to MFH30.

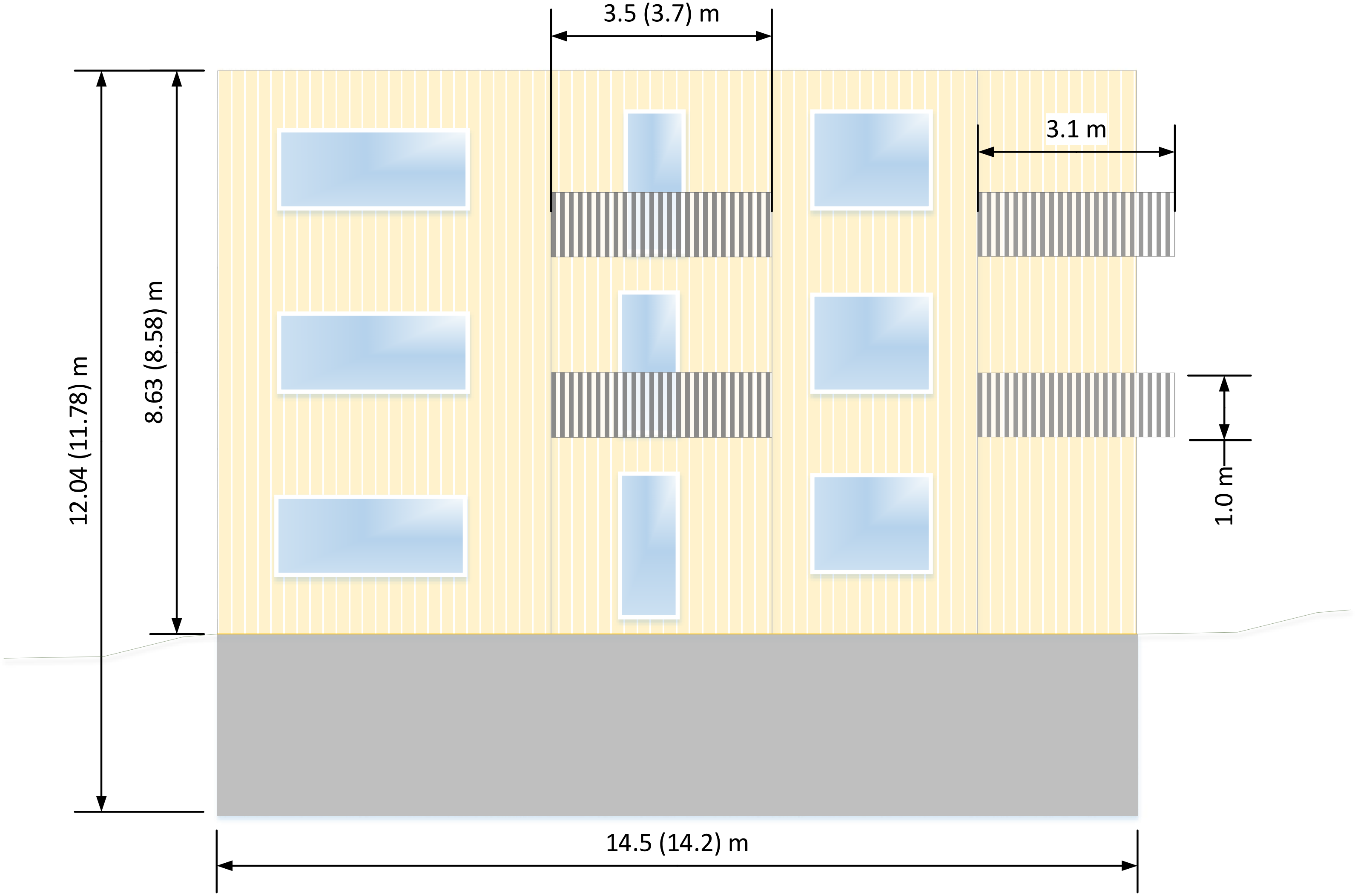

Figure 4: Side view of the building. Dimensions in brackets show values for MFH90, which are different to MFH30.

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 2 and described in detail in Annex A. For the U-value calculations, a total heat transfer coefficient of α_i = 7.69 W/m^{2}K to the inside and α_e = 25 W/m^{2}K 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 2: Summary of the opaque elements

	MFH30		*MFH90*	
	U-value	thickness	U-value	thickness
Element	(W/m^{2}K)	(m)	(W/m^{2}K)	(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 3. The thermal bridges are calculated according to the "Wärmebrückenkatalog" [11]. In Figure 5, the included thermal bridges are marked with "X" in the check boxes.

Table 3: Summary of the thermal bridges with Ψ as length related heat transfer coefficient.

	MFH30		***MFH90***	
	length	Ψ	length	Ψ
Type	(m)	(W/mK)	(m)	(W/mK)
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	

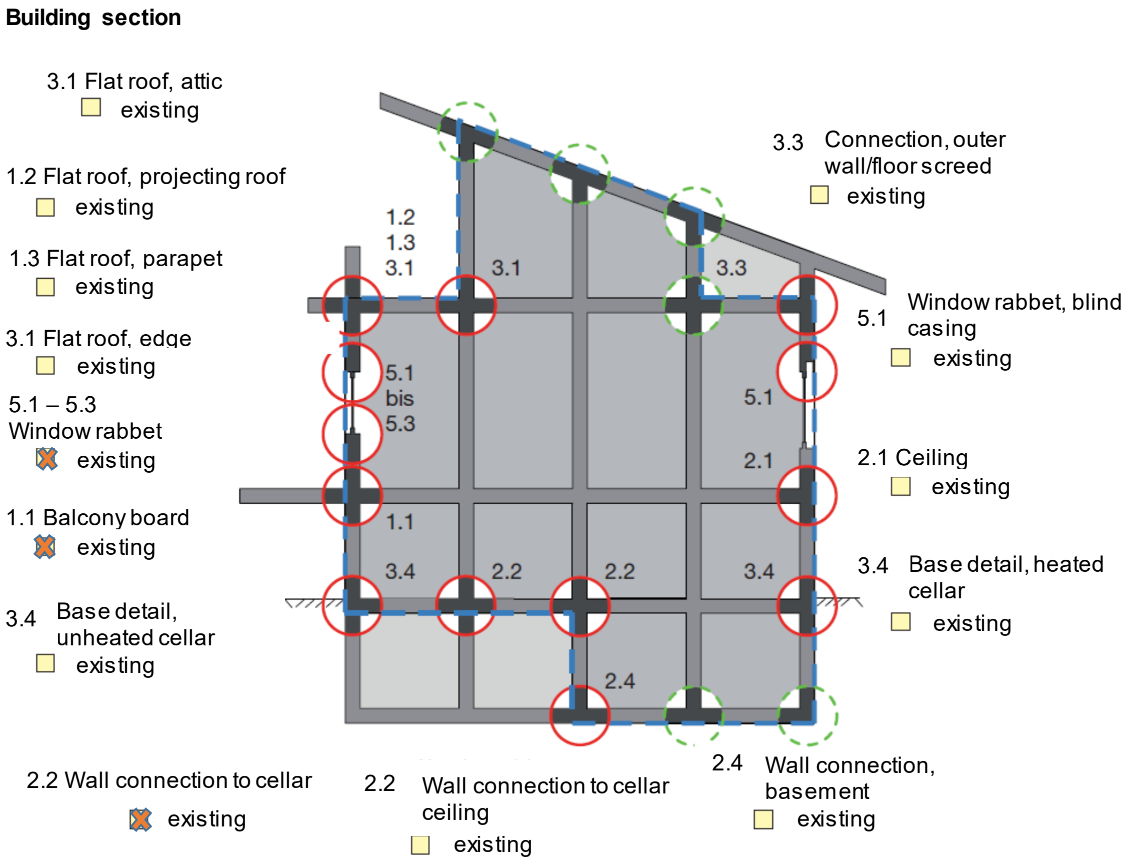

Figure 5: Illustration of the different thermal bridges for a residential building [12].

2.1.3 Windows

The global window parameters are given in Table 4. Specific window parameters for the MFH30 buildings are given in Table 5 and Table 6, and for the MFH90 the information are given in Table 7 and Table 8. The detailed position of the windows is given in Annex A. In addition to the standard U-value for glass (U_{glass}) provided in Table 4, a U-value including the losses of the window spacer are provided in Table 5 for MFH30 and for MFH90 in Table 7.

Table 4: Global window parameter for MFH30 and MFH90.

	MFH30	MFH90	
U_{frame}	1.3	1.6	W/m²K
Tau_e	0.4	0.4	-
G-value	0.45	0.62	-
U_{glass}	0.7	1.5	W/m²K

Table 5: Specific window parameter of MFH30

	U_{window} (W/m²K)	share frame	A_{window} (m²)	height (m)	width (m)	U_{glass} incl. window spacer (W/m²K)
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

Table 6: Window area compared to different reference areas for MFH30

	Window area (m²)	Glass area (m²)	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 7: Window parameter of MFH90

	U_{window} (W/m^2K)	share frame	A_{window} (W/m^2K)	height (m)	width (m)	U_{glass} incl. window spacer (W/m^2K)
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

Table 8: Window area compared to different reference areas for MFH90

	Window area (m²)	Glass area (m²)	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%

[5] Without underground floor

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 ($\mathrm{T_v}$) is calculated according to the standard as a weighted average value of the annual and the monthly mean air temperatures ($\mathrm{T_{mean}}$) and the actual air temperature ($\mathrm{T_{amb}}$), including a calculated time lag (see Eq. 1). The used ground parameters are summarized in Table 9.

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

Table 9: Ground parameters for both buildings.

	Symbol	Value	Unit
Thermal conductivity	λ	2.0	W/mK
Density	ρ	2000	kg/m^3
Heat capacity	c	1000	J/kgK
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

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 6Annex B.

3.2 Domestic hot water

In Table 10 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.

[6] www.spf.ch/MFHref

Table 10: 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/pd)	DHW load[7] (kWh/a)
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/MFHref). The annual electricity demand of the MFH30 building is 16'164 kWh or 15.9 kWh/m^2(NFA) per net floor area. For MFH90 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 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 (MFH30) 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 11. 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.

MFH90 has a constant, passive air exchange of 225.7 l/s (0.7 m^3/hm^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

[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).

In the case of MFH30 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 MFH90 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, MFH30: W1, W3, W5, W6, W7, W10 / MFH90: 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 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

Table 11: Ventilation rates in m³/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 12 and Table 13, 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/m²
- Wind speed is less than 10 m/s
- The moving average op. room temperature over 48 hours is comfortable (see Figure 6)

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.

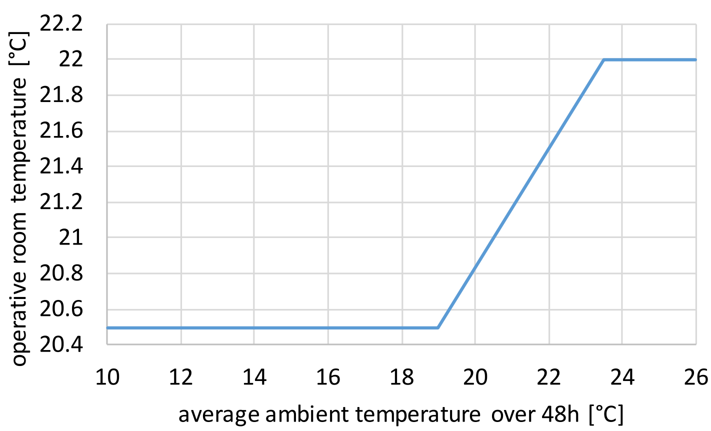

Figure 6: Comfortable operative room temperature depending on the average ambient temperature [15].

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 12: Shading factors of **fixed elements** for the specific façade of building MFH30.*

	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 13: Shading factors of **fixed elements** for the specific façade of building MFH90.*

	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.

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 7 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/MFHref) which matches with the DHW and electric equipment profile. The heat gains from the electrical equipment depends on the electrical power profile described in 3.3. In Figure 8, 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 14. The internal heat gains in the stairwell and the underground floor (cellar) were neglected.

[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).

Table 14: 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)
			MFH 30	MFH90
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

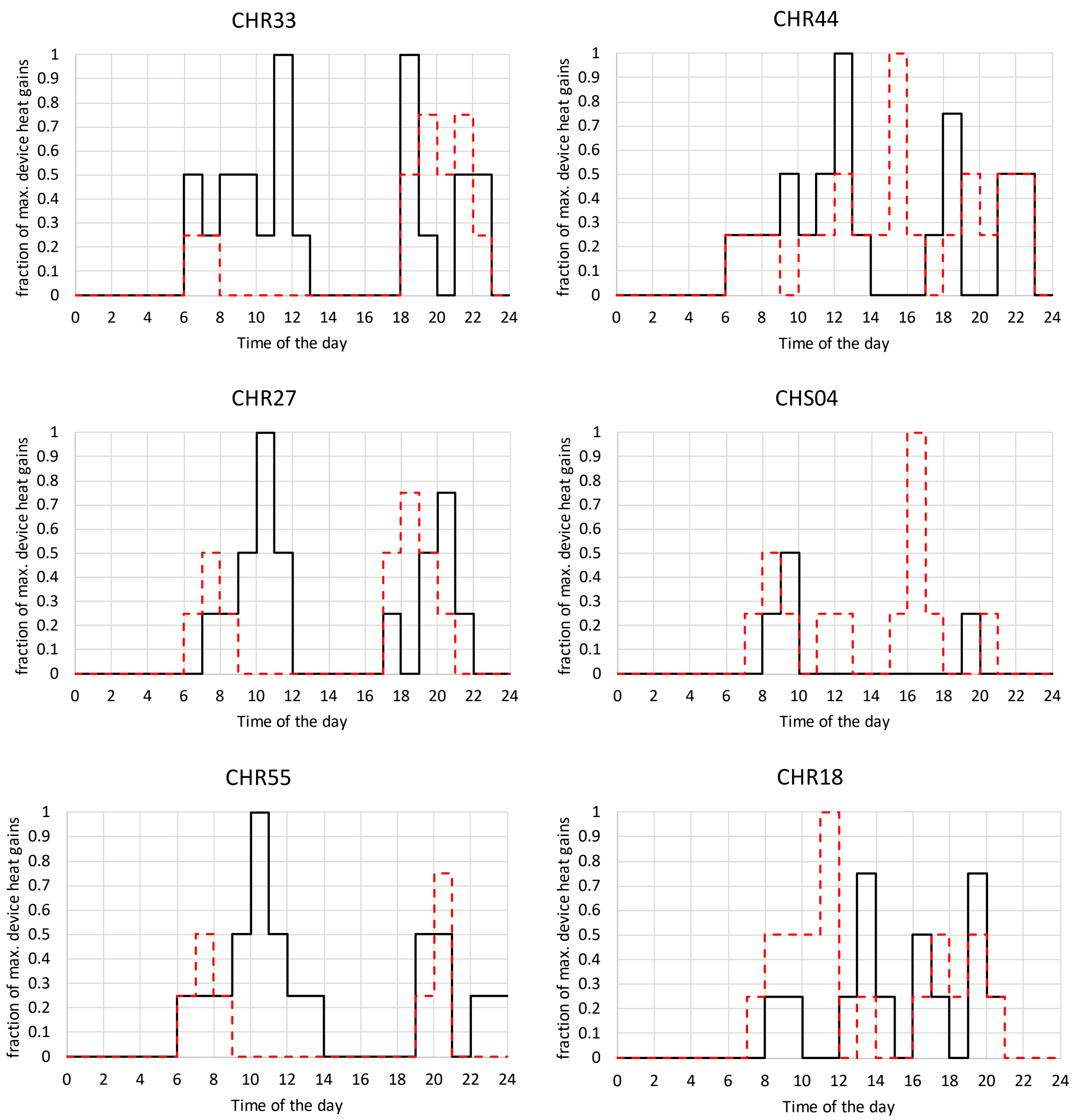

Figure 7: Profiles for the different households regarding the heat gains by electrical devices, in black the weekend (Saturday and Sunday) profile and in red the weekday profile.

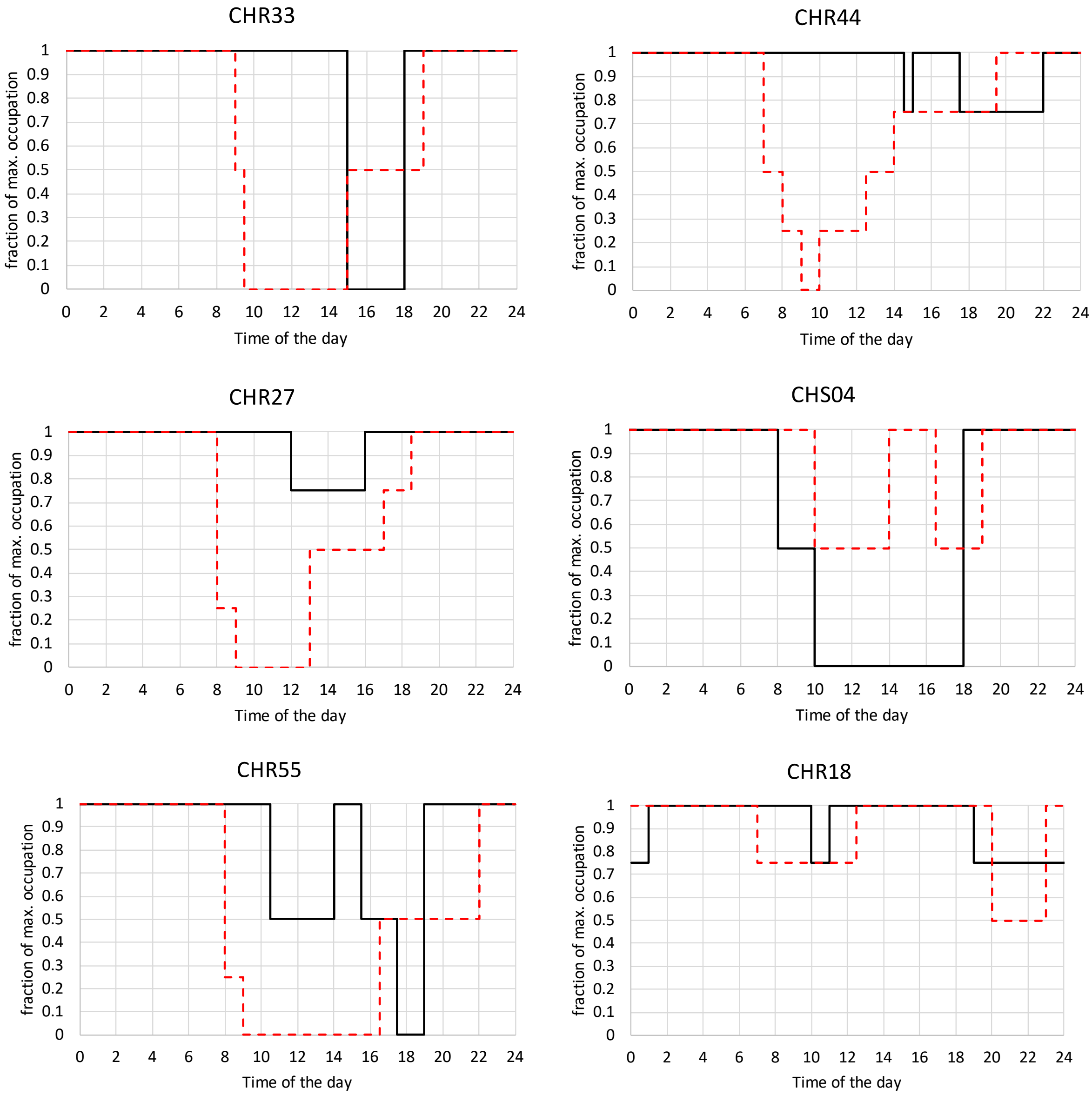

Figure 8: Profiles for the different households regarding the presence of occupants, in black the weekend (Saturday and Sunday) profile and in red the weekday profile.

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/a (30.1 kWh/m^{2}a(ERA)) and 104'584 kWh/a (89.5 kWh/m^{2}a(ERA)) for MFH30 and MFH90 respectively.

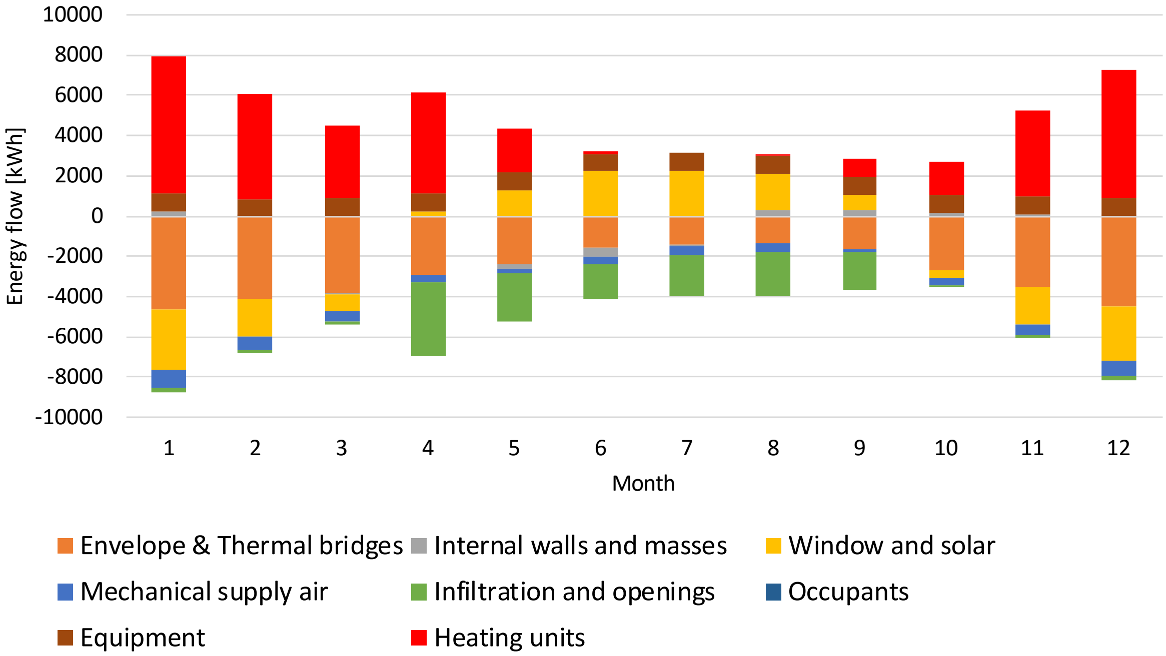

Figure 9: Monthly energy balance of MFH30.

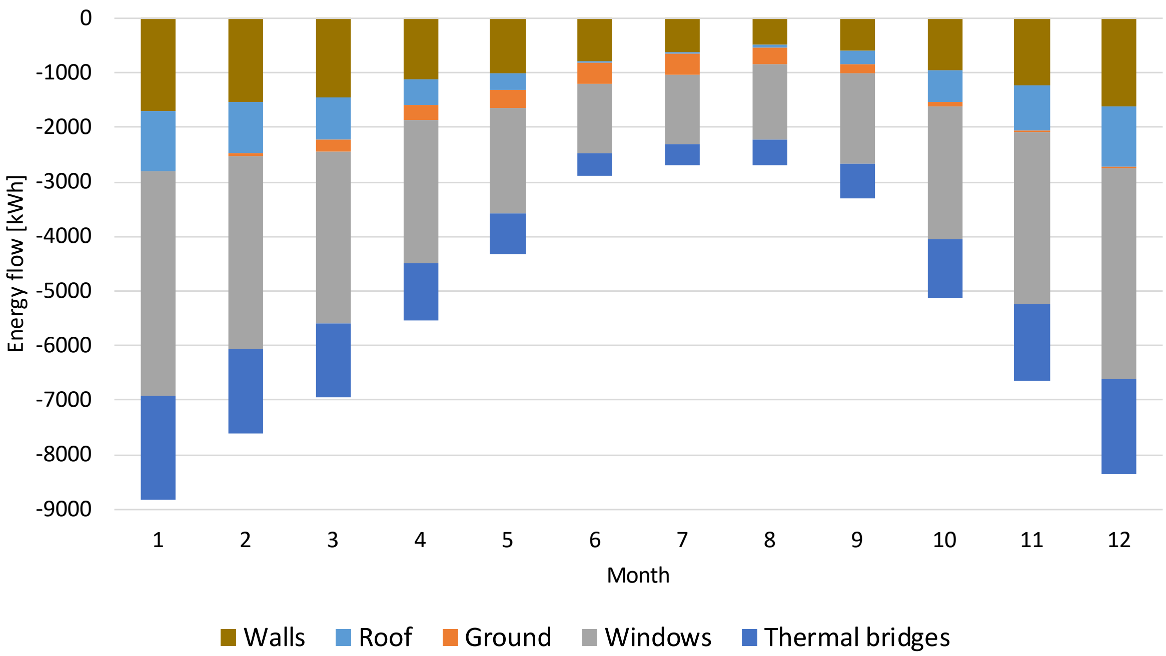

Figure 10: Monthly transmission through the building envelope of MFH30.

[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.

Table 15: Monthly and yearly energy balance of MFH30 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
Total	-34514	255	-2189	-5519	-14803	0	10560	36219

In Figure 11 the monthly heating demand of the MFH30 building is shown. As a result of the window opening behaviour the heating demand is higher in April than in March.

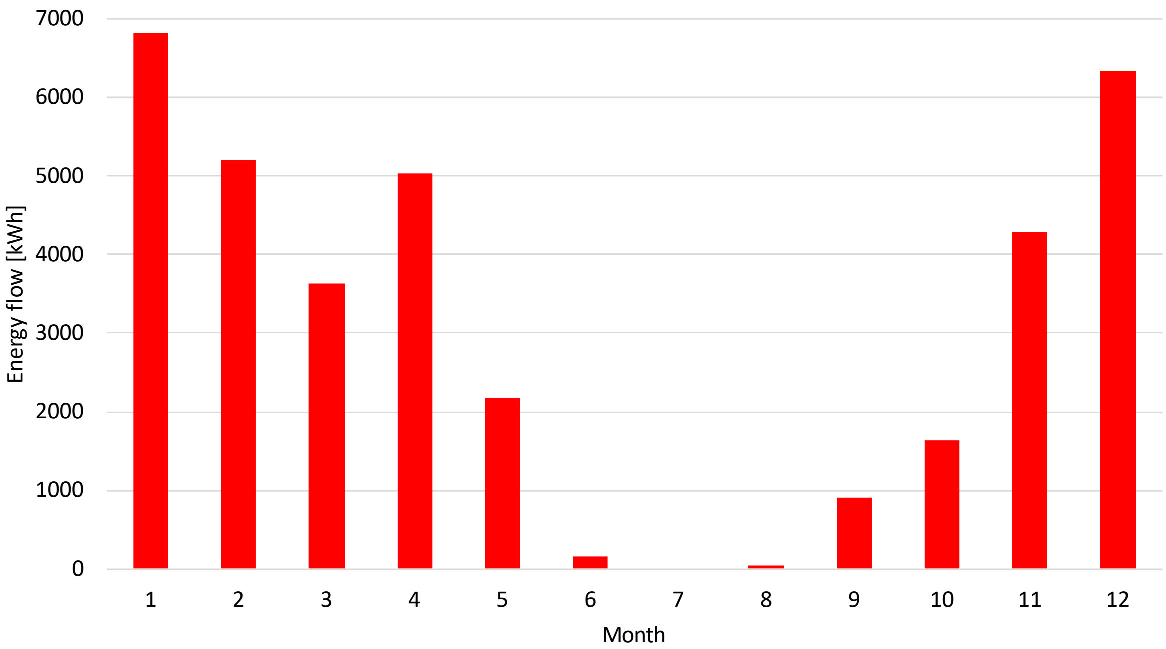

Figure 11: Monthly heat load of MFH30.

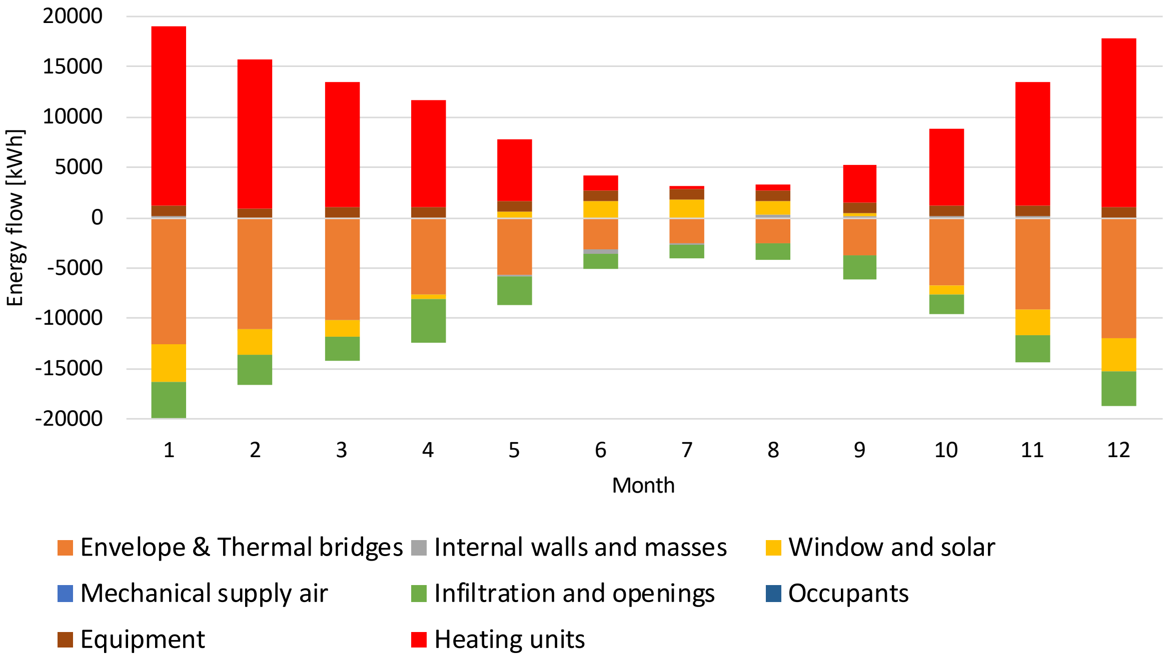

Figure 12: Monthly energy balance of MFH90.

Table 16: Monthly and yearly energy balance of MFH90 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
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

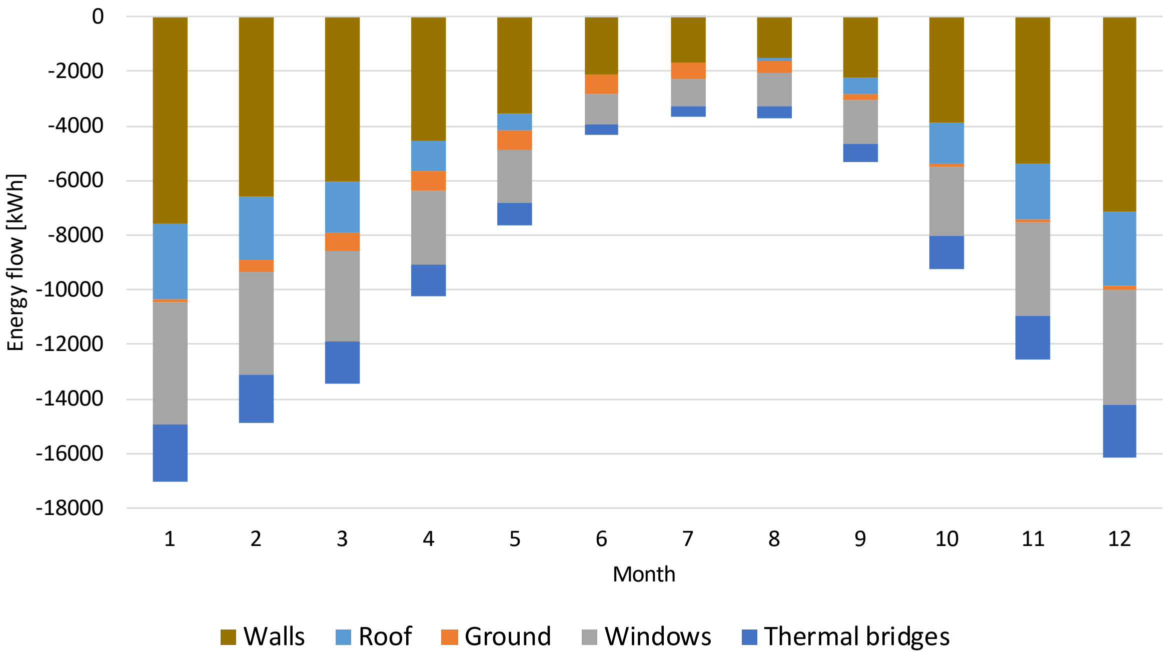

Figure 13: Monthly transmission through the building envelope of MFH90.

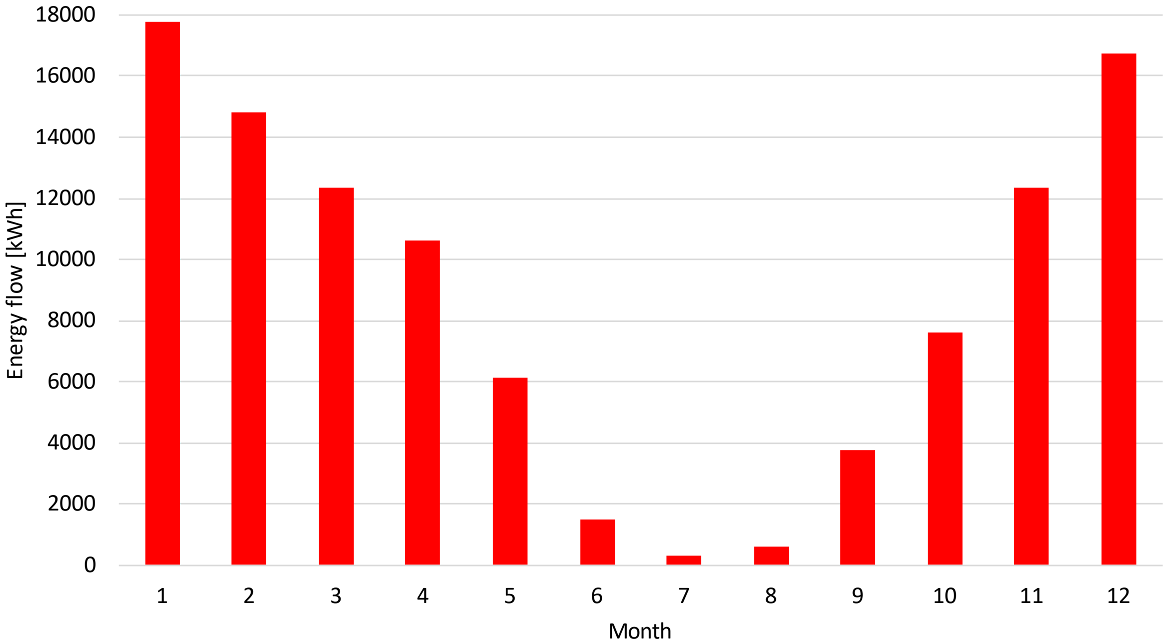

Figure 14: Monthly heat load of MFH90.

5 Literature

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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

Annex A Construction Details

A.1 Detailed opaque element parameters

Table 17: Construction: outer wall facing ambient MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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/m²K**		

Table 18: Construction: outer wall facing ambient MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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/m²K**		

Table 19: Construction: outer wall facing ground MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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/m²K**		

Table 20: Construction: outer wall facing ground MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 21: Construction: interior wall facing unheated room (stairwell) MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 22: Construction: interior wall facing unheated room (stairwell) MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 23: Construction: interior wall facing heated room MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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	1800	0.87	900	0.014
U-value			**2.57 W/m²K**		

Table 24: Construction: interior wall facing heated room MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 25: Construction: floor facing unheated room (basement) MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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**		

Table 26: Construction: floor facing unheated room (basement) MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 (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/m²K**		

Table 27: Construction: floor facing ground MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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/m²K**		

Table 28: Construction: floor facing ground MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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/m²K**		

Table 29: Construction: floor facing heated room (intermediate storey) MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 30: Construction: floor facing heated room (intermediate storey) MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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 31: Construction: roof facing ambient MFH30

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	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
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 32: Construction: roof facing ambient MFH90

Layer	thickness m	density kg/m³	lambda W/mK	Cp J/kgK	R-value m²K/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**		

A.2 Window position

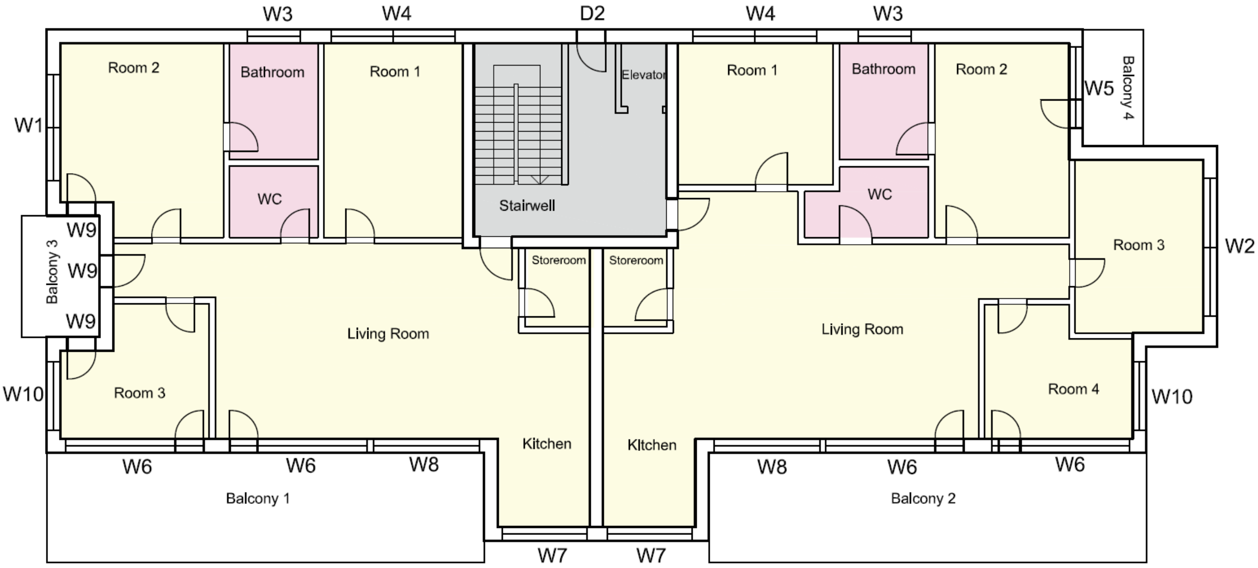

Figure 15: Floor plan for MFH30 with window labelling.

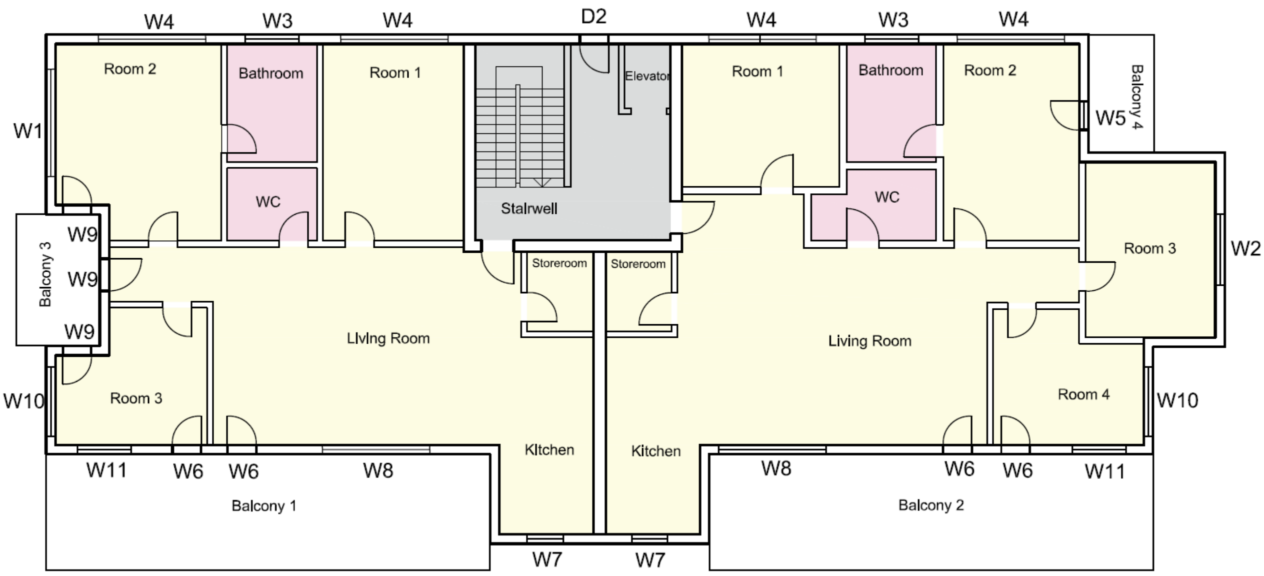

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Figure 16: Floor plan for MFH90 with window labelling.

Table 33: Window height measured from corresponding floor (floor to outer frame).

	MFH30 (m)	MFH90 (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

Annex 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 34: 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 35: 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	

Table 36: 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	

CHR27: Family with two children, both parents working

Table 37: 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	

Table 38: 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	

<u>CHS04: Couple, both retired</u>

Table 39: 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	

CHR55: Couple, both working

Table 40: 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 41: 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	

Table 42: 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	