IAQ Analysis of Portuguese Residential Buildings

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Keywords: indoor air quality, thermal comfort, energy efficiency, building regulations, IAQ audit, residential buildings.

Abstract

In average, man spends about 90% of the time inside enclosed spaces, in both residential and office buildings, exposed to consistently higher concentrations of air pollutants than outdoors, which has led to the increased rate of allergies and asthma incidences.

In the last decade, public and governmental awareness on indoor air quality (IAQ) has been growing. Portugal implemented the National Building Energy and Indoor Air Quality Certification System in 2006 which imposes periodic IAQ audits for office buildings. However, in residential buildings, the only normative imposition related to IAQ is the obligation of a minimum air change rate of 0.6 h^{-1}.

The number of potential pollutants inside residential buildings is significant, and even low concentration levels can cause health problems if combined effects are considered. Additionally, the inhabitants' behaviour can have a significant impact on IAQ. Therefore, the assessment of IQA is very important.

This paper presents the application of the IAQ audit methodology, defined by the Portuguese legislation for office buildings, to residential buildings. The concentration of suspended particles, carbon dioxide, carbon monoxide, ozone, formaldehyde and total volatile organic compounds were measured as well as the air change rate. A standard questionnaire was delivered to the inhabitants to also obtain a subjective assessment of the IAQ.

The goal of this study was to verify the IAQ conditions inside the Portuguese residential buildings and to establish a comprehensive IAQ audit approach for residential buildings. The results gathered will also be used to identify the main problems of Portuguese residential building stock and to develop guidelines to improve IAQ in residential buildings.

1 Introduction

The European building stock is responsible for 33% of raw materials consumption, 33% of final energy consumption, and 50% of electricity use [1]. Therefore, improving the energy performance of the building stock is, without question, one of the biggest challenges that the construction sector has to face.

From the energy performance perspective, the main building requirements are: increase the insulation thickness; reduce thermal bridges; and reduce the air changes. The latter parameter has to be thought carefully, since the reduction of air changes can decrease the intake of fresh outside air and thus increasing the consequent build-up of internally generated pollutants including fungi, microbial contamination, house dust mites, particulates and toxic air contaminants (chemicals), gases, vapours and odours. However, indoor air quality (IAQ) only became an important occupational health and safety concern and a public and governmental awareness in the last decade.

Portugal implemented in 2006, the National Building Energy and Indoor Air Quality Certification System, corresponding to the implementation of the Energy Performance of Building Directive, EPBD [2], which imposes a minimum energy efficiency for the buildings and periodic IAQ audits for office buildings. However, in residential buildings, the only normative imposition related to IAQ is the obligation of a minimum air change rate of $0.6h^{-1}$ [3].

An IAQ problem is suspected if people generally develop symptoms such as headaches, fatigue, shortness of breath, sneezing and coughing, dizziness, nausea, dryness and eye, nose, throat and skin irritation, hypersensitivity and allergies apparently linked to the time they spend inside the building and usually feel better after leaving the building (Sick Building Syndrome). These symptoms may also be caused by other factors, and are not necessarily attributable to poor indoor air quality. It is rarely possible to prove these symptoms are related to any particular indoor air pollutant. In reality, the occupants are simultaneously exposed to a wide variety of indoor air contaminants and even low concentration levels can cause health problems if combined effects are considered.

As with any other work-related illness, not all people are affected. The more sensitive or more exposed people will experience symptoms sooner. Susceptibilities of individuals to the contaminants may vary and some may be sensitized with continued exposure. As indoor air quality deteriorates and/or the duration of exposure increases, more people tend to be affected and the symptoms tend to be more serious. As 90% of the population spends about 90% of the time in enclosed spaces exposed to consistently higher concentrations of air pollutants than outdoors, which has led to the increased rate of allergies and asthma incidences. Thus good indoor air quality has a vital impact in human health.

Asthma affects about 235 million people worldwide and approximately 1 million in Portugal (10% of the population) and its incidence continues to increase, including the young and the elderly [4, 5].

Several factors are thought to contribute to that, namely the atmospheric pollution by ozone and suspended particles, and the indoor pollution by volatile organic compounds and tobacco smoke. Suspended particles are seen as one of the most critical air pollutants, and some estimates have suggested that suspended particles are responsible for up to 10,000 premature deaths in the United Kingdom each year [6].

Therefore, IAQ is an important factor in the well-being, health and productivity of man and must be evaluated, not only in office buildings but also in residential buildings. Indoor air pollution may have many sources in a dwelling, and indoor air quality can vary widely. The harmonization of the buildings energy performance requirements with the indoor air quality should be done in every building project, both for new and for existing buildings.

Thus, in this paper an “in-situ” evaluation of the Portuguese building stock regarding several parameters related to indoor air quality (Carbon Dioxide, CO_2, Carbon Monoxide, CO, Ozone, O_3, Formaldehyde, CHOH, Volatile Organic Compounds, VOC, and Suspended particles, PM_{10}) and also the air change rate is presented.

During the measurement campaign, buildings that encompass different types of construction solutions, climatic zones and construction periods were evaluated. One of the major objectives of this study was to assess the indoor air quality of the Portuguese buildings and to identify the main problems related to the IAQ. This study also aims to show the need to include measures to optimize the IAQ besides the energy efficiency measures during the design process of the buildings.

2 Methodology

This paper presents the “in situ” assessment of the Indoor Air Quality and building air tightness of several Portuguese buildings.

The measurement campaign included the assessment of the IAQ conditions (measurement of the concentration of suspended particles, carbon dioxide, carbon monoxide, ozone, formaldehyde and total volatile organic compounds) and building air tightness (air change rate). Additionally, a standard questionnaire was delivered to the inhabitants to obtain a subjective assessment of the IAQ. The occupants were asked about their perception of the IAQ (fresh, smelly, sources of pollutants) and symptoms such as headaches, fatigue, shortness of breath, sneezing and coughing, dizziness, nausea, dryness and eye, nose, throat and skin irritation, hypersensitivity and allergies.

A total of 16 buildings, selected to represent the typical Portuguese buildings, have been assessed up to date. The buildings are from different decades of construction, have different locations and climatic zones and construction solutions.

3 Building Characteristics

As previously mentioned, the selected buildings encompass a representative sample of the Portuguese buildings stock. These buildings were built in different years, have different typologies and construction solutions, as shown in Table 1, and thus may be considered representative of the Portuguese building stock.

4 Measurement Procedures

To measure the parameters associated to the IAQ "in situ" the procedures defined in national and international standards were followed [7, 8, 9].

The measurement campaign was carried out during the winter season, which means that, in general, the building occupants did not open the windows to ventilate the spaces because the outside temperature was low.

Table 1: Case studies building characteristics

Case Study	Typology	Year of Construction	City	Climatic Zone	Construction solution	
					Windows	Walls
CS1	Single family house	1989	Braga	I2, V2	Single glazing with aluminium frame	Single pane CMU (concrete masonry unit)
CS2	Single family house	1985	Braga	I2, V2	Single glazing with wood frame	Double pane brick masonry
CS3	Single family house	1982	Fafe	I2, V2	Double glazing with aluminium frame Double glazing with aluminium frame	Double pane brick masonry
CS4	Single family house	1982	Guarda	I3, V1	Single glazing with aluminium frame	Double pane brick masonry with injected PUR (polyurethane) in the air gap
CS5	Dwelling	2002	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane brick masonry with XPS (extruded expanded polystyrene) in the air gap
CS6	Dwelling	2005	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane masonry – stone + brick
CS7	Dwelling	1960	Porto	I1, V2	Single glazing with wood frame	Double pane brick masonry
CS8	Dwelling	1990	Porto	I1, V2	Single glazing with aluminium frame	Double pane brick masonry
CS9	Dwelling	2007	Maia	I1, V2	Double glazing with aluminium frame	Double pane brick masonry with XPS in the air gap
CS10	Dwelling	1995	Viseu	I2, V2	Double glazing with PVC frame	Double pane brick masonry with XPS in the air gap
CS11	Dwelling	1999	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane brick masonry with XPS in the air gap
CS12	Single family house	1998	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane brick masonry with XPS in the air gap
CS13	Single family house	1993	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane brick masonry
CS14	Dwelling	1976	Guimarães	I2, V2	Single glazing with aluminium frame	Double pane brick masonry
CS15	Dwelling	1977	Guimarães	I2, V2	Single glazing with aluminium frame	Double pane brick masonry
CS16	Dwelling	2000	Guimarães	I2, V2	Double glazing with aluminium frame	Double pane brick masonry with XPS in the air gap

5 Indoor Air Quality (IAQ)

The thermal regulations in Portugal turned mandatory to carry out IAQ audits for office buildings but not for residential buildings. Therefore, for the present study, targeted to residential buildings, a similar methodology was followed for both physical and chemical pollutants [7, 8]. The physical and chemical pollutants were measured with portable measuring equipments: Testo 435 (CO_2 and CO); TSI DustTrack II (PM_{10}); ZDL-300 (HCHO); ZDL-1200 (O_3); Photovac 2020ppb (VOC).

Table 2 lists the maximum reference concentrations of each pollutant according to the Portuguese regulation [7, 8].

Table 2: Maximum reference indoor concentration of pollutants inside buildings [7, 8].

Type of pollutants	Parameter	Maximum reference concentration	
		mg/m^3	ppm
Physical and Chemical	Suspended particles (PM_{10})	0.15	-
	Carbon Dioxide (CO_2)	1800	984
	Carbon Monoxide (CO)	12.5	10,7
	Ozone (O_3)	0.2	0,10
	Formaldehyde (CHOH)	0.1	0,08
	Volatile Organic Compounds (VOC)	0.6	0.26 (isobutylene) 0.16 (toluene)
	Radon, Rn	400 Bq/ m^3	

6 Air tightness

The air tightness of the building is also an important indicator of the IAQ and of the energy performance of a building and it can be obtained by the building Air Changes Rate (ACH). If the building is naturally ventilated this parameter can be estimated using the methodology presented in the Portuguese residential building thermal code [3]. However, in existing buildings, a more accurate ACH value can be obtained using measuring equipment such as the blower-door, which will pressurize/depressurize the building, measuring the air flow that enters/exits the dwelling while the pressure stabilizes, thus allowing the measurement of the air leak.

A blower-door was applied to measure the number of air changes per rate of the dwellings. The minimum air change rate according to the Portuguese thermal code is of $0.6h^{-1}$.

The air change rate of the dwellings was obtained from Equation (1) [9].

$$Q = C \times P^n \quad (1)$$

with:
Q – Air flow rate (m^3/s);
C – Flow coefficient ($m^3/s/Pa^n$);
P – Pressure difference from indoors and outdoors (Pa);
n – Flow exponent (-).

7 Results

The results obtained through the measurement campaign performed are presented below according to the type of analysis done.

7.1 Indoor Air Quality (IAQ)

The Indoor Air Quality (IAQ) was assessed through the measurement of the concentration of physical pollutants (CO, CO_2, CHOH, VOC, O_3, PM_{10}, Rn). Figure 1 shows the results of the IAQ measurements for one building.

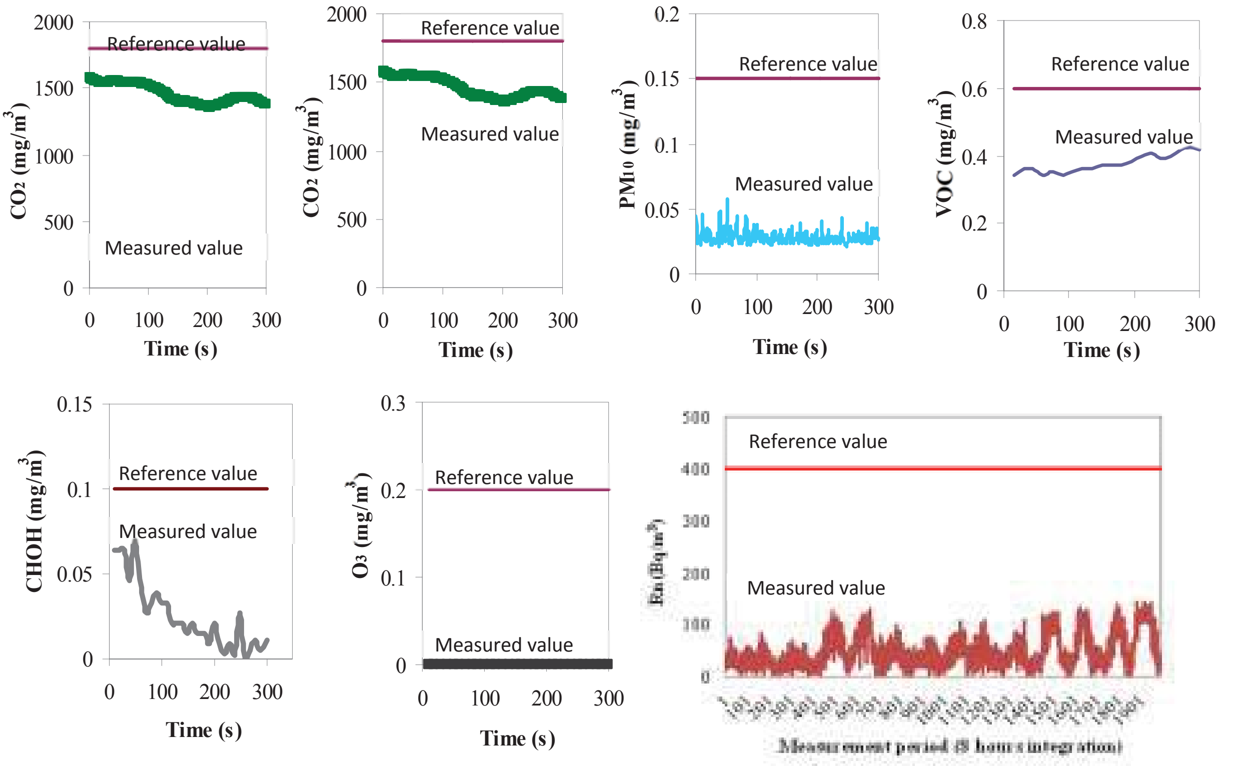

Figure 1: Pollutants concentration and maximum reference values in the living room of one of the dwellings

The main IAQ problems detected were related with CO_2 concentration, due to human occupation, and with small concentrations of carbon monoxide (less than 1/10 of the maximum reference concentration) in kitchens (due to gas-stoves and gas water-heaters), in living rooms (with open fireplaces) and in living rooms and bedrooms where there were smokers present in the dwellings. The presence of suspended particles in higher concentrations was detected in dwellings with fireplaces and smokers when compared to other dwellings (0.05 mg/m^3 in average). The concentration of these three pollutants is also associated to the outdoors concentrations as the buildings are located near heavy traffic circulation roads.

The concentrations of formaldehyde (CHOH) and volatile organic compounds (VOC) detected were not very high but in bedrooms, with perfumes, and in living rooms, with scent candles, the CHOH and VOC concentrations reached values close to the maximum reference values.

The presence of ozone was not detected and the radon concentrations measured were, in general, not high.

The occupants felt that the air quality was just acceptable and reported the existence of a slightly unpleasant odor.

In general, the occupants did not open the windows to ventilate the buildings because the outside temperature was low and the kitchen exhaustion system and the bathroom fans were only turned on in short periods (when cooking or bathing) due to the noise.

7.2 Air tightness

Figure 2 shows the measured values of the number of air change rates of the different case studies in analysis as well as the ACH values obtained following the methodology described in the Portuguese thermal code (RCCTE) and also the minimum allowed ACH value (0.6h^{-1}).

The results show a good approximation between the measured and the calculated ACH values. However, the values are quite high and will also result in substantial heat losses in winter and heat gains in summer. Thus, interventions at this level are essential to increase the energy performance, mainly through the replacement of the windows and use of mechanical ventilation systems with heat recovery. These measures will be the most efficient way to achieve the optimum air change rates in residential buildings and take advantage of the exhaust air to pre-heat the fresh air, reducing the energy needs.

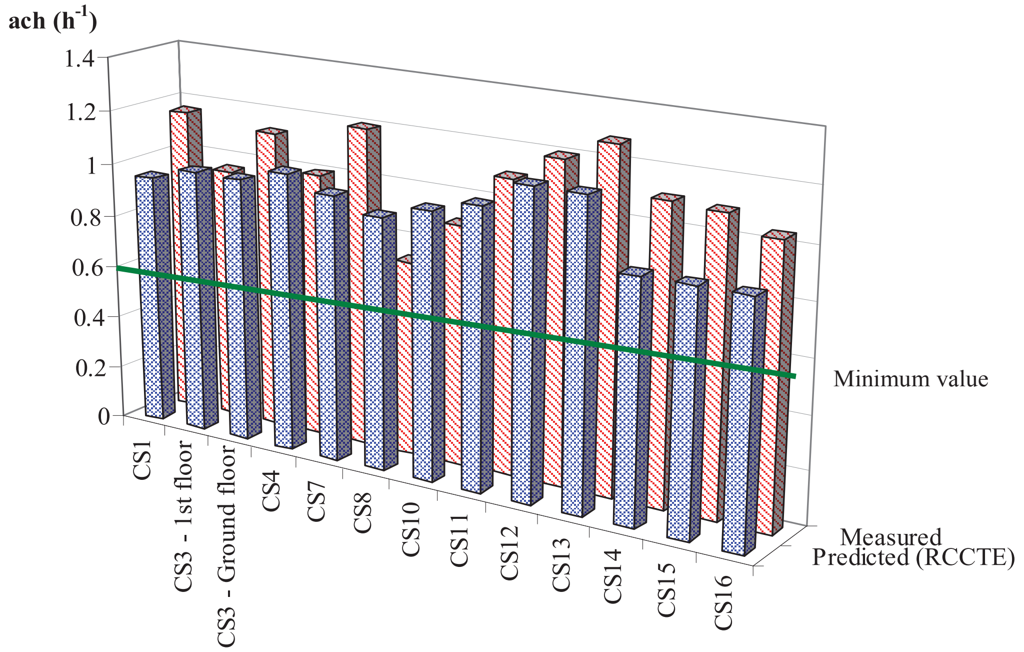

Figure 2: ACH of the different case studies

8 Conclusions

This paper presents the “in situ” assessment of the Indoor Air Quality of several Portuguese buildings. The measurement campaign was divided in two major areas: Indoor Air Quality and air tightness.

With the operating conditions assessment carried out, it was possible to identify some of the most critical problems of the Portuguese building stock, the ones that need particular attention during the rehabilitation interventions.

The measurement campaign confirmed the necessity of reducing the uncontrolled infiltrations through the envelope, using more airtight window frames and doors, with adjustable air inlets to ensure an adequate air change rate and, if necessary, using mechanical ventilation systems with heat recovery units. However, the control of the air change rate must be done very carefully in order to ensure the indoor air quality, since, even with high air change rates, high concentrations of some pollutants like carbon monoxide, volatile organic compounds and formaldehyde, and also small concentrations of carbon monoxide, associated to the use of gas stoves, gas water-heaters and fireplaces, were detected.

Improving the quality of the window frames and doors and increasing the insulation level of the façades, will also have a favourable effect on the acoustic and thermal comfort.

9 References

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