RESHYVENT

Cluster Project on Demand Controlled Hybrid Ventilation in Residential Buildings with Specific Emphasis on the Integration of Renewables

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WP 5 Design parameters

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Description of reference buildings and ventilation systems

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Prepared by:
Andreas Weber, Viktor Dorer; EMPA, Switzerland
Eduardo Maldonado, José Luís Alexandre, Petra Vaquero and Jorge Sousa; IDMEC, Portugal
Åke Blomsterberg; WSP, Sweden
Nicolas Heijmans; BBRI, Belgium
Willem de Gids; TNO, Netherlands

Contents

1. Introduction

This document defines the reference buildings and boundary conditions for the simulations in WP6. These buildings and boundary conditions are based on the definitions given in the IEA Annex 27 “Evaluation and Demonstration of Domestic Ventilation Systems”. They are described in more detail in the document “Volume 2 Indoor Air Quality” [Millet 1998].

Additionally the following RESHYVENT documents are taken into account:

WP5-WR-2 v8	Parameter for the performance assessment of hybrid ventilation system
WP6-WR-6.1 v1-IC3	Input data: Study of IC3 ventilation system and Belgium reference system
WP6-WR-6.2 ref	Input data: Reference system definitions
WP6-WR-6.2.1-PT-IC5	Input Data of the Portuguese Ventilation System
WP6-WR-6.3 v2-IC1	Input data for building modelling IC1- Multi family building

2. Climate

Simulations will be made for four different climates. Energy+ weather data files of the following stations are used:

climate	location
cold	Stockholm
moderate	Amsterdam
warm	Nice
severe	Oslo
warm	Porto

Table 2-1 - Weather data locations and the corresponding climates which are used for the simulations

Energy+ weather data files are used to obtain the information about the various types of climates. In the following figures and tables, a short analysis of each one of the weather data files is done.
According to the Energy Plus weather data is showed the monthly average of the ground temperature for three different depths (0.5, 2 and 4m).
As this parameter is needed only for the calculations of the ground floor slab losses, in the simulations it will be used the first depth, i.e. 0.5 m.

2.1. Data files

Severe (Oslo)

	ºC	Date of occurrence
$T_{máx}$	27.9	31 July_14:00
$T_{mín}$	-16.8	31 December_03:00

Table 2-2 - Outdoor dry bulb temperature limits

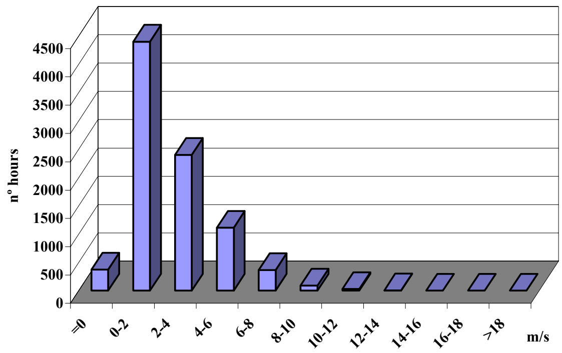


Figure 2-1 - Frequency of different wind speed

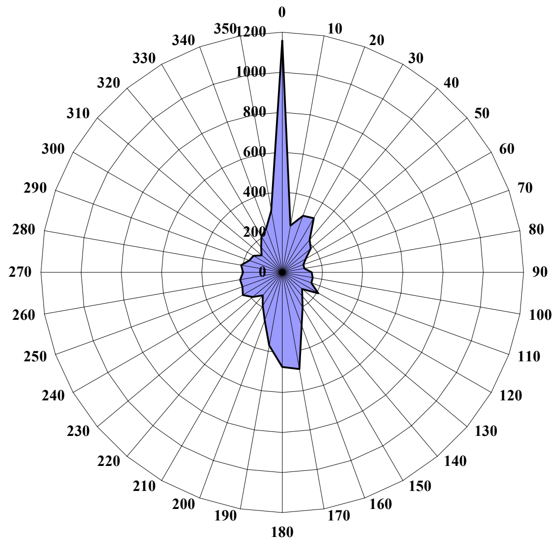


Figure 2-2 - Frequency of wind directions during the whole year

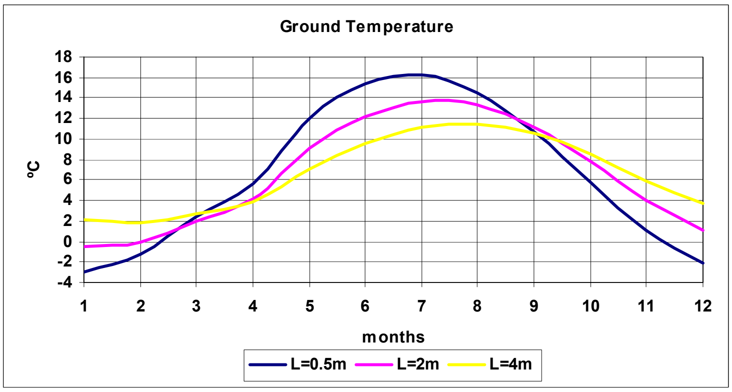


Figure 2-3 – Ground temperature

Cold (Stockholm)

	ºC	Date of occurrence
$T_{máx}$	27.0	24 June_14:00
$T_{mín}$	-17.0	27 January_03:00

Table 2-3 - Outdoor dry bulb temperature limits

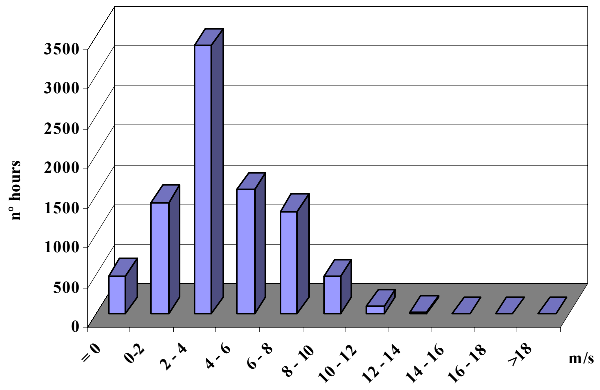


Figure 2-4 - Frequency of different wind speed for all year

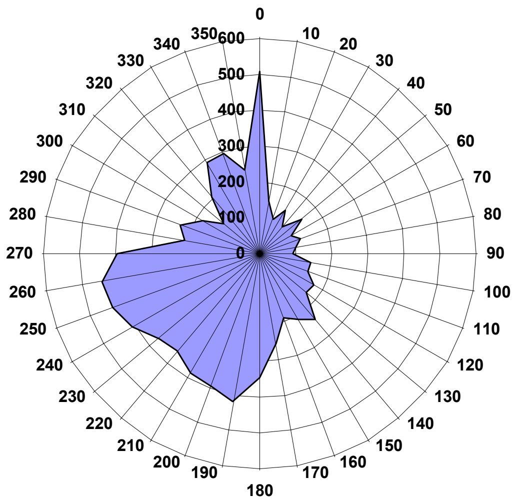


Figure 2-5 - Frequency of wind directions during all year

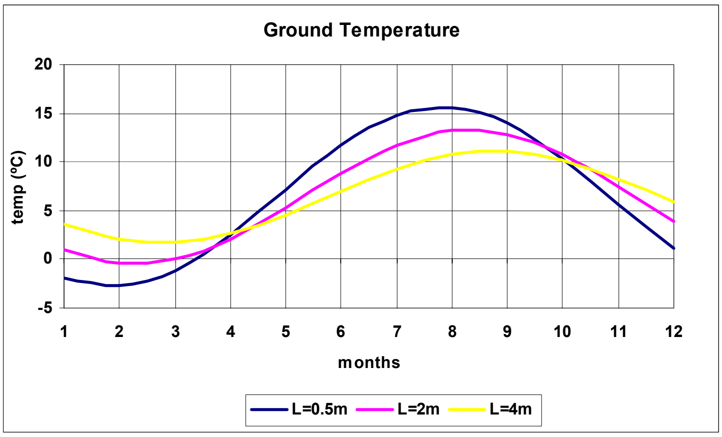


Figure 2-6 - Ground temperature

Moderate (Amsterdam)

	ºC	Date of occurrence
Tmáx	32.5	6 June_15:00
Tmín	-8.15	14 February_03:00

Table 2-4 - Outdoor dry bulb temperature limits

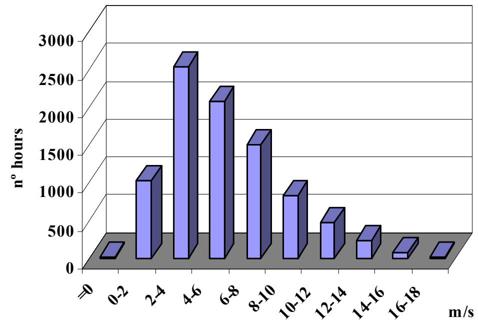


Figure 2-7 - Frequency of different wind speed

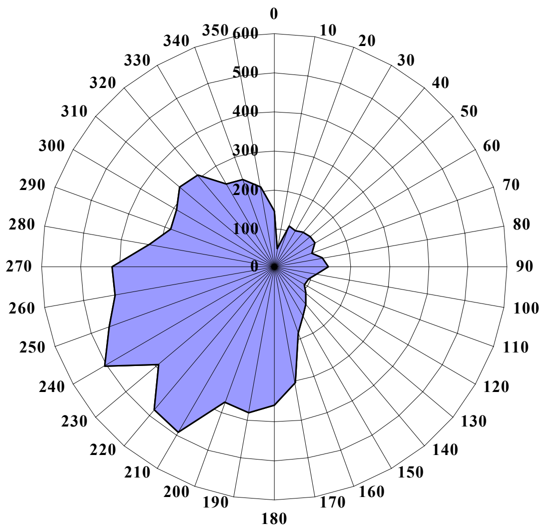


Figure 2-8 - Frequency of wind directions during all year.

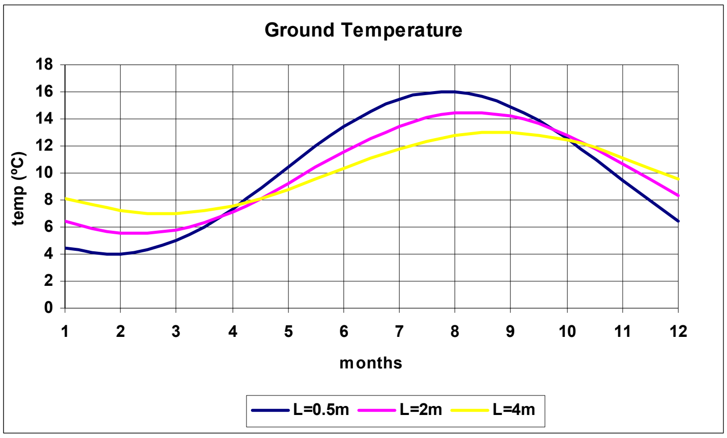


Figure 2-9 – Ground temperature

Warm (Porto)

	ºC	Date of occurrence
Tmáx	31	5 July_11:00
Tmín	0	24 January_5:00

Table 2-5 - Range of outdoor dry bulb temperature

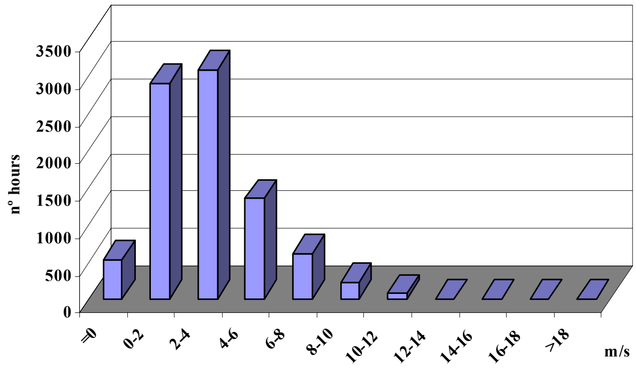


Figure 2-10 - Frequency of wind speed

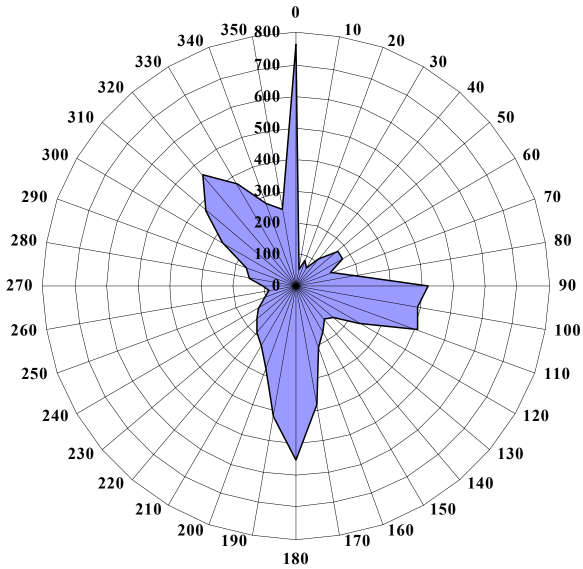


Figure 2-11 - Frequency of wind directions

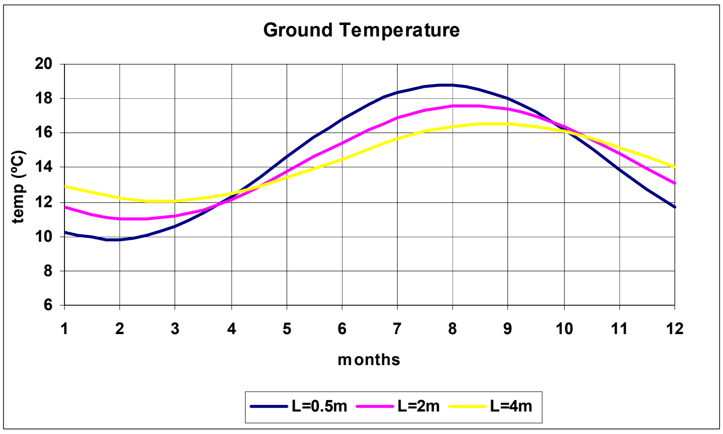


Figure 2-12 - Ground temperature

Warm (Nice)

	ºC	Date of occurrence
Tmáx	31	5 July_11:00
Tmín	0	24 January_5:00

Table 2-6 - Range of outdoor dry bulb temperature

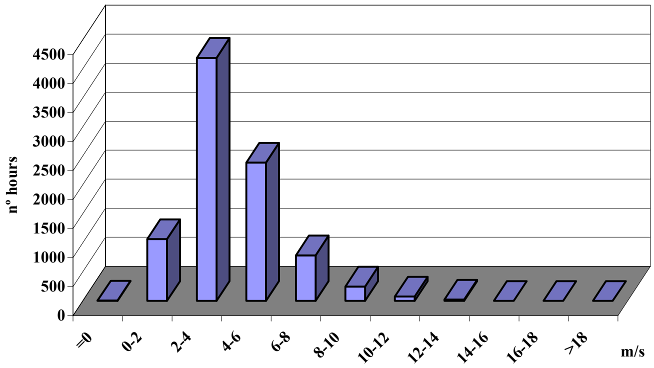


Figure 2-13 - Frequency of different wind speed

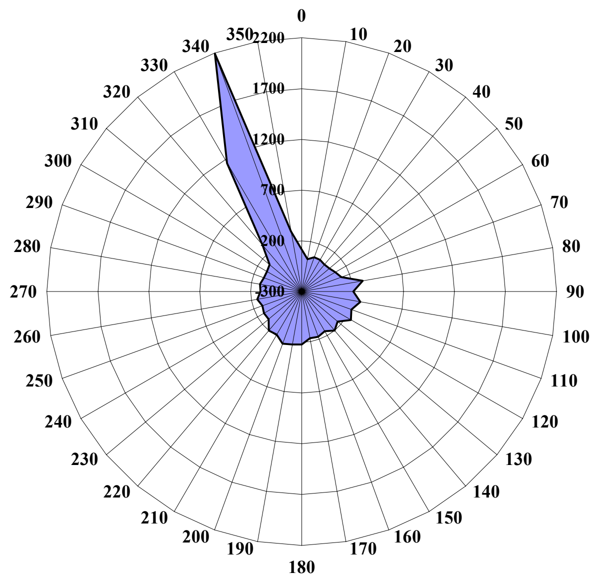


Figure 2-14 - Frequency of wind directions

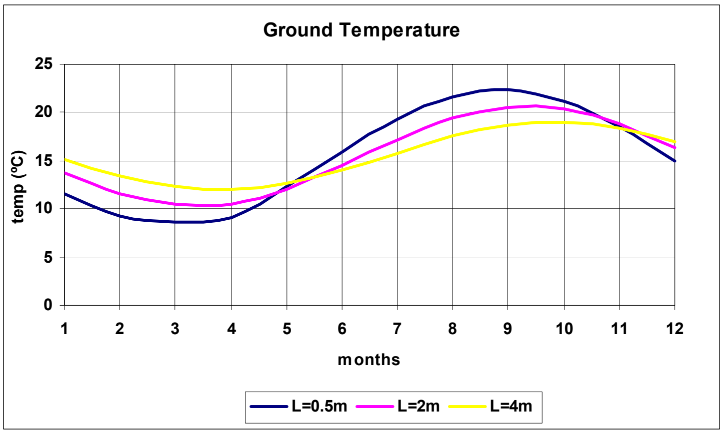


Figure 2-15 - Ground temperature

2.2. Outdoor CO_2 concentration

Outdoor CO_2 is assumed to be constant 350 ppm.

2.3. Heating period

According to RESHYVENT WP5, for space heating energy demand the heating system must be switch on only on those days when the daily averaged heat gains using a conventional utilization factor do not balance the averaged heat losses. On days with the heating system switched off, the room temperature might fall temporary below the set point. The definition according to A27-V2 is:

1. calculate for each day the average outdoor temperature on the period of 15 days before and 15 days after;
2. start in summer;
3. stop when this averaged daily temperature is equal to 13 ºC. This is the starting day of the heating season, which is defined as Monday;
4. restart the calculation of daily average temperature until spring;
5. stop when it is equal to 13 ºC. This is the last day of the heating season, whatever day is.

The conventional heating period for each one of the considered locations is available in table 2-7

climate	location	heating period
cold	Stockholm	from 02/09 to 08/07
moderate	Amsterdam	from 02/10 to 22/05
severe	Oslo	from 04/09 to 21/07
warm	Porto	from 11/10 to 14/04
warm	Nice	from 11/11 to 06/04

Table 2-7 - Heating period according to WP5 recommendations

3. Dwelling types

3.1. General description

The simulations are done for an apartment dwelling and for a single family house based on the dwellings proposed in Annex 27.
The floor area of the SFH is 85 m^2. It has three bedrooms, one living room, one kitchen, one bathroom and a toilet. The apartments have 80 m^2. They have two or three bedrooms, one living room, one kitchen, and one bathroom.

3.2. Floor plans and room floor areas

The following dwelling types are selected for the different ICs:

- IC1 cold:
  Apartment on the ground/top floor in a four storey building based on the Annex 27 – D4a dwelling type but with some modifications according to a typical Swedish apartment of that size. This dwelling Type is called D3c (figure 3-1):
  - Bedroom 3 removed and bedroom 1 and 2 enlarged
  - No wall between living room, kitchen and hallway
  - No separate toilet

- IC2 moderate, IC3 mild and warm, IC4 severe and Portugal IC5 (virtual IC) warm:
  The simulations will be done for both an apartment and a single family house:
  - Apartment on the ground/top floor in a four storey building (A27 – D4a) (figure 3-2)
  - Two storey detached single family house with four rooms (A27 D4c) (figure 3-3).

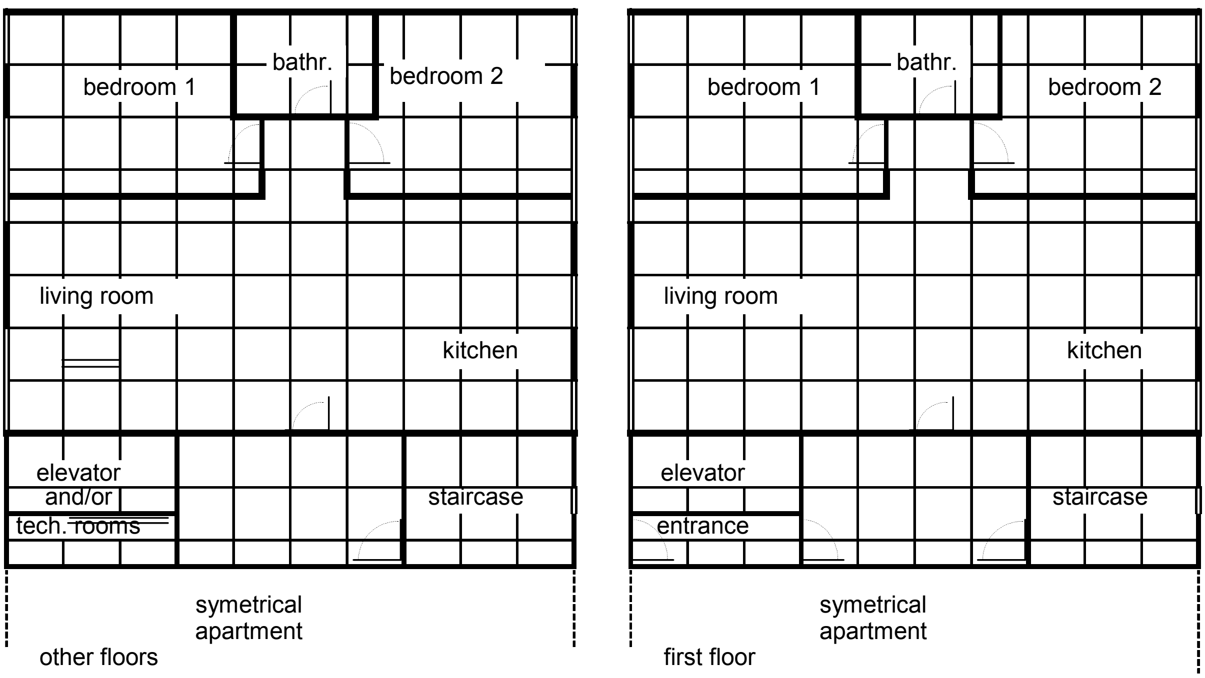


Figure 3-1 - Three room apartment D3c (ground floor and top floor)

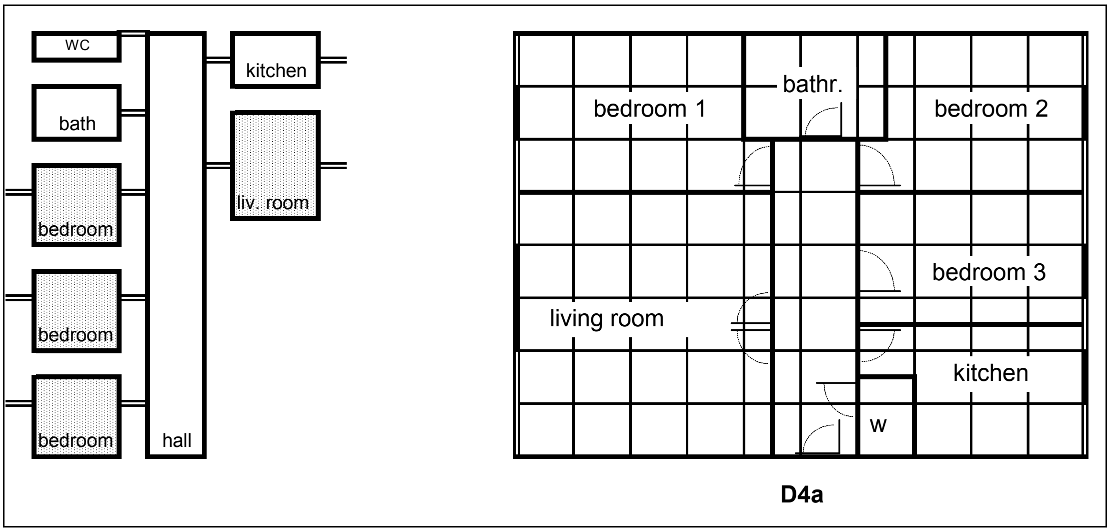


Figure 3-2 - Four room apartment D4a (ground floor and top floor)

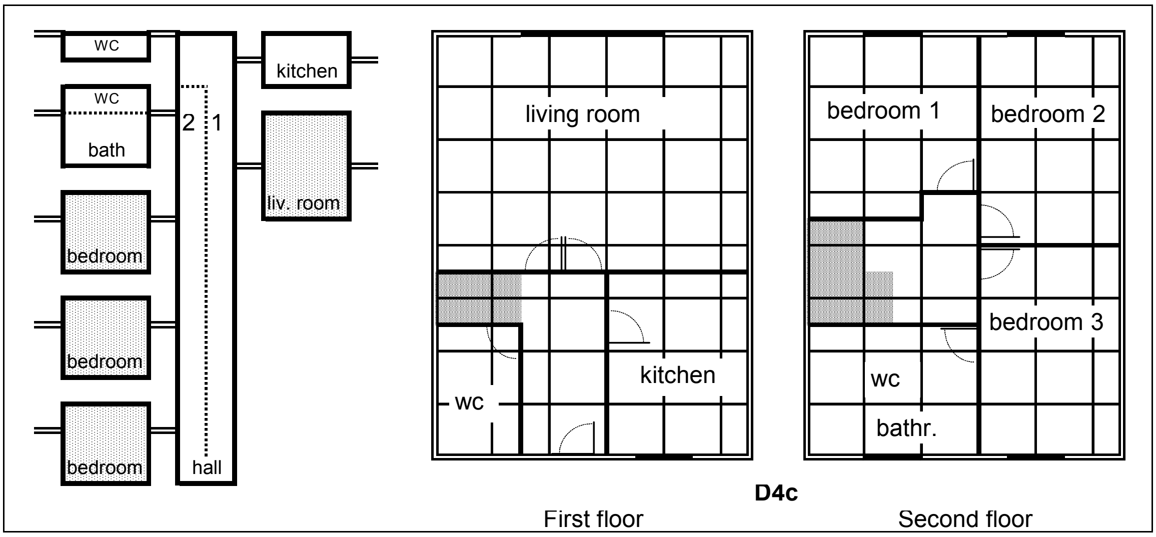


Figure 3-3 - Single family house D4c

The room height is 2.5 m and the construction height is 2.8 m defined to be from the top of the floor on one storey to the top of the floor in the next storey.
Simplified room floor areas are given in table 3-1.

	D3c	D4a	D4c
living room	47.25	22.5	24.75
kitchen		8.5	8.75
bedroom 1	14.75	12.5	10
bedroom 2	13	11	10
bedroom 3	-	10	10
WC	-	1.5	3.75
bathroom	5	5	7.5
hall + staircase	-	9	9.25
total	80	80	84

Table 3-1 - Room floor areas (in m^2)

3.3. Orientation

Three cases of orientations are used for the sensitivity analysis.
The orientation of the main façade of the living room is:

- **north**
- **south**
- **west**

3.4. Number of floor levels

The dwelling types D3a and D4a can be located in a building with different numbers of floor levels. Three cases are assumed for the sensitivity analysis:

- **1 floor level**
- **2 floor levels**
- **4 floor levels**

3.5. Building elements and materials

Walls, floors and roofs

The table 3-2 shows a detailed description of the complete building envelope construction elements, walls, slab floor, etc. Each envelope element is made by different layers material that it is starting from inside to outside element's surface and the properties of that layers are defined in table 3-2.

Element	Layers	Thickness [m]	λ [W/mK]	c_p [J/kgK]	ρ [kg/m^3]	R [m^{2}K/W]	U [W/m^{2}K]
External wall	Internal heat transfer	-	-	-	-	0.140	0.22
	Gypsum board	0.013	0.21	1000	900	0.062	
	Mineral wool	0.11	0.046	750	60	2.391	
	Air gap	0.02	-	-	-	0.174	
	Brick	0.1	0.06	840	1500	1.667	
	External heat transfer	-	-	-	-	0.060	
Internal wall, within apart-ments	Internal heat transfer	-	-	-	-	0.140	1.4
	Gypsum board	0.026	0.21	1000	900	0.124	
	Air Gap	0.02	-	-	-	0.174	
	Gypsum board	0.026	0.21	1000	900	0.124	
	Internal heat transfer	-	-	-	-	0.140	
Internal wall, be-tween apart-ments	Internal heat transfer	-	-	-	-	0.140	2.4
	Concrete	0.2	1.5	830	2300	0.133	
	Internal heat transfer	-	-	-	-	0.140	
Slab be-tween floors	Internal heat transfer	-	-	-	-	0.140	1.9
	Top: wood	0.015	0.13	2500	500	0.115	
	Slab of clay	0.2	1.5	830	2300	0.133	
	Internal heat transfer	-	-	-	-	0.140	
Roof slab	Internal heat transfer	-	-	-	-	0.140	0.15
	Inside: con-crete	0.20	1.5	830	2300	0.133	
	Outside: polystyrene	0.25	0.040	1400	20	6.25	
	External heat transfer	-	-	-	-	0.060	
Floor slab	Internal heat transfer	-	-	-	-	0.140	0.18
	Inside: wood	0.015	0.013	2500	500	1.154	
	concrete	0.15	1.5	830	2300	0.1	
	Polystyrene	0.05	0.04	1045	70	1.250	
	Outside: clay	-	-	-	-	3.00	
	External heat transfer	-	-	-		0.060	

Table 3-2 - Physical proprieties of the walls, slabs and roofs layers for the IC1 building

Element	Layers	Thickness [m]	λ [W/mK]	c_p [J/kgK]	ρ [kg/m³]	R [m²K/W]	U [W/m²K]
External Wall	Internal heat transfer	-	-	-	-	0.130	0.32
	Inner panel	0.1	1	840	2000	0.010	
	Insulation	0.09	0.035	1470	15-30	2.571	
	Air gap	0.03	-	-	-	0.170	
	Outside panel	0.1	1.2	840	1900	0.083	
	External heat transfer	-	-	-		0.040	
Internal Wall	Internal heat transfer	-	-	-	-	0.130	2.8
	lime sand brick	0.1	1	840	2000	0.010	
	Internal heat transfer	-	-	-	-	0.130	
Slab be-tween floors	Internal heat transfer	-	-	-	-	0.130	2.7
	Concrete	0.20	1.9	840	2500	0.105	
	Internal heat transfer	-	-	-	-	0.130	
Floor slab	Internal heat transfer	-	-	-	-	0.130	0.35
	Top floor	0.05	0.5	840	1350	0.100	
	Concrete	0.05	1.7	840	2400	0.029	
	Insulation	0.12	0.045	1470	15-30	2.667	
	External heat transfer	-	-	-		0.040	
Roof slab	Internal heat transfer	-	-	-	-	0.130	0.33
	Insulation	0.12	0.045	1470	15-30	2.667	
	Wooden panels	0.02	0.15	1880	600	0.133	
	Air gap [1)]	0.02	-	-	-	0.0	
	Roof tiles [1)]	-	-	-	-	0.0	
	External heat transfer [1)]	-	-	-		0.130	

Table 3-3 - Physical proprieties of the walls, slabs and roofs layers for the IC2 building

Remarks:

1) Tiles are not considered to calculate the U-value and for the dynamic simulation, as the air gap is strongly ventilated. Furthermore: the external heat transfer coefficient is equal to the internal (7.7 W/m²K)

Element	Layers	Thickness [m]	λ [W/mK]	c_p [J/kgK]	ρ [kg/m^3]	R [m^{2}K/W]	U [W/m^{2}K]
External Wall	Internal heat transfer	-	-	-	-	0.125	0.51
	Bricks SB	0.14	0.32	1000	980	0.438	
	Polystyrene, rigid ex-truded	0.05	0.045	1450	25	1.111	
	Air gap	0.03	-	-	-	0.170	
	Brick	0.09	1.09	1000	1600	0.083	
	External heat transfer	-	-	-		0.043	
Internal Wall	Internal heat transfer	-	-	-	-	0.125	1.7
	cellular con-crete	0.1	0.29	1081	725-775	0.344	
	Internal heat transfer	-	-	-	-	0.125	
Internal Floor	Internal heat transfer	-	-	-	-	0.125	1.3
	(paving) can be neglected	0.003	0.81	2500	750	0.0	
	light concrete	0.05	0.37	1000	1200	0.135	
	concrete slab	0.13	0.95-	1000	1600	0.137	
	air gap	0.05	-	-	-	0.140	
	false-ceiling	0.012	0.15	1000	1300	0.080	
	Internal heat transfer	-	-	-	-	0.125	
Floor above ground	Internal heat transfer	-	-	-	-	0.125	0.48
	(paving) can be neglected	0.003	0.81	2500	750	0.0	
	light concrete	0.05	0.37	1000	1200	0.135	
	polyurethane	0.06	0.035	1400	30	1.714	
	concrete	0.15	1.3	1000	2200	0.115	
	External heat transfer	-	-	-		0.043	
Roof	Internal heat transfer	-	-	-	-	0.125	0.37
	plaster	0.012	-	1000	1300	0.08	
	air gap	0.02	-	-	-	0.140	
	mineral wool	0.10	0.045	1450	25	2.222	
	air gap [1)]	0.05	-	-	-	0.0	
	tiles [1)]	0.03	1.15	880	1900	0.0	
	External heat transfer [1)]	-	-	-		0.125	

Table 3-4 - Physical proprieties of the walls, slabs and roofs layers for the IC3 building

Remarks:

1) Tiles are not considered to calculate the U-value and for the dynamic simulation, as the air gap is strongly ventilated. Furthermore: the external heat transfer coefficient is equal to the internal (8 W/m²K)

Element	Layers	Thickness [m]	λ [W/mK]	c_p [J/kgK]	ρ [kg/m^3]	R [m^{2}K/W]	U (W/m^{2}K)
External Wall	Internal heat transfer	-	-	-	-	0.130	0.47
	Gypsum board	0.02	1.15	837	1950	0.017	
	Brick	0.15	0.44	936	1100	0.341	
	Air gap	0.02	-	-	-	0.174	
	Polystyrene, rigid extruded	0.04	0.035	1210	35	1.143	
	Brick	0.11	0.44	936	1100	0.250	
	Gypsum board	0.02	1.15	837	1950	0.017	
	External heat transfer	-	-	-		0.043	
Internal Wall	Internal heat transfer	-	-	-	-	0.130	1.8
	Gypsum board	0.02	1.15	837	1950	0.017	
	Brick	0.11	0.44	936	1100	0.250	
	Gypsum board	0.02	1.15	837	1950	0.017	
	Internal heat transfer	-	-	-	-	0.130	
Slab be-tween floors	Internal heat transfer	-	-	-	-	0.130	1.8
	Gypsum board	0.02	1.15	837	1950	0.017	
	Slab of clay	0.13	0.93	965	1320	0.140	
	Wood	0.02	0.15	2750	550	0.133	
	Internal heat transfer	-	-	-	-	0.130	
Ground floor slab	Internal heat transfer	-	-	-	-	0.130	2.2
	Wood	0.02	0.15	2750	550	0.133	
	Concrete	0.25	1.75	1080	2200	0.143	
	External heat transfer	-	-	-		0.043	
Roof slab	Internal heat transfer	-	-	-	-	0.130	1.2
	Wood	0.02	0.15	2750	550	0.133	
	Brick	0.15	0.44	936	1100	0.341	
	Mineral wool	0.045	0.58	2.86	12	0.078	
	Tile of clay[1)]	0.03	1.15	880	1900	0.0	
	External heat transfer[1)]	-	-	-		0.130	

Table 3-5 - Physical proprieties of the walls, slabs and roofs layers for the Portugal (IC5) building

Remarks:

1) Tiles are not considered to calculate the U-value and for the dynamic simulation, as the air gap is strongly ventilated. Furthermore: the external heat transfer coefficient is equal to the internal (8 W/m²K)

Windows & Doors

A low-e glazing with an aluminium frame is used for the IC1 to IC4 buildings and double glazing for the Portugal (IC5) building. The main physical windows data is presented in the table 3-6 and table 3-7. As soon as direct beam radiation occurs on the window surface the external shading devices with a shading coefficient of 0.8 is used.

Type of window	Double	
Number of panes	2	thickness = 4 mm
Type of filling gas	Argon	thickness = 16 mm
Frame Material	Aluminium with thermal break	
Type of glass		
Tilt of the glazing system	90º	
Conductivity of glass	1W/mK	
Solar Transmittance of the glazing layer	0.426	
Solar reflectance of the glazing layer, exterior-facing side	0.266	
Solar reflectance of the glazing layer, interior-facing side (diffuse)	0.260	
Solar absorption of the glazing layer, exterior – facing side	0.118	
Solar absorption of the glazing layer, interior-facing side	0.190	
Visible transmittance of the glazing layer	0.706	
Visible reflectance of the glazing layer, exterior-facing side	0.121	
Visible reflectance of the glazing layer, interior-facing side	0.103	
Thermal infrared (longwave) transmittance of the glazing layer	0	
Infrared (longwave) emittance of the glazing layer, exterior-facing side	0.84	
Infrared (longwave) emittance of the glazing layer, interior-facing side	0.84	
g-value (EN 410)	0.591	
Internal shading coefficient (EN 410)	0.68	
external shading coefficient	0.8	
U-value glass	1.3 W/m²K	
TRNSYS 15 Window ID W4-lib.dat (German)	2002	

Table 3-6 - Properties of window for the IC1 to IC4 buildings

Type of window	Double	
Number of panes	2	thickness = 4 mm
Type of filling gas	air	thickness = 6 mm
Frame Material	Aluminum	
Type of glass	Clear	
Tilt of the glazing system	90º	
Conductance of glass	1 W/m.K	
Solar Transmittance of the glazing layer	0.693	
Solar reflectance of the glazing layer, exterior-facing side	0.135	
Solar reflectance of the glazing layer, interior-facing side	0.135	
Visible transmittance of the glazing layer	0.815	
Visible reflectance of the glazing layer, exterior-facing side	0.145	
Visible reflectance of the glazing layer, interior-facing side	0.145	
Thermal infrared (longwave) transmittance of the glazing layer	0.0	
Infrared (longwave) emittance of the glazing layer, exterior-facing side	0.89	
Infrared (longwave) emittance of the glazing layer, interior-facing side	0.89	
g-value	75.1 %	
Internal shading coefficient	0.8	
external shading coefficient	0.8	
U-value	4.5 W/m^{2}K	

Table 3-7 - Properties of window for the Portugal (IC5) building

The table 3-8 shows the total building's glazing area and table 3-9 shows the glazing areas in the different rooms.

	D3c / D4a		**D4c**	
	A (m^2)	**% façade area**	**A (m^2)**	**% façade area**
North façade	6.0	30.0	3	11
South façade	6.0	30.0	4.5	16

Table 3-8 - Glazing area of the building

	D3c [m^2]	**D4a [m^2]**	**D4c [m^2]**
living room	4	4	2.5
bedroom 1	2	2	1
bedroom 2	2	2	1
bedroom 3	-	2	1
kitchen	4	2	1
bathroom	-	-	1

Table 3-9 - Glazing areas in the different rooms

The external door is made of 4 cm wood with an area of 2.2 m^2 and a U-value of 2.0 W/m^{2}K.

3.6. Building leakage

Three leakage classes (tight, average and leak) are considered, according to A27-V2.
The leakage corresponds to the law:

$$\dot{m} = C \cdot \Delta p^n$$

with n = 0.66.

Table 3-10 shows the overall leakages n_{50} and the corresponding C_{total} for the different leakage classes and dwelling types (assumption: 20°C and 101.3 kPa).

	D3c, D4a		D4c	
	n_{50} [ach/h]	C_{total} [kg/s@1Pa]	n_{50} [ach/h]	C_{total} [kg/s@1Pa]
tight	0.6	0.00304	1	0.00531
average	2.5	0.0126	2.5	0.0133
leak	5	0.0253	5	0.0266

Table 3-10 - Overall leakages (n_{50} and corresponding C_{total}) for the different leakage classes

The building leakage is distributed in relation to the room floor areas. This leads to the following fractions of the above values of C_{total}:

Dwelling type	Living	Kit	BR1	BR2	BR3	WC	Bath	Hall down
D3c	0.630		0.197	0.173				
D4a	0.349	0.132	0.194	0.170	0.155			
D4c	0.309	0.109	0.125	0.125	0.125	0.047	0.094	0.077

Table 3-11 - Distribution of the overall leakage in relation to the room floor areas

For the apartment dwelling types D3c and D4a additional leakage data for the staircase is given:

leakage Q_{50} [m³/h@50 Pa] C [kg/s@1Pa]	tight		average		leak	
	Q_{50}	C	Q_{50}	C	Q_{50}	C
staircase north (per level)	9	0.000228	39	0.000986	78	0.001973
staircase south (per level)	9	0.000228	39	0.000986	78	0.001973
staircase bottom	38	0.000961	38	0.000961	38	0.000961
staircase to attic	98	0.00248	98	0.00248	98	0.00248
apartment door to staircase	44	0.00111	44	0.00111	44	0.00111

Table 3-12 - Additional leakage data (Q_{50} and corresponding C) of the staircase for the apartment dwelling (IC1)

All the leakages are situated half at a height of 0.625 m and half at 1.875 m above the respective floor level.

3.7. Air transfer between zones

Internal door size is approximately **2 m²**.

For the simulations:

All doors between habitable rooms are closed
All doors between hall and bath/WC are closed.
The door between the kitchen and the hall is opened.

Device (or hole or undercut) for transferred air at the bottom of the door, 0 m above the floor and the area is 100 cm^2 , in doors to habitable rooms; toilet door 100 cm^2 and bath 200 cm^2. For the living room 2 doors must be taken into account (which means a hole of 200 cm^2). The corresponding C values, calculated with an assumed flow exponent of 0.5 and a discharge coefficient of 0.6, are given in table 3-13.

Area [cm^2]	C [kg/s@1Pa]	n
100	0.0093	0.5
200	0.0186	0.5

Table 3-13 - C and n values for the air transfer between zones with closed doors

3.8. Shielding condition and wind pressures

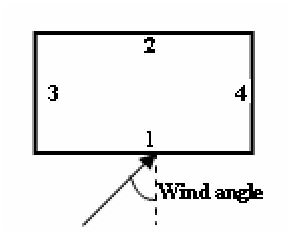
Three levels of shielding conditions are considered according to [Orme 1998].

- **exposed**
- **partially shielded:** surrounded by obstructions equal to half the height of the building.
- **shielded:** surrounded by obstructions equal to the height of the building

The assignment of the rooms to the different facades is given in table 3-14 and the C_p-values of the facades are given in table 3-15. The wind speed reference level is equal to the building height.

Facade 1, Front	**Facade 2, Rear**	**Roof**
Dwelling type D4a/b		
Living room	Bedroom 2	
Bedroom 1	Bedroom 3	
	Kitchen	
Dwelling type D4c		
Living room	Kitchen	
Bedroom 1	Bedroom 3	
Bedroom 2	Bathroom	

Table 3-14 - Assignment of the rooms to the different facades



shielding	Fa-cade	Wind Angle							
		0º	45º	90º	135º	180º	225º	270º	315º
exposed	1	0.5	0.25	-0.5	-0.8	-0.7	-0.8	-0.5	0.25
	2	-0.7	-0.8	-0.5	0.25	0.5	0.25	-0.5	-0.8
partially	1	0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06
	2	-0.5	-0.6	-0.35	0.06	0.25	0.06	-0.35	-0.6
shielded	1	0.06	-0.12	-0.2	-0.38	-0.3	-0.38	-0.2	0.12
	2	-0.3	-0.38	-0.2	-0.12	0.06	-0.12	-0.2	-0.38

Table 3-15 - C_p-values given by [AIVC 1998]

3.9. Building equipment

Space Heating

A boiler with radiators is used as a heating system with different set point temperatures. Table 3-16 gives the set point temperatures for the different zones.

For the building plant use:

- System efficiency equal to 95% - The system efficiency is the quotient between the useful heat delivery by the system to the dwelling and the gross heat delivered to the system by the boiler (heating plant).
- The boiler efficiency during the use is equal to 95%.

	D3c, D4a	D4c
Living room	22 ºC	21 ºC
Bedrooms	22 ºC	17 ºC
Bathroom and Shower	22 ºC	23 ºC
Staircase	15 °C	-
Rest of the building	free - floating	free - floating

Table 3-16: Room air temperature set points for heating

Space cooling

There is no cooling system in the building.

4. Occupant behaviour

4.1. Family types and occupancy density

Table 4-1 defines the four used family types and their behaviour. Table 4-2 gives the detailed schedule of presence in the different rooms.

Family	Member of household	Time at home		Shower		Washing per family
		Weekdays	Sat.- Sun.	Frequency	Duration	Per week
5-pers	man	0-7, 18-24	0-10, 12-24	1/d	5-10 min	7 Once/day
	woman	0-8, 17-24	0-13, 15-24	1/d	5-10 min	
	child, 19 y	0-8, 18-24	2-17	1/d (weekdays only)	5-10 min	
	child, 16 y	0-8, 17-24	0-15,17-20,23-24	1/d	5-10 min	
	child, 13 y	0-8, 17-24	0-12, 15-24	1/d	5-10 min	
4-pers	man	0-7, 18-24	0-10, 13-24	1/d	5-10 min	5 Weekdays
	woman	0-8,12-13,17-24	0-12, 15-24	1/d	5-10 min	
	child, 13 y	0-8, 17-24	0-12, 15-24	1/d	5-10 min	
	child, 10 y	0-8, 17-24	0-10, 13-24	1/d	5-10 min	
2-pers age 45-65	man	0-7, 18-24	0-13, 16-24	1/d	5-10 min	2 Monday Friday
	woman	0-8, 15-24	0-13, 15-24	1/d	5-10 min	
1-pers	woman, eld.	0-10, 11-14, 15-24	-10,11-14,15-24	3/w +1 bath/w	5-10 min	0.5

Table 4-1 - Occupant pattern of the different family types

Family type	Member of house-hold	Time in				
		Kitchen	Living room	Master bedroom	Bedroom 2	Bedroom 3
5 persons Weekdays	man		6-7;18-23	23-6 sleep 23-6		
	woman	7-8;17-18	6-7;18-23	23-6 sleep 23-6		
	child 19 y		7-8;18-19		19-7 sleep 23-7	
	child 16 y		7-8;18-20			17-18;20-7 sleep 22-7
	child 13 y		7-8;18--21			17-18;21-7 sleep 22-7
5 persons Saturday, Sunday	man		8-10;12-24	24-8 sleep 24-8		
	woman	9-12;17-18	8-9;12-13; 15-17;18-24	24-8 sleep 24-8		
	child 19 y		12-13		2-12;13-17 not home	
	child 16 y		11-12; 17-19;23-24			12-15;19-20; 24-11 sleep 1-11
	child 13 y		10-12;15-16; 18-24			16-18;24-10 sleep 24-10
4-persons Weekdays	man		6-7;18-23	23-6 sleep 23-6		
	woman	7-8;12-13; 17-18	6-7;18-23	23-6 sleep 23-6		
	child 13 y		7-8;18-21		17-18;21-7 sleep 22-7	
	child 10 y		7-8;18-20			17-18;20-7 sleep 21-7
4-persons Saturday, Sunday	man		8-10;13-24	24-8 sleep 24-8		
	woman	9-11;17-18	8-9;11-12; 15-17; 18-24	24-8 sleep 24-8		
	child 13 y		10-12;18-24		15-18;24-10 sleep 24-10	
	child 10 y		8-10;13-14; 17-21			14-17;21-8 sleep 22-8
2-persons age 45 – 65 Weekdays	man		6-7;18-19; 20-23	23-6 sleep 23-6	19-20	
	woman	7-8;16-18	6-7;18-19; 21-23	23-6 sleep 23-6		15-16;19-21
2-persons age 45 – 65 Saturday, Sunday	man		8-13;16-24	24-8 sleep 24-8	10-12	
	woman	9-12;17-18	8-9;12-13;18-24	24-8 sleep 24-8		15-17
1-person Weekdays	woman, eld	7-8;11-12	8-10;12-13; 15-22	13-14;22-7		
Saturday, Sunday	woman, eld	7-8;11-12	8-10;12-13; 16-22	15-16;22-7		

Table 4-2 - Occupant pattern of the different family types

note : The Friday night schedule must be based on the weekend period and the Sunday night schedule must be based on the weekdays period.

The combinations of dwelling and family types lead to the three occupancy densities defined in table 4-2. For each dwelling type all three occupancy densities are used for the sensitivity analysis.

Family type	D3c	D4a, D4c
1 person	**spacious**	-
2 person	**average**	**spacious**
4 person	**crowded**	**average**
5 person	-	**crowded**

Table 4-3 - Occupancy densities depending on dwelling and family type

4.2. Water vapour and CO_2 production, and heat gains

Metabolism

		CO_2 [l/(h*p)]	Water evaporation at 20°C [g/(h*p)]	sensible heat gain [W]
Adult 15 years - ∞	awake	18	55	70
	sleeping	12	30	50
Children 13 and 10 years	awake	12	45	40
	sleeping	8	15	35

Table 4-4 - Metabolism of the occupants

Equipment

Due to electrical appliances an internal heat production of about 400 W occurs equally distributed in time and equally distributed in the dwelling in relation to the room floor areas.

Showering

Showering is assumed to take place according to the schedule given in table 4-5.
Water vapour production is assumed to be 300 g per shower.

Case	Person	Weekdays	Saturday, Sunday
Crowded	Man	6.00 - 6.10	9.00 - 9.10
	Woman	6.30 - 6.40	9.30 - 9.40
	Child 19	7.00 - 7.10	no shower
	Child 16	7.15 - 7.25	11.00 - 11.10
	Child 13	7.30 - 7.40	10.00 - 10.10
Average	Man	6.00 - 6.10	9.40 - 9.50
	Woman	6.30 - 6.40	9.30 - 9.40
	Child 13	7.15 - 7.25	10.00 - 10.10
	Child 10	7.30 - 7.40	9.00 - 9.10
Spacious	Man	6.00 - 6.10	9.00 - 9.10
	Woman	6.30 - 6.40	9.30 - 9.40

Table 4-5 - Showering schedules of the different family types

Cooking

It is assumed that the following amount of water vapour is produced.

Breakfast	50 g/person present at home
Lunch	150 g/person present at home
Dinner	300 g/person present at home

Case	Meal	Weekdays		Saturday, Sunday	
		Water prod [g]	Schedule	Water prod [g]	Schedule
Crowded	Breakfast	50 200	6.30 - 7.00 7.00 - 8.00	100 100	9.00 - 10.00 10.00 - 11.00
	Lunch	0	-	750	11.00 - 12.00
	Dinner	1500	17.00 - 18.00	1500	17.00 - 1800
Average	Breakfast	100 100	6.30 - 7.00 7.00 - 8.00	150 50	9.00 - 10.00 10.00 - 11.00
	Lunch	150	12.00 - 13.00	0	-
	Dinner	1200	17.00 - 18.00	1200	17.00 - 18.00
Spacious	Breakfast	100	6.30 - 7.30	100	8.00 - 9.00
	Lunch	0	-	300	11.00 - 12.00
	Dinner	600	17.00 - 18.00	600	17.00 - 18.00

Table 4-6 - cooking schedules of the different family types

Note that if no lunch is scheduled at home, zero water vapour is produced.

Clothes washing and drying

Clothes washing and drying takes place in the bathroom. For the sensitivity cases of water vapour production we have three cases:

- **No washing/drying**
- **with drying machine** 200 g/washing from 8 h to 10 h
- **without drying machine** 200 g/washing from 8 h to 10 h
  1000 g/drying from 10h to 6h

4.3. Window airing

Window airing is only assumed by using windows during the morning for cleaning and refreshing the bedrooms, in all other rooms there is no window airing at all. Window airing can be used for all ventilation systems. Per bedroom it is assumed to use only one casement window with a size of 0.8*0.6 m^2 (height * width) for airing.

The window is placed so that the lower side of the opening is at 1.2 m above the floor. Consequently the upper side of the hole is at 2.0 m above the floor.

The opening positions are:

Position 0 Closed
Position 1 Ajar, an opening of about 0.05 m that means 0.04 m^2
Position 2 Medium open (30° opening angle), that means 0.29 m^2
Position 3 Full open (90° opening angle), that means 0.48 m^2

The duration of the opening time is 1 h from 8.00 to 9.00 o'clock during weekdays.

For the sensitivity analysis three levels of window airing are defined:

- **no use**, which means that all windows are closed all the time
- **medium use**, which is defined as half of the area of the maximum
- **maximum use**

Window position in relation to weather conditions

The window position in case of window airing is, however, depending on the weather conditions.

- If the wind speed is more than 10 m/s, all windows are closed.
- If the outdoor temperature is below -5°C, all windows are closed.

For combinations, the following algorithm can be used:

$$R = Y_{wind} * Y_{temp}$$

where:

R opening ratio of the window, in relation to the maximum opening
Y_{wind} factor for wind
Y_{temp} factor for outdoor temperature

The factors are defined by:

$Y_{wind} = 1\text{-}0.1\ V_{met}$
$Y_{temp} = T_e / 25 + 0.2$

where:

V_{met} meteorological wind speed (m/s)
T_e outdoor temperature (^{O}C)

With this algorithm the exact opening positions can be calculated.
As only four opening positions are considered, after calculating the positions in absolute values one has to round off to one of the four opening positions closest to the value as defined in table 4-7.

Window opening area, m^2	Window position
0 - 0.02	0
0.021 - 0.16	1
0.161 - 0.38	2
>0.38	3

Table 4-7 - Window opening areas and window positions

Examples can be found in table 4-8.

Weather		**Factor**		**Opening**		**Window position**
Windspeed [m/s]	**Outdoor temperature[°C]**	**Y_{wind} [-]**	**Y_{temp} [-]**	**R [-]**	**Area [m²]**	**No**
0	-2	1	0.12	0.12	0.0576	1
2	3	0.8	0.32	0.256	0.12288	1
5	5	0.5	0.4	0.2	0.096	1
8	0	0.2	0.2	0.04	0.0192	1
2	8	0.8	0.52	0.416	0.19968	2
3	10	0.7	0.6	0.42	0.2016	2
5	15	0.5	0.8	0.4	0.192	2
0	15	1	0.8	0.8	0.384	3
2	20	0.8	1	0.8	0.384	3
2	-5	0.8	0	0	0	0
10	5	0	0.4	0	0	0

Table 4-8 -Examples of the window positions depending on the weather conditions

The results in table 4-8 clearly show that:

- Only with high temperatures and low wind speed the window is fully opened.
- For the position 2 both high or medium temperature and low wind speed must apply.
- For all other intermediate weather conditions the window is in position 1.
- In the case that one of the weather parameters is extreme, the window is closed.

5. Parameter variation

Three levels are defined for some of the parameters described in the previous sections (printed in bold type). In table 5-1 these levels are labelled with the signs “-“, “0”, “+”. In the reference case all parameters have the level 0. Only one parameter per case changes for the sensitivity analysis either to level + or to level -. All other parameters have level 0. Table 5-2 gives an overview of all cases.

Parameter	level		
	-	0	+
shielding	unshielded	partially shielded	shielded
building leakage	tight	average	leak
occupancy density	spacious	average	crowded
water vapour production from washing/drying	no	with drying machine	without drying machine
window airing	no use	medium use	maximum use
number of levels (IC1 D4a/b)	1	2	4
orientation	north	south	west

Table 5-1 - Levels for the different parameters

case	shielding	air tightness	occupancy density	water vapour production	window airing	number of levels	orientation
1	0	0	0	0	0	0	0
2	-	0	0	0	0	0	0
3	+	0	0	0	0	0	0
4	0	-	0	0	0	0	0
5	0	+	0	0	0	0	0
6	0	0	-	0	0	0	0
7	0	0	+	0	0	0	0
8	0	0	0	-	0	0	0
9	0	0	0	+	0	0	0
10	0	0	0	0	-	0	0
11	0	0	0	0	+	0	0
12	0	0	0	0	0	-	0
13	0	0	0	0	0	+	0
14	0	0	0	0	0	0	-
15	0	0	0	0	0	0	+

Table 5-2 - Parameter level combinations for sensitivity analysis

6. Probabilistic approach

The Monte Carlo method is used to find the distributions of the evaluation criteria. Case 1 of table 5-2 is used to demonstrate the probabilistic approach. Probability distributions and/or stochastic models for the following input parameters are defined in this chapter:

- air tightness
- leakage distribution
- local wind speed factor
- outdoor CO_2 concentration
- Cp- values
- occupancy density
- occupancy pattern
- window use
- control of ventilation system

A simple normal distribution is used for air tightness, leakage distribution, local wind speed factor and outdoor CO_2 concentration. The assumed mean values, standard deviations and the minimum values are given in table 6-1.

Parameter	mean value	standard deviation	minimum	maximum
air tightness [ach/h]	2.5	1.5	0.3	
leakage distribution: (fractions of overall leakage per room) [1])	values given in table 3-11	0.2	0.01	
local wind speed factor	0.6	0.13	0.3	
outdoor CO_2 concentration	400	50	300	

Table 6-1 - Assumed normal distributions of air tightness, leakage distribution, local wind speed factor and outdoor CO_2 concentration

[1]) In each Monte Carlo run the sum of all the fractions has to be 1. Therefore each individual resulting room value has to be normalized with the total sum of all the room values of this run.

6.1. Cp-Values

The 16 different Cp-values per shielding situation given in table 3-15 for the different wind directions and facades are dependent from each other and may not be varied individually. Therefore a parametrical model described in [Walker 1994] is used to calculate these 16 values for each Monte Carlo run:

$$Cp_1(\theta) = ½ [(Cp_1(0) + Cp_1(180)) (\cos^2\theta)^{1/4} + (Cp_1(0) - Cp_1(180)) \cdot sign(\cos\theta) (|(\cos\theta)|^{3/4} + (Cp_1(90) + Cp_1(270)) (\sin^4\theta) + (Cp_1(90) – Cp_1(270)) (\sin\theta)]$$

$$Cp_2(\theta)=Cp_1(\theta+180°)$$

Where $Cp_1(\theta)$ and $Cp_2(\theta)$ are the dependent Cp-values of the façades 1 and 2 for the wind direction θ. $Cp_1(0)$, $Cp_1(180)$, $Cp_1(90)$ and $Cp_1(270)$ are the independent Cp-values of façade 1 for the main wind directions 0°, 180°, 90°and 270°. If a uniform wind shielding is assumed for all wind directions these four values are also strongly correlated. A linear regression has been found from the Cp-tables given for buildings with length to width ratio of 2:1 published in [Orme 1998]:

$Cp_1(180) = -0.678 \cdot Cp_1(0) - 0.167$
$Cp_1(90) = 1.333 \cdot Cp_1(180) - 0.0333$
$Cp_1(270) = Cp_1(90)$

That means the number of independent Cp-values has been reduced to one. All the other values can be calculated from $Cp_1(0)$. This value will be varied for each Monte Carlo run according to an assumed normal distribution with the mean value and standard deviation given in table 6-2.

	$Cp_1(0)$
Wind angle to facade 1	0°
mean value	0.27
standard deviation	0.22

Table 6-2 - Normal distribution of the independent value $Cp_1(0)$

The procedure to generate the Cp-table for each run using the above relations is as follows:
1. Select a value for $Cp_1(0)$ according to the distribution given in table 6-2
2. calculate $Cp_1(180)$, $Cp_1(90)$, $Cp_1(270)$ with the 3rd, 4th, 5th equation
3. calculate $Cp_1(45)$, $Cp_1(135)$, $Cp_1(225)$, $Cp_1(315)$ with the 1st equation
4. calculate the values for the facade 2 with the 2nd equation :
   $Cp_2(0)$, $Cp_2(45)$, $Cp_2(90)$, $Cp_2(135)$, $Cp_2(180)$, $Cp_2(225)$, $Cp_2(270)$, $Cp_2(315)$

These 16 Cp-values are used as normal Cp input in COMIS, where the actual Cp will be linearly interpolated within the given table according to the actual wind direction

6.2. Occupancy

The proposed stochastic model for the occupancy is based on the probability of presence of the occupant. Daily profiles of the probability of presence are given in [Månson 1995] for different occupant types.
If only the probability of presence per hour of the day without any auto-correlation is taken into account, then the resulting occupancy pattern fluctuates more heavily than it does in reality. The probability of change (that means the probability of entering or leaving the dwelling) is a function of the probability of presence. This function is depending on the auto-correlation of the presence (see figure 6-1).

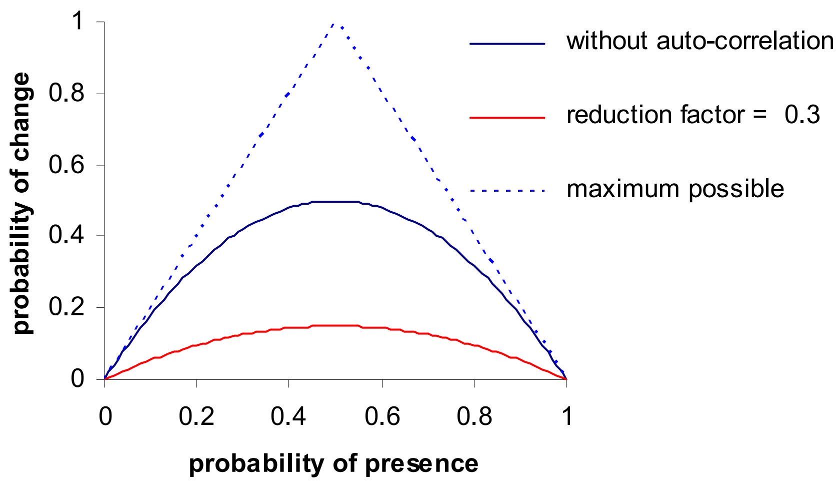


Figure 6-1 - Probability of change vs. probability of presence for the situations: maximum possible probability of change; no auto-correlation is taken into account; reduced probability of change with a reduction factor of 0.3 (auto-correlation is about 0.7)

A reduction factor for this probability of change has been introduced. If this reduction factor is 1 then no auto-correlation is taken into account. With a decreasing reduction factor down to zero the auto-correlation will be increased up to 1 and the fluctuation rate will be reduced without to influence the average probability of presence of the period. But the reduction factor will cause a distortion of the daily profile. That means a change in the probability of presence will undergo a delay. This has the advantage that an abrupt change in the profile will be smoothed out. Thus the profiles can be defined as rectangle profiles with just two values one for the day time and one for the night time. As a result the smoothed out profiles will look quite similar to the realistic ones given in [Månson 1995].(see figure 6-2)

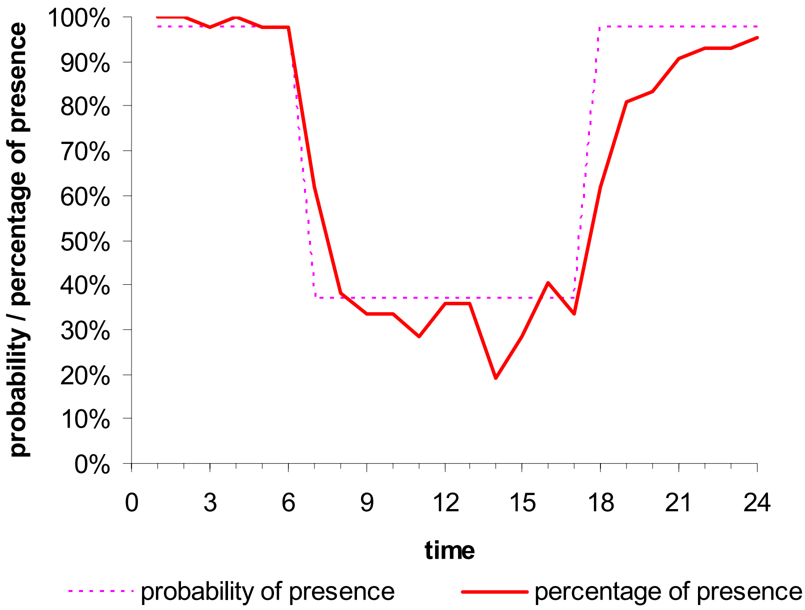


Figure 6-2 - Example of a daily probability profile of presence and a possible resulting profile of the average percentage of presence during a period of 42 days using the parameters from table 6-4

The probability of presence of the actual hour, taking into account the above described reduction factor, can be calculated according to equation (1):

$$p_p(t) = (1 - r) \cdot P(t-1) + r \cdot p_{pa} \qquad (1)$$

where:

$p_p(t)$ probability of presence for the actual hour

p_{pa} average probability of presence for a certain period

$P(t-1)$ presence of the last hour
(P = 1 means occupant is present; P = 0 means occupant is not present)

r reduction factor for the probability of change

This probability is used to decide whether the occupant is present or not:

IF $u \le p_p(t)$ the occupant is present
ELSE the occupant is not present

where:

u uniform random number in the range [0,1]

If the occupant is present in the dwelling it must be decided in which room he is. This can be done with the distribution of the probabilities of presence in the different rooms given in table 6-4.

IF $\sum_{i=1}^{n-1} p_i \leq u \leq \sum_{i=1}^{n} p_i$ then the occupant is present in room number n

where:
p_i probability of presence in room number i (the sum for all rooms has to be 1)
u uniform random number in the range [0,1]

The selection of the room according to the above equation can be graphically shown with the cumulative probability of presence distribution. Figure 6-3 shows as an example the selection of the room for the women of the 5 person family during the day.

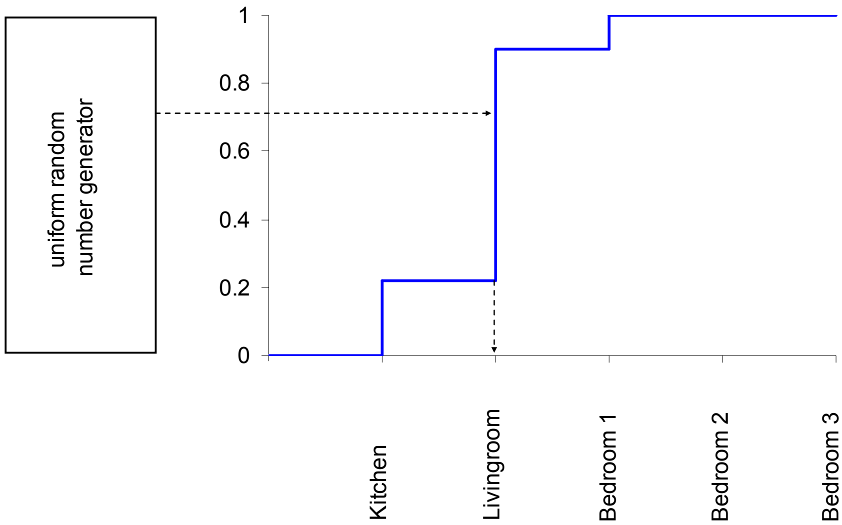


Figure 6-3 - Selection of the room with the help of the cumulative presence probability distribution in the different rooms. Here as an example the cumulative presence probability distribution of the women of the 5 person family during the day according to table 6-4.

The deterministic schedules of presence given in table 4-1 are also used for the stochastic model. But now the schedules are used to define the periods of high probability of presence p_{pa}. During the remaining time the probability of presence is low.
The two levels of high and low probability of presence are kept constant during the simulation period but they have to be selected for each Monte Carlo run according to the assumed normal distributions with the mean values and standard deviations given in table 6-3. The reduction factors r for the probability of change is also given for the same periods. The resulting total average occupant presence probabilities p_{op} for the whole period for the different family types are given in table 6-5. p_{op} is the probability that at least one person is present in the dwelling.

	period with high probability of presence	period with low probability of presence
mean value for p_{pa}	0.99	0.25
standard deviation	0.01	0.1
minimum	0	0
maximum	1	1
reduction factor r	0.5	0.6

Table 6-3 - Assumed normal distributions of the probability of presence p_{pa} and reduction factors r for the probability of change for the two periods with high and low probability of presence

The probability of presence p_i of an occupant in a certain room is derived from table 4-2. During the bed time the probability of presence is 0.95 in the bedroom and 0.05 in the living room. During the remaining time the distribution has been calculated according to the hours of presence in the different rooms defined in table 4-2. The resulting distributions of the probability of presence p_i are given in table 6-4.

Family type	Member of house-hold	S: sleep A: awake	Distribution of the probability of presence p_i				
			Kitchen	Living room	Master bedroom	Bedroom 2	Bedroom 3
5 persons	man	S: 23-6	0	0.05	0.95	0	0
		A: rest	0	0.9	0.1	0	0
Weekdays	woman	S: 23-6	0	0.05	0.95	0	0
		A: rest	0.22	0.68	0.1	0	0
	child 19 y	S: 23-7	0	0.05	0	0.95	0
		A: rest	0	0.33	0	0.67	0
	child 16 y	S: 22-7	0	0.05	0	0	0.95
		A: rest	0	0.5	0	0	0.5
	child 13 y	S: 22-7	0	0.05	0	0	0.95
		A: rest	0	0.67	0	0	0.33
5 persons	man	S: 24-8	0	0.05	0.95	0	0
		A: rest	0	0.9	0.1	0	0
Saturday, Sunday	woman	S: 24-8	0	0.05	0.95	0	0
		A: rest	0.26	0.64	0.1	0	0
	child 19 y	S: 2-12	0	0.05	0	0.95	0
		A: rest	0	0.2	0	0.8	0
	child 16 y	S: 1-11	0	0.05	0	0	0.95
		A: rest	0	0.44	0	0	0.56
	child 13 y	S: 24-10	0	0.05	0	0	0.95
		A: rest	0	0.82	0	0	0.18
4-persons	man	S: 23-6	0	0.05	0.95	0	0
		A: rest	0	0.9	0.1	0	0
Weekdays	woman	S: 23-6	0	0.05	0.95	0	0
		A: rest	0.3	0.6	0.1	0	0
	child 13 y	S: 22-7	0	0.05	0	0.95	0
		A: rest	0	0.67	0	0.33	0
	child 10 y	S: 21-7	0	0.05	0	0	0.95
		A: rest	0	0.6	0	0	0.4
4-persons	man	S: 24-8	0	0.05	0.95	0	0
		A: rest	0	0.9	0.1	0	0
Saturday, Sunday	woman	S: 24-8	0	0.05	0.95	0	0
		A: rest	0.2	0.7	0.1	0	0
	child 13 y	S: 24-10	0	0.05	0	0.95	0
		A: rest	0	0.73	0	0.27	0
	child 10 y	S: 22-8	0	0.05	0	0	0.95
		A: rest	0	0.64	0	0	0.36
2-persons age 45– 65	man	S: 23-6	0	0.05	0.95	0	0
		A: rest	0	0.83	0	0.17	0
	woman	S: 23-6	0	0.05	0.95	0	0
Weekdays		A: rest	0.3	0.4	0	0	0.3
2-persons age 45– 65	man	S: 24-8	0	0.05	0.95	0	0
		A: rest	0	0.87	0	0.13	0
Saturday, Sunday	woman	S: 24-8	0	0.05	0.95	0	0
		A: rest	0.29	0.57	0	0	0.14
1-person Weekdays	woman, eld	S: 23-7	0	0.05	0.95	0	0
		A: rest	0.14	0.72	0.14	0	0
Saturday, Sunday	woman, eld	S: 23-7	0	0.05	0.95	0	0
		A: rest	0.15	0.7	0.15	0	0

Table 6-4 - Distributions of the probability of presence p_i in the different rooms for all occupant types for the period when the occupant sleeps and when he is awake

The presence in the bathroom is very short and has not much influence on IAQ except the water vapour production from showering. Therefore it is not defined in table 6-4 and the deterministic showering schedules defined in table 4-5 is used.

The selection of the family type for a single Monte Carlo run can be done in the same way as the selection of the room for an occupant according to figure 6-3. The assumed probability distribution of the occupancy density is given in table 6-5.

Family type	occupant presence prob. p_{op}	Dwelling type			
		D3c		D4a, D4c	
		density	prob. distrib.	density	prob. distrib
1 person	0.94	**spacious**	0.25	-	
2 person	0.92	**average**	0.50	**spacious**	0.25
4 person	0.87	**crowded**	0.25	**average**	0.50
5 person	0.93	-		**crowded**	0.25

Table 6-5 - Probability distribution of the occupancy density and the total average occupant presence probability p_{op}

The total procedure to generate the occupant schedules for a single Monte Carlo run is concluded as follows:

per Monte Carlo run:

1. Select the family type according to the probability distribution defined in table 6-5

per occupant:

2. Select the mean values of the probability of present p_{pa} for the two periods defined in table 4-2 with low and high probability of presence according to the normal distribution defined in table 6-3.

per time step:

3. Calculate the probability of presence for the actual time step according to equation (1) and decide whether the occupant is present in the dwelling.
4. If the occupant is present in the dwelling, select the room according to the probability of presence p_i in the room defined in table 6-4

6.3. Window use

The proposed stochastic window opening model is based on [Maeyens 2003], where it is described in more detail.

The probability that a window is opened is determined based on the outdoor temperature and the amount of irradiation:

IF I > 500 W/m2 $p = (42/20 \cdot T_{out}+3)/100$
ELSE $p = (29/25 \cdot T_{out}+3)/100$

If the local wind velocity is higher than 3 m/s the probability is corrected as follows:

IF v > 3 m/s $p_v = (1.55 -0.183 \cdot v) \cdot p$

The resulting opening probability is an average value over all rooms of the dwelling. The correction factor C_1 (table 6-8) takes into account observed differences in the average opening durations of the different rooms.
The windows may not be opened if nobody is present in the dwelling. Therefore the window opening probability for the remaining time has to be corrected with the occupant presence probability p_{op} in order to keep the average opening probability over the whole period. Occupant presence probabilities of the different family types are given in table 6-5:

$p_{c1} = (p \text{ or } p_v) \cdot C_1 / p_{op}$

For reasons of simplification only one window per room will be opened in the model. Therefore the opening probability p_{c1} for each window is recalculated from the average total window opening area per room (A_{wtot}) (see table 6-8) to the opening area of one window ($A_{openable}$) which is in this case H * W = 0.8 * 0.6 m^2.

$p_{c2} = p_{c1} \cdot C_2 \cdot A_{wtot} / A_{openable}$

In addition to the model described in [Maeyens 2003] the distribution of the user behaviour from minimum to maximum window use has been added with the correction factor C_2. This correction factor takes also into account the fact that the model has been derived from data of buildings without mechanical ventilation system. In buildings without any mechanical ventilation system the mean value of C_2 is equal to one. As window airing in buildings with a mechanical or hybrid ventilation system is lower, C_2 will be below 1.
No information has been found in literature about the amount of this reduction of the mean value and about the distribution. Therefore more investigation in future work is necessary. For the reference building a normal distribution with the values given in table 6-6 is assumed. The value is selected per Monte Carlo run.

	C_2
mean value	0.3
standard deviation	0.2

Table 6-6 - Assumed normal distribution of the correction factor C_2 for the user behaviour concerning window airing in hybrid ventilated buildings

As well in addition to the model described in [Maeyens 2003], the impact of the occupancy can be taken into account with help of the reduction factor r for the probability of change of the window opening position. The probability p_c of open window has then to be recalculated according to the following equation:

$p_{c3}(t) = (1 - r) \cdot O(t-1) + r \cdot p_{c2}$

where:
$p_{c3}(t)$ probability of open window for the actual hour
p_{c2} probability of open window without occupancy impact
O(t-1) opening position during the last hour
(O = 1 means opening is open; O = 0 means opening is closed)
r reduction factor for the probability of change

The factor r is dependent on the occupancy condition according to table 6-7, where for the bedrooms condition 4 has the higher priority if condition 3 and 4 both are true.

The final probability p_c of open window is used to decide whether the window is open or not:

IF $u \leq p_c$ the window is open
ELSE the window is closed

where:
u uniform random number in the range [0,1]

If the window is open, the degree of window opening (ajar or wide open) is selected according to the probability p_w of wide open window given in table 6-8:

IF $u \leq p_w$ the window is wide open
ELSE the window opening is ajar

condition		reduction factor r	
n	description	Bedrooms	Other rooms
1	nobody is present in the dwelling	0.0	0.0
2	only sleeping persons are present in the dwelling	0.3	0.3
3	somebody is awake in the dwelling	0.8	0.8
4	somebody is sleeping in the concerning bedroom	0.3	-

Table 6-7 -Reduction factor r for the probability of change of the window opening

	Living room	kitchen	bed-room 1	bed-room 2	bed-room 3	bath-room	Ø of all rooms
average duration D [h/day]	0.4	0.9	4	2.6	2.6	1.6	2
Correction C_1 = D / (Ø of all rooms)	0.2	0.45	2	1.3	1.3	0.8	
A_{wtot} [m^2]	4.6	1.8	1.4	1.4	1.4	0.7	
probability p_w of wide open window	0.33	0.25	0.38	0.41	0.41	0.34	

Table 6-8 - Average duration time of the window opened per room and the resulting correction factor, average total window opening area per room A_{wtot} and probability of wide open window per room (averages are taken over the whole building stock).

6.4. Control of ventilation system

Instead of the deterministic model described in chapter 7, for the probabilistic approach, the stochastic model described below is used for the control of the ventilation system.
The ventilation system is assumed to be manually controlled. Therefore the use of the supply provisions and the exhaust system is dependent on the presence of the occupants in the different rooms.

Exhaust system

4 levels are defined for the mechanical exhaust system:

position of exhaust system	exhaust flow in relation to the maximum
0	0
1	0.5
2	0.75
3	1

Table 6-9 - Position of the mechanical exhaust system and the corresponding level of the exhaust flow in relation to the maximum flow

The probability p_{en} that the exhaust fan runs on a certain position is depending on the conditions defined in table 6-10. For each condition this probability is selected per Monte Carlo run according to the defined normal distribution. The actual position during the run is selected per time step according to the actual condition and the corresponding probability:

IF $u \le p_{en}$ the exhaust system runs on the position defined for condition n
ELSE the exhaust system runs one position below
where:
u uniform random number in the range [0,1]

condition		position	distribution for the probability p_{en}	
n	description		mean value	standard deviation
1	nobody is present in the dwelling	1	0.5	0.2
2	one or more persons are present in one of the bed rooms	2	0.9	0.2
3	one or more persons are present in the living room	3	0.5	0.2
4	somebody is showering or some body is in the kitchen	3	0.9	0.1

Table 6-10: Assumed normal distribution for the probability p_{en} that the exhaust fan runs on the defined position when condition n is fulfilled.

If more than one condition is fulfilled at the same time step resulting in different positions the highest evaluated position is selected.

The position for the condition 1 (nobody is present in the dwelling) does not change during successive time steps with this condition. To illustrate this, the following example is given:

E.g. the probabilities for the conditions 1 and 2 were selected according to the distributions defined in table 6-9 as: p_{e1}.= 0.67 and p_{e2}= 0.86.
During the simulation the following sequence is assumed:

time step 57	one or more persons are present…	--> n=2	u=0.84	position 2
time step 58	nobody is present in the dwelling	--> n=1	u=0.73	position 0
time step 59	nobody is present in the dwelling	--> n=1	u=0.48	position 0
time step 60	nobody is present in the dwelling	--> n=1	u=0.33	position 0

At time step 58 all occupants leave the dwelling. According to p_{e1}.and the actual u the fan is off. In time step 59 and 60 there is still nobody present (n=1) and according to p_{e1}.and the actual u's the fan should run on position 1 but as nobody is here who can turn on the fan it stays on position 0. Only the first time step of a series with condition 1 will determine the position for the whole series.

Supply provisions

The probability p_{sn} whether the supply provision in a certain room is open is high:

if there is a person present in this room

and it is low:

if there is no person present

The position of the supply provision does not change during successive time steps with no person present in the room.

The level for high and low probability is selected per Monte Carlo run with the assumed normal distribution according to table 6-11. Per time step it is decided whether the provision is open or closed according to the selected p_{sn}:

IF $u \leq p_{sn}$ the supply provision is open
ELSE the supply provision is closed
where:
u uniform random number in the range [0,1]

condition		distribution for the probability p_{sn}	
n	description	mean value	standard deviation
1	one or more persons are present in the room (high level)	0.9	0.2
2	nobody is present in the room (low level)	0.1	0.2

Table 6-11 - Assumed normal distribution for the probability p_{sn} whether the supply provision is open when condition n is fulfilled

In conclusion, the reference ventilation systems will be controlled depending on the dwelling/zone occupation on two supply grid positions (open/closed) and four exhaust flow levels. In the IC3 natural ventilation system the supply grid is controlled in the same way and the exhaust duct is left open all the time.
If the outside temperature is below -5°C the supply provisions of the IC2 reference system will be opened according to the opening areas defined in table 7-3 and above -5°C according to table 7-4. The opening areas respectively the C-values of the supply provisions of the IC1 and IC3 reference systems are defined in table 7-1 resp. table 7-8. Above -5°C outdoor temperature they will be completely opened and below -5°C they will be opened to 1/3 of there total opening areas.

7. Default ventilation systems

7.1. System for cold climate – IC1

System general description

Mechanical exhaust ventilation with a central pressure controlled exhaust fan for the whole building i.e. there is a centrally located pressure where the pressure is kept at a constant level and the fan frequency of the fan is adjusted accordingly. Air is exhausted from kitchen, bathroom, elevator shaft, garbage chute, and staircase. Air is supplied through slot vents in the living room and bedrooms. There is no heat recovery or in some cases an exhaust air heat pump.
Approximately ¼ of the apartment buildings built during the nineties have a balanced ventilation system with air-to-air heat recovery with efficiency of about 50 %.

Fresh air inlets

There are ventilation slots in the building, typically located above the windows e.g. in the window frame.
The volume flows @ 3.2 Pa and the corresponding C values are given in table 7-1 (assumption: n=0.7; air: 20°C and 101.3 kPa).

Room	Q @ 3.2 Pa [l/s]	C [kg/s@1Pa]
Bedroom 1 and 2	5.9	0.00315
Living room	18.2	0.00971

Table 7-1 - Volume flow @ 3.2Pa and C values for the inlets in the different rooms

Air extraction devices

The airflows and the duct network of the exhaust system is shown in figure 7-1 and figure 7-2. The exhaust air flows are from the bathroom 15 l/s and from the kitchen 10 l/s basic air flow and 30 l/s forced air flow for cooking.
In addition there are exhaust air flows from elevator shaft (36 l/s), from garbage chute (50 l/s) and from staircase (25 l/s).
As described above, there are two extraction points (kitchen and bathroom) connected to only one central fan located in the attic. As the central fan always maintains a constant pressure in the central duct the air flows are almost constant i.e. if someone decides to increase or decrease the opening area of an exhaust air terminal device the air flow through that very device will change, but the flows through other air terminal devices will not be affected.
The main extract duct for each apartment is vertical (ϕ = 160 mm) and it connects the apartment with the exhaust fan in the attic. One horizontal duct branch (ϕ = 100 mm) is used to link the exhaust grilles from the bathroom with the main duct and another (ϕ = 125 mm) to link the cooker hood with the main duct. (See figure 7-1 and figure 7-2)

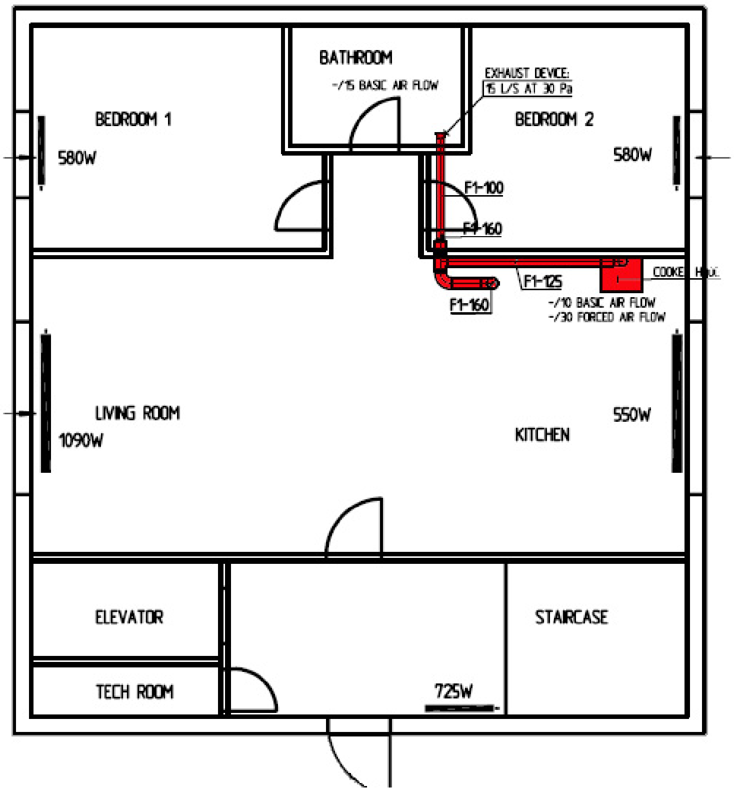


Figure 7-1 – Exhaust system – apartments

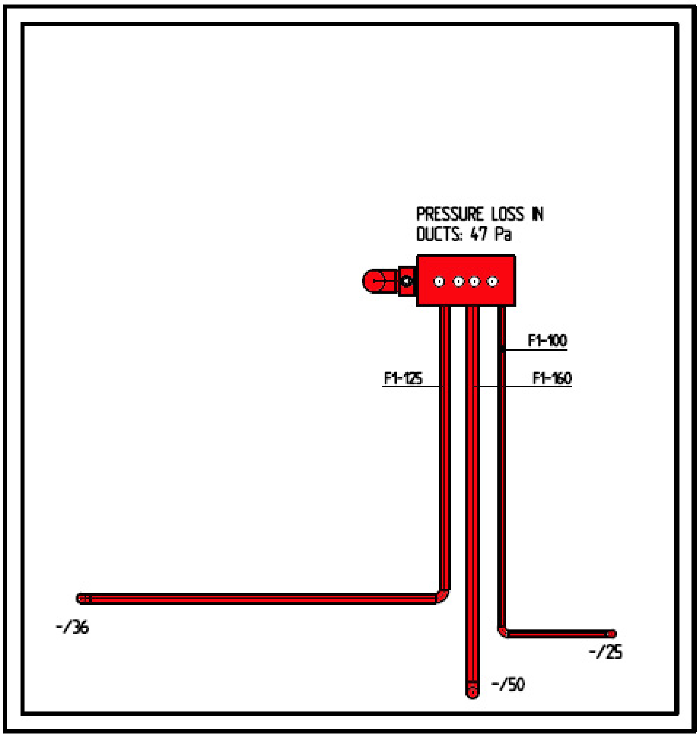


Figure 7-2 - Exhaust system - attic

Fans

In this system there is a central exhaust fan operating continuously with a SPF of 2 kW/m^{3}s.

Air transfer devices between zones

The internal doors have grilles located either upper or down that allows air flow through them (see section 3.7).

7.2. System for moderate climate – IC2

System general description

The reference system used in The Netherlands is a standard mechanical exhaust system with natural supply grids and manual control of the ventilation provisions. This manual control is described below (these results are used in the Dutch NEN 5128)

In the Dutch NEN 5128 the energy performance of dwellings is regulated. The following formula's are of interest.

$Q_{prim} = (330 * A_g + 65 * A_{verlies}) * 1,17$ [MJ]
$q_v = 0,47 * A_g + 0,13 * q_{v,10}$ [dm^3/s]
$q_{mech} = 0,36 * A_g$ [dm^3/s]
$Q_v = q_v * 1,2 * 238 / (\eta_{sys} * \eta_{opw})$

in which:

- Q_{prim} = pre-scribed maximum primary yearly energy consumption of a complete dwelling with all it's installations [MJ]
- A_g = floor surface dwelling [m^2]
- $A_{verlies}$ = surface building envelop [m^2]
- q_v = average ventilation + infiltration flow over the heating season [dm^3/s]
- $q_{v,10}$ = air tightness, airflow at 10 Pa pressure difference over envelop [dm^3/s]
- q_{mech} = average mechanical or natural exhaust flow over heating season [dm^3/s] (this relates to a mechanical as well as a natural exhaust system)
- Q_v = primary energy consumption for ventilation [MJ]
  (238 = 212days * 24h * 3600s * (18ºC- 5ºC)/ 10^{-6})
- η_{sys} = system efficiency (0,95) [-]
- η_{opw} = efficiency heating installation (0,95) [-]

For a somewhat average Dutch single family house, with A_g = 100 m^2, $A_{verlies}$ = 150 m^2 and $q_{v,\,10}$= 100 dm3/s, this leads to:

Q_{prim} = 50018 MJ
q_v = 60 dm^3/s
q_{mech} = 36 dm^3/s
Q_v = 18987 MJ

For the manual use of the ventilation provisions in the reference situation, a distinction is made between five ventilation patterns, namely:

1) The situation with all supply provisions closed;
2) Ventilating of the bedrooms during the night and evening;
3) Airing of the bedrooms in the morning during household work;
4) Ventilating of the living room and kitchen during use of the kitchen;
5) Ventilating of the bathroom during use of the bathroom.

The time periods, over which these several ventilation patterns are simulated, plus the net-opening of the supply provisions are given in the schedules D2 to D4 (see below). These schedules refer to respectively situations with an outside air temperature <5ºC, between 5 and 10ºC and >10ºC.
The use of the mechanical exhaust is given in table 7-2.

Ventilation pattern(1)	level mechanical exhaust	exhaust flow (l/s)		
		kitchen	bathroom	toilet
everything closed	low position (during 2 h/day)	10,5	7	3,5
	high position (rest of the time)	21	14	7
ventilating bedrooms airing bedrooms	middle position	15,5	10,5	5,5
ventilating living and kitchen ventilating bathroom	high position	21	14	7
(1) Time periods are indicated in the schedules D2 to D4				

Table 7-2 - Use of mechanical exhaust and air flows – D1

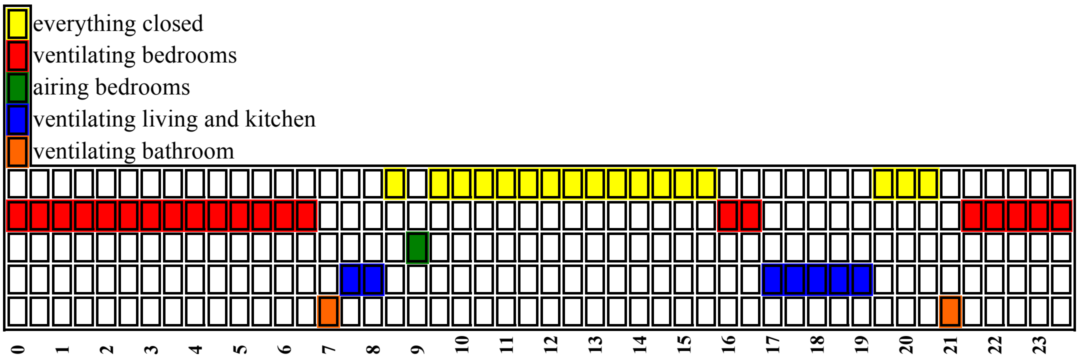


Figure 7-3 – Schedule D2 – time periods, over which the ventilation are simulated – T_{ext} < 5 ºC

ventilation pattern	net-opening supply provision (cm^2)					
	Living room	kitchen	bedroom1	bedroom2	bedroom3	bathroom
everything closed	-	-	-	-	-	-
ventilating bedrooms	-	-	35	35	70	-
airing bedrooms	-	-	1800	1800	1800	-
ventilating living and kitchen	140	140	-	-	-	-
ventilating bathroom	-	-	-	-	-	210

Table 7-3 – Schedule D2 - Net-opening of the supply provisions – T_{ext} < 5 °C

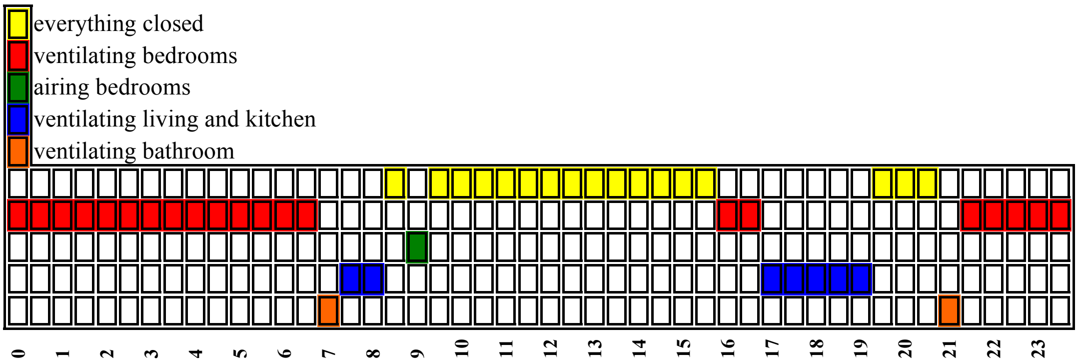


Figure 7-4 - Schedule D3 – time periods, over which the ventilation are simulated – 5 ºC < T_{ext} < 10 ºC

ventilation pattern	**net-opening supply provision (cm²)**					
	Living room	**kitchen**	**bedroom1**	**bedroom2**	**bedroom3**	**bathroom**
everything closed	-	-	-	-	-	-
ventilating bedrooms	-	-	130	130	259	-
airing bedrooms	-	-	1800	1800	1800	-
ventilating living and kitchen	518	518	-	-	-	-
ventilating bathroom	-	-	-	-	-	777

Table 7-4 - Schedule D3 - Net-opening of the supply provisions – 5 °C< T_{ext} < 10 ºC

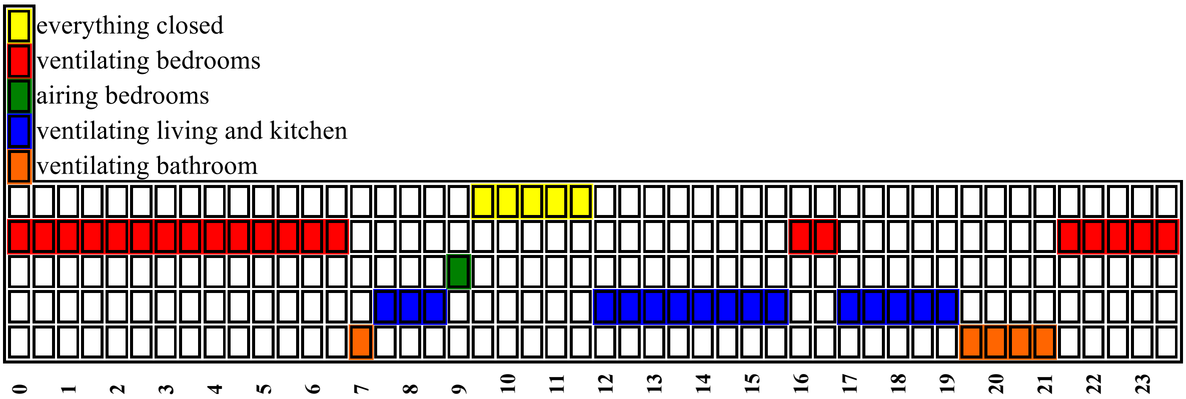


Figure 7-5 - Schedule D4 – time periods, over which the ventilation are simulated – T_{ext} > 10 °C

ventilation pattern	net-opening supply provision (cm^2)					
	Living room	kitchen	bedroom1	bedroom2	bedroom3	bathroom
everything closed	-	-	-	-	-	-
ventilating bedrooms	-	-	130	130	259	-
airing bedrooms	-	-	1800	1800	1800	-
ventilating living and kitchen	2072	2072	-	-	-	-
ventilating bathroom	-	-	-	-	-	3108

Table 7-5 - Schedule D4 - Net-opening of the supply provisions – T_{ext} > 10 ºC

Outdoor air inlets

In the standard ventilation system the air admission is done with natural supply grids. They can be modelled with the crack component with an assumed exponent of 0.6. The C values can be calculated from the opening areas given in table 7-3, table 7-4 and table 7-5 according to the following equation (assumption C_d = 0.6)

$C = \sqrt{2\rho} \cdot A \cdot C_d$ *[kg/s@1Pa]*

Air extraction devices

The exhaust fans will be modelled with a pressure independent constant flow characteristic with the flows defined in table 7-2.
A standard exhaust system in the Netherlands has about 40 to 80 Pa resistance at maximum capacity.

7.3. System for warm climate – IC3

According to the Belgian standard NBN D 50-001, there are four reference systems:

	Natural exhaust	Mechanical exhaust
Natural supply	System A	System C
Mechanical supply	System B	System D

Table 7-6 – Heating temperature set-points

However, system B is seldom applied. The systems are assumed to be manually controlled using the same time schedules defined for the IC2 reference system (see figure 7-3, figure 7-4 and figure 7-5) except the flow pattern “airing bedrooms” as for that purpose window airing is defined in section 4.3. The different flow pattern (everything closed, ventilating bedrooms …) define which supply grids are open and the exhaust flows in relation to the maximum flows (see table 7-7). The maximum exhaust flows and the C-values of the supply grids are given in table 7-8 .

Ventilation pattern	level mechanical exhaust	exhaust flow in relation to the maximum flow	supply grids in livingroom	supply grids in bedrooms
everything closed	low position	0.5	closed	closed
ventilating bedrooms	middle position	0.75	closed	open
ventilating living and kitchen	high position	1.0	open	closed
ventilating bathroom	high position	1.0	closed	open

Table 7-7 – exhaust flow levels and supply grid positions according to the different flow pattern defined in figure 7-3, figure 7-4 and figure 7-5

For the four systems, the airflows to deliver are identical. As a general rule, the nominal airflow is 1 $l/s/m^2$ with a minimum value (compulsory) and a maximum value (indicative).

room	airflow [l/s] @ 2 Pa	supply/exhaust	C [kg/s@1Pa]	n
livingroom	25	supply	0.0210	0.5
bedroom 1	10	supply	0.00850	0.5
bedroom 2	10	supply	0.00851	0.5
bedroom 3	10	supply	0.00851	0.5
kitchen	20	exhaust		
WC	10	exhaust		
bathroom	25	exhaust		

Table 7-8 – Airflows, according to NBN D 50-001 and the corresponding C and n values for the air inlets

<u>Natural supply</u>

In case of natural supply, airflow will be delivered by air inlets usually located above the windows. The nominal airflow must be delivered for a pressure difference of 2 Pa.

These air inlets, if not self-regulating, will follow a law like $Q = C \cdot \Delta P^n$, where n is usually equal to 0.5. The nominal airflow of such an air inlet is generally given in function of its length. The lengths and with it the resulting C values of the inlets are chosen in order to have exactly the nominal airflow of the room given in table 7-8.

Figure 7-6: Air inlet

<u>Natural exhaust</u>

Natural exhaust has to be provided by (almost) vertical ducts and must go directly to outside, above the roof.

The free surface of the air outlet must be at least 140 cm² for wet room as kitchen and bathrooms, with the exception of WC for which 70 cm² is sufficient. The smallest dimension of the exhaust ducts are 5 cm. The dimensioning (table 7-9) followed the rule that the cross section of the ducts is at least 1 $m^2/(m^3/s)$ (based on the Belgian standard NBN D50-001) [Wouters 2004].

	airflow [m^3/s] @ 2 Pa	A_{duct} [cm^2]	D [cm]
Kitchen	0.02	200	15.9
Bathroom	0.025	250	17.8
WC	0.01	100	11.3

Table 7-9 Cross sections in the exhaust ducts

Mechanical supply, mechanical exhaust

The NBN D 50-001 does not specify anything for mechanical ventilation, except the nominal airflow, which is the same than for natural ventilation. Therefore, there is nothing special to mention. Any mechanical system (like the Dutch reference systems) can be used, as soon as the airflows required by the Belgian standards are provided / extracted.

Fan

The exhaust fans will be modelled with a pressure independent constant flow characteristic with the flows defined in table 7-7 and table 7-8

7.4. System for severe climate – IC4

No simulations are made with this climate conditions.

7.5. System for warm climate – Portugal IC 5*

The ventilation strategies include two different types of ventilation:

- Natural ventilation according to the Portuguese standard NP1037-1;
- Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms.

Natural ventilation according to the Portuguese standard

All the zones of the building are enclosed in the ventilation, being the air inlets placed in the habitable rooms (living room and bedrooms) and the air outlets located in the wet rooms (kitchen and bathrooms)

Zone	**Air flow - exhaustion (m^3/h)**	**D_{duct} (mm)**	**Zone**	**Air flow – admission (m^3/h)**
Kitchen	90	140	Living	90
Bathroom	90	140	Bedroom 1/2/3	45
Toilet	45	110		
TOTAL	225			225

Fresh air inlets
Figure 7-7 and figure 7-8 show the self-regulation inlet grilles and the selection curves respectively.

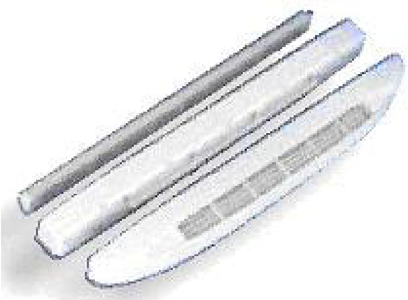


Figure 7-7 - Self-regulation inlet grilles

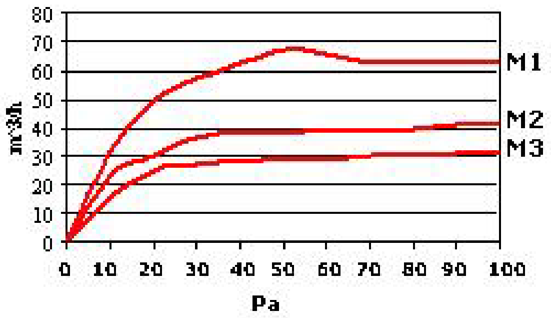


Figure 7-8 - Selection curve for the inlet grilles

Air extraction devices
Figure 7-9 and Figure 7-10 show the extraction valves used in WC and shower (position 3) and in the bathroom (position 9).

Figure 7-9 - Extraction grilles located in wet rooms

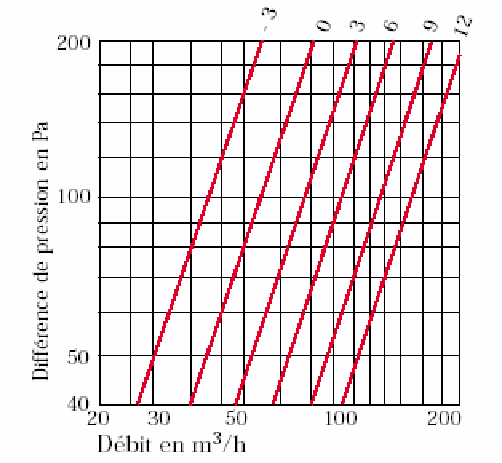


Figure 7-10 - Selection curve for the extraction grilles

The characteristic of the cooker hood used in the kitchen (position 6), is shown in figure 7-11.

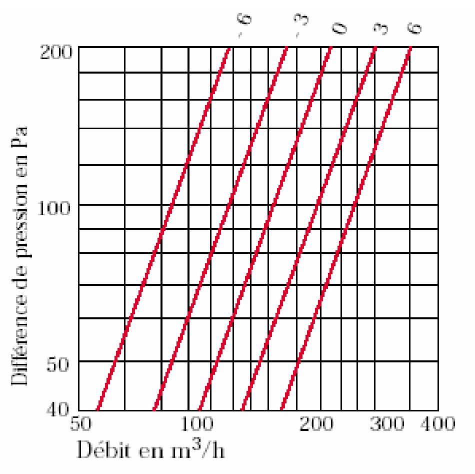


Figure 7-11 - Selection curve for the cooker hood placed in the kitchen

Air transfer between zones
Figure 7-12 and figure 7-13 show the transfer grille and it's characteristic.

Figure 7-12 – Transfer grille

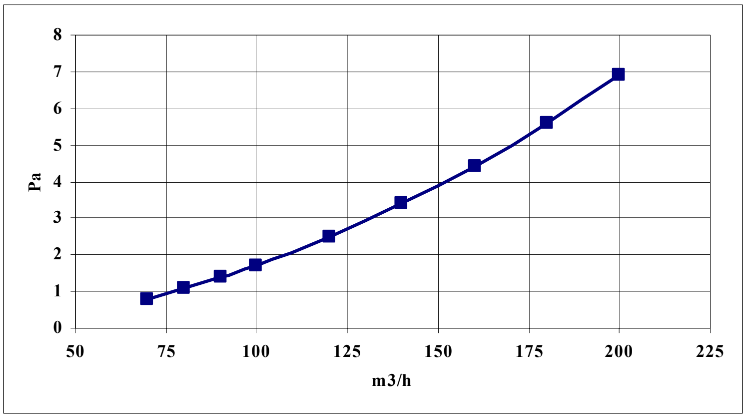


Figure 7-13 - Characteristic curve of the transfer grille

Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms

There are two independent fans, one for extraction of the bathroom and WC (fan 1 – 50 m^3/h/each zone for a total of 100 m^3/h) and another for the kitchen (fan 2 – 100 m^3/h). These fans are on from the 8 o'clock in the morning until the 24 o'clock.
In the habitable rooms (living room and bedrooms) air from the outside is supplied through regulated inlet grilles and the air transfer between zones is guaranteed by a crack of about 80 x 2 cm below each door.

The ventilation duct is Spiro metal sheet with 0.15 mm roughness and with a nominal diameter of 80 mm in the kitchen and 75 mm in the main duct of the bathroom, WC and shower. Each branch of this ventilation section has a 63 mm diameter.

Fan
The fan used for this system was the 100 model. The maximum power of this fan is 41 W.

Figure 7-14 - Centrifugal fan

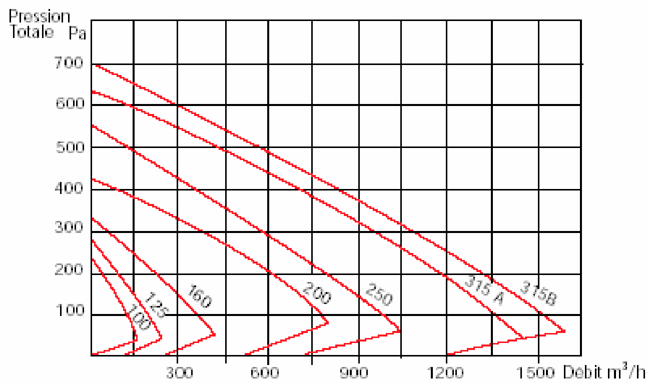


Figure 7-15 - Selection curve of the fan 1 and 2

<u>Air extraction devices</u>

Figure 7-16 and figure 7-17 shows the extraction valves used in WC and bathroom (model 6).

Figure 7-16 - Extraction grilles located in wet rooms

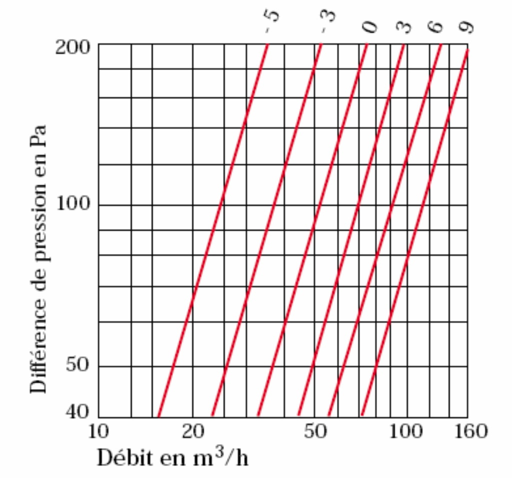


Figure 7-17 - Selection curve of the extraction grilles

In the kitchen, we used a cooker hood with a curve characteristic analogous to the extraction grille which curve (model 6) is showed in figure 7-18.

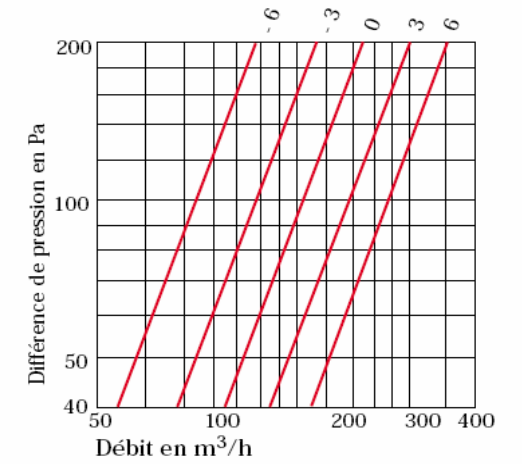


Figure 7-18 - Selection curve of the cooker hood

In the top of each extraction duct there is a rain protection cowl, with the following characteristic.

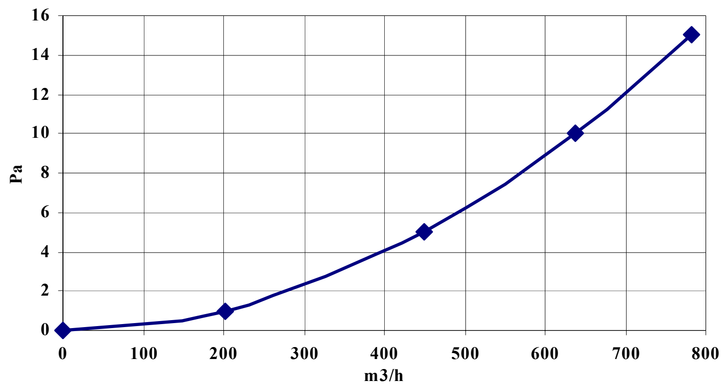


Figure 7-19 - Rain protection cowl

Fresh air inlets
The figure 7-20 and figure 7-21 shows the inlet grilles used in the living room and in the bed-rooms.

Figure 7-20 – Air inlet grilles

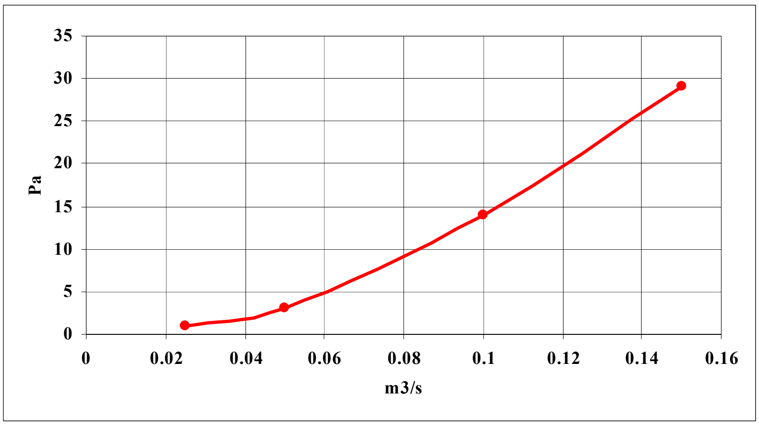


Figure 7-21 - Selection curve of the inlet grilles placed in the habitable rooms

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