Air change rates in multi-family residential buildings in northern Portugal

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ABSTRACT
Existing technical recommendations and standards regarding natural ventilation in Portugal establish one air change rate, ACH, in main rooms (bedrooms and living rooms) and four ACH in service rooms (kitchens and bathrooms). Admittedly these rates are not being observed in most residential buildings recently erected in Portugal.

Two trials (May 2002 and January 2003, lasting approximately 2 weeks each) were carried out for the purpose of estimating the implementation of the rates in a two-bedroom flat which is inhabited and equipped with a ‘mixed’ ventilation system: intake via self-adjusting ventilation inlets in the living room and bedrooms, natural exhaust in the bathroom assisted by discontinuous mechanical extraction in the kitchen.

Some conclusions can be drawn regarding the efficiency of the ventilation system used, namely the results of the study shows that the measured ventilation rate was irregular and lower than the Portuguese recommendations during both seasons.

INDEX TERMS
Ventilation; Dwellings; ACH; PFT; Homogenous emission technique

INTRODUCTION
In recent years, there has been a growing concern with quality and comfort in building. Nevertheless, that concern, which is based on meeting multiple demands, has not been comprehensive and integrated, resulting in buildings which do not present the level of quality intended.

Following the energy crisis in the 1970s, there was a need to limit energy consumption, thereby diminishing air change rates (ACH) in residential buildings with consequences in air quality and relative indoor humidity level. Moreover, window frames with improved sealing reduced permeability to outside air resulting in the risk of condensation and the consequent deterioration of building materials (Piedade and Rodrigues, 2001; Freitas, 2002).

The National Laboratory of Civil Engineering (Viegas, 1995) and the Portuguese standard (IPQ, 2002) for the natural ventilation of residential buildings recommends an average of one ACH in main rooms (bedrooms and living/dining rooms) and four ACHs in service rooms (kitchens and bathrooms).

Most of the recently built residential buildings may not comply with these rates. It is necessary to implement ‘general and permanent ventilation’ systems with continuous air admission through the main rooms and air exhaust in the service rooms.

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SURVEY

In the spring of 2000, a survey of approximately 6700 construction companies (Association of the Northern Industrialists of Civil Construction and Public Works, AICCOPN) was conducted in order to characterize the ventilation systems of residential buildings under construction in the northern region.

One hundred and forty valid replies were obtained totalling 2693 dwellings. The vast majority of the dwellings (2651) are located in the northern region. The survey includes approximately 6% of the dwellings constructed in the northern region in 2000 (INE, 2001).

The buildings under study presented the following characteristics (Pinto, 2002):

- flats (93%) made up the vast majority of the surveys;
- the most widely represented typologies were two- and three-bedroom dwellings (31 and 46%, respectively);
- a large part of the dwellings were four (22.5%), five (18.8%) and six (22.9%) storey buildings.

The systems under study generally presented the following main characteristics (Pinto, 2002):

- there is no preoccupation to provide the dwellings with specific devices for the entry of air in the main rooms (bedrooms and living/dining rooms), only about 8% have fixed air inlets;
- mainly in the bathrooms (59%) or kitchens (77%) air exhaust is carried out through mechanical extraction, continuous or discontinuous;
- static ventilators are very rarely used.

Under these circumstances, one can say that ‘general and permanent ventilation’ is not a current practice in Portugal. We consider the implementation of these ventilation systems of great importance.

REGULATION AND STANDARDIZATION

There is currently no regulation in Portugal with regards to natural ventilation systems in buildings. Nevertheless, the draft standard prNP 1037-1: ‘Ventilation and combustion products evacuation from places with gas-burning appliances, Part 1: Dwellings, Natural ventilation’ (IPQ, 2002) addresses the following topics:

- flow rate-types, ACH, in residential buildings;
- permeability to air through windows and doors;
- dimensioning ventilation systems;
- exhaust of combustion products.

Table 1 presents ACHs recommended in the above draft standard.

Table 1 Recommended ACH in prNP 1037-1

Room	ACH
Kitchen, areas reserved for the installation of gas appliances,[a] bathrooms and laundries	Four (extracted)
Bedrooms and living/dining rooms	One (admitted)

[a]The installation of type A and B gas appliances is not permitted in rooms with a volume that is less than 8 m^3. The ventilation requirements of these appliances must always be respected.

We feel that the approval of this draft standard will be a first step towards implementing ‘general and permanent ventilation’ systems with continuous intake of air throughout the main rooms and exhaust of air in service rooms. The intention is to deal with both aspects related to 'general and permanent ventilation' of residential buildings and with aspects related to the extraction of the products of combustion.

RESEARCH IN PORTUGAL

At the national level, the study of ACH in dwellings using the gas tracer method (decay technique) has been limited.

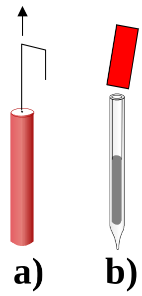
Some theoretical projects (Afonso, 1986, 1989) and others of a more experimental nature (Afonso and Maldonado, 1988; Silva, 1991; Finteiro, 1999; Viegas *et al.*, 2002) have been developed. In light of the results obtained—very irregular ACH rates obtained over short periods—conclusions cannot be drawn regarding the efficiency of the systems installed or the influence of residents' habits on the rates obtained.

Thus, measuring real ventilation conditions in occupied dwellings over a long period of time was considered essential.

MEASUREMENT

Two trials were conducted over an extended period of time in order to estimate the ventilation rates referred to earlier (May 2002 and January 2003) using the PFT technique (more precisely the homogeneous emission technique—Stymne and Boman, 1994), in a two-bedroom flat. Tracer gas source capsules with adjustable emissions were used (one to six per room) as well as a sampler capsule per room (Figure 1).

Figure 1 Example of source and sampler capsules: (a) capillary tracer gas source, with emission adjustment device; (b) passive sampler with charcoal sorbent.



The PFT technique is a passive tracer gas technique for ventilation measurement in which perfluorinated hydrocarbons are used as tracers. The tracer gas is continuously emitted to the room air at a low and constant rate from miniature containers via built-in capillary tubes (Figure 1a). Air sampling is performed using passive diffusive samplers filled with a charcoal sorbent (Figure 1b). Analysis of the amount of tracer trapped in the samplers during the exposure time is made using gas chromatography with an electron capture detector.

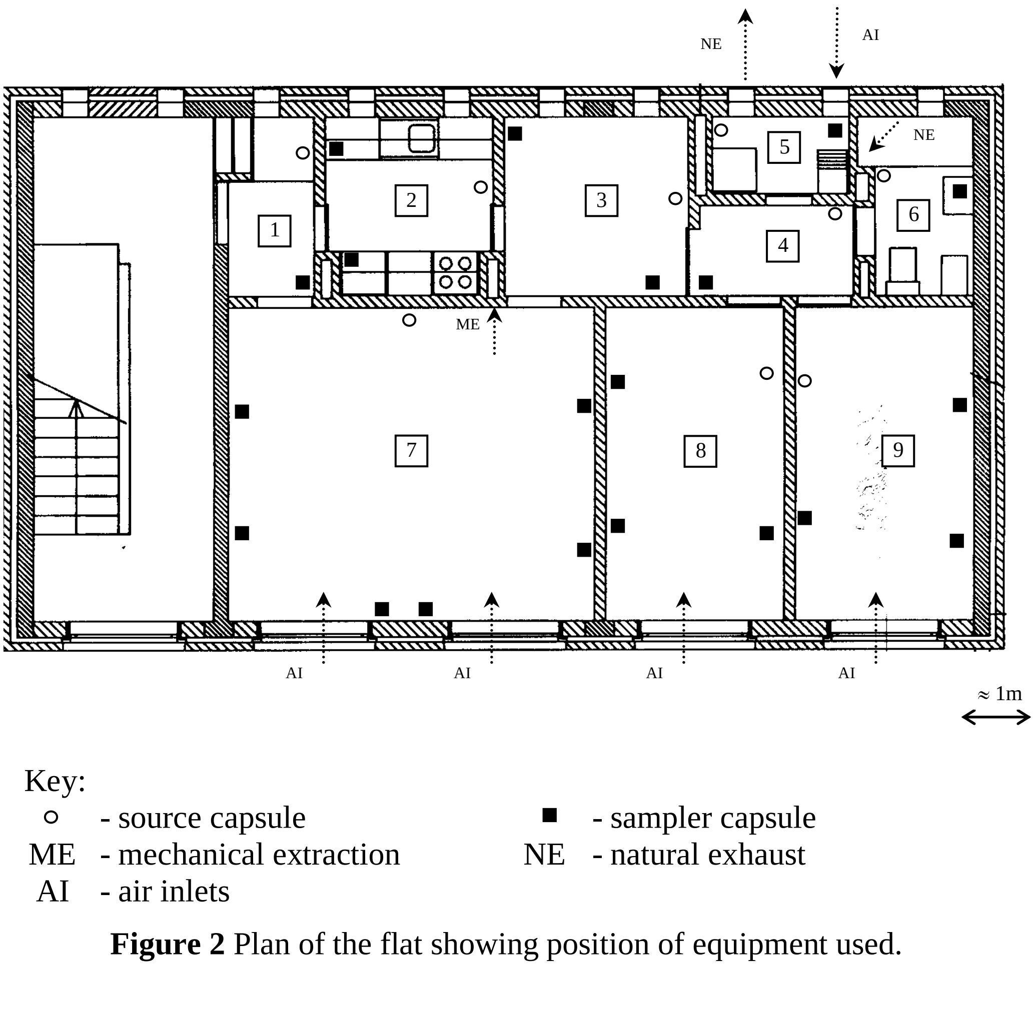
In the homogeneous emission techniques, the tracer gas emission rates from the sources are arranged to yield equal emission rate per volume unit in the measurement object. Adjustment of the emission rate from a source can be provided by a metal wire extending to different depths into the capillary tube.

Using the homogeneous emission technique the local tracer concentration will be proportional to the 'local mean age of air'. Therefore, this particular technique can be used to map the air distribution in a building. The inverted value of the local mean age of air can be interpreted as a 'local air change rate' (ACH_{local}).

The characteristics of the building and flat are as follows:

Location: near Oporto.
Height of building: above ground garage + three floors.
Height of flat: 2nd floor.
Year of construction: 2000.
Typology of flat: two bedrooms and an interior hall used as a room.
Number of people: one adult (two adults at weekend) + three children.
Ventilation system: air admission via self-adjustable inlets (one inlet per room and two inlets in the living room) with a flow rate of 30 m^3/h under a 20 Pa pressure differential; natural exhaust in bathroom (ϕ125); individual discontinuous mechanical extraction in the kitchen; self-ventilated laundry (admission/exhaust via fixed inlets).
Construction characteristics: no central heating; guillotine windows with indoor shutters (both wooden).

The following is a plan of the flat with the location of the instruments used (Figure 2).



Key:
○ - source capsule ■ - sampler capsule
ME - mechanical extraction NE - natural exhaust
AI - air inlets

Figure 2 Plan of the flat showing position of equipment used.

RESULTS AND DISCUSSION

Knowing that the inlets guarantee an admission rate of 120 m^3/h, and considering that the volume of the flat is 160 m^3, the expected ACH rate should be 0.75 h^{-1} (on average for the whole flat). The low rates obtained (Table 2) can be explained by the relative lack of cross-ventilation, the windows are practically all on one side, facing South, while prevailing winds vary between northwest and east. The lack of stack effect due to the small indoor/outdoor temperature difference and to the discontinuous mechanical extraction in the kitchen may also explain the low rate obtained. The habits of the residents, who kept their windows open for long periods of time during the May trial, may also explain the higher ACH rate during this period.

Table 2 ACH in the flat

Trial	Average indoor temperature (ºC)	Average outdoor temperature (ºC)	Wind		ACH (h^{-1})	Uncertainty
			Prevailing direction	Average speed (km/h)		
May	16.0*	14.6	NW-26.8%	19.8	0.41	±12%
January	12.2	9.4	E-34.9%	14.4	0.33	±12%

*Note 1: estimated.
Note 2: the values for outdoor temperature, direction and speed of wind are average values between 1961 and 1990.

Local variation in each room of the renewal rate, ACH, can be found in Table 3, where the rooms with the greatest ACH rate are the laundry and kitchen. A slight increase in the ACH rate in the bathroom was registered, probably due to a slight increase due to a small rise in the stack effect.

Table 3 ACH in each room

Room	No.	ACH_{local} (h^{-1})		ΔACH_{local} (h^{-1})
		May	January	
Hall	1	0.42	0.42	0.00
Kitchen	2	0.49	0.41	–0.08
Hall A (bedroom C)	3	0.40	0.35	–0.05
Hall B	4	0.37	0.33	–0.04
Laundry	5	0.85	0.68	–0.17
Bathroom	6	0.37	0.38	+0.01
Living room	7	0.40	0.35	–0.05
Bedroom A	8	0.46	0.28	–0.18
Bedroom B	9	0.33	0.26	–0.07

CONCLUSIONS

The PFT method was used, it is believed for the first time in Portugal, in order to determine the ACH rates for a two-bedroom flat.

The results obtained are well below what is stipulated in national standards. Nevertheless, these rates were predictable given the weak differential between the indoor and outdoor temperatures normally felt in Portugal. On the other hand, the layout of the windows of this dwelling does not facilitate cross-ventilation of the rooms through air wind effect.

This suggests that the devices installed (30 m^3/h self-adjusting inlets and discontinuous mechanical extraction) are not enough to counteract the low temperature differential and the absence of cross-ventilation.

Under these circumstances one can say that ‘general and permanent ventilation’ is a goal as yet to be reached in Portugal. We consider the implementation of these ventilation systems of great importance.

We intend to continue to carry out research into area, specifically:

- the creation of a trial database which includes device characteristics, method under which the systems work and expected results versus results obtained;
- trial various ventilation systems under similar or different construction and climatic conditions;
- trial new extraction devices, preferably continuously.

ACKNOWLEDGEMENTS
We wish to thank AICCOPN for their cooperation in divulging the survey to their members (approximately 6700 companies). We would also like to thank the staff of the Maia town hall for their cooperation in seeking the flat under study.

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