View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Universidade do Minho: RepositoriUM

Thermal Comfort and IAQ Analysis of two Portuguese Hospital Buildings

Sandra MONTEIRO SILVA 1*, Pedro SILVA 2*, Manuela ALMEIDA 3*

* Department of Civil Engineering, Minho University, Portugal (sms@civil.uminho.pt) 1.
(psilva@civil.uminho.pt) 2
(malmeida@civil.uminho.pt) 3
Keywords: indoor air quality, thermal comfort, IAQ assessment, Hospital buildings

Field of Interest: Building Design; Topic of Interest: Energy and environment efficient buildings.
Main paper focus: General Framework; Paper Content Classification: Practical.

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 IAQ is very important to ensure health, well-being and productivity. This paper presents the results of a thermal comfort conditions and IAQ assessment of two hospital buildings with natural ventilation. 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 goal of this study was to verify the thermal and IAQ conditions inside Portuguese hospital buildings. 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 [1, 2]. Therefore, improving the energy performance of the building stock is one of the biggest challenges that the construction sector has to face.

Accordingly, the main building refurbishment requirements needed to improve energy performance include: increasing insulation thickness; reducing thermal bridges and air change rates. 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, house dust mites, particulates and toxic air contaminants (chemicals), gases, vapours and odours. However, only in the last decade has indoor air quality (IAQ) become an important occupational health and safety concern for the government and also the public.

In 2006, Portugal implemented the National Building Energy and Indoor Air Quality Certification System transposing the European Union's Energy Performance of Building Directive (EPBD) [3], which imposes a minimum energy efficiency for the buildings and periodic IAQ audits for office buildings [4, 5].

Indoor air pollution can result from many sources within the building and thus influencing indoor air quality. An IAQ problem may exist if people generally 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. These symptoms are apparently linked to the time people spend inside the building and usually feel better after leaving the building (Sick Building Syndrome) [6, 7, 8]. They may also be caused by other factors, and are not necessarily attributable to poor indoor air quality. It is rarely possible to prove that 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 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 90% of the population spends about 90% of the time in closed spaces (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 incidence continues to increase, especially among the young and the elderly [9, 10]. 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 [11].
The relative humidity can also be an important factor in air quality. In buildings with low air change rates, the increase in relative humidity can promote fungus growth, with serious health risks [12], and it is known as one of the only parameters that can negatively affect the perception of indoor air quality [6].
The IAQ is then an important factor in the well-being, health and productivity of people [13]. Thus, when planning a building refurbishment, 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. Building 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, has four floors. Building A has double pane walls with 20 cm of stone masonry, an air gap and 11 cm hollow brick, with plaster finishing and 25 cm concrete floors. All the windows are single glazed with a metallic frame and have venetian blinds placed inside. 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 second building (Building B), built in 1997, with nine floors, has double pane hollow brick panes (15 cm + 11 cm) with 4 cm insulation placed in the air gap and have plaster finishing and 25 cm concrete floors. The windows are double glazed with a metallic frame and have roller shade blinds placed on the outside. 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 spaces by air ducts.

2.2. Measurement Procedures

The measurements were performed on March 25th for Building A and on May 10th 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 [5, 14, 15, 16, 17, 18].

2.2.1. Occupants' Survey

The standard questionnaire delivered to the occupants was based in the methodology defined in the EN 15251:2007 standard Annex H [16]. In the survey, besides 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, the occupants were asked to identify the three most relevant aspects for their comfort conditions (thermal, acoustic and visual comfort, ventilation conditions and IAQ).

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 ACH) and global comfort conditions (very uncomfortable, uncomfortable, comfortable and very comfortable).

2.2.2. Thermal Comfort

The quantification of the thermal comfort was carried out applying the ASHRAE standard [15] and the EN ISO standards [16, 18], all recommending the measurement of the PMV – predicted mean vote – and the PPD – percentage of people dissatisfied.

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).

2.2.3. Indoor Air Quality (IAQ)

According to the thermal regulations in Portugal it is mandatory to carry out IAQ audits in office buildings [4, 5]. A complete IAQ audit was not performed in this study. Only a set of physical and chemical pollutants were measured in several spaces 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 2nd 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 space. 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 space, in accordance with the Portuguese thermal regulation [14].

According to the Portuguese regulation, 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 [5].

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 of 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 regulation, the average concentration must be lower than the maximum reference concentration defined taking into account the area of the measured room [5]. 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.

3. Results

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

3.1. 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 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.

3.2. 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 [18] and the EN 15251 [16] standards, the desired thermal environment in a space of an existing building (category C or III buildings, respectively) is: PMV from +/- 0.7; and PPD less than 15%. These conditions were only met in 8 of the 28 rooms analysed in Building A and in 3 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.

Table 2: Thermal conditions in the rooms assessed.

	Zone	PMV	PPD
Building A			
Underground floor	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%

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

3.3 Indoor Air Quality (IAQ)

The concentration of pollutants (CO_2, CO, HCHO, VOC, O_3, PM_{10}) measured in some of the spaces analysed, according to the Portuguese thermal regulation [5], 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 regulation, for the different rooms analysed, is also shown in Table 3. The maximum reference indoor concentration of the other pollutants is listed in Table 1.

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								
Underground floor	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

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. 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 room. A high concentration of suspended particles was also noted in the archive room. The existence of open trash cans and antiseptics in some of the spaces 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.

4. Conclusions

This paper presents the "in situ" assessment of the IAQ and thermal comfort conditions 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 refurbishment 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 spaces were cold or slightly cold, but in some cases the thermal comfort conditions in the rooms were classified as slightly warm and warm.

The concentration of carbon dioxide was high, but complied with the requirements of the Portuguese thermal regulation. The concentration of the volatile organic compounds and formaldehyde exceeded the values established in the regulation. The existence of open trash cans, antiseptics and paints, used in the patients' activities, in some of the spaces, 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 spaces 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, preferably with heat recovery, to reduce the heating needs. The spaces 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. List of References

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

[2] Eurostat - *Europe in figures* - Eurostat yearbook 2010, European Union, 2010.

[3] EPBD - European Commission. Energy Performance of Buildings Directive 2002/91/EC of the European Parliament and of the Council, Official Journal of the European Communities, 2002.

[4] Decree-Law nº78/2006 – Portuguese Energy Certification System - SCE, Ministério das Obras Públicas Transportes e Comunicações, 2006.

[5] Decree-Law nº 79/2006 - Portuguese thermal regulation for office buildings - RSECE, Ministério das Obras Públicas Transportes e Comunicações, 2006.

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

[7] 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; Vol. 1 (1999), pp. 55-57.

[8] 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; Vol. 43/11 (2011), pp. 2988-2997.

[9] WHO - World Health Organization - 10 facts on asthma, 2011.

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

[11] 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.

[12] 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 Vol. 11 (2001), 72-86.

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

[14] ADENE - Technical Note about the Methodology to Perform IAQ Audits in Existent Office Buildings (Nota Técnica NT-SCE-02), 2009.

[15] ASHRAE 55: 2010 - Thermal Environmental Conditions for Human Occupancy.

[16] 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.

[17] EN ISO 7726: 1998 - Ergonomics of the thermal environment - Instruments for measuring physical quantities.

[18] 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.