ASSESSMENT OF VENTILATION IN ELDERLY CARE CENTRES

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Keywords: Elderly Care Centre, Indoor Air Quality, Ventilation.

Abstract *The users of Elderly Care Centres (ECC) often spend all their time inside the premises. Therefore, their exposure to poor indoor air quality (IAQ) is likely to affect their health. Ventilation is a recognized technique to improve IAQ which is expected to have a significant influence on building occupant´s health. The need for studies on the relation between building´s physical characteristics and the indoor environment in ECC led an interdisciplinary team of researchers to develop the project GERIA, funded by the Portuguese Foundation for Science and Technology (FCT). The project objectives are to study the physical and ventilation characteristics of the buildings, the indoor air quality and the elderly people health.*

As part of the project, 33 private institutions for social care, located in the urban area of Lisbon, were randomly selected and invited to participate. In every ECC the characteristics of the building were recorded in a survey and measurements of the indoor air temperature, relative humidity and CO_2 concentration were carried out. Measurements were carried out at two rooms (at least). As the indoor air of these rooms was not affected by combustion appliances, CO_2 emissions were considered as a surrogate marker of human body emissions. In a relevant number of cases it was possible to use indoor CO_2 concentration to estimate the average ventilation rate based on tracer gas constant emission method (during occupancy period) and based on tracer gas decay method (when occupants left the rooms).

It is concluded that 70% of the maximum CO2 concentration in rooms is above 1250 ppm. Furthermore, the estimated ventilation rate is below 0.4 h-1 in 30% of the rooms. Opening the windows and/or doors when leaving the room increases ventilation rate above 1.0 h^{-1} in 50% of the rooms. In this communication the impact of pollutants emitted by human breath in indoor environment of elderly cares and estimated ventilation rates will be studied, analysing the concentration of carbon dioxide (CO_2) in sleeping rooms.

1. INTRODUCTION

Portugal is one of the most aged countries, where the elderly population shows a high prevalence of chronic diseases and respiratory problems. Several studies indicate that the people from this age group spend an average of 19 to 20 hours indoors. The Indoor Air Quality (IAQ) plays a fundamental role in the lives of the elderly, in terms of quality and health. People belonging to the most advanced age group can have weakened immune systems and health problems associated to age which increments their vulnerability to health problems associated to indoors air pollution.

The Project GERIA (Geriatric Study of Health Effects in Interior Quality Air at Elderly Care Centres in Portugal) main goal is to estimate the impact of IAQ on health.

The IAQ does not only depend on the existence and intensity of the pollutant sources (human occupancy, materials emissions and dwellings equipment's emissions, etc.), but also on the site's ventilation (ventilation rates and its efficiency) and the outdoor air quality (1). Human behaviour may significantly influence the ventilation in the occupied locations and, in some cases, the control of the pollutant source (2). Several studies have revealed the existence of high levels of CO_2 in buildings. For example, in schools such levels are caused not only by high occupation density but also by insufficient ventilation (3) (4) (5) (6). This aspect is also being reported in Portuguese schools (7) (8), where it has been observed that the children activities contribute to an increment of suspended particles in the environment. High CO_2 levels often become associated with high levels of other pollutants (9) (10). The existence of high levels of pollutants in kindergartens and nurseries (11) (12) (13) has also been internationally reported, although, in some cases, this indicates that there may exist even higher exposures to some pollutants in dwellings (13). The studies in Elderly Care Centres (ECC) are rare, perhaps because the premise that in these places problems associated to IAQ are less important, due to minor occupation density. The most common studies in this field are related to comfort analysis (14).

The result of human metabolism CO_2 measurement, in the absence of other sources (for example combustion) may be used as a way of evaluating the indoor degree of stale air from anthropic origin. Technical international documents, like the ASHRAE 62.1 (15), recommend that the CO_2 level in indoor environments should not exceed 700 ppm above outdoor ambient levels for the odours originated by human metabolism can go unnoticed. This complies with the 1000 ppm (1800 mg/m^3) limit considered in the previous Portuguese building code, "Regulamento dos Sistemas Energéticos de Climatização de Edificios" (16).. The actual regulation in Portugal (17) states a reference limit of 1250 ppm (2250 mg/m^3).

In this communication preliminary results of building characteristics found in ECC are reported, such as air permeability of the building envelope and ventilation systems in winter and summer situations. The results of measurements of CO_2 concentration in nocturne period in sleeping rooms are also presented. Furthermore, the CO_2 levels are used to assess the ventilation rates, either in the nocturne period or in the morning "aeration" of the rooms (during which the users were asked to keep the doors and windows closed due to further work on the research on air pollutants which is not reported here).

2. METHODOLOGY

In the framework of GERIA Project, using the tool available from the Office of Strategic and Planning of the Ministry of Solidarity, Employment and Social Security (http://www.cartasocial.pt/), 33 ECC in Lisbon were randomly selected in the preliminary phase (but only 18 were studied for IAQ). For the health component, the evaluation of respiratory health and the general perception of health was done by inquiry and gathering of information by the participating processes. In the framework of ventilation analysis and IAQ a survey of the characteristics of building stock was made and the measurement of CO2 concentration, temperature and relative humidity in several sleeping rooms were collected.

2.1. Characterization of the building stock

2.1.1. Survey of the building characteristics

This survey aimed to evaluate the construction characteristics and use of ECC that can have influence on ventilation and IAQ. This survey was always performed by the same technician to keep the consistency of the survey procedure. In the survey were defined thematic groups as follows:

- General information – Identification, general characterization of the building (type of building, number of floors, deployment, year of construction, building occupancy, total area and heated area) and building envelope (zone characterization and pollutants sources);
- Air conditioning of the building – Strategy of used fuel;
- Water heating – Device type and place;
- Cooking – Place and fuel;
- Other pollutants sources;
- Associated pathologies as fungi and mould;
- User habits – HVAC use (heating and cooling), ventilation (fall/winter, spring/summer);
- Users opinion – Comfort and perception of IAQ;

2.1.2. Monitoring the indoor environment

In the framework of the survey, measurements of CO_2 levels, temperature and relative humidity in the indoor and outdoor environment were made. In this study the level of CO_2 was used as indicator of the pollution in the indoor air caused by human breathing. The measurement campaign was conducted between November 2013 and March 2014 and between April 2014 and July 2014. The recording of the measurements in sleeping rooms was carried out overnight about 12 hours on average. The measuring devices have the following expanded uncertainty estimates: (i) for CO_2 of U_{CO2}=62ppm for one measurement of 1000ppm and U_{CO2}=175ppm for one measurement of 3000ppm and (ii) for temperature of U_T=1.16°C. The goal is to find the eventual association between air quality and respiratory health conditions (which is targeted by the selection of higher occupancy and construction envelope less permeable to air).

2.2. Assessment of ventilation rates

2.2.1. Concentration decay method and the constant concentration method

To evaluate the ventilation rates the concentration decay method and the constant emission method were used. To minimize the impact on routines of users, CO_2 originating from the human breath was used as a tracer gas.

In the concentration decay method the measurement of CO_2 concentration is performed when a uniform concentration of gas was achieved and its productions ends. In other words, the measurement starts when the users leave the room. The application of this technique allows evaluating the ventilation rates after the occupants leave the room (they were asked to keep the doors and windows closed). In the constant emission method the tracer gas is released in the room at constant rate. Once the source is constituted by the emissions of the occupants, the success of these measurements depends on the regular activity of the occupants, (uninterrupted) presence of the occupants during the measurements, permanence of the windows and doors closed and the difference between users' physiognomy. The measurement starts when the occupants enter the sleeping rooms and can be performed all night if the registry of CO_2 concentration does not show irregularities (i.e. changes in the pattern of emissions).

Assuming that the indoor temperature and outside temperature of air are constant and uniform (this implies that the respective densities do not change in time), the mass balance can be expressed in terms of volumetric flow rates for the next differential equation:

$$V\frac{dc}{dt} = G + \dot{V}(c_e - c) \tag{1}$$

Where the solution is given by the equation:

$$\mathrm{c(t)} = \left[\frac{\dot{V}.c_e + G}{\dot{V} + G}\right].\left\{1 - e^{\frac{-(\dot{V}+G).t}{V}}\right\} + c_0.e^{\frac{-(\dot{V}+G).t}{V}} \tag{2}$$

Where V is the effective volume of enclosure [m^3], $\dot{V}$ is outdoor air supply rate [m^3.s^{-1}], c_e is the outdoor concentration of pollutant [ppm], c_0 internal concentration of initial pollutant [ppm], c(t) is the volumetric concentration of indoor pollutant at the time t [ppm] and G is the volume of pollutant generated [m^3.s^{-1}] (18).

In the application of the decay technique it is assumed (starting from the equation 2) that the CO_2 production is null, yielding the equation 3, which characterize the decay of CO_2 concentration in the sleeping room:

$$C = C_e + [C_0 - C_e].e^{-\left(\frac{\dot{V}}{V}\right).t} \Leftrightarrow \left(\frac{C - C_e}{C_0 - C_e}\right) = e^{-\left(\frac{\dot{V}}{V}\right).t} \Leftrightarrow \ln(C - C_\mathrm{e}) = \ln(C_0 - C_e) - \left(\frac{\dot{V}}{V}\right).t \tag{3}$$

In the application of the constant emission technique it is assumed that starting form equation 2, the production of CO_2 is constant, yielding to the equation 4, which characterize the constant emission phase of CO_2 in the sleeping room:

$$C = \frac{(\dot{V}.C_e + G)}{(\dot{V} + G)}.\left[1 - e^{-\left(\frac{\dot{V}+G}{V}\right).t}\right] + C_0.e^{-\left(\frac{\dot{V}+G}{V}\right).t} \Leftrightarrow C = \frac{(\dot{V}.C_e + G)}{(\dot{V} + G)} + \left[C_0 - \frac{(\dot{V}.C_e + G)}{(\dot{V} + G)}\right].e^{-\left(\frac{\dot{V}+G}{V}\right).t} \tag{4}$$

2.2.2. Steady-state condition method

As the number of rooms with undetermined ventilation rate values obtained by the previously described method was significant (about 60%), a steady state assumption was made in order to estimate the ventilation rate. Thus, when the equilibrium concentration is reached and, as time tends to infinite, replacing (t→ ∞) in equation 4 it yields a final concentration for the steady-state condition:

$$C\infty = \frac{(\dot{V}.C_e+G)}{(\dot{V}+G)} \quad (5)$$

2.2.3. Estimation of the value of production of carbon dioxide

As it would be too invasive to proceed with the measurement of CO_2 levels of the occupants, we used the following estimate:

$$G = 4.10^{-5}.\mathrm{M}.\mathrm{A_d} \quad (6)$$

Where G is the volume of CO_2 generated [$m^3.s^{-1}$], M is the metabolic rate [$W.m^{-2}$] and (A_d) body surface [m^2] given by Dubois formula:

$$A_d = 0{,}202.m^{0{,}425}.H^{0{,}725} \quad (7)$$

Where m is the body weight [Kg] and H the height [m].

Assuming an average person with 70 Kg and a height of 1,73m, the body surface is:

$$A_d = 0{,}202.70^{0{,}425}.1{,}73^{0{,}725} = 1{,}83\ m^2 \quad (8)$$

Replacing the obtained value in the equation 5 in the equation 4 and considering that the value of the metabolic rate when sleeping is 46W.m^{-2} the following value is obtained (19):

$$G = 0{,}000046.46.1{,}8 = 0.00331\ l.s^{-1} = 0{,}01193\ m^3/h \quad (9)$$

2.2.4. Method for determining the rate of ventilating

To determine the ventilation rates the least squares regression method was used of the built-in analytical tool in Excel. In the decay method the adjustment was only done for $\dot{V}/V$ variable. In the constant emission method, the adjustment was initially made for two variables ($\dot{V}$ and G) and subsequently the G value obtained was compared with the result of expression 9 (then multiplied by the number of occupants). In the situations where the G obtained is significantly different (corresponding to 50% more than the CO_2 emissions expected for an average person) it is assumed that the model does not fit well the user's routines and then just one variable adjustment was applied (being G estimated by 9).

3. ANALYSIS OF RESULTS

3.1. Analysis of built construction characteristics

Eighteen ECC were analysed with the methodology previously described. The following tables summarize some of the results obtained in the survey. In the Table 1 the age of construction is presented and the Table 2 show the windows characteristics.

Year of construction		Absolute frequency	Relative frequency
≤18th Century		4	22%
20th Century	<1950	6	33%
	>1950	5	28%
21st Century		3	17%

Table 1. Age of construction

In Lisbon, 55% of the ECC have been built before 1950. More than 74% of the windows have aluminium frames; 39% of the windows are casement-type windows, which allow opening almost entirely the window aperture. Almost 30% of the windows do not have any gasket; the wooden framed windows are included in this set. 38% of the windows have the blind box inserted in the wall (inside blind box), which is very common in Portugal (20); it is common that the fixed joints of this type of blind boxes have a high air permeability. Some of the sleeping rooms have individual sanitary facilities which in five rooms have mechanical ventilation.

Characteristics		Absolute frequency	Relative frequency
Material of the frame	Wood	20	26%
	Aluminium	57	74%
Opening mode	Casement	30	39%
	Sliding	23	30%
	Vertical sliding sash	12	16%
	Tilt and turn	12	16%
Gasket type	Without gaskets	22	29%
	Rubber gasket	28	36%
	Plushes gasket	27	35%
Type of blind box	Inside	29	38%
	Outside	24	31%
	Without	24	31%

Table 2. Windows characterization

The Figure 1 shows the distribution of the windows characteristics and the estimated ventilations rates. It is clear that a higher ventilation rate corresponds to the windows without gaskets (it also corresponds to the wooden windows, which do not have gaskets). This stresses that the joints of the windows contribute strongly to the ventilation. The dependence of the ventilation on the opening mode is also connected with the type of gaskets: (i) tilt and turn windows are usually new and have good rubber gaskets, therefore the air permeability is the lowest; (ii) most of the casement windows are old wooden framed windows without gaskets, therefore this group has the higher air permeability.

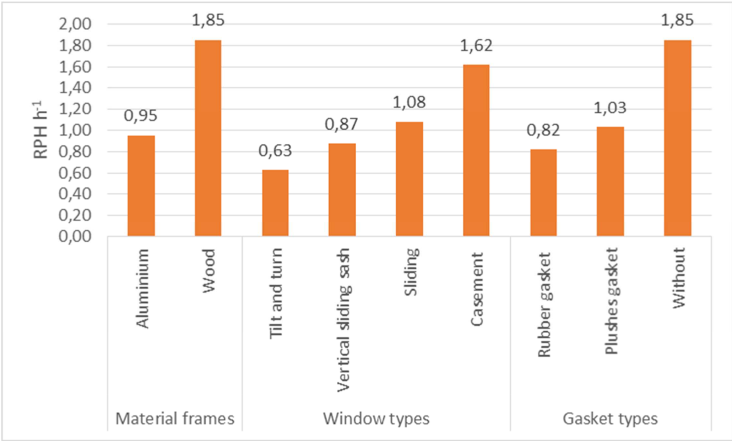

Figure 1. Distribution of the windows characteristics according to the estimated ventilation rates.

3.2. Analysis of indoor environment

The CO_2 concentration levels in 95 sleeping rooms (22 with sanitary facilities) were measured. The application of the method previously described requires that user behaviour during the night is regular (the occupants stay all night in the room). Only in 77 rooms the data showed this regular behaviour, therefore the remaining 18 rooms were rejected. The figure 2 shows an example of the time evolution of the CO_2 in one individual sleeping room and all the different phases defined in this work: growth phase, steady-state (average CO_2 concentration between 00:00 and 6:00) and decay phases. They are also defined different CO_2 peak concentrations: peak nocturne CO_2 (maximum value between 00:00 and 6:00) and maximum CO_2 (maximum value including the period before 00:00 and after 6:00), the blue line represents the adjustment from constant emission method. The figure 3 shows the distributions of the CO_2 measurements levels.

From Figure 3 it is clear that most of the rooms present CO_2 values higher than 1250ppm (2250 mg/m^3). This value is slightly higher in winter period that is explained because in winter people tend to keep more often the windows and doors closed. Having sanitary facilities does not seem to have a significant impact on CO_2 concentration.

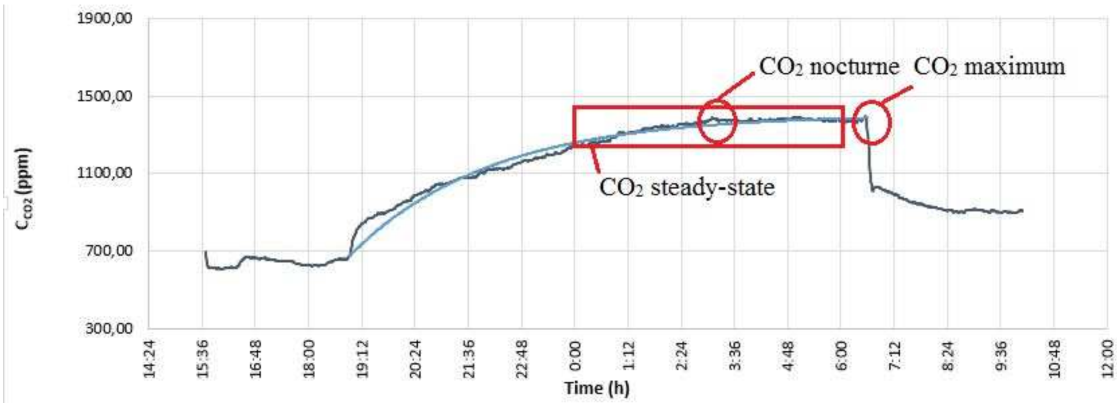

Figure 2. Individual sleeping room reading.

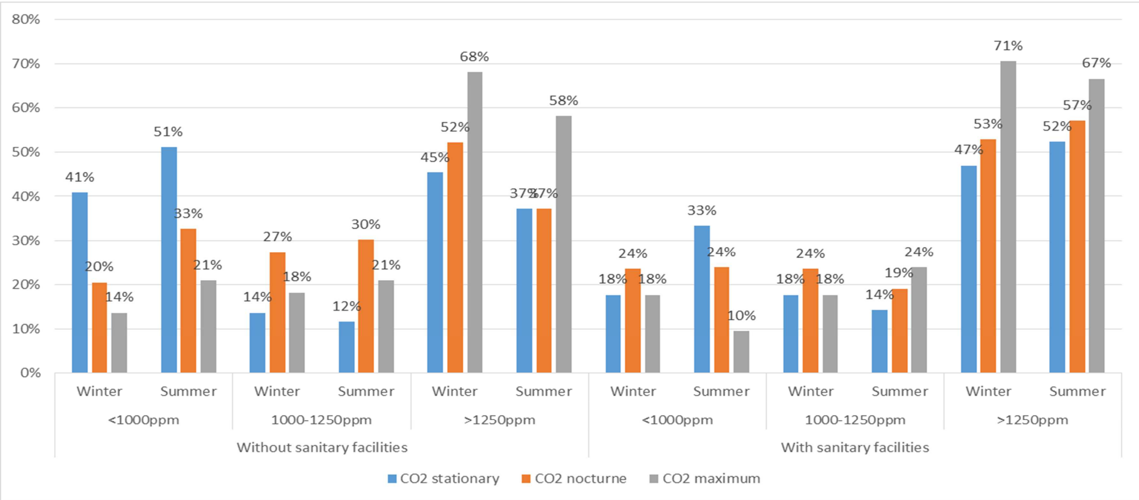

Figure 3. Distributions of the different CO2 levels

3.3. Analysis of ventilation rates

3.3.1. Analysis of ventilation rates (Constant emission method)

In the Figure 4 is displayed the distribution of the results of the ventilation rates measured during the night period in 77 sleeping rooms using the constant emission method with $\dot{V}/V$ as unique variable and with $\dot{V}/V$ and G as variables.

The Figure 4 shows, for one variable adjustment, that only about 31% of sleeping rooms have a ventilation rate below 0.4 RPH. Also, 20% of the rooms presented values closer to the minimum (0.6 RPH) accepted by Portuguese former requirements (16) whereas 50% are above. It was not possible to estimate ventilation rates in 32% of the 77 sleeping rooms.

Using two variables adjustment the percentage of ventilation rates below 0.4 is around 30% in winter and 17% in summer. However, the overall distribution is more or less the same, except that the values above 0.8 RPH also decrease, especially in summer.

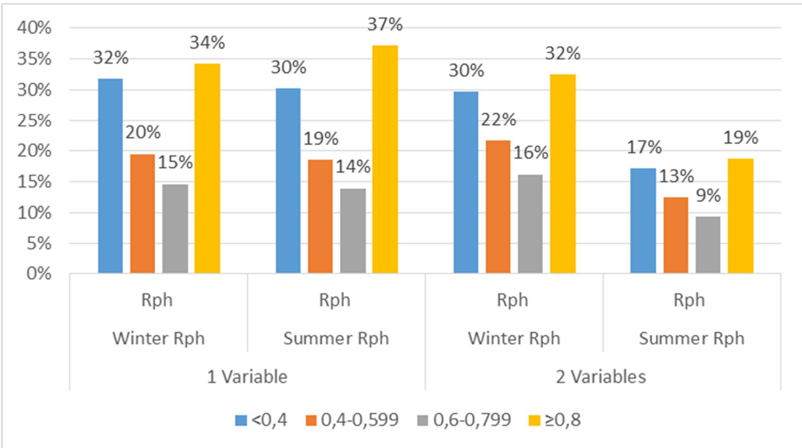

Figure 4. Results of ventilation rates through Constant emission

3.3.2. Analysis of ventilation rates (Concentration decay method)

The estimated ventilation rates by the concentration decay method were obtained in the morning period, when it is assumed that occupants are leaving their room. Due to this requirement, it was only possible to apply the method to approximately 40% of the total number of rooms. About 35% of the estimated ventilation rates is between 1 and 2 RPH (Figure 5) which indicates that windows and/or doors were probably opened. Values under 0.4 RPH are less common that values presented above according to the Constant emission method. When compared with the night period results, it is clear that the ventilation conditions have changed in the morning period.

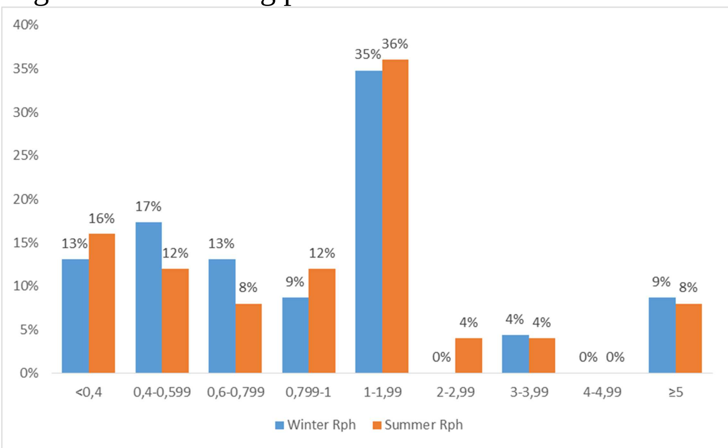

Figure 5. Results of ventilation rates through the Concentration decay method

3.3.3. Analysis of ventilation rates (Steady-state condition method)

The steady-state method uses the average CO_2 concentration level measured between 00:00 and 6:00. Since it is an average value it is less significant than the previously presented methods. The Figure 6 shows that the percentages under 0.8 RPH are similar to the ones obtained in Constant emission method. About 50% of the rooms have ventilation rates above 0.8 RPH.

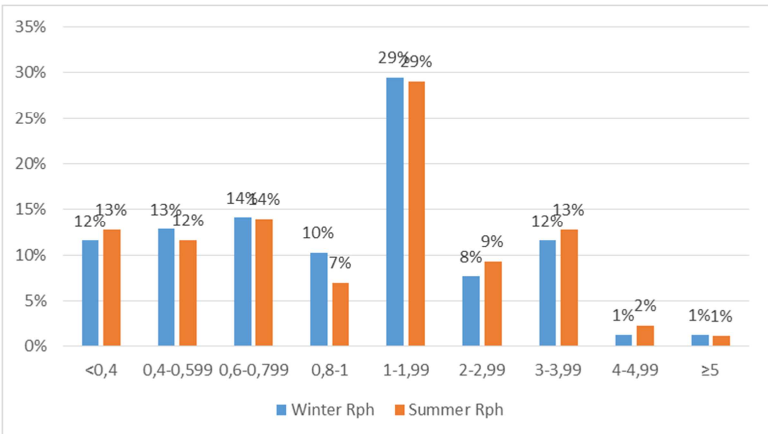

Figure 6. Results of ventilation rates considering a Steady-state period

4. CONCLUSIONS

This study allowed identifying the main characteristics of the envelope of the buildings used for ECC in the city of Lisbon. Furthermore, the indoor environment pollution of anthropic origin was assessed through the measurement of the CO_2 levels, which was used as surrogate marker. The ventilations rates were also estimated using the continuum evolution concentration of CO_2 levels over time.

The following conclusions can be withdrawn from this study:

- About half of the ECC (55%) were constructed before 1950 and have aluminium windows which indicates that they were refurbished;
- More than 74% of windows are aluminium-type windows; 39% of the windows are casement windows;
- 29% of the windows do not have gaskets;
- 38% of the windows have the blind box included in the external wall which are known as having high air permeability;
- 32% of the buildings do not have any type of blind box;
- In more than 68% of the sleeping rooms during winter and in more than 58% during summer the concentration levels of CO2 are than 1250ppm (maximum concentration). This limit is also exceeded in 52% (winter) and 37% (summer) rooms during night and in 45% (winter) and 37% (summer) for steady CO_2 concentration in sleeping rooms without sanitary facilities;
- There is no significant decrease in CO_2 concentration in rooms with sanitary facilities;
- Only less than about 20% of sleeping rooms have ventilation rates below 0.4 RPH according to the three used methods;
- About 20% of the sleeping rooms have ventilation rates above 1 RPH;

5. ACKNOWLEDGEMENT

This research project is supported by Fundação para a Ciência e Tecnologia (PTDC/SAU-SAP/116563/2010).

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