Thermal Comfort and IAQ Analysis of two Portuguese Hospital Buildings

Sandra Monteiro da Silva [1, †], Pedro Silva [2], Manuela Almeida [3]

Universidade do Minho, Departamento de Engenharia Civil
Azurém, P - 4800-058 Guimarães, Portugal

ABSTRACT

In the last decades, public and governmental awareness on thermal comfort and indoor air quality (IAQ) has been growing. In buildings the number of potential pollutants is significant, and even low concentration levels can cause health problems (increased incidence of asthma and allergies, for example) if combined effects are considered. Therefore, the assessment of thermal comfort conditions and IAQ is very important to ensure health, wellbeing and productivity. This paper presents the results of a thermal comfort conditions and IAQ assessment of two hospital buildings with natural ventilation. The goal of this study was to verify the thermal and IAQ conditions inside Portuguese hospital buildings. The air temperature, the black bulb temperature, air velocity, relative humidity and the concentration of suspended particles, carbon dioxide, carbon monoxide, ozone, formaldehyde and total volatile organic compounds were measured. A standard questionnaire was delivered to the occupants to also obtain a subjective assessment of the thermal comfort and IAQ conditions. The results showed that, in general, the occupants were uncomfortable and that the main IAQ problems were related to high concentrations of carbon dioxide, volatile organic compounds and formaldehyde.

1. INTRODUCTION

The European building stock is responsible for consuming 33% of raw materials, 33% of final energy, and 50% of electricity (Balaras, 2005; Eurostat, 2010; Mateus and Bragança, 2011). Therefore, improving the energy performance of the existing building stock is one of the biggest challenges that the construction sector has to face nowadays.

Accordingly, the main building renovation requirements needed to improve energy performance include: increasing insulation thickness; reducing thermal bridges and air change rates. In naturally ventilated buildings the latter parameter has to be carefully considered, since the reduction of air change rates can decrease the intake of fresh air from the exterior and thus increase the consequent build-up of internally generated pollutants, including fungi, microbial contamination, dust mites, particulates and toxic air contaminants (chemicals), gases, vapours and odours. However, only in the last decade has indoor air quality (IAQ)

[1] Assistant Professor
[†] Corresponding author (sms@civil.uminho.pt)
[2] PhD
[3] Associated Professor

become an important occupational health and safety concern for the government and also the public.

Portugal implemented in 2006 the National Building Energy and Indoor Air Quality Certification System transposing the European Union's Energy Performance of Building Directive (EPBD) (European Commission, 2002), which imposes a minimum energy efficiency for the buildings and periodic IAQ audits for office buildings (Decreto-Lei n.º 78/2006; Decreto-Lei n.º 79/2006). The Portuguese Building Energy and Indoor Air Quality Certification System was revised in 2013 (Decreto-Lei n.º 118/2013; Portaria n.º 353-A/2013).

Indoor air pollution can result from many sources within the building and thus influencing indoor air quality. When, in a building, people experience symptoms such as headaches, fatigue, shortness of breath, dizziness, sneezing, coughing and dryness of the eyes, nose and throat as well as skin irritation and allergies an IAQ problem may exist. These symptoms are apparently linked to the time people spend inside the building and usually occupants feel better after leaving the building (Sick Building Syndrome) (Fang et al., 1998; Mendell et al., 1999; Kolarik et al., 2011). They may also be caused by other factors that are not necessarily attributable to poor indoor air quality. It is seldom possible to relate these symptoms with any particular indoor air pollutant as the occupants are simultaneously exposed to a large variety of indoor air contaminants. Additionally even low concentration levels can cause health problems if combined effects and exposure periods are considered.

As with any other work-related illness, not all people are affected. The more sensitive or more exposed people are, the sooner they will experience symptoms. Susceptibilities of individuals to the contaminants may vary and some may be sensitized with continued exposure. As IAQ deteriorates and/or the duration of exposure increases, more people tend to be affected and the symptoms tend to be more serious. As, in industrialized countries, most of the population spends about 90% of the time in closed spaces, in general exposed to consistently higher concentrations of air pollutants than outdoors, the rate of allergies and asthma incidence has strongly increased in the past years.

Asthma affects about 235 million people worldwide and about 1 million in Portugal (10% of the population) and its prevalence tends to increase, especially among the young and the elderly (WHO, 2011; FPP, 2011). Atmospheric pollution by ozone and suspended particles, and the indoor pollution by volatile organic compounds and tobacco smoke are some of the factors that are linked to asthma occurrence. Suspended particles are considered one of the most critical air pollutants, and some estimates suggest that suspended particles are responsible for up to 10,000 premature deaths, each year, in the United Kingdom (UK DEFRA, 2010).

The relative humidity can also have an important contribute to poor indoor air quality and it is known as one of the only parameters that can negatively affect the perception of indoor air quality (Fang et al., 1998). Besides the sources of indoor air pollution, outdoor air quality, relative humidity and the ventilation rates have a strong effect on IAQ.

In buildings with low air change rates and high relative humidity, fungus growth increases posing serious health risks (Bornehag et al., 2001). High relative humidity and inadequate ventilation are the keys to proliferation of toxic moulds and dispersion of spores in air and might also lead to increasing volatile organic compound (VOCs) release, especially in buildings with low thermal insulation levels. This will affect the indoor environment quality of a building and can cause an adverse impact on occupants' health due to exposure (Yu and Kim, 2010; Singh et al., 2010). The IAQ is then an important factor in the well-being, health and productivity of people (Clements-Croome, 2006).

In general, if the outdoor air quality is adequate, ventilating the buildings (replacing saturated indoor air by outside fresh air) is sufficient to avoid these problems.

Prevention is thus essential to ensure indoor air quality and thermal comfort in buildings. But to prevent IAQ and health issues in buildings it is necessary to know the existing conditions in the buildings. To do so an IAQ and thermal comfort assessment is needed through an environmental monitoring. This is also an important first step when planning a building's renovation.

The occupants' perception is also a significant aspect to consider when assessing IAQ and thermal comfort as they are a useful and inexpensive source of information about building conditions (Baird and Dykes, 2012). The occupants are able to recognize when the indoor air quality is deteriorating, as they can perceive the room to be stuffy or unpleasantly smelling when pollutant levels are elevated but still relatively low and at healthy levels (Engvall et al., 2005). Additionally the behaviour of the occupants can affect the sources of pollutants due to the selection of cleaning products (Baird and Dykes, 2012; WHO, 2006; Newell and Newell, 2011), habits, as opening windows and activating shading systems, etc., that impact both IAQ and comfort conditions.

But, in general, renovation plans are based on energy saving and efficiency potential, focusing on the reduction of energy consumption and carbon dioxide emissions, neglecting the IAQ, thermal comfort and occupants' perception.

Thus, when planning a building renovation, as well as in new buildings, energy performance requirements should be merged with the indoor air quality requirements.

In this context, this paper presents the "in situ" assessment of the indoor air quality and also the thermal comfort conditions of two Portuguese hospital buildings.

2. METHODOLOGY

A measurement campaign was carried out to assess the IAQ conditions (through the measurement of the concentration of several pollutants: Carbon Dioxide, CO_2; Carbon Monoxide, CO; Ozone, O_3; Formaldehyde, HCHO; Volatile Organic Compounds, VOC; and Suspended Particles, PM_{10}) and the thermal comfort conditions (through the assessment of the operative temperature and Predicted Mean Vote, PMV). Additionally, a standard questionnaire was delivered to the occupants to obtain a subjective assessment of the IAQ and comfort conditions and to identify the occupants' main complaints.

2.1.Buildings' Characteristics

The measurements were performed in the psychiatric and internal medicine departments (administrative areas, doctors and nurses offices, wards, common rooms, bar, corridors, waiting room, meeting rooms) of two hospital buildings, both located in Viseu, Portugal.

The first building (Building A), built in 1969 (Figure 1), has four floors. Building A has cavity walls with 20 cm of stone masonry, an air gap and 11 cm hollow brick, with plaster finishing (the thermal transmittance - U-value = 1.51W/m^2.ºC) and 25 cm concrete floors. All the windows are single glazed with a metallic frame and have venetian blinds placed inside (U-value = 4.50 W/m^2.ºC). The building is naturally ventilated and has a diesel boiler associated with water radiators in all areas except the offices that have electric oil radiators. The building does not have cooling systems.

The rooms, of Building A, that were studied are represented on Figure 2. In the basement were assessed the general office (1), doctor office (2), meeting room (3), corridors (4, 9, 12), social services offices (5, 6), archive (7), doctors meeting room (8), waiting room (10), bar (11). In the ground floor were studied the corridor (14), internment ward (15), cafeteria (16), waiting room (17), meeting room (18), general office (19), nurses office (20). In the 1st and 2nd floors were assessed the dressing room (21), waiting room (22), meeting room (23, 26), library (24), eating disorder office (25), activities room (27), psychiatric office (28).

Figure 1 – General view of Building A.

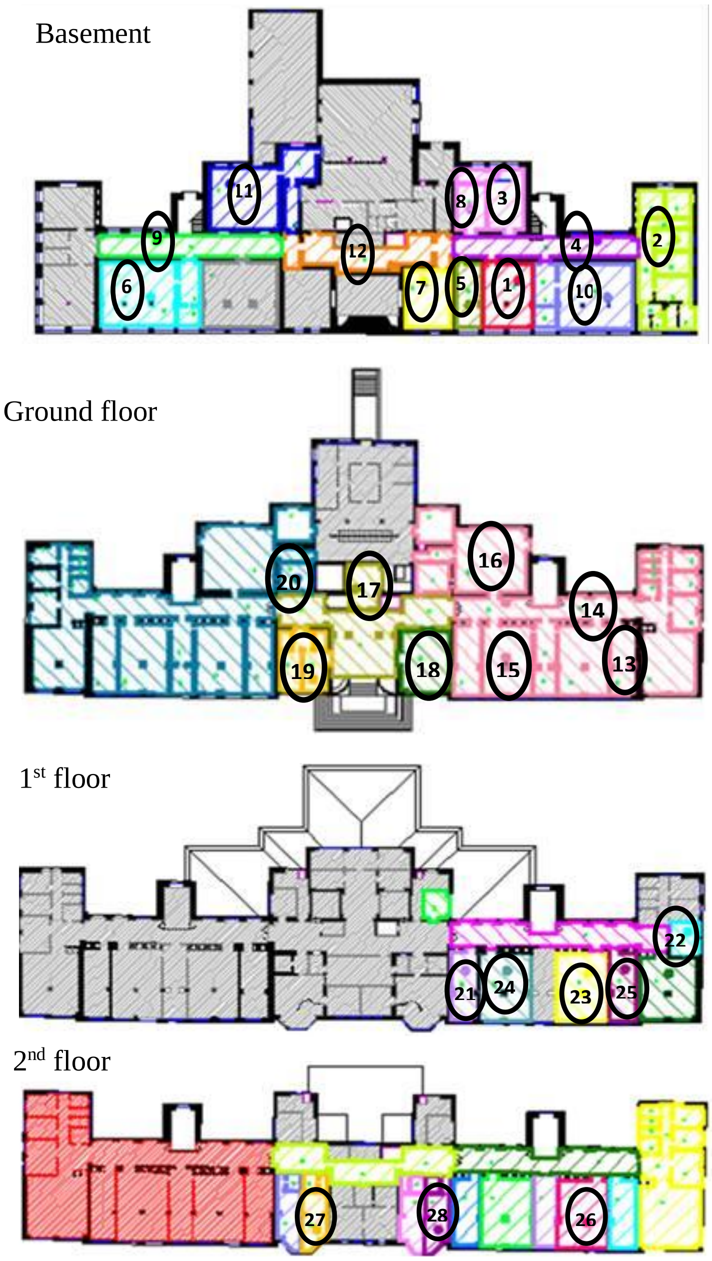

Figure 2 – Floor plans and studied rooms for Building A.

The areas represented in grey in Figure 2 are areas that are not being used and the areas represented in red in 2nd floor plan were not assed due to the patient restrictions (children psychiatric ward).

The second building (Building B), built in 1997 (Figure 3), with nine floors, has cavity walls (15 cm + 11 cm hollow brick) with 4 cm insulation (expanded polystyrene) placed in the air gap and have plaster finishing (U-value = 0.54 W/m^2.ºC) and 25 cm concrete floors. The windows are double glazed with a metallic frame and have roller shade blinds placed on the outside (U-value = 3.60 W/m^2.ºC). Building B has Air Handling Units connected to gas boilers and chillers, for heating and cooling. The warm or cool air is driven to the different rooms by air ducts.

Figure 3 – General view of Building B.

In Building B was also studied the psychiatric service areas, located in the 7th floor (Figure 4). The areas that were studied (Figure 4) were the head nurse office (1), corridors (2, 4, 6, 7), ward (3), general office (5), office (8), meeting room (9).

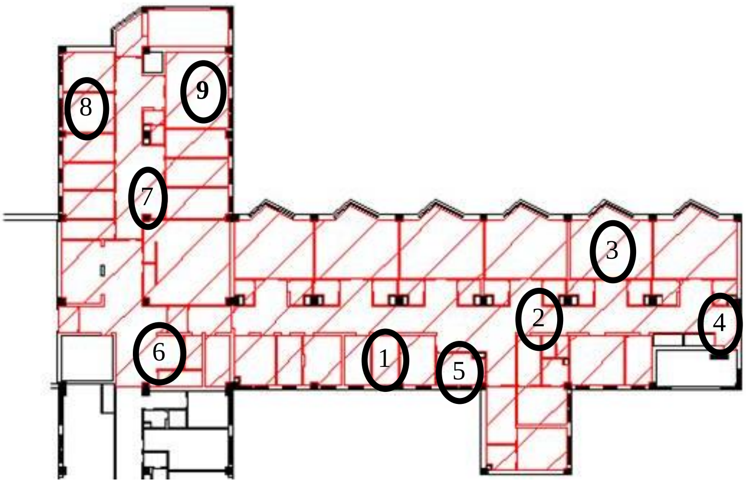

Figure 4 – Floor plans and studied rooms of Building B.

2.2. Measurement Procedures

The measurements were performed on March 25th 2012 for Building A and on May 10th 2012 for Building B. The measurements were performed in operating conditions – with all elements (shading, lighting, and HVAC systems) defined by the occupants.

To measure the “in situ” parameters associated to the IAQ and to the thermal comfort, procedures defined in international and national standards were followed (Decreto-Lei n.º118/2013; Portaria n.º 353-A/2013; ADENE, 2009; ASHRAE, 2010; EN, 2007; EN ISO, 1998; EN ISO, 2005).

2.2.1. Thermal Comfort

The quantification of the thermal comfort was carried out applying the ASHRAE standard (ASHRAE, 2010) and the EN ISO standards (EN, 2007; EN ISO, 2005), all recommending the measurement of the PMV – predicted mean vote (seven-point thermal sensation scale: - 3, cold, to +3, hot, with 0 being neutral) – and the PPD – percentage of people dissatisfied.

According to the EN ISO 7730 (EN ISO, 2005) and the EN 15251 (EN, 2007) standards, the studied buildings are category A or I buildings, respectively, were it is foreseen a high level of expectation, as they are hospital buildings (spaces occupied by very sensitive and fragile persons with special requirements like sick persons).

In order to obtain the required parameters for the calculation of PMV and PPD the measuring equipment Delta Ohm HD32.1 - Thermal Microclimate Data Logger was used. This equipment monitors in parallel the following parameters: black bulb temperature, to calculate the mean radiant temperature (-10 ºC to 100 °C); air speed and direction (0 to 5 m/s); air temperature and relative humidity (-10 ºC to 80 °C and 5 to 98%) and dry and wet bulb temperature (4 °C to 80 °C).

2.2.2. Indoor Air Quality

According to the thermal legislation in Portugal it is necessary to carry out IAQ audits in office buildings when there are complaints (Decreto-Lei n.º118/2013; Portaria n. 353-A/2013). A complete IAQ audit was not performed in this study. Only a set of physical and chemical pollutants were measured in several rooms with portable measuring equipments: Testo 435 (CO_2 and CO; 0 to 10000 ppm); TSI DustTrack II (PM_{10}; 0.001 to 400 mg/m^3); ZDL-300 (HCHO; of 0 to 30 ppm); ZDL-1200 (O_3; 0 to 2 ppm) and Photovac 2020ppb (VOCs; 10 ppb to 10 ppm). The presence of radon and microbiological contaminants was not assessed at this phase since they require significantly higher measurement times and thus were scheduled for a 2^{nd} measurement phase.

The rooms where the measurements were performed were selected in accordance with the occupancy pattern, number of occupants and activity carried out in the room. During a normal working day, at least three measurements of 5 minutes each were taken in each room. The number of measurement points in each room was defined considering the area of the room, in accordance with the Portuguese thermal regulations (Decreto-Lei n.º118/2013; Portaria n.º 353-A/2013; ADENE, 2010).

According to the Portuguese regulations, for all but the CO_2, the IAQ fulfils the requirements if the maximum concentration of the pollutant measured is inferior to the maximum reference concentration value (listed in Table 1).

Table 1 – Maximum reference indoor concentration of pollutants inside buildings (Decreto-Lei n.º118/2013; Portaria n.º 353-A/2013).

Type of pollutants	Parameter	Maximum reference concentration	
		mg/m^3	ppm
Physical and Chemical	Suspended particles (PM_{10})	0.15	-
	Carbon Dioxide (CO_2)	depends on the area of the room	
	Carbon Monoxide (CO)	12.5	10.7
	Ozone (O_3)	0.2	0.10
	Formaldehyde (HCHO)	0.1	0.08
	Volatile Organic Compounds (VOC)	0.6	0.26 (isobutylene) 0.16 (toluene)

For the CO_2, to comply with the Portuguese thermal regulations, the average concentration must be lower than the maximum reference concentration defined taking into account the area of the measured room (Decreto-Lei n.º118/2013; Portaria n.º 353-A/2013). If the maximum reference concentration is exceeded, additional measurements should be performed to verify if the maximum measured value does not exceed 1.5 times the maximum reference concentration. If the second condition is respected, CO_2 concentration fulfils the requirements.

2.3.Occupants' Survey

The occupants' survey and the measurements were carried out at the same time (March 25th 2012 for Building A and on May 10th 2012 for Building B).

The standard questionnaire delivered to the occupants was based in the methodology defined in the EN 15251:2007 standard Annex H (EN, 2007).

In the survey, the occupants were asked to answer questions related to age, gender, metabolic activity, clothes and characteristics of the offices, number of occupants, position related to the windows, identification of appliances and systems and patterns of use.

Additionally, the occupants were asked to indicate their opinion about the: thermal conditions (hot, warm, slightly warm, neutral, slightly cool, cool and cold) and temperature variation during the day; IAQ (clearly unacceptable, unacceptable, acceptable and clearly acceptable); ventilation conditions (5 levels from insufficient to excessive air change rates) and global comfort conditions (very uncomfortable, uncomfortable, comfortable and very comfortable).

3. RESULTS AND DISCUSSION

A total of 28 rooms in Building A and 9 rooms in Building B were assessed (Figure 2 and Figure 4), covering administrative areas, doctors and nurses offices, common rooms, bar, corridors, waiting rooms and meeting rooms.

3.1. Thermal Comfort

According to the results obtained in the measurement campaign the comfort conditions were not reached in several of the rooms assessed.

According to the EN ISO 7730 (EN ISO, 2005) and the EN 15251 (EN, 2007) standards, the desired thermal environment in a room of a hospital building (category A or I buildings, respectively) is: Predicted Mean Vote, PMV, from +/- 0.2; and Percentage of People Dissatisfied, PPD, less than 6%. These conditions were only met in 7 of the 28 rooms analysed in Building A and in 1 of the 9 rooms studied in Building B. In both buildings PPD varied in general from 15% to 20%. In the other rooms assessed, PPD is over 20% (PMV of + 1 and - 1), exceeding 60% (PMV of - 2) in the waiting room, in the meeting room and in the internment ward of Building A and also in the meeting room of Building B, were the heating systems were only occasionally used. Table 2 lists the PMV and PPD for some of the rooms that were analysed.

The results showed that the thermal comfort conditions were not met even with heating systems, with the results corresponding to cool and slightly cool rooms. In some cases the results correspond to slightly warm conditions. The results of the occupants' survey were in accordance with the measurements.

Table 2 – Thermal conditions in the rooms assessed.

	Zone	PMV	PPD
Building A			
Basement	General office	+ 1	20%
	Waiting room	- 1	29%
	Bar	+ 1	22%
Ground floor	Internment Ward	- 2	67%
	Waiting room	- 2	62%
	Meeting room	0	8%
2nd floor	Meeting room	0	8%
	Activities room	+ 1	22%
Building B			
7th Floor	Ward	+ 1	31%
	General office	0	8%
	Meeting room	- 2	51%

3.2. Indoor Air Quality (IAQ)

The concentration of pollutants (CO_2, CO, HCHO, VOC, O_3, PM_{10}) measured in some of the rooms analysed, according to the Portuguese thermal regulations (Decreto-Lei n.º118/2013; Portaria n.º 353-A/2013), is presented in Table 3. The concentration of CO_2 is the average concentration of the measurements and for the rest of the pollutants the value presented is the maximum concentration of the pollutant measured. The maximum reference value of the CO_2 concentration, according to the Portuguese thermal legislation, for the different rooms analysed, is also shown in Table 3, as it depends on the area of the room. The maximum reference indoor concentration of the other pollutants is listed in Table 1.

The main IAQ problems detected were related with the high CO_2 concentrations, due to human occupation, even if the maximum measured value did not exceeded 1.5 times the maximum reference value of the CO_2 concentration, in accordance with Portuguese legislation.

The concentrations of volatile organic compounds and formaldehyde detected were in general five times higher than the maximum recommended value especially in the general and social service office, meeting and activities rooms. A high concentration of suspended particles was also noted in the archive room. The existence of open trash cans and the use of antiseptics in some of the rooms and the use of paints in the activities room are the main causes of the concentrations values measured.

Building A is naturally ventilated and, in general, the occupants did not open the windows due to the external climatic conditions.

Even considering the differences in the thermal quality of the buildings' envelope characteristics, the main results of the study are similar as both have a low thermal quality and inadequate air change rates and incorrect use of the heating systems and rooms (use, storage and disposal of paints, antiseptics, cleaning and disinfection products and other chemicals) as the thermal discomfort and high concentration of pollutants indicate.

Table 3 – Concentration of pollutants measured.

	Zone	CO_2 [ppm]		Max CO [ppm]	Max PM_{10} [mg/m^3]	Max O_3 [ppm]	Max VOC [ppm]	Max HCHO [ppm]
		Average	Max. ref. value					
Building A								
Basement	General office	1325.92	1055.54	1.00	0.15	0.01	3.28	0.00
	Social service	1086.81	1054.87	1.00	0.09	0.00	4.29	0.04
	Archive	566.30	1044.59	2.00	0.39	0.04	0.09	0.07
	Waiting room	1077.59	1048.74	2.00	0.09	0.00	1.73	0.22
	Bar	632.57	1044.04	5.00	0.06	0.00	0.06	0.09
Ground floor	Internment Ward	693.24	1050.52	2.00	0.07	0.00	0.36	0.00
	Waiting room	750.95	1045.83	1.00	0.12	0.00	0.51	0.02
	Meeting room	668.36	1049.77	1.00	0.07	0.02	0.12	0.07
1st floor	Waiting room	563.00	1051.00	0.00	0.07	0.00	0.68	0.05
	Meeting room	465.92	1048.16	0.00	0.11	0.00	0.00	0.01
2nd floor	Meeting room	833.35	1055.24	0.00	0.08	0.00	6.35	0.05
	Activities room	518.00	1057.00	1.00	0.04	0.00	5.80	0.01
Building B								
7th Floor	Ward	863.96	1049.72	1.00	0.028	0.00	3.29	0.05
	General office	798.02	1049.06	2.00	0.022	0.00	3.91	0.02
	Meeting room	651.38	1045.19	1.00	0.040	0.00	0.61	0.11

3.3. Occupants' Survey

A total of 65 questionnaires were analysed, where 34% corresponded to males and 66% to females, with an average age of 41 years. The complaints were similar in both buildings.

The occupants' main complaints were due to the inexistence of thermal comfort conditions and of poor indoor air quality.

In general the occupants referred that the rooms were cold or slightly cold, but in some cases they denoted that they felt uncomfortable due to a slightly warm or warm thermal comfort conditions. The occupants felt that the air quality was just unacceptable and reported the existence of a slightly unpleasant odour.

4. CONCLUSIONS

This paper presents the "in situ" assessment of the IAQ and thermal comfort conditions in 37 rooms of two Portuguese hospital buildings. With the IAQ and thermal comfort conditions assessment carried out, it was possible to identify some of the most critical problems of the buildings that need particular attention during the renovation interventions.

The measurements showed the presence of high concentrations of some pollutants like carbon monoxide, volatile organic compounds and formaldehyde. The study also showed that although the buildings had heating systems, the thermal conditions were not achieved in most of the rooms of neither building due to the inadequate thermal insulation of the envelope and the inappropriate use of the heating systems. In general, the rooms were cold or slightly cold, but in some cases the thermal comfort conditions in the rooms were classified as slightly warm and warm, due to the inadequate use of the heating systems.

The concentration of carbon dioxide was high, but complied with the requirements of the Portuguese thermal legislation. The concentration of the volatile organic compounds and formaldehyde exceeded the values established in the legislation. The existence of open trash cans, antiseptics and paints, used in the patients' activities, in some of the rooms, in addition to the lack of an adequate air change rate, contributed to the high concentration of pollutants measured.

It was concluded that it is necessary to increase the insulation levels in the walls and windows of both buildings in order to increase the thermal comfort conditions (reducing heat losses by radiation). It was also verified that it is essential to verify if the heating systems are adequate to the buildings and to correctly establish the temperature in terminal units of the heating system in the different rooms, as in some situations the rooms were classified as slightly warm or even warm and slightly cold in other cases. To ensure the existence of an adequate air change rate it is necessary to install a mechanical ventilation system, or ventilation grids that ensure a correct air flow even with different atmospheric pressures, wind velocity and direction, to ensure an adequate air change rate and reduce the heating needs. The rooms where paints are used and antiseptics and other similar products are stored and used should have a higher air change rate. This kind of products should be stored in rooms that are not used in permanence. Additionally, the trash cans should be replaced by closed ones to reduce the release of pollutants to the rooms.

5. REFERENCES

ADENE – Nota Técnica NT-SCE-02 – Metodologia para auditorias periódicas de QAI em edifícios de serviços existentes no âmbito do RSECE (Technical Note about the Methodology to Perform IAQ Audits in Office Buildings), Lisboa (2009).

ASHRAE 55: 2010 - Thermal Environmental Conditions for Human Occupancy (2010).

Baird, G.; Dykes, C. The Potential for the Use of the Occupants' Comments in the Analysis and Prediction of Building Performance. *Buildings*, 2, 33-42 (2012).

Balaras, C.; Droutsa, K.; Dascalaki, E. and Kontoyiannidis, S. - Deterioration of European apartment buildings. *Energy and Buildings*, 37, 515-527 (2005).

Bornehag, C.-G.; Blomquist, G.; Gyntelberg, F.; Järvholm, B.; Malmberg, P.; Nordvall, L.; Nielsen, A.; Pershagen, G. and Sundell, J. - Dampness in buildings and health. Nordic interdisciplinary review of the scientific evidence on associations between exposure to "dampness" in buildings and health effects (NORDDAMP). *Indoor Air*, 11, 72-86 (2001).

Clements-Croome, D. (ed). - *Creating the Productive Workplace*, E&FN Spon, Taylor & Francis Group, London/New York (2006).

Decreto-Lei n.º 78/2006 – Sistema de Certificação Energética dos Edifícios - SCE (Decree-Law n.º 78/2006 – Portuguese Energy Certification System), Ministério das Obras Públicas Transportes e Comunicações, Lisboa (2006).

Decreto-Lei n.º 79/2006 – Regulamento dos Sistemas Energéticos e de Climatização dos Edifícios – RSECE (Decree-Law n.º 79/2006 – Portuguese thermal regulation for office buildings), Ministério das Obras Públicas Transportes e Comunicações, Lisbon (2006).

Decreto-Lei n.º 118/2013 – Sistema de Certificação Energética dos Edifícios, Regulamento de Desempenho Energético dos Edifícios de Habitação e Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços (Decree-Law n.º 118/2013 -

Portuguese Building Thermal Legislation), Ministério das Obras Públicas Transportes e Comunicações, Lisboa (2013).

EN 15251: 2007 - Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics (2007).

EN ISO 7726: 1998 - Ergonomics of the thermal environment - Instruments for measuring physical quantities (1998).

EN ISO 7730: 2005 - Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (2005).

Engvall, K.; Wickman, P.; Norbäck, D. Sick building syndrome and perceived indoor environment in relation to energy saving by reduced ventilation flow during heating season: A 1 year intervention study in dwellings. *Indoor Air*, 15, 120–126 (2005).

European Commission. Energy Performance of Buildings Directive (EPBD) 2002/91/EC of the European Parliament and of the Council, *Official Journal of the European Communities* (2002).

Eurostat - Europe in figures - Eurostat yearbook 2010, European Union (2010).

Fang, L.; Clausen, G. and Fanger, P.O. - Impact of temperature and humidity on the perception of indoor air quality, *Indoor Air*, 8(2), 80-90 (1998).

FPP - Fundação Portuguesa do Pulmão (Portuguese Lungs Association) – Relatório do Observatório Nacional das Doenças Respiratórias (2011).

Kolarik, J.; Toftum, J.; Olesen, B.W. and Jensen, K.L. - Simulation of Energy Use, Human Thermal Comfort and Office Work Performance in Buildings with Moderately Drifting Operative Temperatures, *Energy and Buildings*, 43(11), 2988-2997 (2011).

Mateus, R.; Bragança, L. - Sustainability Assessment and Rating of Buildings: Developing the Methodology SBToolPT–H. *Building and Environment*, 46(10), 1962-1971 (2011).

Mendell, M.J.; Fisk, W.J.; Dong, M.X.;, Petersen, M.; Hines, C.J.; Faulkner, D.; Deddens, J.A.; Ruder, A.M.; Sullivan, D. and Boeniger, M.F. - Enhanced particle filtration in a non-problem office environment: Preliminary results from a double-blind crossover intervention study, *American Journal of Industrial Medicine Supplement*, 1, 55-57 (1999).

Newell, T.; Newell, B. *Comfort Conditioning and Indoor Air Quality*; American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.: New York, NY (2011).

Portaria n.º 353-A - Condições de referência para os poluentes do ar interior dos edifícios de comércio e serviços (Ordinance n.º 353-A/2013- Portuguese Building Thermal Legislation – Indoor Air Quality Audits), Ministério das Obras Públicas Transportes e Comunicações, Lisboa (2013).

Singh J, Yu CWF and Kim JT: Building Pathology, Investigation of Sick Buildings – Toxic Moulds: *Indoor Built Environ*, 19(1), 40-47 (2010).

UK DEFRA - Department for Environment, Food & Rural Affairs and the Devolved Administrations, Part IV of the Environment Act 1995: Local Air Quality Management, LAQM, London, UK (2010).

WHO - World Health Organization. Development of WHO guidelines for indoor air quality. Presented at a Working Group Meeting, Bonn, Germany, 23–24 October (2006).

WHO - World Health Organization - 10 facts on asthma (2011).

Yu CWF and Kim JT: Building Pathology, Investigation of Sick Buildings – VOC emissions: *Indoor Built Environ*, 19(1), 30-39 (2010).