

IDMEC

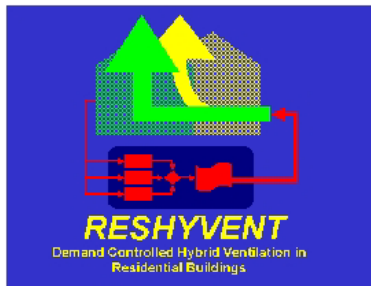
Instituto de Engenharia Mecânica
Pólo FEUP

RESHYVENT

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

Contract No: ENK6 – CT – 2001 – 00533

WP 6 Performance assessment Support Unit



Report Title:

Portuguese Ventilation System (IC5)

RESHYVENT Working report No:

RESH-WP6-D6.2.5.IC5

Date:

December 2004

{file: RESH-WP6-D6_2_5_IC5.doc}

Prepared by:

Eduardo Maldonado, José Luís Alexandre, Petra Vaquero, Jorge Sousa
IDMEC – Institute of the Department of Mechanical Engineering of the University of Porto
Porto, Portugal

CONTENTS

Nomenclature.....	6
1. Introduction	7
2. Site description	7
2.1. Geographical information.....	7
2.2. Climate information	7
2.2.1. Other meteorological parameters	9
3. Building description	10
3.1. General description	10
3.2. Components and materials	11
3.2.1. Walls, floors and roofs.....	11
3.2.2. Windows & Doors	12
3.3. Infiltration – air leakage data	13
3.4. Wind pressure coefficients	13
4. Building Services	14
4.1. Space Heating.....	14
4.2. Space cooling.....	14
4.3. Internal loads	14
4.3.1. Family types and occupancy density.....	14
4.3.2. Water vapour and CO ₂ production, and heat gains.....	16
4.3.2.1. Metabolism.....	16
4.3.2.2. Equipment	16
4.3.2.3. Showering.....	17
4.3.2.4. Cooking.....	17
4.3.2.5. Clothes washing and drying	17
5. Ventilation.....	19
5.1. System I – Natural ventilation according to the Portuguese standard.....	19
5.1.1. Devices technical data.....	21
5.2. System II – Natural ventilation in wet rooms – old Pt standard.....	23
5.2.1. Technical data	24
5.3. System III – Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms 25	
5.3.1. Technical data	26
5.4. System IV – Mechanical Exhaust Ventilation System in the wet rooms and self-regulated inlet grids in the other rooms.....	28
5.4.1. Technical data.....	29
6. Simulation conditions and Results analysis	32

6.1.	Reference simulation conditions	32
6.2.	System I	35
6.3.	System II	43
6.4.	System III	50
6.5.	System IV	58
7.	System Global Analysis	66
8.	Sensitivity Analysis	69
8.1.	Parameter variation	69
8.2.	Orientation Analysis	70
8.2.1.	Global Analysis for building orientation effect.....	70
8.2.2.	Summary tables.....	72
8.3.	Air leakage Analysis	74
8.3.1.	Global Analysis for air leakage effect.....	74
8.3.2.	Summary tables.....	75
8.4.	Shielding Analysis	77
8.4.1.	Global Analysis for shielding effect	77
8.4.2.	Summary tables.....	78
8.5.	Water vapor production	80
8.5.1.	Global Analysis for water vapour production effect.....	80
8.5.2.	Summary tables.....	81
8.6.	Occupancy density Analysis	83
8.6.1.	Global Analysis Occupancy density effect	83
8.6.2.	Summary tables.....	84
9.	Conclusion	86
10.	Appendix A - Different humidity models analysis	87
10.1.	Humidity models explanation	87
10.1.1.	Effective Capacitance Humidity Model.....	87
10.1.2.	Buffer Storage Humidity Model.....	88
10.2.	Models results analysis	90
10.2.1.	Effective Capacitance Humidity Model (ECHM_1).....	91
10.2.2.	Effective Capacitance Humidity Model (ECHM_10).....	94
10.2.3.	Buffer Storage Humidity Model (BSHM).....	97
10.3.	Models Comparison and Conclusions	101
11.	Appendix B – Detailed Simulations Results	104
11.1.	System I	104
11.1.1.	Heating Energy consumption	104
11.1.2.	CO ₂ Concentration	104
11.1.3.	Exhaust air flow rate	105
11.1.4.	Inlet air flow rate through grilles and cracks.....	107
11.1.5.	Thermal Comfort PPD	109
11.1.6.	Relative Humidity	111

11.1.7.	Absolute humidity	112
11.2.	System II.....	113
11.2.1.	Heating Energy consumption	113
11.2.2.	CO ₂ Concentration	113
11.2.3.	Exhaust air flow rate	114
11.2.4.	Inlet air flow rate through grilles and cracks.....	117
11.2.5.	Thermal Comfort PPD	118
11.2.6.	Relative Humidity	120
11.2.7.	Absolute humidity	121
11.3.	System III	122
11.3.1.	Heating Energy consumption	122
11.3.2.	Energy consumption of the fans.....	122
11.3.3.	CO ₂ Concentration	122
11.3.4.	Exhaust air flow rate	124
11.3.5.	Inlet air flow rate through grilles and cracks.....	125
11.3.6.	Thermal Comfort PPD	127
11.3.7.	Relative Humidity	129
11.3.8.	Absolute humidity	130
11.4.	System IV.....	131
11.4.1.	Heating Energy consumption	131
11.4.2.	Energy consumption of the fans.....	131
11.4.3.	CO ₂ Concentration	131
11.4.4.	Exhaust air flow rate	133
11.4.5.	Inlet air flow rate through grilles and cracks.....	135
11.4.6.	Thermal Comfort PPD	136
11.4.7.	Relative Humidity	139
11.4.8.	Absolute humidity	139
12.	Appendix C – Sensitivity Analysis Detailed Results	140
12.1.	Detailed results of orientation analysis	140
12.1.1.	System I.....	140
12.1.2.	System II	141
12.1.3.	System III.....	143
12.1.4.	System IV.....	144
12.2.	Detailed results of air leakage analysis	146
12.2.1.	System I.....	146
12.2.2.	System II	147
12.2.3.	System III.....	149
12.2.4.	System IV.....	150
12.3.	Detailed results of shielding analysis.....	152
12.3.1.	System I.....	152
12.3.2.	System II	153
12.3.3.	System III.....	155
12.3.4.	System IV.....	156
12.4.	Detailed results of water vapor production analysis.....	158
12.4.1.	System I.....	158
12.4.2.	System II	159
12.4.3.	System III.....	161
12.4.4.	System IV.....	162
12.5.	Detailed results of occupancy density analysis.....	164
12.5.1.	System I.....	164
12.5.2.	System II	165
12.5.3.	System III.....	167
12.5.4.	System IV.....	168

13. References 170

Nomenclature

C_d – Discharge coefficient [-]

C_p – Specific heat [J/kg.°K]

C_s –Flow coefficient [kg/s @ 1 Pa]

g - Shading coefficient [%]

n – Flow exponent [-]

R – Thermal resistance [$m^2 \cdot ^\circ K/W$]

T_{max} – Maximum temperature in a zone [°C]

U – Heat transfer coefficient [$W/m^2 \cdot ^\circ K$]

λ – Thermal conductivity [$W/m \cdot ^\circ K$]

ρ – Density [kg/m^3]

1. Introduction

The aim of the present report is to define Reference Ventilation Systems used in Portugal and the new strategies of ventilation in the buildings. The studied ventilation strategies include four different types of ventilation:

- Natural ventilation according to the Portuguese standard;
- Natural ventilation in wet rooms – old Pt standard;
- Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms;
- Mechanical Exhaust Ventilation System in the wet rooms and self-regulated inlet grids in the other rooms.

A single family house located in Porto was used with the different strategies mentioned above. For each case, it is intended to evaluate the impact of those systems in the indoor air quality and in the heating energy consumption.

The assumptions done in these simulations tests were based in the recommendations from the Annex 27 handbook [1] and from the RESHYVENT – WP5 – WR – 4, 28th November 2003 report [2].

2. Site description

2.1. Geographical information

The single family house is located in Porto - Portugal.

Latitude = 41.13 ° N

Longitude = 8.68 ° W

Altitude = 73 m

2.2. Climate information

The weather information for Porto is obtained from an Energy Plus data file. Table 2-1, figure 2-1 and figure 2-2 show a few important statistics of the climate file. The wind direction is predominately from North, with a speed between 2 and 4 m/s.

	°C	Date of occurrence
T_{max}	27	2 October_14:00
T_{min}	0	24 January_5:00

Table 2-1 Range of outdoor dry bulb temperature for the winter season

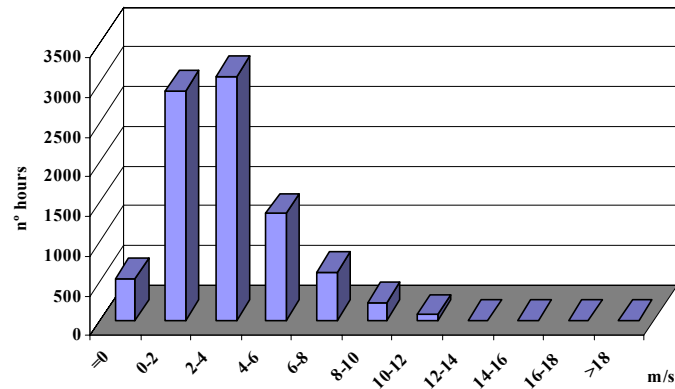


Figure 2-1 - Frequency of wind speed

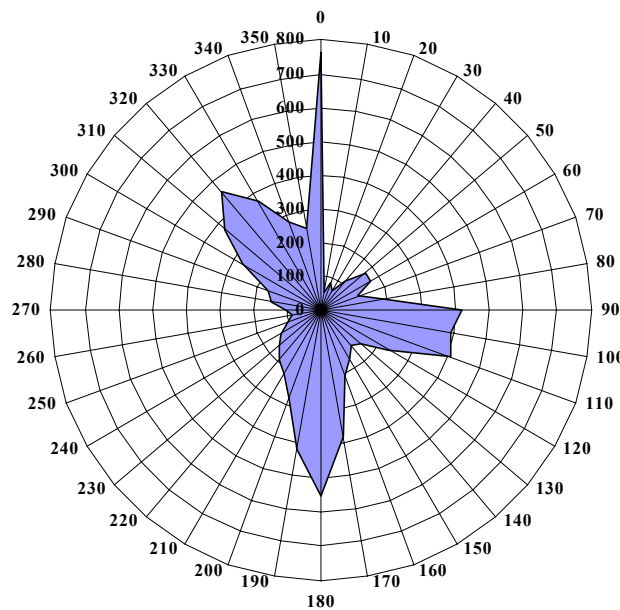


Figure 2-2 - Frequency of wind directions during the whole year
(0° for wind from North, 90 from East, 180 from South and 270 from West)

According to RESHYVENT WP5 [3], 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 °C. 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 °C. This is the last day of the heating season, whatever day is.

The conventional heating period begins in the October 11th that has an average outdoor temperature below 13 °C and ends in April 14th when the same temperature exceeds 13°C, which means about six months for heating.

2.2.1. Other meteorological parameters

The ground floor temperature will be need for evaluate the heating losses below grade, basements and ground floor slab. Different methodologies can be preformed to obtain the temperature of the ground for small depth, one, the simplest, is to assume that the temperature will be constant throughout all year and another is assume that the daily average dry bulb temperature is the same as the temperature of the ground. Therefore, some times the ground temperature could be know and obtained directly from the weather data (Energy plus weather data). Those temperatures are available as a monthly average temperature of the ground for three different depths, 0.5, 2 and 4 m (figure 2-3). In the simulations only the first depth will be considerate because only the ground floor slab losses will be evaluated. Figure 2-4 shows the difference between the year distribution of the average dry bulb air temperature (Tdb), the daily air Tdb average and the ground temperature from Energy + (with 0.5 m depth). The last two methods are quite similar but so far from the first one, constant year ground temperature method.

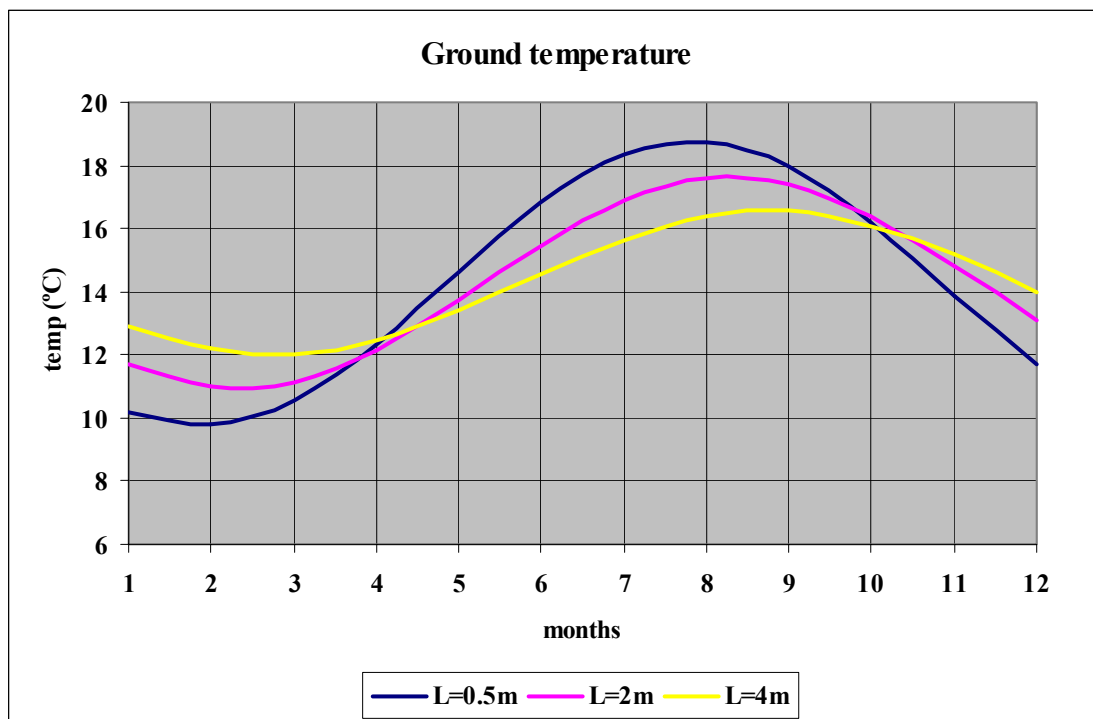


Figure 2-3 - Ground temperature evolution throughout the year

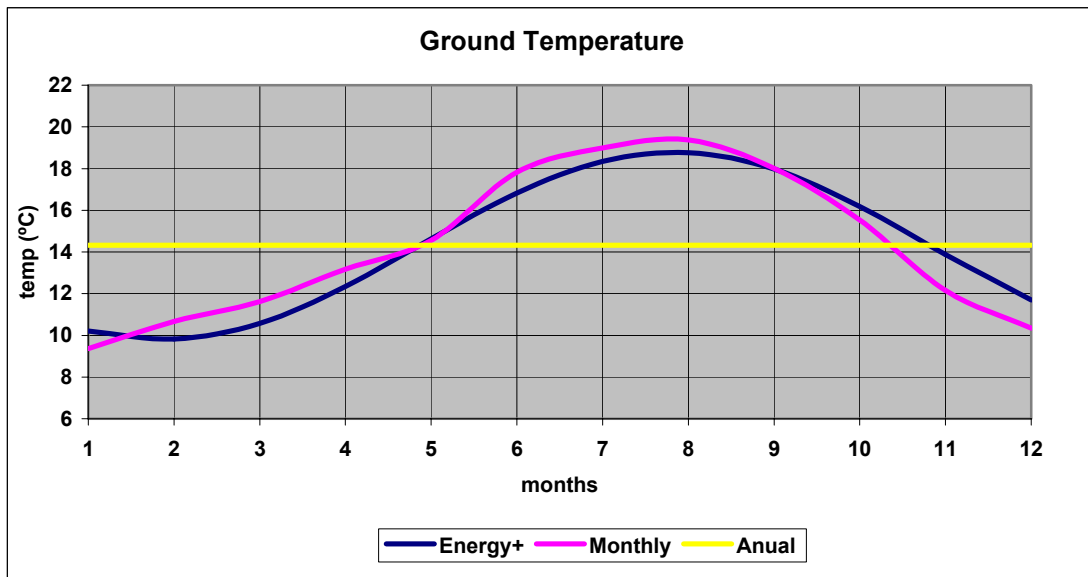


Figure 2-4 - Analyses between different methods of defining ground temperature

3. Building description

3.1. General description

The simulation will be done for a single family house (SFH) based on the dwellings proposed in Annex 27 [1].

The dwelling's useful floor area is 85 m². It has three bedrooms, one living room, one kitchen, one bathroom and one toilet, corresponding to two main floors. The floor to ceiling height is 2.5 m. There are eight independent zones and only 71 % of the useful area is treated by the HVAC system. The following table shows the areas distribution and location of the different rooms.

	Floor	Area (m ²)
Living room	First	24.75
Kitchen	First	8.75
WC	First	3.75
Bathroom	Second	7.5
Bedroom 1	Second	10
Bedroom 2	Second	10
Bedroom 3	Second	10
Hall	Both	9.75

Table 3-1 - Room floor areas [m²]

Figure 3-1 and figure 3-2 show the floor plans and the cross-section the dwelling.

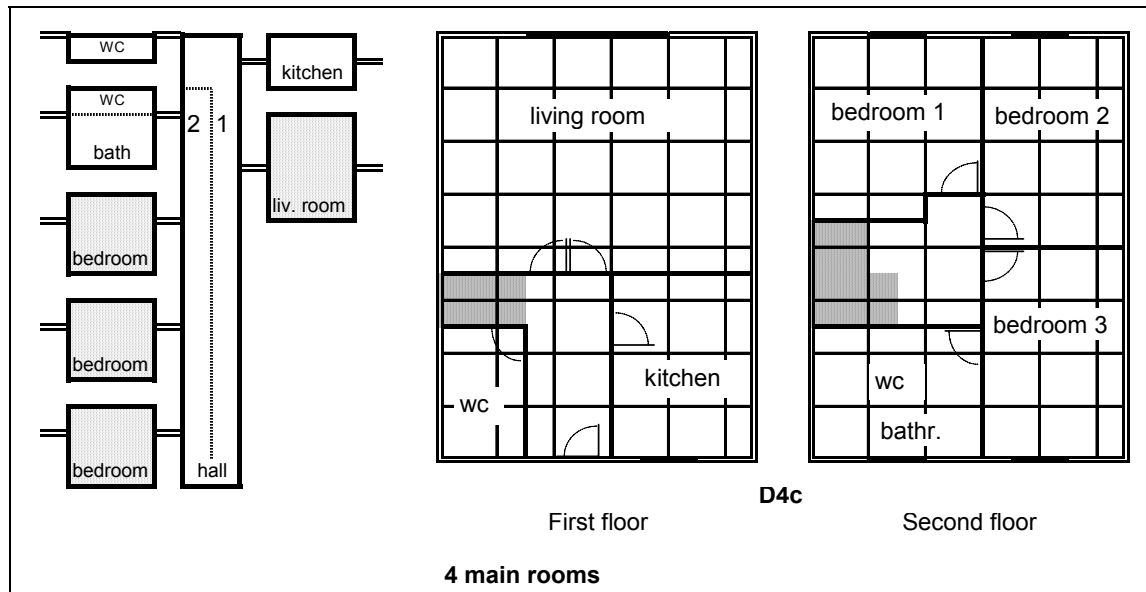


Figure 3-1– Floor Plans

The orientation of the main façade (living room) of the building is to South.

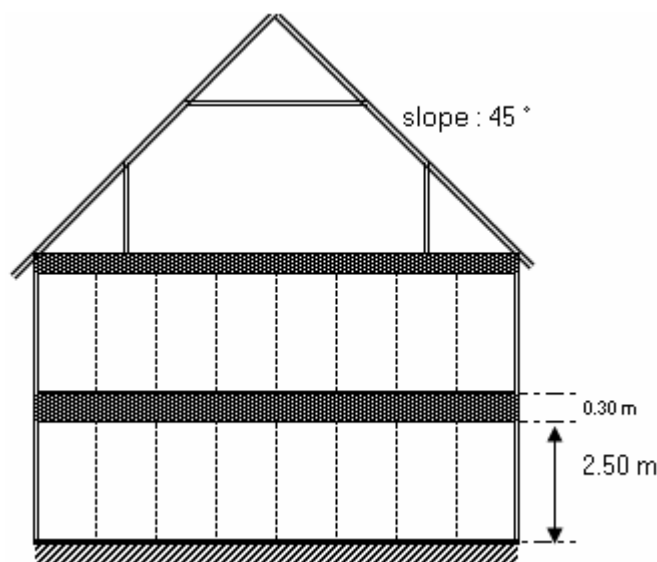


Figure 3-2 – Cross section of the dwelling

3.2. Components and materials

3.2.1. Walls, floors and roofs

Table 3-2 presents a detailed description of the complete building envelope. Each envelope element is made of different layers of material, starting from inside. The properties of those layers are defined in the same table. The U-values of the different elements are calculated assuming conventional values for the external and internal Convective Heat Transfer Coefficient (CHTC) of a vertical wall as 25 W/m².K and 7.7 W/m².K, respectively

In this table the layers are placed from the internal façade to the external façade.

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

Element	Layers	Thickness [m]	λ [W/m.°K]	c_p [J/kg.°K]	ρ [kg/m ³]	R [m ² .°K/W]	U (W/m ² .°K)
External Wall	Gypsum board	0.02	1.15	837	1950		0.45
	Brick	0.15	0.44	936	1100		

Element	Layers	Thickness [m]	λ [W/m. $^{\circ}$ K]	c_p [J/kg. $^{\circ}$ K]	ρ [kg/m 3]	R [m 2 . $^{\circ}$ K/W]	U (W/m 2 . $^{\circ}$ K)
	Air gap	0.02	-	-	-	0.16	
	Polystyrene, rigid extruded	0.04	0.035	1210	35		
	Brick	0.11	0.44	936	1100		
	Gypsum board	0.02	1.15	837	1950		
	Gypsum board	0.02	1.15	837	1950		
Internal Wall	Brick	0.11	0.44	936	1100		2.20
	Gypsum board	0.02	1.15	837	1950		
	Gypsum board	0.02	1.15	837	1950		
Slab between floors	Gypsum board	0.02	1.15	837	1950		2.17
	Slab of clay	0.13	0.93	965	1320		
	Wood	0.02	0.15	2750	550		
Ground floor slab	Wood	0.02	0.15	2750	550		0.98
	Concrete	0.25	1.75	1080	2200		
Roof slab	Wood	0.02	0.15	2750	550		0.61
	Brick	0.15	0.44	936	1100		
	Mineral wool	0.045	0.58	2.86	12		
	Tile of clay ¹⁾	0.03	1.15	880	1900		

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 convective heat transfer coefficient is equal to the internal (7.7 W/m 2 K)

3.2.2. Windows & Doors

Typical Portuguese windows consist of double glazing with an aluminium frame - see table 3-3. All windows are assumed to have interior curtains with a shading coefficient of 0.8 and an external blind which is open when all day and closed all night. The shading coefficient of this protection is 0.04 and is constant through all the year. For the base case simulation, the windows are always closed.

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	90 $^{\circ}$	
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	
U-value	4.5 W/m 2 K	

Table 3-3 - Properties of double glass window

Table 3-4 lists the glazed areas in each façade.

	A (m ²)	% façade area
North façade	6	30
South façade	6	30

Table 3-4 - Glazing area of the building

The external and internal doors are made of 4 cm wood with an area of 2.2 m². Table 3-5 lists the U-values of these elements.

	U (W/m ² .°C)
Internal door	2.2
External door	2.3

Table 3-5 – U values for the doors.

3.3. Infiltration – air leakage data

Three leakage classes (tight, average and leak) are considered, according to A27-V2 [1]. The leakage corresponds to the law:

$$\dot{m} = C \cdot \Delta p^n \quad \text{with } n = 0.66.$$

Table 3-6 shows the overall leakages n_{50} and the corresponding C_{total} for the different leakage classes (assumption: 20°C and 101.3 kPa).

	D4c	
	n_{50} [ach/h]	C_{total} [kg/s@1Pa]
tight	1	0.00531
average	2.5	0.0133
leak	5	0.0266

Table 3-6: 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	Kitchen	Bed1	Bed2	Bed3	WC	Bath	Hall down	Hall up
D4c	0.262	0.107	0.143	0.119	0.119	0.024	0.107	0.060	0.060

Table 3-7: Distribution of the overall leakage

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

From these three leakage levels, the last is the closest to the Portuguese case. Thus, in these simulations we will assume that the main building leakage is 5 ACH@ 50 Pa.

In an advanced simulation stage, the windows have an opening schedule and they are assumed as large openings with a discharge coefficient C_d of 0.6.

3.4. Wind pressure coefficients

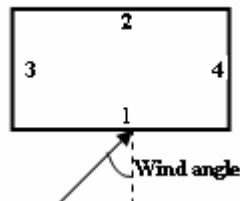
Three levels of shielding conditions are considered according to Orme [4] for evalu

- **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 3-8 and the C_p -values of the facades are given in table 3-9. The wind speed reference level is equal to the building height.

Facade 2, Front	Facade 1, Rear	Roof
Living room	Kitchen	-
Bedroom 1	Bedroom 3	-
Bedroom 2	Bathroom	-

Table 3-8: assignment of the rooms to the different facades



shielding	Facade	Wind Angle							
		0°	45°	90°	135°	180°	225°	270°	315°
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 3-9 - C_p -values given by [AIVC 1998]

In these first simulations it was assumed a partially shielded building.

4. Building Services

4.1. Space Heating

There is a natural gas boiler with radiators. Set points are shown in table 4-1 and are the same throughout the whole Winter (i.e., October 11th until April 14th).

Livingroom	20 °C
Bedrooms	18 °C
Bathroom	23 °C
Rest of the building	free - floating

Table 4-1– Heating temperature set points

4.2. Space cooling

There is no cooling system in the building because, in Summer, the temperature is free floating in the entire dwelling.

4.3. Internal loads

4.3.1. Family types and occupancy density

Table 4-2 defines the four family types used and their behaviour. Table 4-3 gives the detailed schedule of presence in the different rooms.

Table 4-2 Occupant pattern of the different family types

Family	Member of household	Time at home		Shower		Washing per family Per week
		Weekdays	Sat.- Sun.	Frequency	Duration	
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	

Table 4-3: Occupant pattern of the different family types

Family type	Member of household	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

Family type	Member of household	Time in				
		Kitchen	Living room	Master bedroom	Bedroom 2	Bedroom 3
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

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 4-4. For each dwelling type all three occupancy densities are used for the sensitivity analysis. In these first simulations it will be assumed a standard family type with four persons.

Family type	D4c
2 person	spacious
4 person	average
5 person	crowded

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

4.3.2. Water vapour and CO₂ production, and heat gains

4.3.2.1. 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 4-5: metabolism of the occupants

4.3.2.2. 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.

ZONE	AREA [m ²]	Internal gain [W]
Living	24.75	117.2
Kitchen	8.75	41.4
WC	3.75	17.8
Bath	7.5	35.5
Bed1	10	47.3

Bed2	10	47.3
Bed3	10	47.3
Hall	9.75	46.2

Table 4-6 - Internal heat production due to electrical appliances

4.3.2.3. Showering

Showering is assumed to take place according to the schedule given in table 4-7. 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 4-7: Showering schedules of the different family types

4.3.2.4. 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	6.30 - 7.00	100	9.00 - 10.00
		200	7.00 - 8.00	100	10.00 - 11.00
	Lunch	0	-	750	11.00 - 12.00
	Dinner	1500	17.00 - 18.00	1500	17.00 - 18.00
Average	Breakfast	100	6.30 - 7.00	150	9.00 - 10.00
		100	7.00 - 8.00	50	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 4-8: cooking schedules of the different family types

Note that if no lunch is scheduled at home then 0 water vapour is produced.

4.3.2.5. 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

In the present cases the second option, “with drying machine” was chosen.

5. Ventilation

The studied ventilation strategies include four different types of ventilation:

- Natural ventilation according to the Portuguese standard;
- Natural ventilation in wet rooms – old Portuguese regulation;
- Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms;
- Mechanical Exhaust Ventilation System in the wet rooms and self-regulated inlet grids in the other rooms.

5.1. System I – Natural ventilation according to the Portuguese standard

A new Natural Ventilation regulation was approved last year (NP – 1037-1¹) [ref. xx] but as a new one regulation means that there aren't, yet, many buildings that fulfil this regulation.

Two different natural ventilation strategies are allowed in the new Portuguese regulation

- Joined ventilation –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 exhaust air devices located in the wet rooms (kitchen and bathrooms) (see figure 5-1).

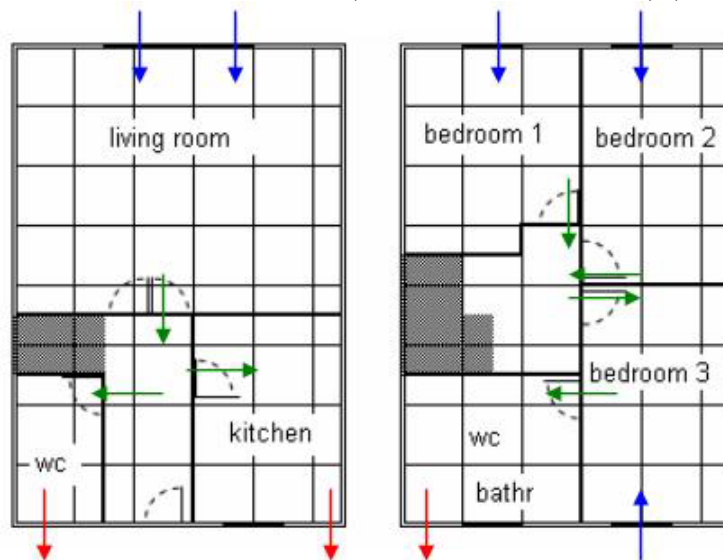


Figure 5-1 – Sample of joined ventilation

- Separate ventilation – the building is divided in several independent zones, which one has their own air inlets and outlets devices (see figure 5-2).

¹ NP 1037-1: Ventilação e evacuação dos produtos da combustão dos locais com aparelhos de gás, 2002

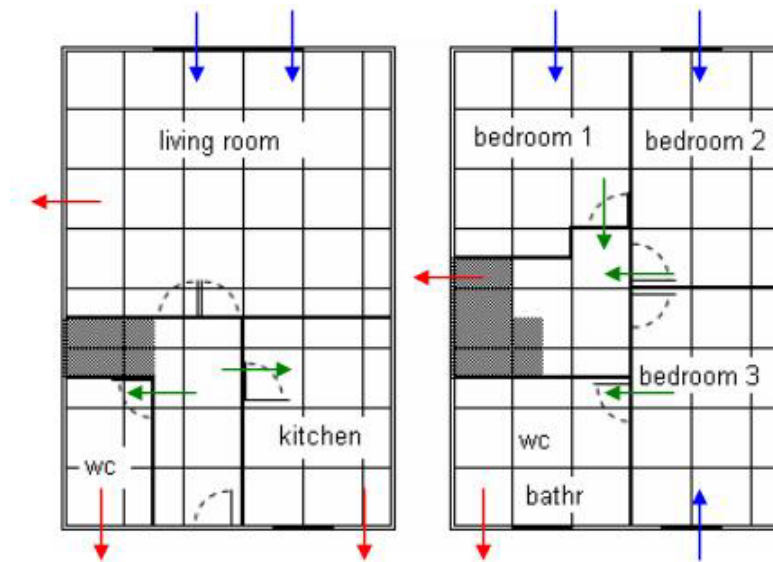


Figure 5-2 - Sample of separate natural ventilation

The most common strategy of natural ventilation is the first one, joined ventilation, which will be used in this study and is represented in figure 5-3.

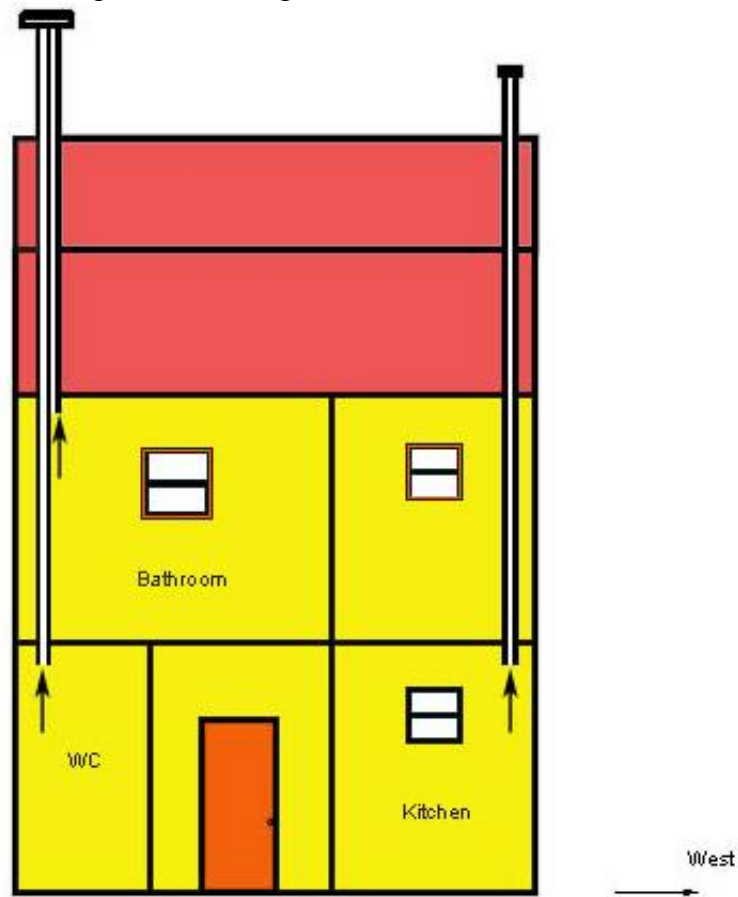


Figure 5-3 - Natural ventilation duct scheme

The duct sizing for the exhausts and outlets is based on several requirements of this standard, for instance:

- the selection of the different ventilation devices installed in the building is dependent of the air flow that is based in the following two rules:
 - the air changes of living rooms, bedrooms, dinning rooms must be at least 1 ACH
 - the air changes of kitchens, bathrooms, laundries must be at least 4 ACH

- the air flow admission is made through grilles placed in the façades of the living room and bedrooms;
- the air exhaustion, from different places (kitchen and sanitary installations) is done through exhaust valves connected to individual vertical ducts (chimneys);
- the minimum height of the extraction chimney is 4.25 m;
- the air channel between the different zones is made by the transfer grilles that are placed in internal doors.

According to the new Portuguese regulation, the standard values for the air flow are shown in table 5-1 and, also, the minimum dimension for the exhaust air ducts.

Zone	Exhaust air flow rate (m ³ /h)	D _{duct} (mm)	Zone	Inlet Air flow rate (m ³ /h)
Kitchen	90	140	Living	90
Bathroom	90	140	Bedroom 1/2/3	45
Toilet	45	110		
TOTAL	225			225

Table 5-1 - Portuguese recommendation for natural ventilation- new regulation

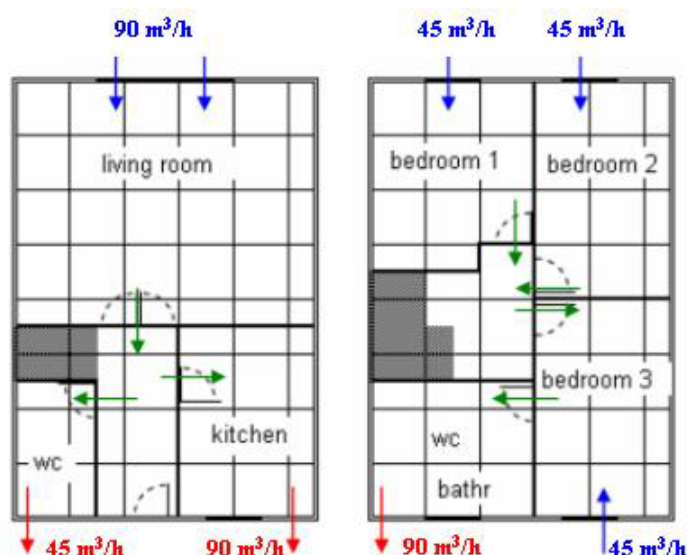


Figure 5-4 – Schematic Portuguese recommendation for the minimum air flows – natural ventilation

5.1.1. Devices technical data

This section shows the technical information of the fans, grilles and ducts used in the simulation of the natural ventilation system.

Figure 5-5 and figure 5-6 show the self-regulation inlet grilles and the selection curves respectively.



Figure 5-5 - Self-regulation inlet grilles

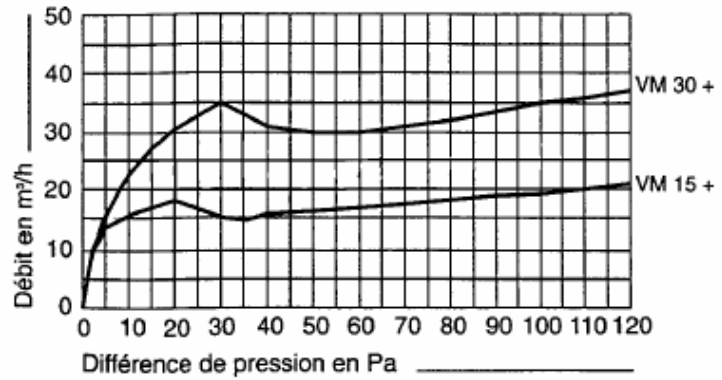


Figure 5-6 - Selection curve for the inlet grilles

Zone	VM15	VM30
Living	2	-
Bedroom 1	1	-
Bedroom 2	1	-
Bedroom 3	1	-

Table 5-2 – Number and type of grilles in each zone

Figure 5-7 and figure 5-8 show the extraction valves used in WC and shower (position 3) and in the bathroom (position 9).



Figure 5-7 - Extraction grilles located in wet rooms

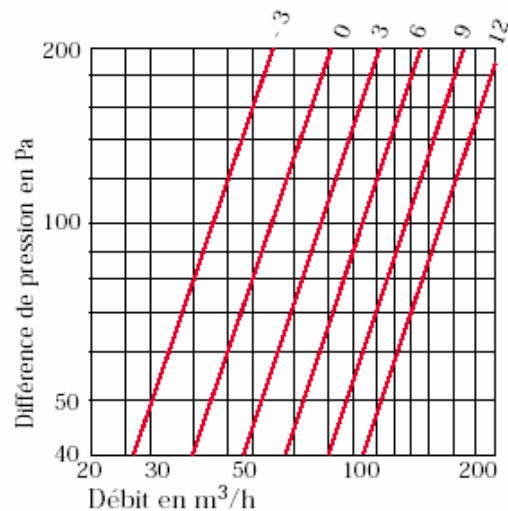


Figure 5-8 - Selection curve for the extraction grilles

The characteristic of the cooker hood used in the kitchen (position 6), is shown in figure 5-9.

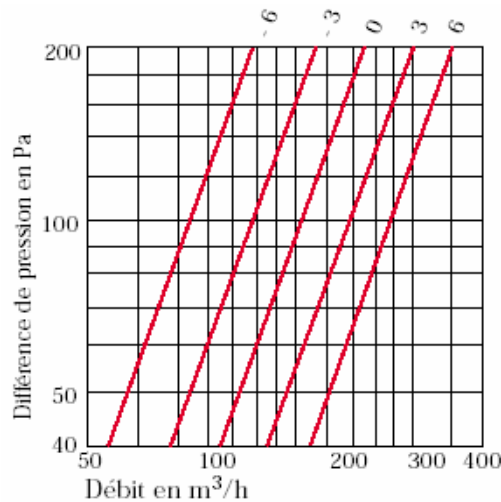


Figure 5-9 - Selection curve for the cooker hood placed in the kitchen

The ventilation duct is Spiro metal sheet with 0.15 mm roughness and with a nominal diameter presented in table 5-1.

Figure 5-10 and Figure 5-11 show the transfer grille and its characteristic.



Figure 5-10 – Transfer grille

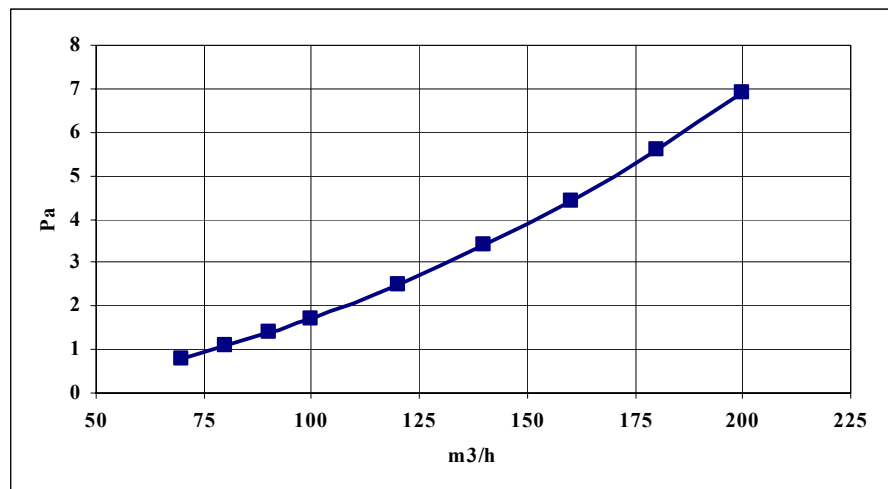


Figure 5-11 - Characteristic curve of the transfer grille

5.2. System II – Natural ventilation in wet rooms – old Pt standard

Typical Portuguese Ventilation System, before the new Natural Ventilation System Regulation (NP –1037-1), is based on a Standard Natural Ventilation system that is quite similar to the previous one presented above (System I). The type of the inlet airflow devices is the main difference between both ventilation systems. The first ventilation system only allows the self-regulating grilles as inlet airflow devices; therefore, the airflow rate is always quite constant and independent of external/internal pressure difference (Δp). There is not any kind of inlet airflow devices placed in the building façade in the second one (System II). Therefore the airflow rate is function of internal/external pressure difference due to the cracks located in the external building's façades and strongly dependent of the wind effect. The air flow transfer between internal zones is made through the door undercut of each internal door.

The air exhaust is done in the kitchen (100 m³/h), bathroom (50 m³/h) and WC (50 m³/h), though vertical ducts connecting each zone to an external point above the roof. The air from outside comes into the building through the existing cracks and the air transfer between zones is guaranteed by a crack of about 80 x 2 cm below each door is present. The ventilation duct is a Spiro metal sheet with 0.15 mm roughness and with a diameter of 140 mm in the kitchen and 100 mm in the main duct of the bathroom and WC.

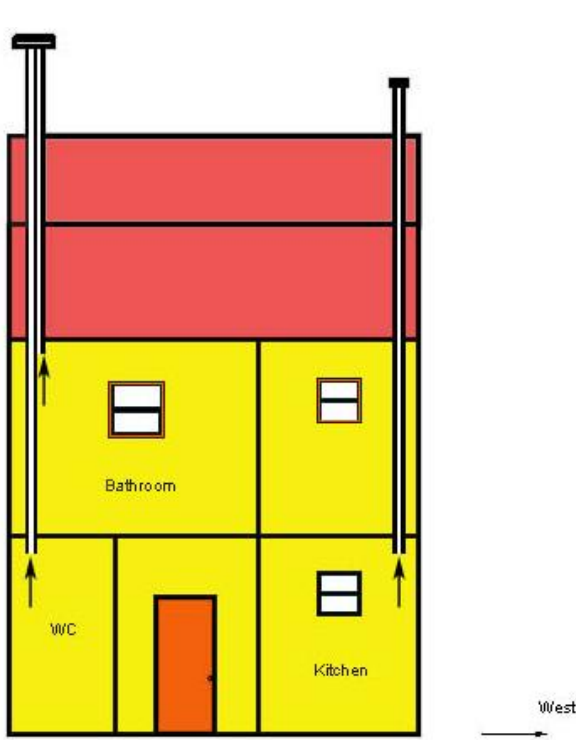


Figure 5-12 – Standard Natural Ventilation system

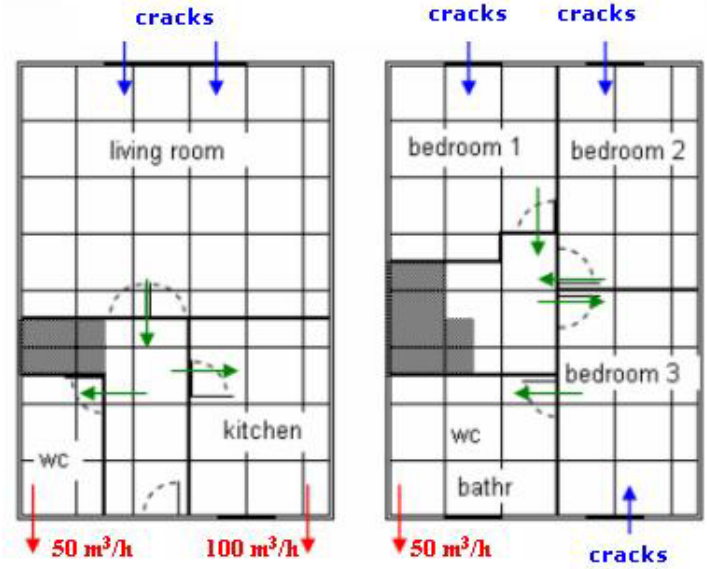


Figure 5-13 – Standard Natural Ventilation system flow rates scheme

5.2.1. Technical data

Figure 5-14 and figure 5-15 show the extraction valves used in WC and bathroom (position 6).



Figure 5-14 - Extraction grilles located in wet rooms

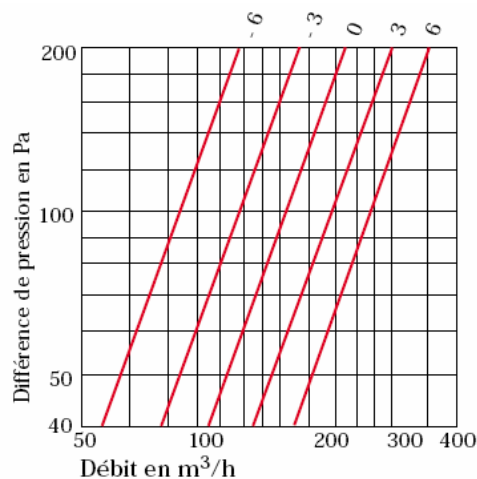


Figure 5-15 - Selection curve of the extraction grilles

The characteristic of the cooker hood used in the kitchen (position 6), is shown in figure 5-16.

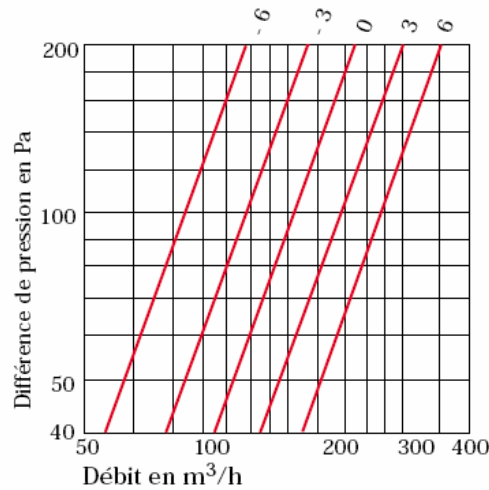


Figure 5-16 - Selection curve of the cooker hood

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

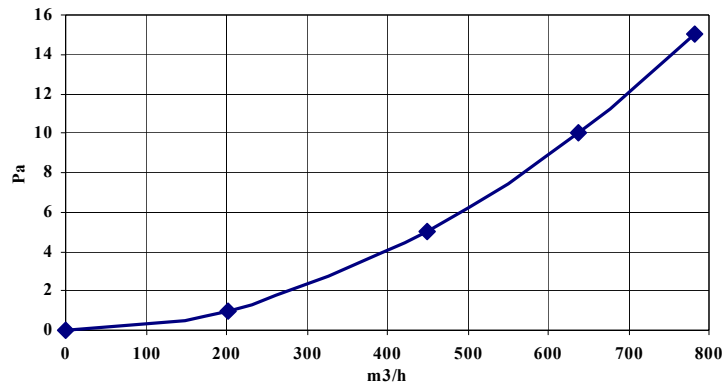


Figure 5-17 - Rain protection cowl

5.3. System III – Mechanical Exhaust Ventilation system in the wet rooms and inlet grids in the other rooms

The mechanical ventilation exhaust system used in the simulations is schematically represented in figure 5-18. There are two independent fans, one for extraction of the bathroom and WC (fan 1 – 50 m³/h/each zone for a total of 100 m³/h) and another for the kitchen (fan 2 – 100 m³/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.

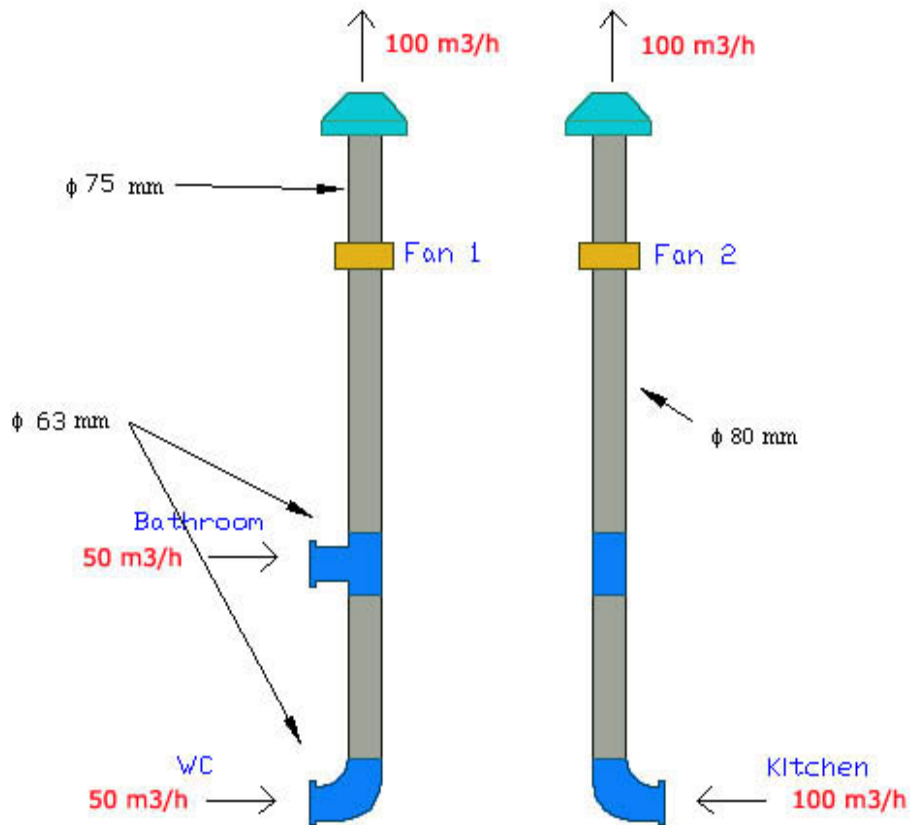


Figure 5-18 – Mechanical Exhaust system

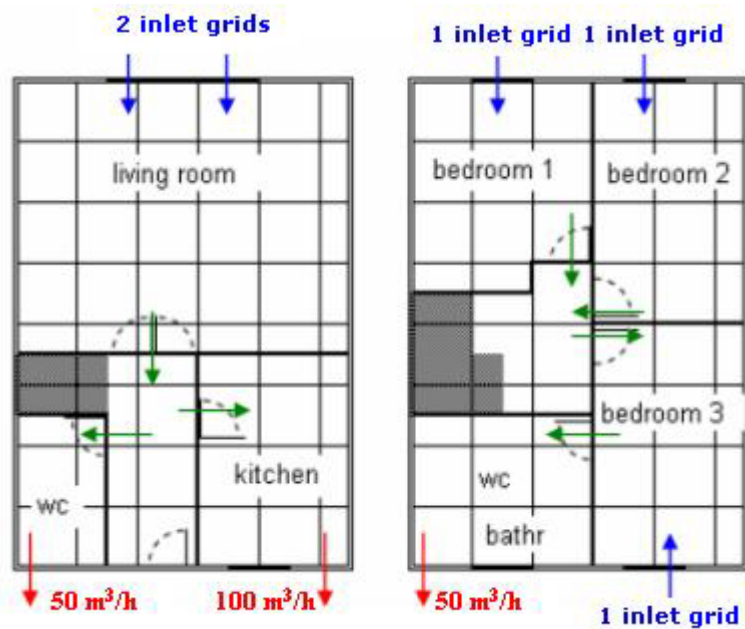


Figure 5-19 - Mechanical ventilation system scheme

5.3.1. Technical data

This section shows the technical information of the fans, grilles and ducts used in the simulation of the mechanical ventilation system.



Figure 5-20 - Centrifugal fan

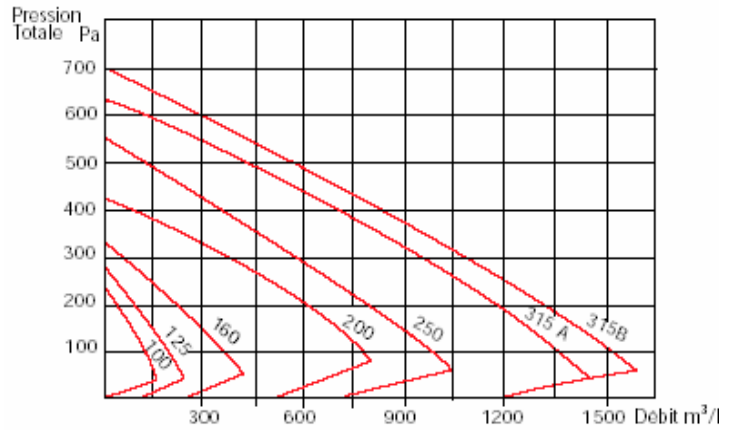


Figure 5-21 - Selection curve of the fan 1 and 2

The fan used for this system was the 100 model. The maximum power of this fan is 41 W. Figure 5-22 and figure 5-23 shows the extraction valves used in WC and bathroom (model 6).



Figure 5-22 - Extraction grilles located in wet rooms

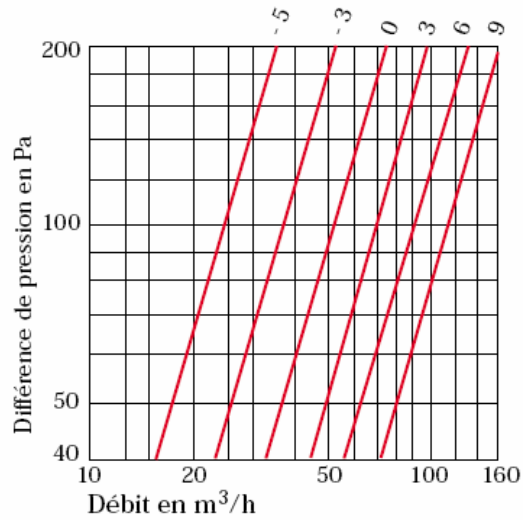


Figure 5-23 - Selection curve of the extraction grilles

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 5-24.

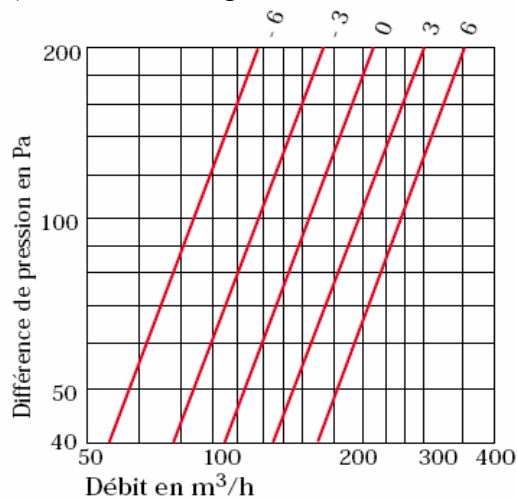


Figure 5-24 - Selection curve of the cooker hood

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

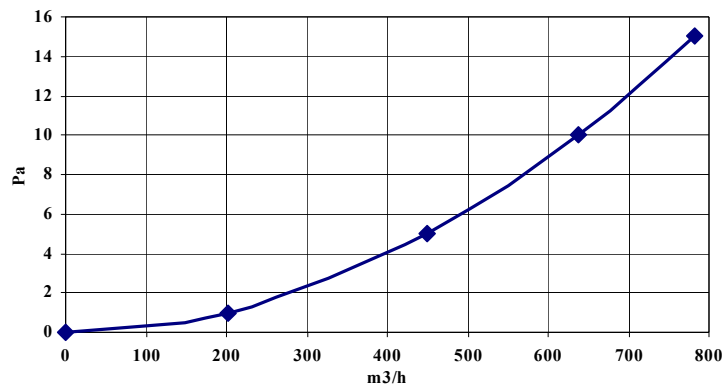


Figure 5-25 - Rain protection cowl

The figure 5-26 and figure 5-27 shows the inlet grilles used in the living room and in the bedrooms.



Figure 5-26 – Air inlet grilles

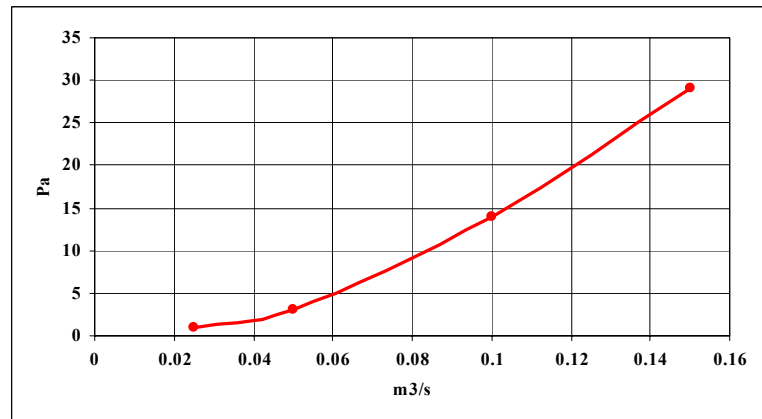


Figure 5-27 - Selection curve of the inlet grilles placed in the habitable rooms

5.4. System IV – Mechanical Exhaust Ventilation System in the wet rooms and self-regulated inlet grids in the other rooms

The mechanical system used in the simulations is schematically represented in figure 5-28. There are two fans, one for extraction of the bathroom and WC (fan 1 – 50 m³/h/each zone for a total of 100 m³/h) and another for the kitchen (fan 2 – 100 m³/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 self-regulation inlet grilles and the air transfer between zones is guaranteed by a crack of about 80 x 2 cm in 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 80 mm in the main duct of the bathroom, WC and shower. Each branch of this ventilation section has a 63 mm diameter.

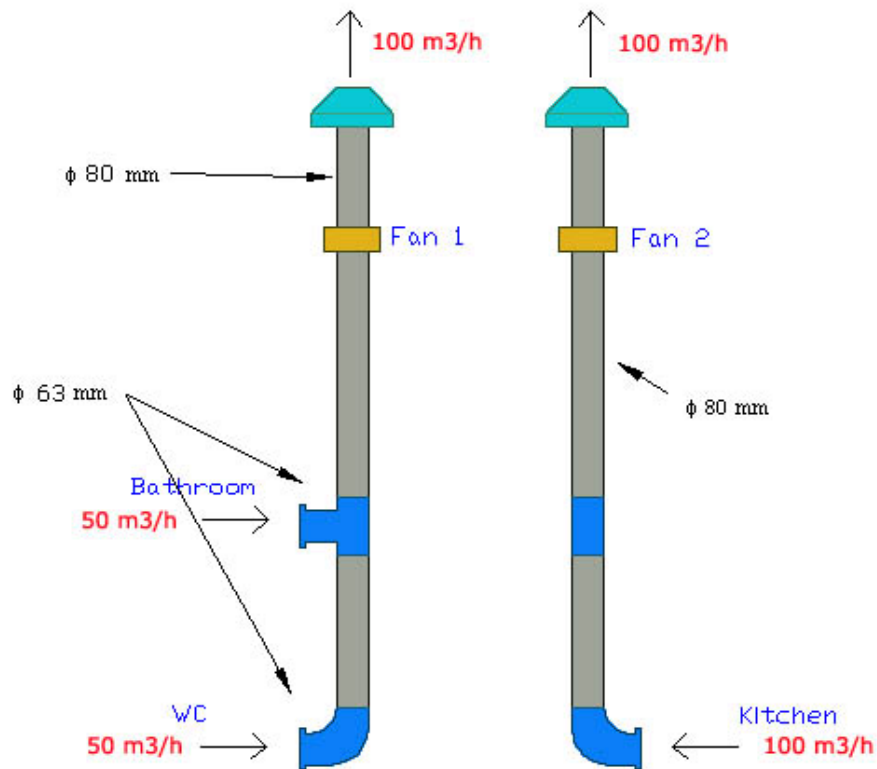


Figure 5-28 – Mechanical Exhaust system

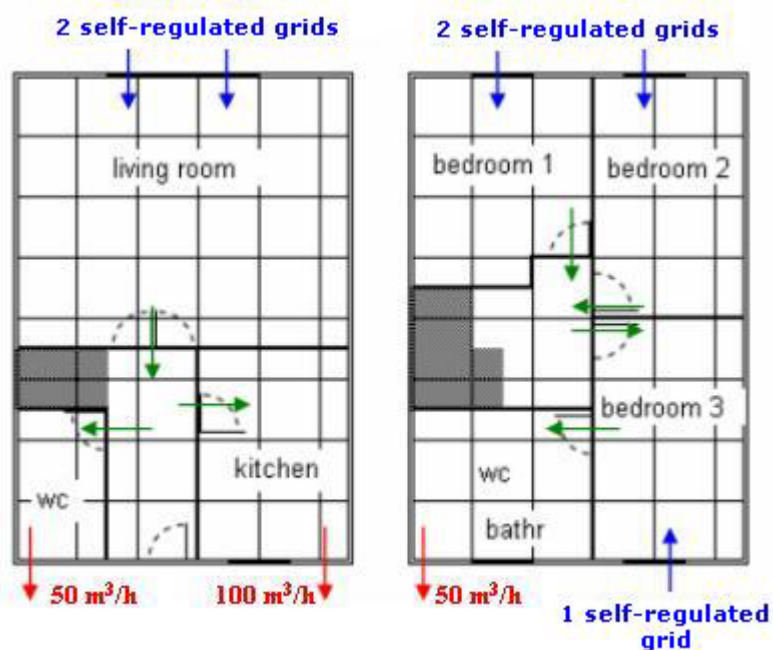


Figure 5-29 - Mechanical ventilation system scheme

5.4.1. Technical data

This section shows the technical information of the fans, grilles and ducts used in the simulation of the mechanical ventilation system.



Figure 5-30 - Centrifugal fan

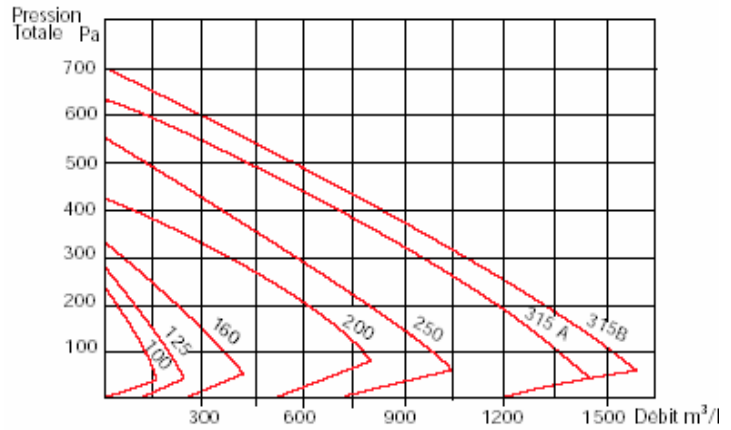


Figure 5-31 - Selection curve of the fan 1 and 2

The fans used in this system were the 100 model, which points were measured at 1900 RPM. The maximum power of these fans is 41 W.

Figure 5-32 and figure 5-33 show the extraction valves used in WC and bathroom (position 9).



Figure 5-32 - Extraction grilles located in wet rooms

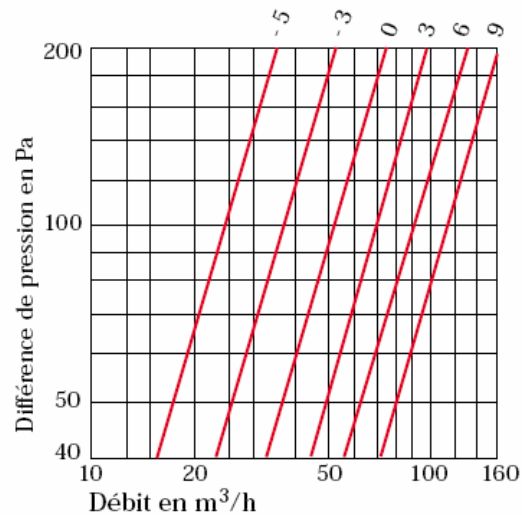


Figure 5-33 - Selection curve of the extraction grilles

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 5-34.

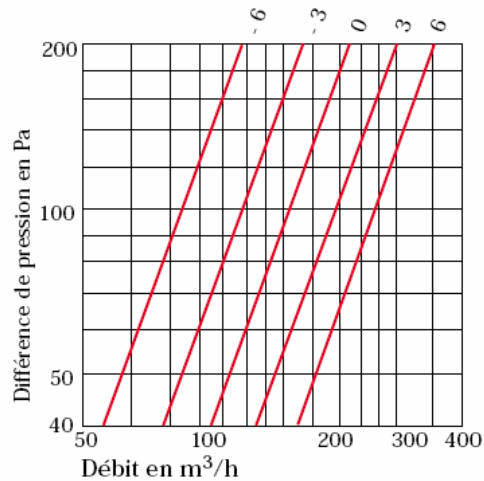


Figure 5-34 - Selection curve of the cooker hood

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

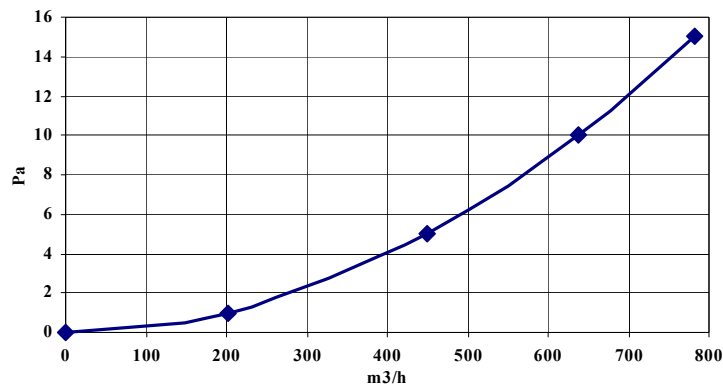


Figure 5-35 - Rain protection cowl

Figure 5-36 and figure 5-37 show the self-regulated grilles used in the living room and in the bedrooms. The model selected for the living room, bedroom1, bedroom 2 and bedroom3 was the M1. Table 5-3 shows the number of grilles used per zone.



Figure 5-36 - Self-regulation inlet grilles

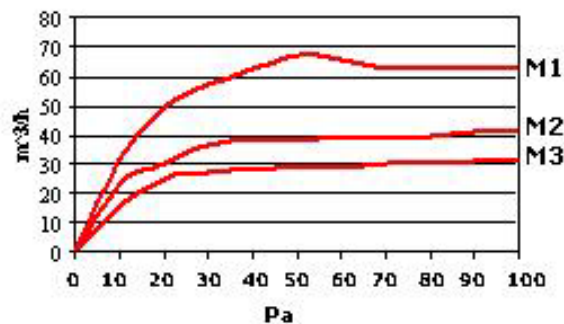


Figure 5-37 - Selection curve of the inlet grilles

Zone	M1	M2	M3
Living	2	-	-
Bedroom 1	1	-	-
Bedroom 2	1	-	-
Bedroom 3	1	-	-

Table 5-3 – Number and type of grilles in each zone

6. Simulation conditions and Results analysis

6.1. Reference simulation conditions

Some of the parameters referred above can have different values and will be used in the sensitivity analysis. Table 6-1 shows the parameters assumed to the reference simulations (reference cases for each one of the ventilation systems).

Shielding	Partially shielded
Airtightness	Leak
Occupancy density	Average
Water vapour production	With drying machine
Orientation	Living room -South orientation

Table 6-1 – Base default simulation conditions

The mainly reference case is assumed as a building without any ventilation system implemented. The ventilation of the building occurs due to the cracks envelope only. For that case an analysis of the heating consumption, thermal comfort (PPD), indoor air quality (CO₂ level) and relative humidity was done. All the other parameters of the simulation, occupation density, shielding, airtightness, water vapour production and orientation are the same as the four reference ventilation systems and are shown in table 6-1.

As it was expected this reference base case has low heating consumption, high PPD and CO₂ concentration values as well as high relative humidity in the bathroom, as shown in the figures bellow.

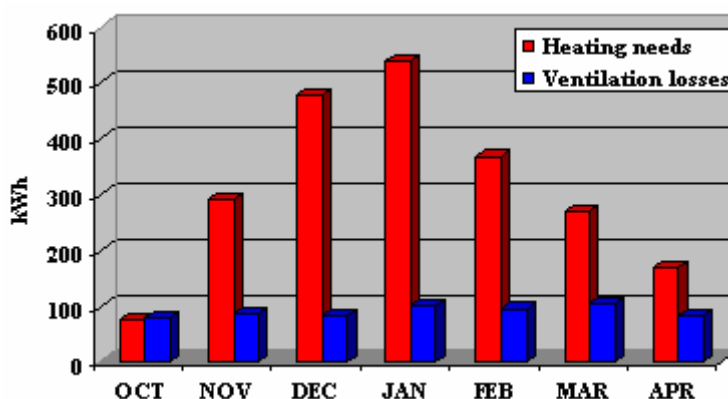
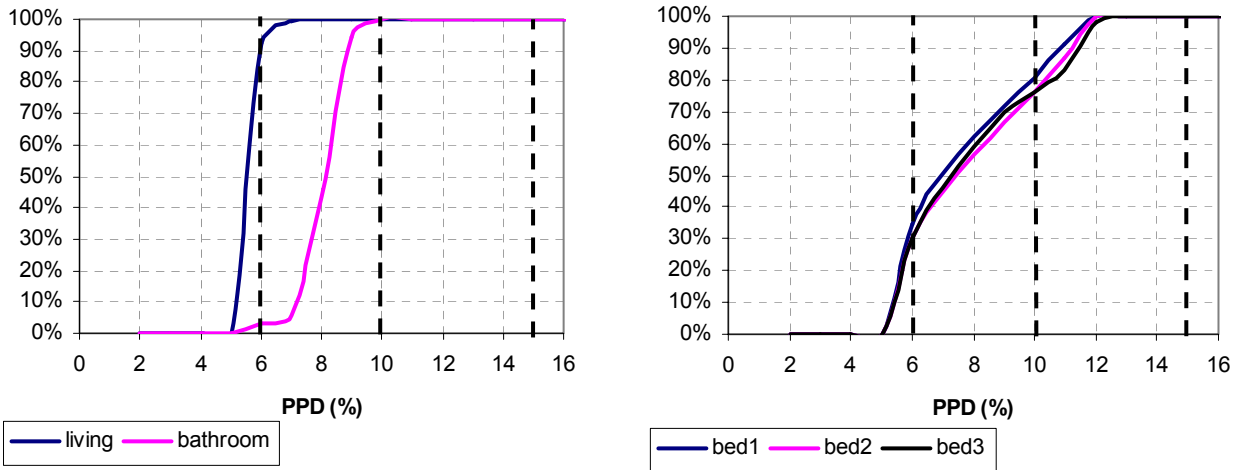


Figure 6-1 – Heating consumption evolution along the heating period

	kWh/year	kWh/m ² .year
Heating Energy consumption	2191	25.8
Ventilation losses energy	630.2	7.4

Table 6-2 - Heating energy consumption

In figure 6-2 is possible to observe the Cumulative frequency of PPD for the heating season.



--- Thermal Comfort PPD Classes
Figure 6-2 – Cumulative frequency of PPD

The Predicted Percentage of Dissatisfied Person (PPD) is mainly related to the thermal comfort. It would be desirable that for a level of PPD lower than 15 % (which means that only 15 % of the persons in the zone are uncomfortable) the probability of the occurrence must be near the 100 %, i.e., for each zone (or building compartment) 85 % of the occupants are satisfied with thermal behaviour of the system.

According to the performance criteria imposed in reference [3], the values of PPD were evaluated in three classes:

- Class 1: % hours with PPD \leq 6 %;
- Class 2: % hours with PPD \leq 10 %;
- Class 3: % hours with PPD \leq 15 %
- Class 4: % hours with PPD > 15 %

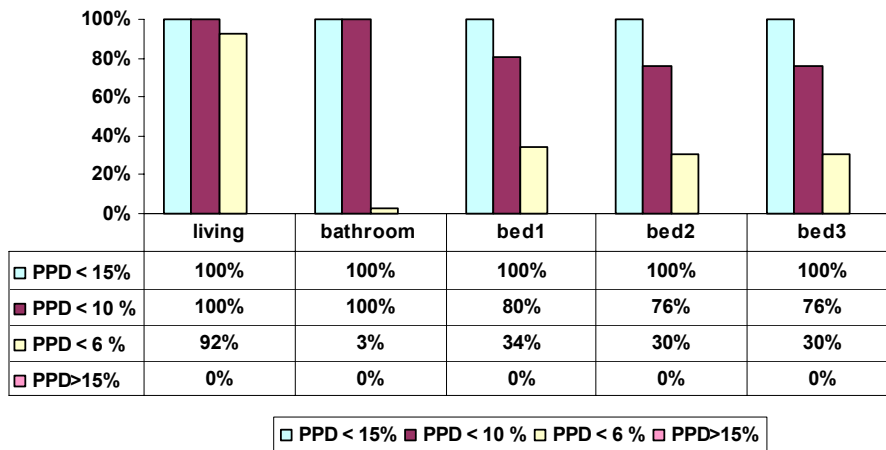


Figure 6-3 - PPD distribution for the several classes

The figure 6-4 shows the cumulative frequency of the CO₂ concentration during all year, it was assumed that the concentration of outdoor CO₂ is equal to 350 ppm (reference value)

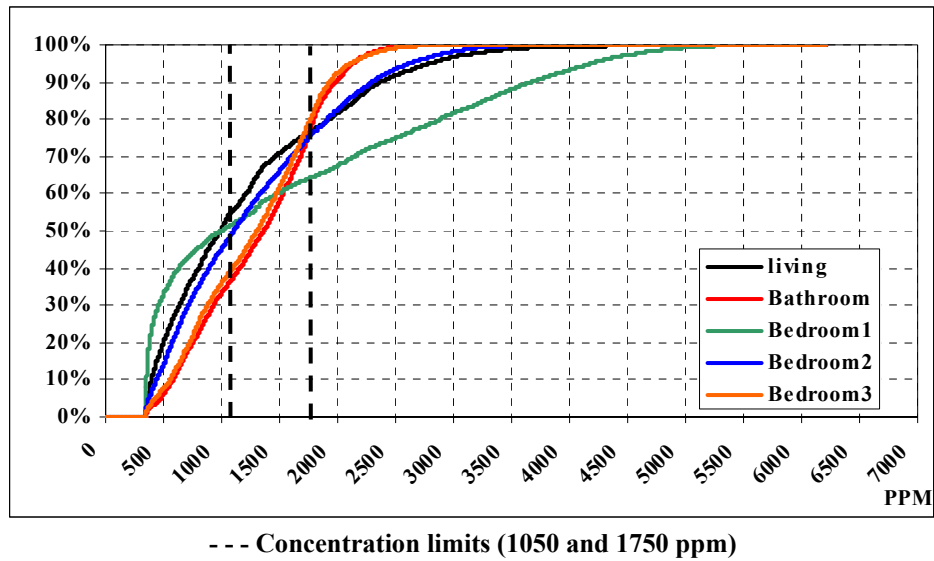


Figure 6-4 - Cumulative frequency of CO₂ concentration

The average and maximum values of the CO₂ concentration evaluated for different zones of the building are the following.

	CO ₂ annual average values	CO ₂ annual maximum values
Living	1213	5242
Kitchen	1202	2746
WC	1053	2408
Bathroom	1311	2946
Bedroom 1	1554	5818
Bedroom 2	1255	4079
Bedroom 3	1271	3138
Hall	1064	2901

Table 6-3 - CO₂ annual values analysis [ppm]

Figure 6-5 shows the value CO₂ concentration in kppm.h, i.e., number of hours that the CO₂ is higher than the concentration limit (1050 ppm) multiplied by the exceeding difference. The target or threshold value for this parameter is 500 kppm.h (values proposed in reference [3]).

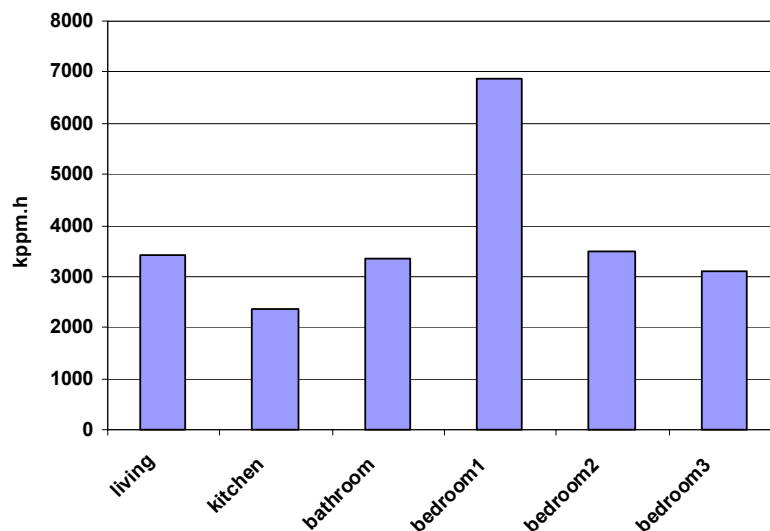


Figure 6-5 - CO₂ concentration exceeding (kppm.h)

Figure 6-6 shows cumulative frequency of relative humidity in bathroom and kitchen. As expected these values are very high for the whole year.

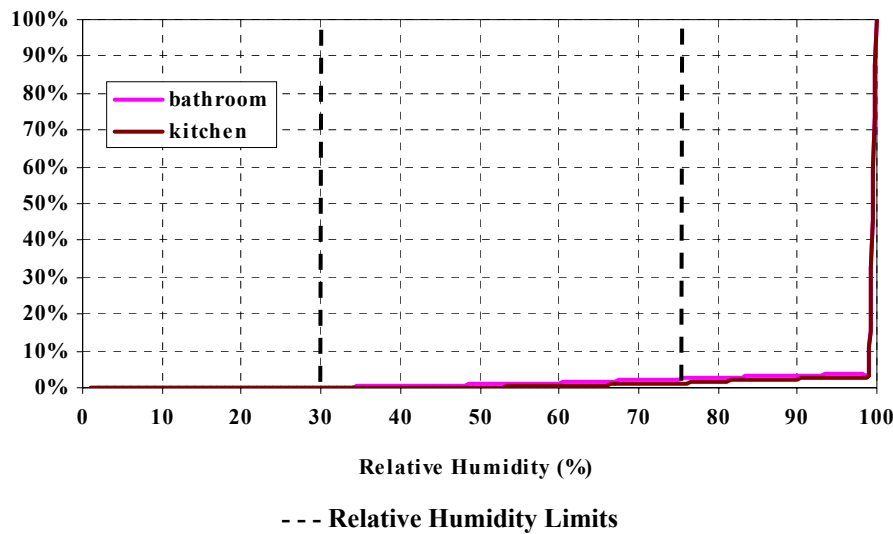


Figure 6-6 – Cumulative frequency of relative humidity

6.2. System I

The first performance assessment issue is to base upon the total energy consumption for heating, and/or cooling and the second main issue is comfort and indoor air quality (IAQ). This system has an increase of ventilation air flow rate due to the new inlet air devices placed on the external façades, therefore an increase of the total heat energy consumption was expected and strongly depended of the ventilation energy losses. The effect of the ventilation losses upon the total energy heating represents almost 76% the energy consumption throughout all year (4095 kWh/year). This effect is more intense on the beginning and ending of the heating season (see Appendix B - figure 11-1).

The inlet airflow rate exerts one’s influence in IAQ thus it is expected some variations on IAQ (CO2 concentration) when ever the flow rate changes. For all year the extreme ventilation values, maximum and minimum, occurs in Winter (January) and Fall (October), respectively. The tables below (table 6-4 and Table 6-5) show the different inlet and outlet airflow rates throughout the year.

	desired air flows rate	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Kitchen	90	63.3	122.4	92.0	63.3	122.4	92.8
WC	45	32.50	64.4	47.2	32.5	64.4	47.6
Bathroom	90	68.93	113.7	92.8	68.9	113.7	93.1

Table 6-4 –Minimum and maximum extraction airflow, [m³/h]

	Desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Living	90	0.0*	226.5	69.1	0.0	226.5	70.2
Bedroom 1	45	0.0*	133.7	38.8	0.0	133.7	39.3
Bedroom 2	45	0.0*	115.8	34.2	0.0	115.8	34.6
Bedroom 3	45	0.0*	82.8	27.8	0.0	82.8	27.9

* - 0.0 air flow rate means start of exhaust air through the building cracks

Table 6-5 –Minimum and maximum inlet of airflow [m³/h]

The next figures show the relationship between the changes of the flow rate, the wind speed and direction for both months January and October. The conclusion is obvious: for January (1

to 745h) the wind blows from south and leads to a reduction of inlet air flow rate from the north façade and it increases the inlet air flow rate from the south. The pressure difference between inside and outside rises and the extract airflow rate increases. An opposite effect is obtained in Fall (October -from 6555 h to 7297 h) when the wind is blowing from north and it leads to a reduction of the inlet airflow rate. The sensibility to the wind effect is high because natural driving forces control the phenomena of the ventilation.

The wind characteristics affect the ventilation profile because of the following aspects:

- the inlet grilles are located on the south façade,
- there are more infiltrations through cracks on the south façade,
- the main natural exhaust duct comes up from north side of the roof

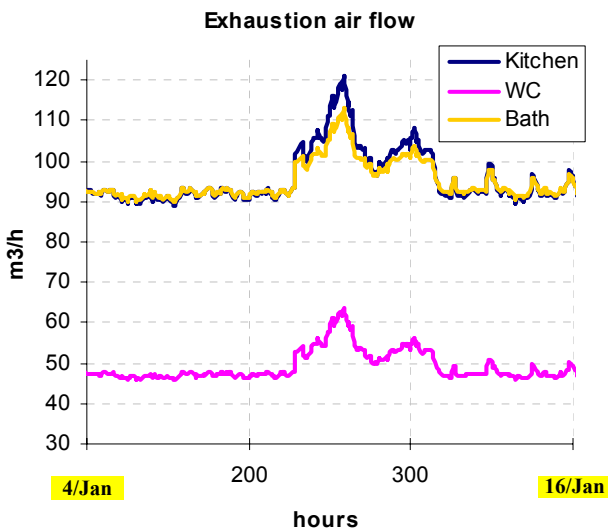


Figure 6-7 – Exhaustion airflow (wind from south quadrant)

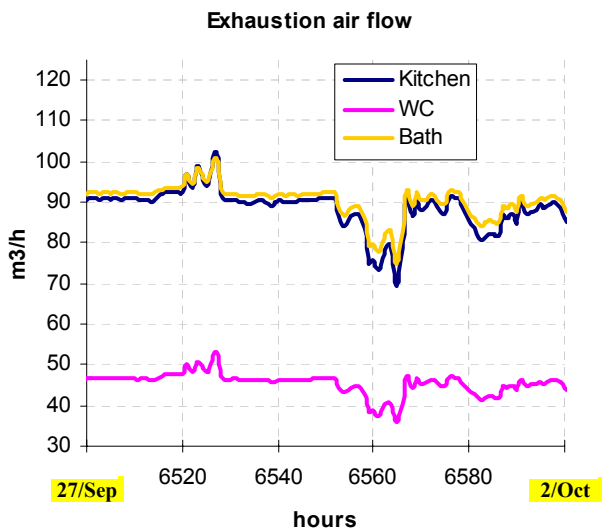


Figure 6-8 – Exhaustion airflow (wind from north quadrant)

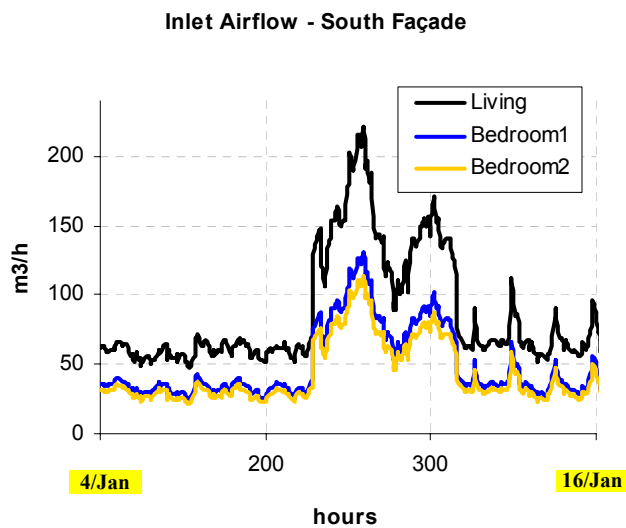


Figure 6-9 – Inlet airflow (wind from south quadrant)

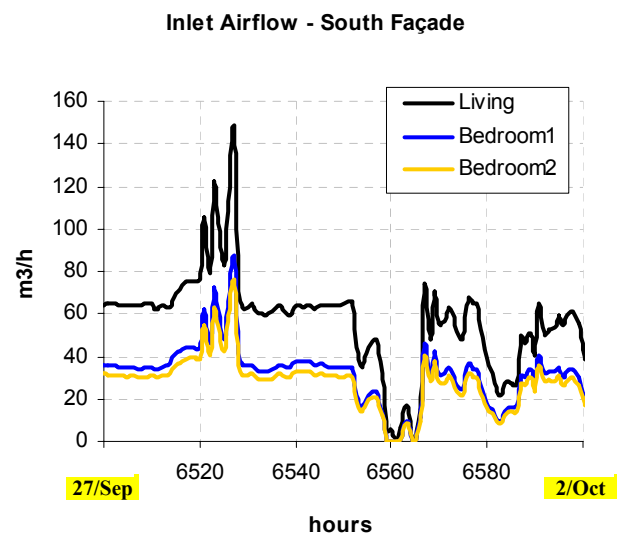


Figure 6-10 – Inlet airflow (wind from north quadrant)

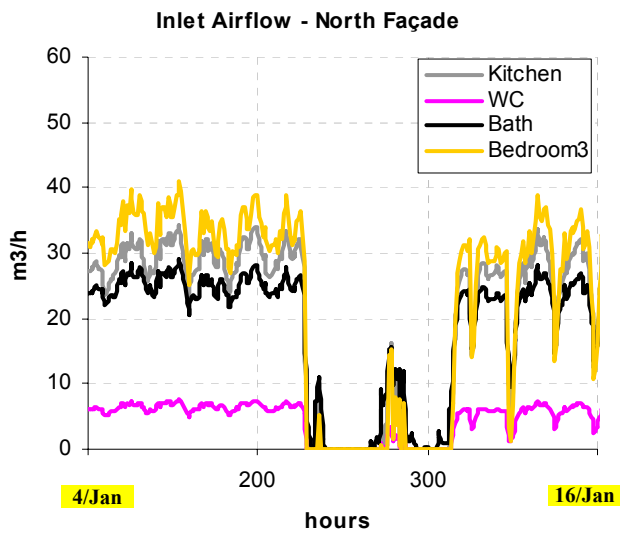


Figure 6-11 – Inlet airflow (wind from south quadrant)

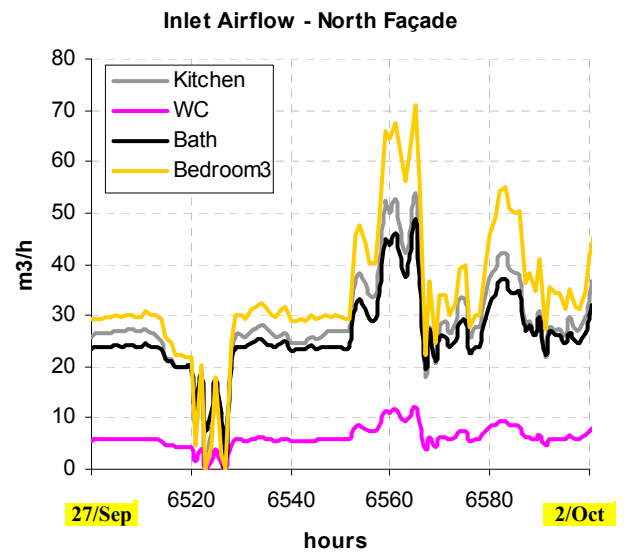


Figure 6-12 – Inlet airflow (wind from north quadrant)

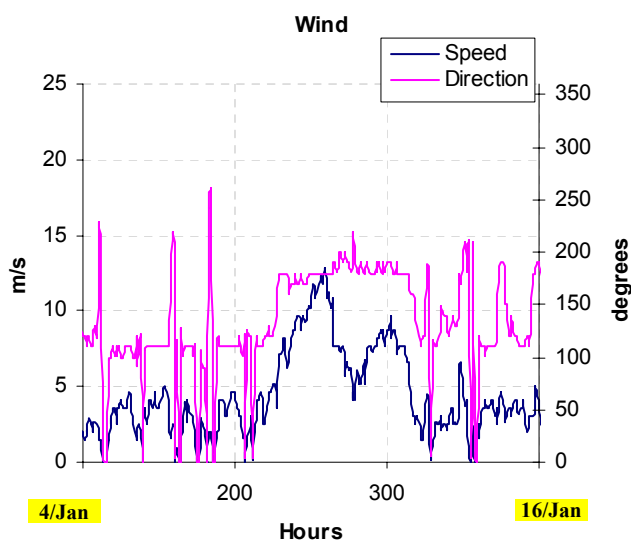


Figure 6-13 – Wind characteristics

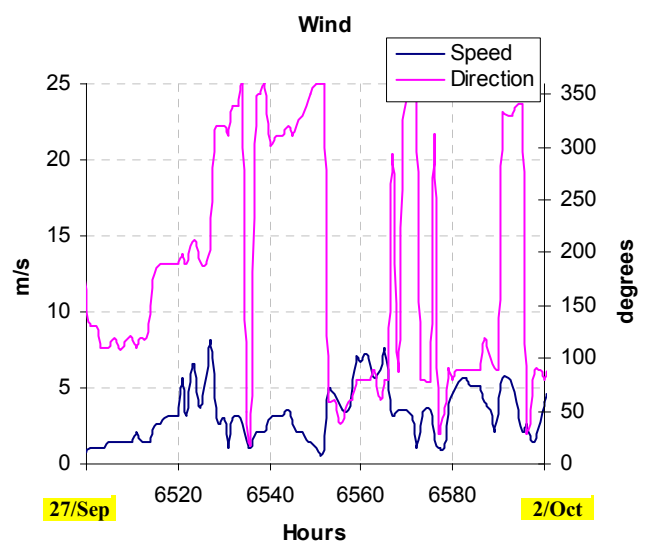


Figure 6-14 – Wind characteristics

The CO₂ concentration is also affected by the wind characteristics (figure 6-15 and figure 6-16). As it was expected a big ventilation air flow rate benefits the indoor air quality inside the building. A detailed analysis of the CO₂ concentration for two different compartments (Bedroom 1 and Bedroom 3) shows this effect (figure 6-17 and figure 6-18). Bedroom 1 (a critical zone in terms of CO₂ because of the night occupation) shows a significant variation of the CO₂ concentration when the wind is blowing from south.

As for bedroom 3, which has a north façade, there is no significant improvement when the wind comes from northern quadrant because for most part of the year this room receives air from the hall, which has a low CO₂ concentration.

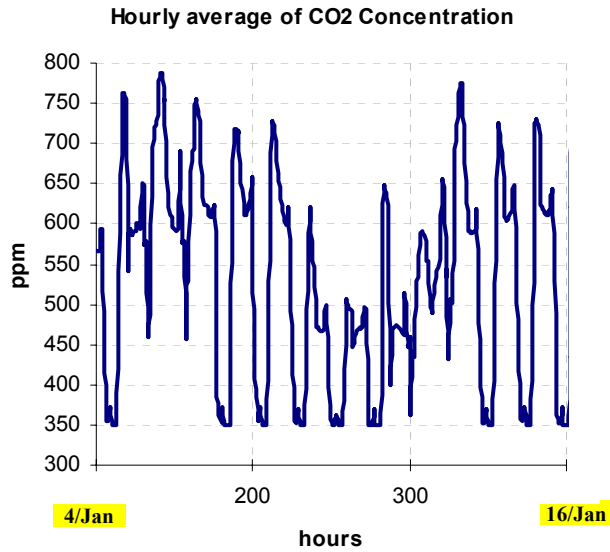


Figure 6-15 – Hourly average of the CO₂ concentration for all building (wind from south quadrant)

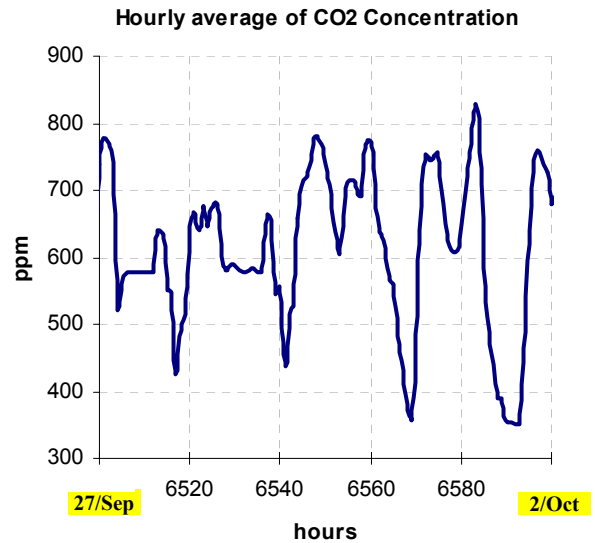


Figure 6-16 – Hourly average of the CO₂ concentration for all building (wind from north quadrant)

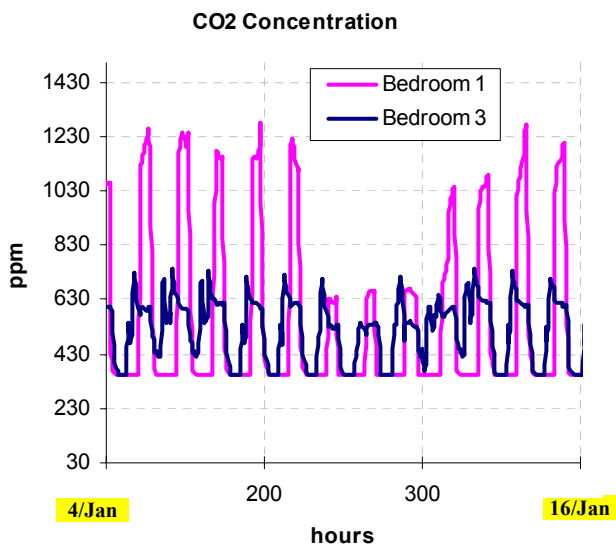


Figure 6-17 –CO₂ concentration in bedrooms 1 and 3 (wind from south quadrant)

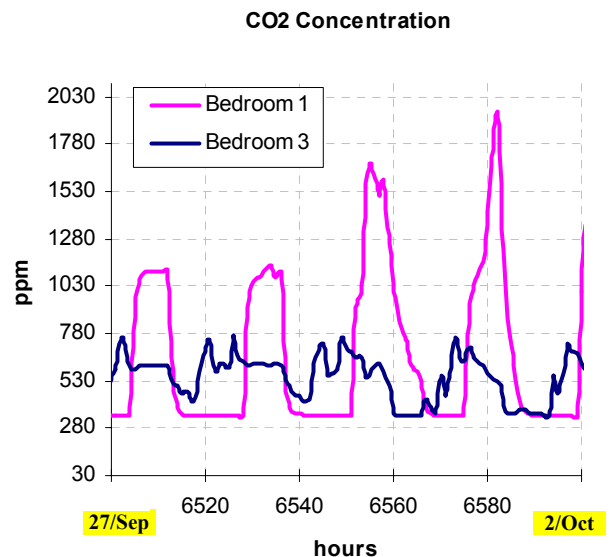


Figure 6-18 –CO₂ concentration in bedrooms 1 and 3 (wind from north quadrant)

Absolute humidity is more dependent of the outside humidity conditions and water vapour production profile than the wind characteristics. This parameter is independent of the location of the each room, i.e., it s not dependent of the different façade orientation (figure 6-19 to figure 6-22). The distribution of the absolute humidity inside the building follows the outside humidity profile (figure 6-23 and figure 6-24), except for the peaks, which result from the water vapour production inside the dwelling.

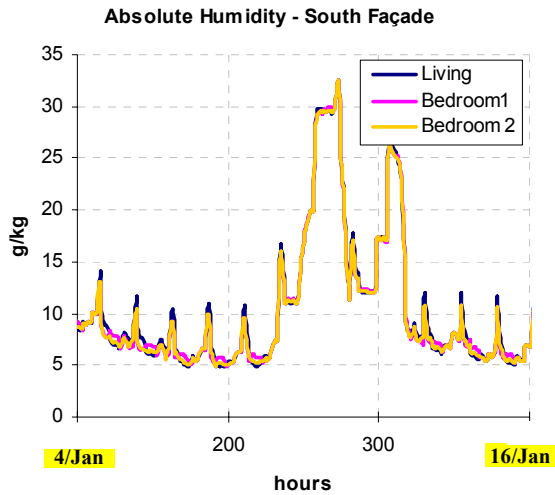


Figure 6-19 –Absolute Humidity (wind from south quadrant)

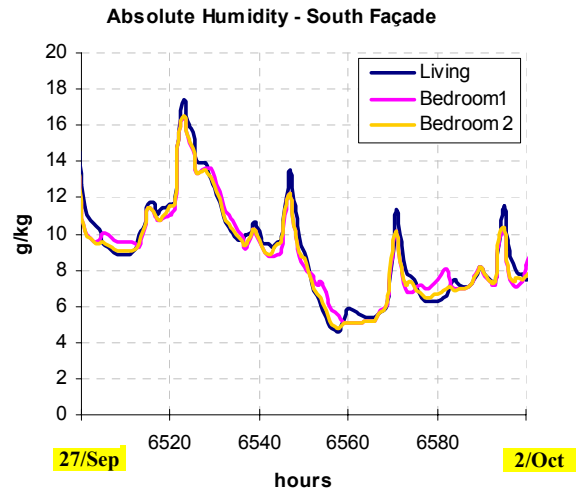


Figure 6-20 –Absolute Humidity (wind from north quadrant)

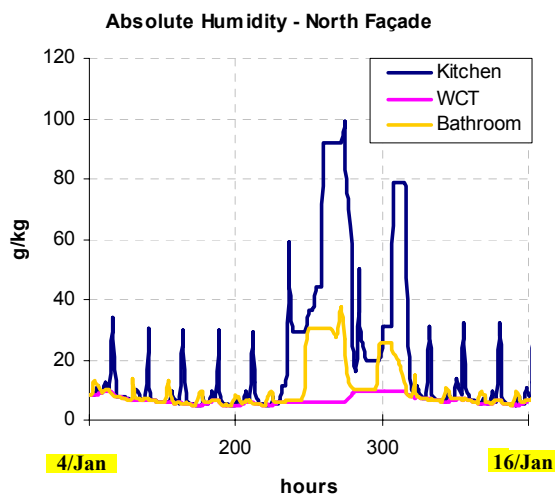


Figure 6-21 –Absolute Humidity (wind from south quadrant)

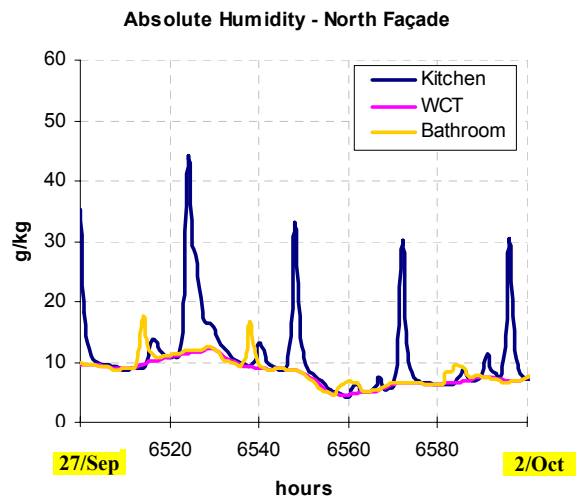


Figure 6-22 –Absolute Humidity (wind north direction)

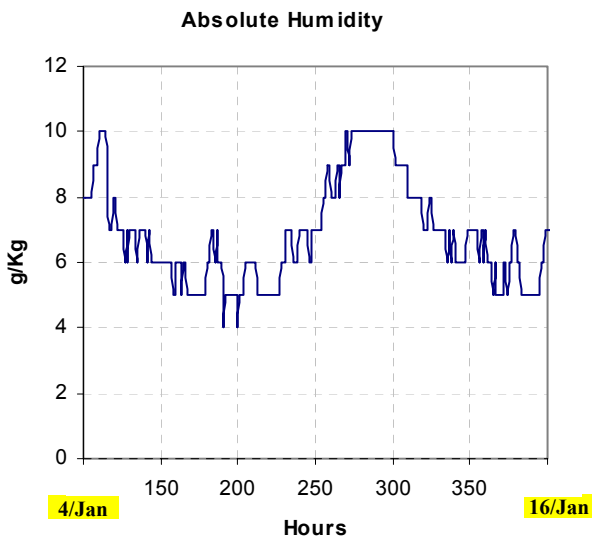


Figure 6-23 –Outside absolute humidity (wind from south quadrant)

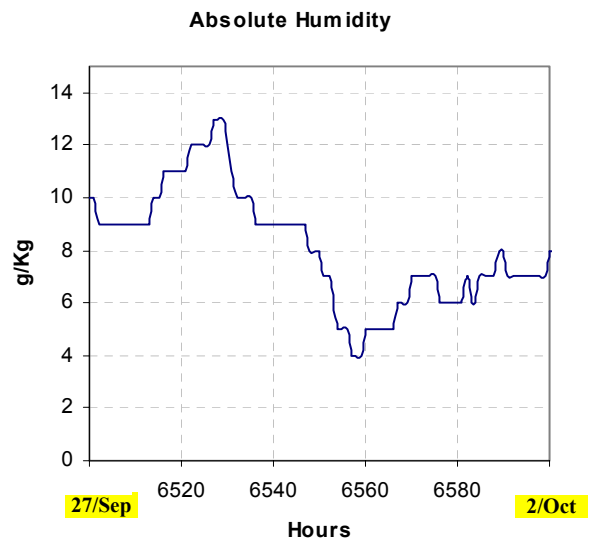


Figure 6-24 –Outside absolute humidity (wind from north quadrant)

Thermal comfort is influenced by the indoor temperature (associated to the sensible heat transfer) and the indoor relative humidity (related to the latent heat transfer). TRNSYS has two kinds of parameters for evaluation of the comfort: the PPD (Predicted Percentage of Dissatisfied Person) and PMV (Predicted Mean Vote). The first parameter, in an ideal situation of comfort, should not exceed the 15 % and the second one, PMV, must be between the -0.5 and 0.5 limits, which indicates a comfortable situation.

However these values have some fluctuations, which are related to temperature or relative humidity changes (see figures bellow).

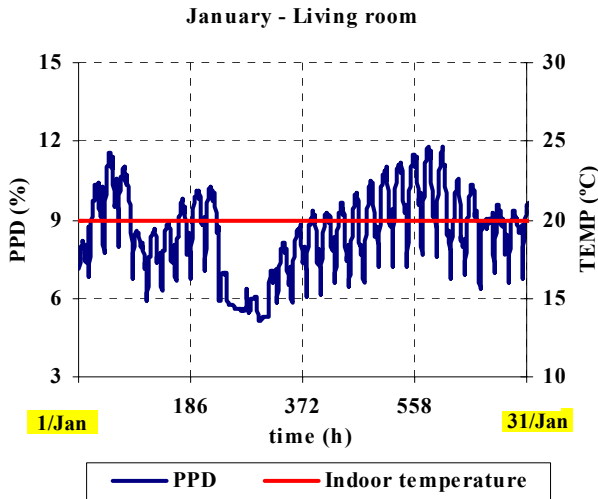


Figure 6-25 - PPD versus Indoor temperature evolution (Living room)

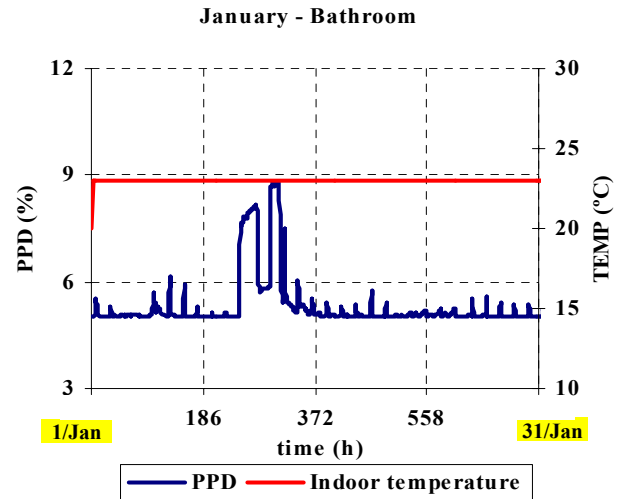


Figure 6-26 - PPD versus Indoor temperature evolution (Bathroom)

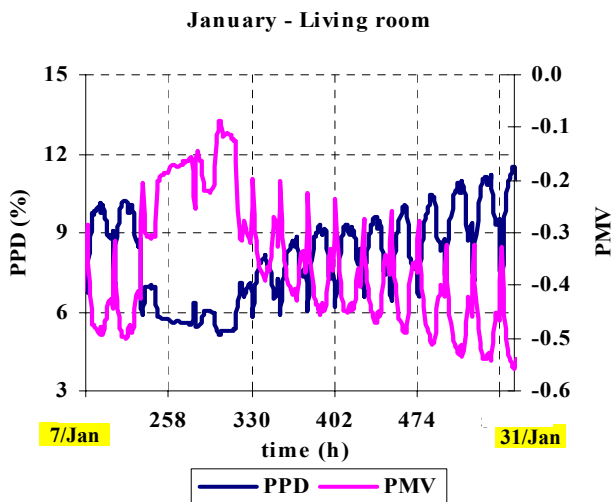


Figure 6-27- PPD versus PMV (Living room)

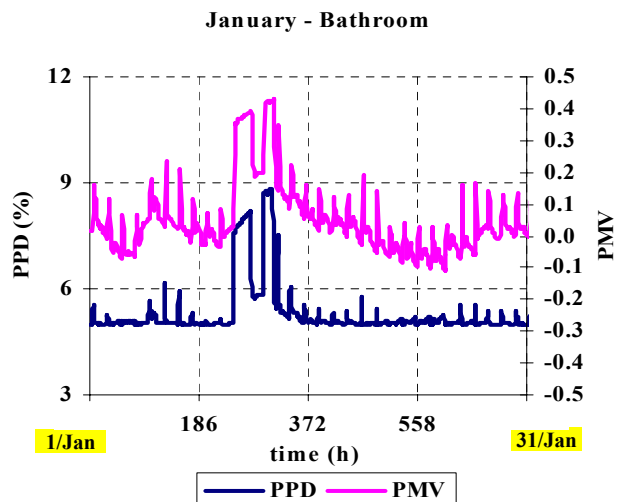


Figure 6-28 - PPD versus PMV evolution (Bathroom)

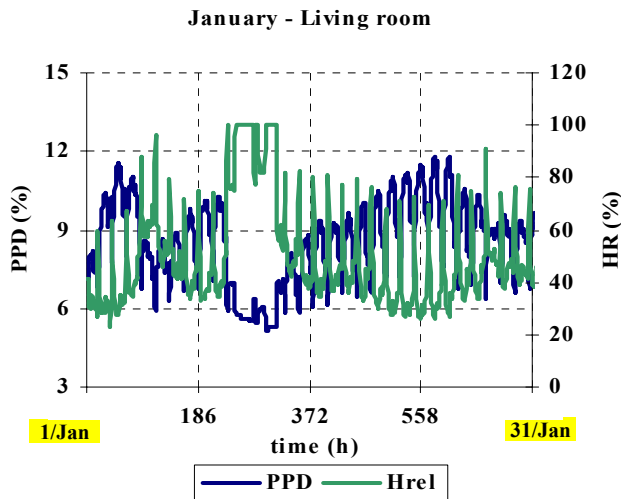


Figure 6-29 - PPD versus Relative humidity (Living room)

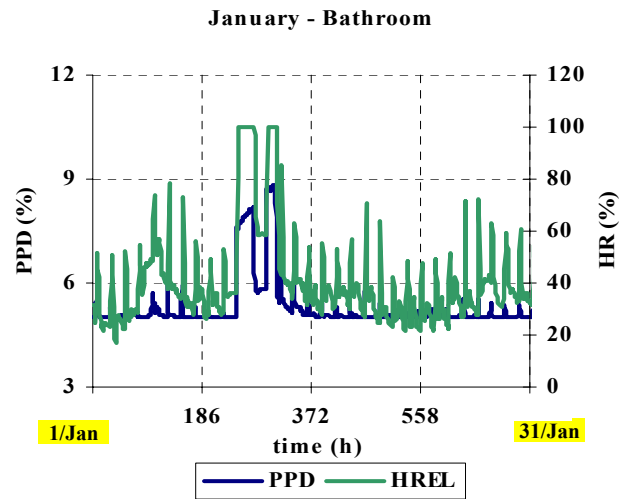


Figure 6-30 - PPD versus Relative humidity (Bathroom)

The PPD evolution in living room and bathroom when compared to the Relative Humidity variation has an opposite behaviour. In living room, when the relative humidity increases the PPD decreases and vice versa in bathroom. This happens because, for the same humidity level, the indoor temperature is lower in the living room than the bathroom, which improves the heat sensation and, consequently, the PPD and PMV.

In figures below the same analysis is done for the month of July. As we can see, in this month (Summer), the temperature is determinant in the PPD and PMV values. A higher indoor temperature results in a PPD increase.

Finally all variables and threshold values are presented in Appendix B.

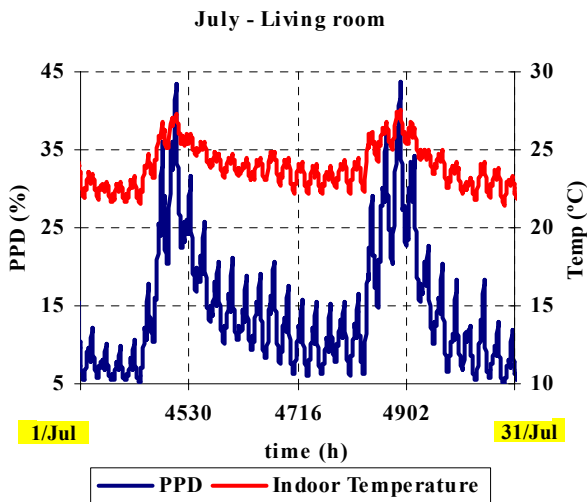


Figure 6-31 - PPD versus Indoor temperature evolution (Living room)

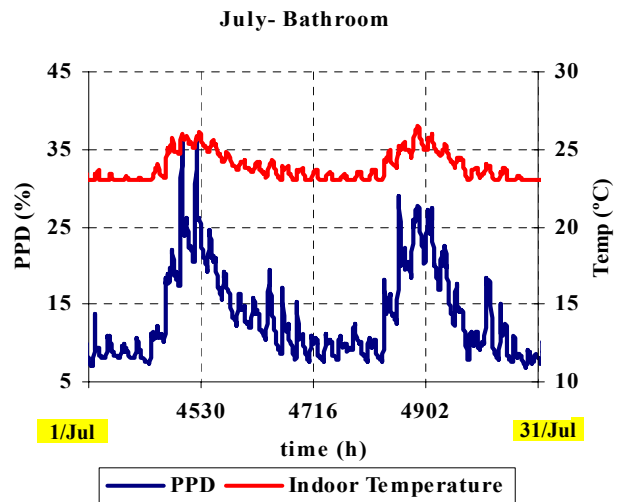


Figure 6-32 - PPD versus Indoor temperature evolution (Bathroom)

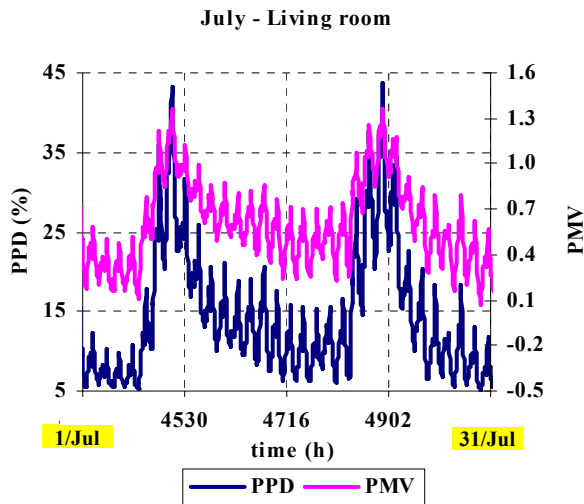


Figure 6-33- PPD versus PMV (Living room)

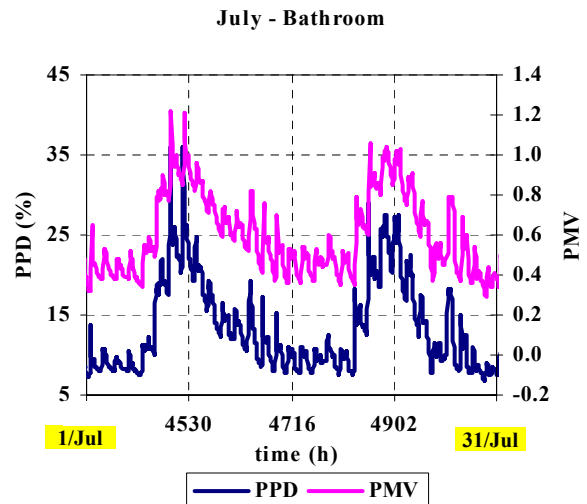


Figure 6-34- PPD versus PMV evolution (Bathroom)

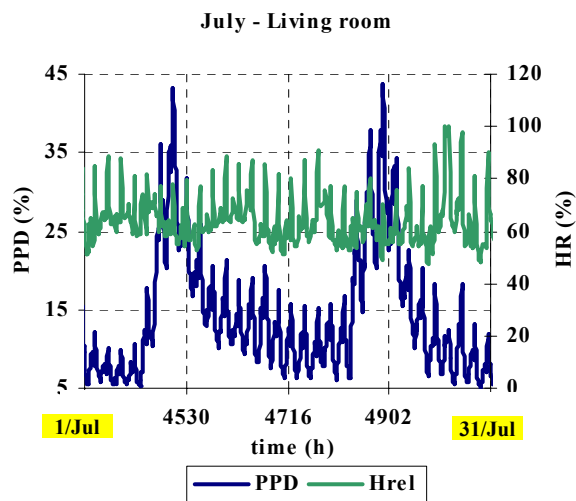


Figure 6-35 - PPD versus Relative humidity (Living room)

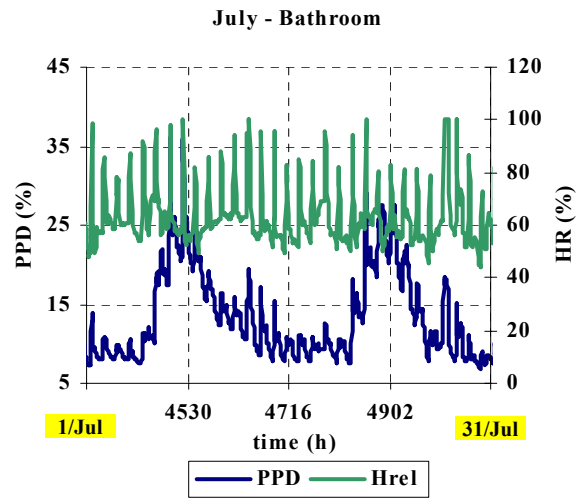


Figure 6-36 - PPD versus Relative humidity (Bathroom)

6.3. System II

Applying the same analyses done in the ventilation system (VS) before, the VS II has only cracks as air inlets, which means a decrease of global ventilation. Therefore, lower energy consumption will be expected for both heating (3783kWh/year) and ventilation (2560kWh/year which means 68% of total heating energy). The total heating energy consumption is 73% higher than the same energy obtained for the reference case (2191kWh/year).

Figures below show the relationship between the changes of the flow rate and the wind speed and direction. The conclusion is obvious: for January (1 to 745h) when the wind blows from south leads to a reduction of inlet air flow rate from the north façade and it increases the inlet air flow rate from the south. The pressure difference between inside and outside rises and the extract air flow rate increases. An opposite effect is obtained when the wind is blowing from north (October -from 6555 h to 7297 h) and leads to a reduction of the inlet air flow rate. The sensibility of the wind effect is very high as the natural driving forces control the phenomena of the ventilation. This effect can be realised in figure 6-37 to figure 6-44, where the left and right columns correspond to ventilation profile when the wind blows from south and north, respectively.

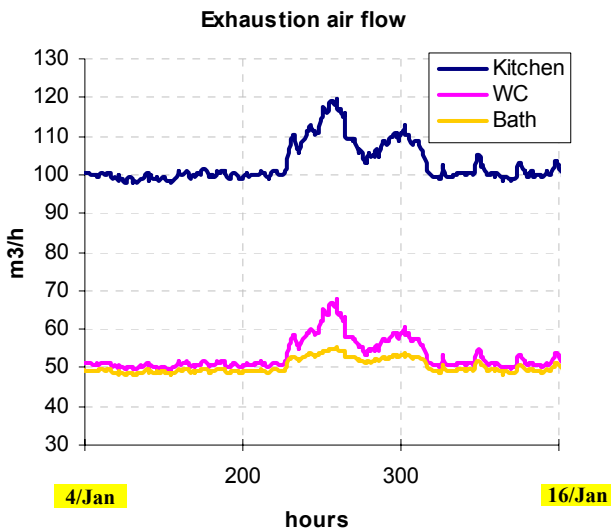


Figure 6-37 – Exhaustion airflow (wind from south quadrant)

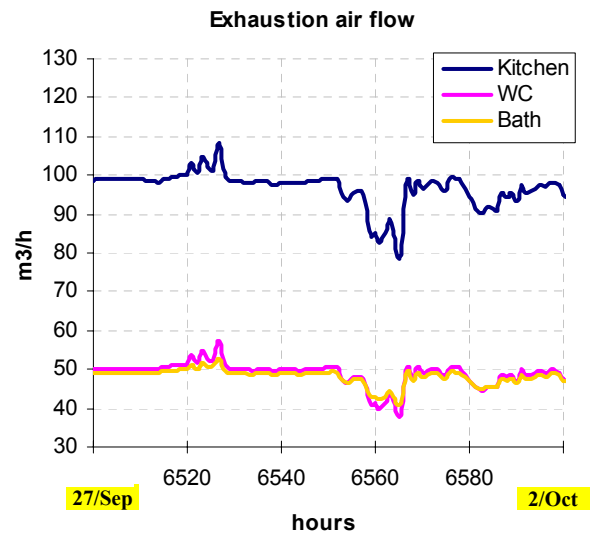


Figure 6-38 – Exhaustion airflow (wind from north quadrant)

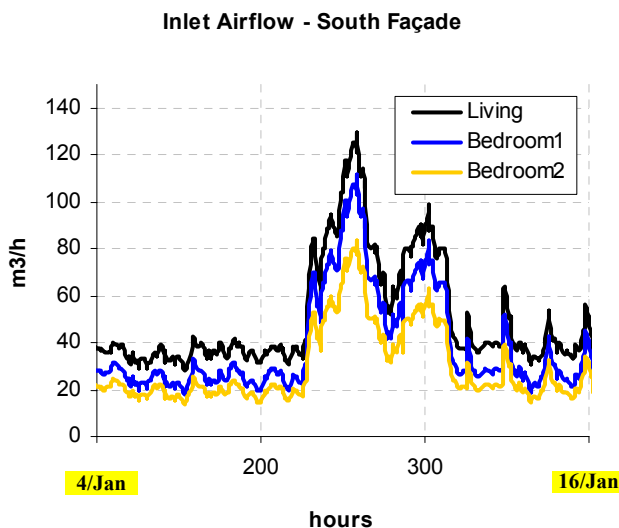


Figure 6-39 – Inlet airflow (wind from south quadrant)

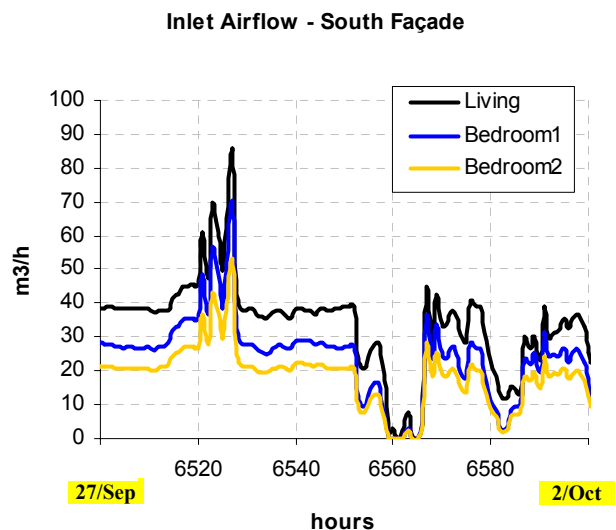


Figure 6-40 – Inlet airflow (wind from north quadrant)

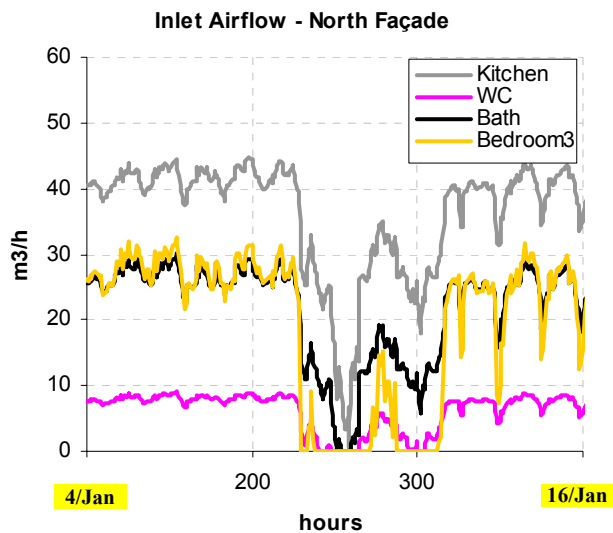


Figure 6-41 – Inlet airflow (wind from south quadrant)

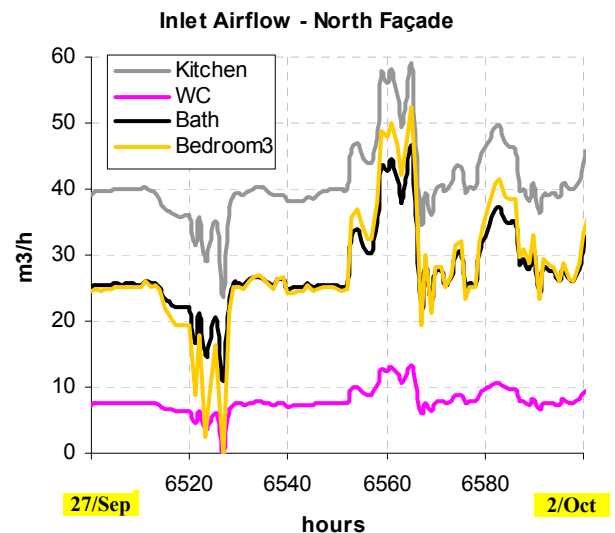


Figure 6-42 – Inlet airflow (wind from north quadrant)

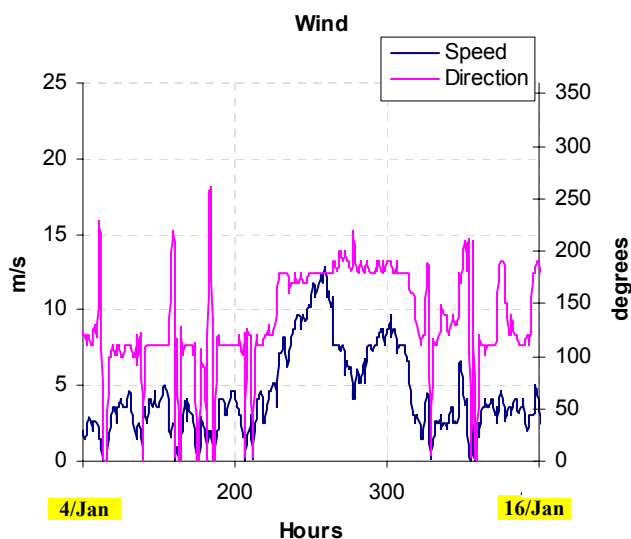


Figure 6-43 – Wind characteristics

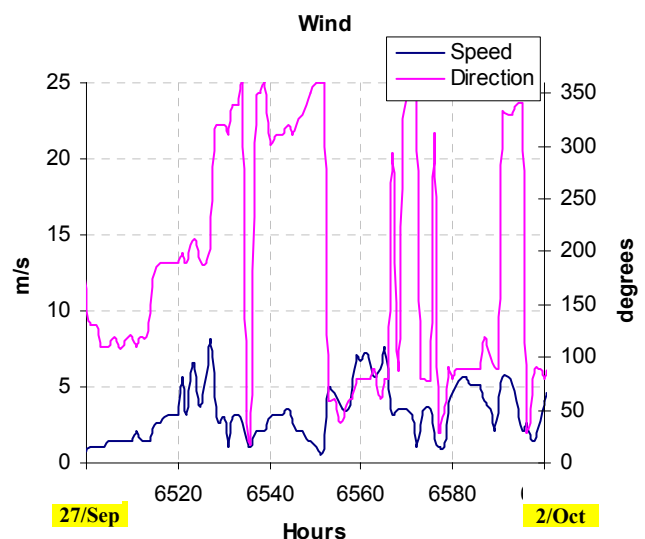


Figure 6-44 – Wind characteristics

The deviation of the ventilation profile is related to the wind characteristics associated to the following aspects:

- the inlet grilles are located on the south façade,
- there are more infiltrations through cracks on the south façade,
- the exterior point of the ventilation system is located on the northern side of the roof

The concentration of CO₂ is also affected indirectly by the wind conditions as it is shown in figure 6-45 to figure 6-48. If the airflow rate increase then the CO₂ concentration decreases and this effect is more intense when the wind blows from the south. A specific analysis of the bedroom 1 (a critical zone in terms of CO₂) shows a significant decrease of the CO₂ concentration when the wind comes from south. The opposite room to bedroom 1 (bedroom 3), which has a north façade wall has some decrease when the wind blows from north direction, but this variation is not so significant as in bedroom 1 because of the reasons mentioned in VS I (figure 6-49 to figure 6-52 show the effect of CO₂ concentration).

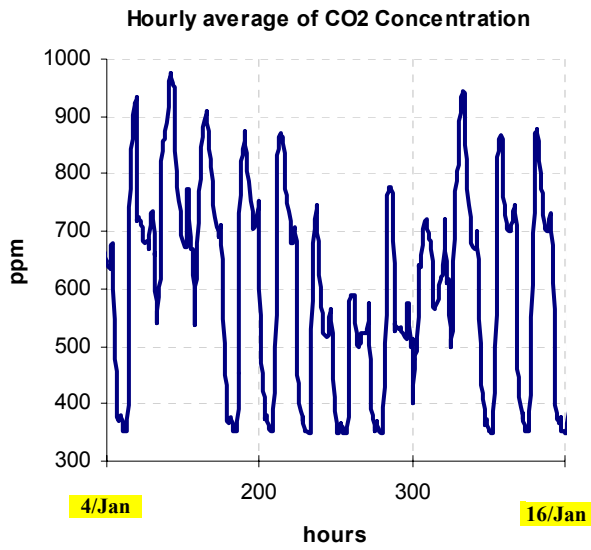


Figure 6-45 – Hourly average of the CO₂ concentration for all building (wind from south quadrant)

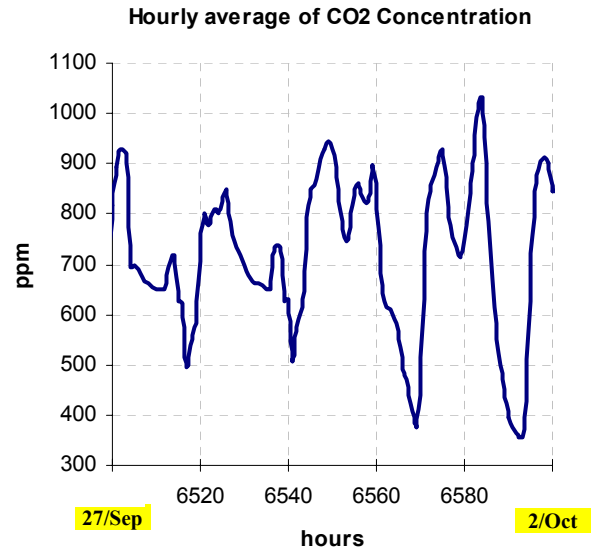


Figure 6-46 – Hourly average of the CO₂ concentration for all building (wind from north quadrant)

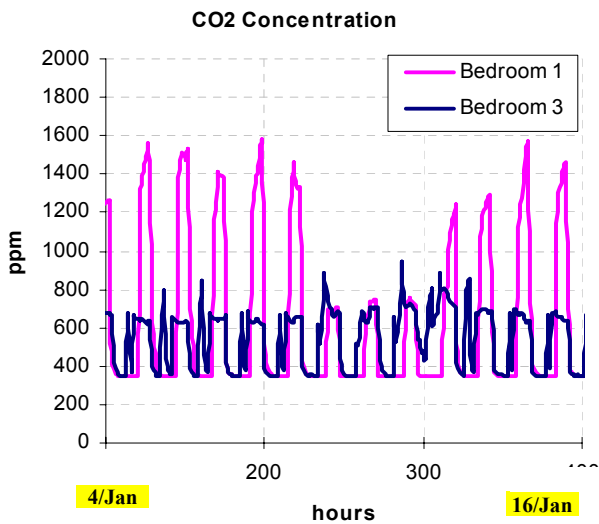


Figure 6-47 – CO₂ concentration in bedrooms 1 and 3 (wind from south quadrant)

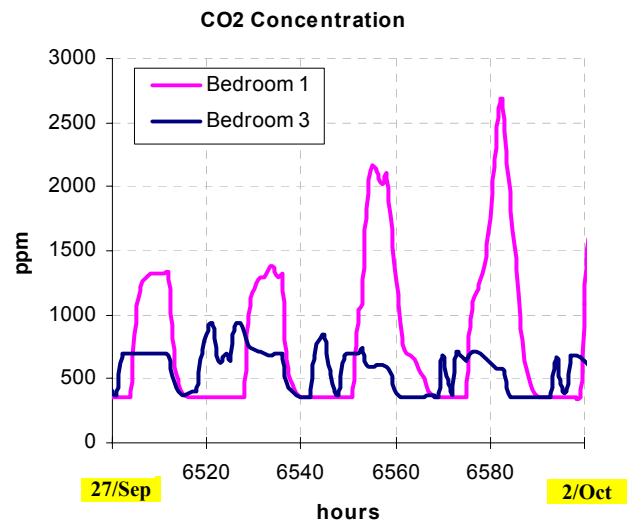


Figure 6-48 – CO₂ concentration in bedrooms 1 and 3 (wind from north quadrant)

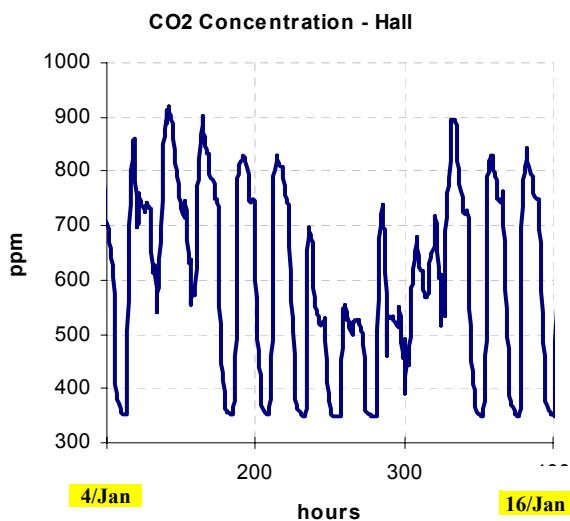


Figure 6-49 – CO₂ concentration in Hall (wind from south quadrant)

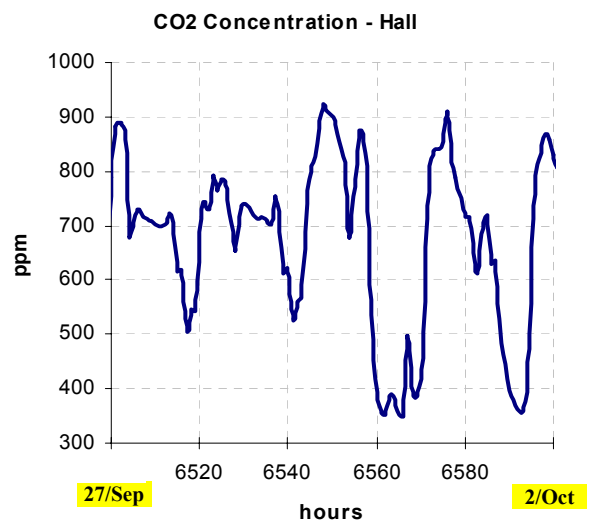


Figure 6-50 – CO₂ concentration in Hall (wind from north quadrant)

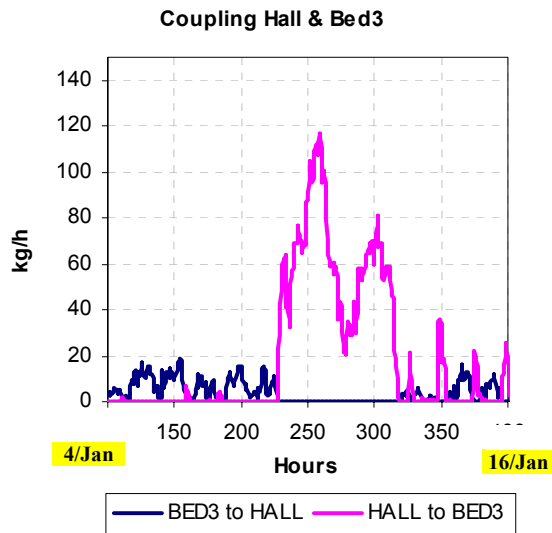


Figure 6-51 –Coupling Hall and Bedroom 3 (wind from south quadrant)

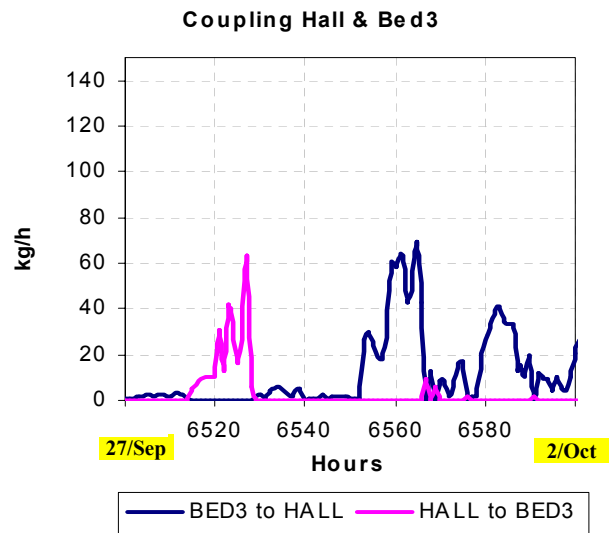


Figure 6-52 –Coupling Hall and Bedroom 3 (wind from north quadrant)

As in the previous system absolute humidity is more dependent of the outside humidity conditions and water vapour production than the wind characteristics. This parameter is independent of the location of the each room, i.e., it is not dependent of the different façade orientation (figure 6-53 to figure 6-58).

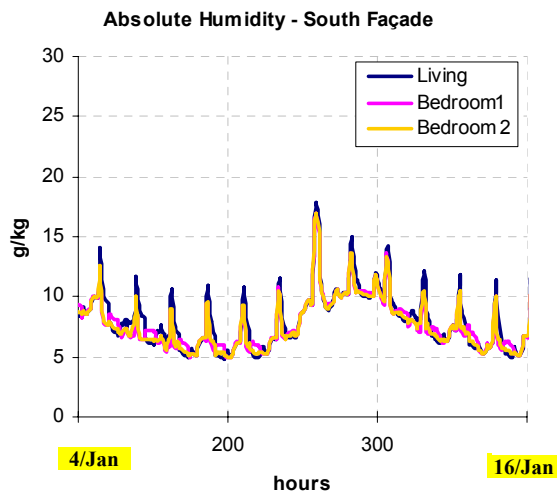


Figure 6-53 –Absolute Humidity (wind from south quadrant)

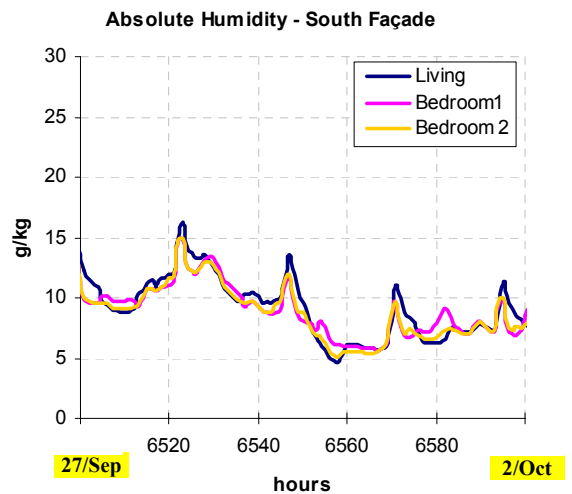


Figure 6-54 –Absolute Humidity (wind from north quadrant)

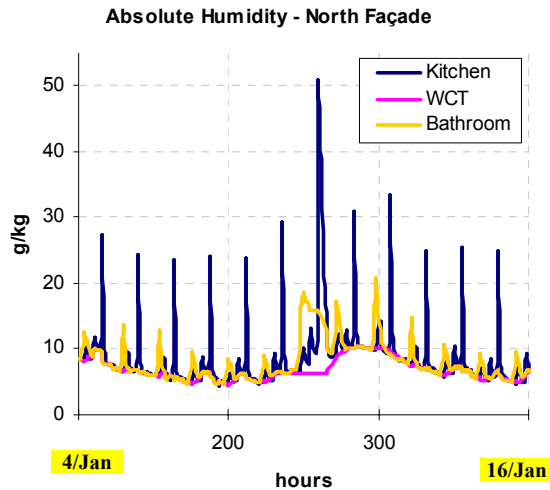


Figure 6-55 –Absolute Humidity (wind from south quadrant)

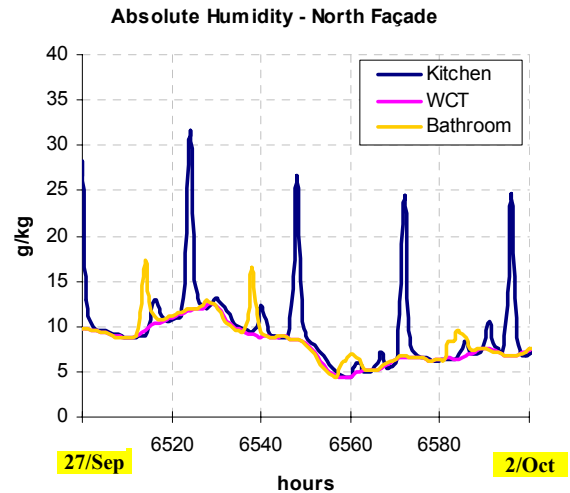


Figure 6-56 –Absolute Humidity (wind from north quadrant)

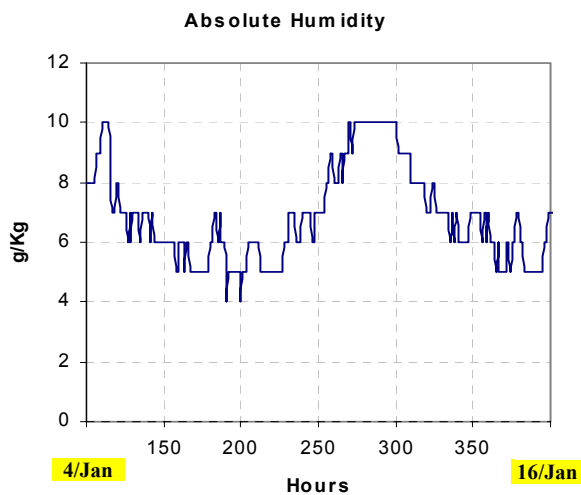


Figure 6-57 –Absolute Humidity (wind from south quadrant)

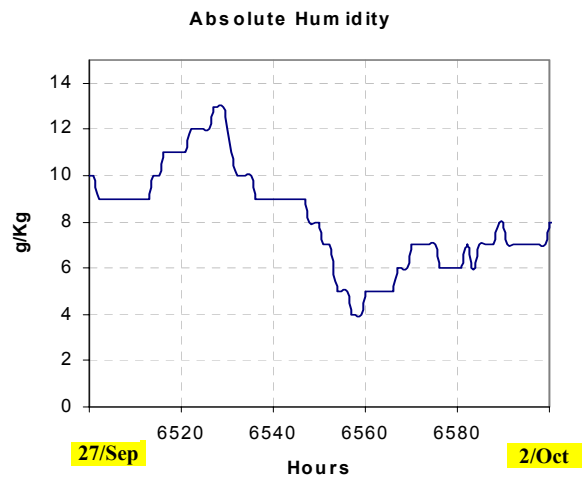


Figure 6-58 –Absolute Humidity (wind from north quadrant)

Thermal comfort is influenced by the indoor temperature (associated to the sensible heat transfer) and the indoor relative humidity (related to the latent heat transfer). TRNSYS has two kinds of parameters for evaluation of the comfort: the PPD (Predicted Percentage of Dissatisfied Person) and PMV (Predicted Mean Vote). The first parameter, in an ideal situation of comfort, should not exceed the 15 % and the second one, PMV, must be between the -0.5 and 0.5 limits, which indicates a comfortable situation.

However these values have some fluctuations, which are related to temperature or relative humidity changes (see figures below).

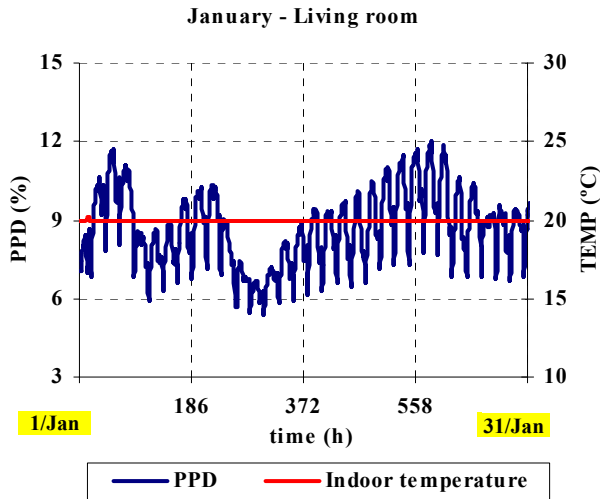


Figure 6-59 - PPD versus Indoor temperature evolution (Living room)

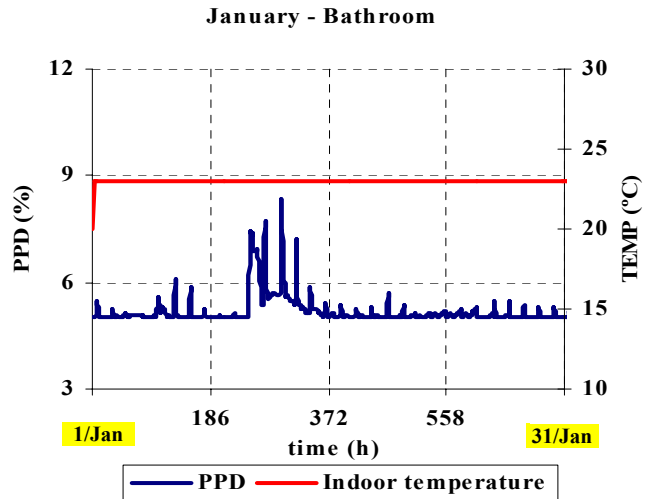


Figure 6-60 - PPD versus Indoor temperature evolution (Bathroom)

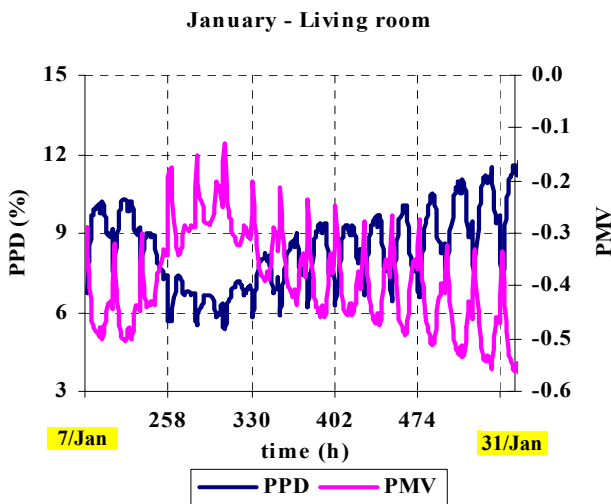


Figure 6-61- PPD versus PMV (Living room)

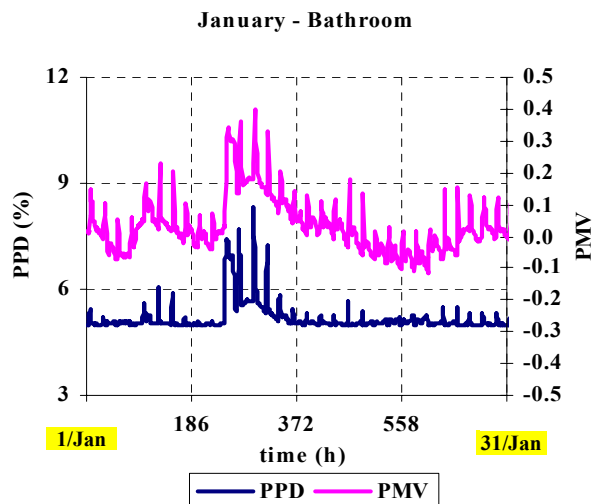


Figure 6-62- PPD versus PMV evolution (Bathroom)

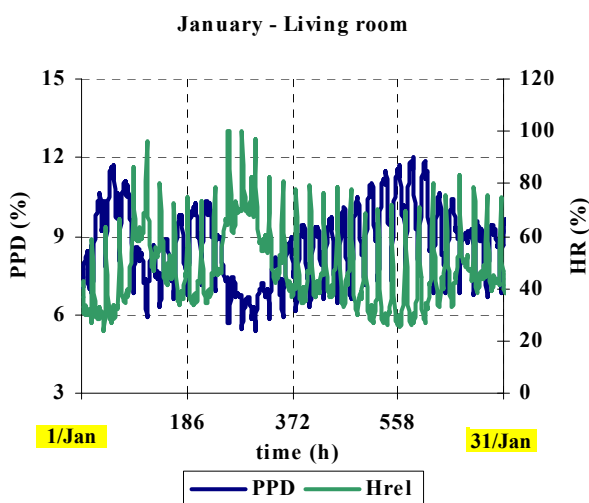


Figure 6-63 - PPD versus Relative humidity (Living room)

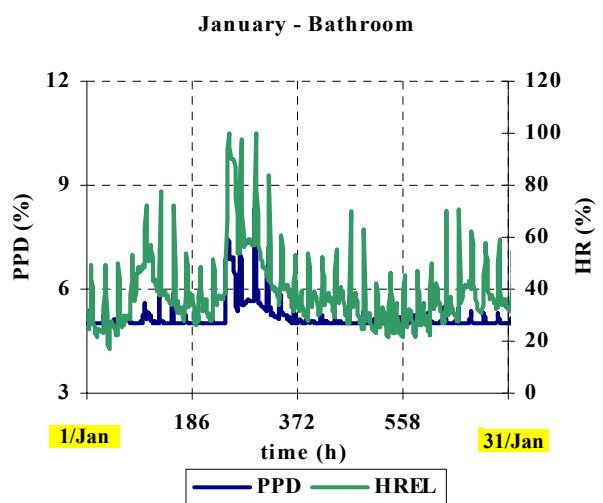


Figure 6-64 - PPD versus Relative humidity (Bathroom)

In the living room, when the relative humidity increases the PPD decreases and in bathroom, with the same relative humidity variation, the PPD increases. This happens because, to a same humidity level, the indoor temperature is lower in the living room than in the bathroom, which improves the heat sensation and, consequently, the PPD and PMV.

In figures below the same analysis is done for the month of July. As we can see, in this month (Summer), the temperature is determinant in the PPD and PMV values. A higher indoor temperature results in a PPD increase.

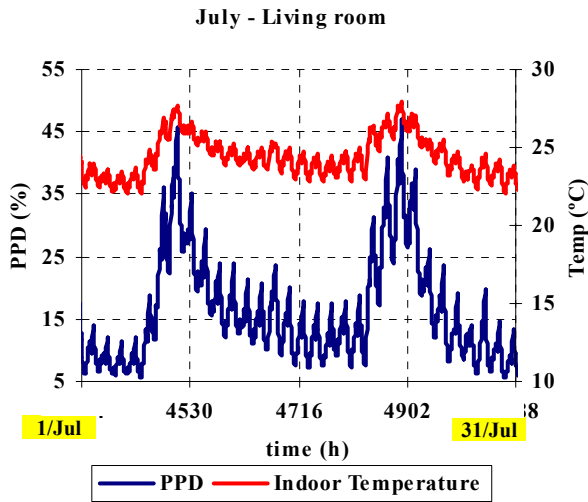


Figure 6-65 - PPD versus Indoor temperature evolution (Living room)

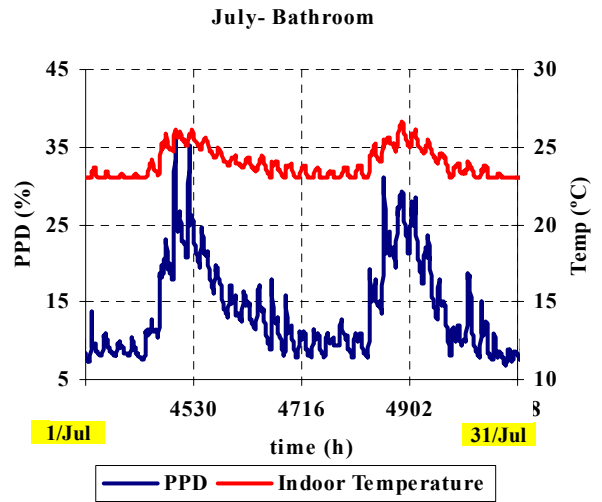


Figure 6-66 - PPD versus Indoor temperature evolution (Bathroom)

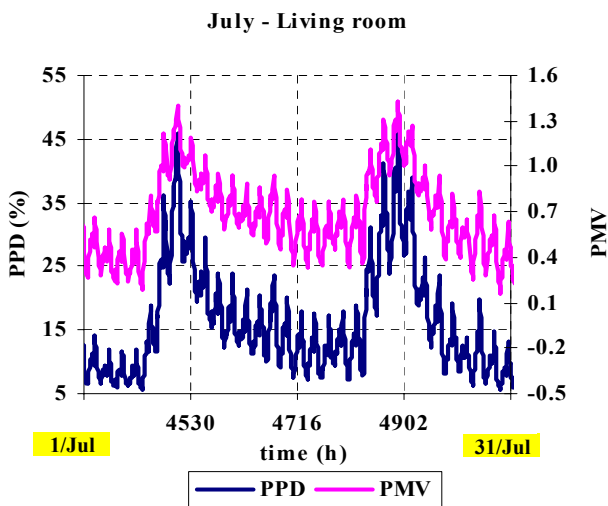


Figure 6-67- PPD versus PMV (Living room)

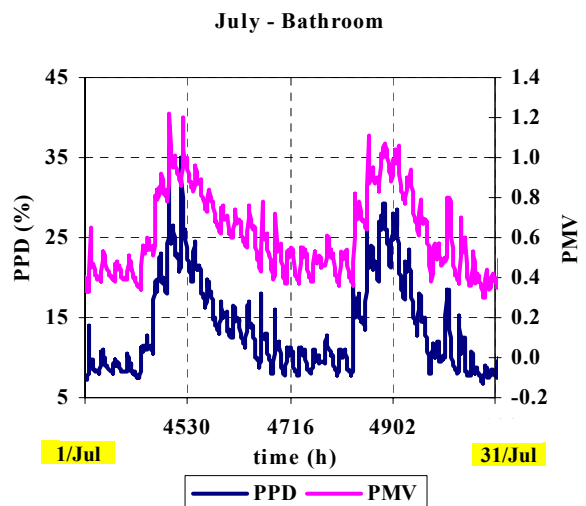


Figure 6-68- PPD versus PMV evolution (Bathroom)

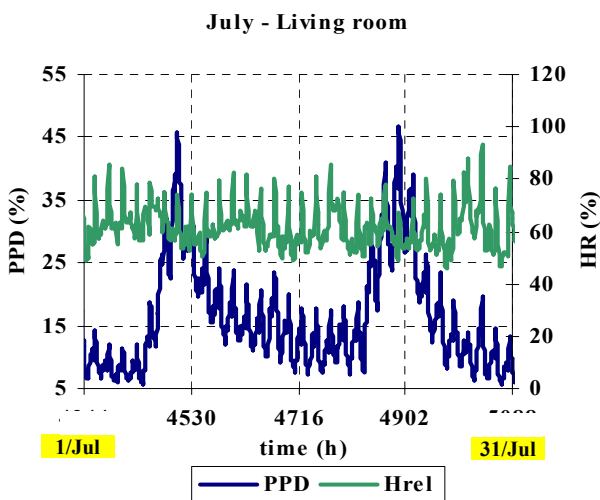


Figure 6-69 - PPD versus Relative humidity (Living room)

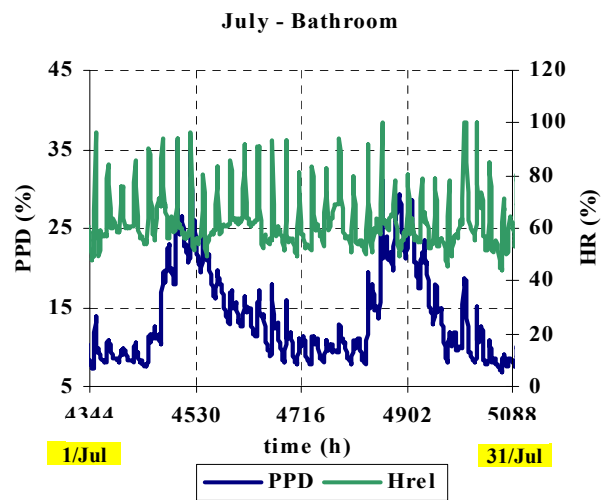


Figure 6-70 - PPD versus Relative humidity (Bathroom)

6.4. System III

Mechanical ventilation system is not so dependent of the effect of the weather conditions than the others systems already presented, i.e., dependent of the wind characteristics speed and direction. This effect will be presented in the next paragraphs. The first effect is related to the total heat energy consumption and the ventilation losses that are more controlled. The total heating energy consumption is about 3541kWh/year, the lowest value presented so far, and the ventilation losses represents about 2310kWh/year that means 65%.

The behaviour of the outlet air flow rate seems always constant because the mechanical ventilation system attenuates the wind effect on exhaustion airflow. When the wind is blowing with significant speed, it affects air admission, increasing or decreasing the inlet airflow rate when its direction is from south or north, respectively. This can be seen in Figure 6-71 to Figure 6-78, where the left and right columns correspond to ventilation profile when the wind blows from south and north respectively.

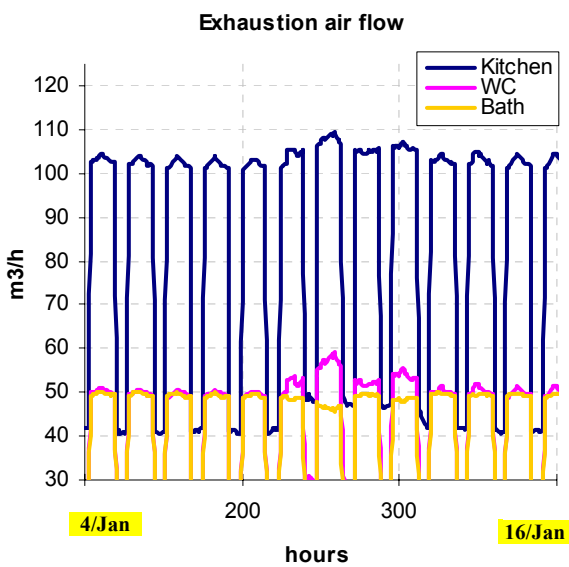


Figure 6-71 – Exhaustion airflow (wind from south quadrant)

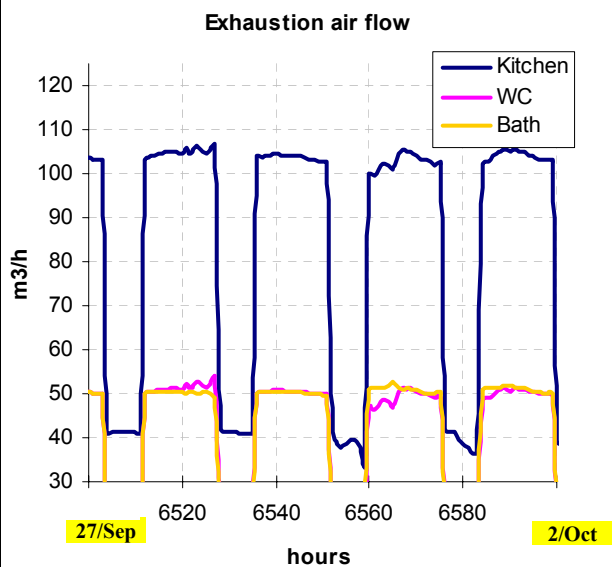


Figure 6-72 – Exhaustion airflow (wind from north quadrant)

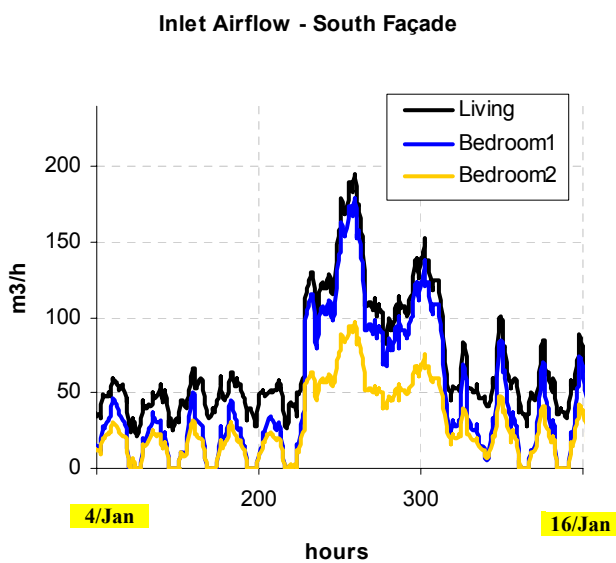


Figure 6-73 – Inlet airflow (wind from south quadrant)

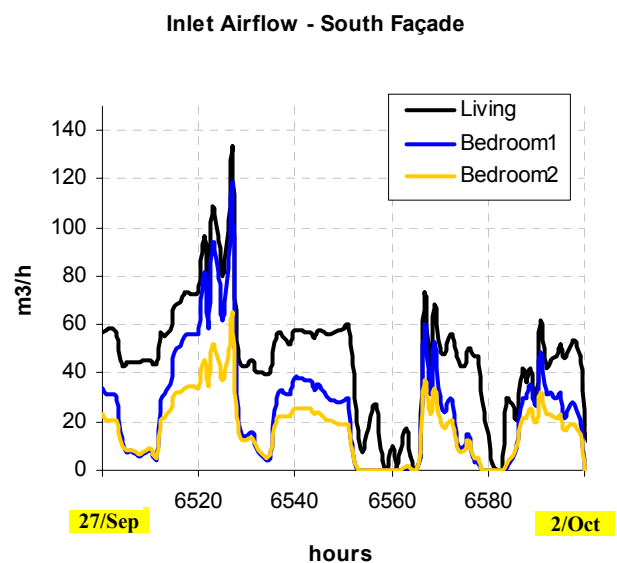


Figure 6-74 – Inlet airflow (wind from north quadrant)

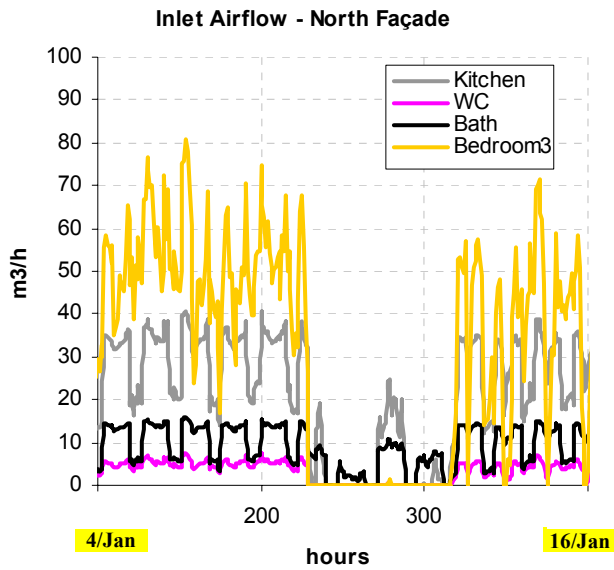


Figure 6-75 – Inlet airflow (wind from south quadrant)

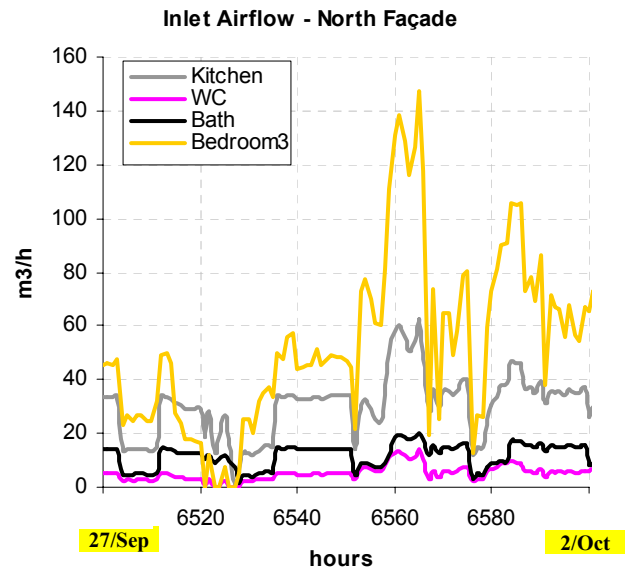


Figure 6-76 – Inlet airflow (wind from north quadrant)

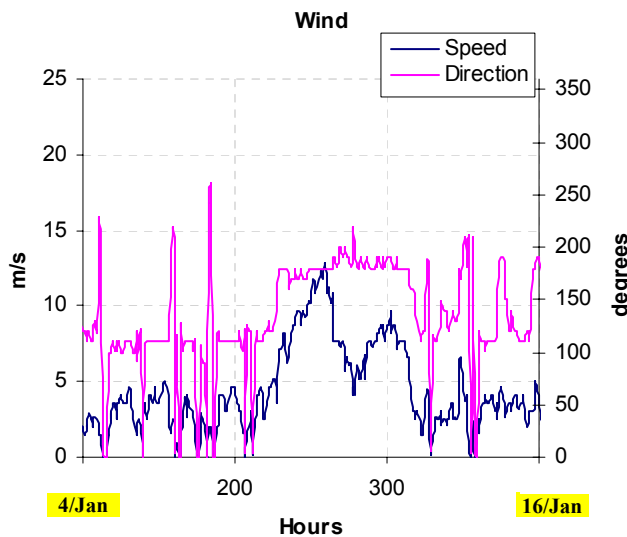


Figure 6-77 – Wind characteristics

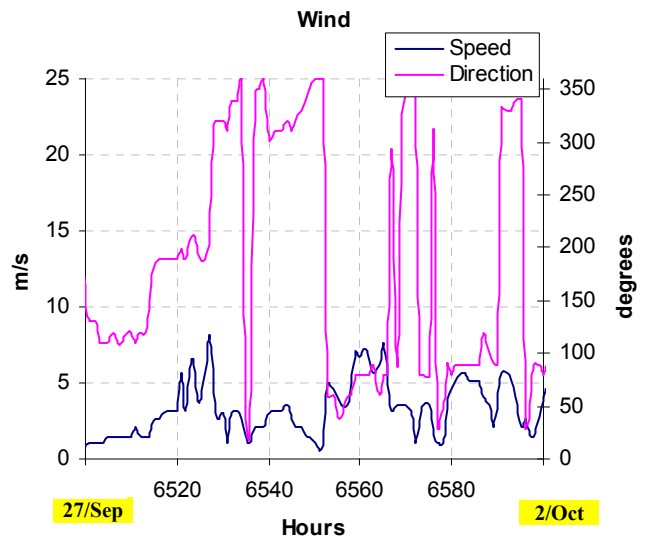


Figure 6-78 – Wind characteristics

The variation of the ventilation profile is affected by the wind characteristics because of the following reasons:

- The inlet grilles are located in the south façade
- There are more infiltrations through cracks on the south façade

The concentration of CO₂ is also affected by the wind conditions as it is shown in figure 6-45 to figure 6-48. It is evident that a bigger infiltration flow benefits the air quality in the house, which happens when the wind is blowing from south. A more specific analysis to bedroom 1 (a critical zone in terms of CO₂ because of the night occupation with 2 persons) shows a significant improvement of the CO₂ concentration in the same conditions of wind as mentioned before.

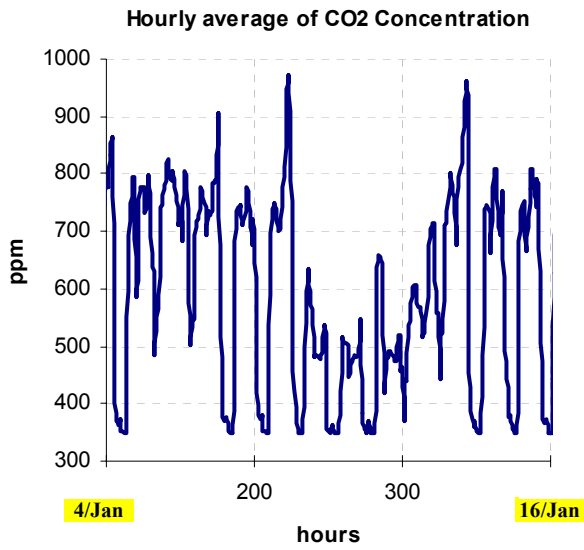


Figure 6-79 – Hourly average of the CO₂ concentration for all building (wind from south quadrant)

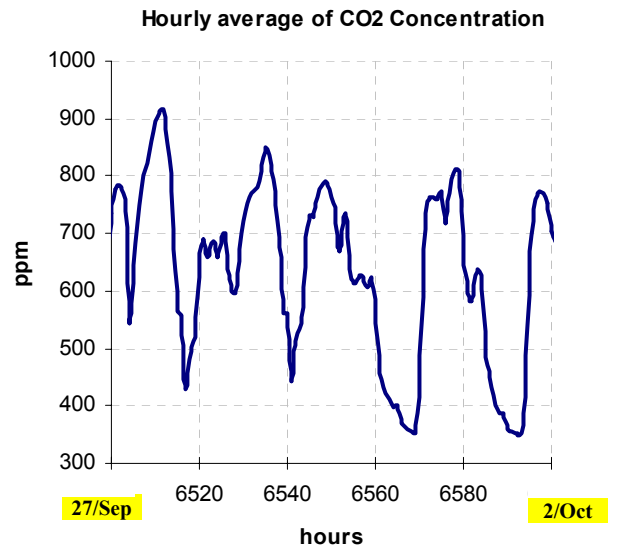


Figure 6-80 – Hourly average of the CO₂ concentration for all building (wind from north quadrant)

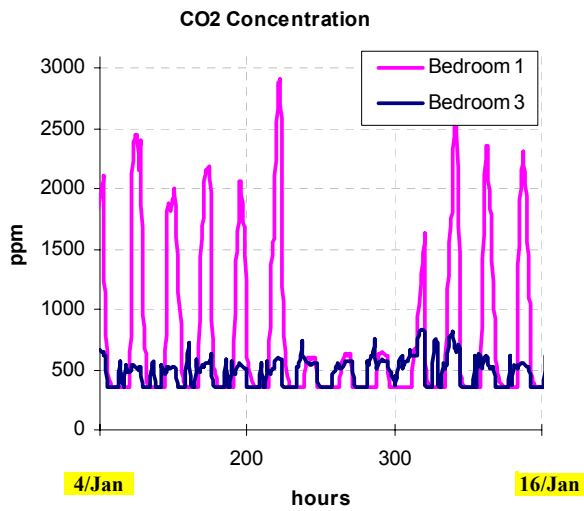


Figure 6-81 – CO₂ concentration in bedrooms 1 and 3 (wind from south quadrant)

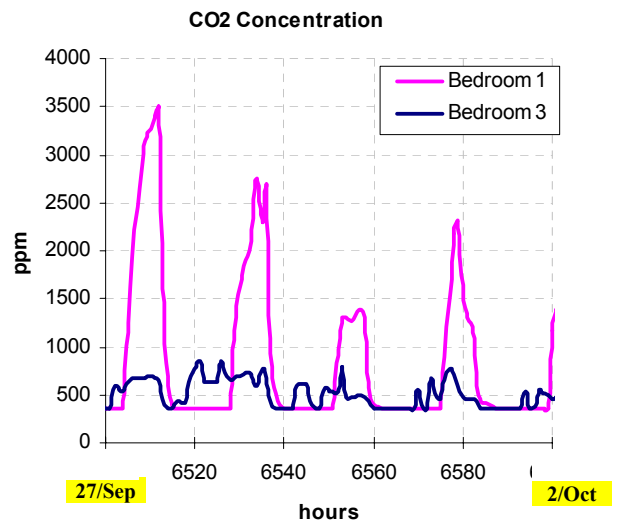


Figure 6-82 – CO₂ concentration in bedrooms 1 and 3 (wind from north quadrant)

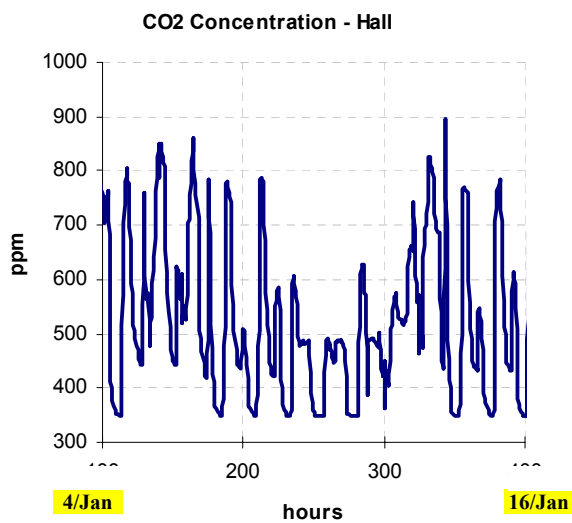


Figure 6-83 – CO₂ concentration in Hall (wind from south quadrant)

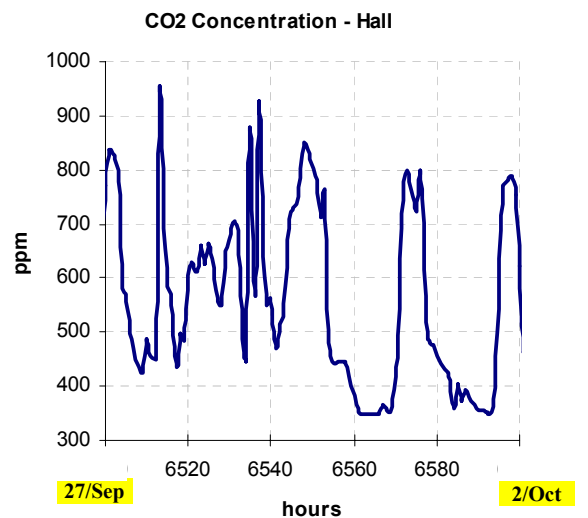


Figure 6-84 – CO₂ concentration in Hall (wind from north quadrant)

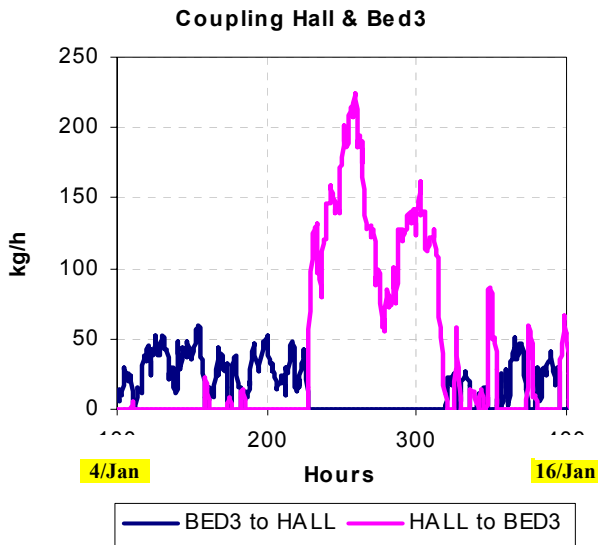


Figure 6-85 –Coupling Hall and Bedroom 3 (wind from south quadrant)

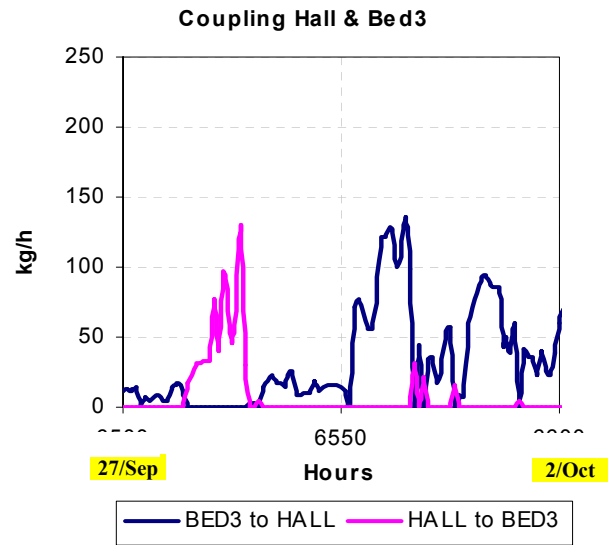


Figure 6-86 –Coupling Hall and Bedroom 3 (wind from north quadrant)

Absolute humidity is more dependent on outside humidity conditions than on wind characteristics. This is demonstrated by the fact that this parameter has an identical profile for rooms with either south or north façades (Figure 6-87 to Figure 6-90), and demonstrated by outside humidity profile shown on Figure 6-91 and Figure 6-92. The peaks that are visible in the graphics result from the occupation and activities that differ from zone to zone.

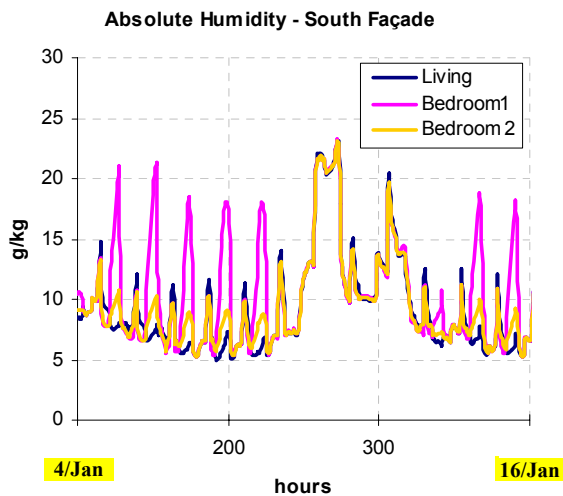


Figure 6-87 –Absolute Humidity (wind from south quadrant)

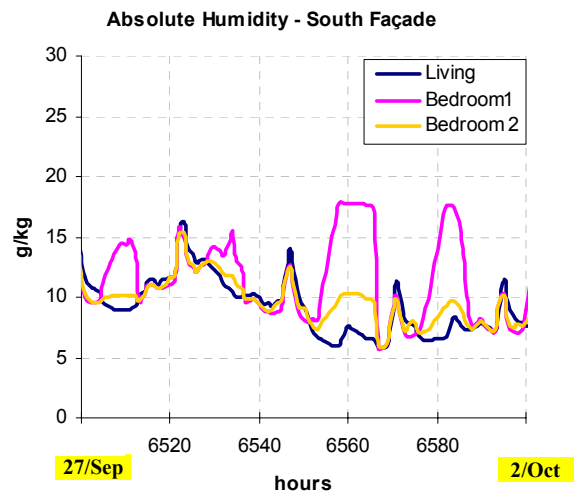


Figure 6-88 –Absolute Humidity (wind from north quadrant)

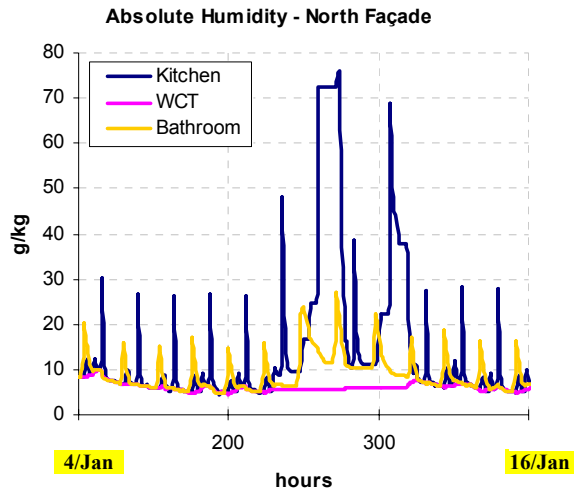


Figure 6-89 –Absolute Humidity (wind from south quadrant)

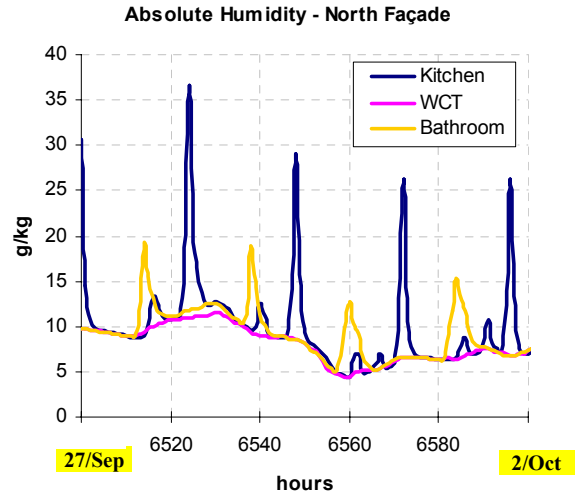


Figure 6-90 –Absolute Humidity (wind from north quadrant)

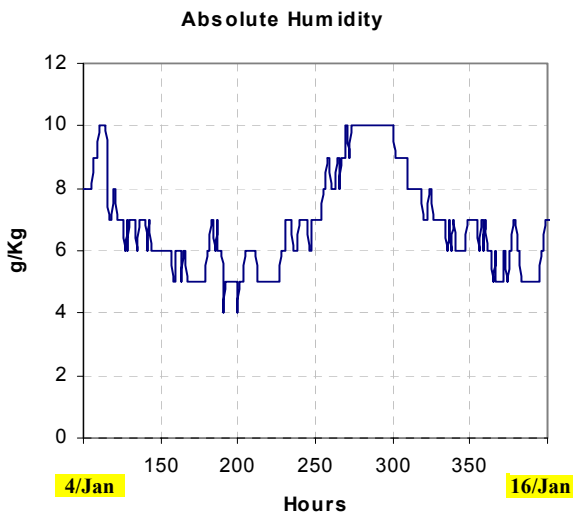


Figure 6-91 –Absolute Humidity (wind from south quadrant)

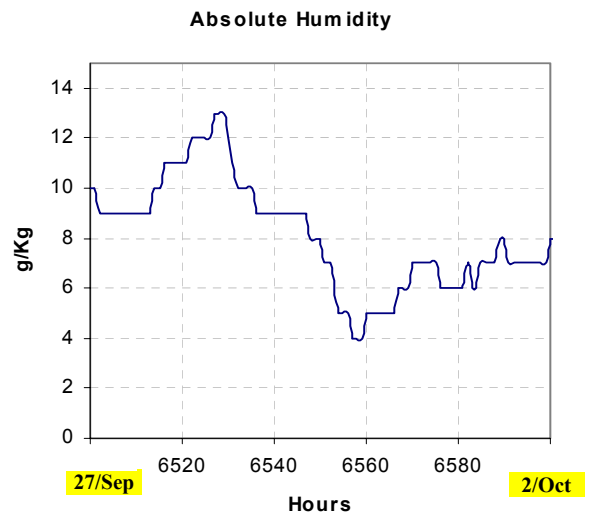


Figure 6-92 –Absolute Humidity (wind from north quadrant)

Thermal comfort is influenced by the indoor temperature (connected to the sensible heat transfer) and the indoor relative humidity (related to the latent heat transfer). In TRNSYS there are two kinds of parameters for its evaluation: the PPD (Predicted Percentage of Dissatisfied Person) and PMV (Predicted Mean Vote). The first parameter, in an ideal situation of comfort should not exceed the 15 % and the second one, PMV, must be between the -0.5 and 0.5 limits, which indicates a comfortable situation.

However these values have fluctuations, which are related to temperature or relative humidity changes. This can be seen below, where the left and right columns correspond to PPD, Indoor Temperature, PMV and Relative Humidity evolution in living room and bathroom, respectively.

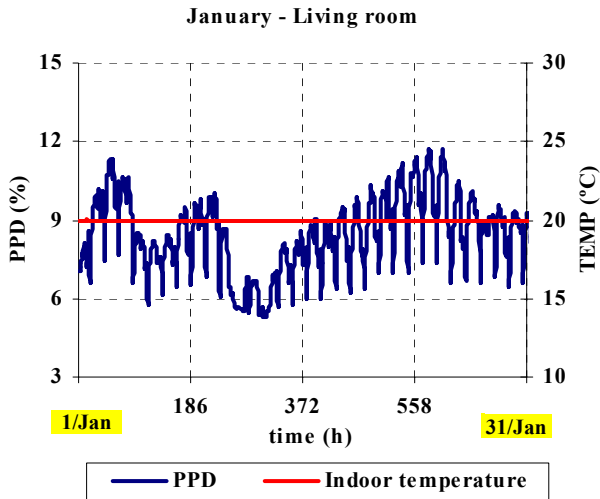


Figure 6-93 - PPD versus Indoor temperature evolution (Living room)

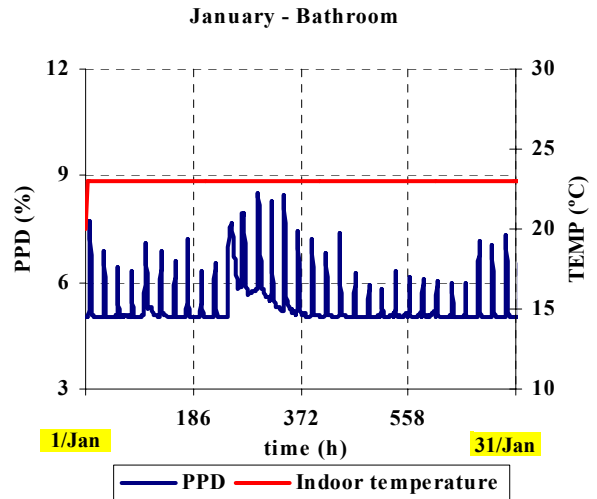


Figure 6-94 - PPD versus Indoor temperature evolution (Bathroom)

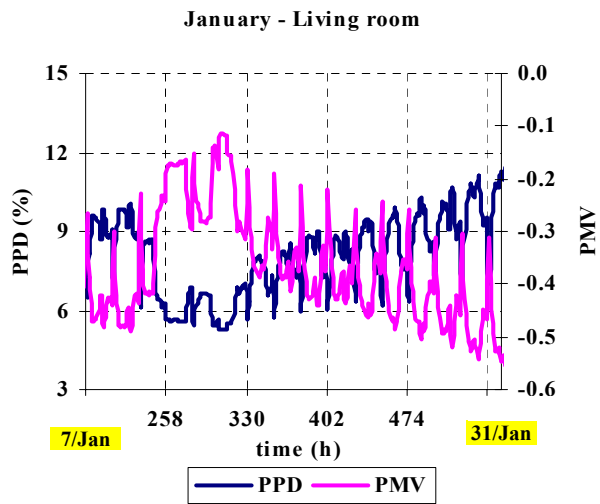


Figure 6-95- PPD versus PMV (Living room)

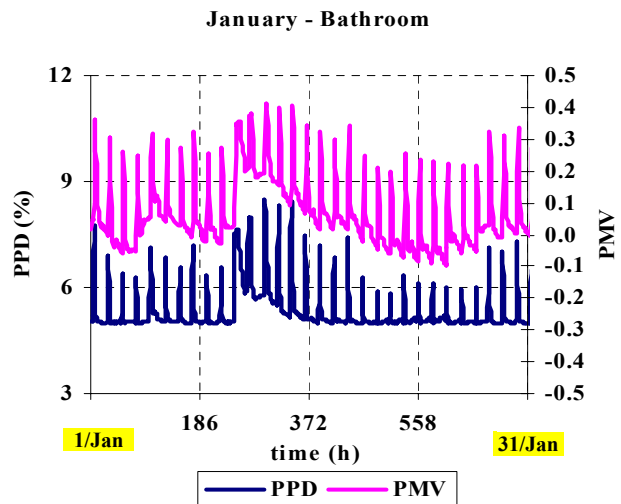


Figure 6-96- PPD versus PMV evolution (Bathroom)

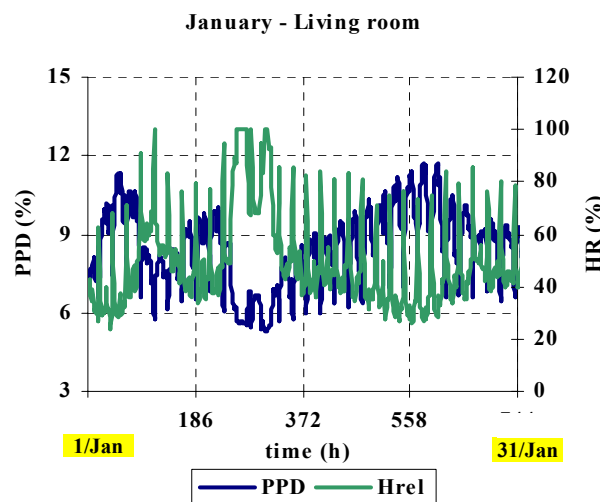


Figure 6-97 - PPD versus Relative humidity (Living room)

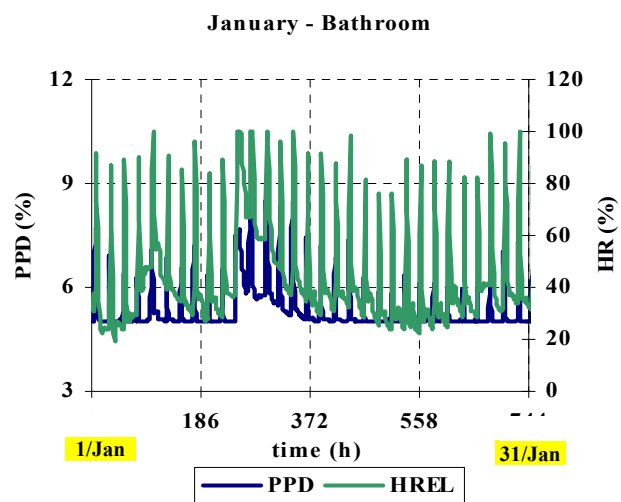


Figure 6-98 - PPD versus Relative humidity (Bathroom)

Comparing the PPD evolution in living room and bathroom with the Relative Humidity variation we conclude that they have a different behaviour. In living room, when the relative humidity increases the PPD decreases and in bathroom, with the same relative humidity change, the PPD increases. This happens because, to a same humidity level, the indoor temperature is lower in the living room than in the bathroom, which improves the heat sensation and, consequently, the PPD and PMV.

In figures below the same analysis is done for the month of July. As we can see, in this month (Summer), the temperature is determinant in the PPD and PMV values. A higher indoor temperature causes a PPD increase.

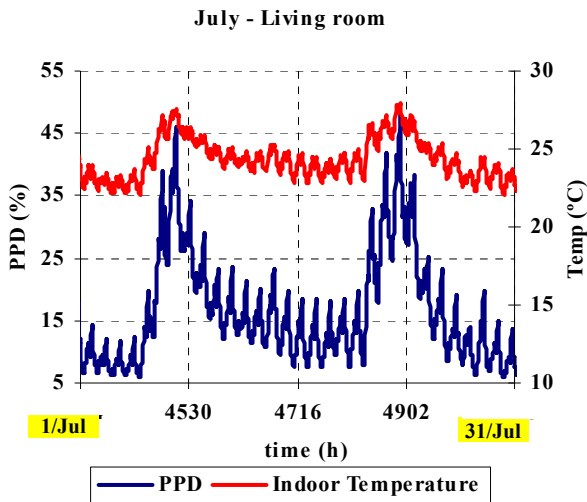


Figure 6-99 - PPD versus Indoor temperature evolution (Living room)

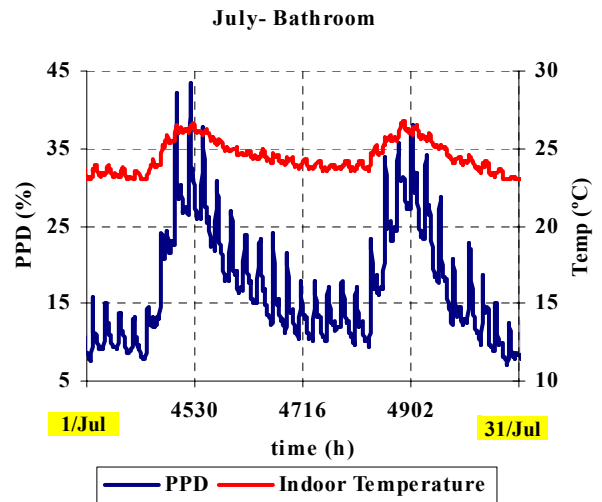


Figure 6-100 - PPD versus Indoor temperature evolution (Bathroom)

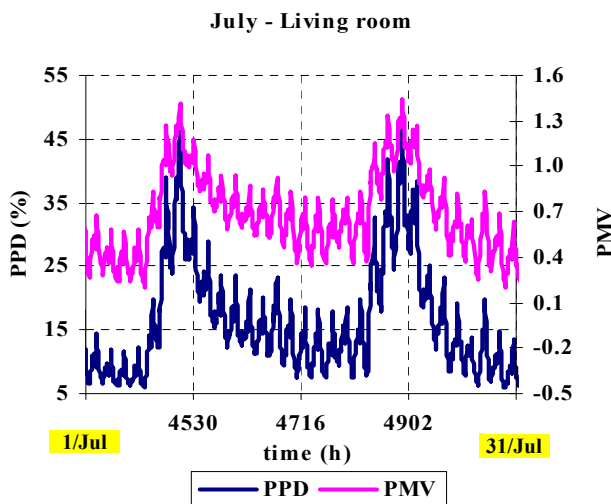


Figure 6-101- PPD versus PMV (Living room)

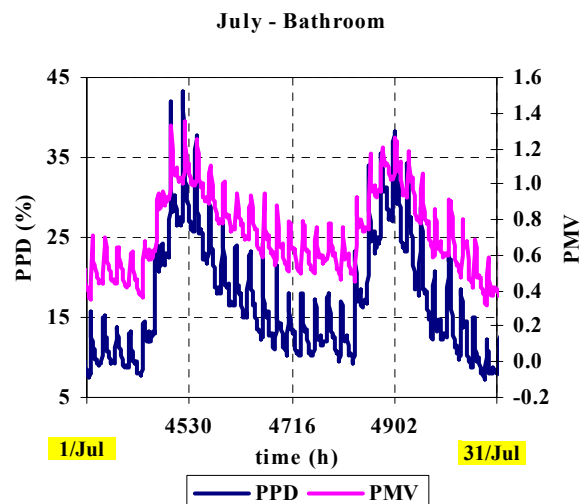


Figure 6-102- PPD versus PMV evolution (Bathroom)

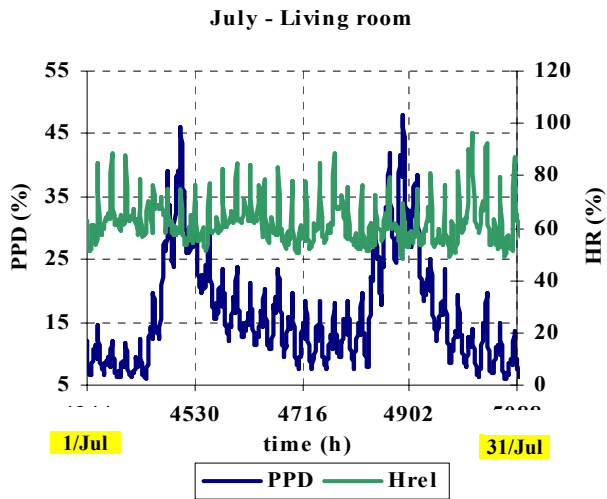


Figure 6-103 - PPD versus Relative humidity (Living room)

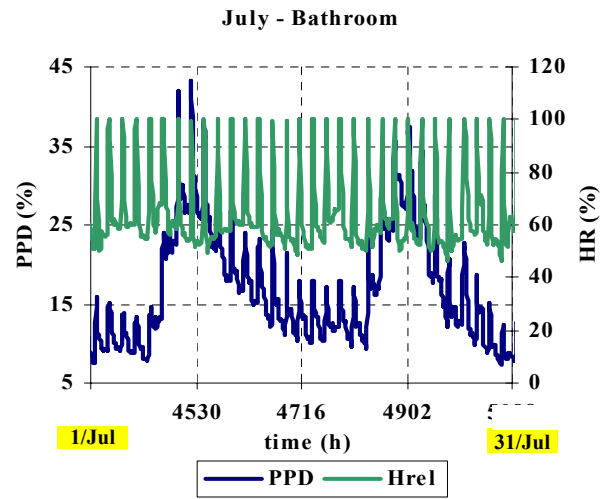


Figure 6-104 - PPD versus Relative humidity (Bathroom)

6.5. System IV

The total heating energy consumption is about 3365kWh/year and the ventilation losses represents about 2055kWh/year that means 61% of total energy.

There are disturbances in the normal airflow of the ventilation in the dwelling but the presence of a mechanical ventilation system attenuates the wind effect on exhaust air flow. When the wind is blowing with significant speed it affects the ventilation, increasing or decreasing inlet airflow when it's direction is from south or north quadrant respectively. This can be seen in Figure 6-105 to Figure 6-112, where the left and right columns correspond to ventilation profile when the wind blows from south and north respectively.

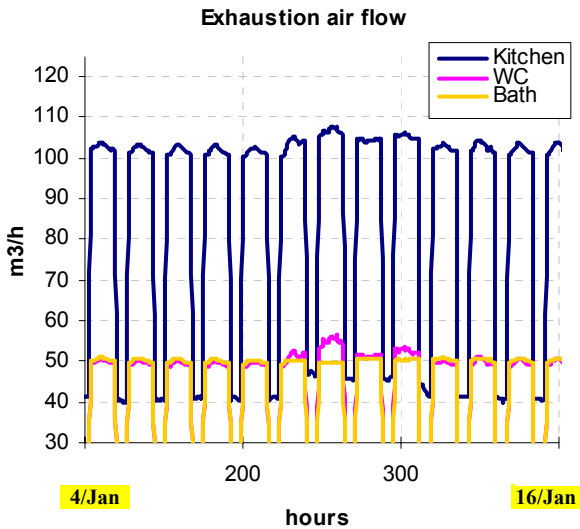


Figure 6-105 – Exhaustion air flow (wind from south quadrant)

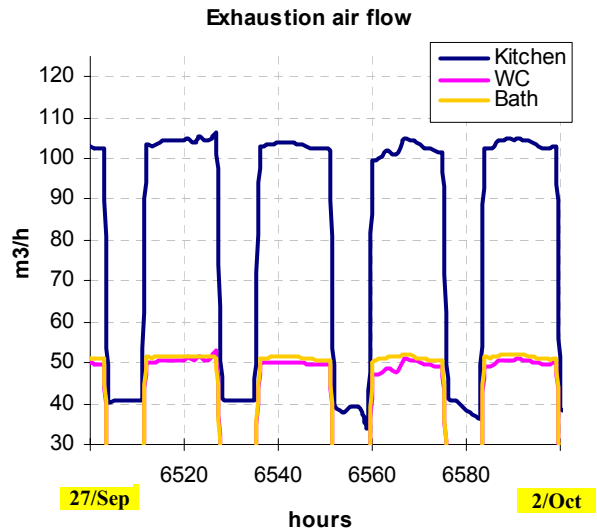


Figure 6-106 – Exhaustion air flow (wind from north quadrant)

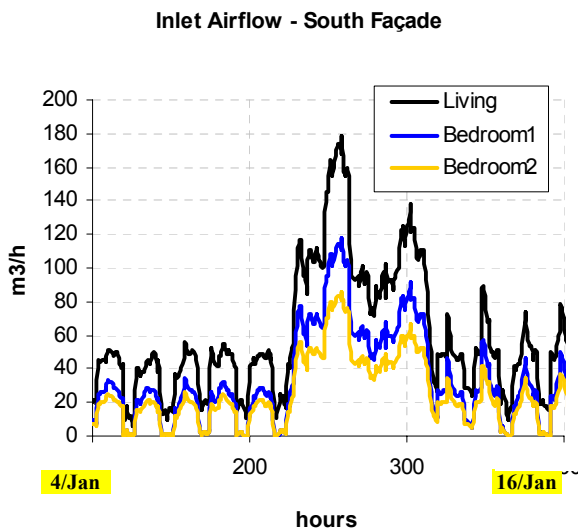


Figure 6-107 – Inlet airflow (wind from south quadrant)

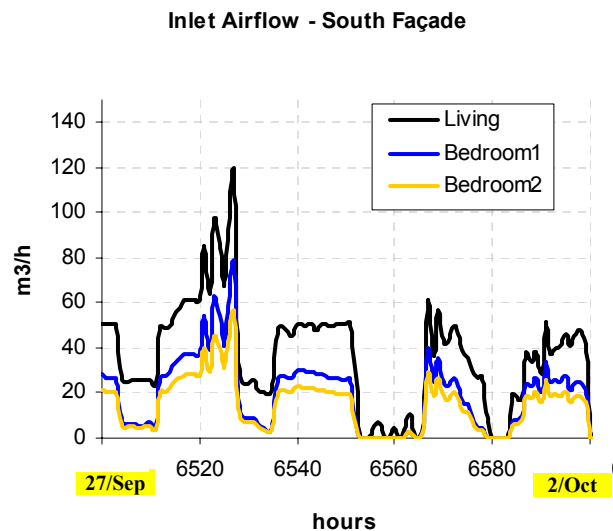


Figure 6-108 – Inlet airflow (wind from north quadrant)

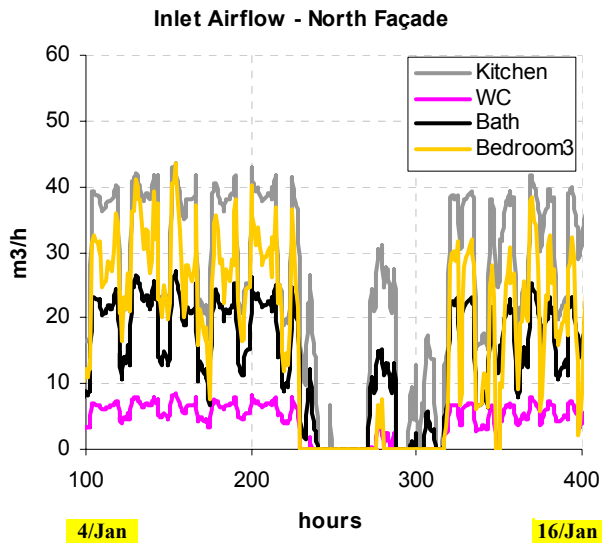


Figure 6-109 – Inlet airflow (wind from south quadrant)

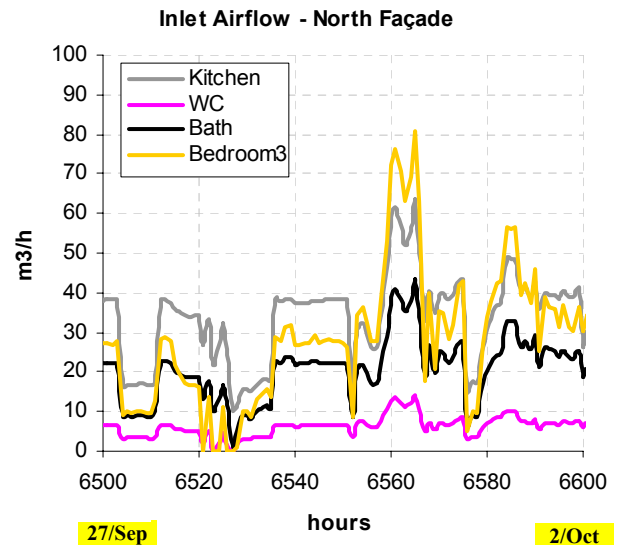


Figure 6-110 – Inlet airflow (wind from north quadrant)

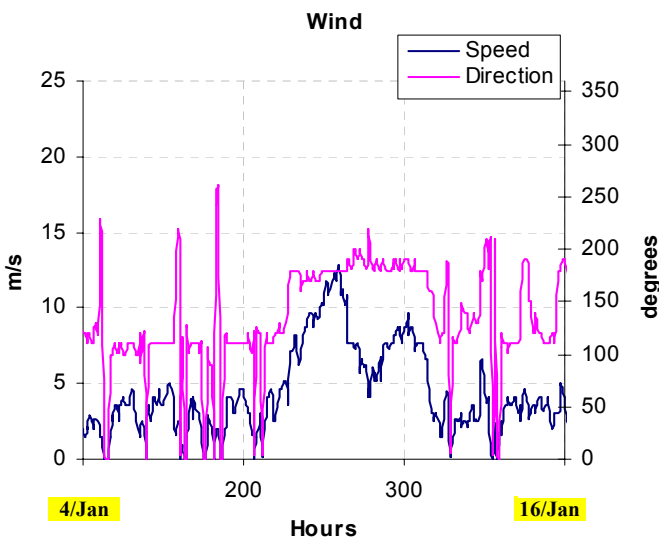


Figure 6-111 – Wind characteristics

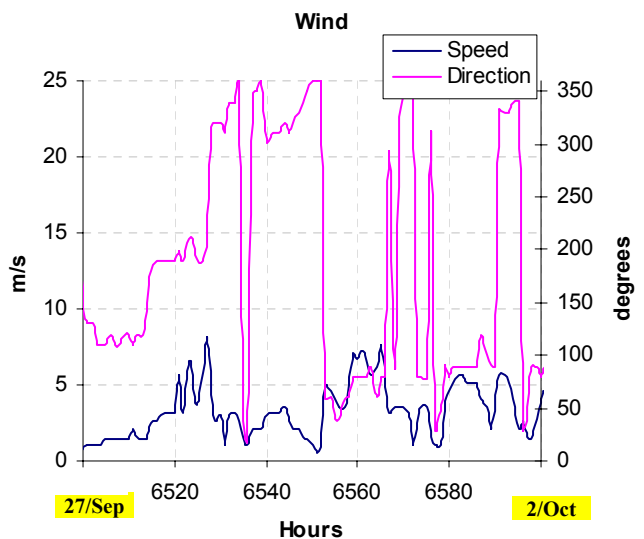


Figure 6-112 – Wind characteristics

The variation of the ventilation profile is affected by the wind characteristics because of the following reasons:

- The inlet grilles are located in the south façade
- There are more infiltrations through cracks in the south façade

The concentration of CO₂ is also affected by the wind conditions as it is shown in Figure 6-113 to Figure 6-120. It is evident that a bigger infiltration flow benefits the air quality in the house, which happens when the wind is blowing from south. A more specific analysis to bedroom 1 (a critical zone in terms of CO₂ because of the night occupation with 2 persons) shows a significant improvement of the CO₂ concentration in the same conditions of wind as mentioned before.

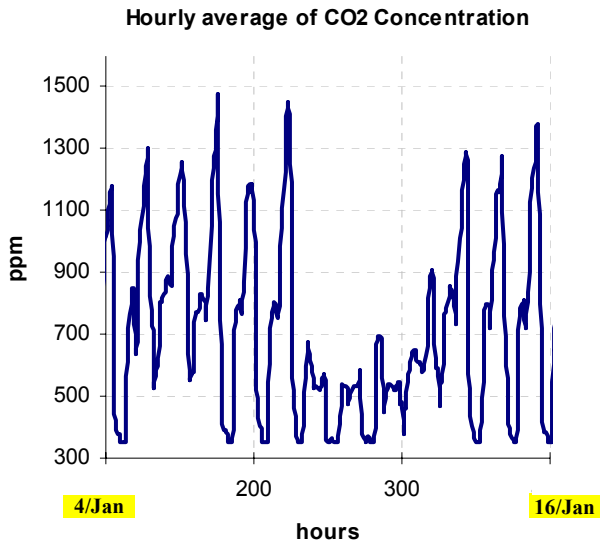


Figure 6-113 – Hourly average of the CO₂ concentration for all building (wind from south quadrant)

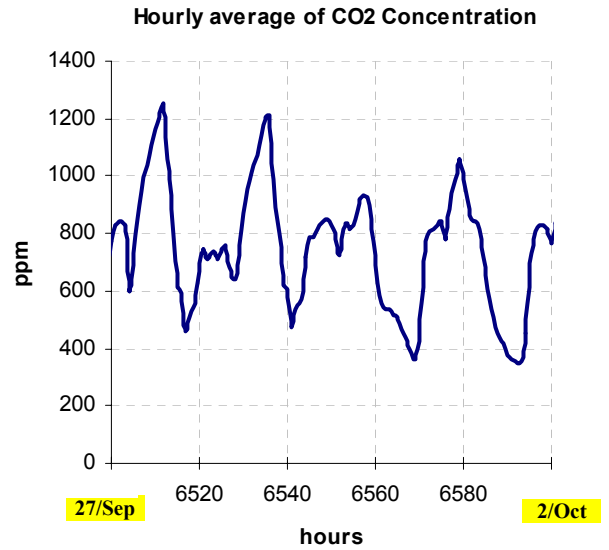


Figure 6-114 – Hourly average of the CO₂ concentration for all building (wind from north quadrant)

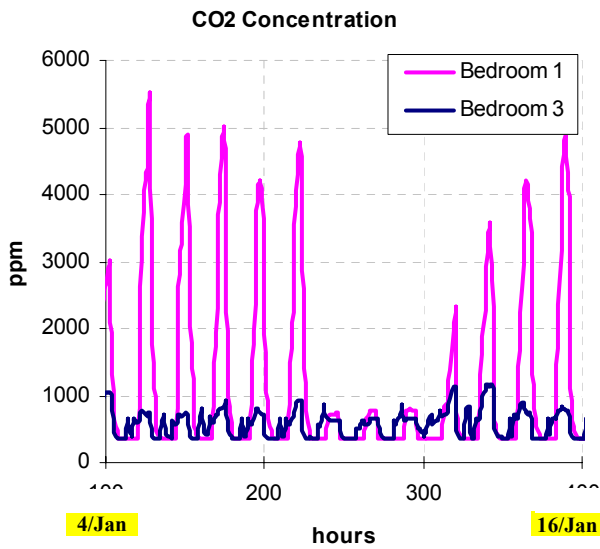


Figure 6-115 –CO₂ concentration in bedrooms 1 and 3 (wind from south quadrant)

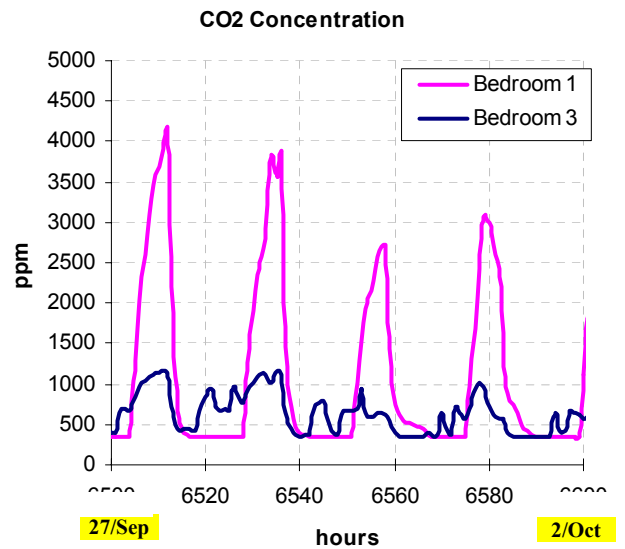


Figure 6-116 –CO₂ concentration in bedrooms 1 and 3 (wind from north quadrant)

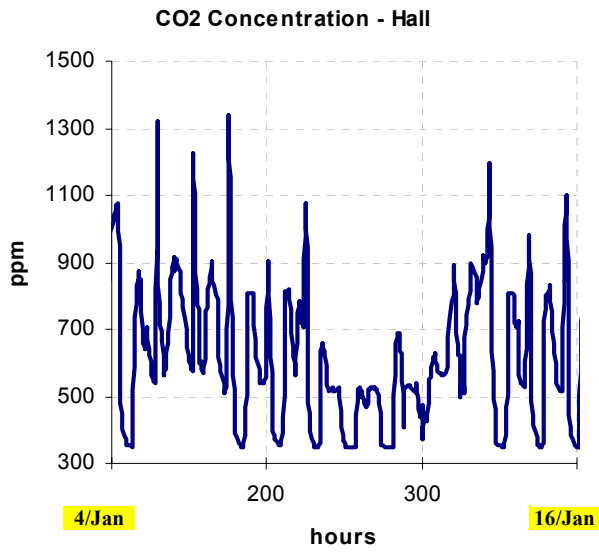


Figure 6-117 –CO₂ concentration in Hall (wind from south quadrant)

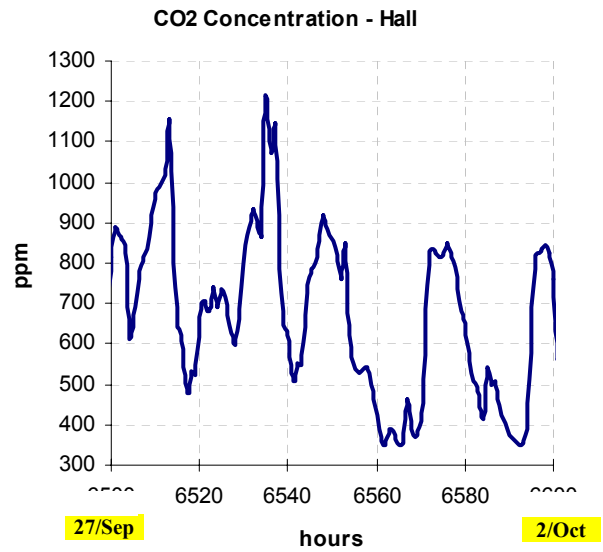


Figure 6-118 –CO₂ concentration in Hall (wind from north quadrant)

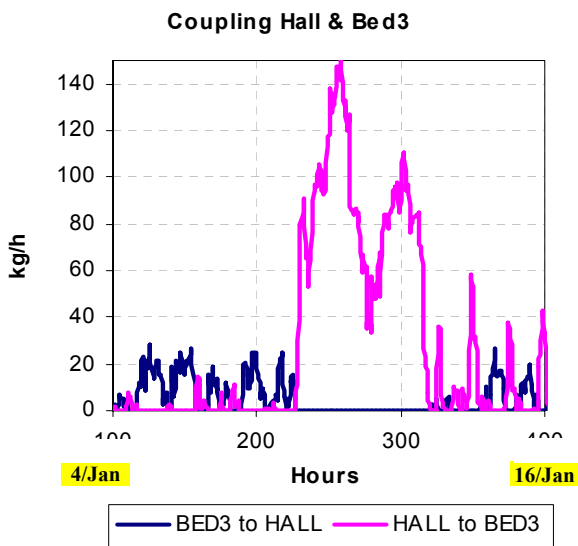


Figure 6-119 –Coupling Hall and Bedroom 3 (wind from south quadrant)

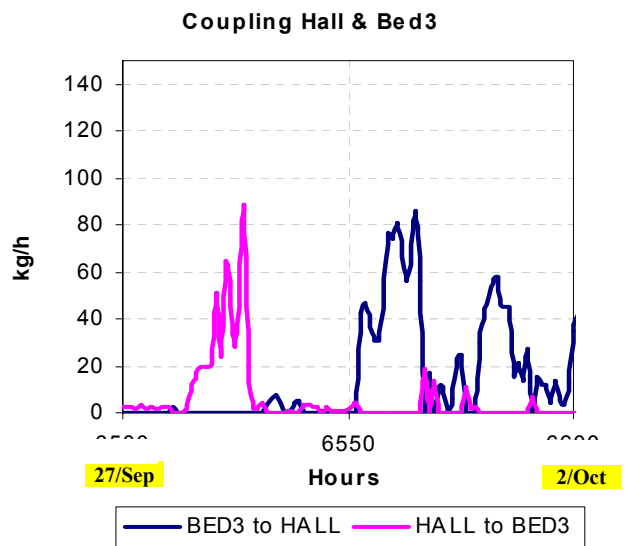


Figure 6-120 –Coupling Hall and Bedroom 3 (wind from north quadrant)

Absolute humidity is more dependent on outside humidity conditions than on wind characteristics. This is demonstrated by the fact that this parameter has an identical profile for rooms with either south or north façades (figure 6-121 to figure 6-124), and demonstrated by outside humidity profile shown on figure 6-125 and figure 6-126. The peaks that are visible in the graphics result from the occupation and activities that differ from zone to zone.

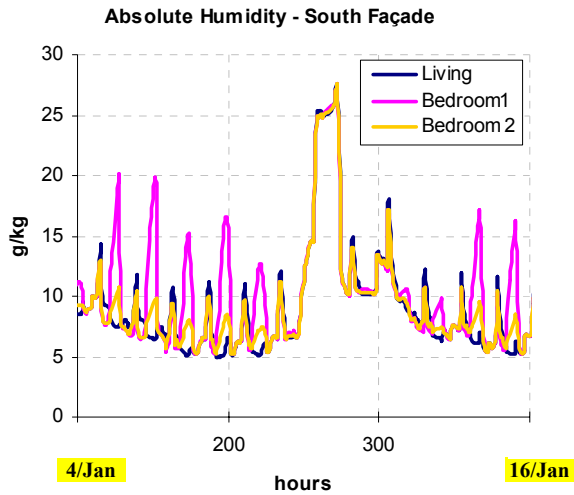


Figure 6-121 –Absolute Humidity (wind from south quadrant)

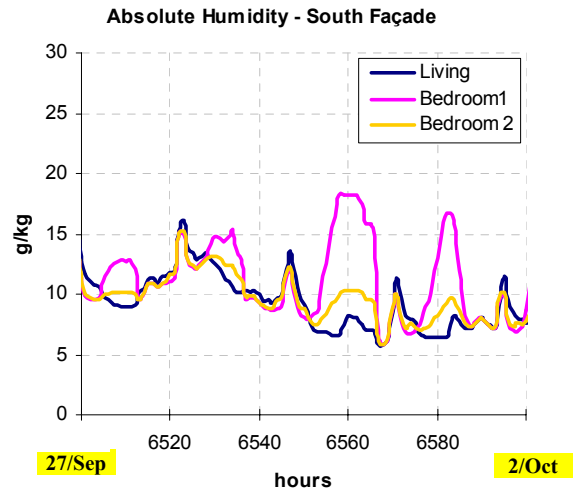


Figure 6-122 –Absolute Humidity (wind from north quadrant)

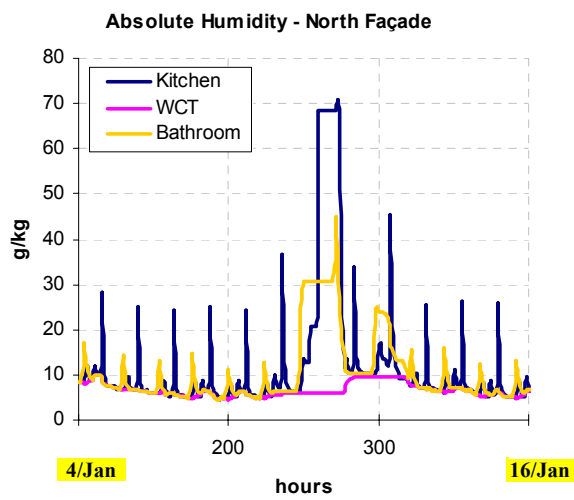


Figure 6-123 –Absolute Humidity (wind from south quadrant)

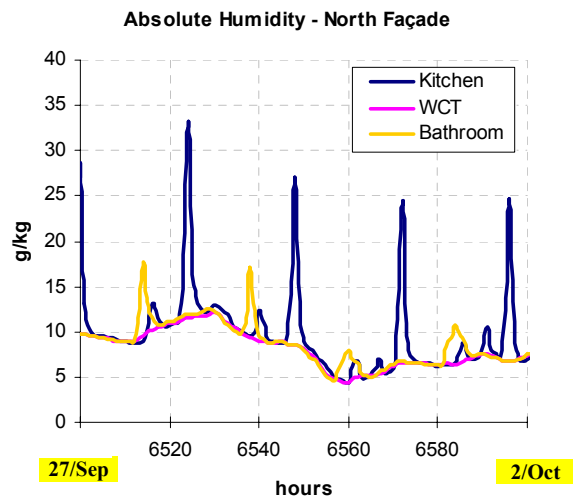


Figure 6-124 –Absolute Humidity (wind from north quadrant)

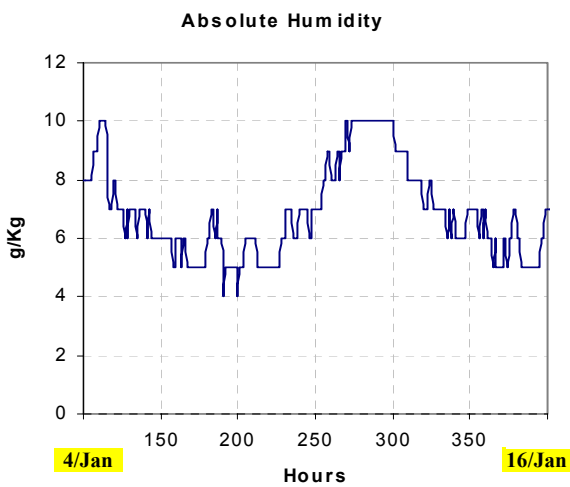


Figure 6-125 –Absolute Humidity (wind from south quadrant)

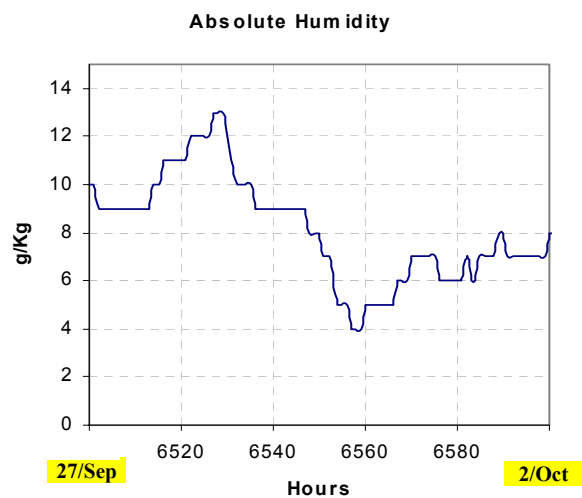


Figure 6-126 –Absolute Humidity (wind from north quadrant)

Thermal comfort is influenced by the indoor temperature (connected to the sensible heat transfer) and the indoor relative humidity (related to the latent heat transfer). In TRNSYS

there are two kinds of parameters for its evaluation: the PPD (Predicted Percentage of Dissatisfied Person) and PMV (Predicted Mean Vote). The first value, in an ideal situation of comfort should not exceed the 15 % and the second one, PMV, must be between the -0.5 and 0.5 limits, which indicates a comfortable situation.

However these values have fluctuations, which are related to temperature or relative humidity changes. This can be seen in figure 6-127 to figure 6-132, where the left and right columns correspond to PPD, Indoor Temperature, PMV and Relative Humidity evolution in living room and bathroom, respectively.

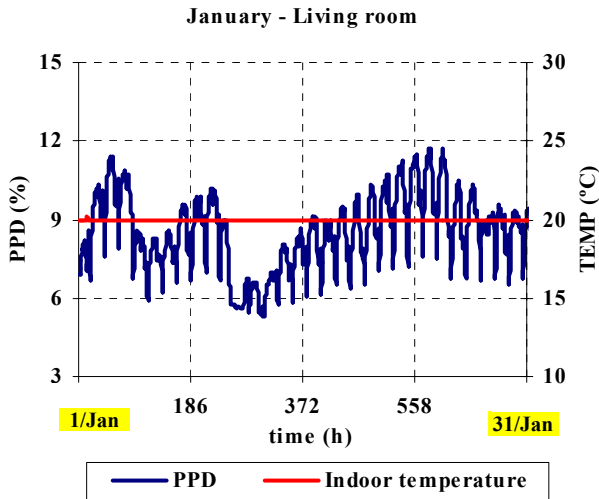


Figure 6-127 - PPD versus Indoor temperature evolution (Living room)

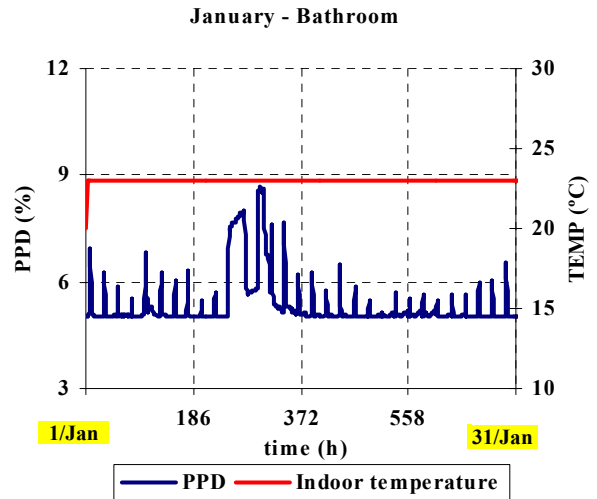


Figure 6-128 - PPD versus Indoor temperature evolution (Bathroom)

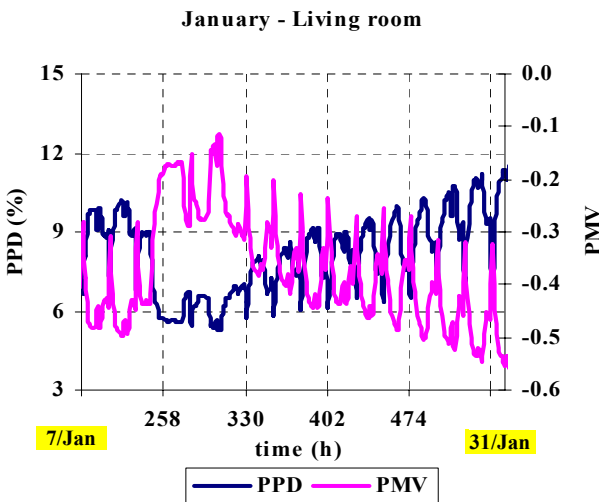


Figure 6-129- PPD versus PMV (Living room)

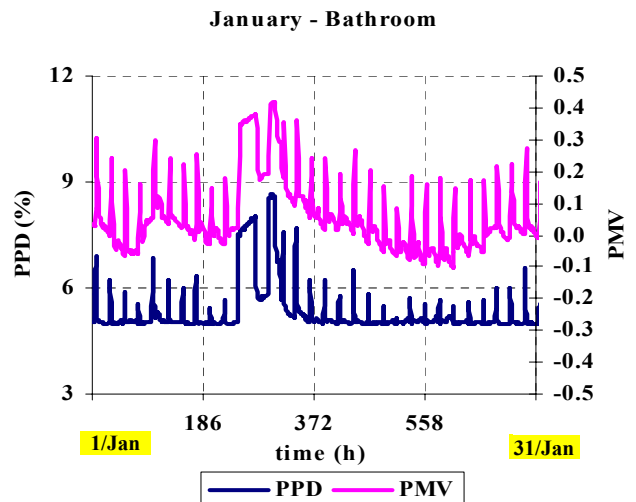


Figure 6-130- PPD versus PMV evolution (Bathroom)

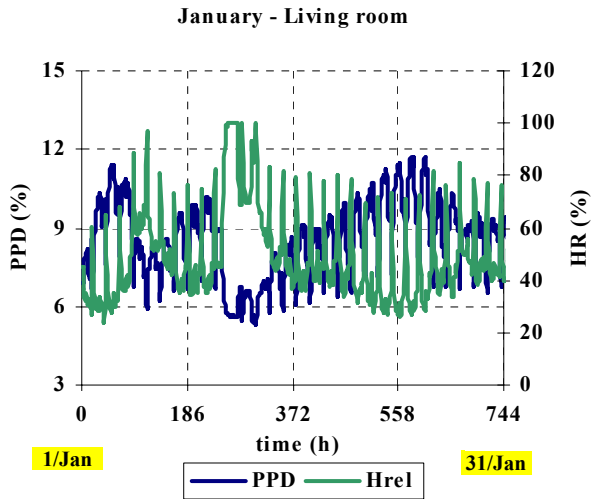


Figure 6-131 - PPD versus Relative humidity (Living room)

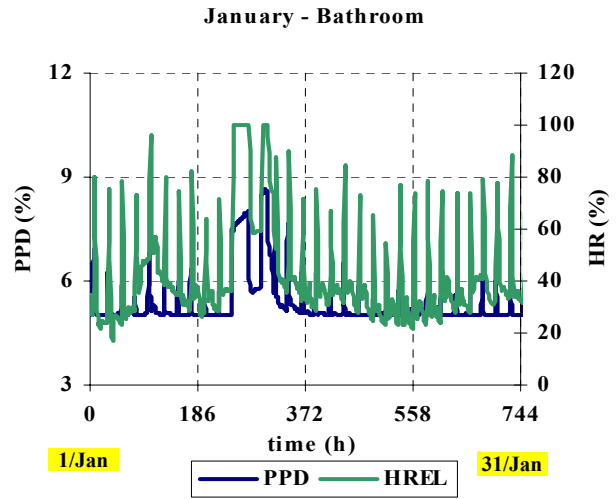


Figure 6-132 - PPD versus Relative humidity (Bathroom)

Comparing the PPD evolution in living room and bathroom with the Relative Humidity variation we conclude that they have different behaviours. In living room, when the relative humidity increases the PPD decreases and in bathroom, with the same relative humidity change, the PPD increases. This happens because, to a same humidity level, the indoor temperature is lower in the living room than in the bathroom, which improves the heat sensation and, consequently, the PPD and PMV.

In figures below the same analysis is done for the month of July. As we can see, in this month (Summer), the temperature is determinant in the PPD and PMV values. A higher indoor temperature provokes a PPD increase.

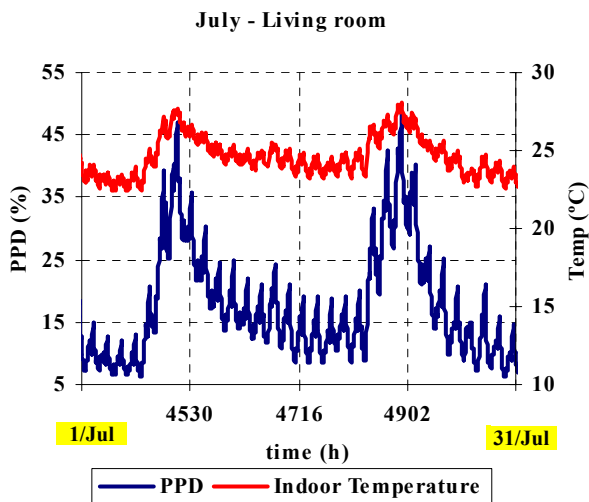


Figure 6-133 - PPD versus Indoor temperature evolution (Living room)

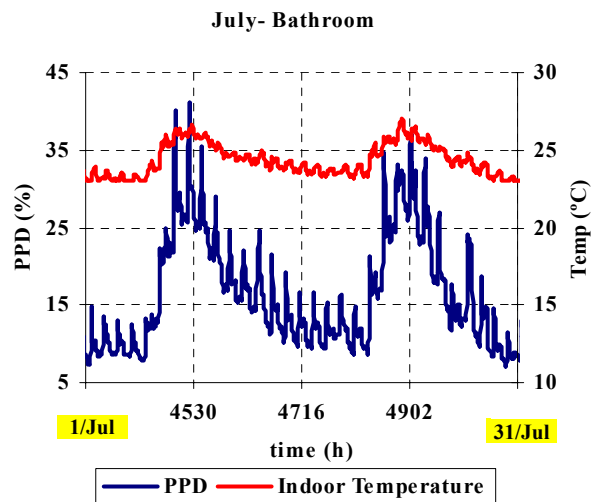


Figure 6-134 - PPD versus Indoor temperature evolution (Bathroom)

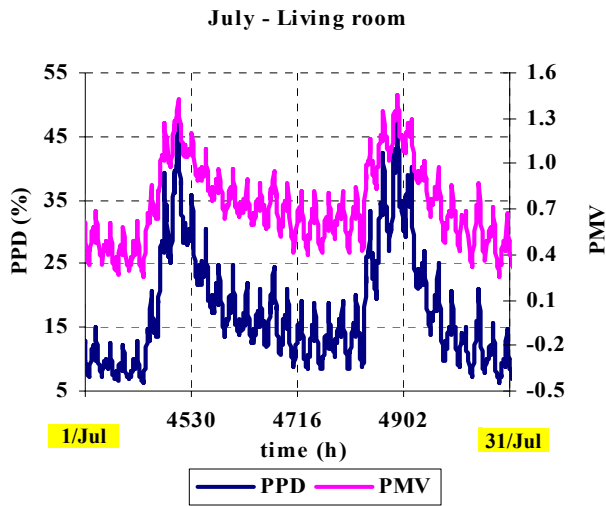


Figure 6-135- PPD versus PMV (Living room)

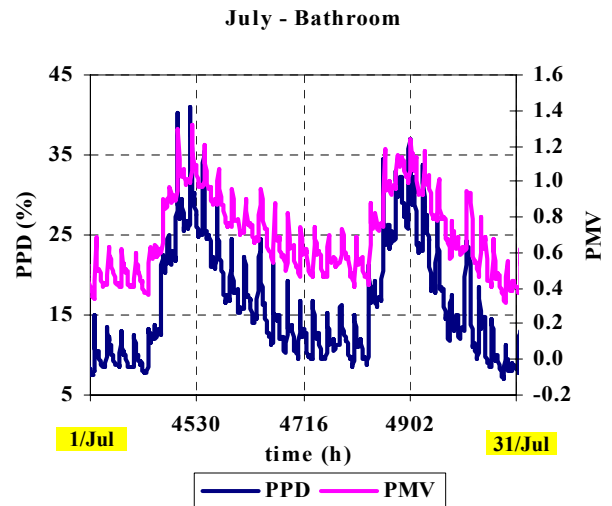


Figure 6-136- PPD versus PMV evolution (Bathroom)

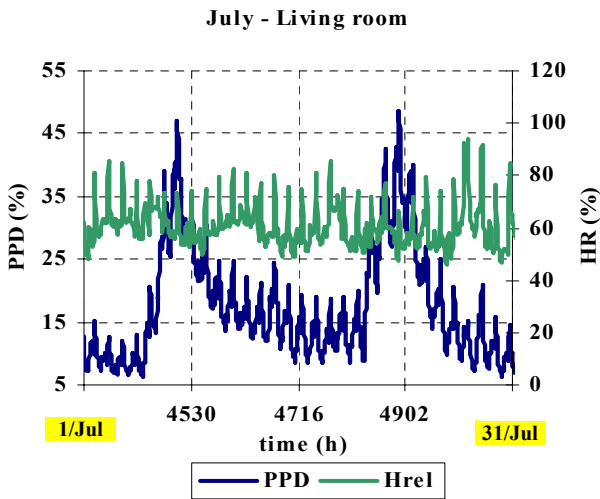


Figure 6-137 - PPD versus Relative humidity (Living room)

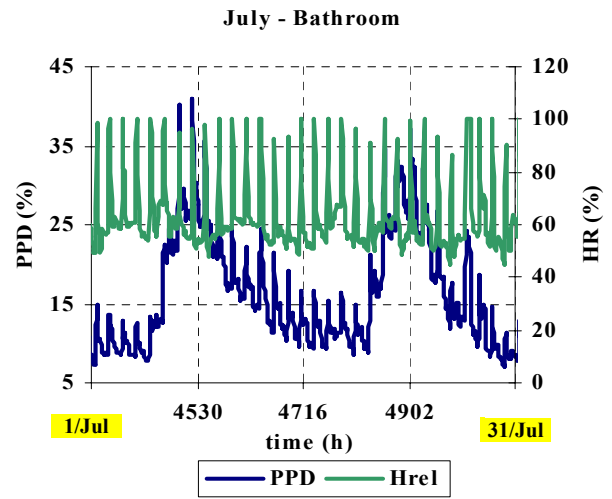


Figure 6-138 - PPD versus Relative humidity (Bathroom)

7. System Global Analysis

First analyses show that more precise control of the ventilation system result in less energy consumption and lower energy ventilation losses as it is expected.

The relative analyses between the different systems simulated in terms of heating energy consumption and ventilation losses are shown in figure 7-1 and figure 7-2, respectively. The responsibility of the effect of the reduction of energy consumption between natural and mechanical ventilation is the control schedule of the mechanical ventilation that shuts off the system during the night, on the other hand the natural ventilation is running all time that leads to a higher energy consumption.

The difference between system III and IV (both mechanical ventilation) is explained by the presence of self regulated inlet grilles that prevent exfiltrations and more control of the inlet airflow.

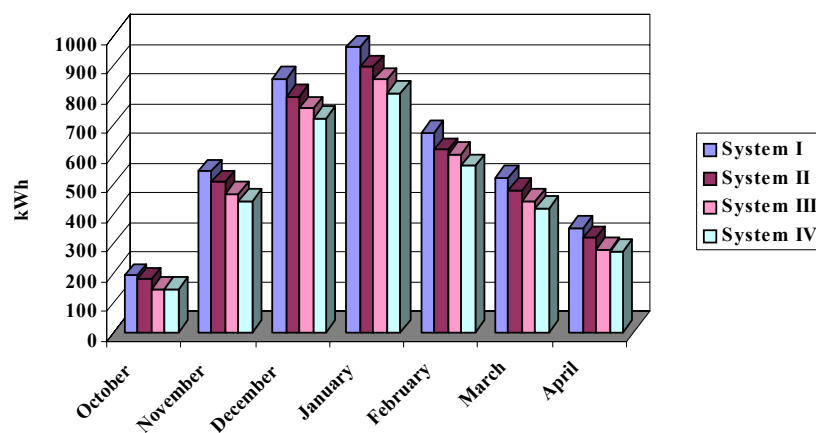


Figure 7-1 –Energy Heating consumption during heating period

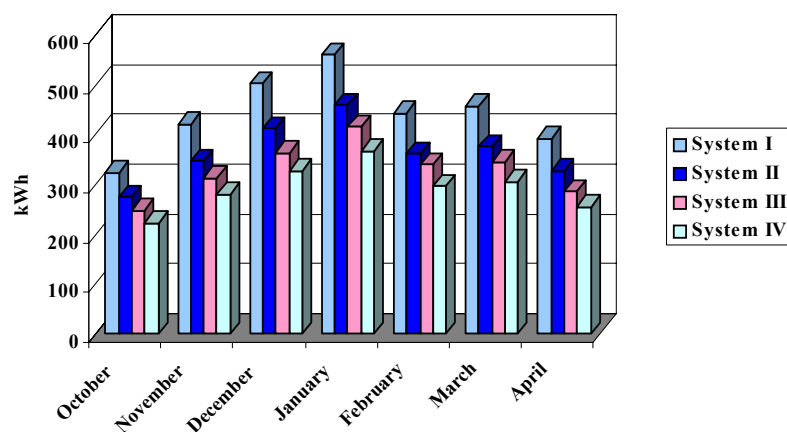


Figure 7-2 –Ventilation losses during heating period

The indoor quality (CO₂ concentration) for the different ventilation systems is shown in figure 7-3. The mechanical ventilation systems have a worse performance than the natural systems because they are turned off during the night when the occupancy of the bedrooms is high. System IV is penalized, in terms of CO₂ concentration, by the presence of the self-regulated grids, which also prevent exfiltrations.

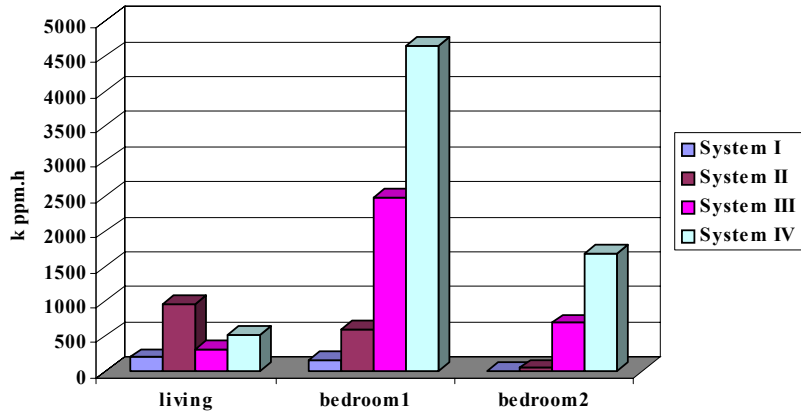


Figure 7-3 – Annual CO₂ concentration [kppm.h]

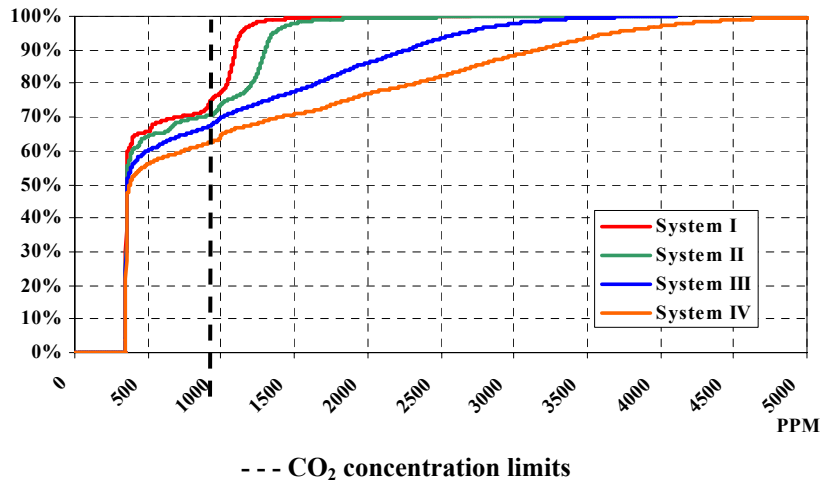


Figure 7-4 – Cumulative frequency of CO₂ concentration – bedroom 1

PPD values for class $\leq 15\%$ are presented in figure 7-5 for the systems simulated, as well as cumulative frequency of PPD in kitchen (figure 7-6).

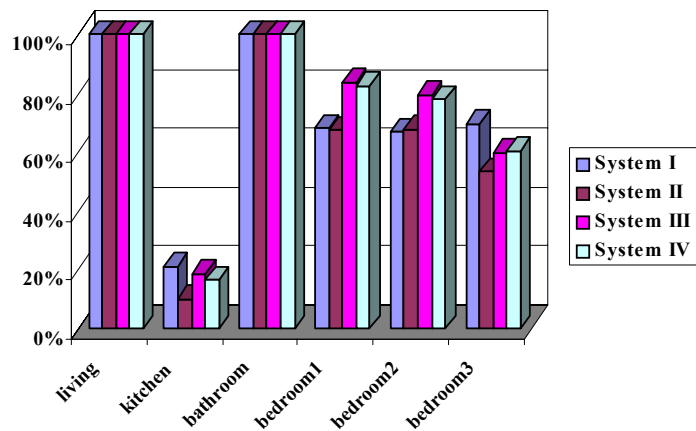


Figure 7-5 – Values of PPD for class $\leq 15\%$ during heating period

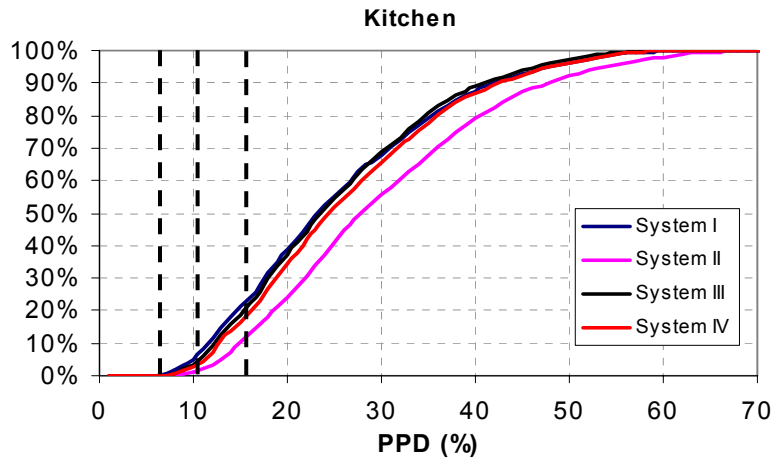


Figure 7-6 – Cumulative frequency of PPD during heating period – kitchen

Cumulative frequency of relative humidity in wet rooms is shown in the figures bellow. Production of water vapour rate is bigger and happens during longer time intervals in the kitchen than in the bathroom. In the first zone referred system I have a better performance than all others systems because the exhaust airflow is also bigger throughout the year (e.g.: table 11-3 and table 11-12 in Appendix B).

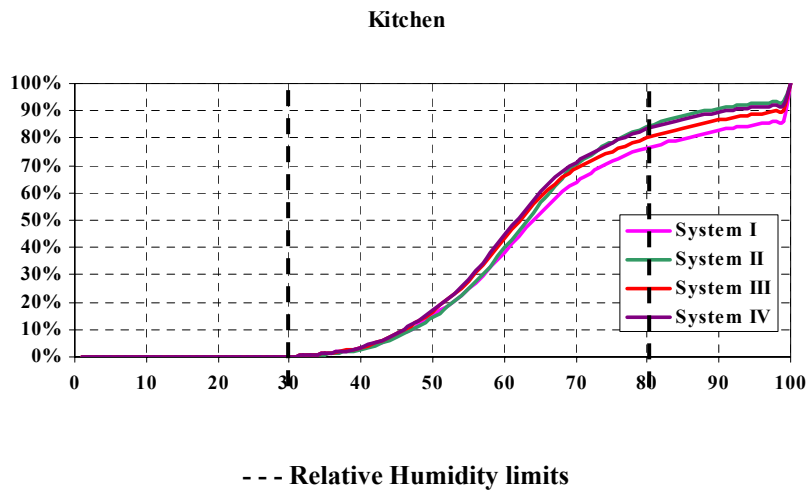


Figure 7-7 – Cumulative frequency for relative humidity in kitchen

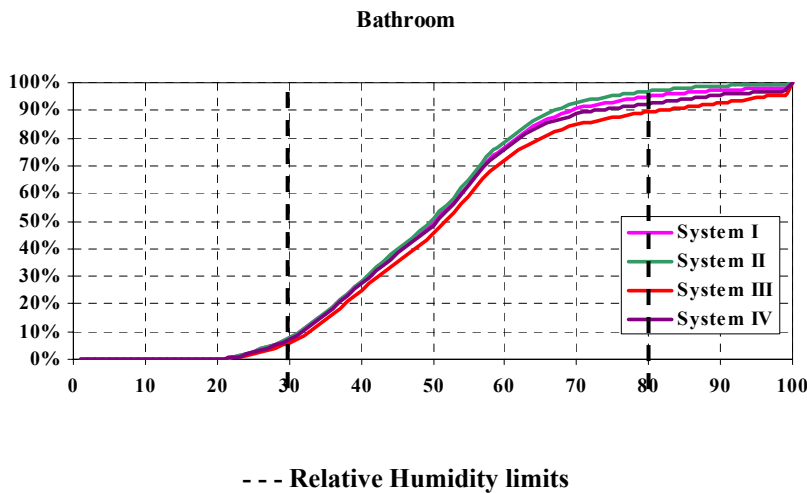


Figure 7-8 – Cumulative frequency for relative humidity in bathroom

8. Sensitivity Analysis

The main goal is to evaluate the effect of different input variables in the performance parameters of each ventilation system that were already presented before. Basically, five input conditions were performed separately for each system and the main conclusions are presented in the next chapters.

8.1. Parameter variation

Three levels are defined for each one of the parameters in study. In Table 8-1 these levels are labeled with the signs “-”, “0” and “+”. In the reference case all parameters have the level “0”. Table 8-2 was obtained from WP5 document [2] and shows the various combinations proposed for all parameters levels.

Only one parameter per case changes for the sensitivity analysis either for level “+” or “-”.

	-	0	+
Shielding	unshielded	partially shielded	shielded
Air leakage	tight	leak	average
Occupancy density	spacious	average	Crowded
Water vapor production	no	with drying machine	without drying machine
Orientation	north	south	west

Table 8-1 – Levels for the different parameters

Combination	shielding	airtightness	occupancy density	water vapour production	window airing	number of levels ²	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 8-2 - Parameter level combinations for sensitivity analysis ref [3]

The different simulations that were executed and the respective denomination are presented in table 8-3 and table 8-4. The cases I.a, II.a, III.a and IV.a are the reference cases and were studied in detail in the previous chapter.

² In the simulations of a single family house this parameter doesn't apply

Case	System I											System II										
	a	b	c	d	e	f	g	h	i	j	k	a	b	c	d	e	f	g	h	i	j	k
Orientation	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0
Airtightness	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0
Shielding	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0
Water vapour production	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	0	-	+	0
Occupancy density	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+

Table 8-3 - Parameter level combinations for sensitivity analysis

Case	System III											System IV										
	a	b	c	d	e	f	g	h	i	j	k	a	b	c	d	e	f	g	h	i	j	k
Orientation	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0
Airtightness	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0
Shielding	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0
Water vapor production	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	0	-	+	0
Occupancy density	0	0	0	0	0	0	0	0	0	-	+	0	0	0	0	0	0	0	0	0	-	+

Table 8-4 - Parameter level combinations for sensitivity analysis

The analysis and comparison of each one of those cases will be based in the study of the parameter changing effect in the energy consumption, CO₂ level and PPD value.

8.2. Orientation Analysis

Table 8-5 shows a summary of the various combinations for orientation sensitivity analysis.

Case number	System I			System II			System III			System IV		
	a	b	c	a	b	c	a	b	c	a	b	c
Shielding	0	0	0	0	0	0	0	0	0	0	0	0
Airtightness	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy density	0	0	0	0	0	0	0	0	0	0	0	0
Water vapor production	0	0	0	0	0	0	0	0	0	0	0	0
Orientation	0	-	+	0	-	+	0	-	+	0	-	+

Table 8-5 - Parameter level combinations for orientation sensitivity analysis

In the next chapter is presented the comparison of results obtained for different cases of all systems. The detailed results are shown in Appendix C.

8.2.1. Global Analysis for building orientation effect

The ventilation losses are not affected by the building orientation as it is presented in figure 8-2. Energy needs reach minimum when the main façade (living and bedrooms 1 and 2) is facing south, which is justified by the bigger glazing area of that façade. This happens for all systems.

Figure 8-3, figure 8-4 and figure 8-5 shows that the performance of ventilation systems is not affected by façade orientation. In terms of IAQ the overall performance of mechanical systems are worse because the fans are turned off during the night, precisely the time interval that the bedrooms have occupation and not an effect of the building orientation.

The building orientation has not a big influence in the bathroom humidity level, as shown in figure 8-7. In figure 8-6, kitchen humidity, there is a decrease for the North orientation, caused by a better efficiency of the exhaust system when the kitchen is facing South.

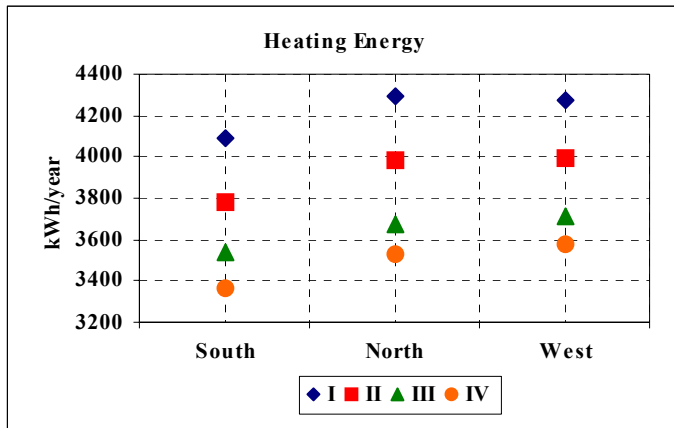


Figure 8-1 – Heating energy needs for all systems

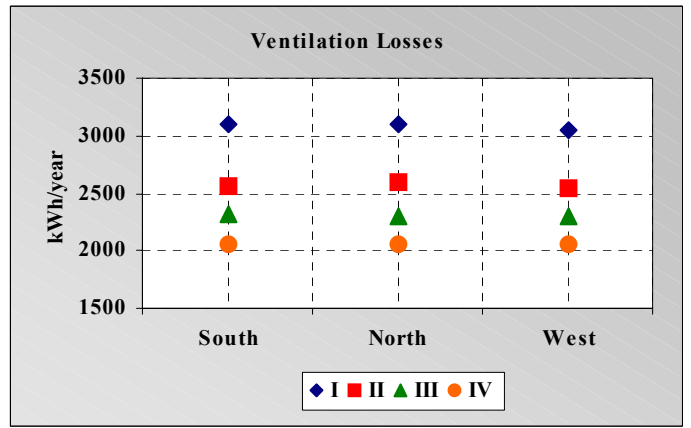


Figure 8-2 – Ventilation losses energy for all systems

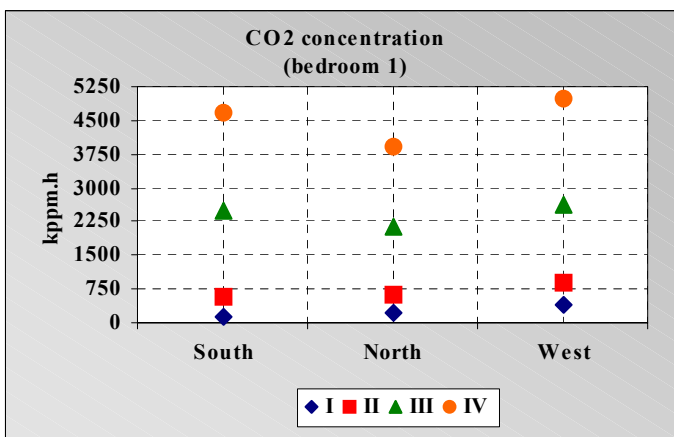


Figure 8-3 – Time integrated CO₂ concentration exceeding outdoor level in bedroom 1 for all systems

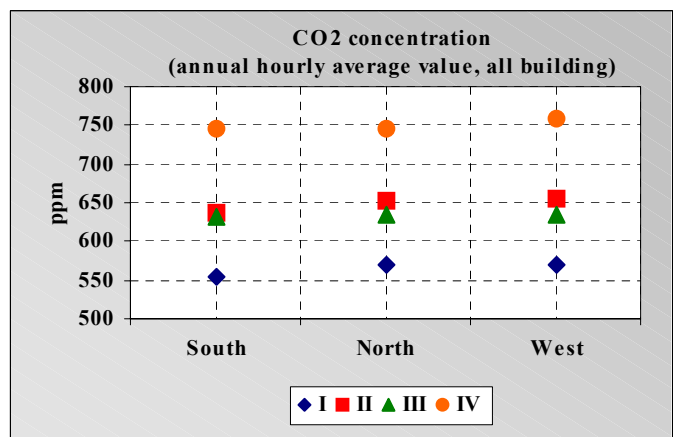


Figure 8-4 – Annual hourly average value of CO₂ concentration in building for all systems

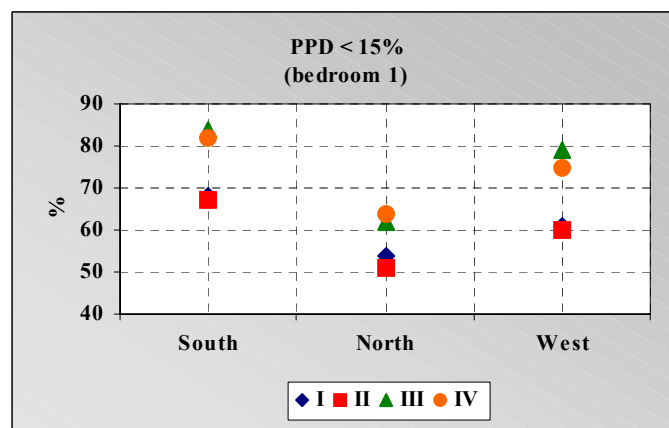


Figure 8-5 – PPD frequency class 3 (< 15 %) in bedroom 1 for all systems

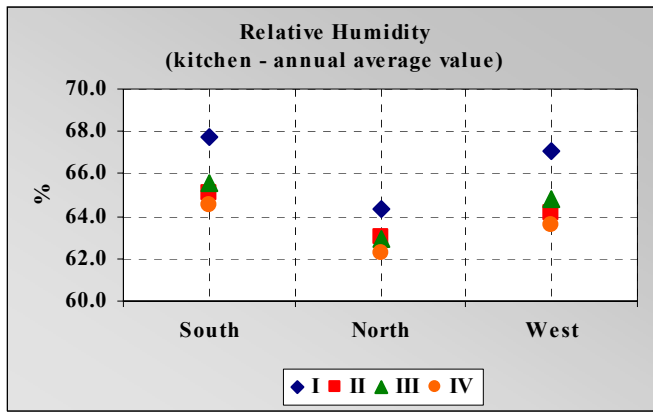


Figure 8-6 - Annual average value of relative humidity in the kitchen for all systems

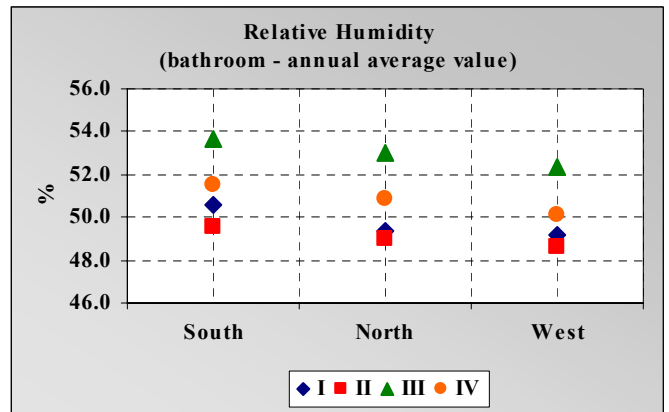


Figure 8-7 - Annual average value of relative humidity in the bathroom for all systems

8.2.2. Summary tables

In the tables below the summary of the values for heating needs, ventilation losses, CO₂ (for the critical zone and annual average value for all building) and PPD (only for occupied zones) is available.

System I

I	System I												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
South (a)	4095	3099	203	154	6	100	21	100	68	67	70	67.7	50.6
North (b)	4289	3097	442	237	37	100	33	100	54	54	87	64.4	49.4
West (c)	4277	3043	369	393	58	100	21	100	61	56	72	67.1	49.2

Table 8-6 – Summary of results obtained for different cases of system I

System II

II	System II												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
South (a)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	49.6
North (b)	3985	2588	1295	637	82	100	20	100	51	51	75	63.0	49.0
West (c)	3991	2539	1162	901	147	100	11	100	60	55	57	64.1	48.7

Table 8-7 – Summary of results obtained for different cases of system II

System III

System III													
III	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
South (a)	3541	2310	322	2489	690	100	19	100	84	80	60	65.6	53.6
North (b)	3670	2292	449	2137	469	100	32	100	62	60	83	62.9	53.0
West (c)	3710	2297	400	2608	713	100	19	100	79	70	65	64.8	52.3

Table 8-8 – Summary of results obtained for different cases of system III

System IV

System IV													
IV	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
South (a)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	51.5
North (b)	3533	2062	801	3901	1311	100	28	100	64	61	84	62.2	50.8
West (c)	3575	2048	719	4969	1829	100	17	100	75	67	64	63.6	50.1

Table 8-9 – Summary of results obtained for different cases of system IV

8.3. Air leakage Analysis

In this chapter the sensitivity of the systems to air leakage will be analyzed. Three levels of air leakage were studied and presented: tight (1 ach), average (2.5 ach) and leak (5 ach).

Air Leakage	-			0			+					
	Tight			Leak			Average					
Case number	System I			System II			System III			System IV		
	a	d	e	a	d	e	a	d	e	a	dc	e
Shielding	0	0	0	0	0	0	0	0	0	0	0	0
Air Leakage	0	+	-	0	+	-	0	+	-	0	+	-
Occupancy density	0	0	0	0	0	0	0	0	0	0	0	0
Water vapor production	0	0	0	0	0	0	0	0	0	0	0	0
Orientation	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-10 - Parameter level combinations for sensitivity analysis

The analysis and comparison of each one of these cases will be based in the study of the parameter changing effect in the energy consumption, CO₂ level and PPD value. These results are described in the following sections.

8.3.1. Global Analysis for air leakage effect

The heating energy needs and ventilation losses are sequentially greater as the air leakage class increases (figure 8-8 and figure 8-9). It's also evident that, for these parameters, system IV has the better performance, because is the system that permits the better control of ventilation airflows.

In respect to IAQ there are different behaviours with the air leakage parameter. Mechanical exhaust system IV has little variation with this parameter.

The relative humidity is highly dependent of the infiltration level of the building, as shown in figure 8-13 and figure 8-14, where, with a lower leakage level (1 ACH) the relative humidity level for kitchen and bathroom is higher than for the other two levels.

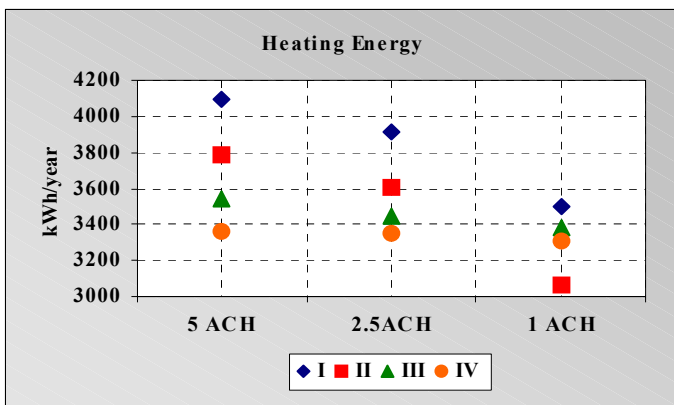


Figure 8-8 – Heating energy needs for all cases of different systems

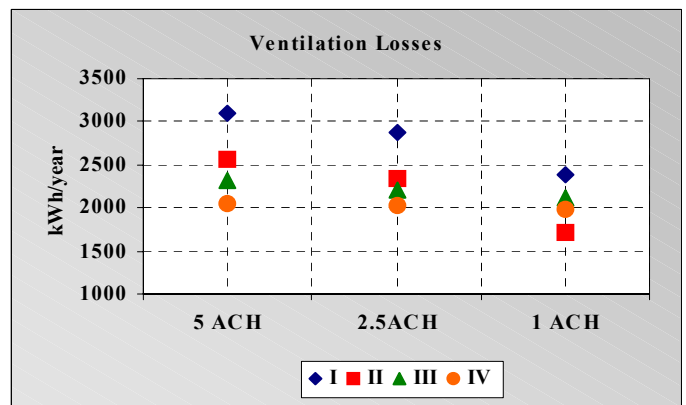


Figure 8-9 – Ventilation losses energy for all cases of different systems

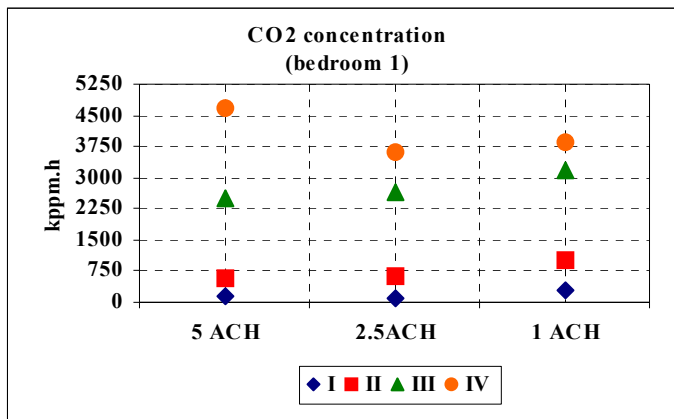


Figure 8-10 – Time integrated CO₂ concentration exceeding outdoor level in bedroom 1 for all systems

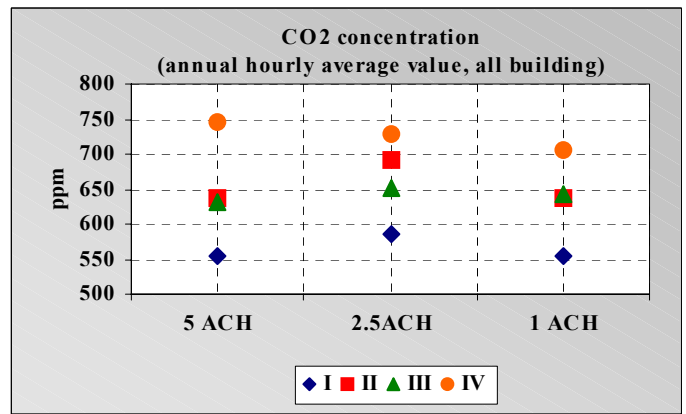


Figure 8-11 – Annual hourly average value of CO₂ concentration in building for all systems

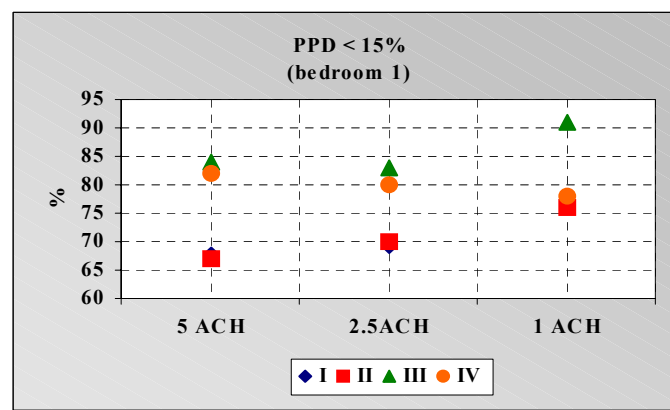


Figure 8-12 – PPD frequency class 3 (< 15 %) in bedroom 1 for all cases of different systems

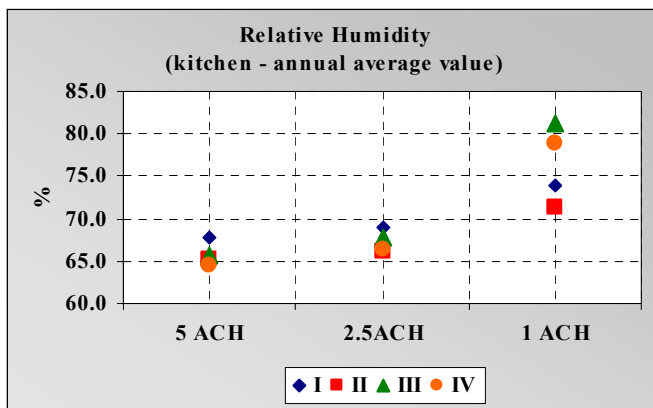


Figure 8-13 - Annual average value of relative humidity in the kitchen for all systems

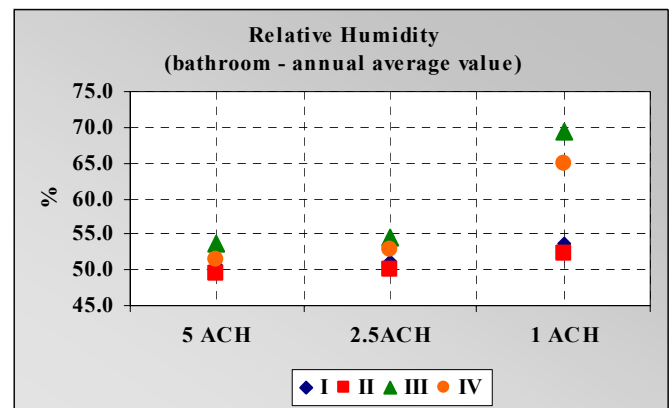


Figure 8-14 - Annual average value of relative humidity in the bathroom for all systems

8.3.2. Summary tables

In the tables below the summary of the values for heating needs, ventilation losses, CO₂ (for the critical zone and annual average value for all building) and PPD (only for occupied zones) is available.

System I

System I													
I	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
5 ACH (a)	4095	3099	203	154	6	100	21	100	68	67	70	67.7	50.6
2.5ACH (d)	3914	2875	173	103	0	100	25	100	69	68	72	69.0	51.2
1 ACH (e)	3500	2388	283	297	0	100	34	100	76	74	76	73.8	53.6

Table 8-11 – Summary of results obtained for different cases of system I

System II

System II													
II	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
5 ACH (a)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	49.6
2.5ACH (d)	3601	2331	798	621	5	100	15	100	70	70	57	66.2	50.1
1 ACH (e)	3066	1704	1147	1013	91	100	21	100	76	74	61	71.4	52.4

Table 8-12 – Summary of results obtained for different cases of system II

System III

System III													
III	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
5 ACH (a)	3541	2310	322	2489	690	100	19	100	84	80	60	65.6	53.6
2.5ACH (d)	3447	2198	355	2655	764	100	24	100	83	77	65	67.8	54.7
1 ACH (e)	3378	2126	213	3192	1061	100	43	100	91	88	79	81.2	69.3

Table 8-13 – Summary of results obtained for different cases of system III

System IV

System IV													
IV	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
5 ACH (a)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	51.5
2.5ACH (d)	3349	2018	293	3592	1041	100	22	100	80	75	62	66.5	52.9
1 ACH (e)	3313	1980	582	3856	1187	100	32	100	78	72	71	78.8	64.8

Table 8-14 – Summary of results obtained for different cases of system IV

8.4. Shielding Analysis

In this chapter the sensitivity of the systems to shielding will be analyzed. Three levels of shielding will be studied: unshielded, partially shielded and shielded.

Shielding	-			0			+					
	unshielded			partially shielded			shielded					
Case number	System I			System II			System III			System IV		
	a	f	g	a	f	g	a	f	g	a	f	g
Shielding	0	-	+	0	-	+	0	-	+	0	-	+
Air Leakage	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy density	0	0	0	0	0	0	0	0	0	0	0	0
Water vapor production	0	0	0	0	0	0	0	0	0	0	0	0
Orientation	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-15 - Parameter level combinations for sensitivity analysis

The analysis and comparison of each one of these cases will be based in the study of the parameter changing effect in the energy consumption, CO₂ level and PPD value. These results are described in the following sections.

8.4.1. Global Analysis for shielding effect

The building shielding level has a small effect in the heating energy needs and the ventilation losses (figure 8-15 and figure 8-16). Even though, these values are slightly higher to the unshielded case (dweeling without surrounder buildings).

In respect to IAQ, the CO₂ concentration of the bedroom 1 (critical zone) are lower in the unshielded case because the air flows in this zone are higher than in the other cases (proved by the higher ventilation losses). For the same reason, the PPD value for this room as also a better level than the other two cases.

The humidity levels remain constant whatever the considered building shielding.

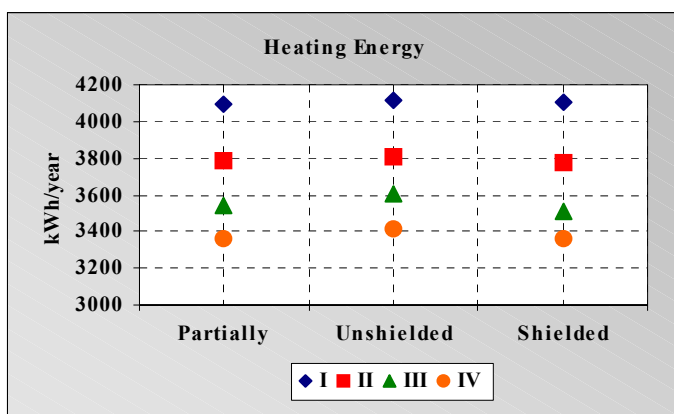


Figure 8-15 – Heating energy needs for all cases of different systems

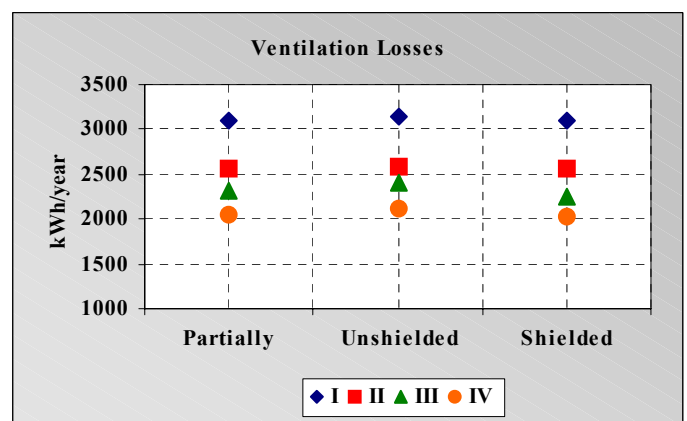


Figure 8-16 – Ventilation losses energy for all cases of different systems

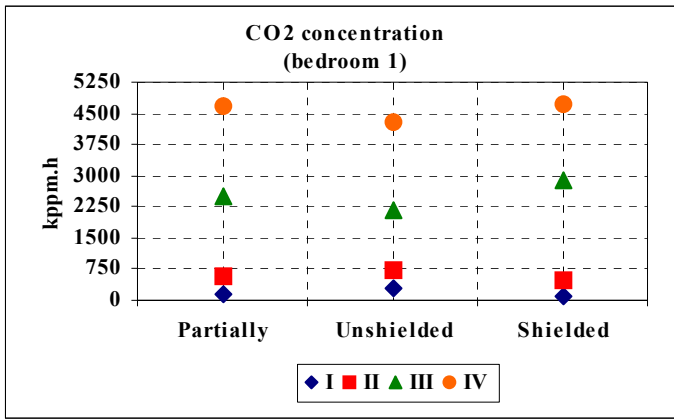


Figure 8-17 – Time integrated CO₂ concentration exceeding outdoor level in bedroom 1 for all systems

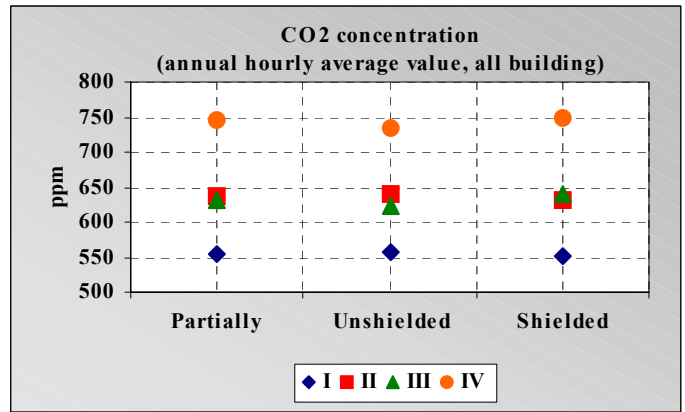


Figure 8-18 – Annual hourly average value of CO₂ concentration in building for all systems

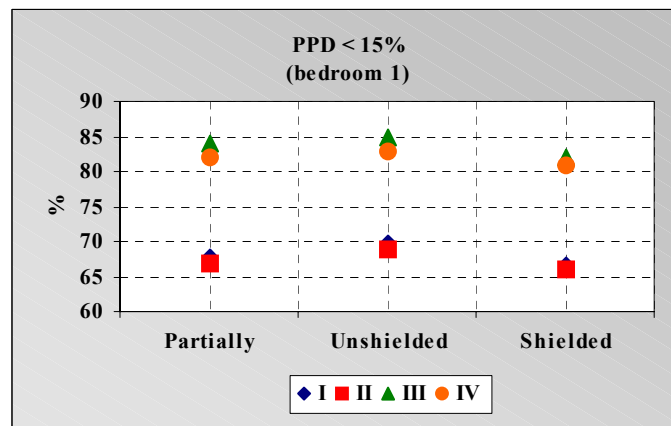


Figure 8-19 – PPD frequency class 3 (< 15 %) in bedroom 1 for all cases of different systems

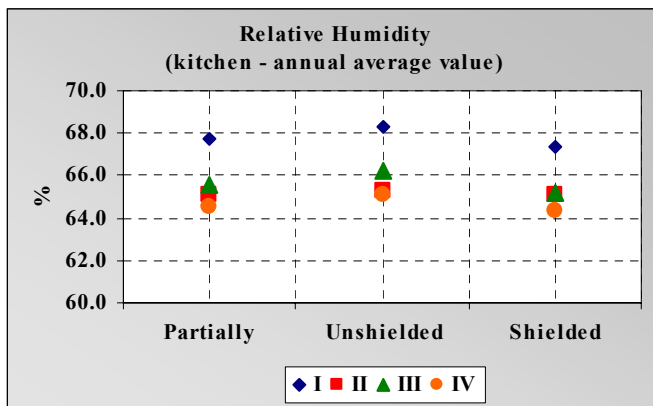


Figure 8-20 - Annual average value of relative humidity in the kitchen for all systems

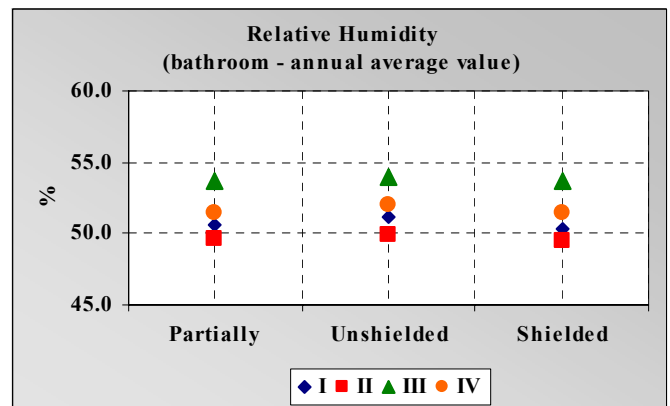


Figure 8-21 - Annual average value of relative humidity in the bathroom for all systems

8.4.2. Summary tables

In the tables below the summary of the values for heating needs, ventilation losses, CO₂ (for the critical zone and annual average value for all building) and PPD (only for occupied zones) are available.

System I

System I													
I	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Partially (a)	4095	3099	203	154	6	100	21	100	68	67	70	67.7	50.6
Unshielded (f)	4113	3132	247	289	39	100	22	100	70	68	69	68.3	51.2
Shielded (g)	4102	3096	175	74	0	100	20	100	67	65	72	67.4	50.3

Table 8-16 – Summary of results obtained for different cases of system I

System II

System II													
II	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Partially (a)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	49.6
Unshielded (f)	3803	2578	1014	734	113	100	11	100	69	69	54	65.3	49.9
Shielded (g)	3778	2561	930	470	2	100	10	100	66	67	54	65.1	49.5

Table 8-17 – Summary of results obtained for different cases of system II

System III

System III													
III	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Partially (a)	3541	2310	322	2489	690	100	19	100	84	80	60	65.6	53.6
Unshielded (f)	3606	3507	355	2183	607	100	20	100	85	82	61	66.3	53.9
Shielded (g)	3507	2260	293	2871	760	100	18	100	82	77	60	65.2	53.6

Table 8-18 – Summary of results obtained for different cases of system III

System IV

System IV													
IV	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Partially (a)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	51.5
Unshielded (f)	3414	2117	585	4289	1574	100	18	100	83	79	60	65.1	52.1
Shielded (g)	3357	2023	477	4714	1662	100	16	100	81	76	62	64.3	51.4

Table 8-19 – Summary of results obtained for different cases of system IV

8.5. Water vapor production

In this chapter the sensitivity of the systems to water vapor production will be analyzed. Three levels of water vapor production will be studied, which are: no production at all of water vapor in cloth washing, cloth washes and without drying machine and finally with drying machine (reference case).

Water vapor production	-			0			+					
	no			with drying machine			without drying machine					
	System I			System II			System III			System IV		
Case number	a	h	i	a	h	i	a	h	i	a	h	i
Shielding	0	0	0	0	0	0	0	0	0	0	0	0
Air Leakage	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy density	0	0	0	0	0	0	0	0	0	0	0	0
Water vapor production	0	-	+	0	-	+	0	-	+	0	-	+
Orientation	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-20 - Parameter level combinations for sensitivity analysis

The analysis and comparison of each one of these cases will be based in the study of the parameter changing effect in the energy consumption, CO₂ level and PPD value. These results are described in the following sections.

8.5.1. Global Analysis for water vapour production effect

The water vapour production has no effects in the heating needs, ventilation losses and IAQ parameters. This happens because this rate of water vapour is release in the bathroom not affecting the other zones because of the exhaust system outlet present in this zone. However, in table 8-21 to table 8-24 the PPD values for the bedroom 3 (bathroom neighbour) changes, proving the presence of different rates of water vapour in the bathroom.

As expected, there are differences in the bathroom humidity levels. As shown in figure 8-28, when there is clothes washing in the bathroom and there isn't a drying machine, the relative humidity reaches the higher level.

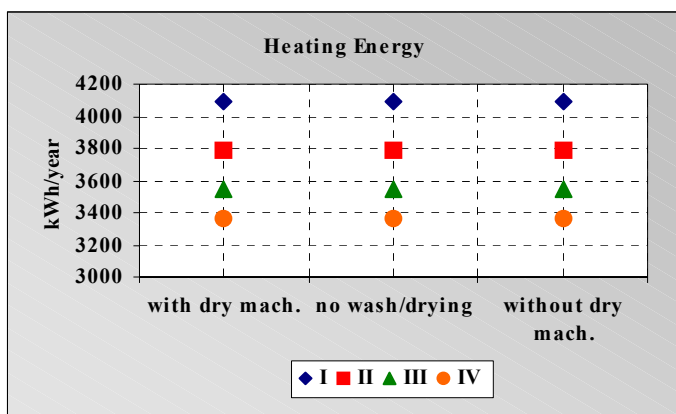


Figure 8-22 – Heating energy needs for all cases of different systems

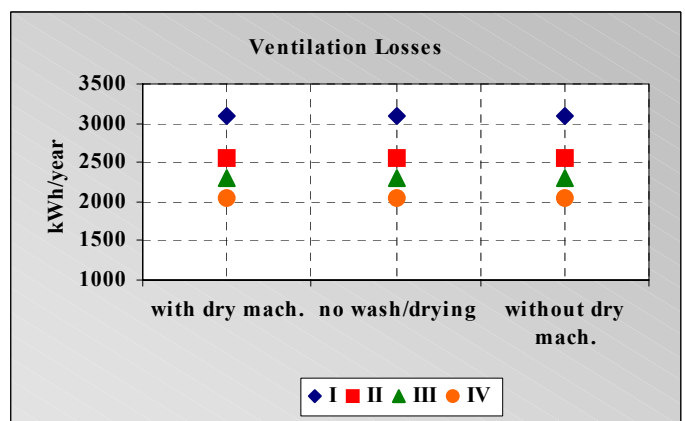


Figure 8-23 – Ventilation losses energy for all cases of different systems

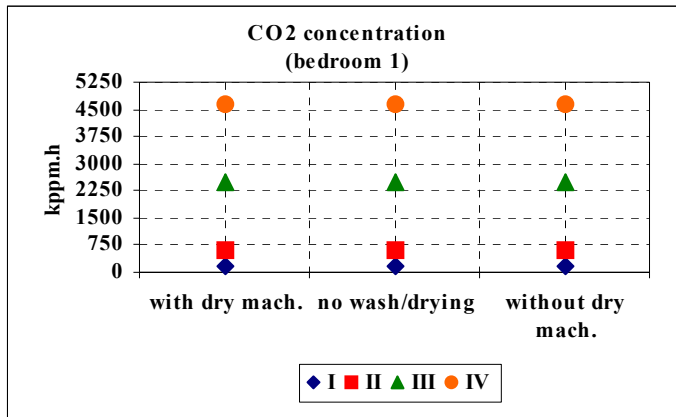


Figure 8-24 – Time integrated CO₂ concentration exceeding outdoor level in bedroom 1 for all systems

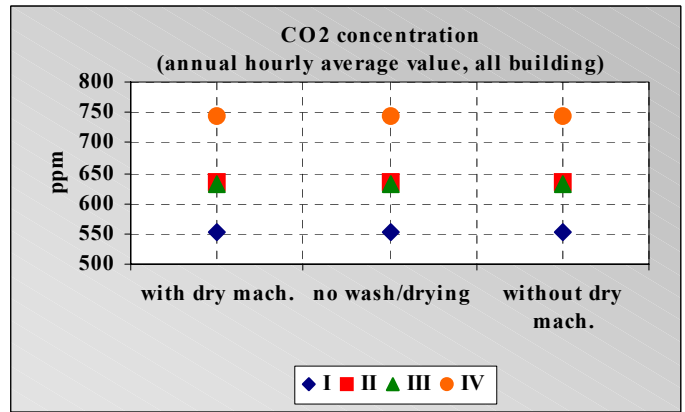


Figure 8-25 – Annual hourly average value of CO₂ concentration in building for all systems

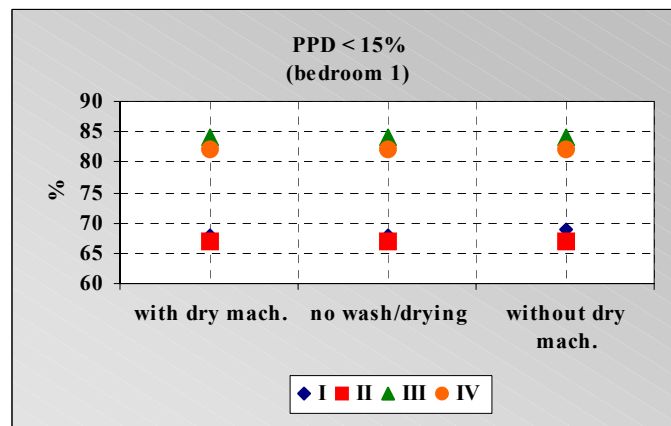


Figure 8-26 – PPD frequency class 3 (< 15 %) in bedroom 1 for all cases of different systems

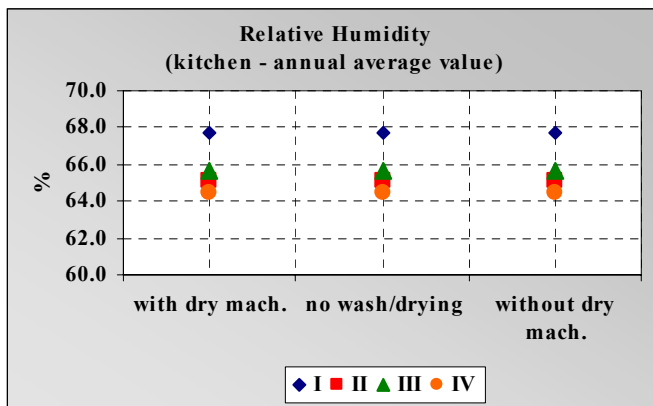


Figure 8-27 - Annual average value of relative humidity in the kitchen for all systems

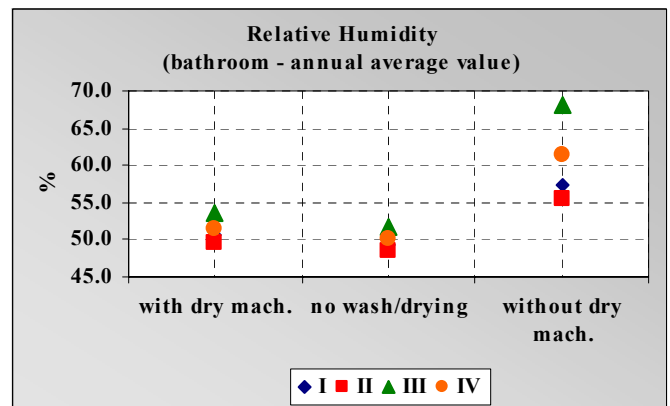


Figure 8-28 - Annual average value of relative humidity in the bathroom for all systems

8.5.2. Summary tables

In the tables below the summary of the values for heating needs, ventilation losses, CO₂ (for the critical zone and annual average value for all building) and PPD (only for occupied zones) is available.

System I

System I													
I	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
with dry mach.(a)	4095	3099	203	154	6	100	21	100	68	67	70	67.7	50.6
no wash/drying(h)	4095	3099	203	154	6	100	21	100	68	67	69	67.7	49.2
without dry mach.(i)	4095	3099	203	154	6	100	21	100	69	68	74	67.7	57.2

Table 8-21 – Summary of results obtained for different cases of system I

System II

System II													
II	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
with dry mach.(a)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	49.6
no wash/drying(h)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	48.4
without dry mach.(i)	3783	2560	965	600	45	100	10	100	67	68	57	65.1	55.4

Table 8-22 – Summary of results obtained for different cases of system II

System III

System III													
III	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
with dry mach.(a)	3541	2310	322	2489	690	100	19	100	84	80	60	65.6	53.6
no wash/drying(h)	3541	2310	322	2489	690	100	19	100	84	80	59	65.6	51.7
without dry mach.(i)	3541	2310	322	2489	690	100	19	100	84	80	71	65.6	68.1

Table 8-23 – Summary of results obtained for different cases of system III

System IV

System IV													
IV	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
with dry mach.(a)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	51.5
no wash/drying(h)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	50.2
without dry mach.(i)	3364	2055	524	4655	1689	100	17	100	82	78	67	64.5	61.3

Table 8-24 – Summary of results obtained for different cases of system IV

8.6. Occupancy density Analysis

In this chapter the sensitivity of the systems to occupancy density will be analyzed. Three levels of occupancy will be studied, which are: spacious (two persons in the building), average (four persons in the building) and crowded (5 persons in the building).

	-			0			+					
Occupancy density	spacious			average			crowded					
	System I			System II			System III			System IV		
Case number	a	j	k	a	j	k	a	j	k	a	j	k
Occupancy density	0	-	+	0	-	+	0	-	+	0	-	+
Air Leakage	0	0	0	0	0	0	0	0	0	0	0	0
Shielding	0	0	0	0	0	0	0	0	0	0	0	0
Water vapor production	0	0	0	0	0	0	0	0	0	0	0	0
Orientation	0	0	0	0	0	0	0	0	0	0	0	0

Table 8-25 - Parameter level combinations for sensitivity analysis

The analysis and comparison of each one of these cases will be based in the study of the parameter changing effect in the energy consumption, CO₂ level and PPD value. These results are described in the following sections.

8.6.1. Global Analysis Occupancy density effect

From these test cases, we conclude that the occupation density highly affects the heating needs values, as showed in figure 8-29. The building with a 5 person’s family has, as expected, a lower value for the heating needs than the other two cases. In the ventilation losses parameter, this sensitivity test has no significant effect.

In respect to IAQ there are big differences in the CO₂ concentration (figure 8-31 and figure 8-32). In the spacious case these concentrations are lower than in the average and crowded occupation, because the CO₂ production decreases a lot.

The building occupancy density has no considerable effects in the relative humidity levels in the kitchen and bathroom because these two zones have not a daily high occupation.

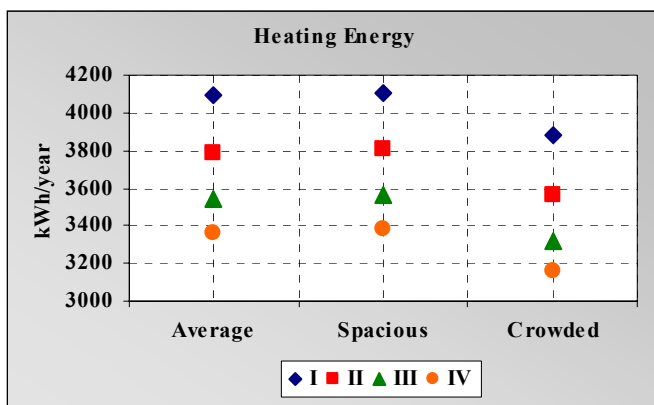


Figure 8-29 – Heating energy needs for all cases of different systems

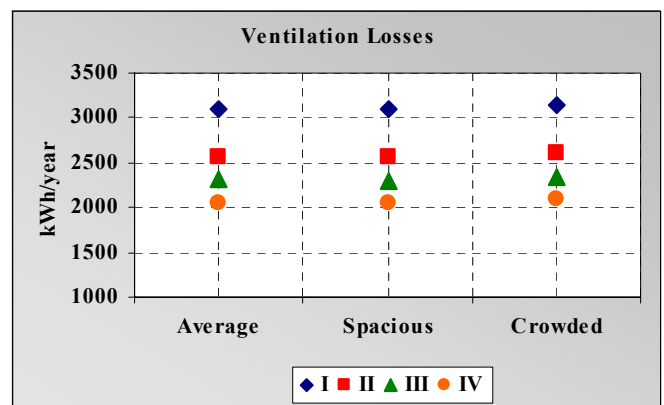


Figure 8-30 – Ventilation losses energy for all cases of different systems

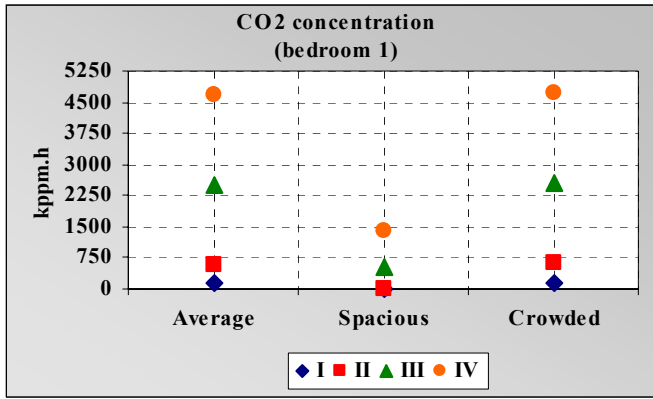


Figure 8-31 – Time integrated CO₂ concentration exceeding outdoor level in bedroom 1 for all systems

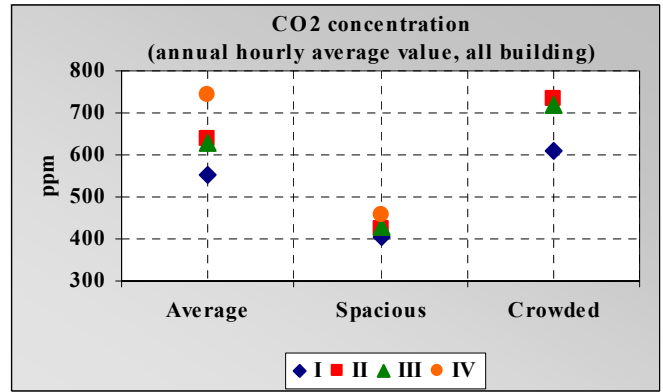


Figure 8-32 – Annual hourly average value of CO₂ concentration in building for all systems

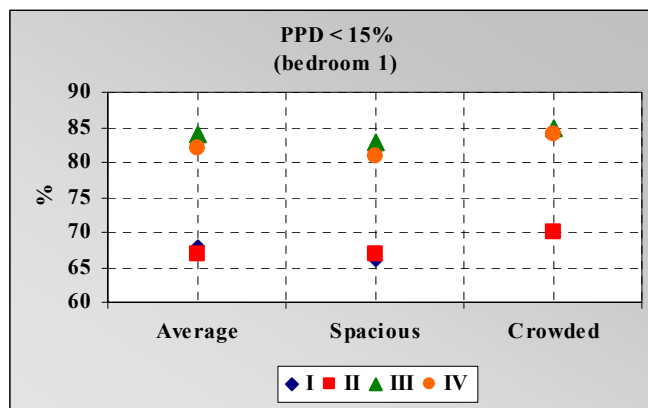


Figure 8-33 – PPD frequency class 3 (< 15 %) in bedroom 1 for all cases of different systems

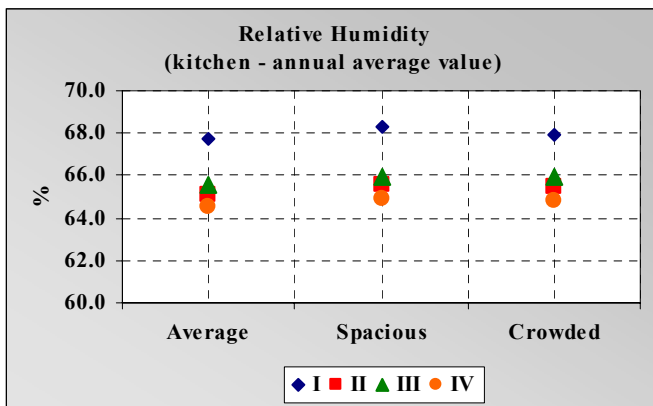


Figure 8-34 - Annual average value of relative humidity in the kitchen for all systems

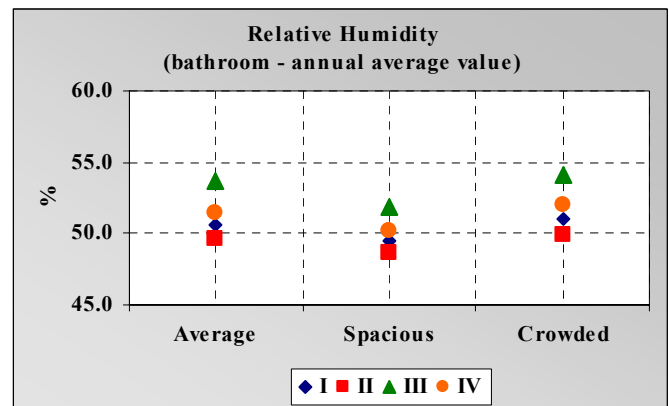


Figure 8-35 - Annual average value of relative humidity in the bathroom for all systems

8.6.2. Summary tables

In the tables below the summary of the values for heating needs, ventilation losses, CO₂ (for the critical zone and annual average value for all building) and PPD (only for occupied zones) is available.

System I

I	System I												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Average (a)	4095	3099	203	154	6	100	21	100	68	67	70	67.7	50.6
Spacious (j)	4108	3088	0	4	0	100	21	100	66	61	65	68.3	49.5
Crowded (k)	3879	3142	337	156	25	100	23	100	70	73	81	67.9	51.0

Table 8-26 – Summary of results obtained for different cases of system I

System II

II	System II												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Average (a)	3783	2560	965	600	45	100	10	100	67	68	53	65.1	49.6
Spacious (j)	3804	2552	0	23	0	100	10	100	67	61	49	65.5	48.6
Crowded (k)	3564	2597	1358	602	256	100	11	100	70	74	66	65.5	50.0

Table 8-27 – Summary of results obtained for different cases of system II

System III

III	System III												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Average (a)	3541	2310	322	2489	690	100	19	100	84	80	60	65.6	53.6
Spacious (j)	3559	2302	0	514	0	100	19	100	83	68	54	66.0	51.8
Crowded (k)	3317	2347	507	2547	1365	100	21	100	85	86	70	65.9	54.1

Table 8-28 – Summary of results obtained for different cases of system III

System IV

IV	System IV												
	Heating needs [kWh/year]	Ventilation losses [kWh/year]	CO ₂ [kppm.h]			PPD < 15%						Rel. Hum.	
			Living	Bedroom1	Bedroom2	Living	Kitchen	Bathroom	Bedroom1	Bedroom2	Bedroom3	Kitchen	Bathroom
Average (a)	3364	2055	524	4655	1689	100	17	100	82	78	60	64.5	51.5
Spacious (j)	3386	2047	0	1391	0	100	16	100	81	67	54	64.9	50.2
Crowded (k)	3158	2090	826	4712	2575	100	18	100	84	85	73	64.8	52.0

Table 8-29 – Summary of results obtained for different cases of system IV

9. Conclusion

System Global Analysis

The reduction of energy consumption between natural and mechanical ventilation systems is a consequence of the control schedule of the mechanical system that shuts off the ventilation during the night, opposite to natural ventilation that is running all the time.

The difference between system III and IV (both mechanical ventilation) is explained by the presence of self regulated inlet grilles in system IV that prevent exfiltrations and control inlet flow.

The mechanical systems have worse performances, in terms of CO₂ concentration, than the natural systems because they are turned off during the night. Furthermore, System IV is penalized by the presence of the self-regulated grids.

Sensitivity Analysis

There were done five sensitivity analyses in this report. From the results is possible to conclude that some of the parameters don't have a high influence in the Heating Needs (HN) and in the indoor air quality (IAQ).

From the *building orientation* effects analysis, the conclusion is that the HN reaches the minimum value when the main façade (living and bedrooms 1 and 2) is facing south, which is justified by the bigger glazing area of this façade. This happens for all systems. In terms of IAQ the overall performance of mechanical systems is worse because the fans are turned off during the night, precisely the time interval that the bedrooms have occupation.

In respect to the *air leakage* effects, the HN are sequentially greater as the air leakage class increases (from 1 ACH to 5 ACH), while ventilation losses follow an opposite variation. It's also evident that, for these parameters, system IV has the better performance, because is the system that permits the better control of ventilation airflows due to the self-inlet grids presence in the building.

The building *shielding level* has a small effect in the heating energy needs and the ventilation losses. Even though, these values are slightly higher to the unshielded case (dweeling without surround buildings).

In respect to IAQ, the CO₂ concentration of the bedroom 1 (critical zone) is lower in the unshielded case because the air flows in this zone are higher than in the other cases (proved by the higher ventilation losses). For the same reason, the PPD value for this room has also a better level than the other two cases.

The *water vapour production* has no effects in the heating needs, ventilation losses and IAQ parameters. This happens because this rate of water vapour is released in the bathroom not affecting the other zones because of the exhaust system outlet present in this zone.

From the *occupancy density* test cases, the conclusion is that the occupation density highly affects the heating needs values. The building with a 5 person's family has, as expected, a lower value for the heating needs than the other two cases. In the ventilation losses parameter, this sensitivity test has no significant effect.

In respect to IAQ there are big differences in the CO₂ concentration. In the spacious case these concentrations are lower than in the average and crowded occupation, because the CO₂ production decreases a lot.

10. Appendix A - Different humidity models analysis

In parallel with the sensible energy balance calculation, TRNSYS calculates a moisture balance considering free floating humidity ratios or humidification/dehumidification to a certain set point. In this case, TRNSYS calculates the latent load. There are two models for the calculation of the moisture balance available in this simulation tool. The first model (Effective Capacitance Humidity Model) considers sorption effects with an enlarged moisture capacity of the air; the second (Buffer Storage Humidity Model) is more sophisticated and offers a surface and a deep moisture buffer in the walls of the zone.

In the sections below, a description of each models and an analysis of its effects in the humidity levels are done.

To evaluate the effect of the different humidity models there were done three simulations considering the System I - Natural ventilation system according to the Portuguese standard - and the two models referred above.

10.1. Humidity models explanation

10.1.1. Effective Capacitance Humidity Model

In the first model, the buffer effect of sorptive and desorptive materials, soil areas, or plants is considered by an effective moisture capacitance which is defined as the product of the zone air mass and a moisture capacitance ratio:

$$M_{eff,i} = W_{capr} \times M_{air,i} \quad (1)$$

where

$M_{eff,i}$ = effective moisture capacitance of the zone

$M_{air,i}$ = the mass of air in the zone

W_{capr} = multiplication factor generally in the range of 1 to 10

A moisture balance for any zone results in the following differential equation.

$$M_{eff,i} \frac{dw_i}{dt} = m_{inf,i} (w_a - w_i) + \sum_k^{nvent} m_{v,k,i} (w_{v,k,i} - w_i) + W_{g,i} + \sum_{i-j}^{surfaces} m_{cplg,s} (w_j - w_i) \quad (2)$$

where

w_i = the humidity ratio of the zone i [kg water/kg air]

w_a = the ambient humidity ratio

$w_{v,k,i}$ = the humidity ratio of the ventilation air from ventilation type k

$W_{g,i}$ = internal moisture gains [kg water/h]

w_j = the humidity ratio of an adjacent zone j

In order to simplify the solution of the simultaneous set of differential equations, the values of w at the end of the previous timestep are used in the above expression. Subroutine DIFFEQ is then used to independently solve for the final and average values of the humidity ratio over each timestep for each zone. If the average humidity ratio of the zone falls below or rises above a setpoint for humidification or dehumidification, then latent energy is added or removed to maintain the humidity ratio at the setpoint. It is assumed that the change in zone humidity ratio occurs instantly so that $\overline{w_i} = w_{\tau,i}$. In this case

$$Q_{lat,i} = h_v \left[m_{inf,j} (w_a - w_{req,i}) + \sum_k^{nvent} m_{v,k,i} (w_{v,k,i} - w_{req,i}) + W_{g,i} + \sum_{i-j}^{surfaces} m_{cplg,s} (w_{j,\tau-\Delta\tau} - w_{i,\tau-\Delta\tau}) - \frac{M_{eff,i} (w_{req,i} - w_{i,\tau-\Delta\tau})}{\Delta t} \right] \quad (3)$$

where

$Q_{lat,i}$ = latent energy removed (+ dehumidification, -humidification)

h_v = the heat of vaporization of water

$w_{req,i}$ = the setpoint for humidification or dehumidification

Between the two setpoints, the humidity ratio is free floating.

10.1.2. Buffer Storage Humidity Model

The buffer storage model describes a separate humidity buffer divided into a surface and deep storage. These buffers are connected to each other as shown in the figure below. The surface buffer is additionally connected with the zone node. Each buffer is defined with three parameters.

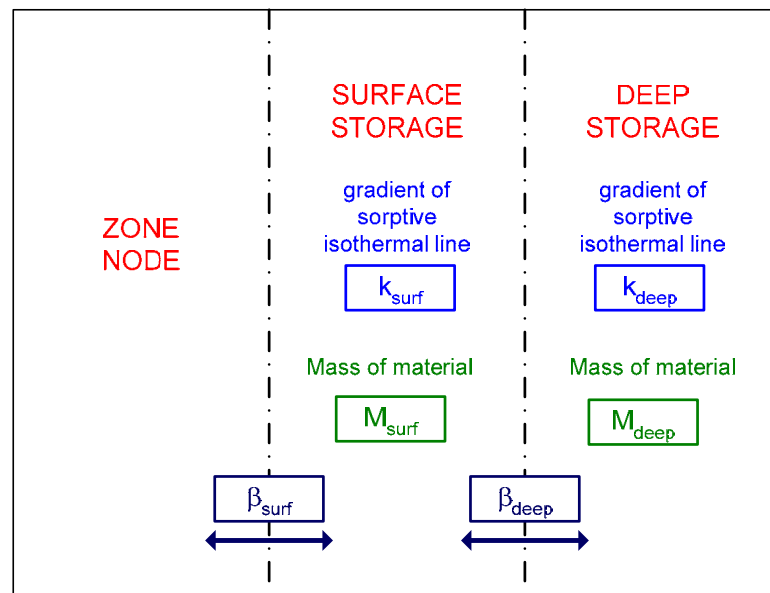


Figure 10-1 – Buffer Storage Humidity Model

The first parameter is the gradient of the sorptive isothermal line k of the material. These values represent the water storage capacity of the material. The second parameter is the mass of the material. The third parameter β controls the moisture transport from the storage to the zone node.

Mathematical Description of the Buffer Storage Humidity Model

The differential equation for the calculation of the zone humidity was extended by a term taking into account the exchange of moisture between the zone node and the surface storage. A comparison of the old and the new differential equations are shown below.

Effective Capacitance Model:

$$M_{air,i} \times W_{capr} \frac{dw_i}{dt} = m_{inf,i} (w_a - w_i) + \sum_k^{nvent} m_{v,k,i} (w_{v,k,i} - w_i) + W_{g,i} + \sum_{i-j} m_{cplg,s} (w_j - w_i) \quad (4)$$

Buffer Storage Model:

$$M_{air,i} \frac{dw_i}{dt} = m_{inf,i} (w_a w_i) + \sum_k^{nvent} m_{v,k,i} (w_{v,k,i} - w_i) + W_{g,i} + \sum_{i-j} m_{cplg,s} (w_j - w_i) + \beta_{surf} (w_{surf} - w_i) \quad (5)$$

where,

w_i = the humidity ratio of the zone i [kg_{water}/kg_{air}]

w_a = the ambient humidity ratio

$w_{v,k,i}$ = the humidity ratio of the ventilation air from ventilation type k

$W_{g,i}$ = internal moisture gains [kg_{water}/h]

w_j = the humidity ratio of an adjacent zone j

w_{surf} = the humidity ratio of the surface storage

m, β = exchange coefficients

Additionally, two new differential equations were introduced to describe the dynamics of the water content of the surface and the deep storage.

$$M_{surf} k_{surf} f(\varphi, w) \frac{dw_{surf}}{dt} = \beta_{surf} (w_i - w_{surf}) + \beta_{deep} (w_{deep} - w_{surf}) \quad (6)$$

$$M_{deep} k_{deep} f(\varphi, w) \frac{dw_{deep}}{dt} = \beta_{deep} (w_{surf} - w_{deep}) \quad (7)$$

with

w_{deep} = the humidity ratio of the deep storage

k_{surf} = gradient of sorptive isothermal line of surface buffer [kg_{water}/kg_{material}/rel.humidity]

k_{deep} = gradient of sorptive isothermal line of deep buffer

$f(\varphi, w)$ = conversion factor relative humidity to humidity ratio

β_{surf} = the exchange coefficient zone to surface storage [kg_{air}/h]

β_{deep} = the exchange surface storage to deep storage [kg_{air}/h]

By means of the equation

$$\beta_{surf} = 0.1 \frac{A}{0.094 \frac{1}{\beta'} + \sum_i d_i \mu_i} \quad (8)$$

β_{surf} can be calculated. It depends on the surface size A in m², the steam transition coefficient β' (~12 m/h), the thickness d in m and the diffusion resistance μ of layer i. For the calculation of β_{deep} , the steam transition coefficient can be neglected:

$$\beta_{deep} = 0.1 \frac{A}{\sum_i d_i \mu_i} \quad (9)$$

If the thickness d is chosen, the corresponding mass

$$M = 2d \times A \times \rho \quad (10)$$

of the buffer material and the coefficients β can easily be determined. To determine the size of the thickness d the following should be considered. If, for example, the surface buffer is defined only by the first millimeter of gypsum and the deep buffer by the second millimeter, the humidity storage of the wall surface is well described but the capacity of the deeper parts is neglected. Measurements of air humidity in an office have shown that the influence of walls can be well described if

$$\frac{\beta_{surf}}{A} = 3 \frac{kg_{air}}{m^2 h} \text{ and } \frac{\beta_{deep}}{A} = 1 \frac{kg_{air}}{m^2 h}$$

The reason for this lies in the fact that the first value describes the mass flow within minutes and the second the mass flow within several hours. Measurements and detailed simulations have also shown that the moisture flow from central parts of the walls to the room air can be neglected. The moisture flow from surrounding to the zone is much higher and must be well defined by the infiltration parameters.

With equations (8) and (10), the thickness d and therefore the corresponding mass M then can easily be determined.

10.2. Models results analysis

The simulation tests were done using one of the reference systems. System I (Natural ventilation system according to the Portuguese standard) was chosen and three cases were considered:

- **ECHM_1**: Effective Capacitance Model, with $W_{capr} = 1$ (this value for the multiplication factor indicates that envelope has any sorptive capacity)
- **ECHM_10**: Effective Capacitance Model, with $W_{capr} = 10$ (this value for the multiplication factor indicates that envelope has the maximum sorptive capacity)
- **BSHM**: Buffer Storage Humidity Model

10.2.1. Effective Capacitance Humidity Model (ECHM_1)

The first case ECHM_1 corresponds to the humidity calculation model used, until this moment, in all the simulations. Below the hourly values of relative humidity, absolute humidity and PPD to January and October are shown as well as the cumulative frequency for the three parameters.

➤ *Relative Humidity*

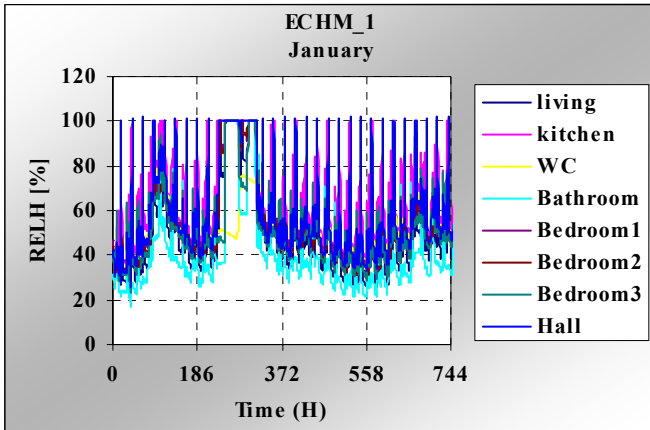


Figure 10-2 - Hourly values of relative humidity – January

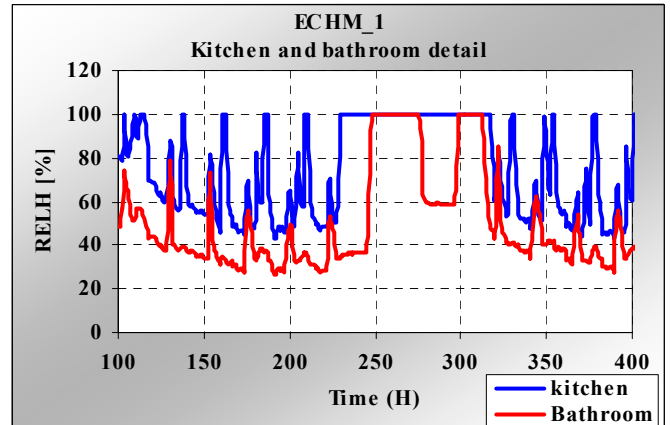


Figure 10-3 - Hourly values of relative humidity - January

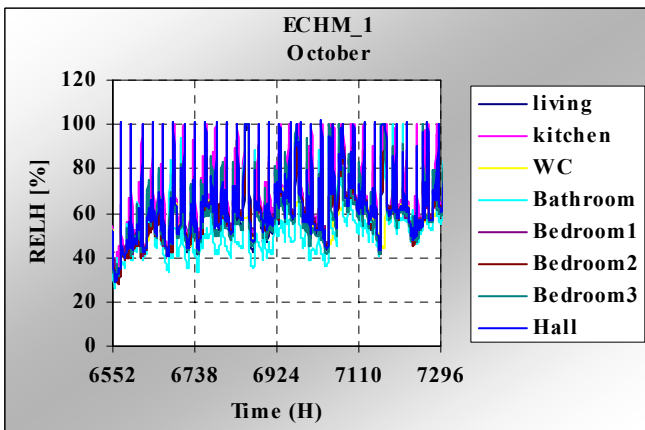


Figure 10-4 - Hourly values of relative humidity – October

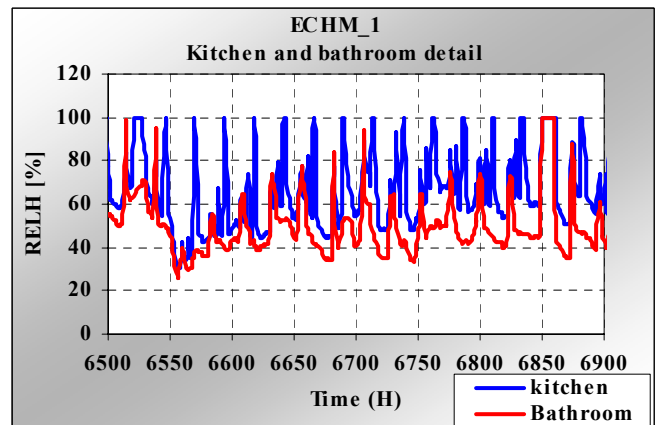


Figure 10-5 - Hourly values of relative humidity - October

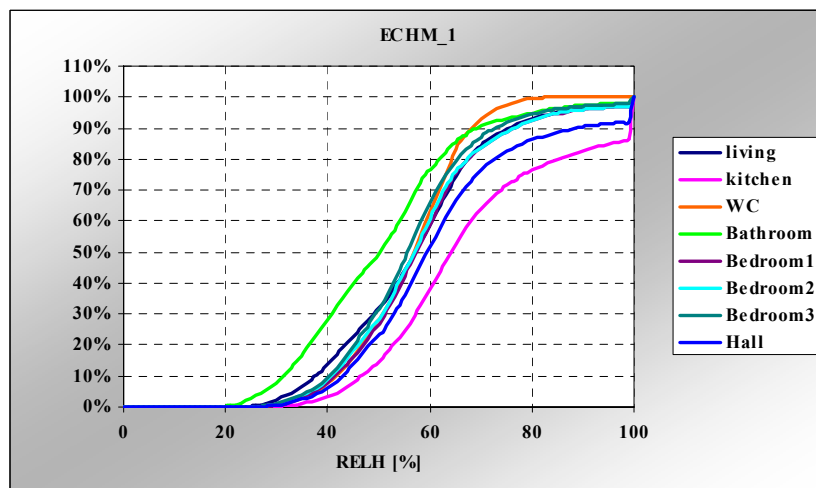


Figure 10-6 - Cumulative frequency of relative humidity (annual)

➤ Absolute Humidity

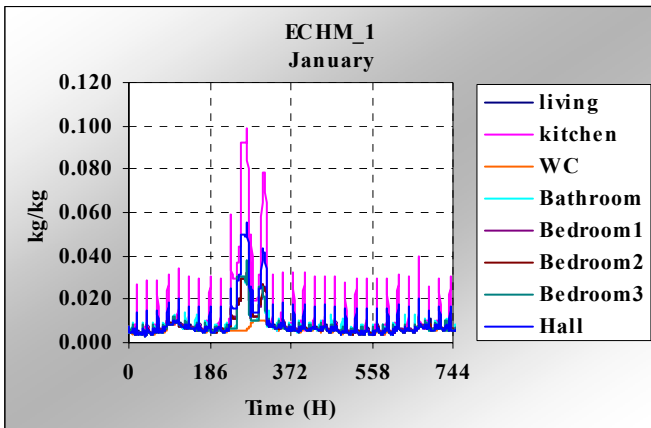


Figure 10-7 - Hourly values of absolute humidity – January

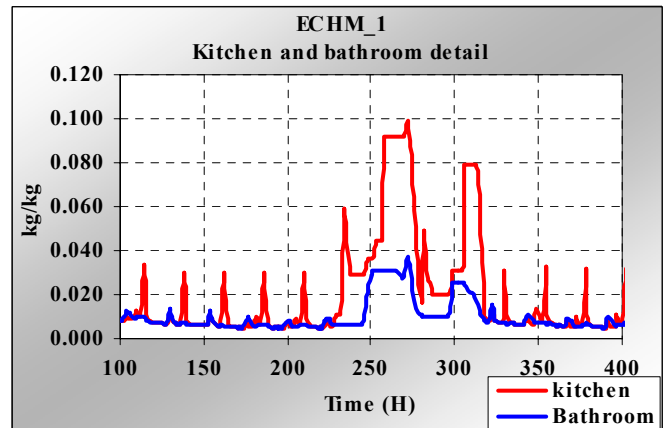


Figure 10-8 - Hourly values of absolute humidity - January

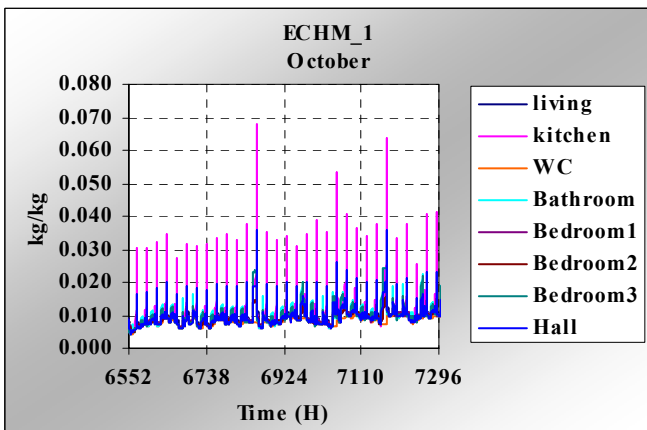


Figure 10-9 - Hourly values of absolute humidity – October

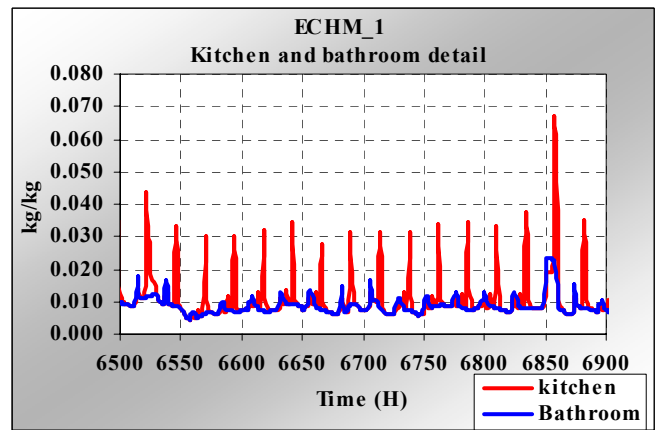


Figure 10-10 - Hourly values of absolute humidity - October

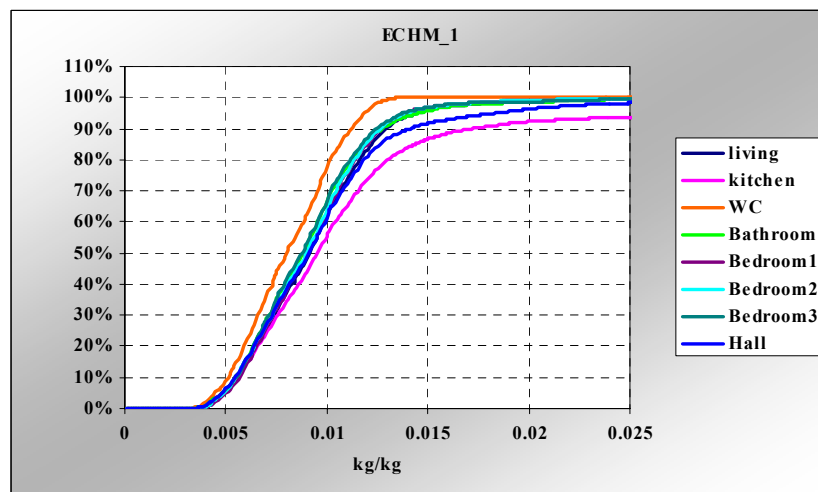


Figure 10-11 - Cumulative frequency of absolute humidity (annual)

➤ PPD

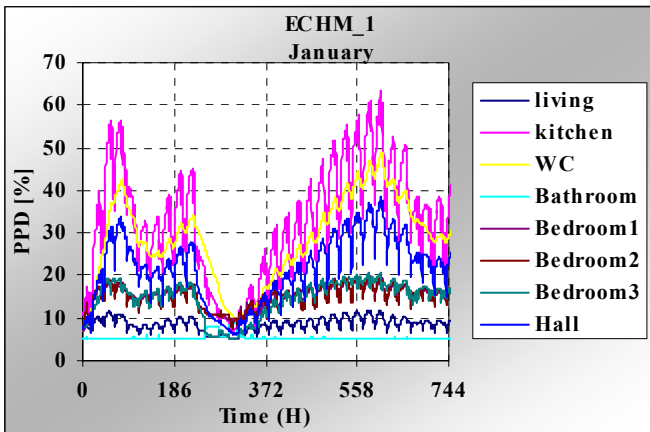


Figure 10-12 - Hourly values of PPD – January

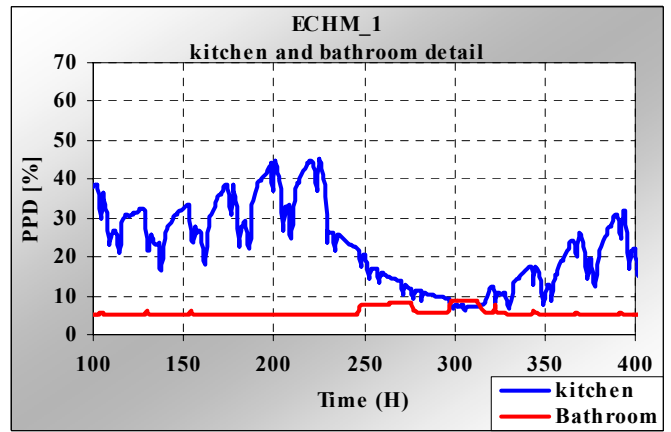


Figure 10-13 - Hourly values of PPD - January

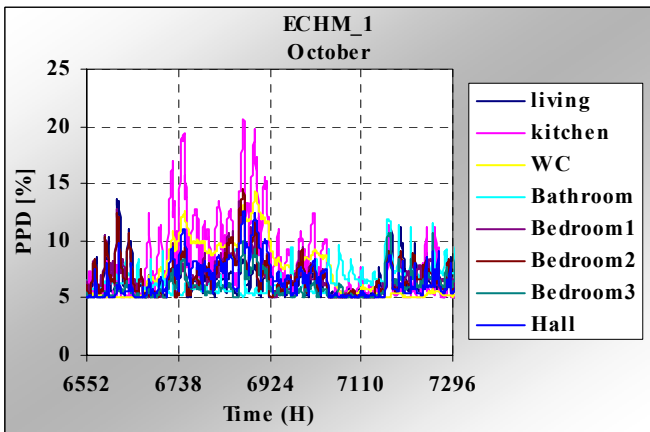


Figure 10-14 - Hourly values of PPD – October

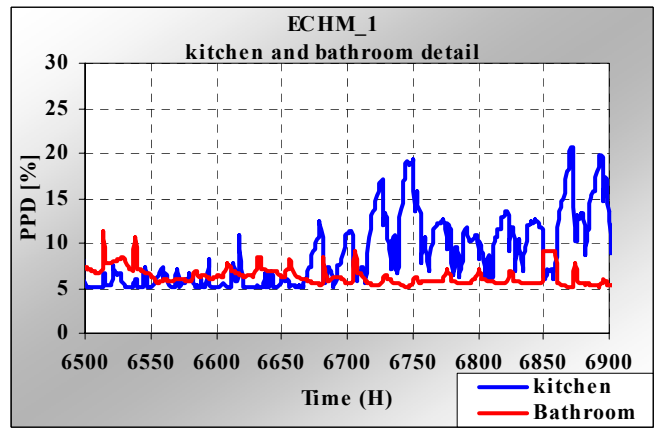


Figure 10-15 - Hourly values of PPD - October

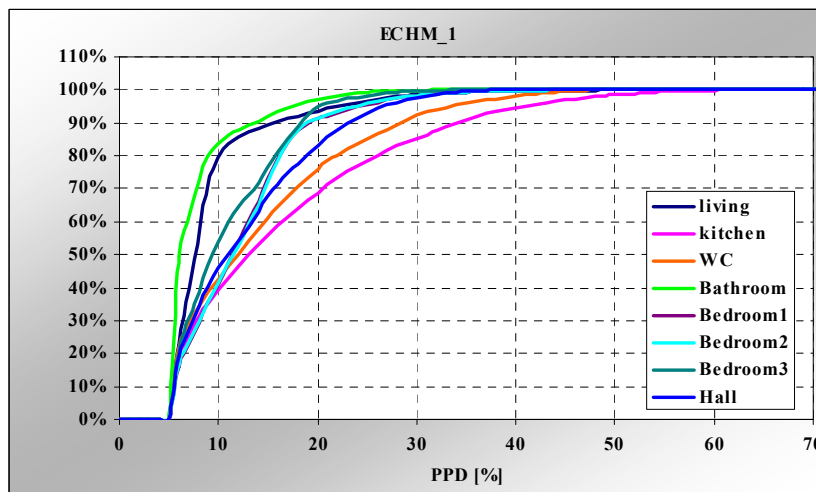


Figure 10-16 - Cumulative frequency of PPD (annual)

10.2.2. Effective Capacitance Humidity Model (ECHM_10)

In this second case, the multiplication factor W_{capr} has its maximum value (=10) which means the maximum effective moisture capacitance of the walls.

Below the hourly values of relative humidity, absolute humidity and PPD to January and October are shown as well as the cumulative frequency for the three parameters.

➤ *Relative Humidity*

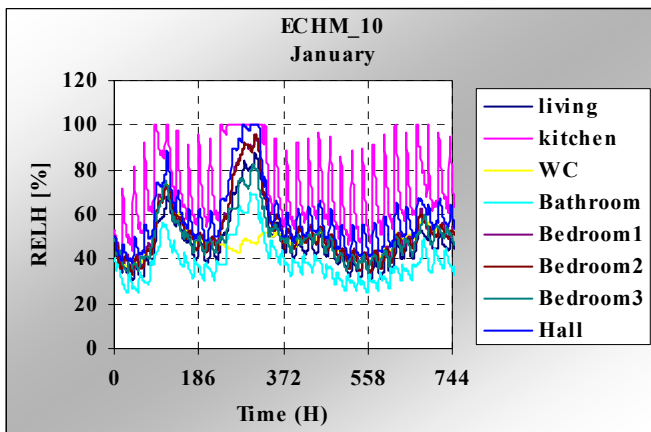


Figure 10-17 - Hourly values of relative humidity – January

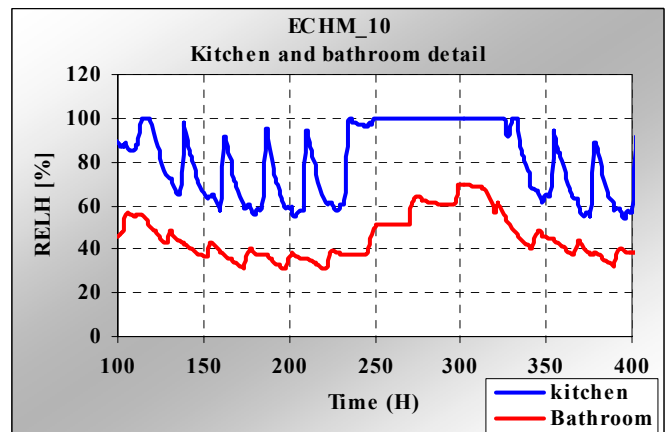


Figure 10-18 - Hourly values of relative humidity - January

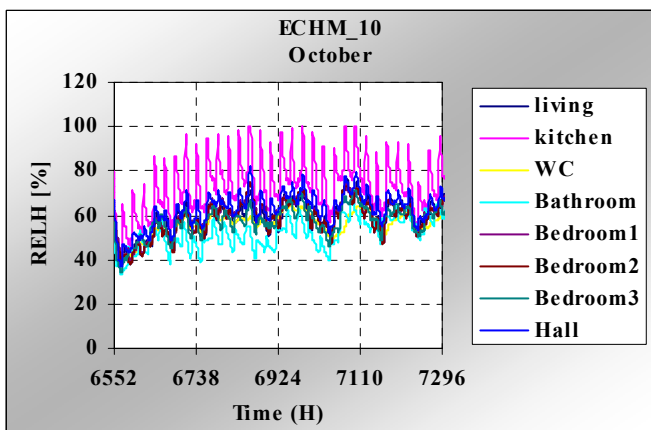


Figure 10-19 - Hourly values of relative humidity – October

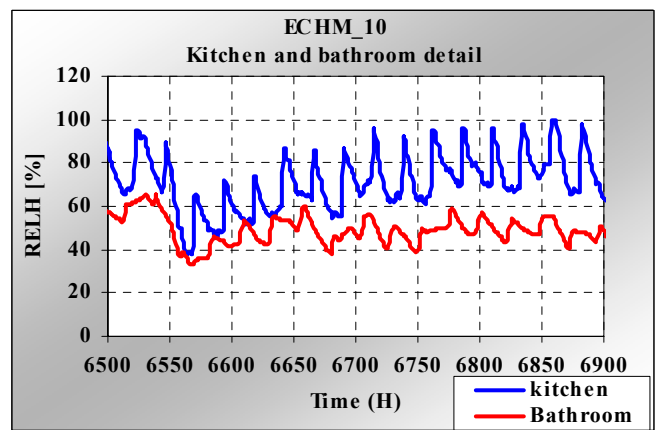


Figure 10-20 - Hourly values of relative humidity - October

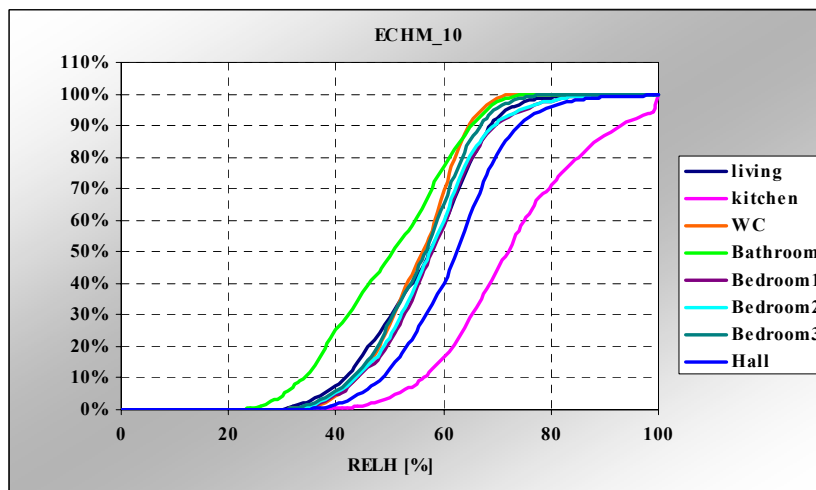


Figure 10-21 - Cumulative frequency of relative humidity (annual)

➤ **Absolute Humidity**

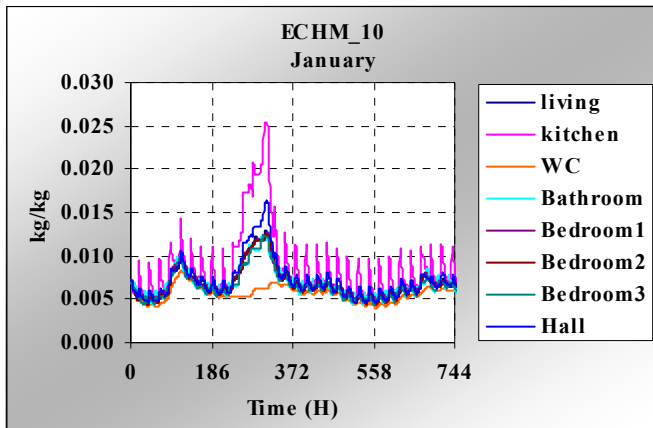


Figure 10-22 - Hourly values of absolute humidity – January

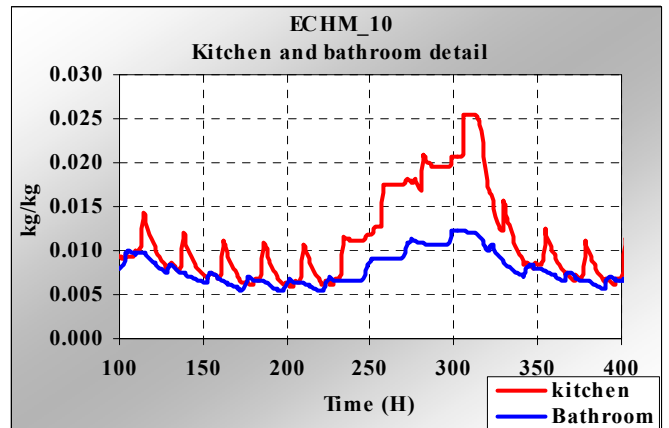


Figure 10-23 - Hourly values of absolute humidity - January

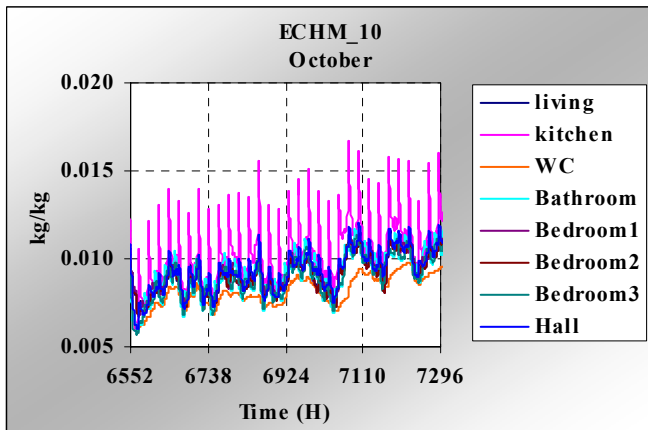


Figure 10-24 - Hourly values of absolute humidity – October

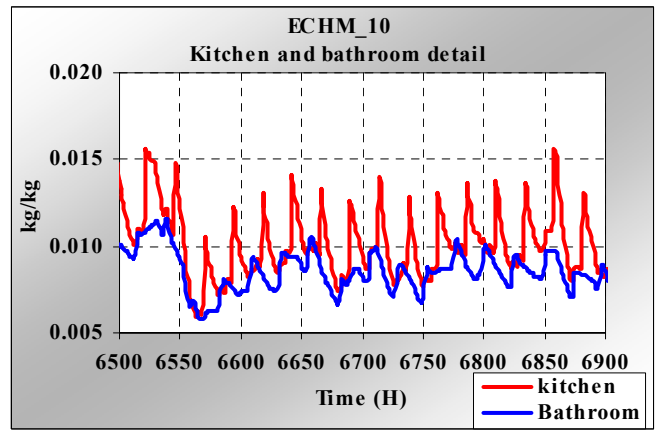


Figure 10-25 - Hourly values of absolute humidity - October

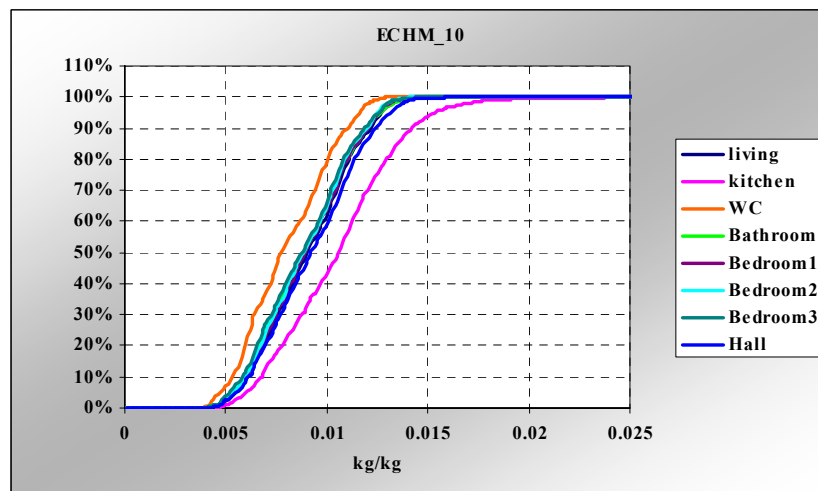


Figure 10-26 - Cumulative frequency of absolute humidity (annual)

➤ PPD

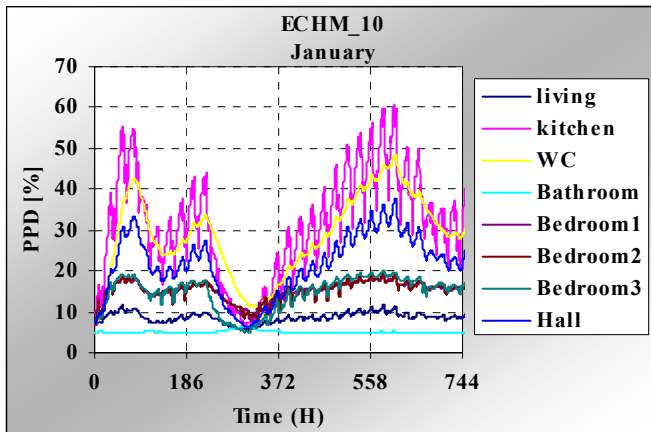


Figure 10-27 - Hourly values of PPD – January

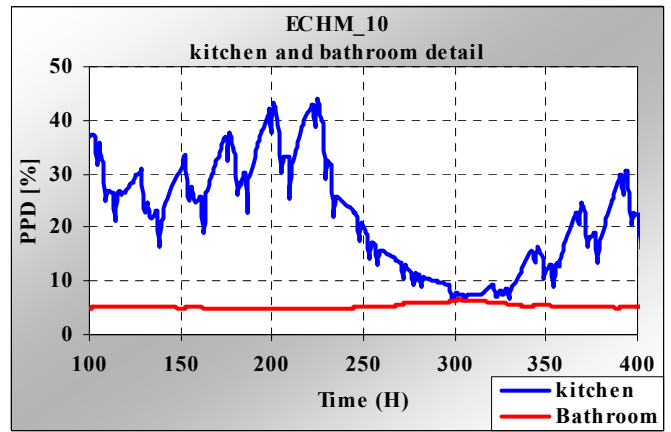


Figure 10-28 - Hourly values of PPD - January

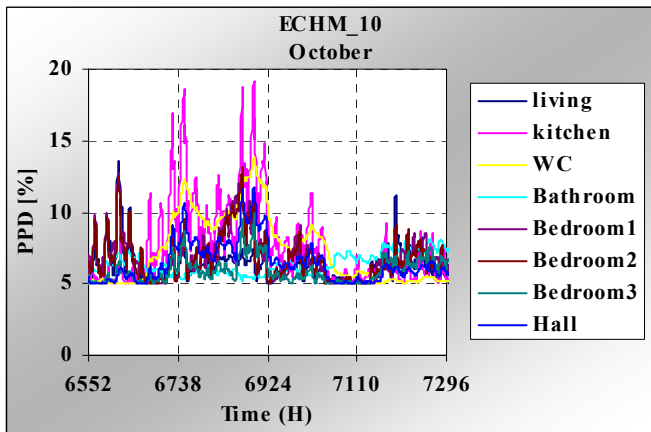


Figure 10-29 - Hourly values of PPD – October

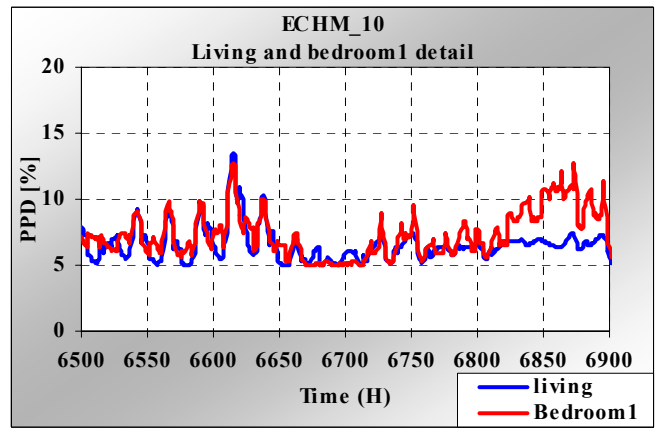


Figure 10-30 - Hourly values of PPD - October

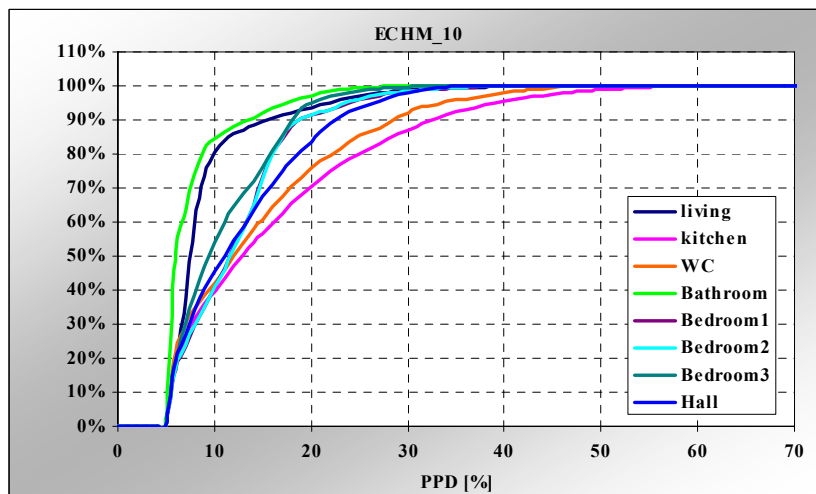


Figure 10-31 - Cumulative frequency of PPD (annual)

10.2.3. Buffer Storage Humidity Model (BSHM)

This is the more sophisticated model. Associated with the surface buffer and deep buffer there are three parameters to calculate and based on them TRNSYS determines the humidity for each timestep.

Below the parameters values needed for the model and the hourly values of relative humidity, absolute humidity and PPD to January and October are shown as well as the cumulative frequency for the three parameters.

In each zones there are two kinds of surface layers: gypsum (walls and roof) and wood (floor). In these material data are available and, in the next tables, the parameters calculated values for each zone.

Material	Density [kg/m ³]	Ksurf [(kg _{water} /kg _{mat})/RH]	Diffusion Resistance
Gypsum	1950	0.015	8
Wood	550	0.2	40

Table Fout! Opmaakprofiel niet gedefinieerd.-1 - Material data for buffer storage humidity model

	A _{roof} [m ²]	A _{walls} [m ²]	A _{total} [m ²]	A _{floor} [m ²]
	Gypsum			Wood
living	24.75	46.85	71.6	24.75
kitchen	8.75	27.9	36.65	8.75
WC	3.75	17.9	21.65	3.75
bathroom	7.5	25.4	32.9	7.5
bed1	10	30.4	40.4	10
bed2	10	30.4	40.4	10
bed3	10	28.3	38.3	10
hall	6.5	44.25	50.75	5.25

Table Fout! Opmaakprofiel niet gedefinieerd.-2 - Surface buffer areas

For the surface buffer, only material with the lowest diffusion resistance is relevant, in this case, the gypsum.

	living	kitchen	wc	bathroom	bed1	bed2	bed3	hall
k _{surf}	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
k _{deep}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
d [mm]	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
M _{surf} [kg]	2670.2	1366.8	807.4	1227.0	1506.7	1506.7	1428.4	1892.7
M _{deep} [kg]	50.5	24.2	13.7	21.6	26.8	26.8	25.6	30.6
β _{surf}	214.8	110.0	65.0	98.7	121.2	121.2	114.9	152.3
β _{deep}	71.6	36.7	21.7	32.9	40.4	40.4	38.3	50.8

Table Fout! Opmaakprofiel niet gedefinieerd.-3 - Parameters for buffer storage humidity model

The value of k_{deep} is 1 for all the zones because the deep buffer takes into account different materials.

➤ **Relative humidity**

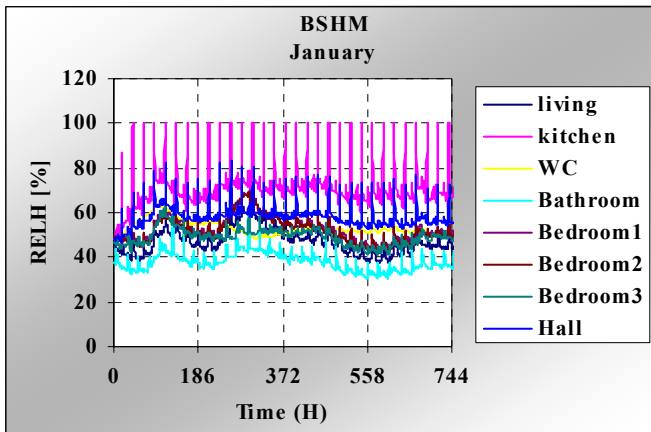


Figure 10-32 - Hourly values of relative humidity – January

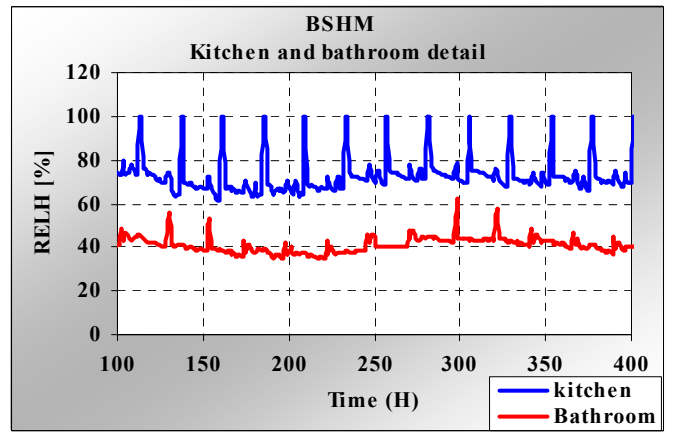


Figure 10-33 - Hourly values of relative humidity - January

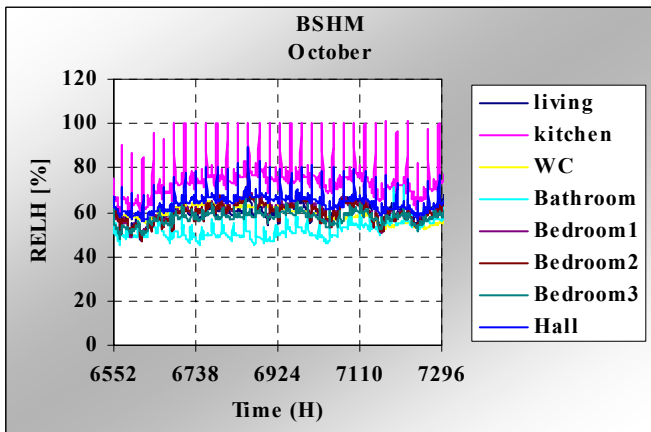


Figure 10-34 - Hourly values of relative humidity – October

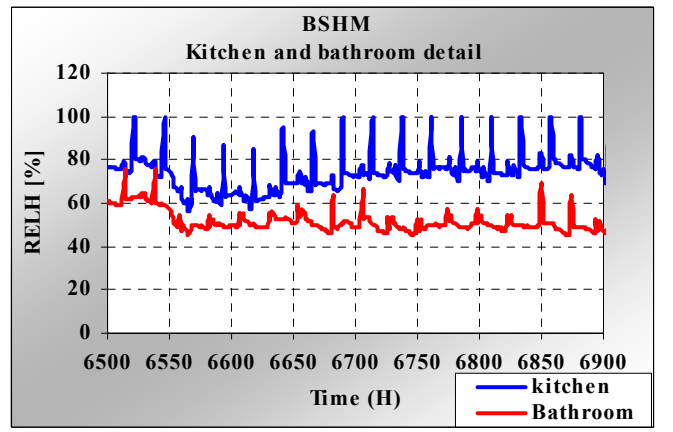


Figure 10-35 - Hourly values of relative humidity - October

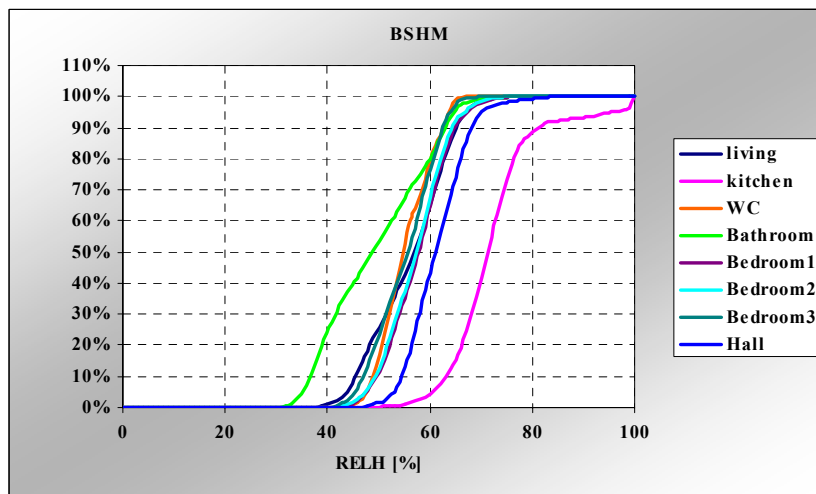


Figure 10-36 - Cumulative frequency of relative humidity (annual)

➤ Absolute Humidity

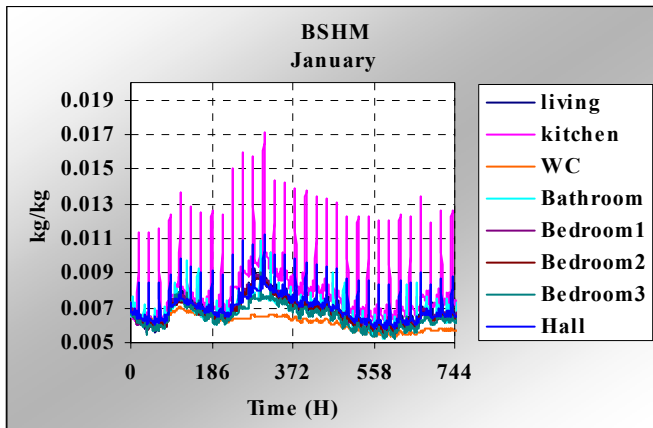


Figure 10-37 - Hourly values of absolute humidity – January

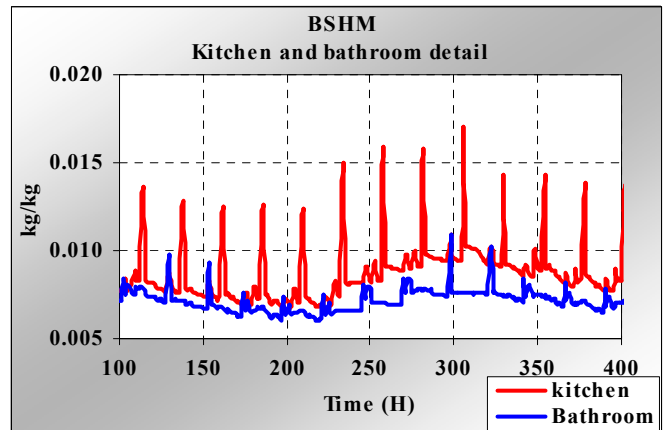


Figure 10-38 - Hourly values of absolute humidity - January

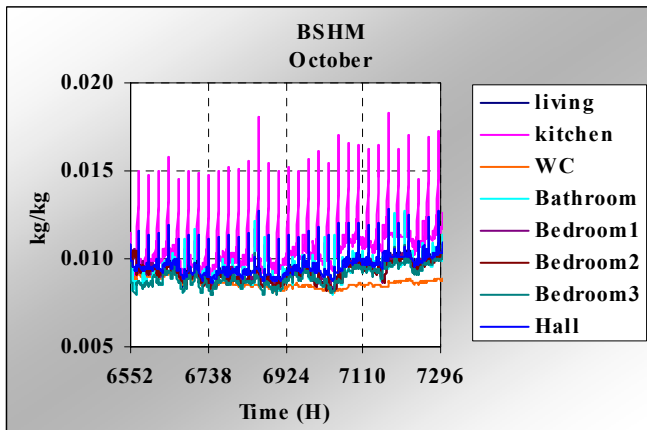


Figure 10-39 - Hourly values of absolute humidity – October

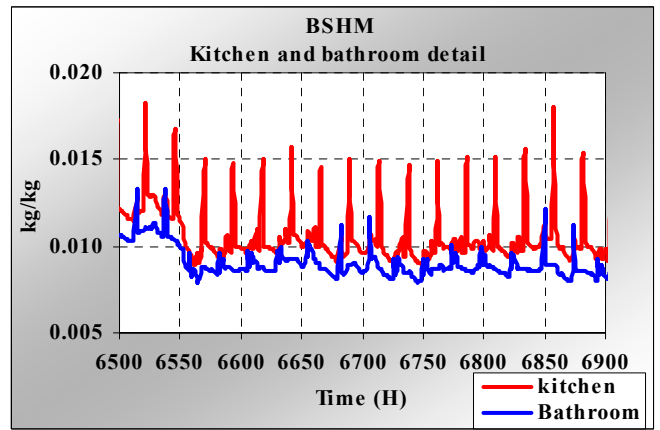


Figure 10-40 - Hourly values of absolute humidity - October

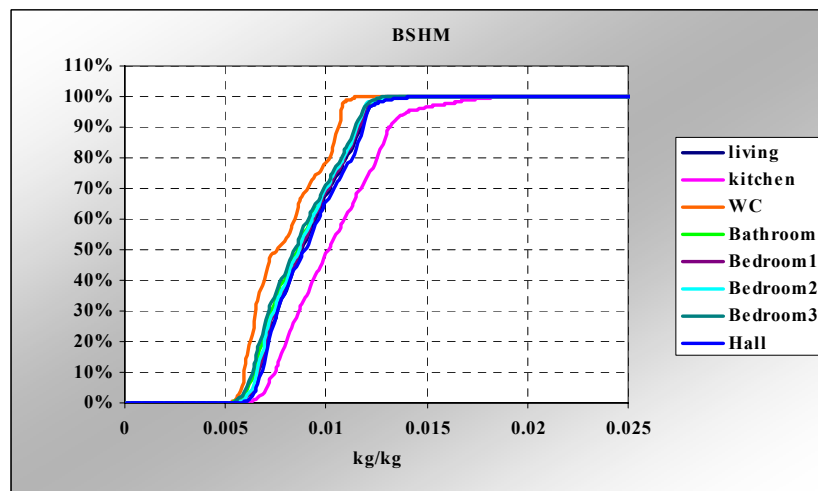


Figure 10-41 - Cumulative frequency of absolute humidity (annual)

➤ PPD

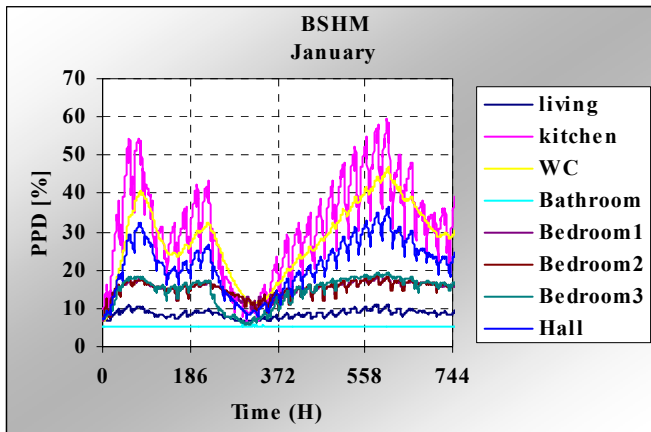


Figure 10-42 - Hourly values of PPD – January

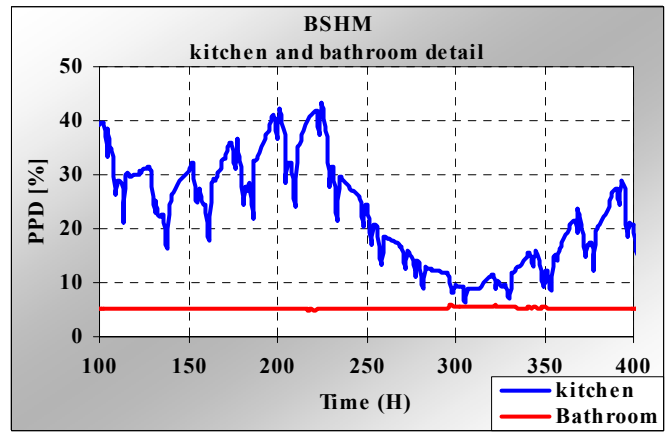


Figure 10-43 - Hourly values of PPD - January

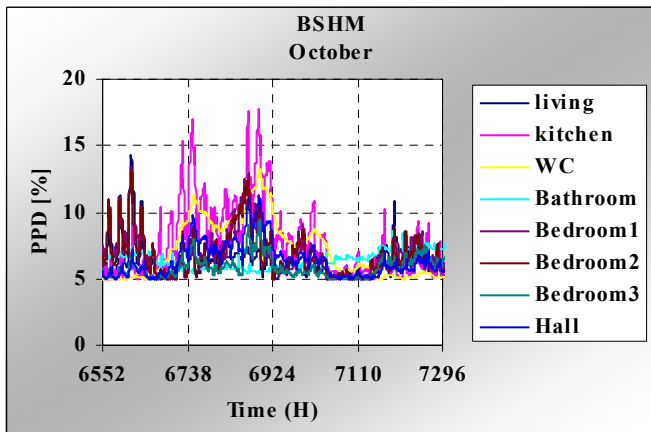


Figure 10-44 - Hourly values of PPD – October

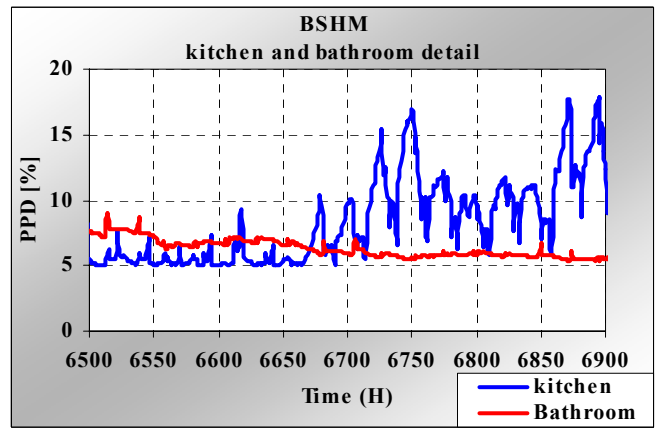


Figure 10-45 - Hourly values of PPD - October

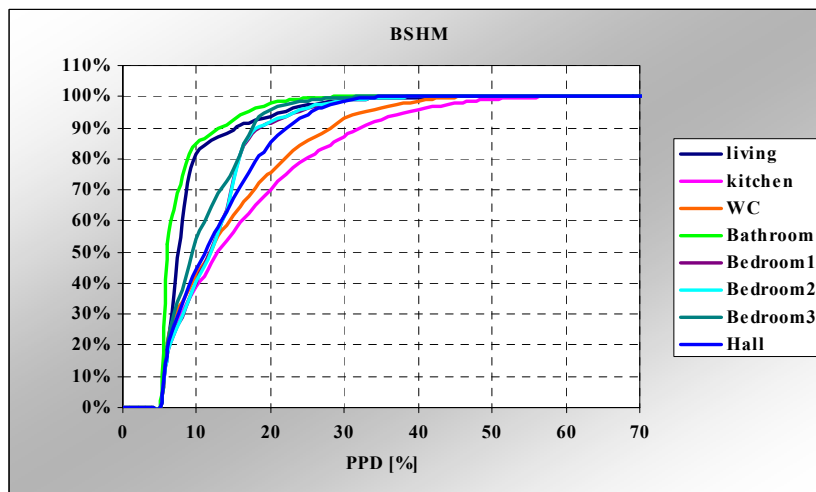


Figure 10-46 - Cumulative frequency of PPD (annual)

10.3. Models Comparison and Conclusions

First analysis shows that, as expected, the buffer effect of adsorptive materials has a high influence on the humidity level of each zone.

In case ECHM_1, the buffer effect it's not considered and the humidity reaches the higher values (figure 10-47 to figure 10-52). When the moisture capacitance ratio (W_{capr}) increases (ECHM_10) these values become lower, as an effect of the materials water sorption. However, the lowest values of humidity occurs for the Buffer Storage Humidity level, a more sophisticated analysis, which takes into account the layer type of the walls surfaces.

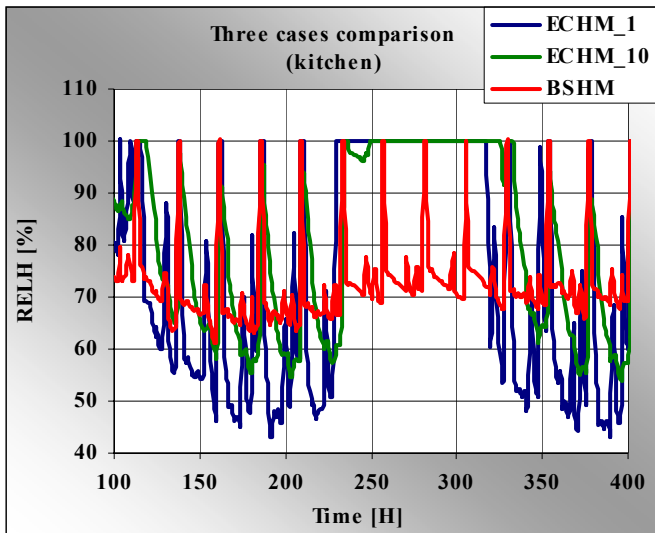


Figure 10-47 - Relative Humidity hourly values comparison (kitchen)

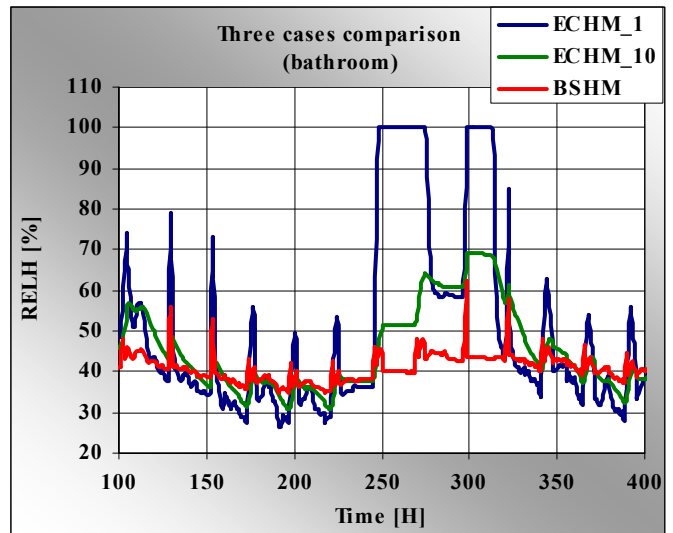


Figure 10-48 - Relative Humidity hourly values comparison (bathroom)

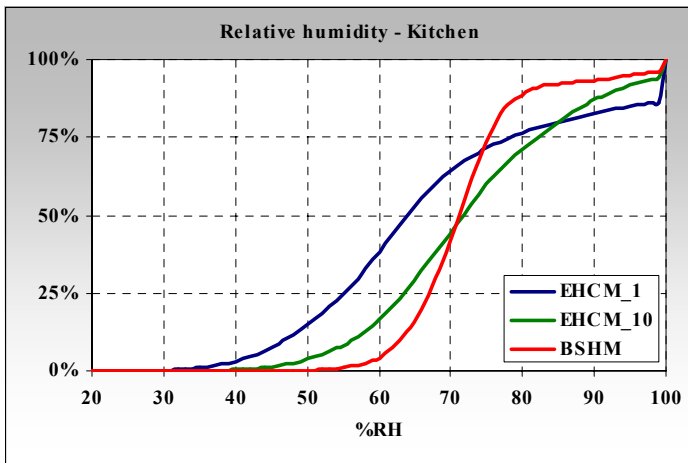


Figure 10-49 – Comparison of the cumulative frequency of Relative humidity in kitchen

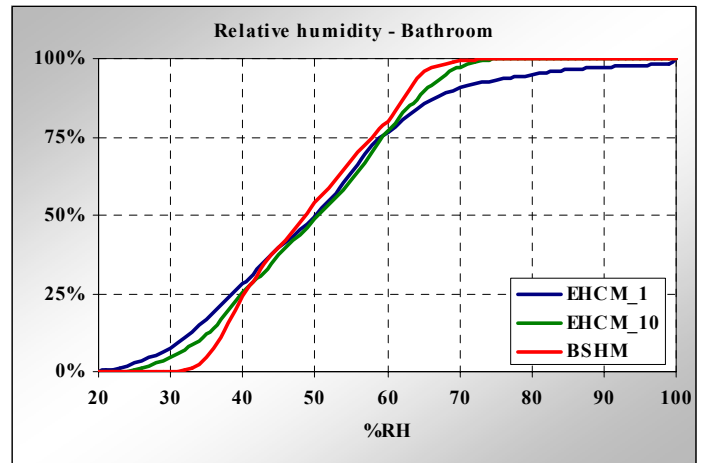


Figure 10-50 – Comparison of the cumulative frequency of Relative humidity in Bathroom

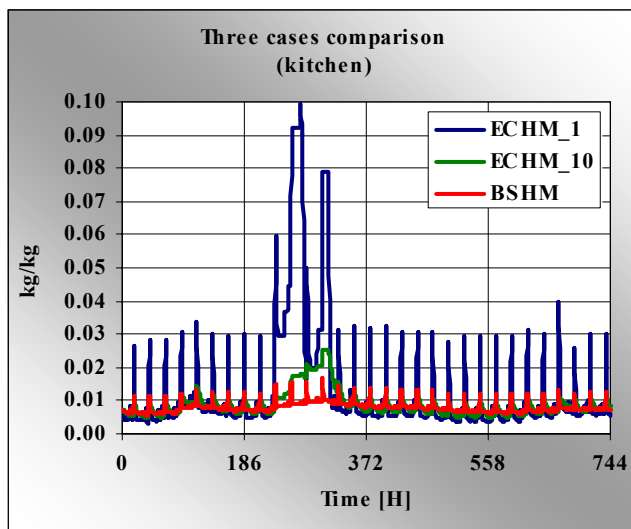


Figure 10-51 - Absolute Humidity hourly values comparison (kitchen)

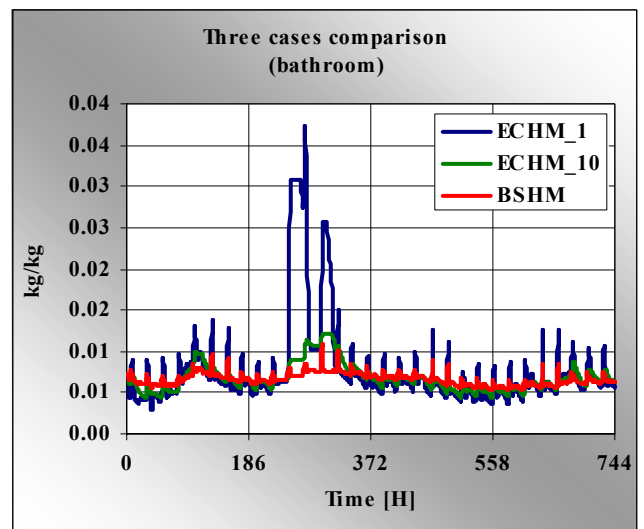


Figure 10-52 - Absolute Humidity hourly values comparison (bathroom)

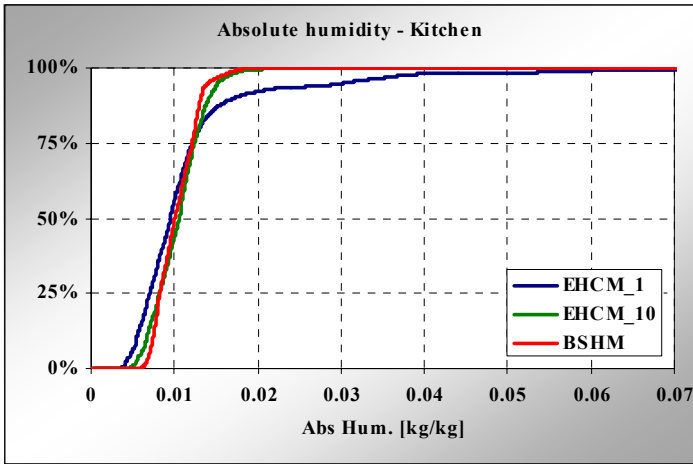


Figure 10-53 – Comparison of the cumulative frequency of Absolute humidity in kitchen

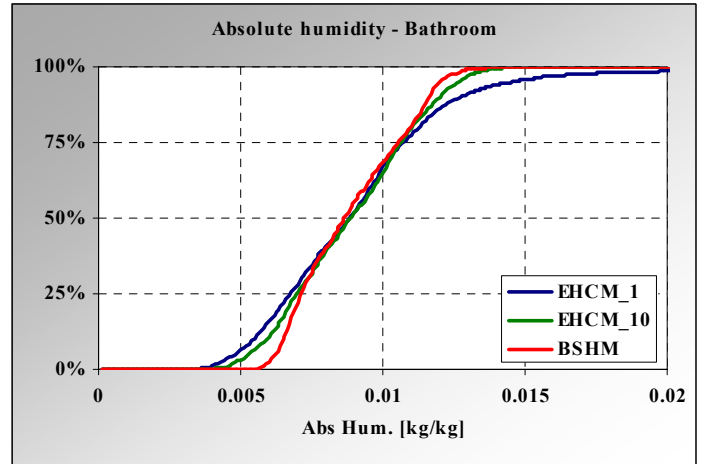


Figure 10-54 – Comparison of the cumulative frequency of Absolute humidity in bathroom

In relation to PPD also the BSHM model reaches better levels in kitchen and bathroom, this happens because the amount of water vapor is directly related to the PPD parameter.

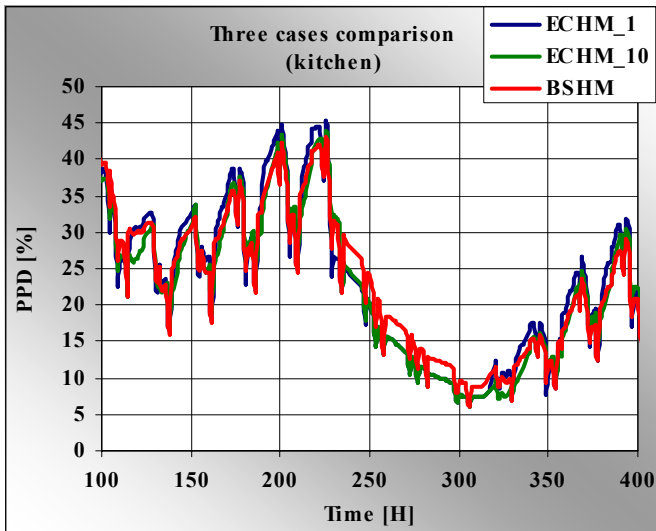


Figure 10-55 - PPD hourly values comparison (kitchen)

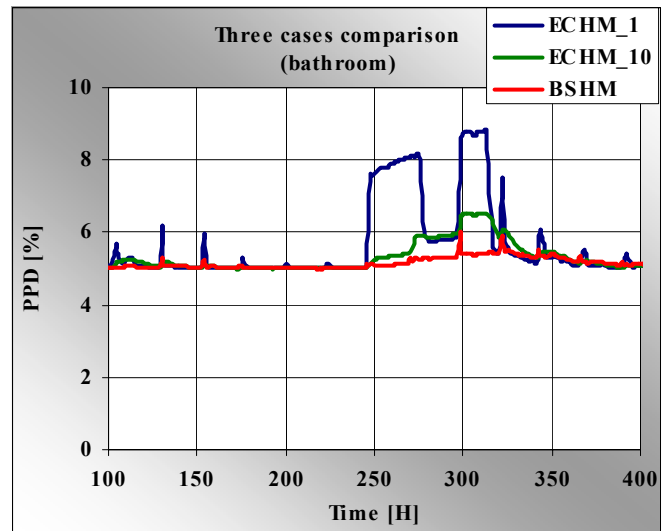


Figure 10-56 - PPD hourly values comparison (bathroom)

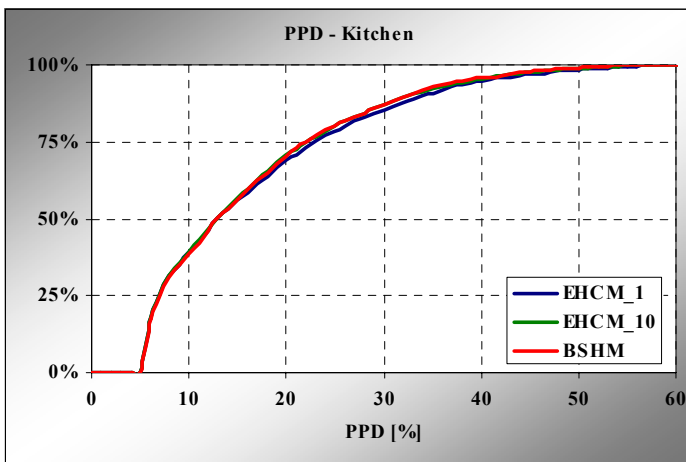


Figure 10-57 – Comparison of the cumulative frequency of PPD in kitchen

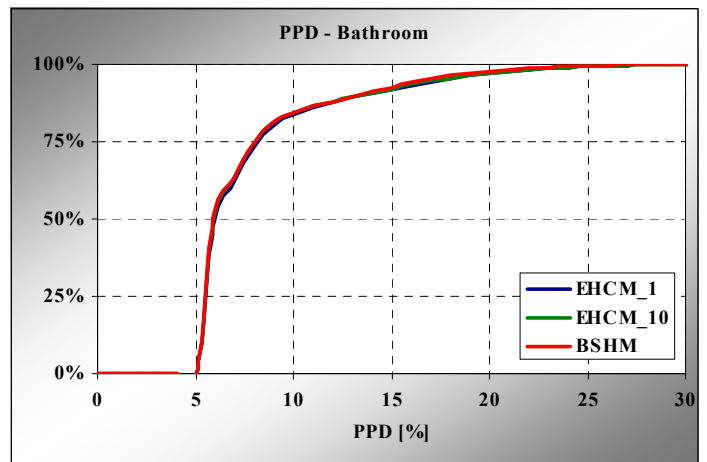


Figure 10-58 – Comparison of the cumulative frequency of PPD in bathroom

11. Appendix B – Detailed Simulations Results

11.1. System I

11.1.1. Heating Energy consumption

Table 11-1 shows the total energy consumption during the heating season. The monthly heating energy consumption (October – April) and also the losses due to the ventilation are shown in figure 11-1.

	kWh/year	kWh/m ² .year
Heating Energy consumption	4095	48.17
Ventilation losses energy	3099	36.46

Table 11-1 - Heating energy consumption

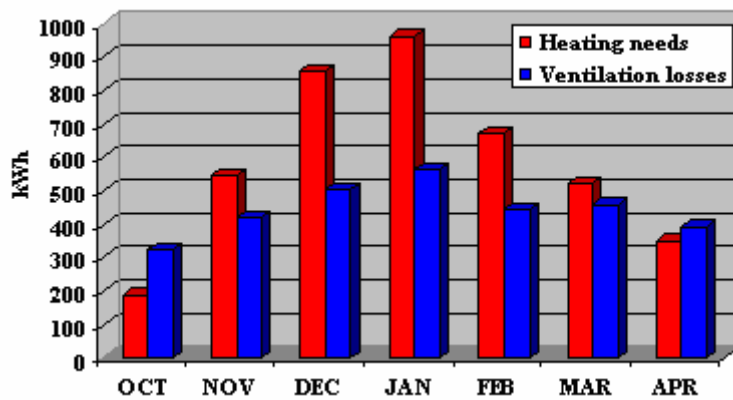
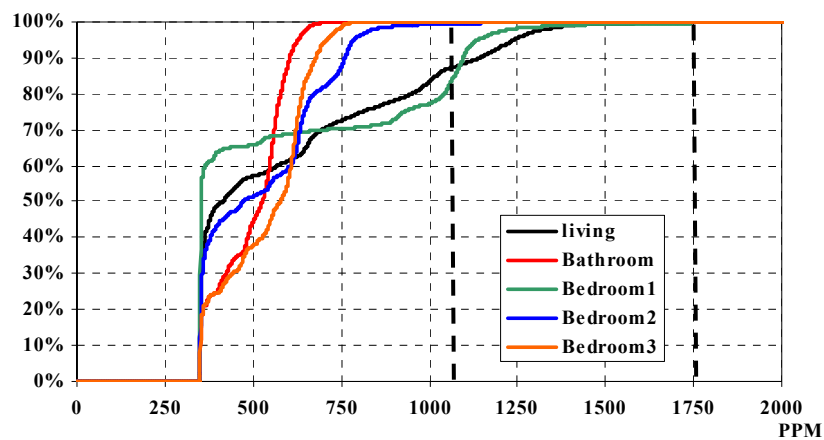


Figure 11-1 -Heating consumption and ventilation losses evolution along the heating period

11.1.2. CO₂ Concentration

Figure 11-2 shows the annual cumulative frequency of CO₂ concentration. It was assumed that the outdoor CO₂ concentration is equal to 350 ppm (reference value).



--- Concentration limits (1050 and 1750 ppm)

Figure 11-2 – Cumulative frequency of CO₂ concentration

The mean values of the CO₂ concentration measured in the different zones of the building are the following.

	CO ₂ annual mean values	CO ₂ annual maximum values
Living	602	2058
Kitchen	518	888
WC	525	893
Bathroom	494	726
Bedroom 1	578	2631
Bedroom 2	521	1468
Bedroom 3	534	803
Hall	550	1022

Table 11-2 - CO₂ annual values analysis [ppm]

Figure 11-3 shows the value CO₂ concentration in kppm.h, i.e., hours above concentration limit (1050 ppm) multiplied by the exceeding CO₂ difference. The target value for this parameter is 500 kppm.h (values proposed in [3]).

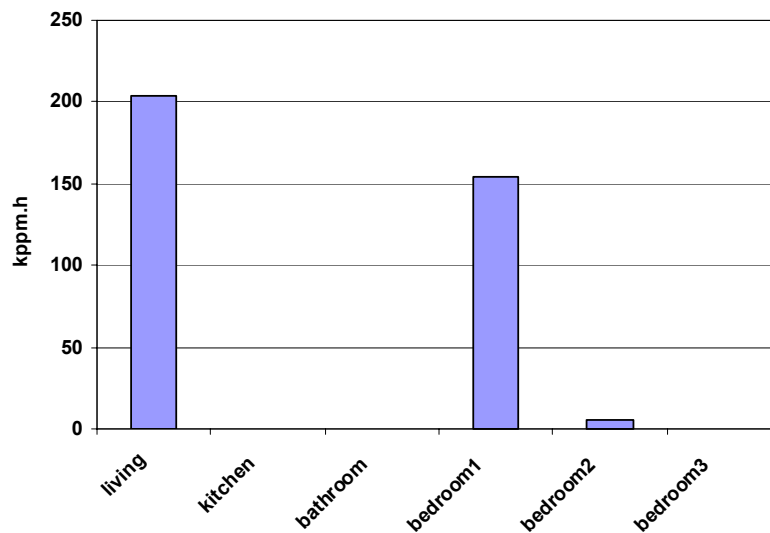


Figure 11-3 - CO₂ concentration exceeding (kppm.h)

11.1.3. Exhaust air flow rate

The minimum and maximum exhaust air flow rate (wet rooms) are shown in table 11-3.

	desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Kitchen	90	63.3	122.4	92.0	63.3	122.4	92.8
WC	45	32.50	64.4	47.2	32.5	64.4	47.6
Bathroom	90	68.93	113.7	92.8	68.9	113.7	93.1

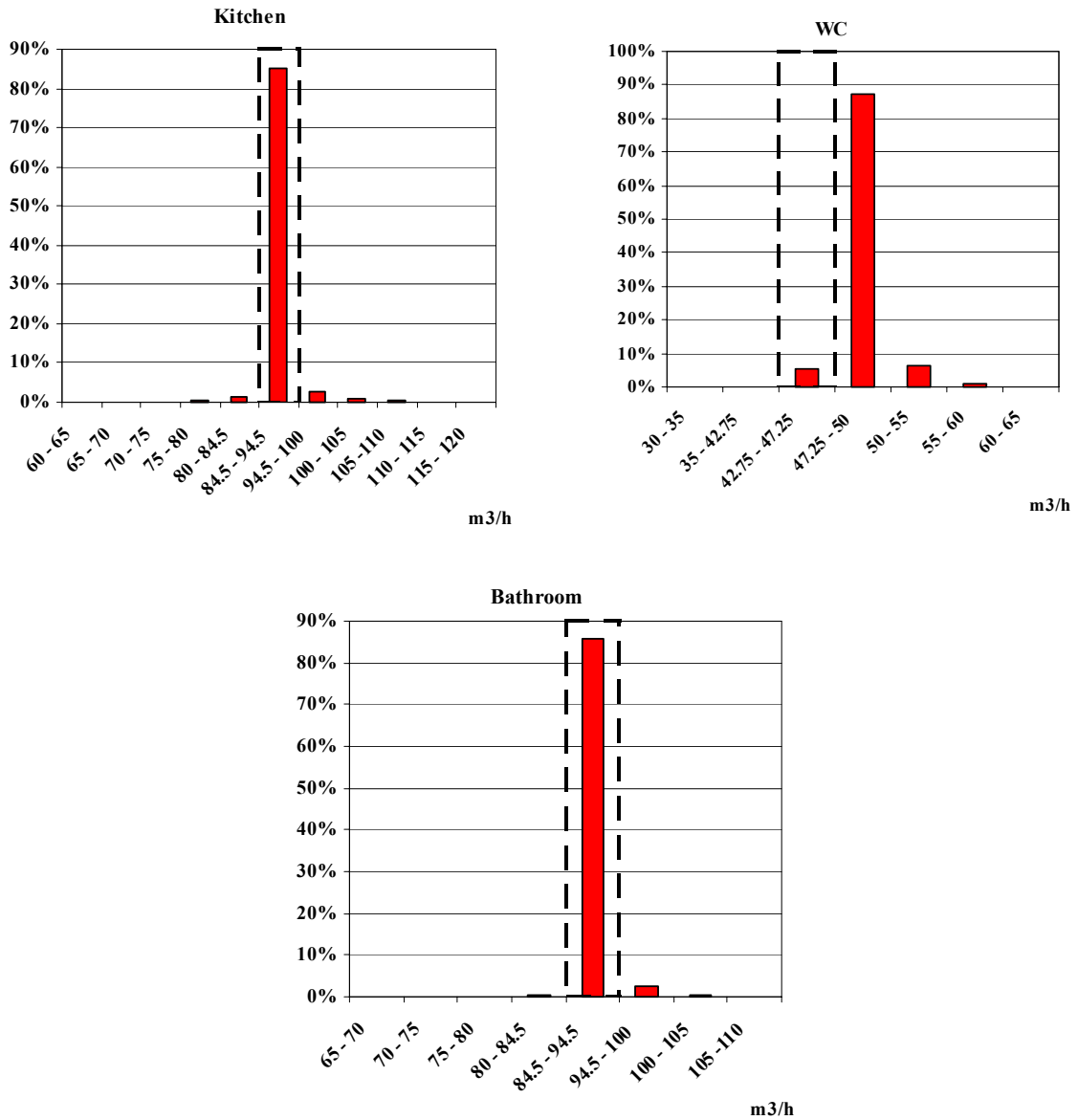
Table 11-3 –Minimum and maximum values of airflow exhaust [m³/h]

Figure 11-4 gives the analysis of the air flow stability, which means, the % of hours of the year in which air flows are within $\pm 5\%$ tolerance band of the design air flow rates.



Figure 11-4 - Air flow stability

Figure 11-5 represents the frequency of the exhaust air flow rate for different rooms. The exhaust air flow rate for all rooms for a typical heating month (January) is presented in figure 11-6 as generic air flow month distribution.



- - - designed air flow rate [m³/h]
 Figure 11-5 - Frequency of exhaust air flows

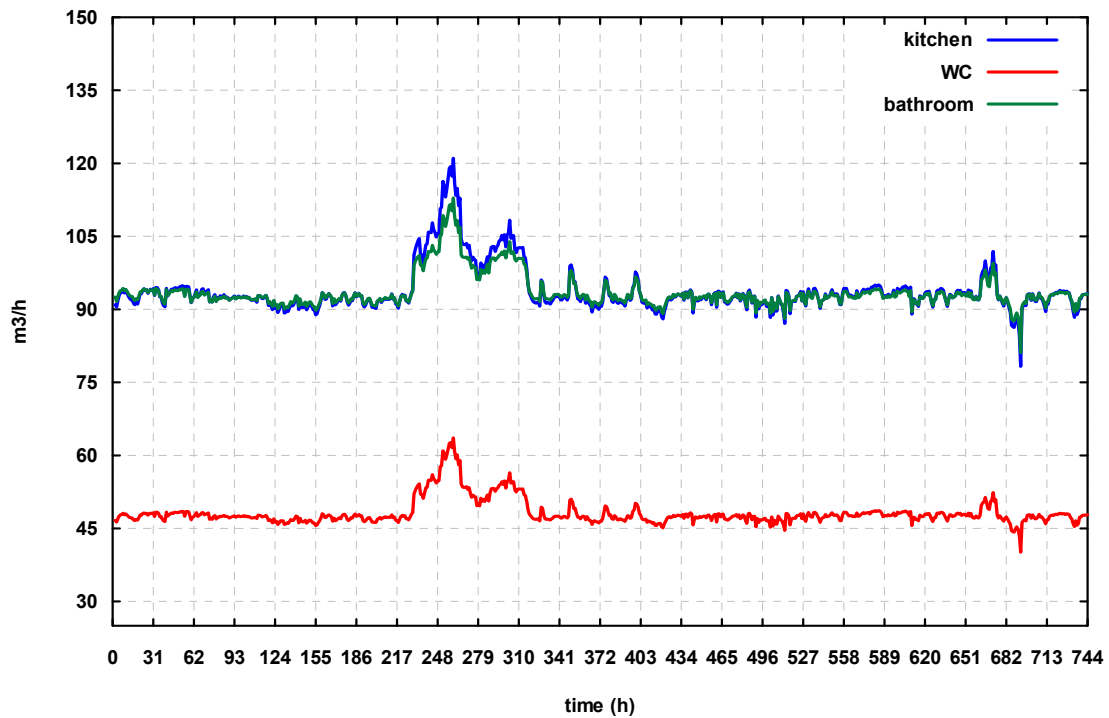


Figure 11-6 – Exhaustion air flow – January

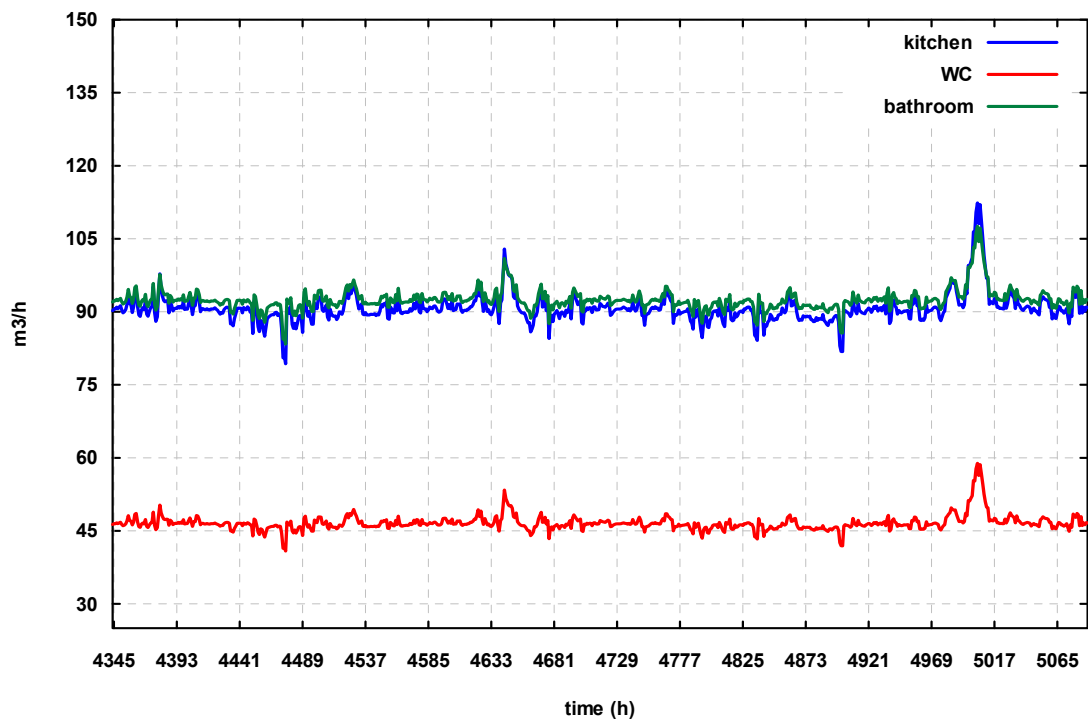


Figure 11-7 – Exhaustion air flow – July

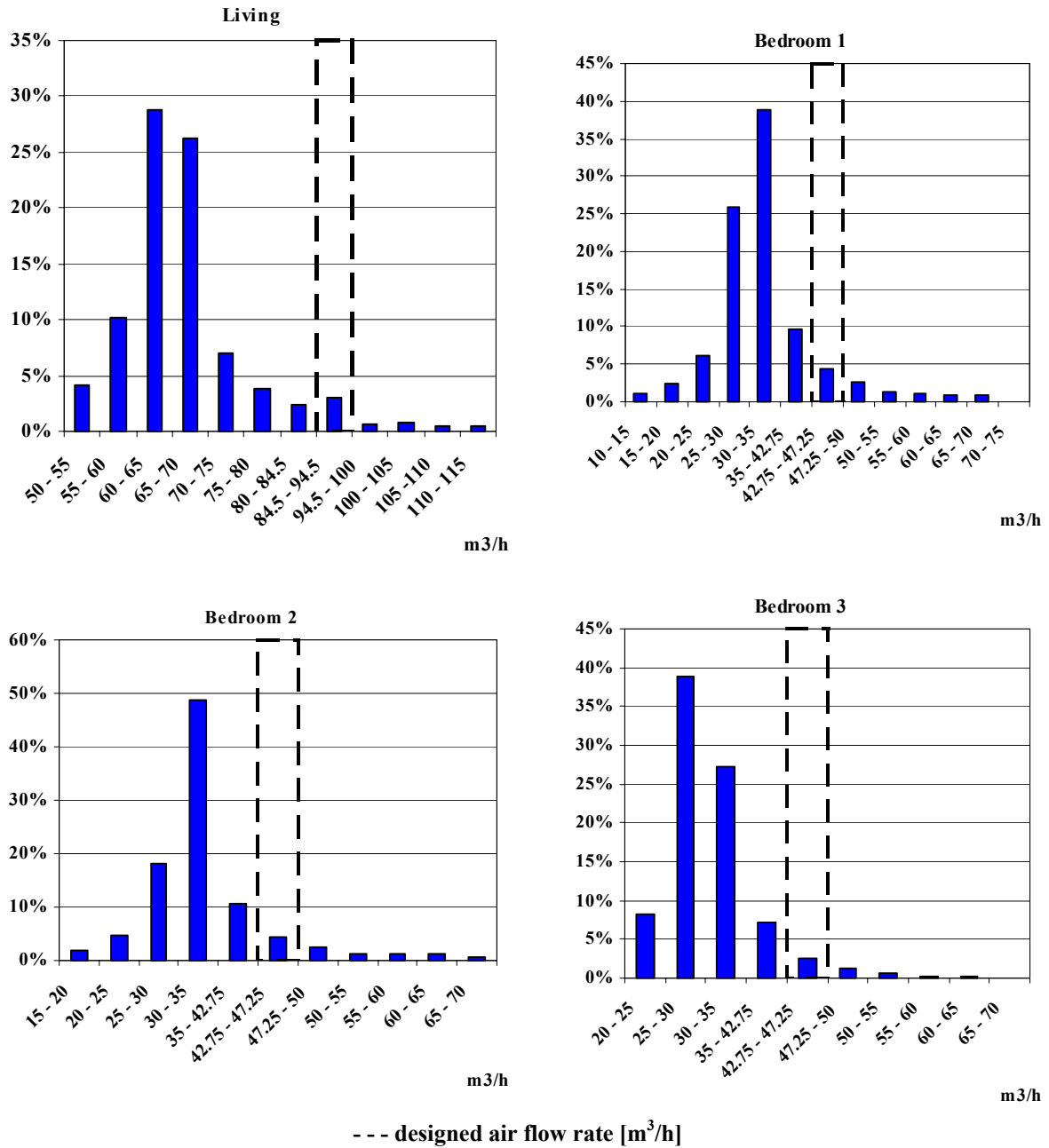
11.1.4. Inlet air flow rate through grilles and cracks

The inlet air flow rate in habitable rooms can reach the maximum of the 226.5 m³/h (Living room) and a minimum of 0 m³/h (in all rooms) as it is shown in table 11-4 and the figure 11-8 represents the frequency of the inlet air flow rate for different rooms. The inlet air flow rate

for all rooms and for a typical heating month (January) and a typical cooling month (July) is presented in figure 11-9 and figure 11-10 as generic air flow month distribution.

	Desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Living	90	0.0	226.5	69.1	0.0	226.5	70.2
Bedroom 1	45	0.0	133.7	38.8	0.0	133.7	39.3
Bedroom 2	45	0.0	115.8	34.2	0.0	115.8	34.6
Bedroom 3	45	0.0	82.8	27.8	0.0	82.8	27.9

Table 11-4 –Minimum and maximum values of outdoor airflow inlet [m³/h]



--- designed air flow rate [m³/h]
 Figure 11-8 - Frequency of admission air flows

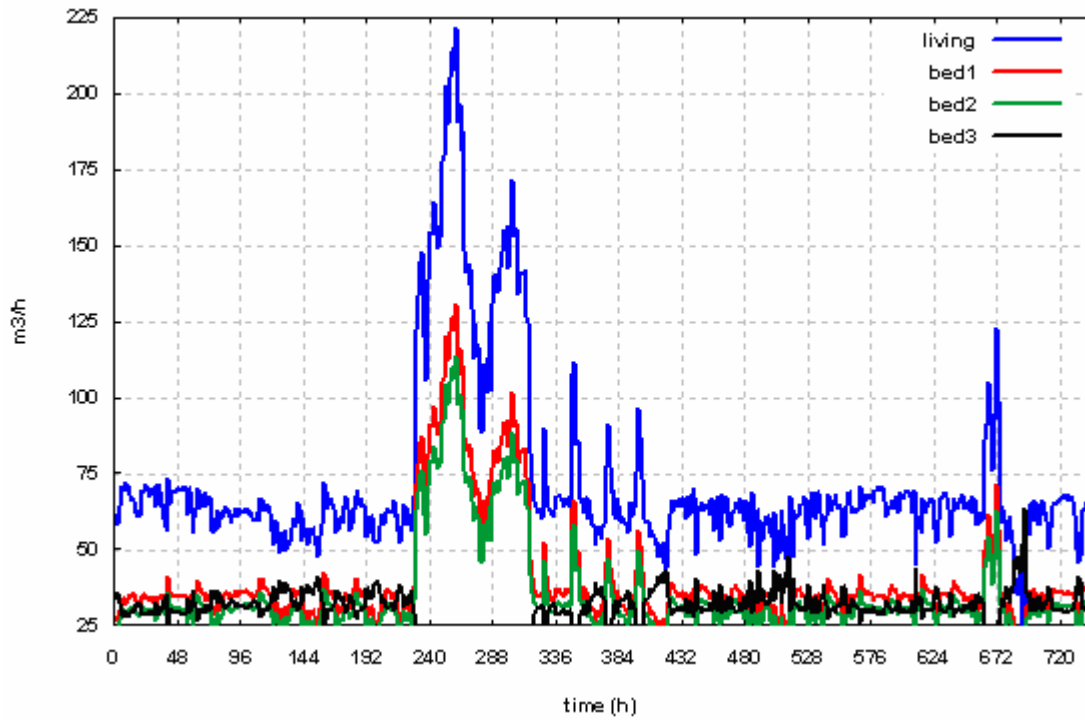


Figure 11-9 – Inlet air flow – January

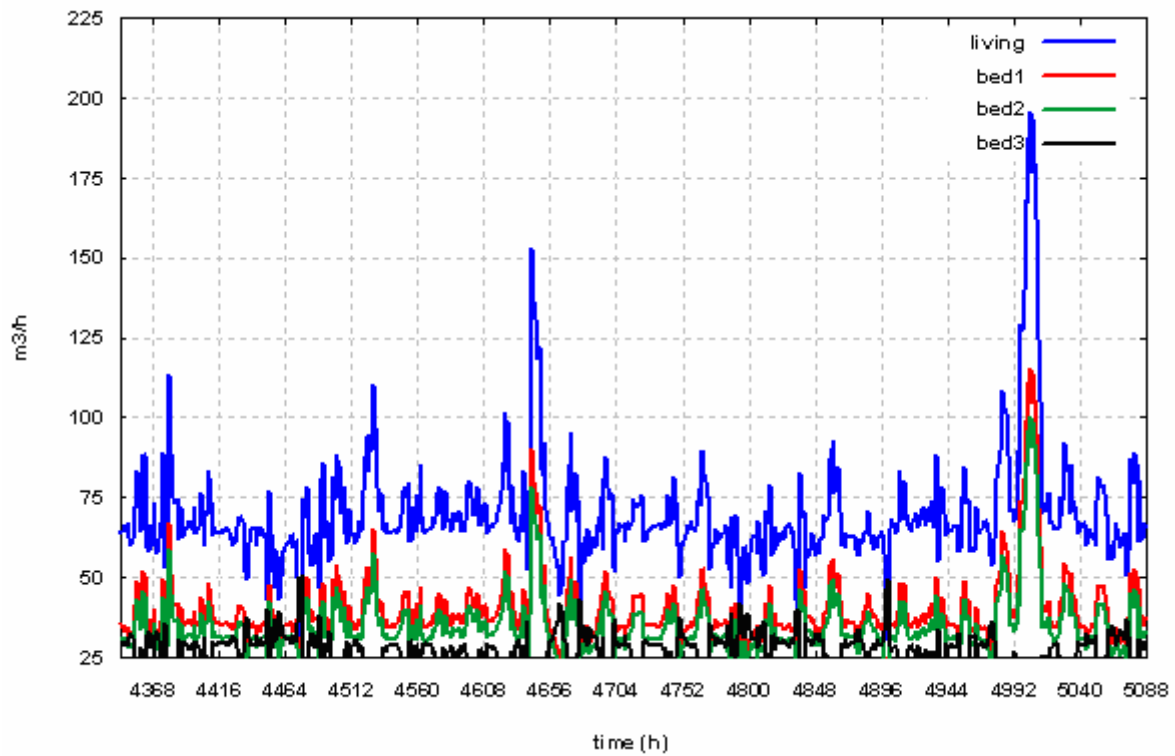


Figure 11-10 – Inlet air flow – July

11.1.5. Thermal Comfort PPD

In figure 11-11 is possible to observe the Cumulative frequency of PPD for the heating season.

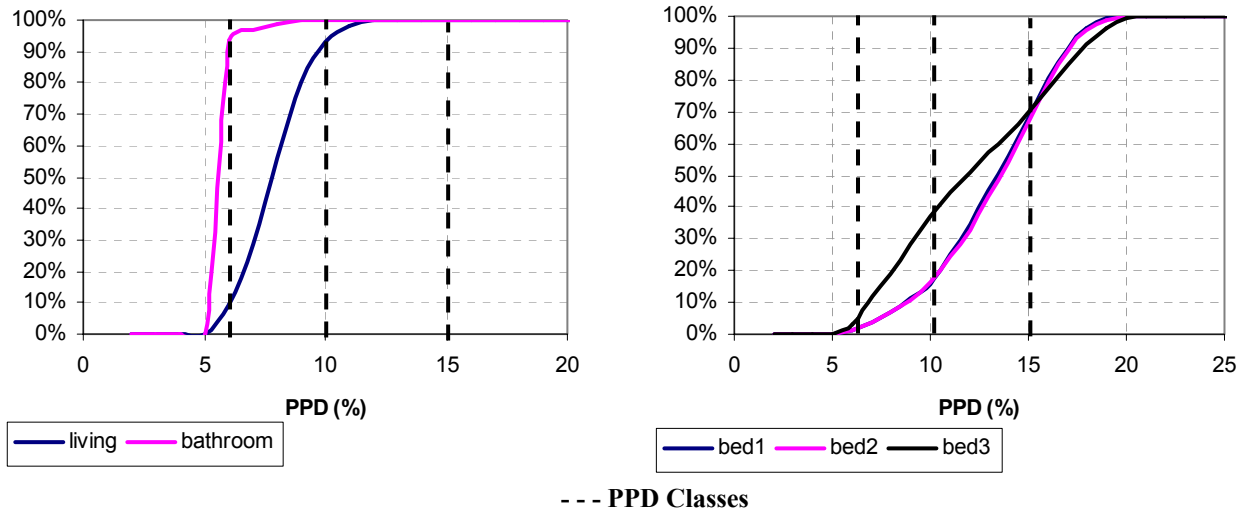


Figure 11-11 – Cumulative frequency of PPD

The Predicted Percentage of Dissatisfied Person (PPD) is mainly related to the thermal comfort. It would be desirable that for a level of PPD lower than 15 % (which means that only 15 % of the persons present in the zone are uncomfortable) the values in figure 11-12 are near the 100 %.

According to the performance criteria imposed by [3], the values of PPD were evaluated in three classes:

- Class 1: % hours with $PPD \leq 6 \%$;
- Class 2: % hours with $PPD \leq 10 \%$;
- Class 3: % hours with $PPD \leq 15 \%$;
- Class 4: % hours with $PPD > 15 \%$

The following table shows lesser hours percentage that theoretically should be reached. This happens because there are hours where the temperature exceeds the limits initially predefined (set point temperatures).

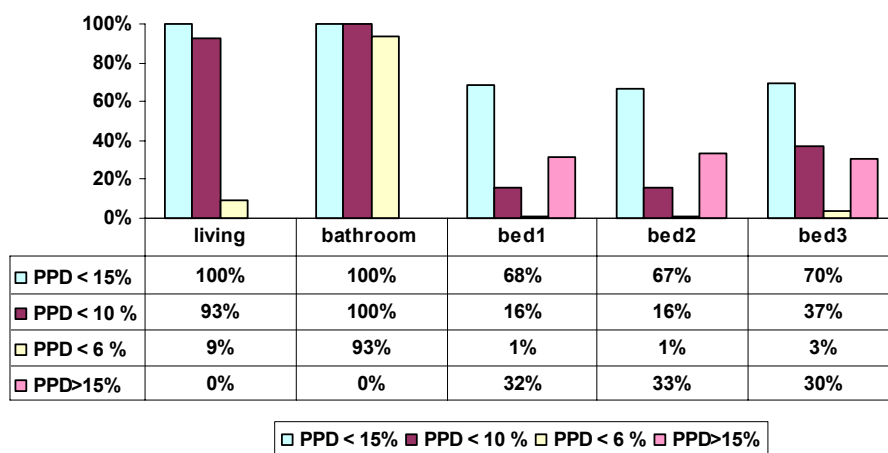


Figure 11-12 – PPD distribution for the several classes

The Cumulative frequency of the temperature is shown in Figure 11-13.

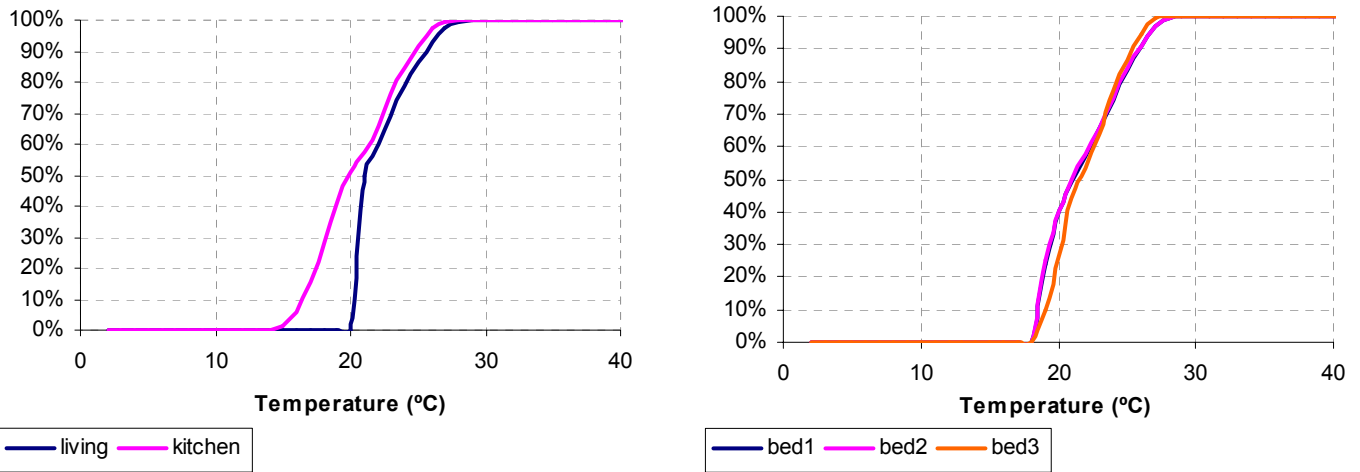


Figure 11-13 – Cumulative frequency of temperature during all year

Figure 11-14 shows the cumulative frequency of PMV (Predicted Mean Vote).

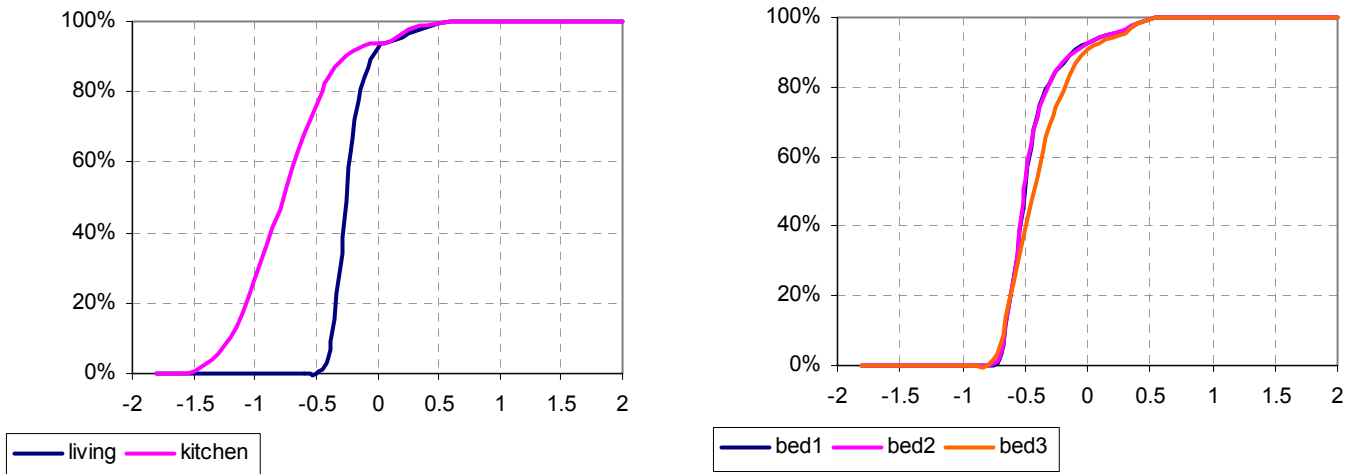
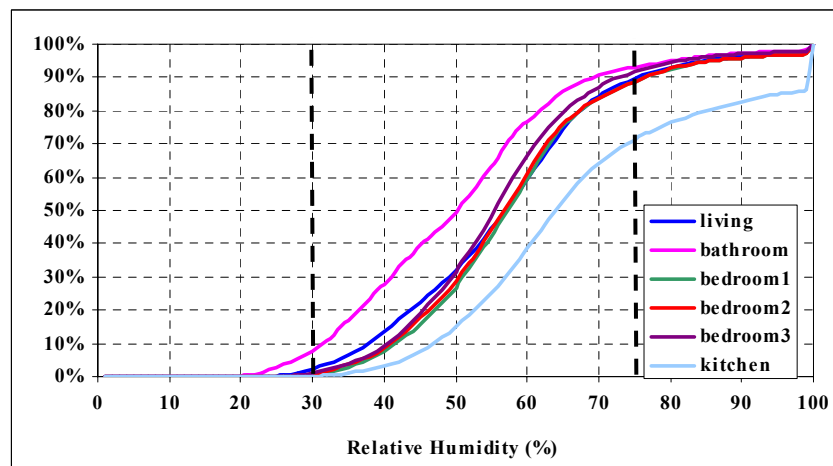


Figure 11-14 – Cumulative frequency of PMV during all year

11.1.6. Relative Humidity

Figure 11-15 shows annual cumulative frequency of relative humidity.



--- Relative Humidity Limits
Figure 11-15 – Cumulative frequency of relative humidity during all year

11.1.7. Absolute humidity

Figure 11-16 shows the Cumulative frequency of absolute humidity.

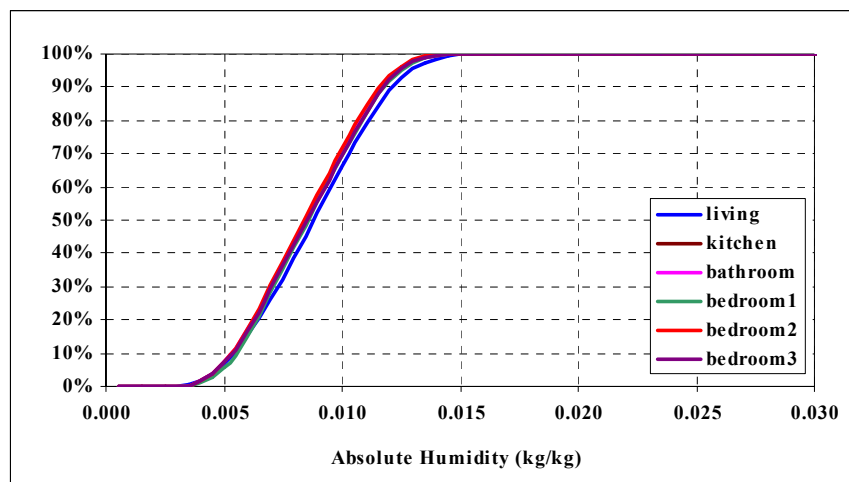


Figure 11-16 – Cumulative frequency of absolute humidity during all year

11.2. System II

11.2.1. Heating Energy consumption

Table 11-5 shows the total energy consumption during the heating season. The monthly heating energy consumption (October – April) and the losses due to the ventilation are shown in figure 11-17.

	kWh/year	kWh/m ² .year
Heating Energy consumption	3783	44.5
Ventilation losses energy	2560	30.12

Table 11-5 - Heating energy consumption

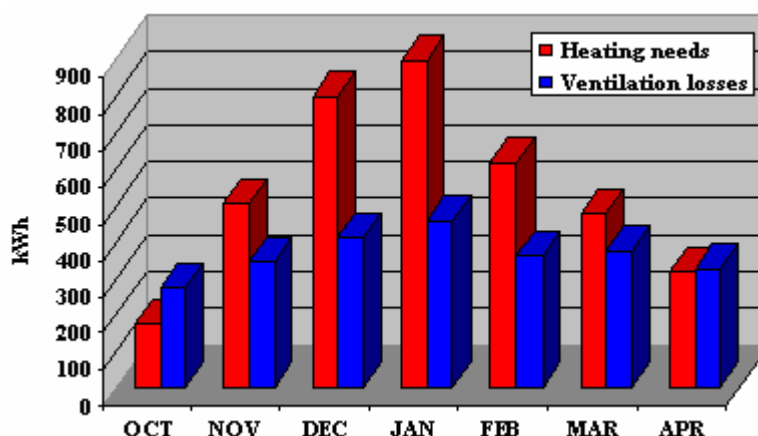
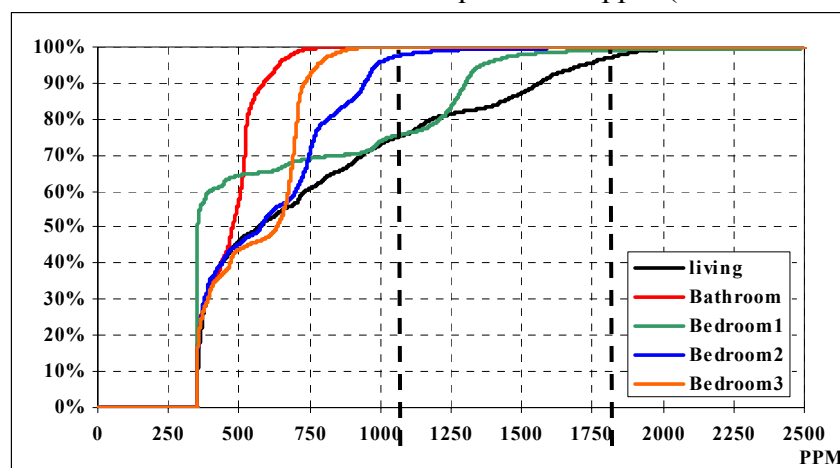


Figure 11-17 - Heating consumption evolution along the heating period

11.2.2. CO₂ Concentration

Figure 11-18 shows the annual cumulative frequency of the CO₂ concentration. It was assumed that the concentration of outdoor CO₂ is equal to 350 ppm (reference value).



--- Concentration limits (1050 and 1750 ppm)

Figure 11-18 - Cumulative frequency of CO₂ concentration

The mean values of the CO₂ concentration measured in the different zones of the building are the following.

	CO ₂ annual mean values	CO ₂ annual maximum values
Living	770	2789
Kitchen	543	880
WC	589	1005
Bathroom	467	832
Bedroom 1	649	4011
Bedroom 2	604	2077
Bedroom 3	559	1013
Hall	631	1146

Table 11-6 - CO₂ annual values analysis [ppm]

The figure 11-19 shows the CO₂ concentration value in kppm.h, i.e., hours above concentration limit (1050 ppm) multiplied by the exceeding CO₂ difference. The target value for this parameter is 500 kppm.h (values proposed in [3]).

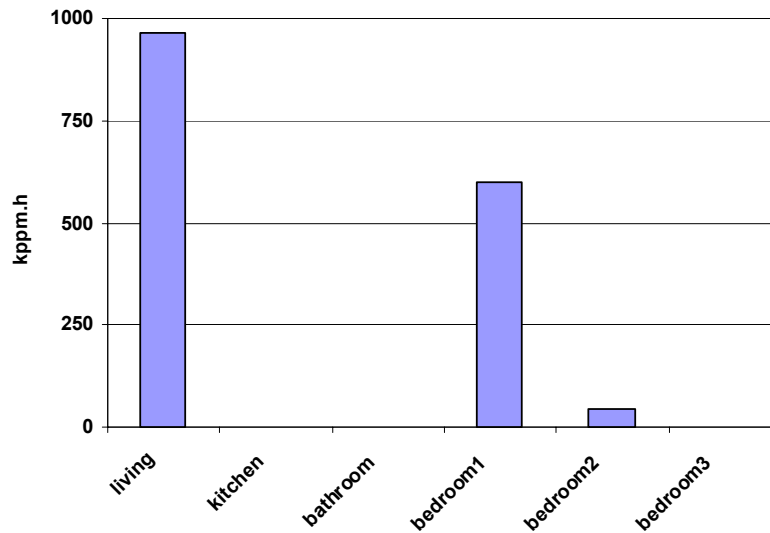


Figure 11-19 - CO₂ concentration exceeding (kppm.h)

11.2.3. Exhaust air flow rate

The minimum and maximum exhaust air flow rate (wet rooms) are shown in table 11-7.

	Desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Kitchen	100	71.5	120.2	99.8	71.5	120.2	100.6
WC	50	33.9	68.6	51.0	33.9	68.6	51.4
Bathroom	50	39.1	55.4	49.4	39.1	55.4	49.5

Table 11-7 –Minimum and maximum values of airflow exhaust [m³/h]

Figure 11-4 gives the analysis of the air flow stability, which means, the % of hours of the year in which air flows are within $\pm 5\%$ tolerance band of the design air flow rates.

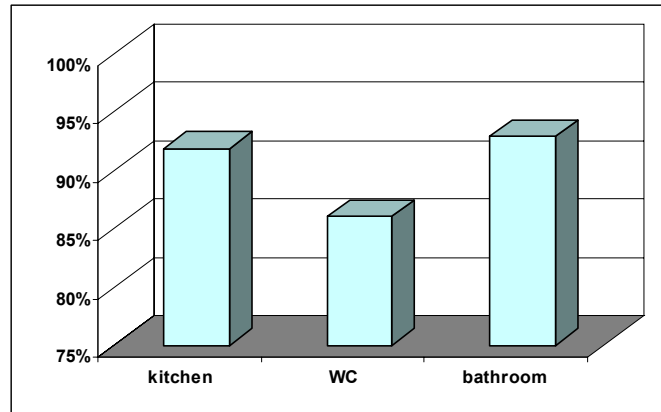


Figure 11-20 - Air flow stability

Figure 11-21 represents the frequency of the exhaust air flow rate for different rooms.

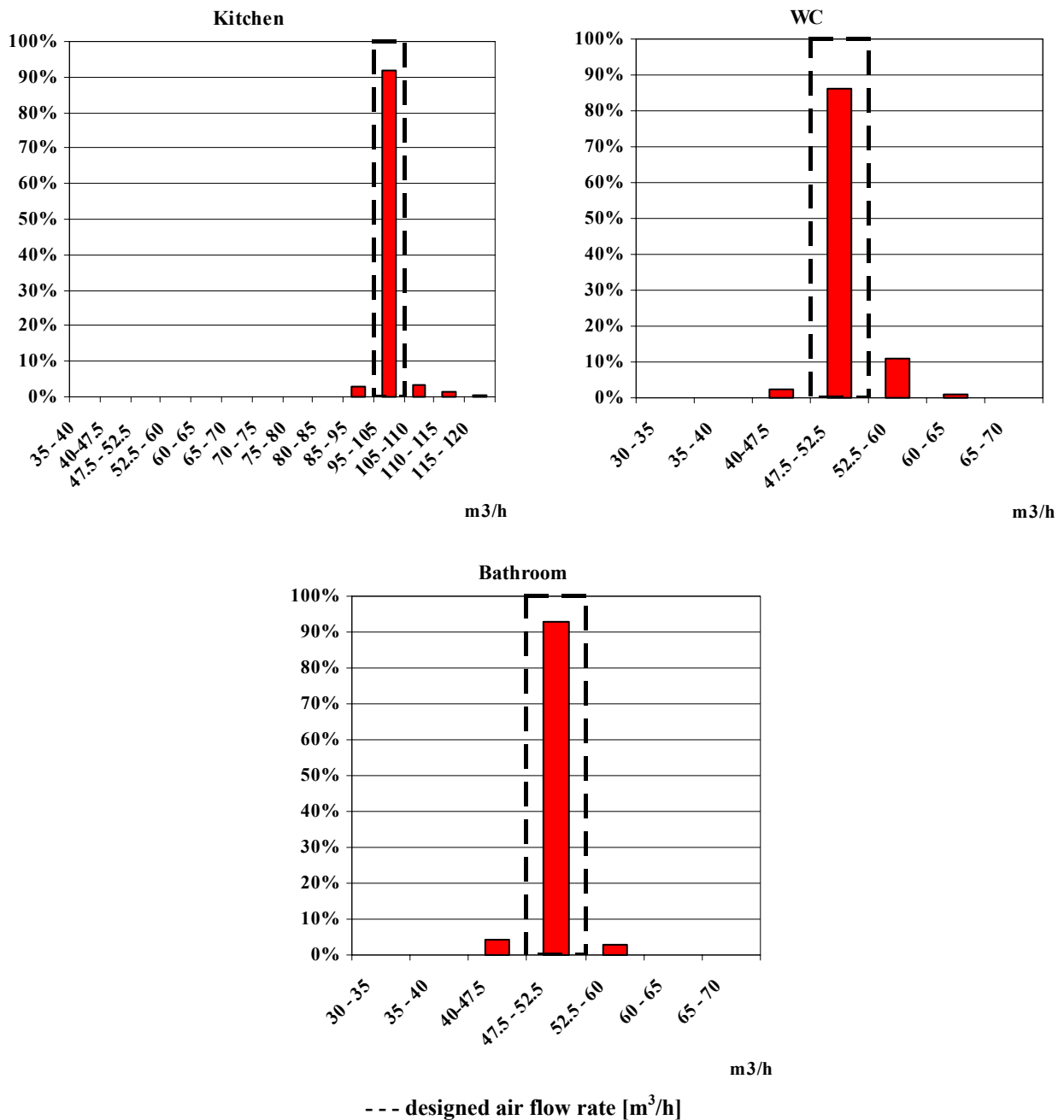


Figure 11-21 - Frequency of exhaust air flows

The exhaust airflow rates of all rooms for a typical heating month (January) and a typical cooling month (July) are presented in figure 11-22 and figure 11-23 as generic airflow month distribution.

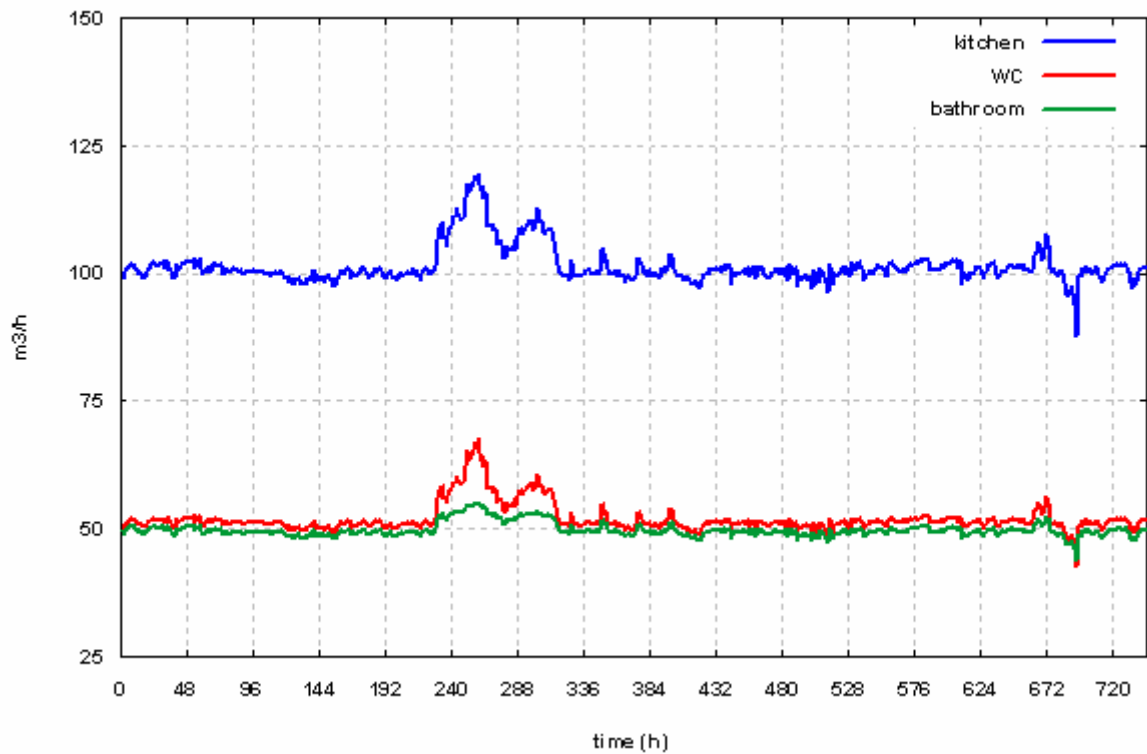


Figure 11-22 – Exhaustion air flow – January

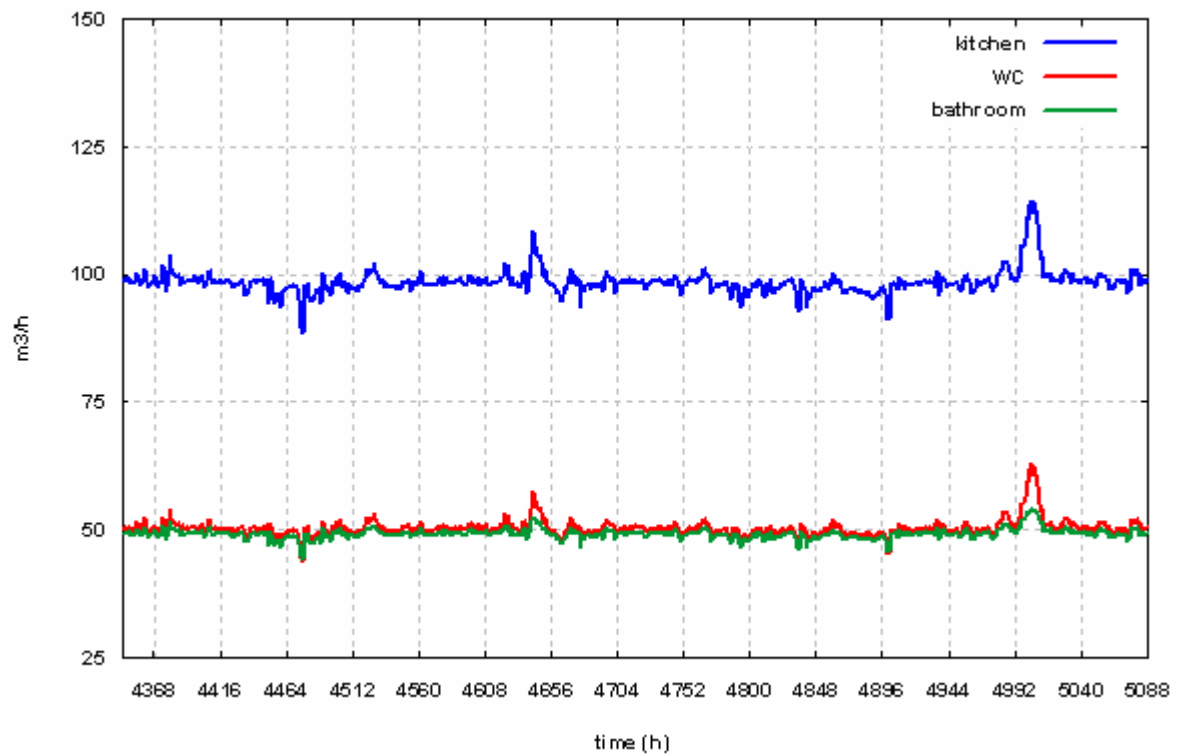


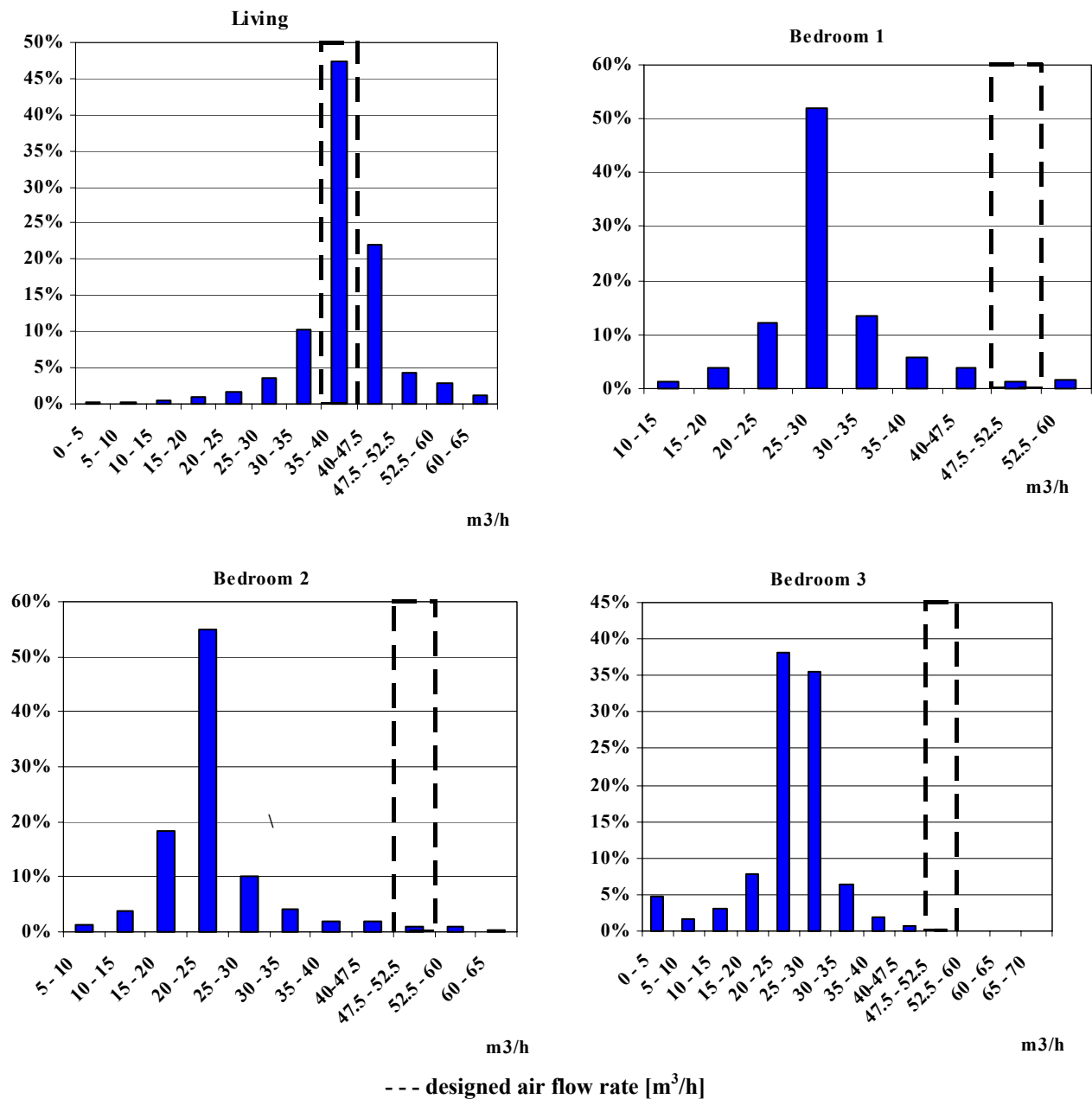
Figure 11-23 – Exhaustion air flow – July

11.2.4. Inlet air flow rate through grilles and cracks

The inlet air flow rate in habitable rooms can reach the maximum of the 132.5 m³/h (Living room) and a minimum of 0 m³/h (in all rooms) as it is shown in Table 11-8 and the figure 11-24 represents the frequency of the inlet air flow rate for different rooms.

	Desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Living	90	0.0	132.5	41.1	0.00	132.50	41.60
Bedroom 1	45	0.0	114.4	30.3	0.0	114.4	30.6
Bedroom 2	45	0.0	85.4	23.2	0.0	85.4	23.4
Bedroom 3	45	0.0	59.9	23.5	0.0	59.9	23.6

Table 11-8 –Minimum and maximum values of outdoor airflow inlet [m³/h]



--- designed air flow rate [m³/h]
 Figure 11-24 - Frequency of admission air flows

The inlet air flow rate for all rooms and for a typical heating month (January) and a typical cooling month (July) is presented in figure 11-25 and figure 11-26 as generic air flow month distribution.

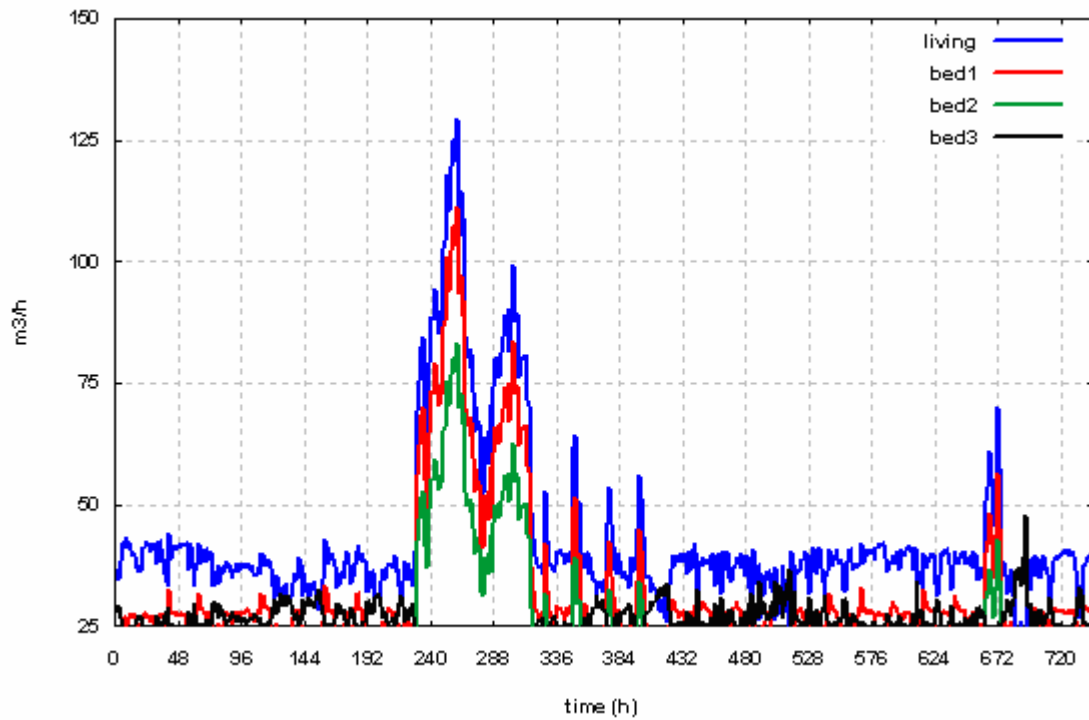


Figure 11-25 – Inlet air flow rate– January

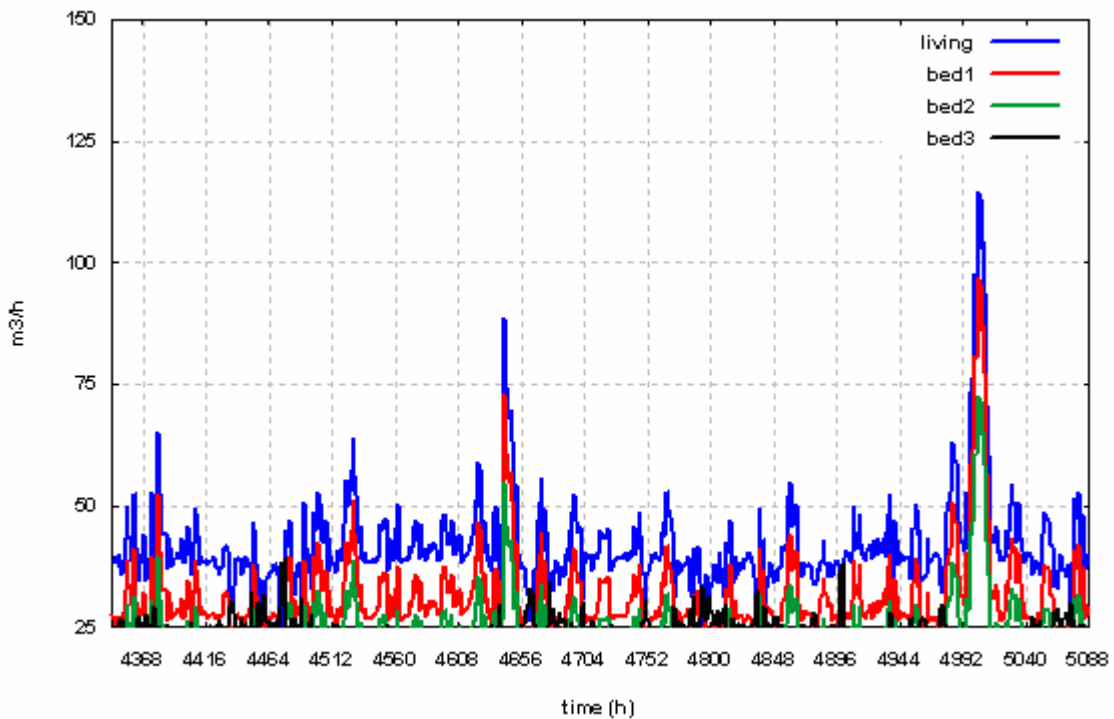
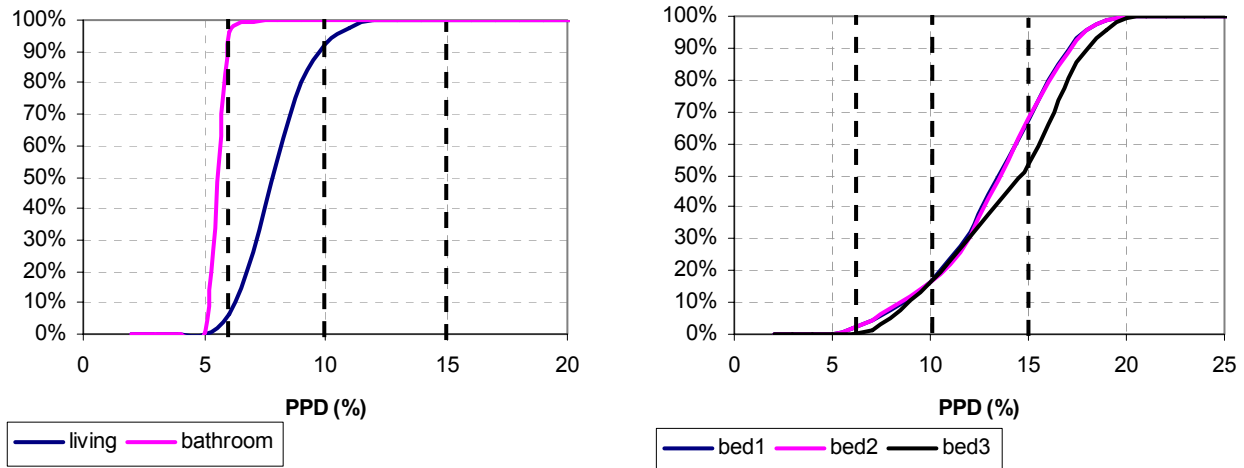


Figure 11-26 – Inlet air flow – July

11.2.5. Thermal Comfort PPD

Figure 11-27 is possible to observe the Cumulative frequency of PPD for the heating season.



--- Thermal Comfort PPD Classes
 Figure 11-27 – Cumulative frequency of PPD

The Predicted Percentage of Dissatisfied Person (PPD) is mainly related to the thermal comfort. It would be desirable that for a level of PPD lower than 15 % (which means that only 15 % of the persons present in the zone are uncomfortable) the values in figure 6-3 are near the 100 %.

According to the performance criteria imposed by the RESHYVENT (WP5), the values of PPD were evaluated in three classes:

- Class 1: % hours with PPD \leq 6 %;
- Class 2: % hours with PPD \leq 10 %;
- Class 3: % hours with PPD \leq 15 %;
- Class 4: % hours with PPD > 15 %.

The following table shows lesser hours percentage that theoretically should be reached. This happen because there are hours where the temperature exceeds the limits initially predefined.

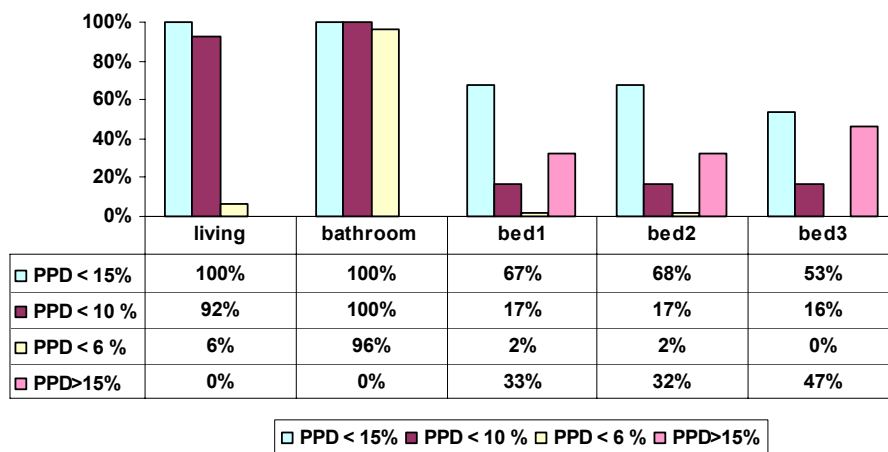


Figure 11-28 – PPD distribution for the several classes– annual values

The Cumulative frequency of the temperature is shown in figure 11-29.

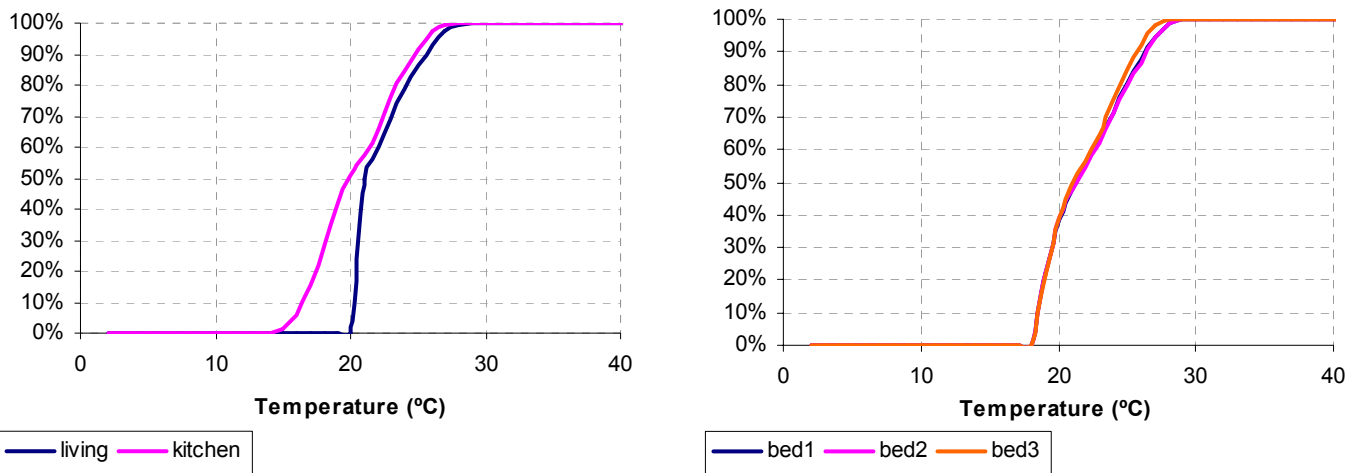


Figure 11-29 – Cumulative frequency of temperature during all year

Figure 11-30 shows the cumulative frequency of PMV (Predicted Mean Vote).

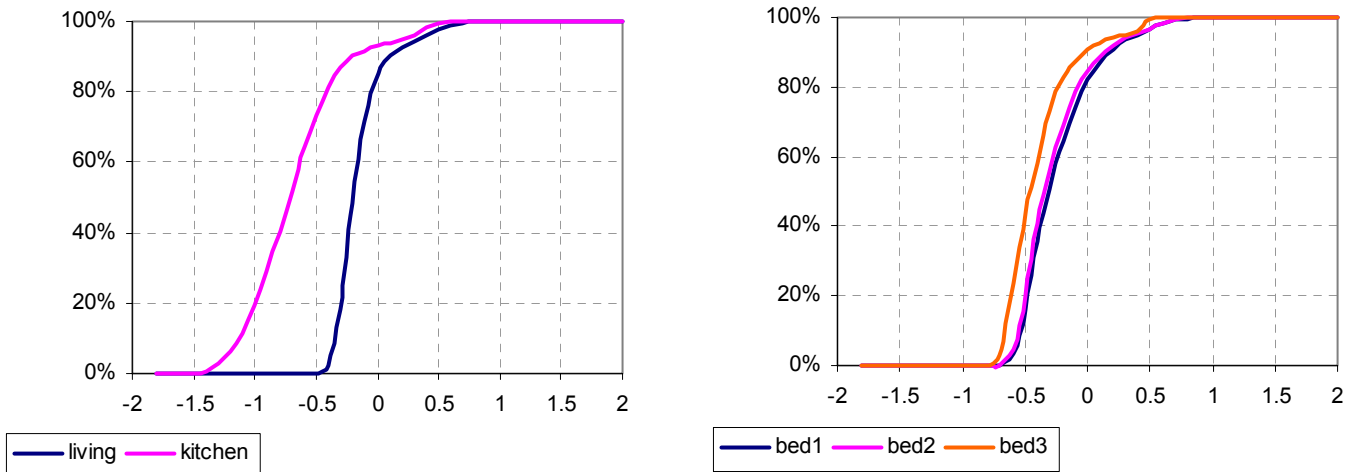
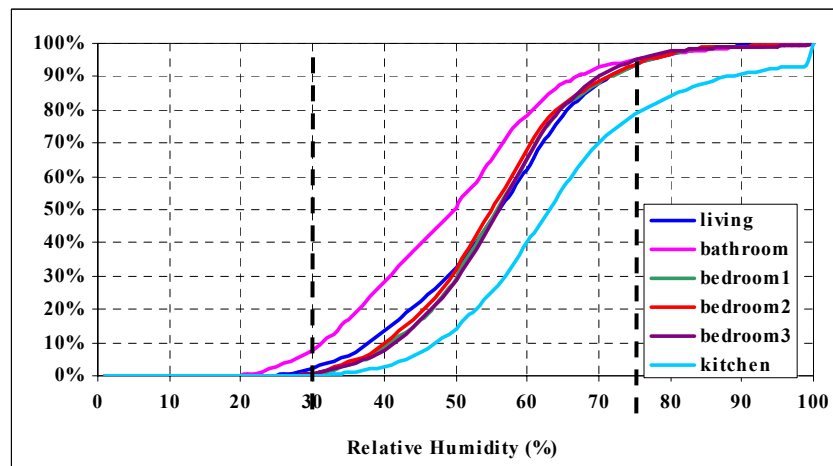


Figure 11-30 – Cumulative frequency of PMV during all year

11.2.6. Relative Humidity

Figure 11-31 shows annual cumulative frequency of relative humidity.



--- Relative Humidity Limits

Figure 11-31 – Cumulative frequency of relative humidity

11.2.7. Absolute humidity

Figure 11-32 shows annual cumulative frequency of absolute humidity.

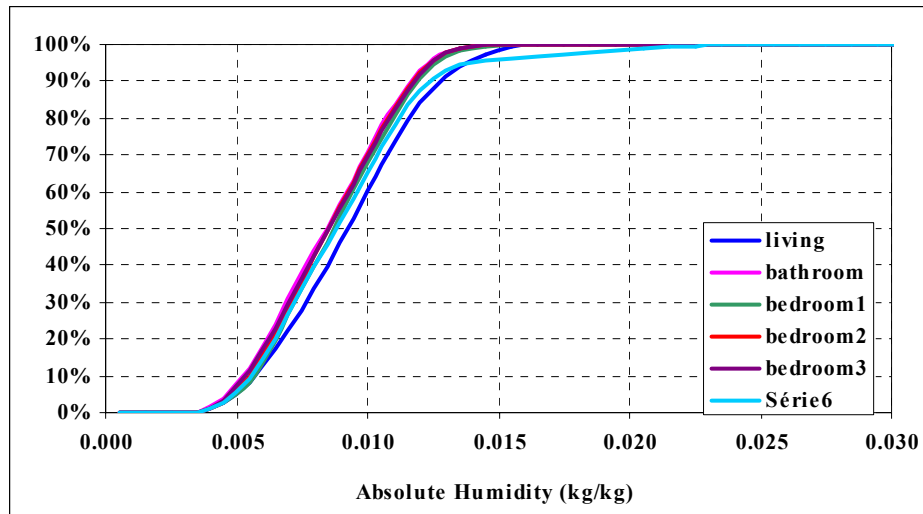


Figure 11-32 – Cumulative frequency of absolute humidity

11.3. System III

11.3.1. Heating Energy consumption

Table 11-9 shows the total energy consumption during heating season. The monthly heating energy consumption (October – April) and the losses due to the ventilation are shown in figure 11-33.

	kWh/year	kWh/m ² .year
Heating Energy consumption	3541	41.7
Ventilation losses energy	2310	27.18

Table 11-9 - Heating energy consumption

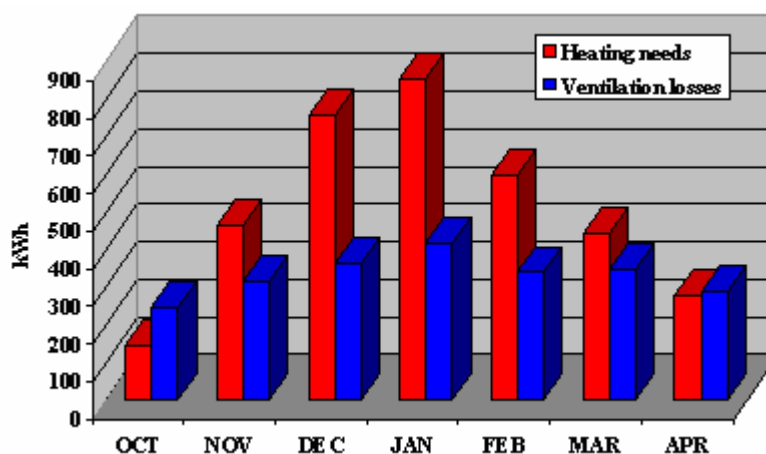


Figure 11-33 - Heating consumption evolution along the heating period

11.3.2. Energy consumption of the fans

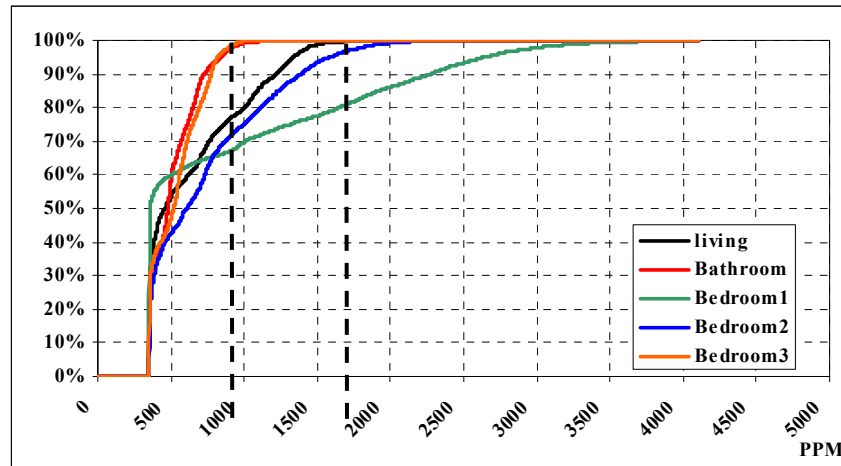
Table 11-10 shows the total energy consumption due to the fans during the whole year. The system has two equal fans for exhaust air flow and the total power consumption is 82 W.

Fans Energy consumption	Porto
kWh/year	490.6
kWh/m ² .year	5.77

Table 11-10 - Fan energy consumption

11.3.3. CO₂ Concentration

Figure 11-34 shows the annual cumulative frequency of the CO₂ concentration. It was assumed that the concentration of outdoor CO₂ is equal to 350 ppm (reference value).



--- Concentration limits (1050 and 1750 ppm)

Figure 11-34 - Cumulative frequency of CO₂ concentration

The mean values of the CO₂ concentration measured in the different zones of the building are the following.

	CO ₂ annual mean values [ppm]	CO ₂ annual maximum values [ppm]
Living	640	2087
Kitchen	528	1107
WC	547	987
Bathroom	511	1205
Bedroom 1	890	4194
Bedroom 2	736	2518
Bedroom 3	527	1059
Hall	567	1038

Table 11-11 - CO₂ annual values analysis

The figure 11-35 shows the value CO₂ concentration in kppm.h, i.e., hours above concentration limit (1050 ppm) multiplied by the exceeding CO₂ difference. The target value for this parameter is 500 kppm.h (values proposed in [3]).

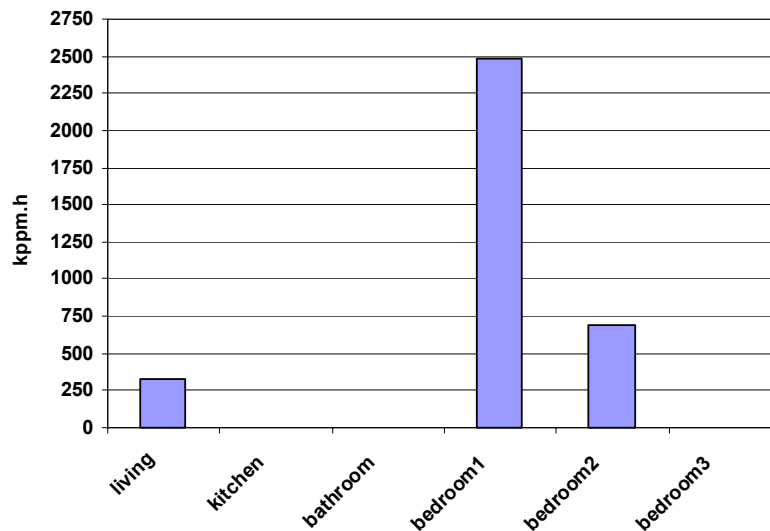


Figure 11-35 - CO₂ concentration exceeding (kppm.h)

11.3.4. Exhaust air flow rate

The minimum and maximum exhaust air flow rate (wet rooms) is shown in table 11-12 and the figure 11-36 represents the frequency of the exhaust air flow rate for different rooms.

	Desired air flows	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Kitchen	100	33.4	109.5	82.9	33.4	109.5	82.7
WC	50	19.56	59.5	41.8	19.6	59.5	41.7
Bathroom	50	20.65	53.0	41.0	20.6	52.6	40.7

Table 11-12 –Minimum and maximum values of airflow exhaust, [m³/h]

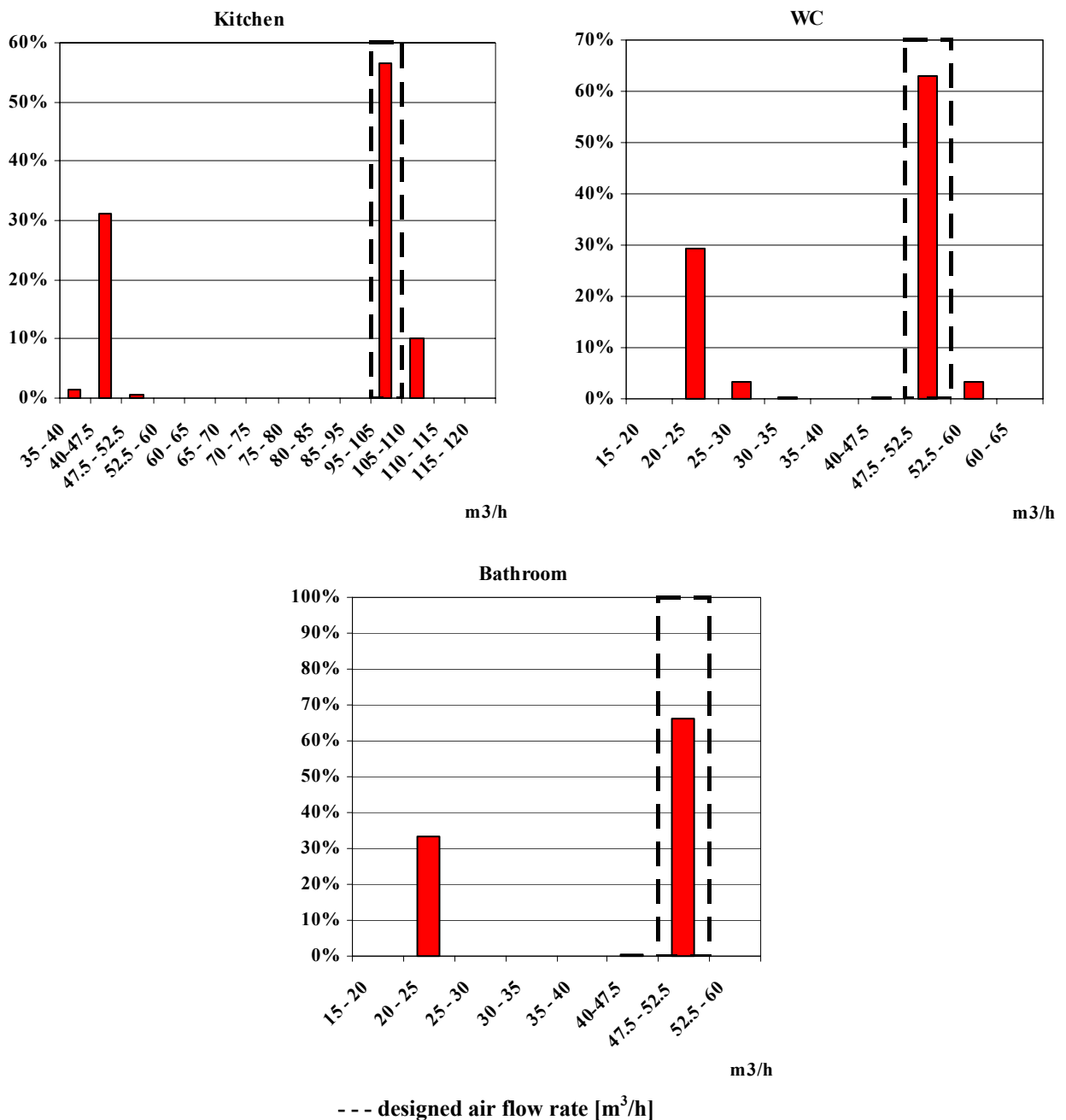


Figure 11-36 - Frequency of exhaustion air flows

The exhaust airflow rates of all rooms for a typical heating month (January) and a typical cooling month (July) are presented in figure 11-37 and figure 11-38 as generic airflow month distribution.

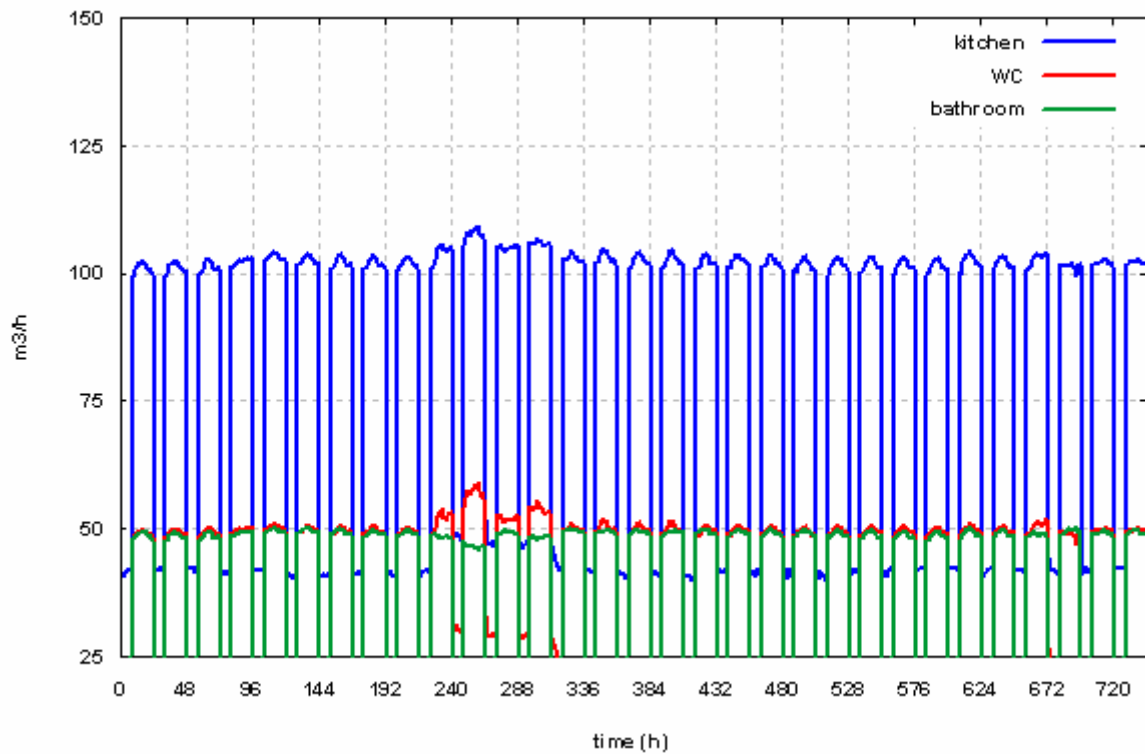


Figure 11-37 – Exhaustion air flow – January

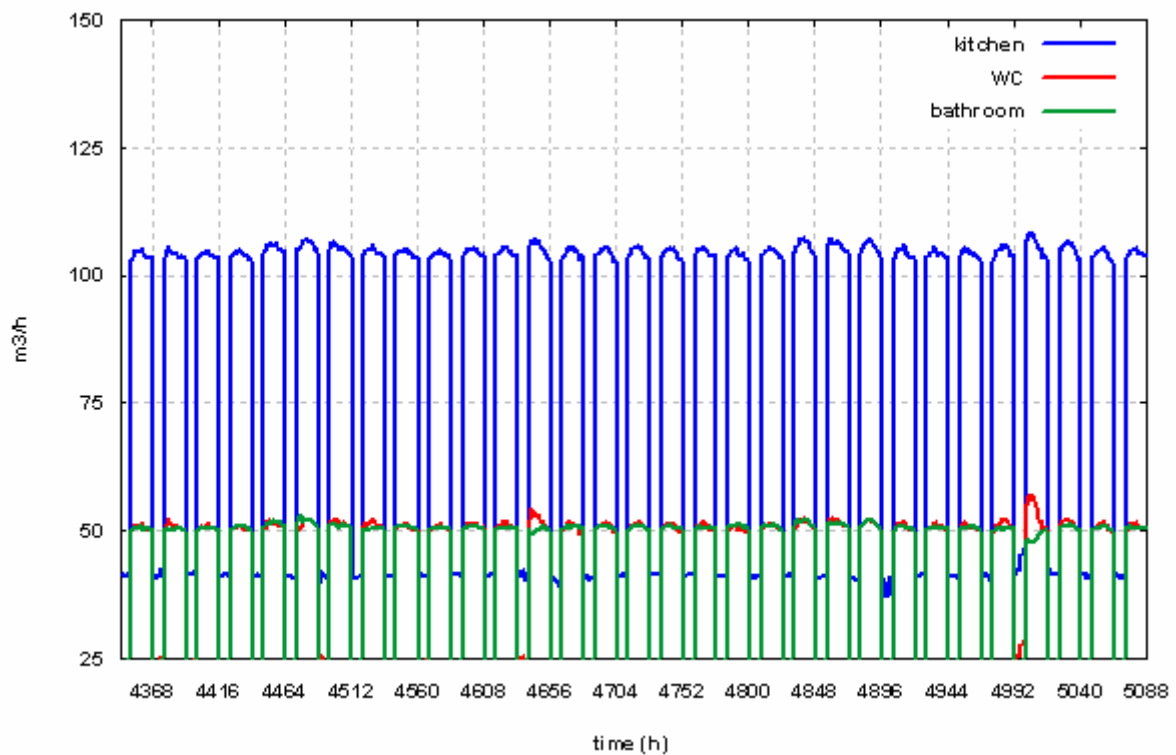


Figure 11-38 – Exhaustion air flow – July

11.3.5. Inlet air flow rate through grilles and cracks

The inlet air flow rate in habitable rooms is shown in table 11-13 and the figure 11-39 represents the frequency of the inlet air flow rate for different rooms.

	Desired	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Living room	90	0.0	199.2	57.9	0.0	199.2	58.0
Bedroom 1	45	0.0	183.3	32.2	0.0	183.3	32.3
Bedroom 2	45	0.0	98.8	21.2	0.0	98.8	20.9
Bedroom 3	45	0.0	170.9	35.7	0.0	170.9	37.2

Table 11-13 –Minimum and maximum values of outdoor airflow inlet [m³/h]

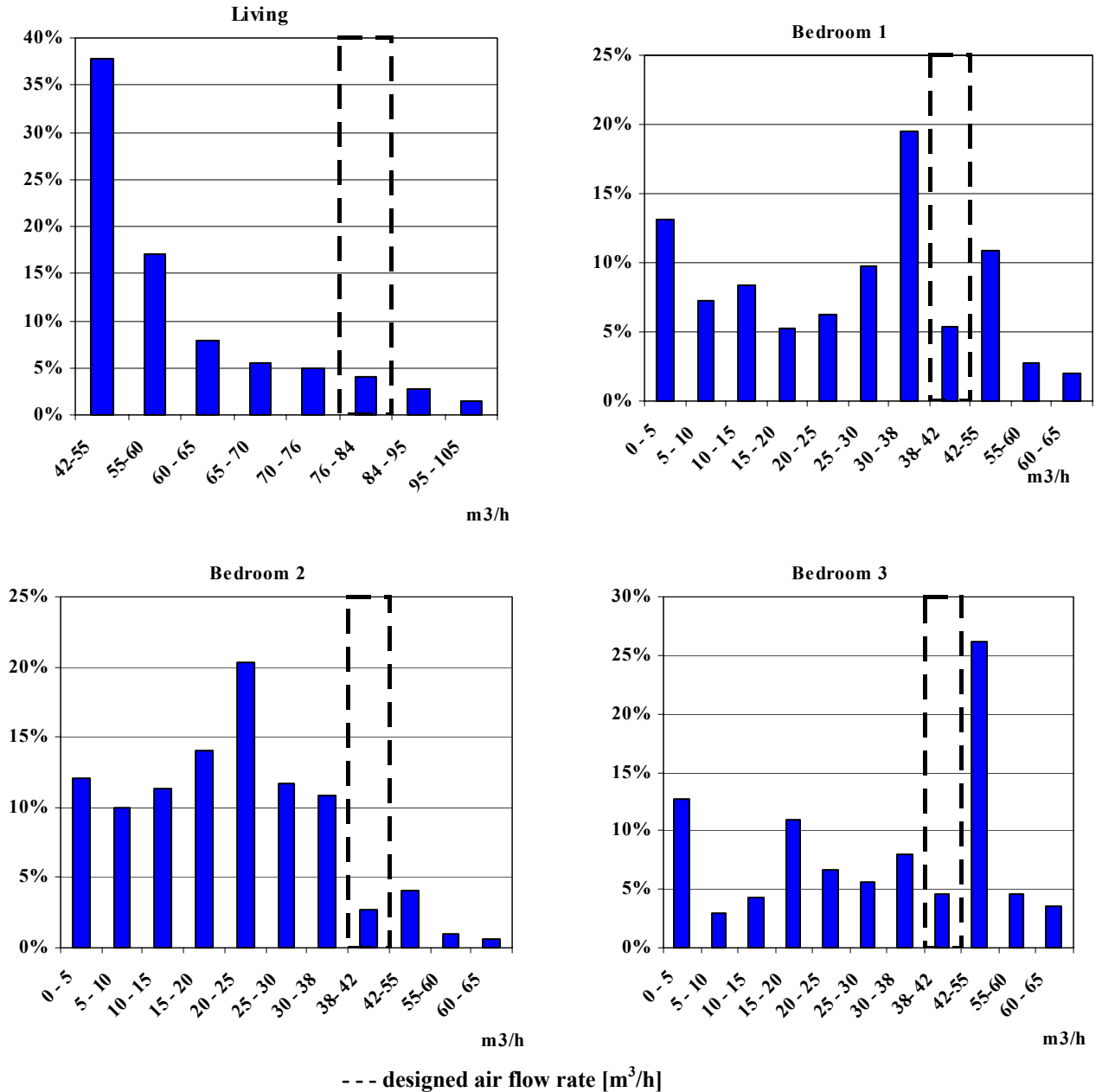


Figure 11-39 - Frequency of admission air flows

The inlet air flow rate for all rooms and for a typical heating month (January) and a typical cooling month (July) is presented in figure 11-40 and Figure 11-41 as generic air flow month distribution.

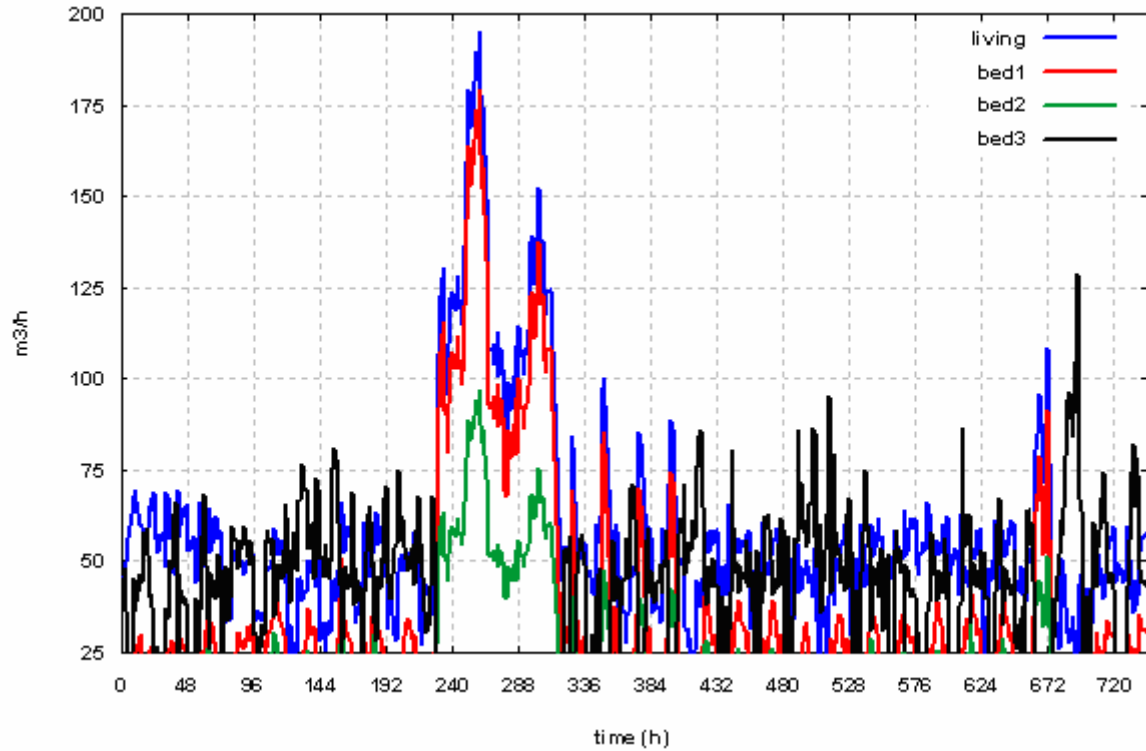


Figure 11-40 – Inlet air flow – January

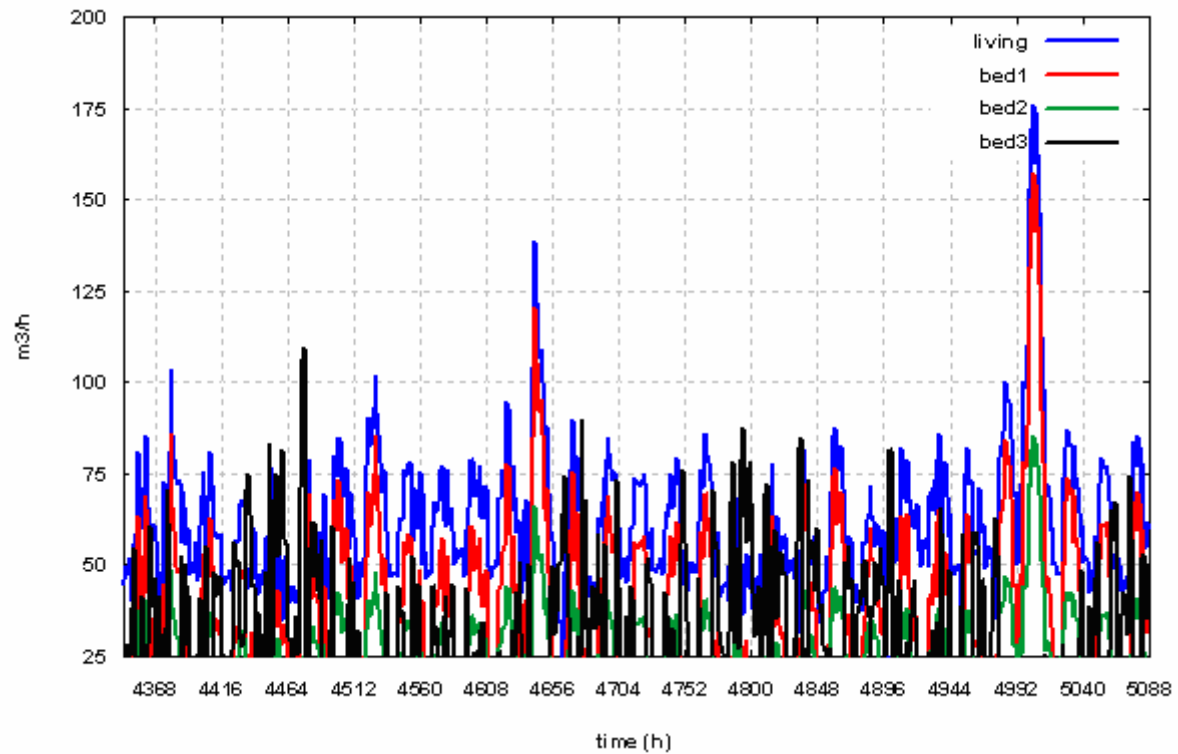
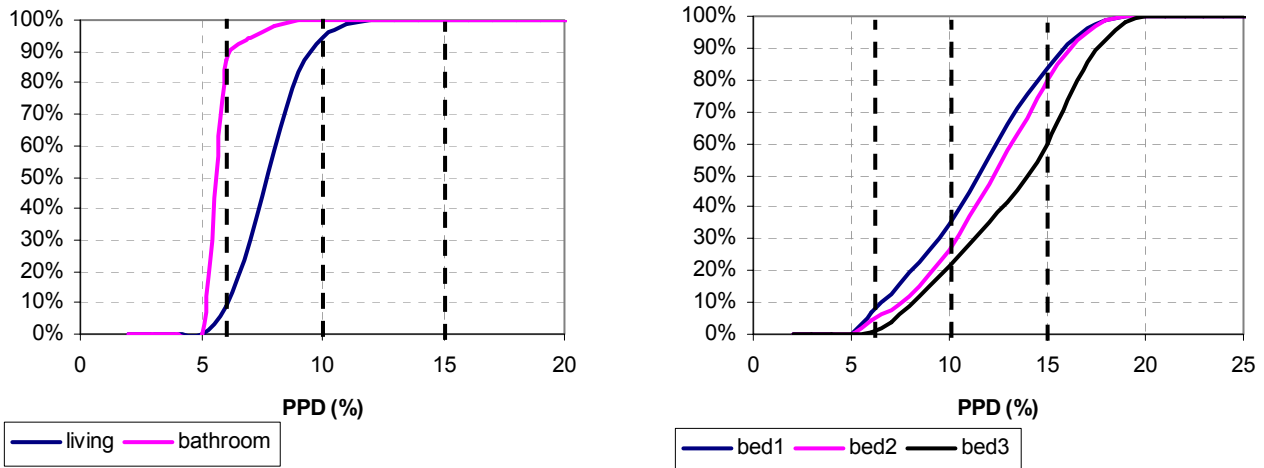


Figure 11-41 – Inlet air flow – July

11.3.6. Thermal Comfort PPD

Figure 11-42 is possible to observe the Cumulative frequency of PPD for the heating season.



--- Thermal Comfort PPD Classes
 Figure 11-42 – Cumulative frequency of PPD

The Predicted Percentage of Dissatisfied Person (PPD) is mainly related to the thermal comfort. It would be desirable that for a level of PPD lower than 15 % (which means that only 15 % of the persons present in the zone are uncomfortable) the values in figure 6-3 are near the 100 %.

According to the performance criteria imposed by the RESHYVENT, the values of PPD were evaluated in three classes:

- Class 1: % hours with PPD \leq 6 %;
- Class 2: % hours with PPD \leq 10 %;
- Class 3: % hours with PPD \leq 15 %
- Class 4: % hours with PPD > 15 %.

The following table shows lesser hours percentage that theoretically should be reached. This happen because there are hours where the temperature exceeds the limits initially predefined (set point temperatures), as seen in next tables.

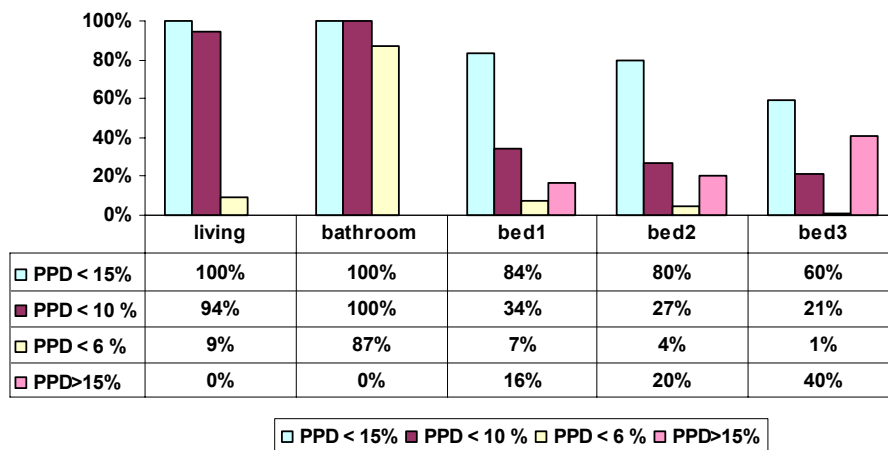


Figure 11-43 – PPD distribution for the several classes - annual values

The Cumulative frequency of the temperature is shown in Figure 11-44.

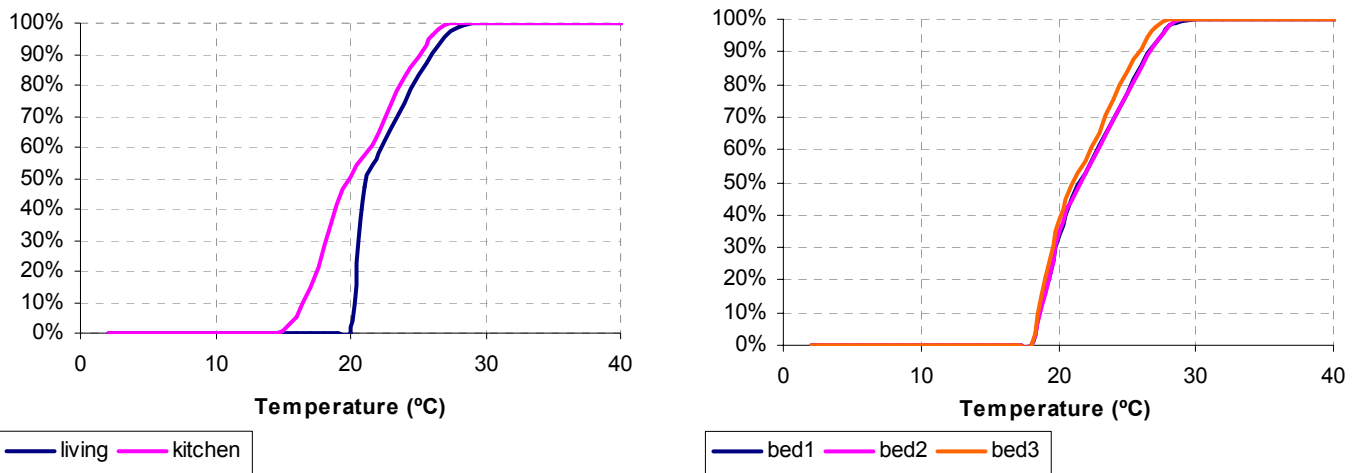


Figure 11-44 – Cumulative frequency of temperature during all year

Figure 11-45 shows the cumulative frequency of PMV (Predicted Mean Vote).

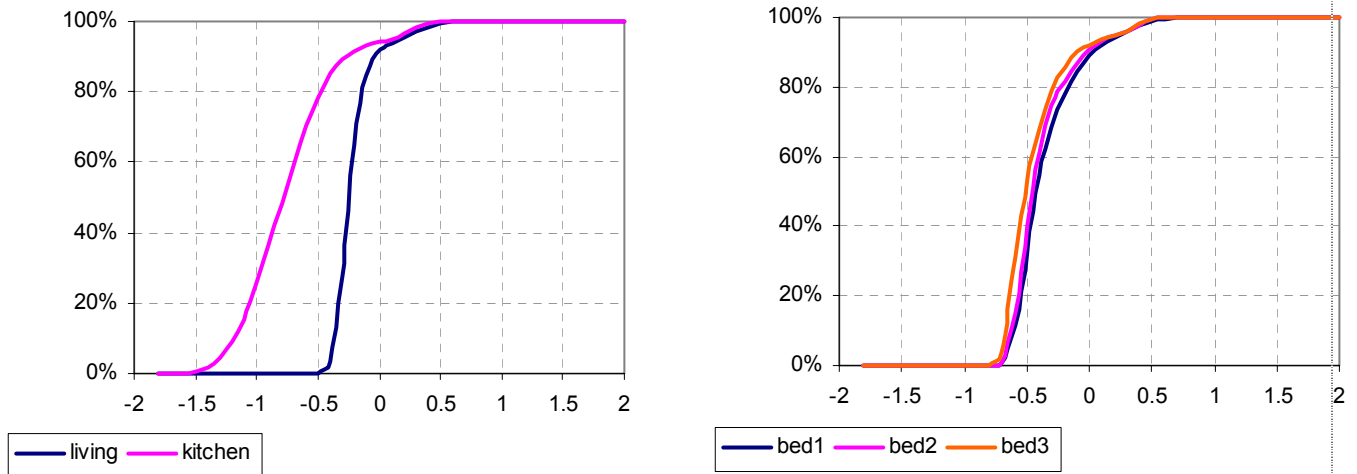
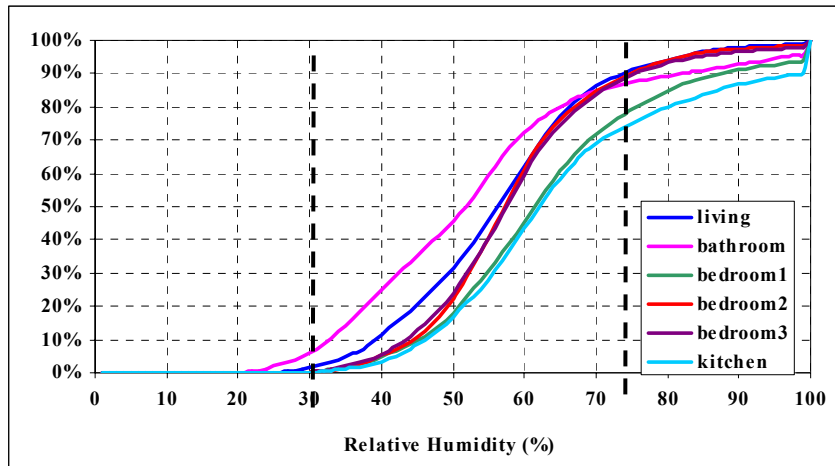


Figure 11-45 – Cumulative frequency of PMV during all year

11.3.7. Relative Humidity

Figure 11-46 shows annual cumulative frequency of relative humidity.



--- Relative Humidity Limits
 Figure 11-46 – Cumulative frequency of Relative Humidity

11.3.8. Absolute humidity

The figure 11-47 shows annual cumulative frequency of absolute humidity.

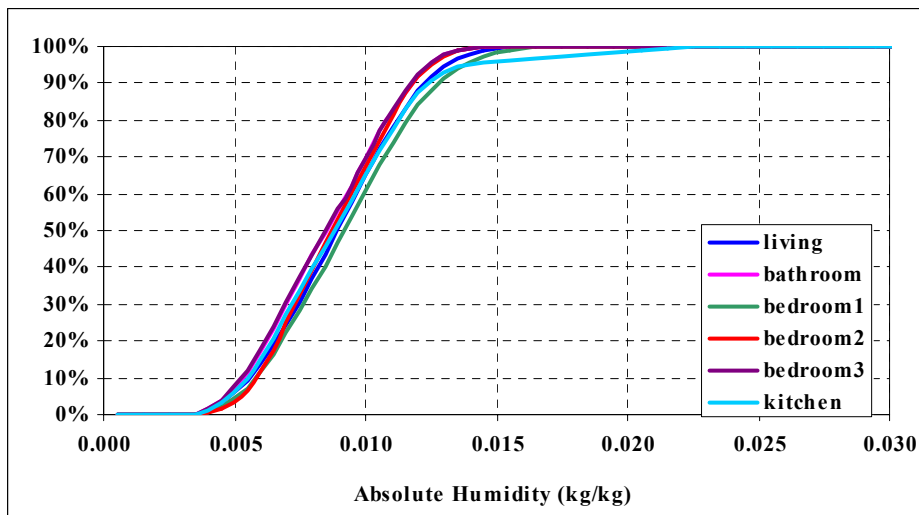


Figure 11-47 - Cumulative frequency of Absolute Humidity

11.4. System IV

11.4.1. Heating Energy consumption

Table 11-14 shows the total energy consumption during heating season. The monthly heating energy consumption (October – April) and the losses due to the ventilation are shown in figure 11-48.

	kWh/year	kWh/m ² .year
Heating Energy consumption	3364.9	39.6
Ventilation losses energy	2055	24.2

Table 11-14 - Heating energy consumption

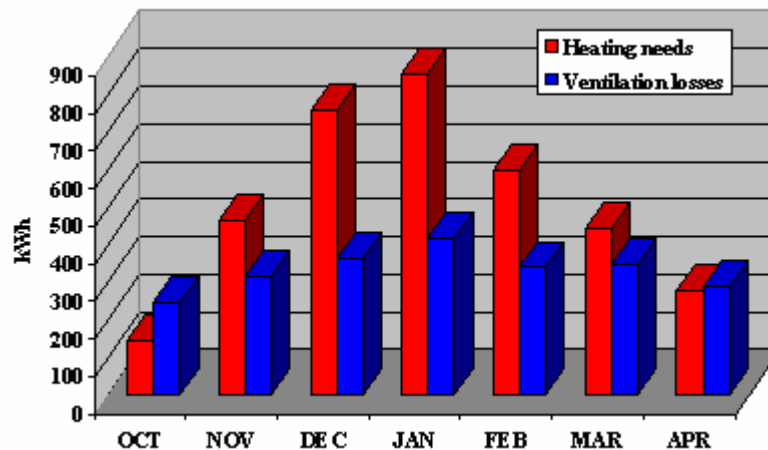


Figure 11-48 - Heating consumption evolution along the heating period

11.4.2. Energy consumption of the fans

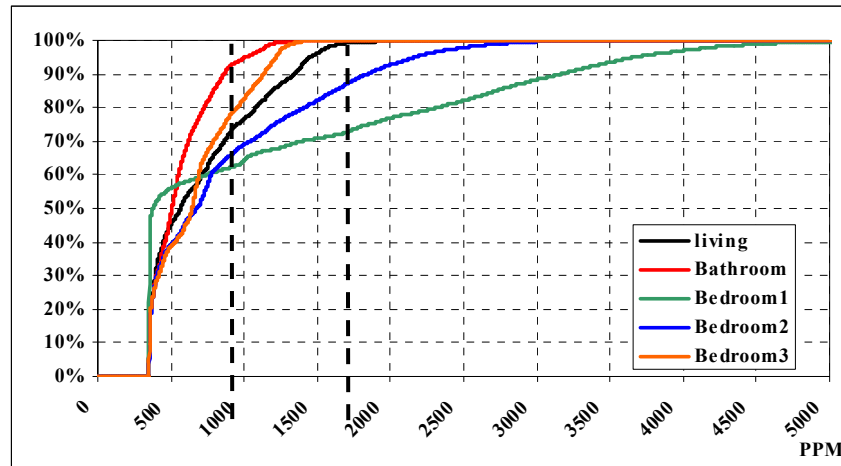
Table 11-15 shows the total energy consumption due to the fans during the whole year. The system has two equal fans for exhaust air flow and the total power consumption is 82 W.

Fans Energy consumption	Porto
kWh/year	490.6
kWh/m ² .year	5.77

Table 11-15 - Fan energy consumption

11.4.3. CO₂ Concentration

Figure 11-49 shows the annual cumulative frequency of the CO₂ concentration in the heating period. It was assumed that the concentration of outdoor CO₂ is equal to 350 ppm (reference value).



--- Concentration limits (1050 and 1750 ppm)

Figure 11-49 - Cumulative frequency of CO₂ concentration

The mean values of the CO₂ concentration measured in the different zones of the building are the following.

	CO ₂ annual mean values [ppm]	CO ₂ annual maximum values [ppm]
Living	688	2299
Kitchen	574	1343
WC	623	1272
Bathroom	544	1337
Bedroom 1	1096	6039
Bedroom 2	839	3613
Bedroom 3	643	1410
Hall	667	1485

Table 11-16 - CO₂ annual mean values

Figure 11-50 shows the value CO₂ concentration in kppm.h, i.e., hours above concentration limit (1050 ppm) multiplied by the exceeding CO₂ difference. The target value for this parameter is 500 kppm.h (values proposed in [3]).

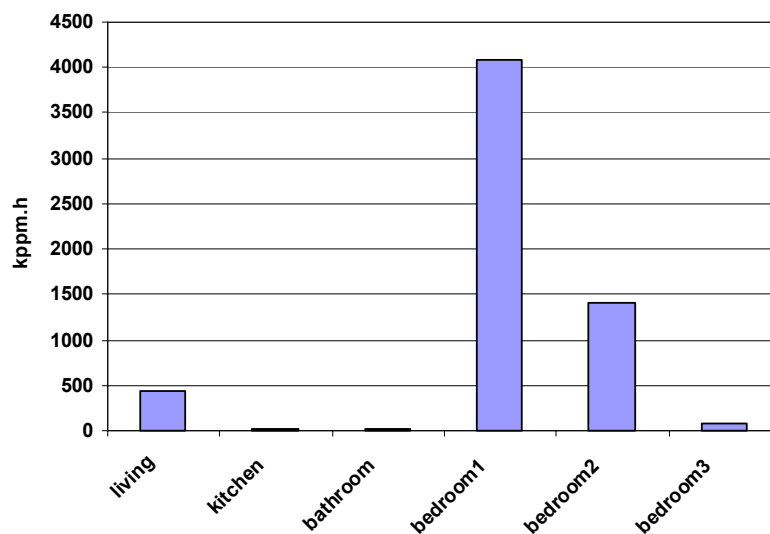


Figure 11-50 - CO₂ concentration exceeding (kppm.h)

11.4.4. Exhaust air flow rate

The minimum and maximum exhaust air flow rates (wet rooms) are shown in table 11-17 and the figure 11-51 represents the frequency of the exhaust air flow rate for different rooms.

	desired air flow	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Kitchen	100	34.51	108.00	82.47	34.51	108.00	82.24
WC	50	17.49	56.73	40.42	17.49	56.73	40.37
Bathroom	50	19.46	52.89	40.68	19.46	52.48	40.43

Table 11-17 –Minimum and maximum values of airflow exhaust [m³/h]

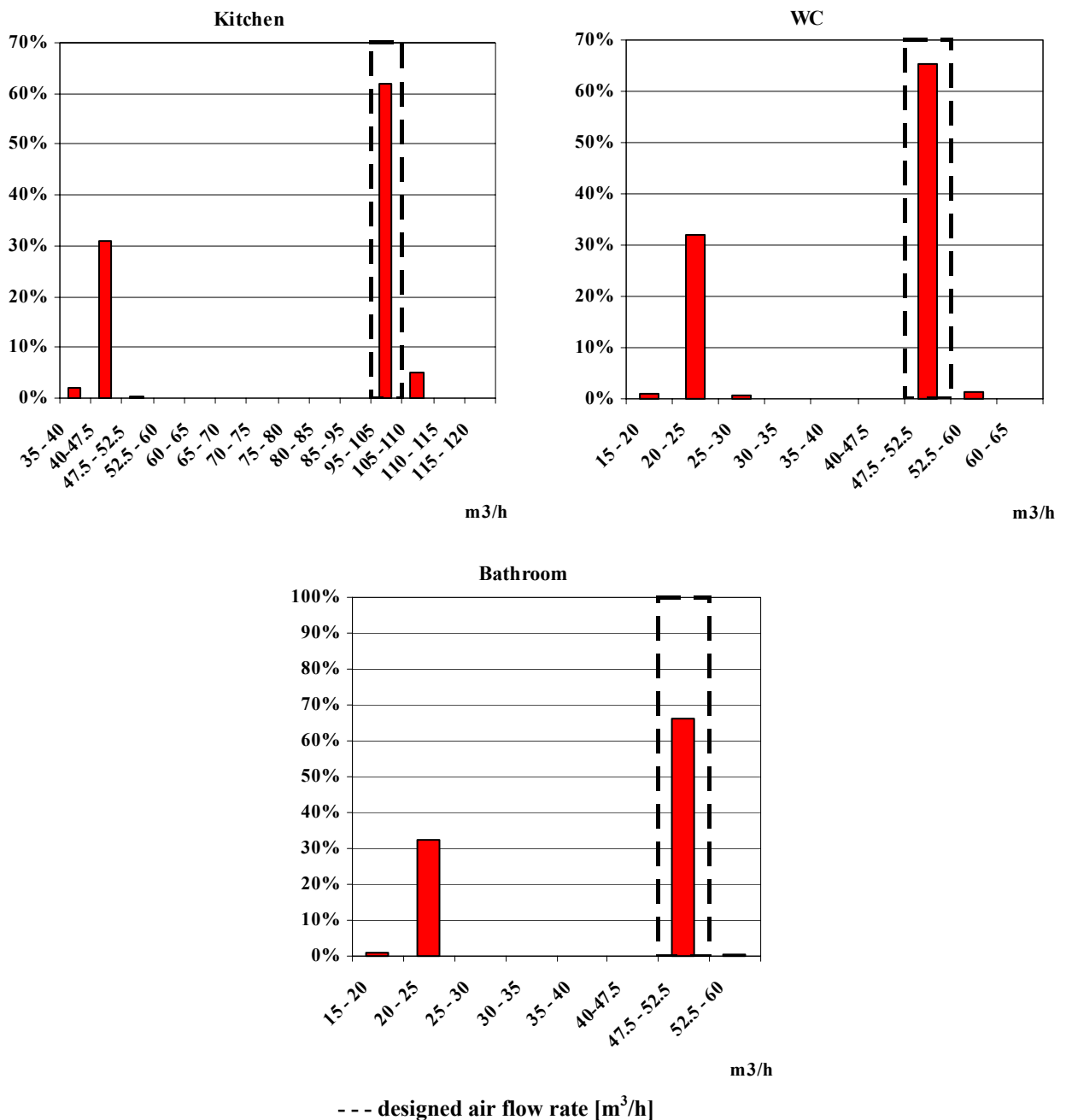


Figure 11-51 - Frequency of exhaustion air flows

The exhaust air flow rate for all rooms for a typical heating month (January) and cooling month (July) is presented in figure 11-52 and figure 11-53 as generic air flow month distribution.

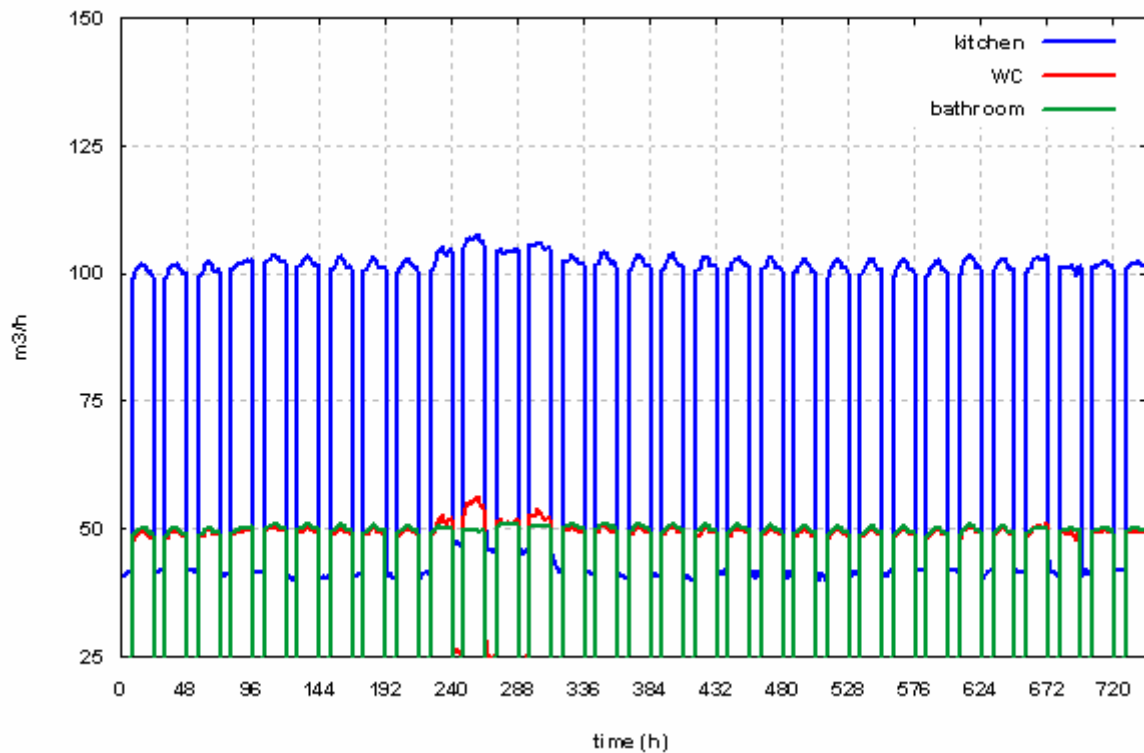


Figure 11-52 – Exhaustion air flow – January

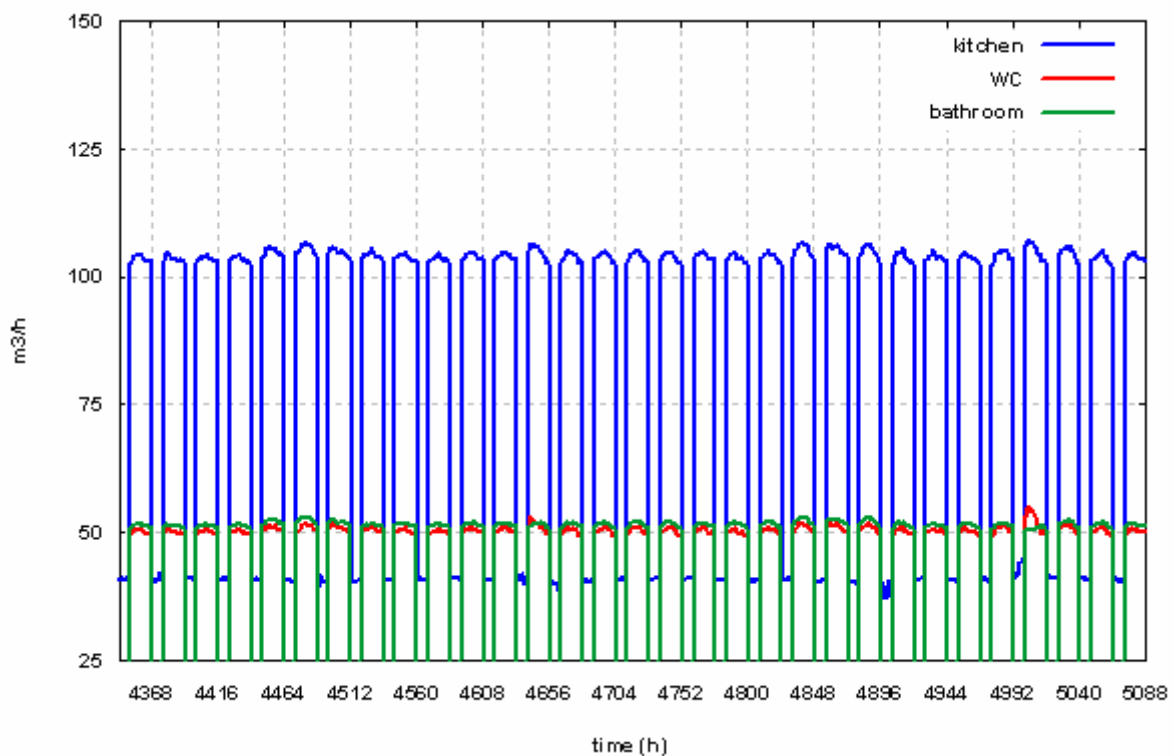


Figure 11-53 – Exhaustion air flow – July

11.4.5. Inlet air flow rate through grilles and cracks

The inlet air flow rate in habitable rooms can reach the maximum of the 182.35 m³/h (Living room) and a minimum of 0 m³/h (in all rooms) as it is shown in table 11-18. The figure 11-54 represents the frequency of the inlet air flow rate for different rooms.

	desired	Year minimum	Year maximum	Average (Year)	Winter minimum	Winter maximum	Average (Winter)
Living	90	0.0	182.3	46.1	0.0	182.3	46.5
Bedroom 1	45	0.0	121.0	24.3	0.0	121.0	24.6
Bedroom 2	45	0.0	88.0	18.3	0.0	88.0	18.4
Bedroom 3	45	0.0	91.9	20.2	0.0	91.9	20.7

Table 11-18 –Minimum and maximum values of outdoor airflow inlet [m³/h]

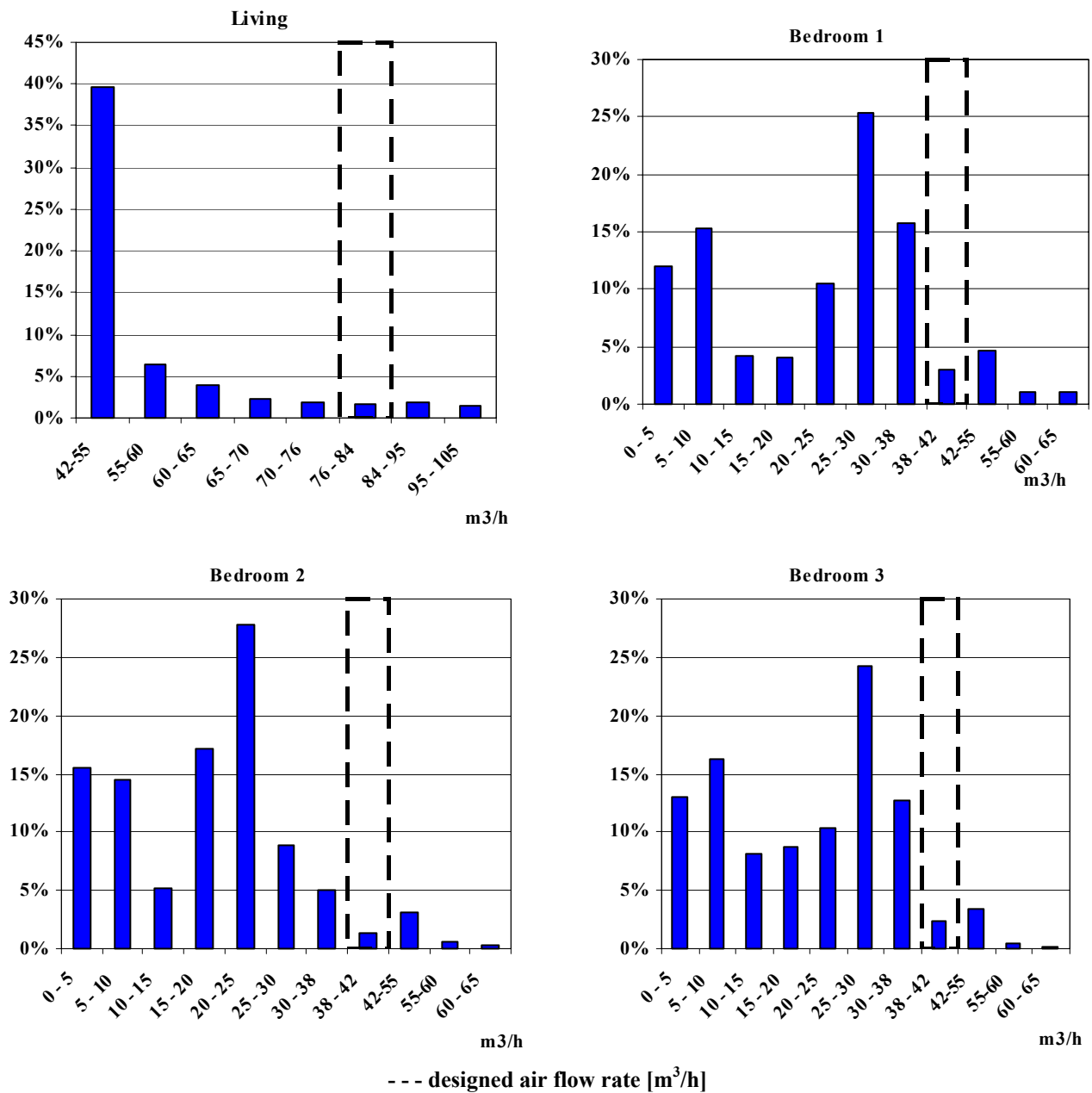


Figure 11-54 - Frequency of admission air flows

The inlet air flow rate for all rooms and for a typical heating month (January) and a typical cooling month (July) is presented in figure 11-55 and figure 11-56 as generic air flow month distribution.

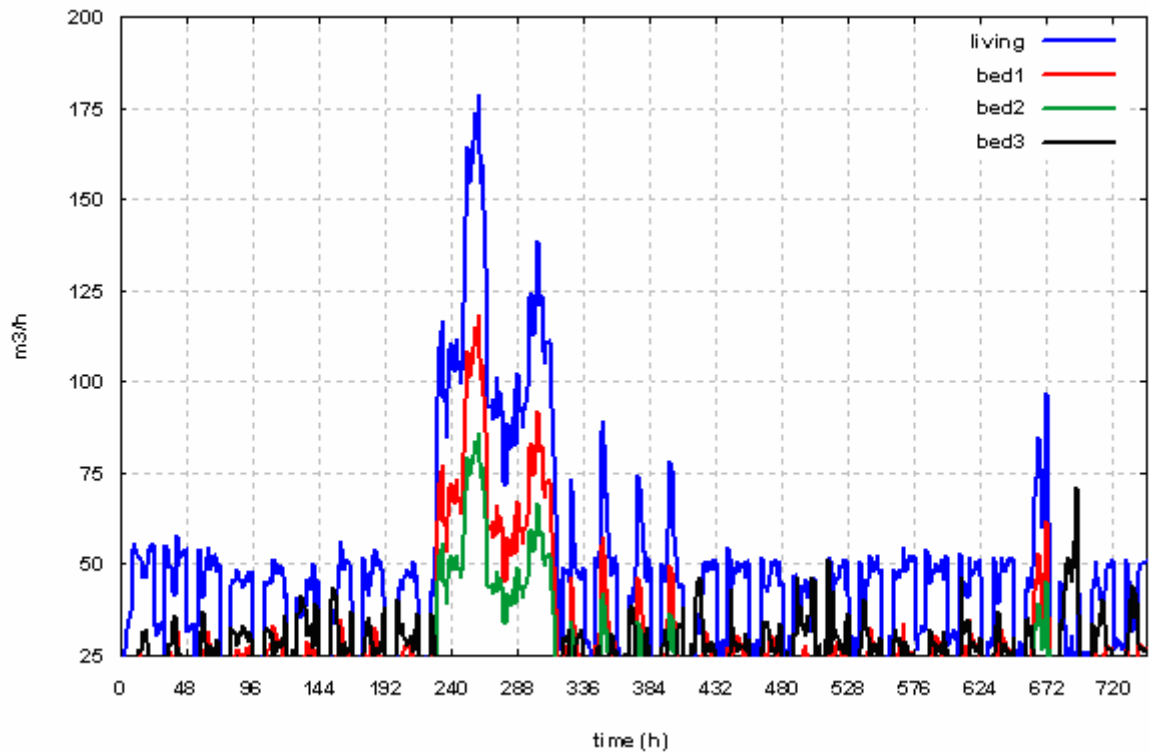


Figure 11-55 – Inlet air flow – January

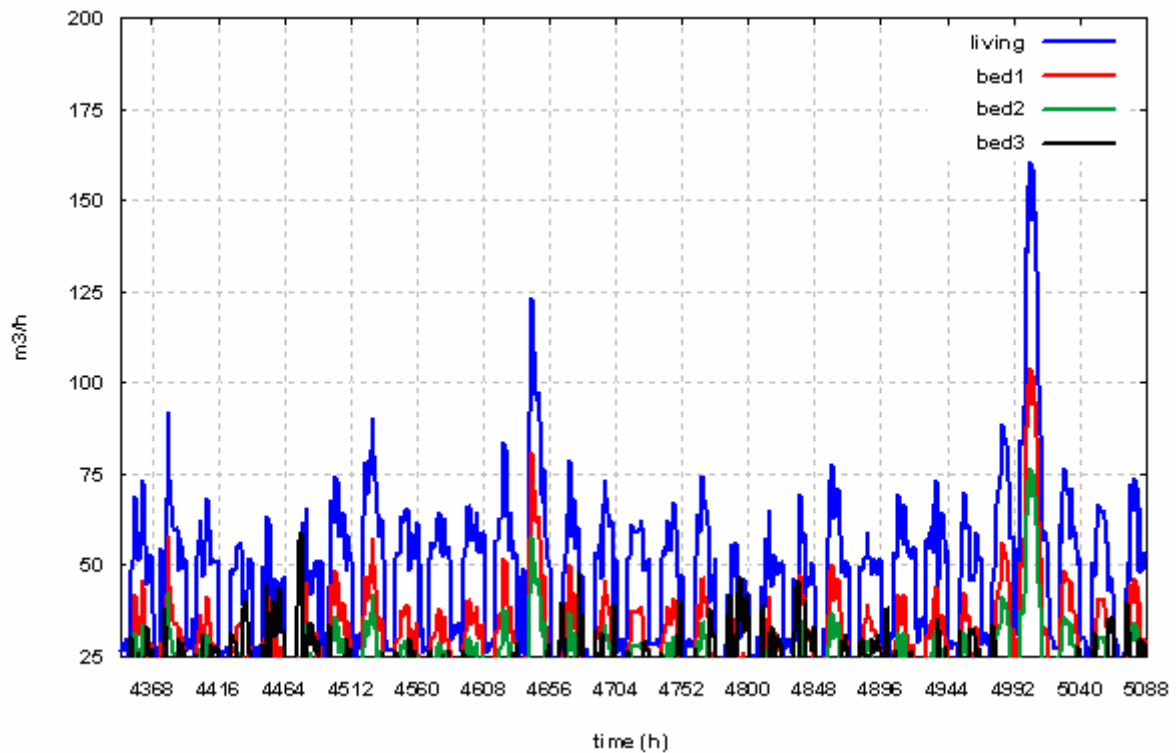
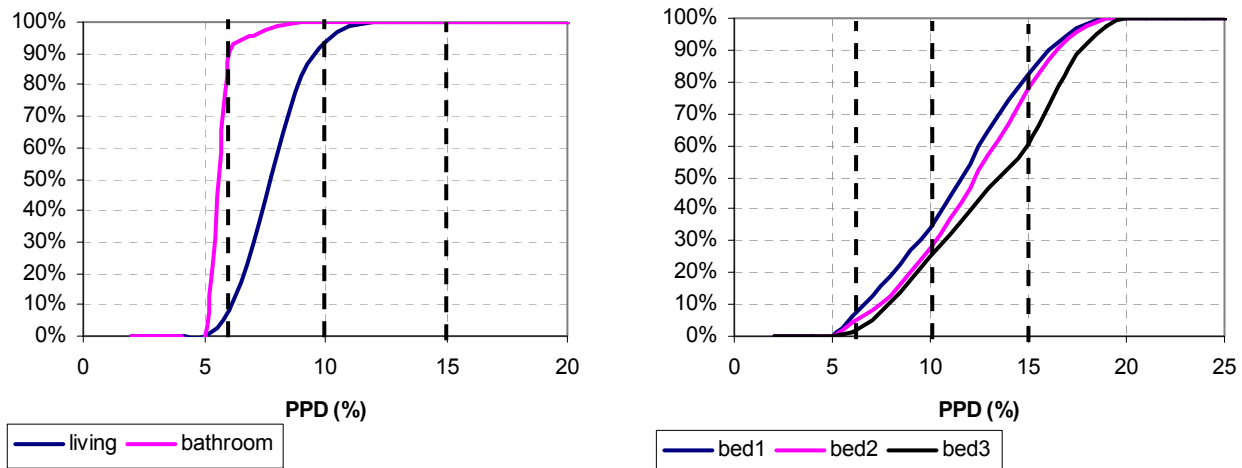


Figure 11-56 – Inlet air flow – July

11.4.6. Thermal Comfort PPD

Figure 11-57 is possible to observe the Cumulative frequency of PPD for the heating season.



--- Thermal Comfort PPD Classes
 Figure 11-57 – Cumulative frequency of PPD

The Predicted Percentage of Dissatisfied Person (PPD) is mainly related to the thermal comfort. It would be desirable that for a level of PPD lower than 15 % (which means that only 15 % of the persons present in the zone are uncomfortable) the values in figure 6-3 are near the 100 %.

According to the performance criteria imposed by the RESHYVENT, the values of PPD were evaluated in three classes:

- Class 1: % hours with PPD \leq 6 %;
- Class 2: % hours with PPD \leq 10 %;
- Class 3: % hours with PPD \leq 15 %
- Class 4: % hours with PPD > 15 %.

The following table shows lesser hours percentage that theoretically should be reached. This happen because there are hours where the temperature exceeds the limits initially predefined (set point temperatures), as seen in next tables.

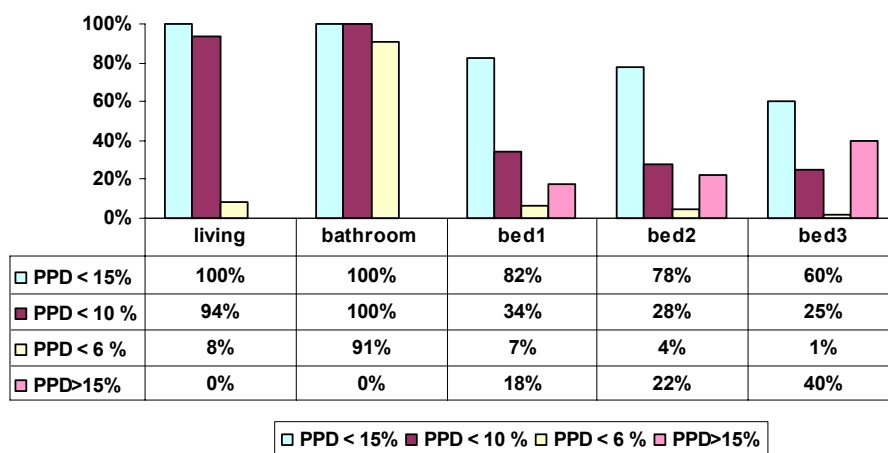


Figure 11-58 – PPD distribution for the several classes – annual values

The Cumulative frequency of the temperature is shown in Figure 11-59.

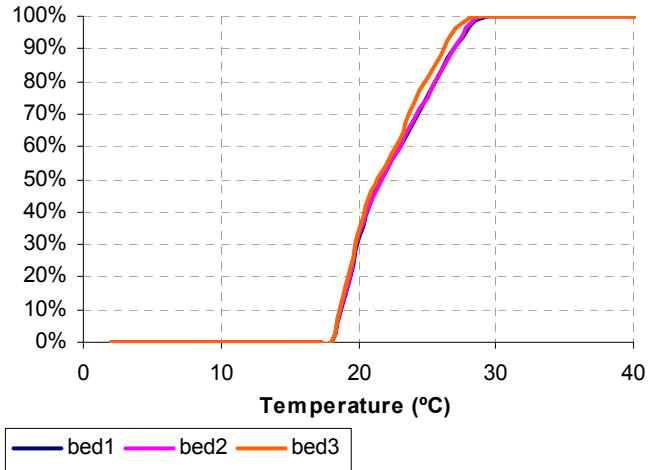
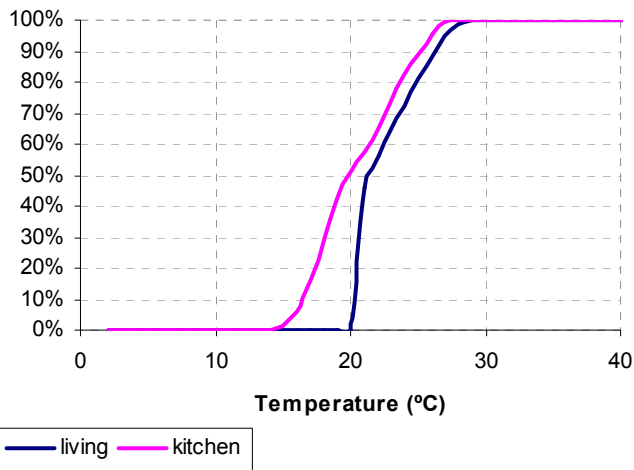


Figure 11-59 – Cumulative frequency of temperature during all year

Figure 11-60 shows the cumulative frequency of PMV (Predicted Mean Vote).

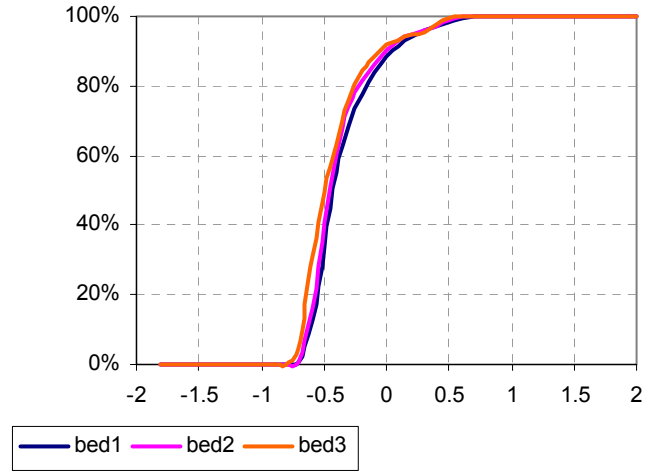
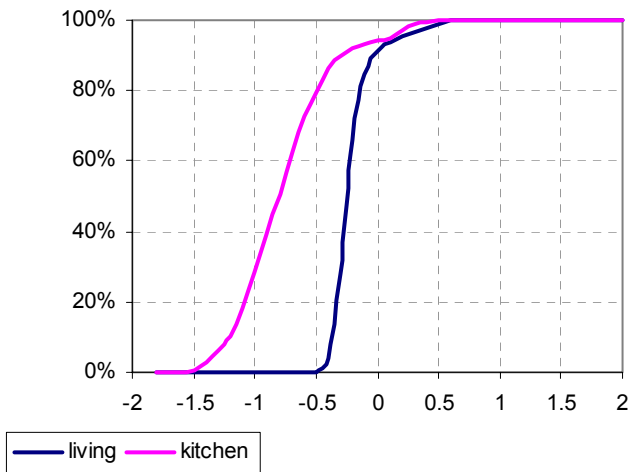
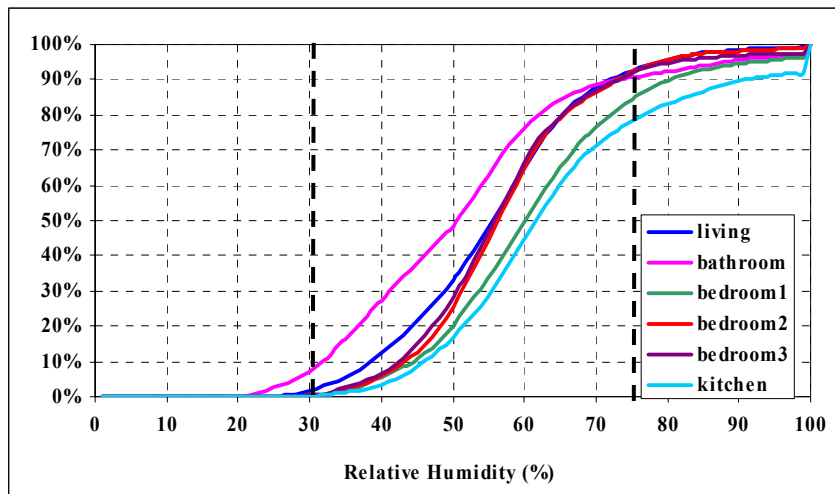


Figure 11-60 – Cumulative frequency of PMV during all year

11.4.7. Relative Humidity

Figure 11-61 shows the cumulative frequency of the Relative Humidity values.



--- Relative Humidity Limits
 Figure 11-61 – Cumulative frequency of Relative Humidity

11.4.8. Absolute humidity

The figure 11-62 shows the cumulative frequency of the Absolute Humidity values.

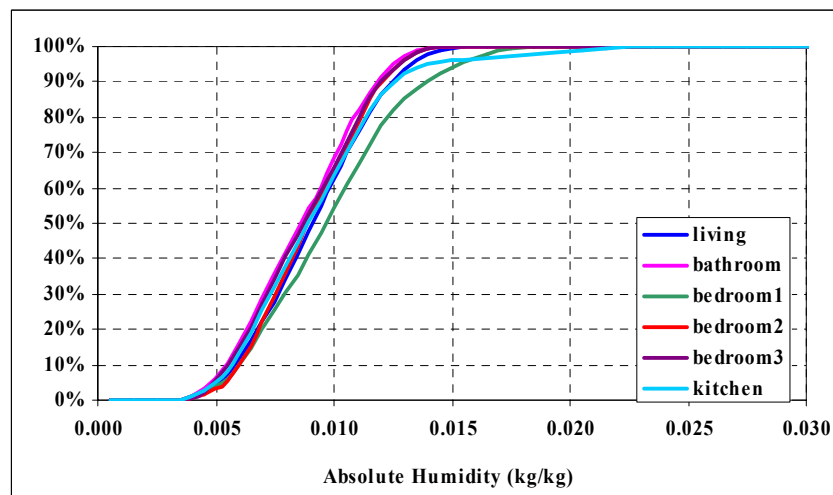


Figure 11-62 - Cumulative frequency of Absolute Humidity

12. Appendix C – Sensitivity Analysis Detailed Results

12.1. Detailed results of orientation analysis

12.1.1. System I

In figure 12-1 and figure 12-2 the heating needs and the ventilation losses for the three cases are compared. In terms of heating needs the best orientation is that with the living room facing South.

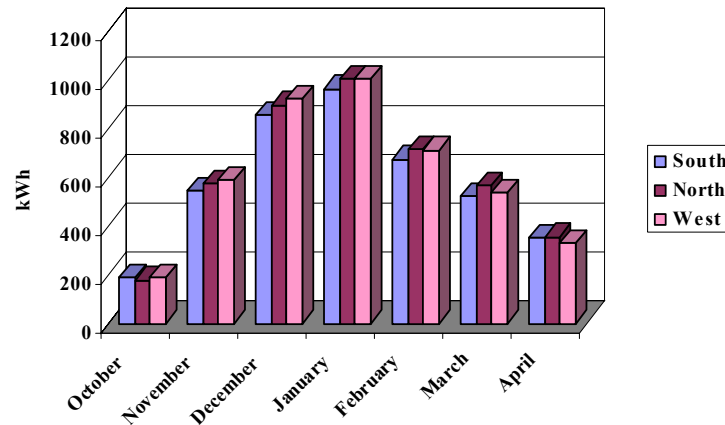


Figure 12-1 – Heating energy needs comparison

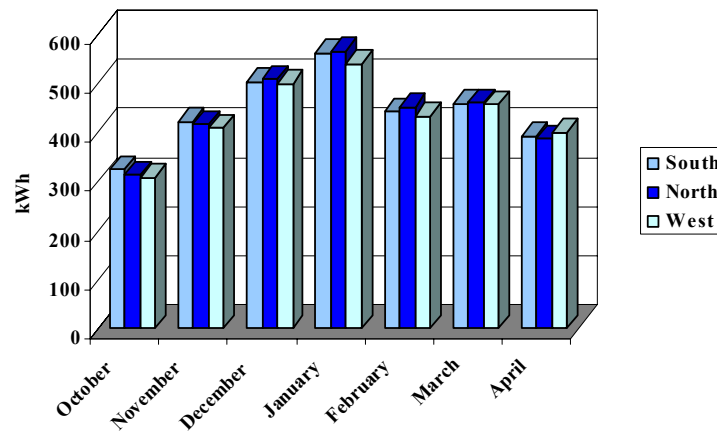


Figure 12-2 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

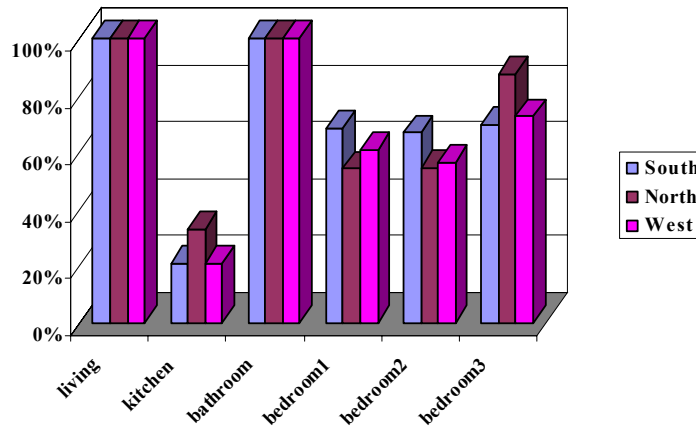


Figure 12-3 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

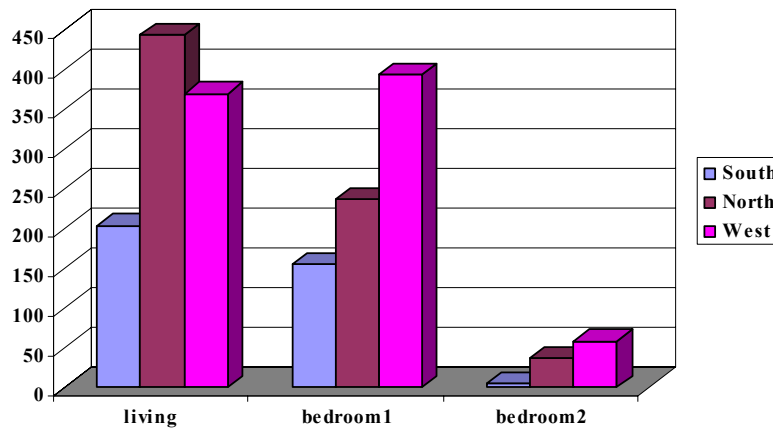


Figure 12-4 - CO₂ concentration comparison

12.1.2. System II

In figure 12-5 and figure 12-6 the heating needs and the ventilation losses for the three cases are compared. In terms of heating needs the best orientation is that with the living room facing South.

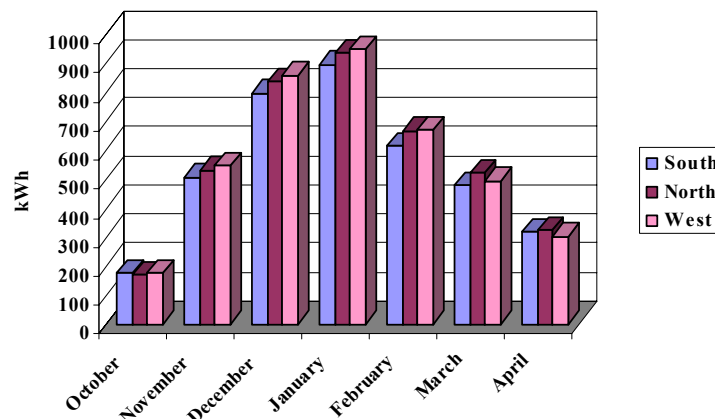


Figure 12-5 - Heating energy needs comparison

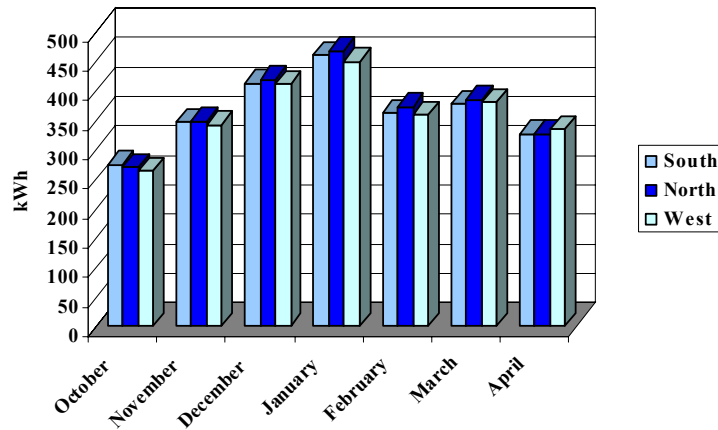


Figure 12-6 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

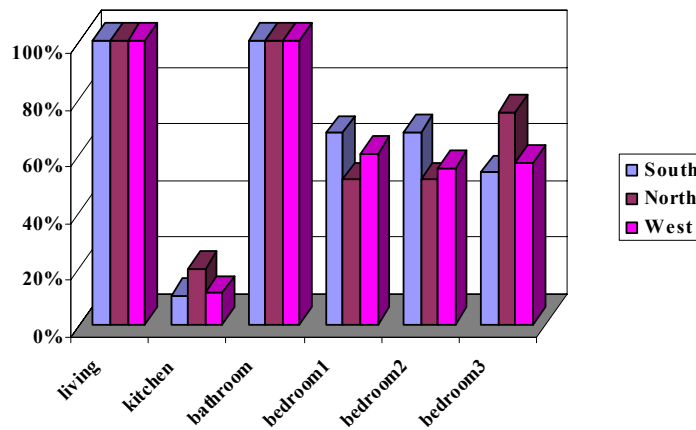


Figure 12-7 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

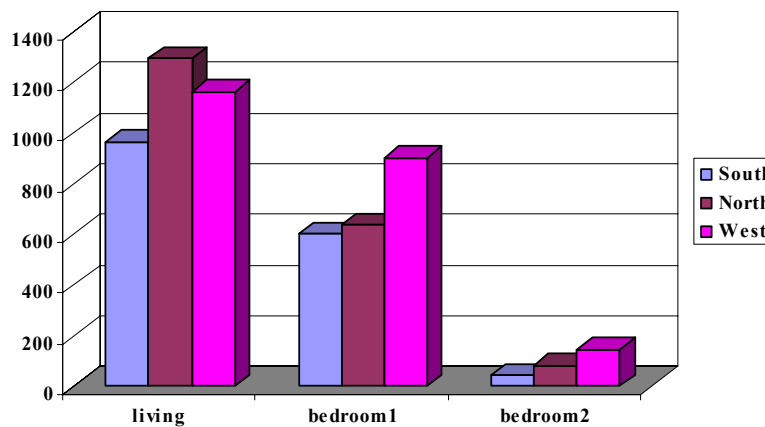


Figure 12-8 - CO₂ concentration comparison

12.1.3. System III

In figure 12-9 and figure 12-10 the heating needs and the ventilation losses for the three cases are compared. In terms of heating needs the best orientation is that with the living room facing South.

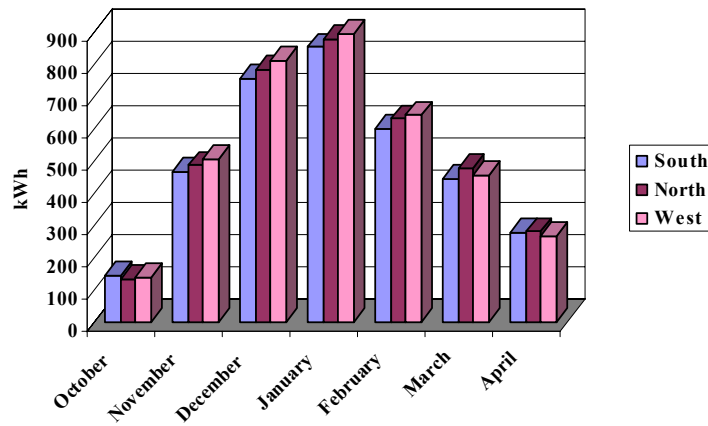


Figure 12-9 - Heating energy needs comparison

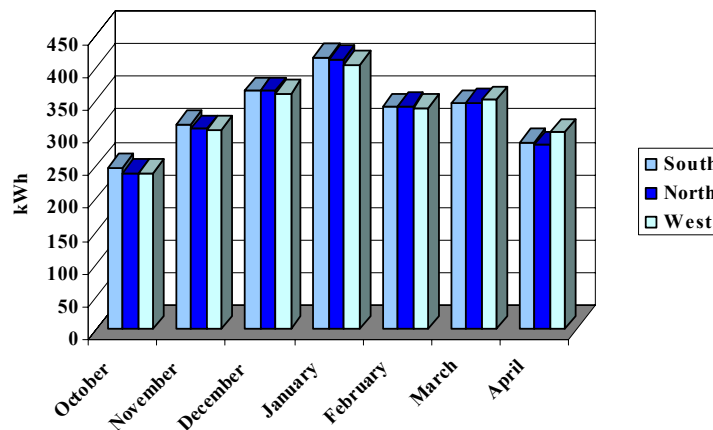


Figure 12-10 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

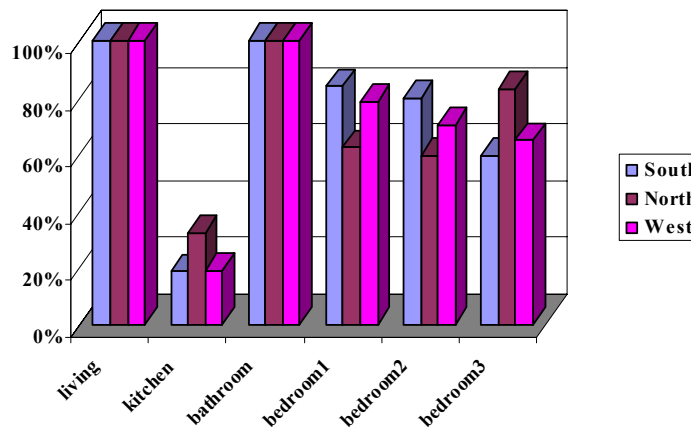


Figure 12-11 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

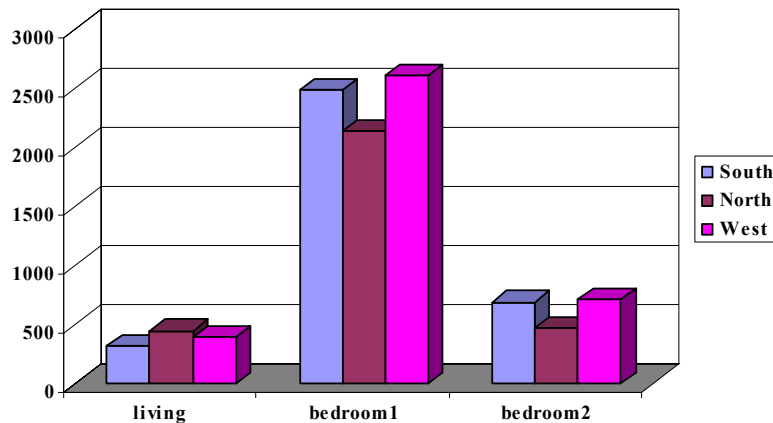


Figure 12-12 - CO₂ concentration comparison

12.1.4. System IV

In figure 12-13 and figure 12-14 the heating needs and the ventilation losses for the three cases are compared. In terms of heating needs the best orientation is that with the living room facing South.

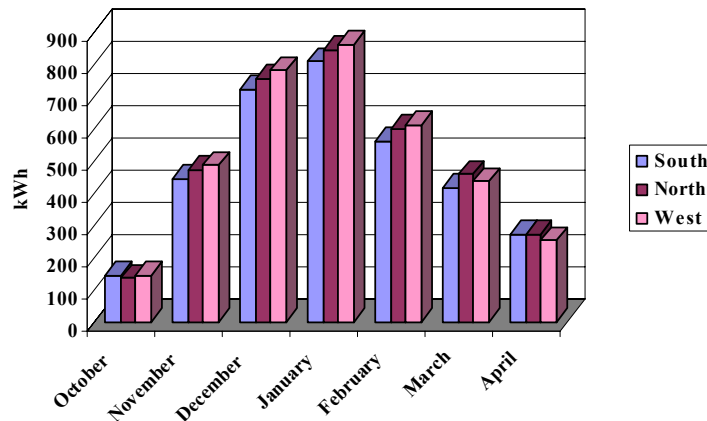


Figure 12-13 - Heating energy needs comparison

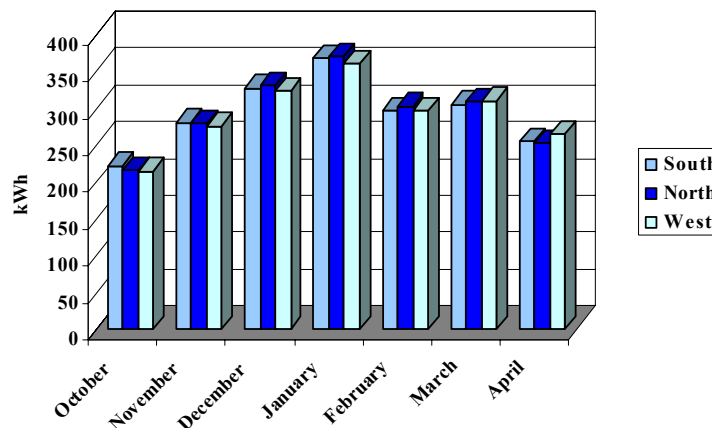


Figure 12-14 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

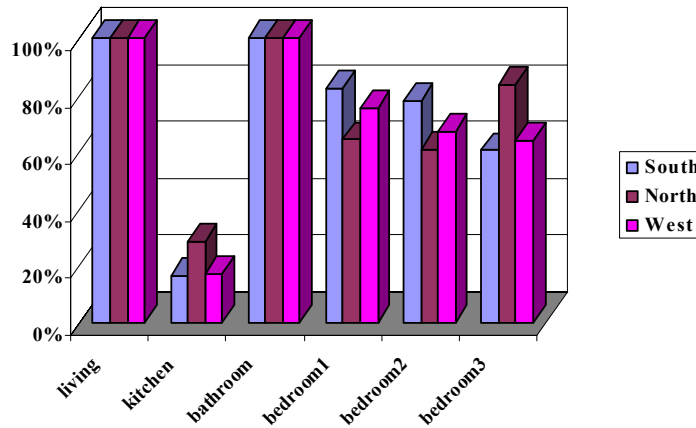


Figure 12-15 – PPD class 2 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

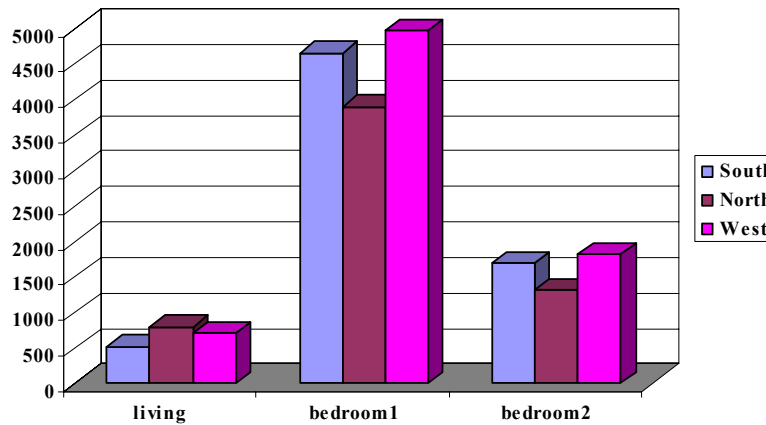


Figure 12-16 - CO₂ concentration comparison

12.2. Detailed results of air leakage analysis

12.2.1. System I

As expected, a higher value of air leakage implies a higher value for the heating needs and for the ventilation losses (figure 12-17 and figure 12-18).

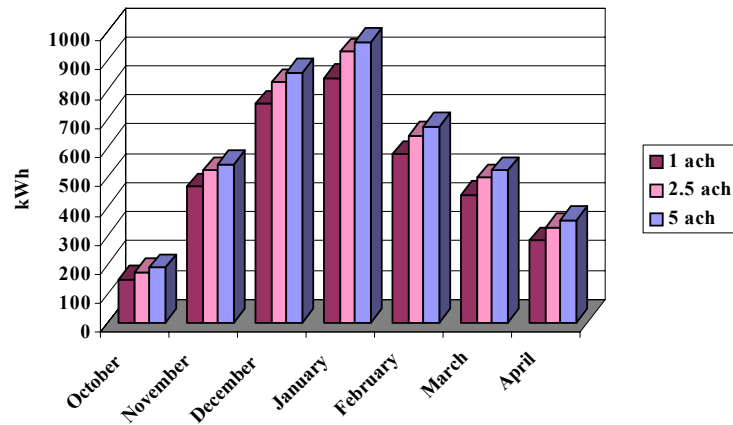


Figure 12-17 – Heating energy needs comparison

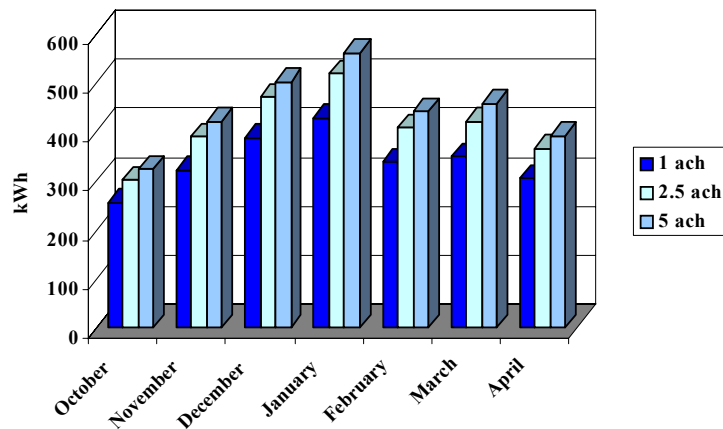


Figure 12-18 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

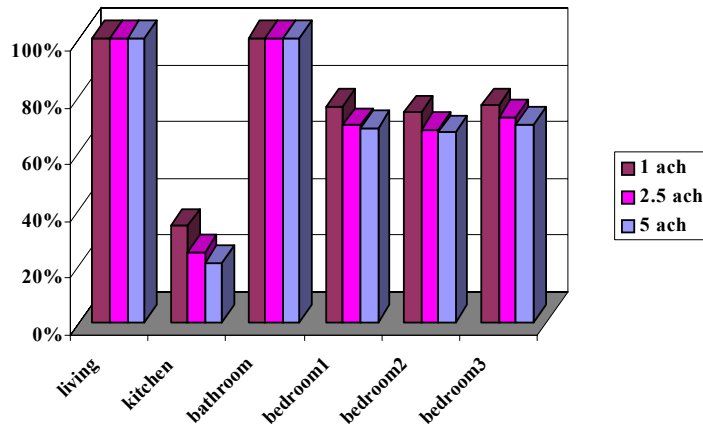


Figure 12-19 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with a high value of kppm, i.e., living room, bedroom 1 and 2.

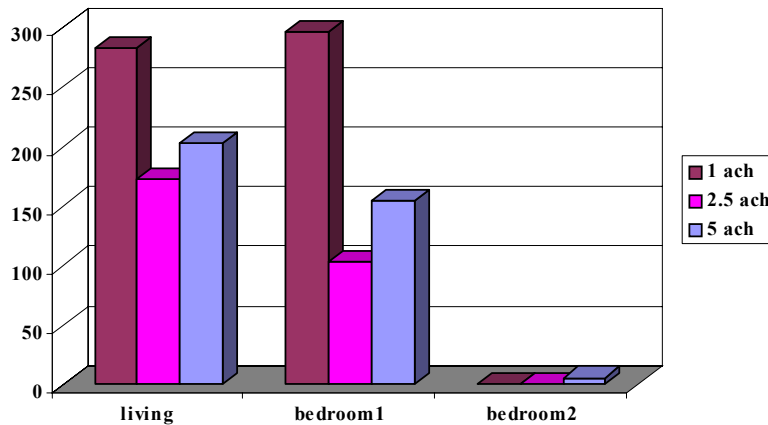


Figure 12-20 - CO₂ concentration comparison

12.2.2. System II

As expected, a higher value of air leakage implies a higher value for the heating needs and for the ventilation losses (figure 12-21 and figure 12-22).

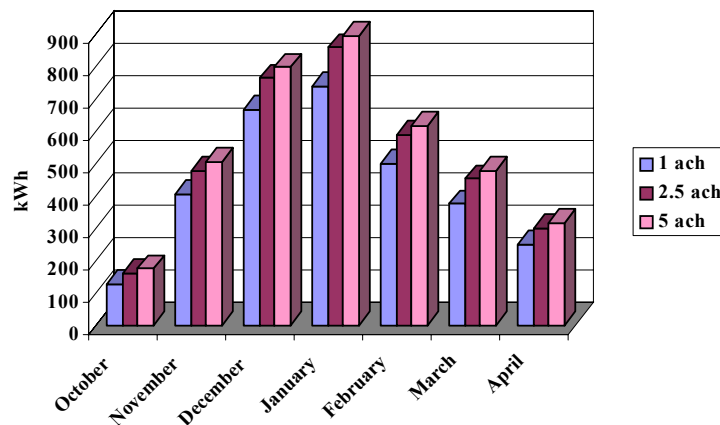


Figure 12-21 - Heating energy needs comparison

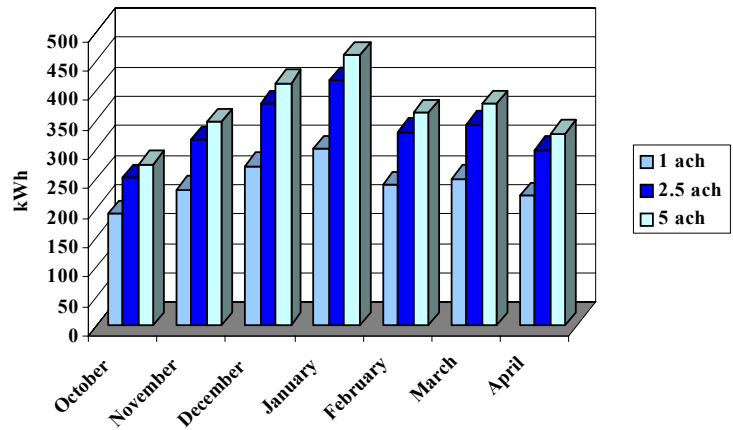


Figure 12-22 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

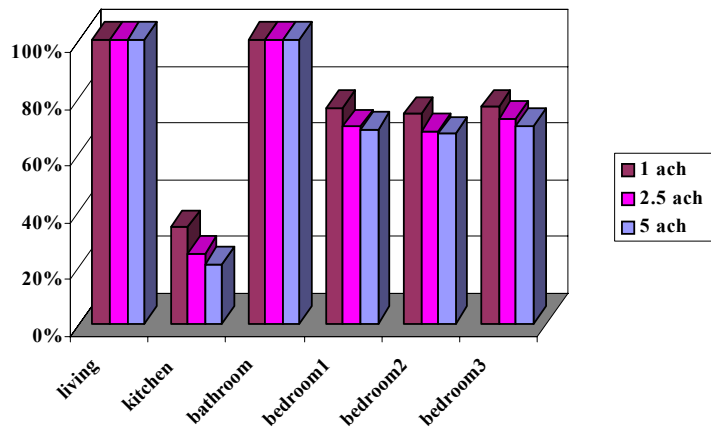


Figure 12-23 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

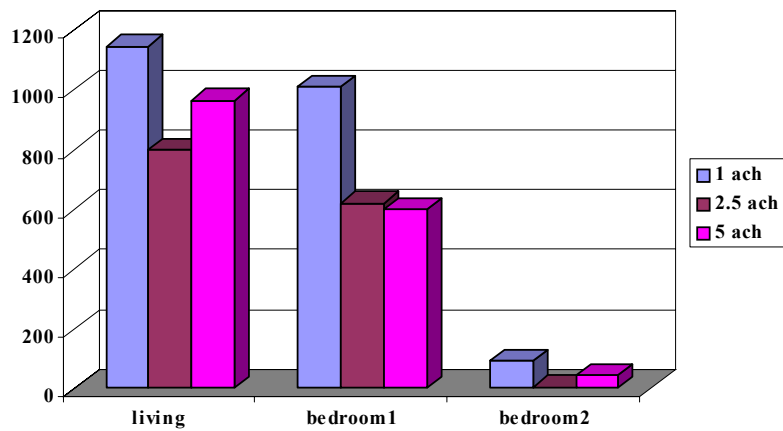


Figure 12-24 - CO₂ concentration comparison

12.2.3. System III

As expected, a higher value of air leakage implies a higher value for the heating needs and for the ventilation losses (figure 12-25 and figure 12-26).

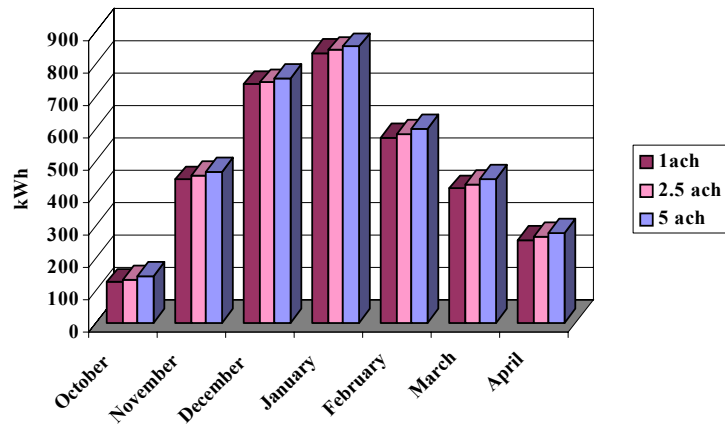


Figure 12-25 - Heating energy needs comparison

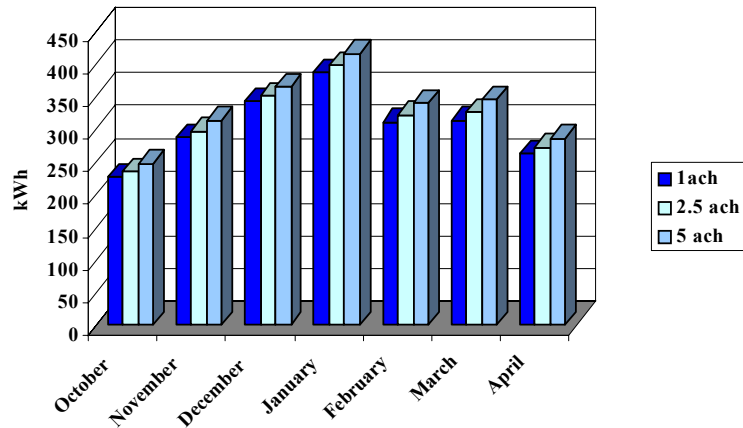


Figure 12-26 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

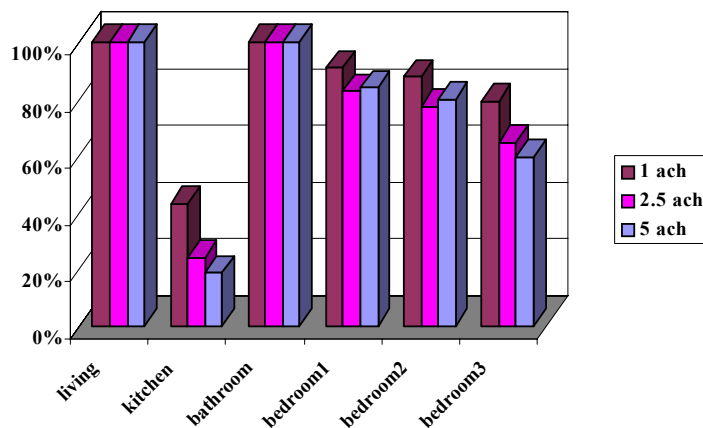


Figure 12-27 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

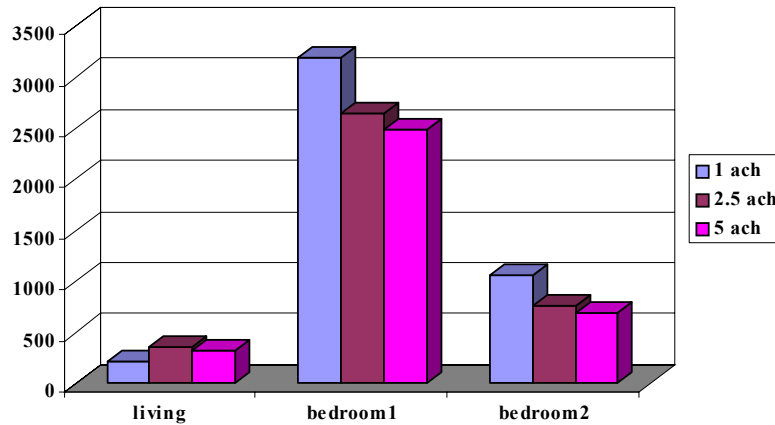


Figure 12-28 - CO₂ concentration comparison

12.2.4. System IV

As expected, a higher value of air leakage implies a higher value for the heating needs and for the ventilation losses (figure 12-29 and figure 12-30).

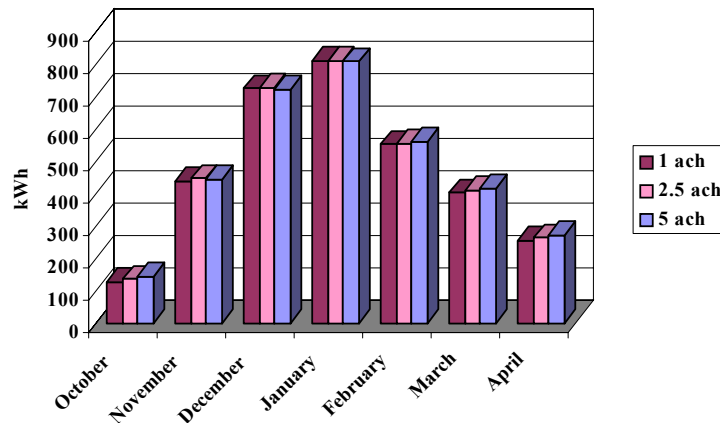


Figure 12-29 - Heating energy needs comparison

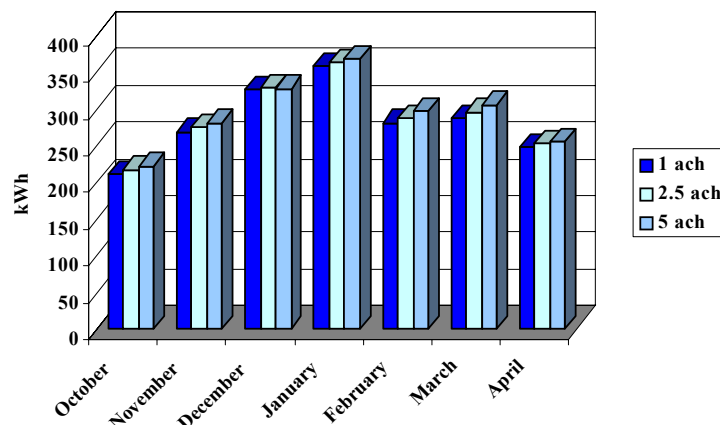


Figure 12-30 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

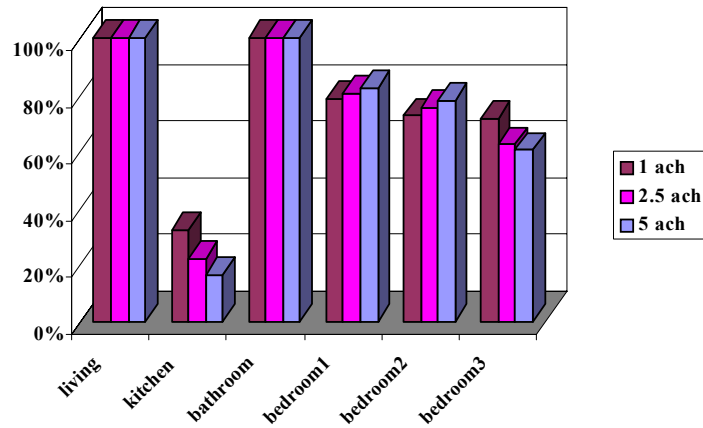


Figure 12-31 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

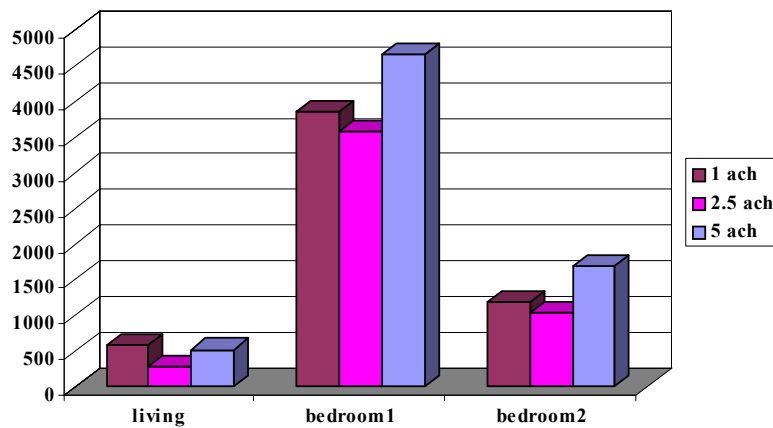


Figure 12-32 - CO₂ concentration comparison

12.3. Detailed results of shielding analysis

12.3.1. System I

In figures below it is possible to see that an unshielded building has higher heating needs and ventilation losses.

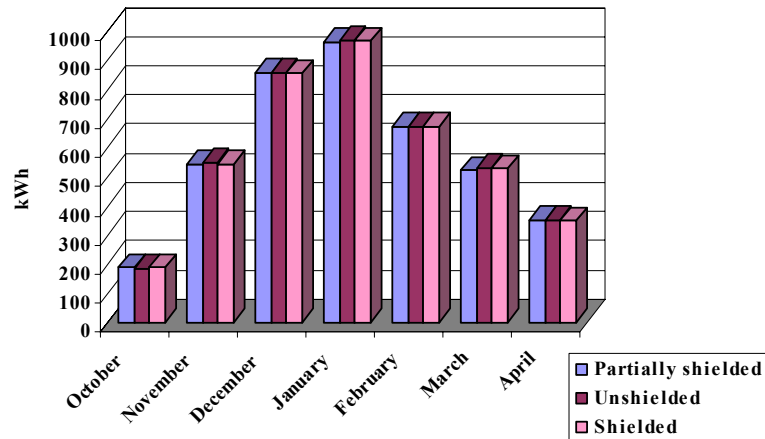


Figure 12-33 – Heating energy needs comparison

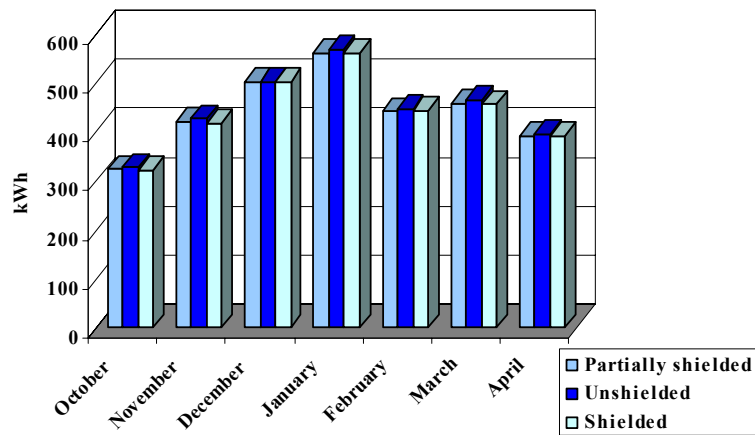


Figure 12-34 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

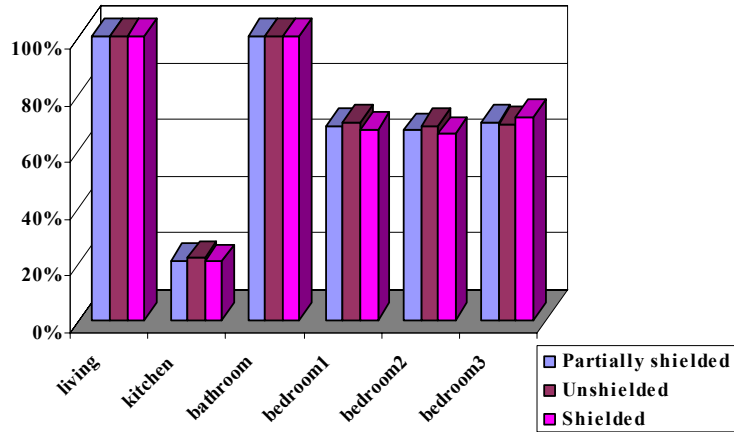


Figure 12-35 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with a high value of kppm, i.e., living room, bedroom 1 and 2.

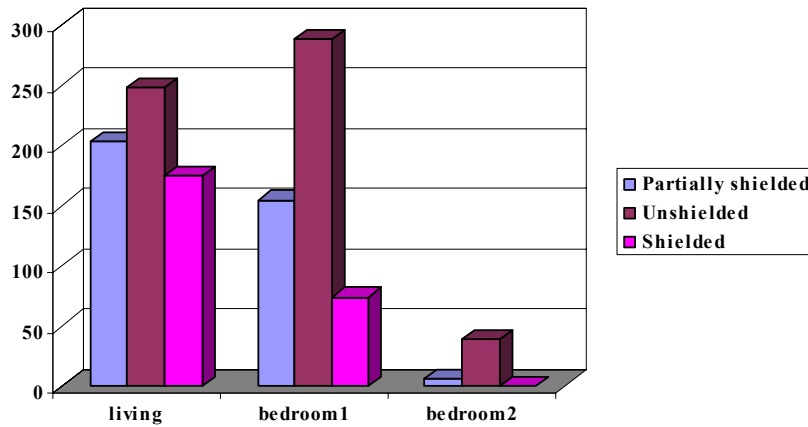


Figure 12-36 - CO₂ concentration comparison

12.3.2. System II

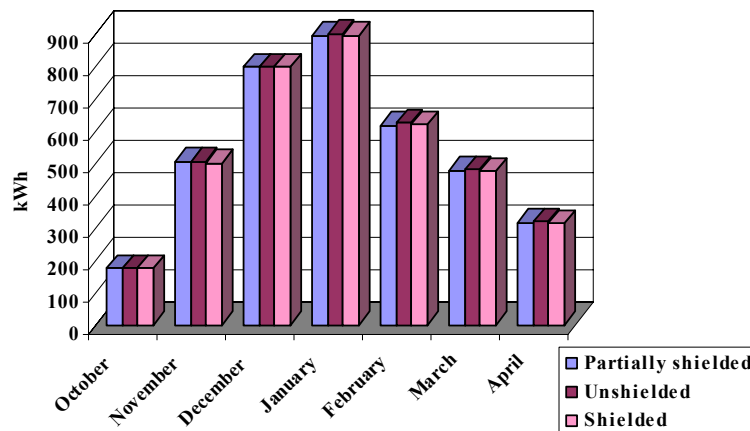


Figure 12-37 - Heating energy needs comparison

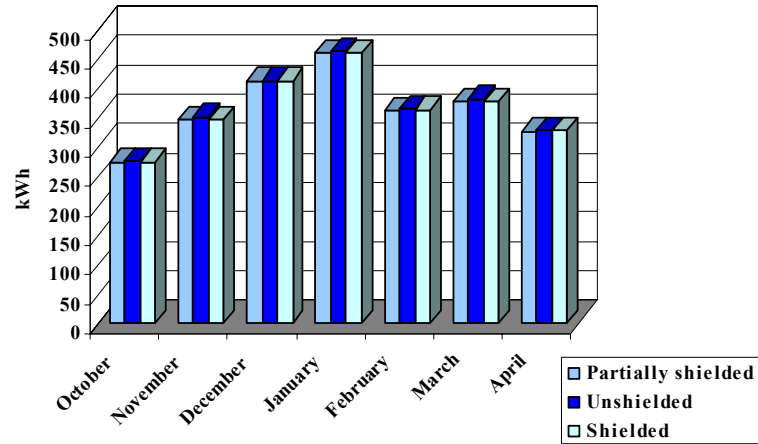


Figure 12-38 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

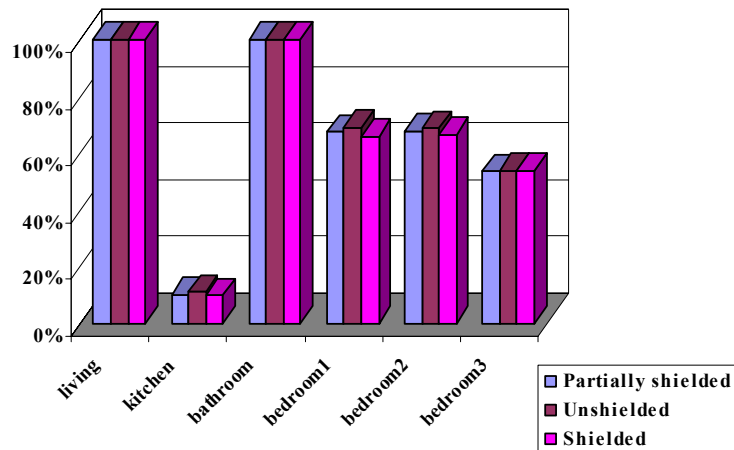


Figure 12-39 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

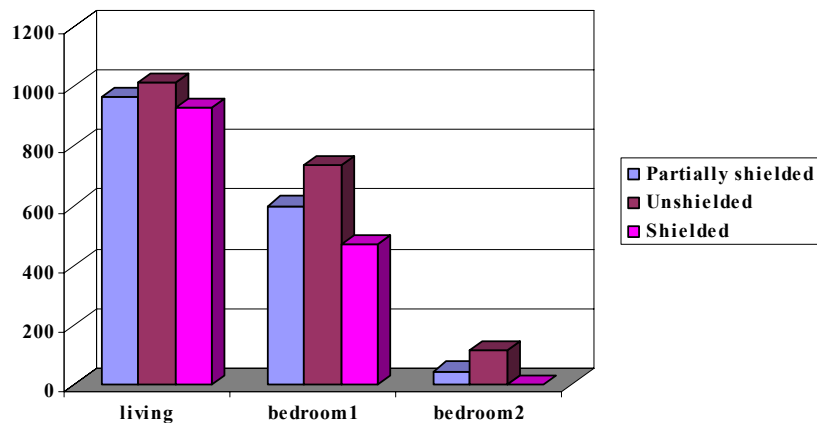


Figure 12-40 - CO₂ concentration comparison

12.3.3. System III

In figures below it is possible to see that an unshielded building has higher heating needs and ventilation losses.

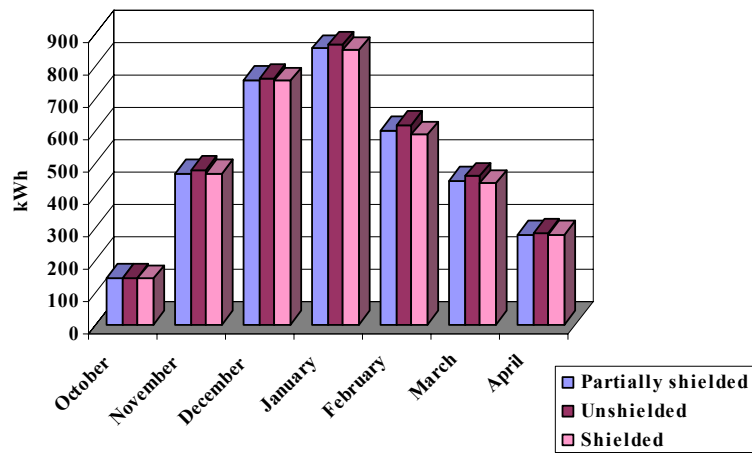


Figure 12-41 - Heating energy needs comparison

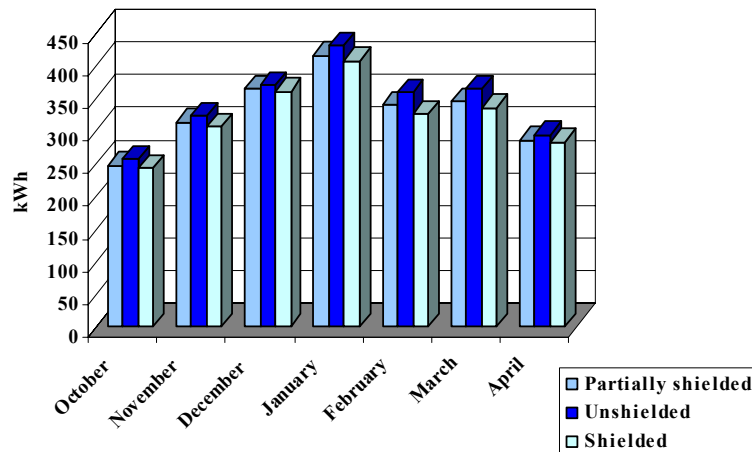


Figure 12-42 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

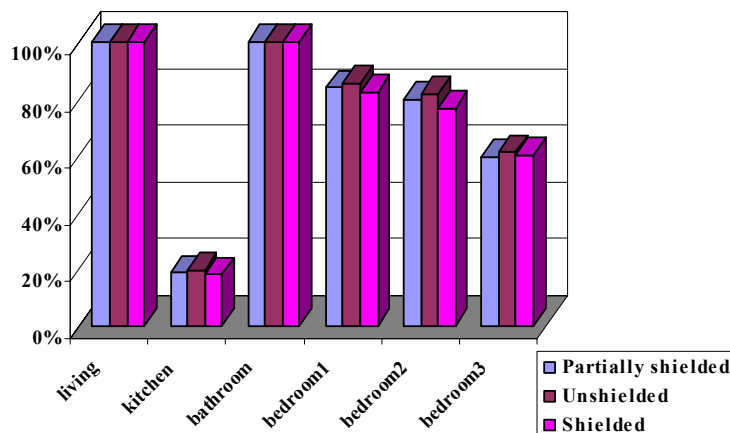


Figure 12-43 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

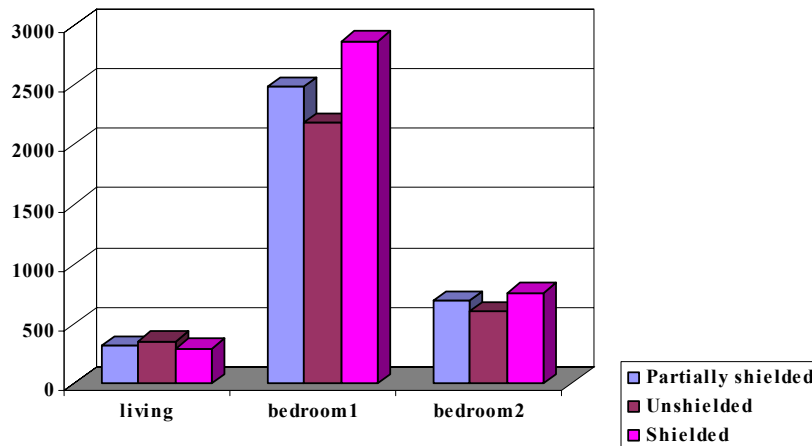


Figure 12-44 - CO₂ concentration comparison

12.3.4. System IV

In figures below it is possible to see that an unshielded building has higher heating needs and ventilation losses.

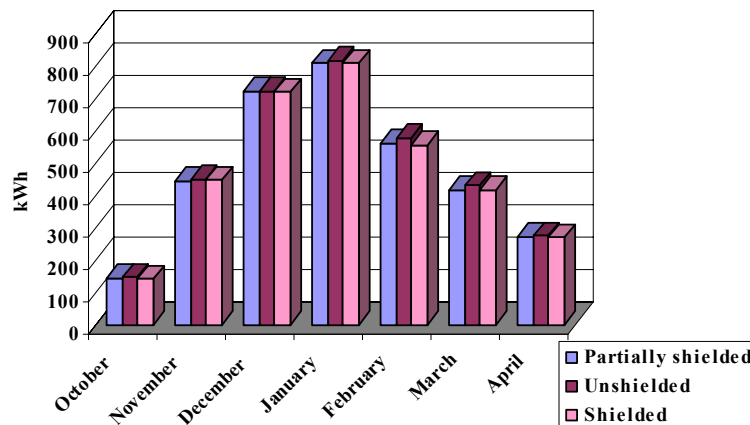


Figure 12-45 - Heating energy needs comparison

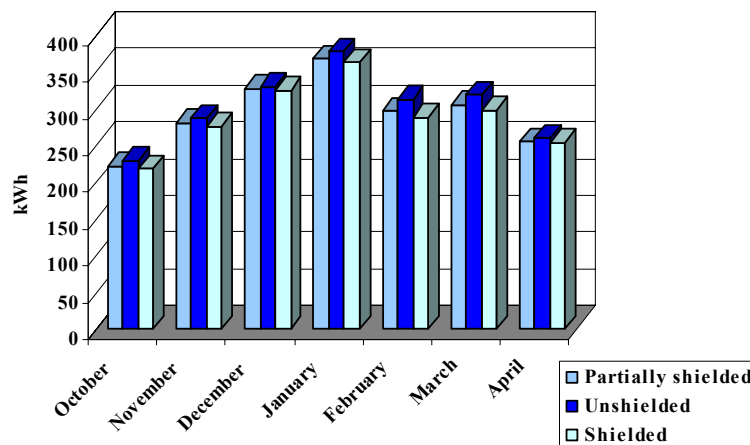


Figure 12-46 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

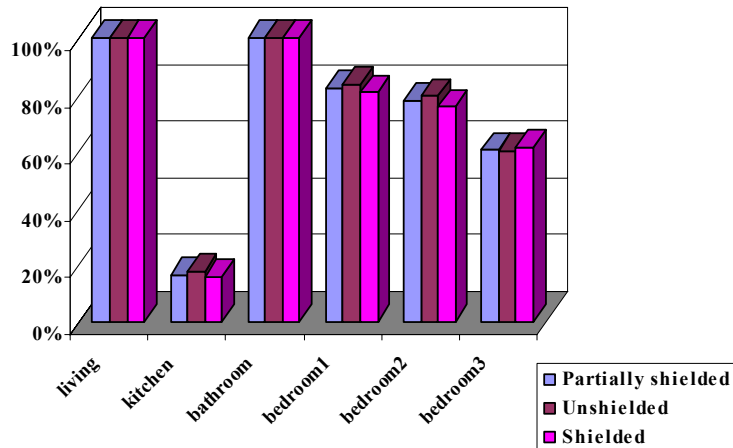


Figure 12-47 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

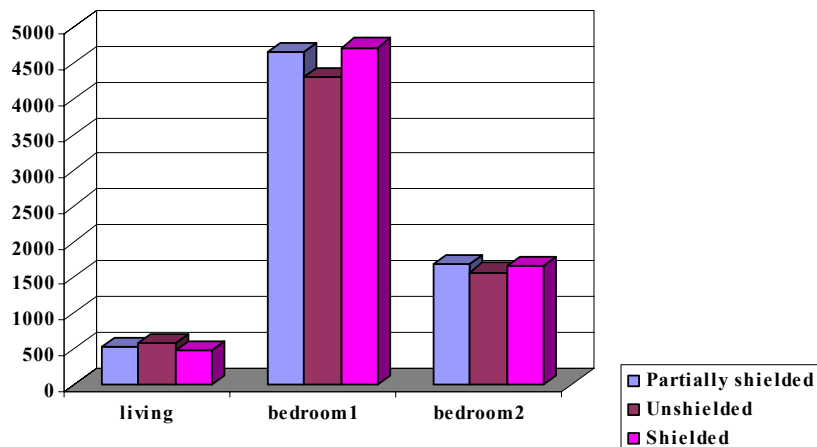


Figure 12-48 - CO₂ concentration comparison

12.4. Detailed results of water vapor production analysis

12.4.1. System I

The water vapour production variation has no effects in the heating needs and ventilation losses (see figures below).

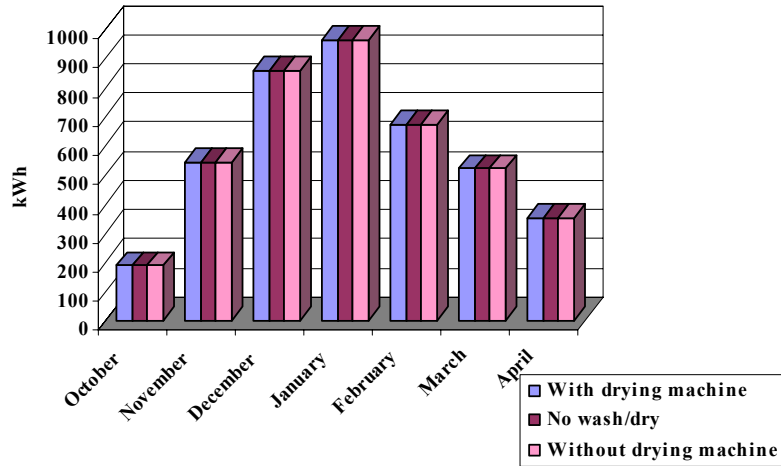


Figure 12-49 – Heating energy needs comparison

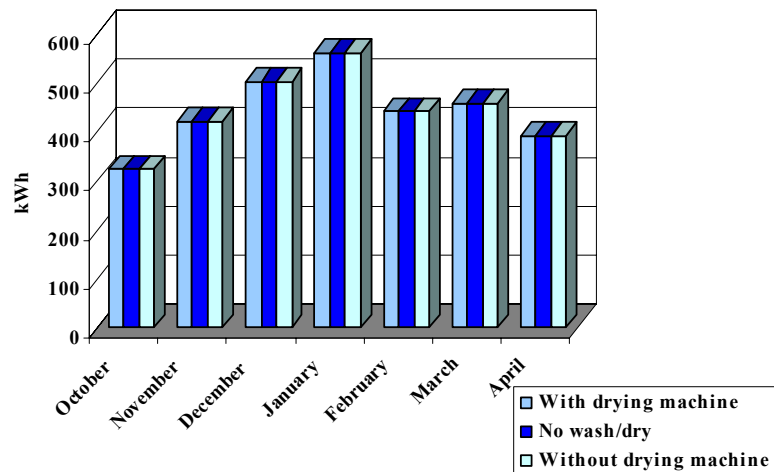


Figure 12-50 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

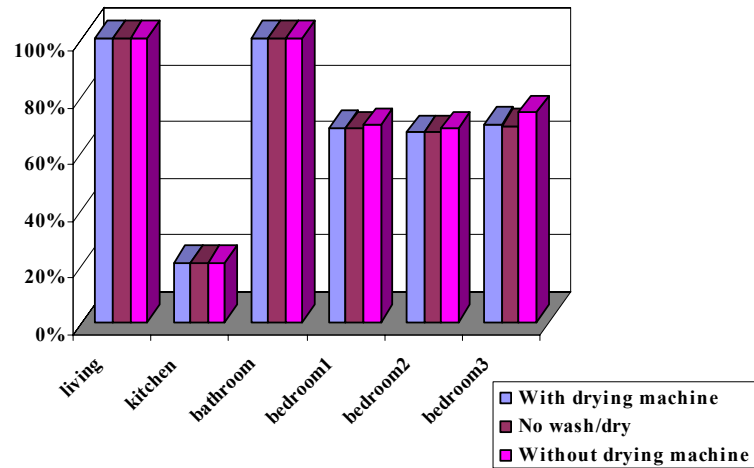


Figure 12-51 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with a high value of kppm, i.e., living room, bedroom 1 and 2.

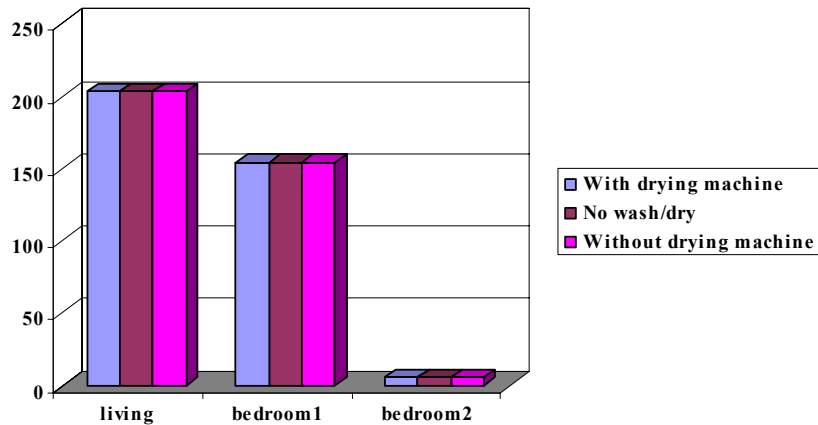


Figure 12-52 - CO₂ concentration comparison

12.4.2. System II

The water vapour production variation has no effects in the heating needs and ventilation losses (see figures below).

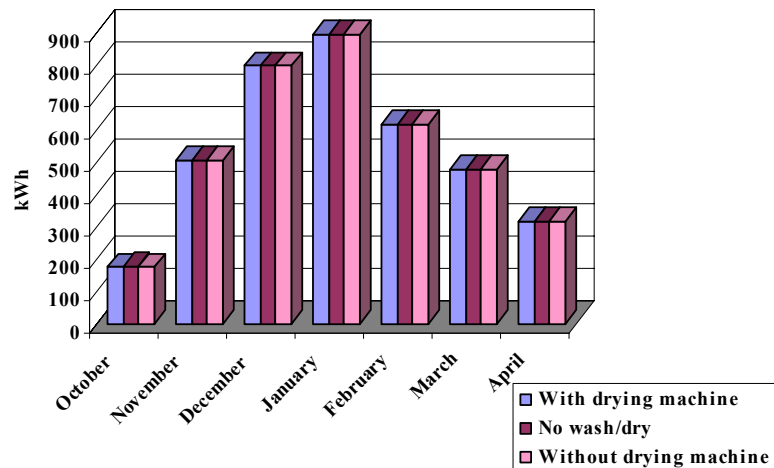


Figure 12-53 - Heating energy needs comparison

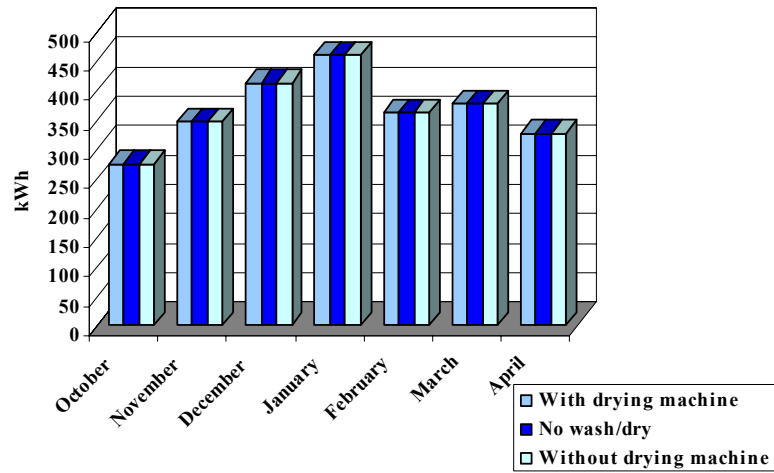


Figure 12-54 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

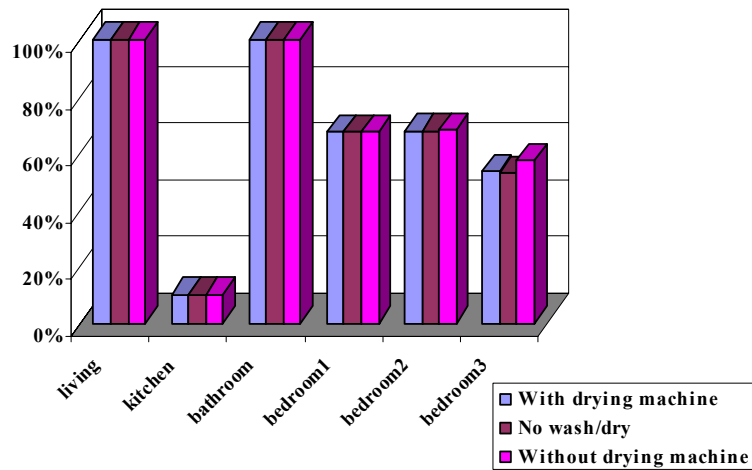


Figure 12-55 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

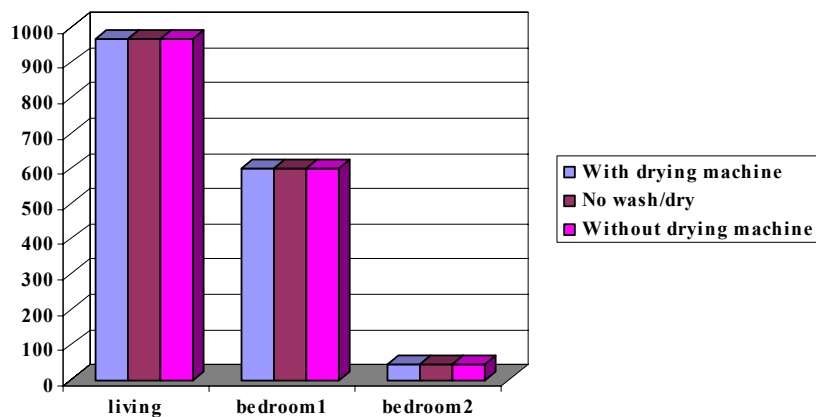


Figure 12-56 - CO₂ concentration comparison

12.4.3. System III

The water vapour production variation has no effects in the heating needs and ventilation losses (see figures below).

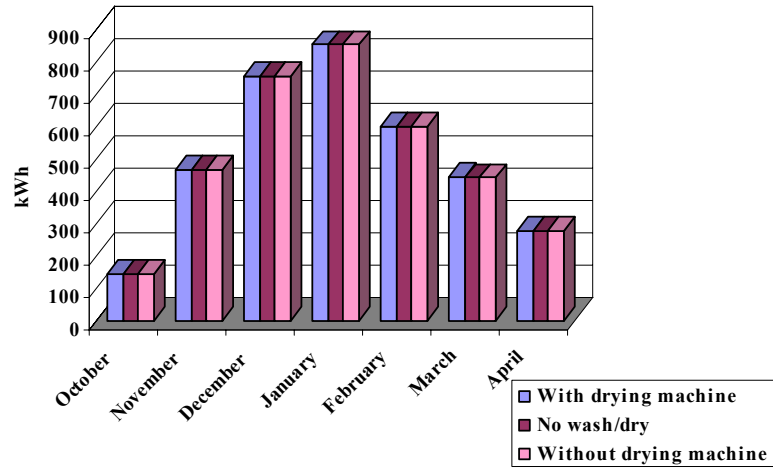


Figure 12-57 - Heating energy needs comparison

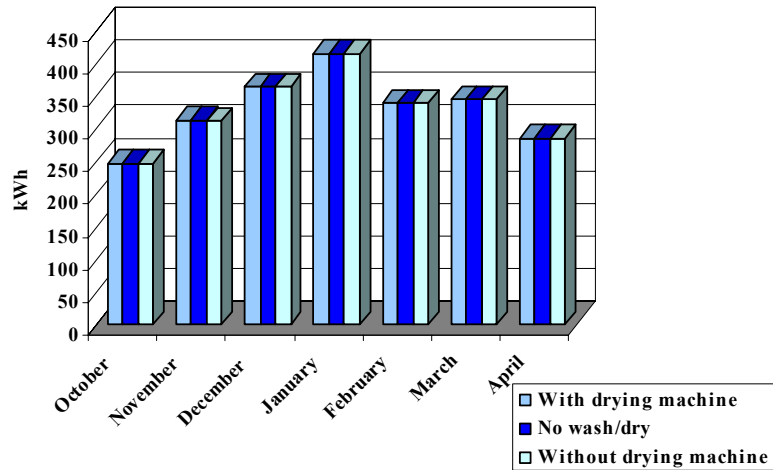


Figure 12-58 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

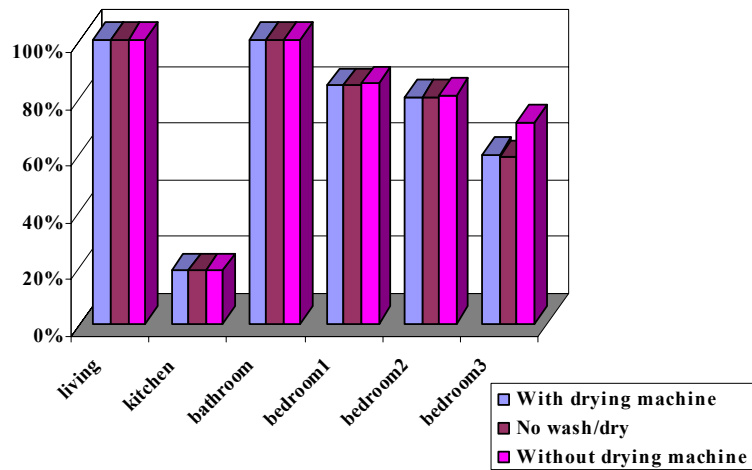


Figure 12-59 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

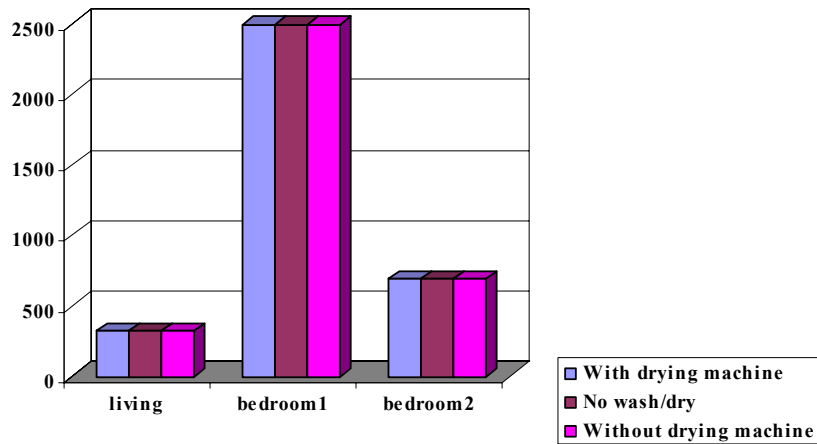


Figure 12-60 - CO₂ concentration comparison

12.4.4. System IV

The water vapour production variation has no effects in the heating needs and ventilation losses (see figures below).

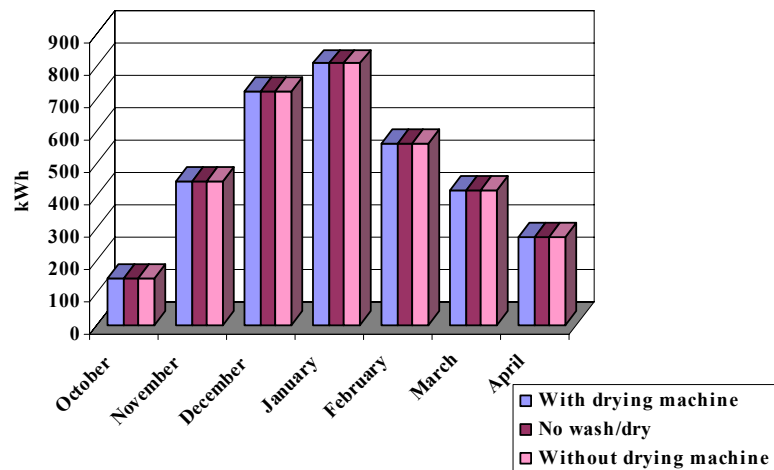


Figure 12-61 - Heating energy needs comparison

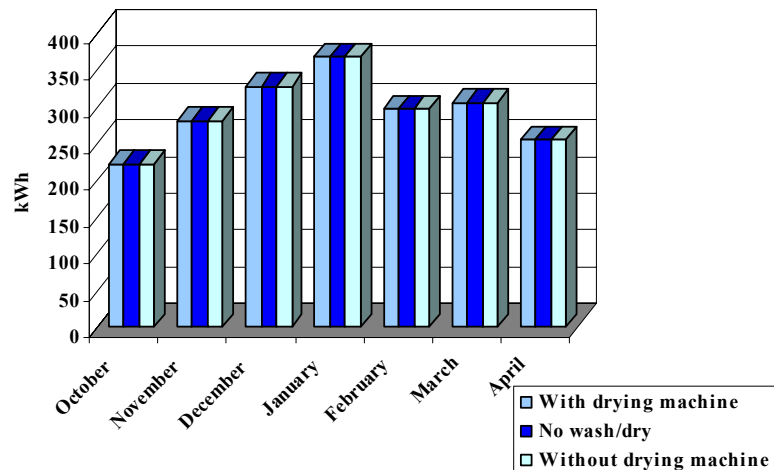


Figure 12-62 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

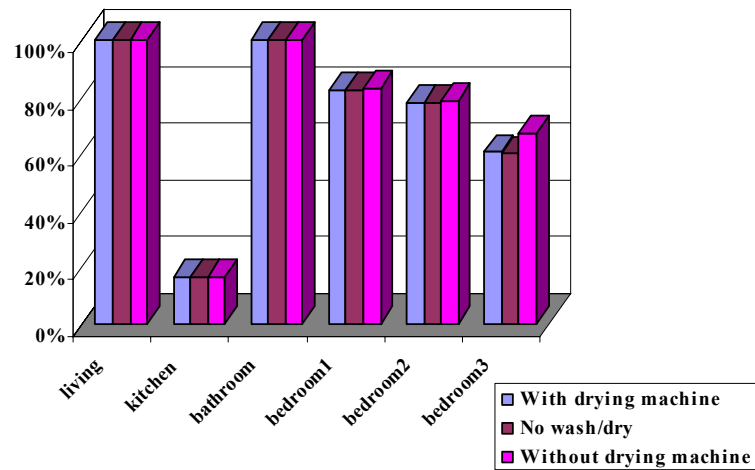


Figure 12-63 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

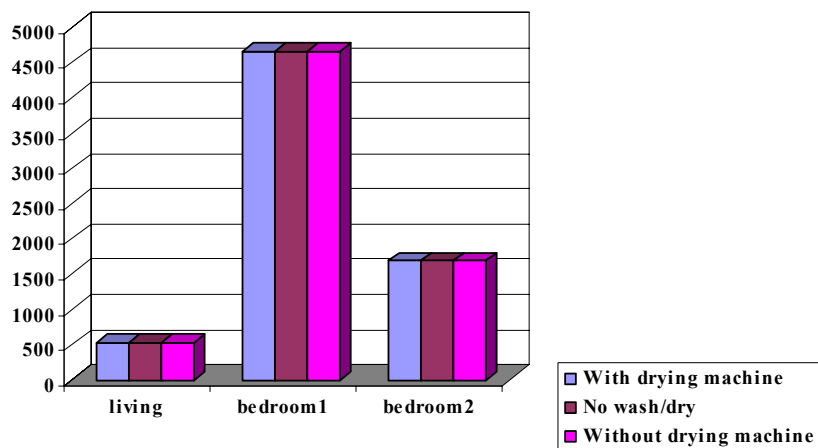


Figure 12-64 - CO₂ concentration comparison

12.5. Detailed results of occupancy density analysis

12.5.1. System I

From the figures below, it is clear that with the increase of the number of persons in the building there is a decrease in the heating needs and a small difference in the ventilation losses for (higher in the crowded case).

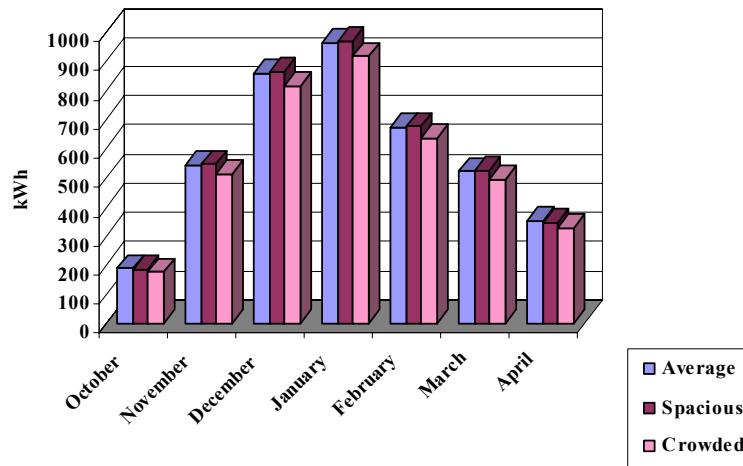


Figure 12-65 – Heating energy needs comparison

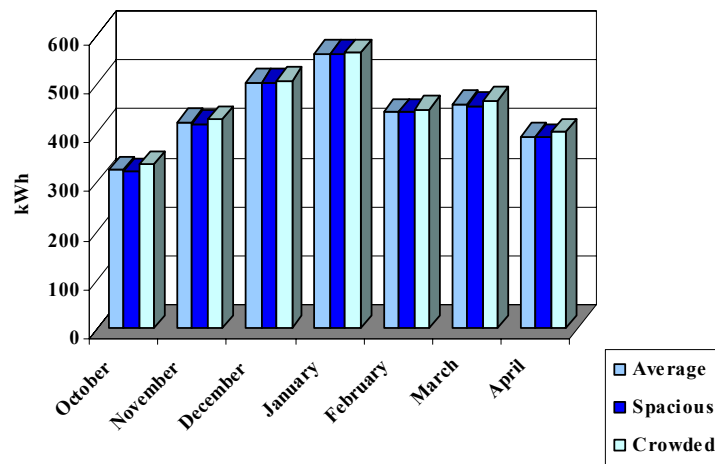


Figure 12-66 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

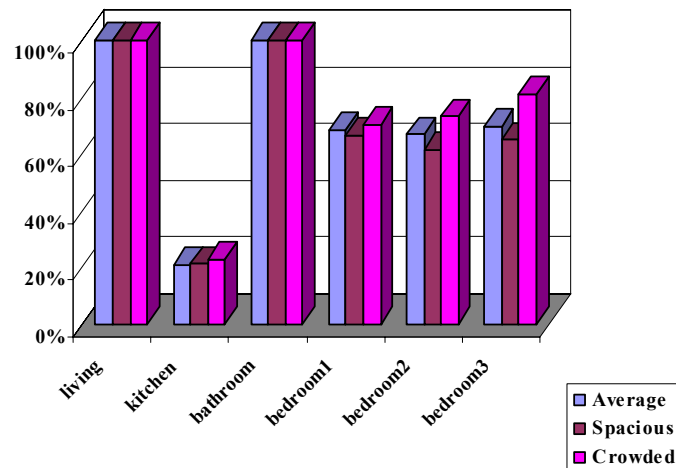


Figure 12-67 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with a high value of kppm, i.e., living room, bedroom 1 and 2.

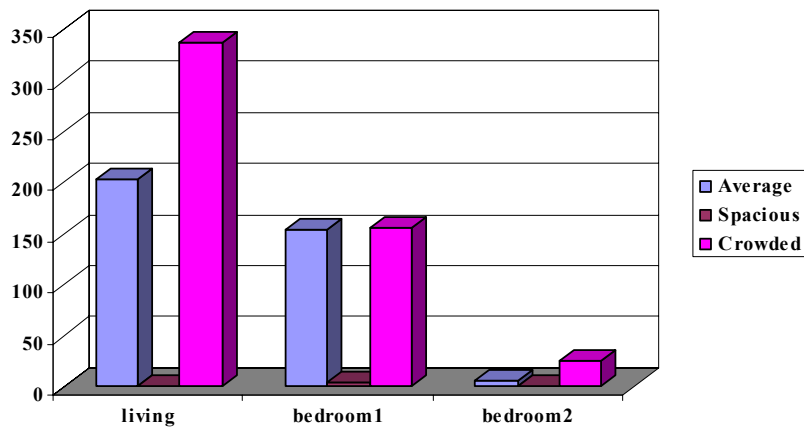


Figure 12-68 - CO₂ concentration comparison

12.5.2. System II

From the figures below, it is clear that with the increase of the number of persons in the building there is a decrease in the heating needs and a small difference in the ventilation losses for (higher in the crowded case).

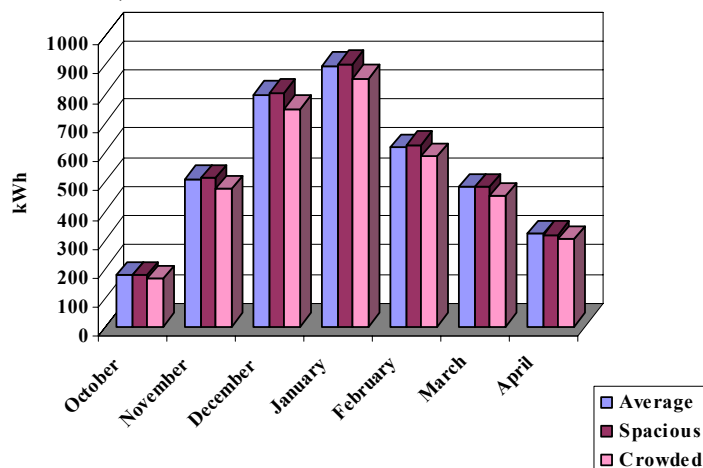


Figure 12-69 - Heating energy needs comparison

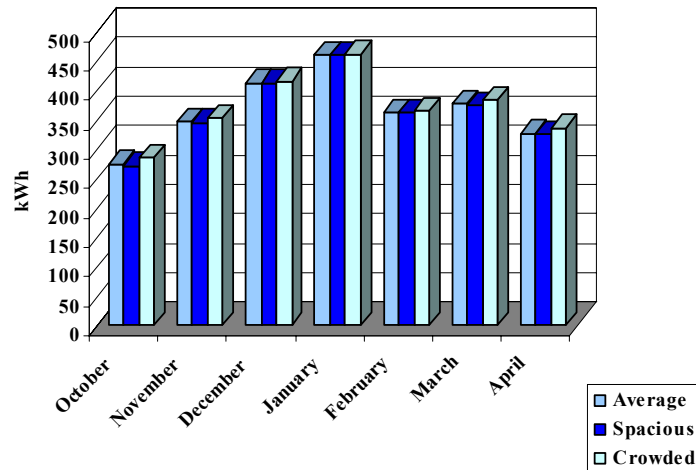


Figure 12-70 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

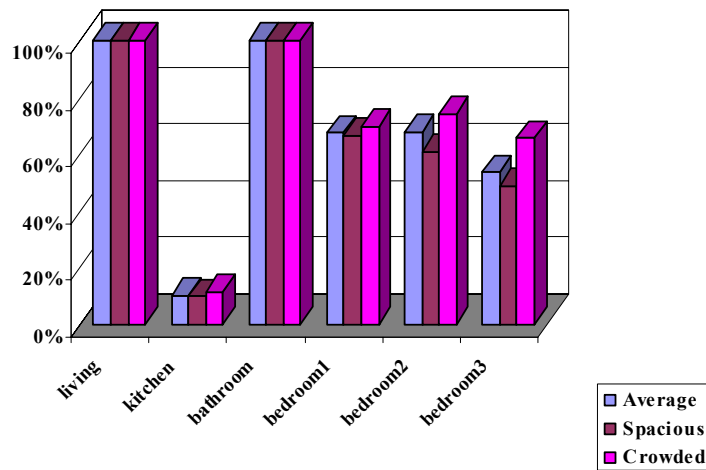


Figure 12-71 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

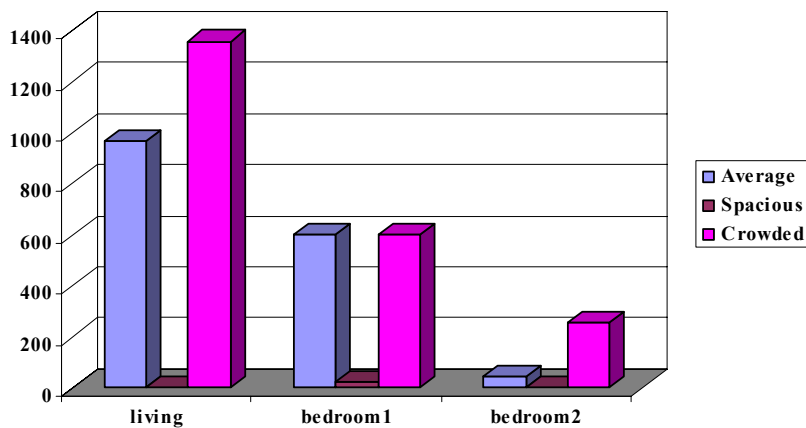


Figure 12-72 - CO₂ concentration comparison

12.5.3. System III

From the figures below, it is clear that with the increase of the number of persons in the building there is a decrease in the heating needs and a small difference in the ventilation losses for (higher in the crowded case).

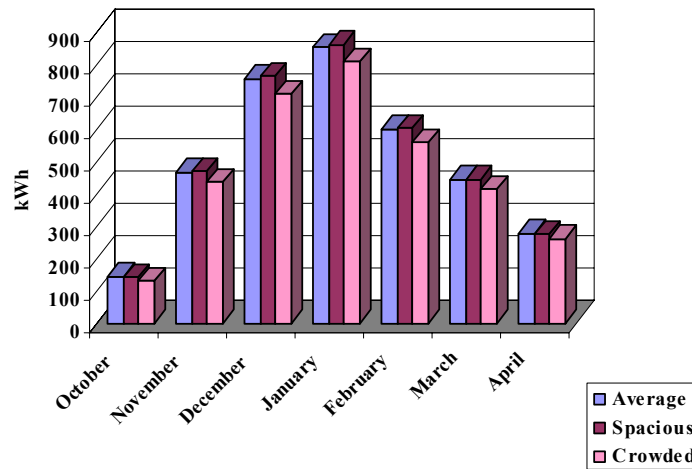


Figure 12-73 - Heating energy needs comparison

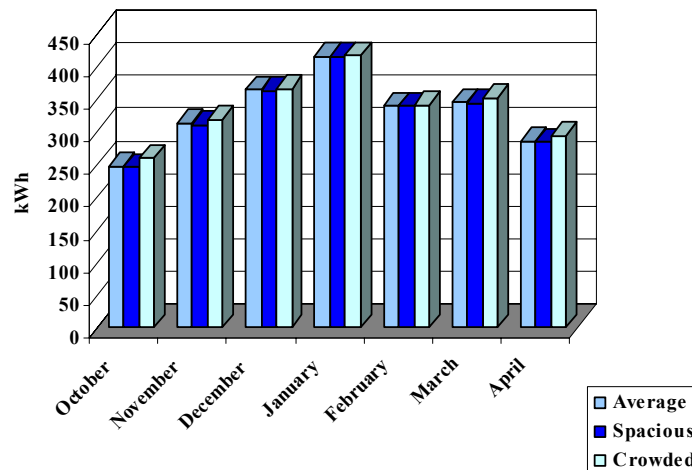


Figure 12-74 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

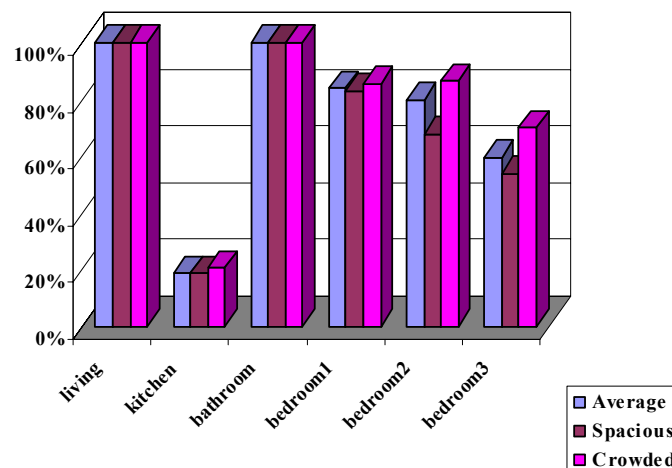


Figure 12-75 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

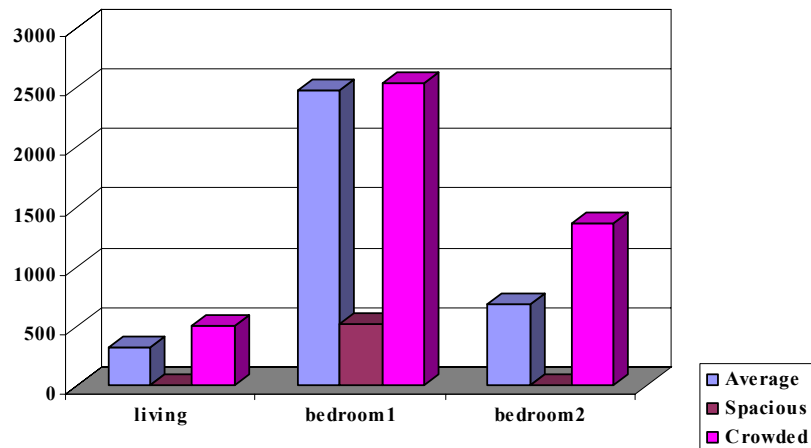


Figure 12-76 - CO₂ concentration comparison

12.5.4. System IV

From the figures below, it is clear that with the increase of the number of persons in the building there is a decrease in the heating needs and a small difference in the ventilation losses for (higher in the crowded case).

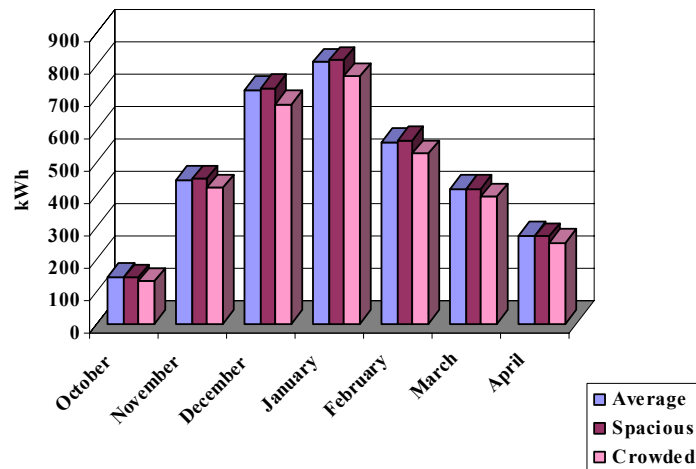


Figure 12-77 - Heating energy needs comparison

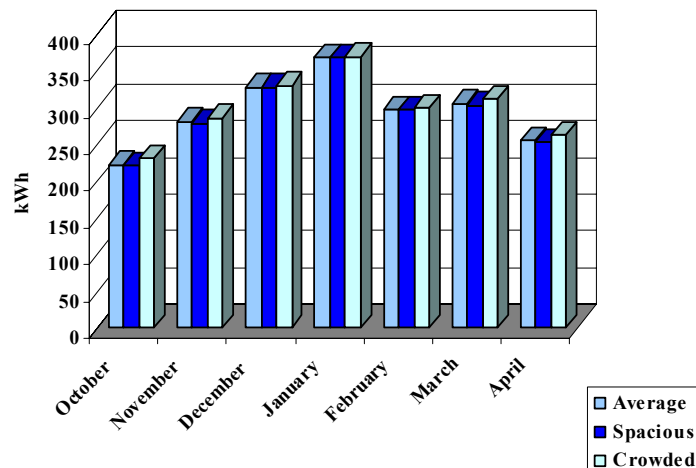


Figure 12-78 – Ventilation losses comparison

To compare the PPD values and modifications that result from building rotation, the Class 3, i.e. $PPD \leq 15\%$, was chosen.

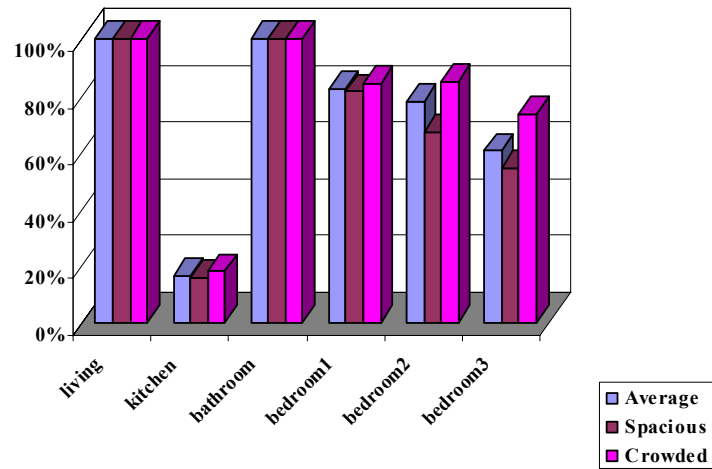


Figure 12-79 – PPD class 3 comparison

The CO₂ comparison for the different orientations will be done only for the zones with higher variations of kppm.h, i.e., living room, bedroom 1 and 2.

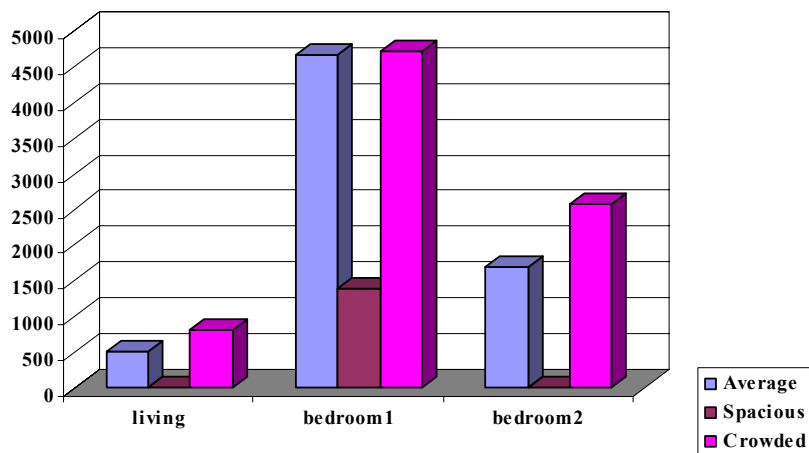


Figure 12-80 - CO₂ concentration comparison

13. References

- [1] Mansson, Lars-Goran and others; “IEA ECBCS ANNEX 27 HANDBOOK - Evaluation and demonstration of Domestic Ventilation systems”, 2002
- [2] Weber, Andreas and Dorer, Viktor; “Description of reference buildings and boundary conditions – WP5-WR-4”, November 2003
- [3] Weber, Andreas and Dorer, Viktor; “Parameter for the performance assessment of hybrid ventilation system – WP5-WR-2.Version 8”, September 2003
- [4] Orme, Malcom and others; “Numerical data for air infiltration and Natural Ventilation Calculations – AIVC-TN44”, February 1998
- [5] Instituto Português da Qualidade, “NP 1037-1, 2002 – Ventilation and combustion products evacuation from places with gás-burning appliances _Part 1: Dwellings. Natural ventilation”, 2002
- [6] Maldonado, Eduardo and Alexandre, José and others, “Input Data - Study of Portuguese Ventilation System (IC5)”, January 2004