NATURAL VENTILATION OF RESIDENTIAL BUILDINGS IN PORTUGUESE WINTER CLIMATIC CONDITIONS

M. Ferreira[1], H. Corvacho[2] and J. L. Alexandre[3]

[12] *Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Civil, Secção de Construções Civis, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; mce02013@fe.up.pt[1]; corvacho@fe.up.pt[2]*
[3] *Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Mecânica e Gestão Industrial, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; jla@fe.up.pt*

ABSTRACT

In this paper, the current situation of Portuguese residential buildings in terms of ventilation systems is presented. The indoor air renewal is, normally, obtained by providing fresh air exclusively by air leakage of doors and windows and their occasional opening and exhausting the air through ducts placed in kitchens and bathrooms. A recent revision of the Portuguese standard NP 1037-1, concerning natural ventilation of dwellings, is studied and its influence upon heating energy consumption and indoor temperatures is reported. In order to evaluate both thermal and ventilation impact of the adoption of NP 1037-1, a dynamic simulation was undertaken, using Trynsis 15 and Comis 3.1 software. Some results of this study concerning a residential building, located in different Portuguese winter climatic regions, are presented. The relative influence of both wind and thermal stack effect has been evaluated, the cooling effect of ventilation for unheated indoor environments has been quantified and the importance of parameters like the location of the dwelling in the building, its orientation and the opening height have been analysed. Some ventilation devices were simulated, like self-regulated inlet grilles (trickle ventilators). Finally, other strategies of improving ventilation, keeping low heating energy consumption, have been considered, namely demand controlled ventilation.

KEYWORDS

Dwellings, Natural Ventilation, Heating Energy Consumption, Indoor Temperatures.

INTRODUCTION

The most ecological solution to renew indoor room air in dwellings is, undoubtedly, natural ventilation using exclusively the forces of nature to originate differences in pressure, which subsequently generate air circulation. However, during the heating season, the Portuguese climate presents relatively mild weather conditions and the differences between indoor and outdoor temperatures are not as high as in, for example, northern European countries. In this context, it is hard to guarantee that natural ventilation systems are capable of providing an adequate air renewal in buildings by themselves. On the other hand, in order to maintain the ventilation flow rates above the minimum quality standards, ensuring the thermal comfort of the dwellings, it is necessary to consume additional energy to heat indoor spaces (Leal and Maldonado, 2000).

The purpose of this study is to analyze the consequences, in terms of energy requirements for heating and temperatures reached inside the buildings, of the adoption of different natural ventilation systems in a dwelling (Figure 1) with a floor area of 80 m^2, located in three climatic zones in Portugal, with different orientations and opening heights and also with distinct heating regimes. For this purpose, we will use the TRNSYS 15 and COMIS 3.1 programs, which are detailed and dynamic simulation tools. These programs were used together, according to well-defined rules (Dorer and Weber, 2001). The climatic data used for the simulations are included in a climatic database available for the ENERGYPLUS simulation programme (US Department of Energy, 2001).

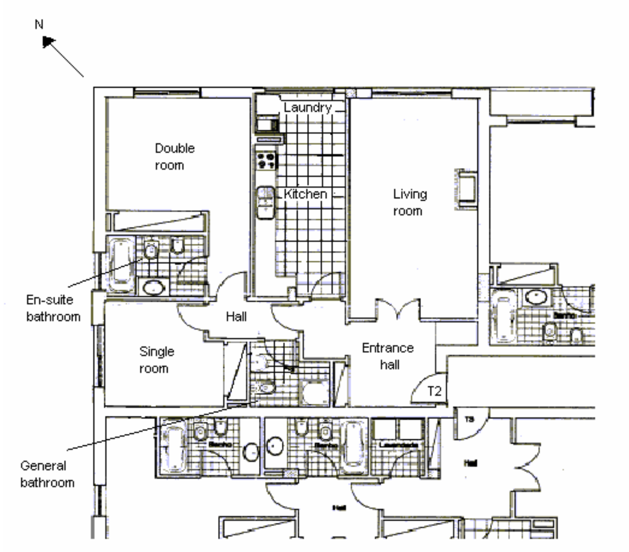

Figure 1: Plan of the Dwelling used in the Simulation

The energy and efficiency analysis is based on three types of natural ventilation systems:
- Air leakage of windows and doors (infiltration), their temporary opening and use of exhaust ducts fitted with cowls. This is a common system in Portugal;
- Natural ventilation using self-regulated inlet grilles located in the various façades. This is the system proposed by the NP 1037-1 Portuguese Standard (I.P.Q., 2002) and can be used not only for the construction of new buildings but also to rehabilitate the existing ones;
- Demand-controlled ventilation.

INFILTRATION AND TEMPORARY OPENING OF WINDOWS

Infiltration Only

In this study, three types of windows were used, belonging to different air permeability classes (I.P.Q., 2002), starting with the less permeable: A2, A1 and non-classified (NC). The building was located in three different cities: Bragança (I3 Zone, Degrees Days (Tb =15ºC) = 1600 ºC day/year), Porto (I2 Zone, DD (Tb=15ºC) = 800ºC. day/year) and Faro (I1 Zone, DD (Tb=15ºC) = 400 ºC day/year) (M.O.P.T.C, 1990) and three heating regimes were used: without heating, permanent heating of the entire dwelling with temperatures of 20ºC, intermittent heating with temperatures of 20ºC only in the bedrooms from 6 p.m. to 22 p.m. in weekdays and from 8 a.m. to 22 p.m. during the weekend. The dwelling faces NE/NW and is located on the 7th floor of a building. Table 1 presents the variations (in percentage terms) of the mean ventilation flows obtained in relation to the figures recommended by the NP 1037-1 Standard, for the entire heating season and for the whole dwelling.

TABLE 1
Percentage of mean flows obtained in relation to the flows recommended by the Standard

%	Without heating			Heating 20ºC			Intermittent heating		
	A2	A1	NC	A2	A1	NC	A2	A1	NC
Bragança	16	40	60	23	56	88	20	49	76
Porto	19	46	71	23	58	91	21	53	82
Faro	24	57	88	27	67	107	26	63	96

Table 2 presents, in kWh/year, the corresponding energy losses exclusively associated with natural ventilation in the heating season for the entire dwelling.

TABLE 2
Heat losses caused exclusively by natural ventilation

kWh/year	Without heating			Heating 20ºC			Intermittent heating		
	A2	A1	NC	A2	A1	NC	A2	A1	NC
Bragança	306	580	723	1437	3739	6140	921	2048	2923
Porto	239	460	594	867	2274	3743	599	1348	1943
Faro	142	259	323	534	1382	2380	367	797	1125

It was found that the proportion of this energy in relation to the total energy consumed to heat the apartment with a temperature of 20ºC varies between 30% and 75% according to the city and to the type of windows used, for an insulation level of $U_{Exterior\ Wall}$ = 0,70 W/m^2. ºC and $U_{Windows}$ =1,5 W/m^2. ºC.

Table 3 indicates the mean and lowest temperatures in the double room (Figure 1) and the percentage of hours, in relation to the total number of hours of the heating season, in which the temperature inside the double room is below 16ºC and 8ºC.

TABLE 3
Mean and lowest temperatures in the double room and frequency analysis for infiltration through windows

ºC	Without heating						Intermittent heating					
	A2		A1		NC		A2		A1		NC	
	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest
Bragança	11.6	4.3	10.9	3.7	10.6	3.1	17.4	11.4	16.9	8.6	16.4	6.8
Porto	13.9	9.5	13.3	8.8	13.0	8.2	18.1	14.5	17.7	13.5	17.3	12.5
Faro	15.2	11.7	14.7	10.5	14.4	9.6	18.5	15.4	18.1	13.7	17.7	12.2
%	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**	**< 16**	**< 8**
Bragança	83	27	89	31	90	34	29	0	38	0	44	0
Porto	79	0	82	0	85	0	9	0	21	0	31	0
Faro	69	0	74	0	78	0	3	0	8	0	16	0

Infiltration and Temporary Opening of Windows

In many Portuguese dwellings, the dwellers have the habit of temporarily opening windows, especially during the morning, in order to remove excess moisture, pollutants and odours that are released during the night. This procedure, especially in the cases where heating is not a common practice, often leads to a relevant decrease in indoor temperature and to high energy losses caused by the natural ventilation throughout the heating season. These results are presented in tables 4 and 5, for windows with an opening percentage of 1.5% of its total area, from 8 to 9 a.m.

TABLE 4

Mean and lowest temperatures in the double room in a situation of infiltration through windows and an opening percentage of 1.5% from 8 to 9 p.m.

ºC	Without heating						Intermittent heating					
	A2		A1		NC		A2		A1		NC	
	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest	Mean	Lowest
Bragança	11.4	3.6	10.7	2.8	10.5	3.0	17.2	6.2	16.8	5.6	16.4	5.1
Porto	13.7	8.9	13.2	8.5	13.0	8.1	17.9	12.0	17.5	11.3	17.3	10.9
Faro	14.9	9.2	14.5	8.9	14.3	8.7	18.3	11.5	17.9	11.0	17.6	10.6

TABLE 5

Energy losses caused exclusively by natural ventilation for the entire dwelling in a situation of infiltration through windows and an opening percentage of 1.5% from 8 to 9 p.m.

kWh/year	Without heating			Heating 20ºC			Inttermitent heating		
	A2	A1	NC	A2	A1	NC	A2	A1	NC
Bragança	384	631	748	1905	4202	6378	1153	2140	2978
Porto	323	493	612	1199	2523	3916	748	1462	1987
Faro	188	285	332	762	1561	2585	475	848	1152

CONTINUOUS WHOLE-HOUSE VENTILATION ACCORDING TO NP 1037-1

In 2002, the NP 1037-1 Standard was approved, implementing a series of rules concerning natural ventilation in dwellings. This Standard recommends, among other things, the use of continuous whole-house ventilation systems, in which the air inlet consists of special devices placed on the façade. As regards air exhaust, the Standard recommends the use of exhaust ducts, which can be fitted with cowls with appropriate wind pressure coefficients. These ventilators allow for a substantial increase in the inlet and exhaust flows, as well as for a significant decrease in reflux phenomenon. In the simulations that were carried out we used the same apartment, with the same ducts used previously but now with self-regulating inlet grilles on the façades of the main rooms. We also made a comparative study of the use of non-regulated and self-regulated inlets and we concluded that the latter allow for a substantial decrease in the maximum inlet and exhaust flow (sometimes up to 60%), which leads to a reduction of energy losses caused exclusively by natural ventilation, especially in the higher hourly values (up to 30%).

We also analyzed the relative importance of wind and of the thermal stack effect to the ventilation flows, for both heating and non-heating situations. The results of this analysis are shown in table 6 and are related to the dwelling on the 7th floor, in Bragança, facing NE/NW.

TABLE 6

Average air renewal flows for the entire dwelling, according to the different hypotheses (m^3/h)

Without heating		Heating 20ºC	
with wind	**without wind**	**with wind**	**without wind**
165	105	355	320

These data allow us to conclude that thermal stack effect is the most common phenomenon, and that the wind is responsible for just 10% of the flow when the apartment is heated and for about 36% when it is not heated.

We also made an analysis, based on the mean values throughout the heating season, of the impact of the use of self-regulated inlet grilles in terms of energy, according to the different cities, orientations and opening heights. We used the same exhaust ducts and cowls of the previous simulations. For all simulations we assumed that the apartment was heated and had a temperature of 20ºC. Table 7 shows the results for the various situations.

TABLE 7
Energy losses caused exclusively by natural ventilation in systems with self-regulated inlet grilles and its importance in relation to the energy consumed for heating at 20 ºC

(kWh/year)	BRAGANÇA				PORTO				FARO			
	3TH FLOOR		7TH FLOOR		3TH FLOOR		7TH FLOOR		3TH FLOOR		7TH FLOOR	
	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE	NE NW	SW SE
Losses caused by natural ventilation	9073	9825	8694	8305	5608	5315	4394	4829	2804	3282	2502	2302
% of the energy consumed	75	85	74	83	75	84	71	82	76	95	74	93

DEMAND CONTROLLED VENTILATION

In order to reduce thermal losses during operation, and at the same time guarantee the necessary flows to allow for a regular use of the dwelling, we decided to reduce the fresh air flows in every grille, in the periods in which the dwelling was unoccupied. The idea was to get minimum values, corresponding to half the flows recommended by the Standard (Viegas, 2001), thus reducing proportionally the operating sections of the self-regulated grilles. For this purpose, we used presence sensors and differential pressure sensors in order to try to further decrease the energy consumption. For example, as regards the simulation of the apartment located in Bragança, facing NE/NW and part of the building's 3rd floor, the use of these two types of sensors, in comparison with the use of the presence sensors on their own, allowed for a reduction of about 30% of losses caused by natural ventilation. Table 8 shows the results obtained in Bragança, with an apartment facing NE/NW.

TABLE 8
Energy losses caused only by natural ventilation in demand-controlled ventilation systems and its importance in relation to the energy consumed for heating at 20 ºC

	BRAGANÇA NE/NW	
	3RD FLOOR	7TH FLOOR
Energy loss caused by natural ventilation (kWh/year)	5534	5227
% of the energy consumed	64	63

CONCLUSIONS

We conclude that the traditional system in which the air intake is made only by leakage through windows, even with heating with temperatures of 20ºC and with windows with large chinks, is hardly enough to guarantee the flows recommended by the NP-1037-1 Standard throughout the heating season. The opening of the windows in the morning is enough to surpass the flows recommended by the same Standard, but it has negative consequences, such as high energy losses and extremely low indoor temperatures.

As regards the study of the system recommended by the NP 1037-1 Standard, we conclude that the use of cowls with adequate wind pressure coefficients is essential for a good operation of the natural ventilation system and that the use of self-regulated grilles, in comparison to the non-regulated ones, allows for a substantial reduction in the maximal flows and, consequently, for a reduction of energy losses caused exclusively by natural ventilation, especially in terms of its maximum values per hour. In addition, it has been shown that the thermal stack effect is predominant in relation to the wind effect, as would be expected. The geographical location, the orientation and the opening height of the dwellings also imply variations both on the resulting ventilation flows and on the energy lost and indoor temperatures. Concerning this ventilation system, we conclude that for all the situations tested, the value of energy losses by ventilation in relation to the total of energy consumed for heating at 20ºC is always higher than 70%. We have also shown that in dwellings without heating or with intermittent heating the flows obtained are always below those recommended by the Standard and the indoor temperatures are significantly low, especially in the first case.

The simultaneous use of presence and pressure differential sensors, in the situation we analyzed, allowed for a reduction of about 40% in energy losses caused by ventilation. This clearly highlights the potential of these types of ventilation systems.

ACKNOWLEDGMENT

This work was co-funded by the Foundation for Science and Technology (FCT - Fundação para a Ciência e a Tecnologia) and by European structural funds (FEDER/EU) in the context of the POCTI/ECM/46877/2002 project.

REFERENCES

I.P.Q.-Instituto Português da Qualidade (2002). *Ventilação e Evacuação dos Produtos da Combustão dos Locais com Aparelhos a Gás – Norma Portuguesa NP 1037-1*. Portugal, Instituto Português da Qualidade.

Leal, V. e Maldonado, E. (2000). Energy Impact of Ventilation in Buildings. *In: Proceedings of Innovations in Ventilation Technology – 21stAIVC Annual Conference.* The Hague, Netherlands, paper 38.

M.O.P.T.C.-Ministério das Obras Públicas Transportes e Comunicações (1990). *Regulamento das Características do Comportamento Térmico dos Edifícios - Decreto-Lei n.º40/90 de 6 de Fevereiro*. Portugal, Diário da República.

Viegas, J. (2001). *Ventilação Natural de Edifícios de Habitação*. Lisboa, Portugal, Laboratório Nacional de Engenharia Civil.

U.S. Department of Energy (2001). *Energy Efficiency and Renewable Energy - Energyplus*. <http://www.eere.energy.gov/buildings/energy_tools/energyplus/weatherdata_html> (accessed on 6 Oct. 2002).