Indoor Air Quality in Office Buildings – experimental investigation

Tamara S. Bajc [a] (CA), Maja N. Todorović [b] and Agis M. Papadopoulos [c]

[a] *Faculty of Mechanical Engineering, University of Belgrade, Belgrade, RS, tbajc@mas.bg.ac.rs*
[b] *Faculty of Mechanical Engineering, University of Belgrade, Belgrade, RS, mtodorovic@mas.bg.ac.rs*
[c] *Department of Mechanical Engineering, Aristotle University Thessaloniki, Thessaloniki, GR, agis@eng.auth.gr*

Abstract: This paper presents the part of the research that has been done at the Universities both in Belgrade, Serbia and Thessaloniki, Greece, taking into account indoor air quality (IAQ) in office buildings and classrooms. The measurements that are presented were done in Process Equipment Design Laboratory at Aristotle University Thessaloniki, during March 2015. IEQ, regarding air temperature, relative humidity and CO_2 concentration in two representative offices is observed. The similar offices are located one on the north-east and the other one on the south-west side of the University building, so as to be representative of the orientation's impact. Furthermore, the impact of natural ventilation on CO_2 concentration and temperature is monitored, together with the offices' occupancy. Recommended parameters for IAQ are compared and discussed on the base of several standards: SRPS EN 15251:2010, ASHRAE standards 55 and 62.1 and ISO 7730. The main objectives, as set from these standards are discussed, together with the investigation results.

Keywords: ASHRAE standards 55 and 62.1, Building occupancy, CO_2 concentration and temperature measurements, IAQ, SRPS EN 15251:2010.

1. Introduction

Looking at the global trends in IAQ field of research, there are several common problems, that are discussed in most of the papers: the correlation of IAQ and health problems, the required number of air changes when regarding mechanical ventilation and the possible energy savings and natural ventilation direction.

According to the Environmental Protection Agency, around 50% of elementary and secondary schools in the U.S. have problems connected to the poor IAQ [1]. Children are the most vulnerable population category, but so are adults who are spending most of their time indoors. According to the US Environmental Protection Agency, American spend 90% of their time indoors [2] and the significant period of that time, at work, in the offices [3]. A lot of studies were dedicated to the research of the impact of poor IAQ to human health, and Wolkoff gave a detailed survey of various studies and theirs conclusions [4]. The parameters mostly used for describing IEQ are temperature, relative humidity and CO_2 concentration. The main contributor to the CO_2 generation is high occupancy and inappropriate ventilation. Mechanical ventilation can maintain adequate level of IAQ, but accounts for significant energy consumption, with a share of about one-third of overall energy consumption [5]. Natural ventilation contributes to energy savings, with about 40% lower energy costs comparing to an air-conditioned building [5], but there are authors who see a connection between the air change number per hour and different type of diseases [6]; a property that is difficult to control in naturally ventilated buildings. Fisk, Black and Brunner investigated the relation between the low ventilation rate and short-time absence from the work that is caused by respiratory infection, and they estimated that absence was decreased 2,9% for each 1 l/s per person increase in ventilation rate [7]. Having in mind the adequate decisions for sustainable buildings and system designing, it is suitable to apply appropriate multi-criteria analysis that could lead to the optimal solution between lower ventilation rates and desirable indoor air quality [8].

Recommended parameters for IAQ are given in several standards worldwide: SRPS EN 15251:2010, ASHRAE standards 55 and 62.1 and ISO 7730 are discussed in this paper, together with the part of the results that have been measured in Process Equipment Design Laboratory at Aristotle University Thessaloniki, during March 2015.

2. Building and equipment description

The measurements that are presented in this paper were done in Process Equipment Design Laboratory at Aristotle University Thessaloniki, during March 2015. IEQ, regarding air temperature, relative humidity and CO_2 concentration were measured in two representative offices. The similar offices are located one on the north-east and the other one on the south-west side of the University building, so as to be representative of the orientation's impact. The University building is oriented South-West with its main façade and has nine floors. The Process Equipment Design Laboratory is placed at eight floor and its plan is presented on the Figure1, as a representative of one typical floor at the Aristotle University building. The positions of data loggers which are placed in two offices in order to measure desired IAQ indicators are marked with red spots (number 1 and 2) and shown on Figure 1. The sensors were placed 0,6 m above the floor, in the level for seated occupants, as it is recommended by ASHRAE standard 55. The office on the South-West side is marked with number 1, and the other one on the North-East is numerated as 2. The office 1 has one occupant and in office 2, the number of occupants varies from one to four, depending of the day and duty.

HOBO UX100-03 data loggers are used in both offices for temperature and relative humidity measurement and logging. In the office 2, the CO_2 concentration is measured, using Telaire 7001 manual CO_2 sensor. CO_2 concentration is measured taking into account a number of occupants and natural ventilation. The different natural ventilation rates are enacted, by opening the window and the door of the office.

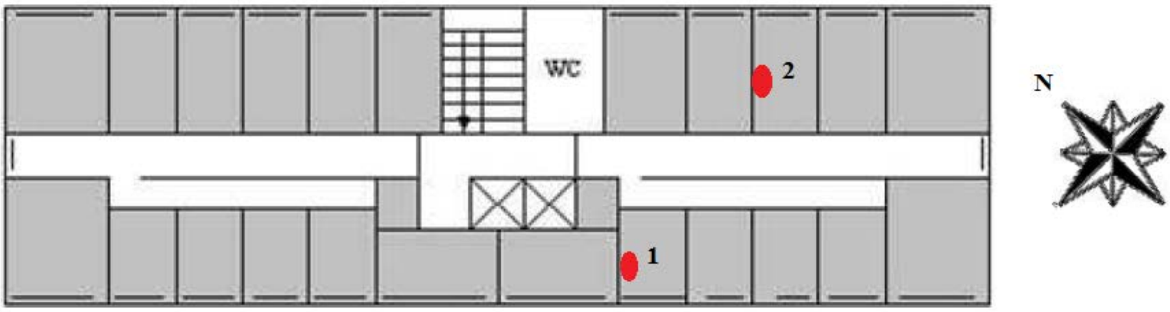

Figure 1. Process Equipment Design Laboratory at Aristotle University Thessaloniki – floor plan [9] *and data logger displacement*

The HOBO data logger records temperature with ±0,21% accuracy and humidity within ±3,5% accuracy. The temperature range is from -20°C to 70°C and humidity sensor range is from 15% to 95%. The Telaire 7001 manual CO_2 sensor has a measurement range from 0 to 10000 ppm, with ±5% accuracy.

The instruments were calibrated and positioned away from the internal heat sources, as well as from the reach of the direct sunrays in order to gather as more as precise results.

3. Standards for IAQ

3.1. SRPS EN 15251:2010

Basic criteria for indoor air quality and ventilation rates in non-residential buildings are given in SRPS EN 15251:2010 trough Method based on person and building component, Method based on ventilation rate per person or per m^2 floor area, and Recommended values of CO_2 for energy calculation [10]. This standard is identical to EN15251:2007, and valid in Europe, and also in Republic of Serbia, according to Institute for Standardization of Serbia. Recommended ventilation rates can be calculated, according to this standard, using the equation (1):

$$q_{tot} = nq_p + Aq_B \tag{1}$$

where:
q_{tot} is total ventilation rate of the room [l/s],
n is design value for the number of the persons in the room,
q_p is ventilation rate for occupancy per person [l/s/pers]
A is room floor area [m^2]
q_B is ventilation rate for emission from building [l/s/m^2].

The ventilation rates for given occupants and building's emissions are given in the standard as a function of the building category. For category II, temperature range for heating is between 20 and 25°C, and recommended airflow per person is 7 l/s/pers and 0,7 l/s/m^2 for low polluting building. Expected percentage of dissatisfied is 20. Corresponding CO_2 above outdoors for energy calculation is 500 ppm for category II as it is given in standard [10].

3.2. ISO 7730

International standard 7730 determines the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) as a function of the activity and clothing. The PPD and PMV express warm and cool discomfort for the whole body. The limits for the light, mainly sedentary activity during the winter period are given in standard. The operative temperature shall be between 20°C and 24°C. The vertical air temperature difference between head and ankle level shall be less than 3°C. The relative humidity shall be between 30 and 70% [11].

3.3. ASHRAE Standard 55

This standard defines the thermal environmental conditions for human occupancy. It describes the metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, humidity and position of the measuring equipment. Operative temperature or PPD, PMV shall be measured or calculated at a height of 0,6 m level above the floor for seated occupants and at the 1,1 m level for standing occupants [12].

3.4. ASHRAE Standard 62.1

Standard 62.1 gives ventilation criteria for acceptable IAQ when the mechanical ventilation system is designed. According to this standard, minimum ventilation outdoor air rate in breathing zone for office space per person is 2,5 l/s/pers, while the outdoor air rate per area is 0,3 l/s/m2 [13]. Maximal allowed CO_2 concentration for offices, according to ASHRAE 62.1:2013 is 700ppm higher than outdoor air level. Typical CO_2 concentration level in outdoor air is between 300 and 500 ppm [13], so maximal recommended CO_2 concentration for offices is from 1000 to 1200 ppm, but it should be emphasized that the CO_2 concentration level is not the only and the most representative criteria for IAQ. Besides this, also Volatile Organic Compounds influence on IAQ. It is important to emphasize that the allowed concentration should always be determined as the difference between indoor and outdoor concentration.

4. Measurement results and discussion

During the two weeks (10 working days), starting from 09.03.2015 to the 20.03.2015 the CO_2 concentration measurements were every 15 minutes taken during the working hours in office 2. The CO_2 concentration values are considered together with the number of the people in the office, and door and windows opening. Opening the window and the door was performed in order to simulate the influence of natural ventilation. It was observed only in office 2. The results for the minimum and maximum values are shown in Table 1.

Table 1. Maximal and minimal CO_2 concentrations during two weeks in office 2

Date	CO_2 max [ppm]	CO_2 min [ppm]	Time	Window	Door	People
9.3.2015.	1394		13:47	open	open	2
		991	12:15	closed	open	3
10.3.2015.	1025		13:44	open	closed	2
		564	10:09	open	open	1
11.3.2015.	1089		12:38	closed	closed	2
		513	9:50	closed	closed	0
12.3.2015.	692		14:15	closed	open	1
		403	10:15	open	open	0
13.3.2015	681		13	closed	closed	1
		480	9:50	closed	closed	1
16.3.2015.	1080		13:41	half closed	closed	3
		440	10	closed	closed	0

17.3.2015.	1406		13:17	closed	half closed	3
		470	10	open	closed	0
18.3.2015		433	10	closed	open	1
	930		14:30	closed	half closed	3
19.3.2015.		450	10	open	open	0
	743		13:44	closed	open	2
20.3.2015.		402	9:45	closed	closed	0
	1023		13:35	closed	closed	3

The biggest CO_2 concentration is recorded during the day when the window was not opened and the number of the people in the office was 3. In that period, the lack of working concentration and productivity was observed, together with some of people suffering headaches and a bad odor. The indoor air temperature was varying from 20,28°C to 25,09°C, depending on the window opening and the number of the people in the office. During most periods of time, the CO_2 concentration was slightly higher than recommended. The variation of CO_2 concentration is different during the working hours and very difficult to predict in a naturally ventilated office buildings. It depends on the number of occupants and on the arbitrary natural ventilation.

Also, the relative humidity and the temperature are measured in this office, in a period from 02.03.2015 until 20.03.2015. with data logging every 15 minutes. The heating system in the University building is central, two-pipe system with radiators and with thermostatic valves. The results of the measurements are presented in Figure 2, together with the boundaries of recommended criteria. The green line represents the lowest criteria for relative humidity, which is considered to be comfortable for occupants (recommended values are from 30% to 70%, according to ISO 7730 [11]). The orange lines represent the range of recommended temperatures according to ISO 7730 [11] (recommended values are from 20 to 24°C), while SRPS EN 15251:2010 allows a little wider range: from 20 to 25°C. Seppänen had investigated the impact of the high temperature on working performance, and concluded that the working performance increases with temperature up to 21-22°C, and decreases with around 23-24°C [6]. Also, quite a number of studies deals with indoor air temperature's influence on thermal comfort, air quality, sick building syndrome and performance in work [14], [15], [16]. The influence of changing set-up temperature by occupants on total energy consumption is considered in paper [17].

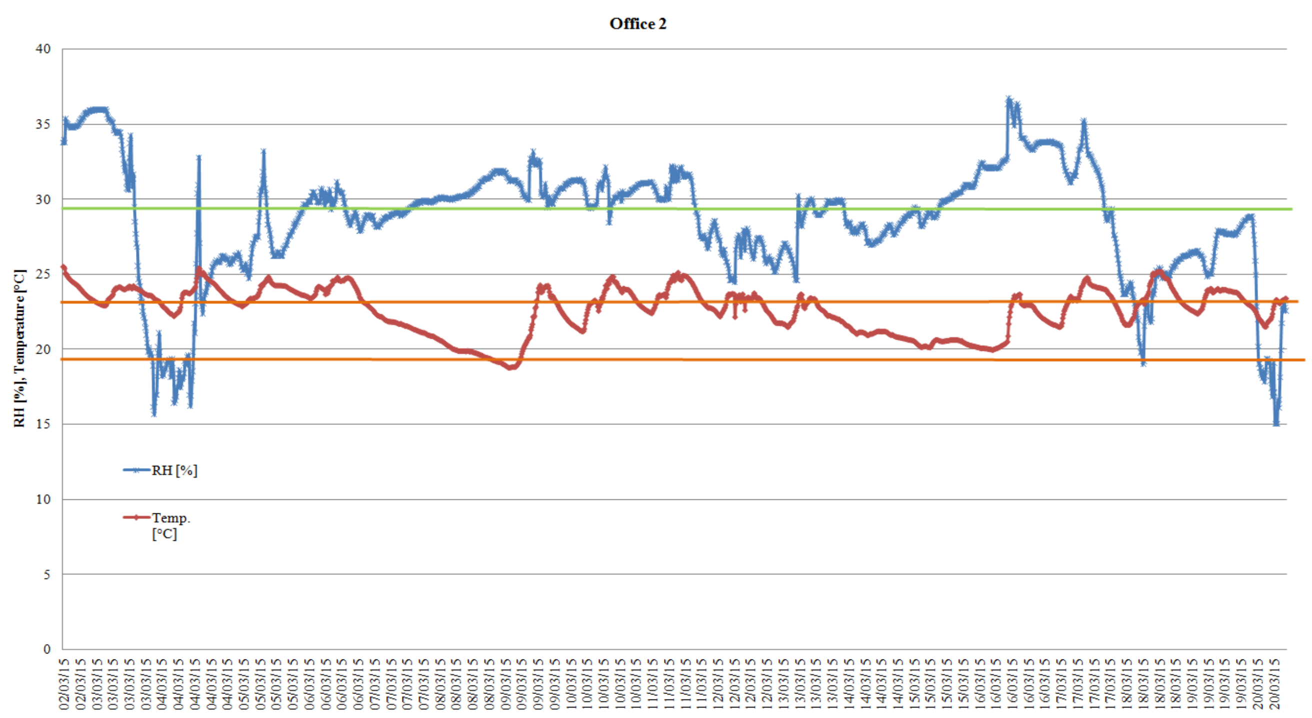

Figure 2. Temperature and humidity measured in Office 2

From Figure 2. it can be seen that the temperatures are in the desired range for more than 75% of the time. Only 6,5% of the time, temperature was lower than 20°C, but still higher than 18°C. Around 18,5% of the time, the temperature was higher than 24°C, but it has never reached 26°C. These results are expected, having in mind the heating system with the thermostatic valves.

The situation with a relative humidity is a quite different one: more than 61% of the time, the relative humidity was lower than recommended 30%, and only 39% of the time, it stayed within the recommended boundaries. Around 49% of the time, the relative humidity was between 25% and 30%. . This is clearly a result of overheating and of less ventilation than required. The lowest recorded value was RH=15%, and it was recorded at 8:15 a.m., in the period when the office was empty. During the working hours, from 10 a.m. till 2 p.m. the significant number of values, about 92%, was lower than minimal recommended value. During the only 8% of the working hours, the relative humidity was higher than 30%, and due to that, in a desired range

According to the previous results, it could be concluded that the IAQ, during the most of the working hours was not satisfying. Looking at the negative influence of low humidity on human's health, some authors were investigated the symptoms such as: dryness of the eyes and skin, dryness of the nasal mucous membrane [18]. It is stated that the low humidity influence increasing of bacterial, viral and other respiratory infection [18].

In office 1, the measurement of temperature and humidity are also taken. The results are shown on Figure 3.

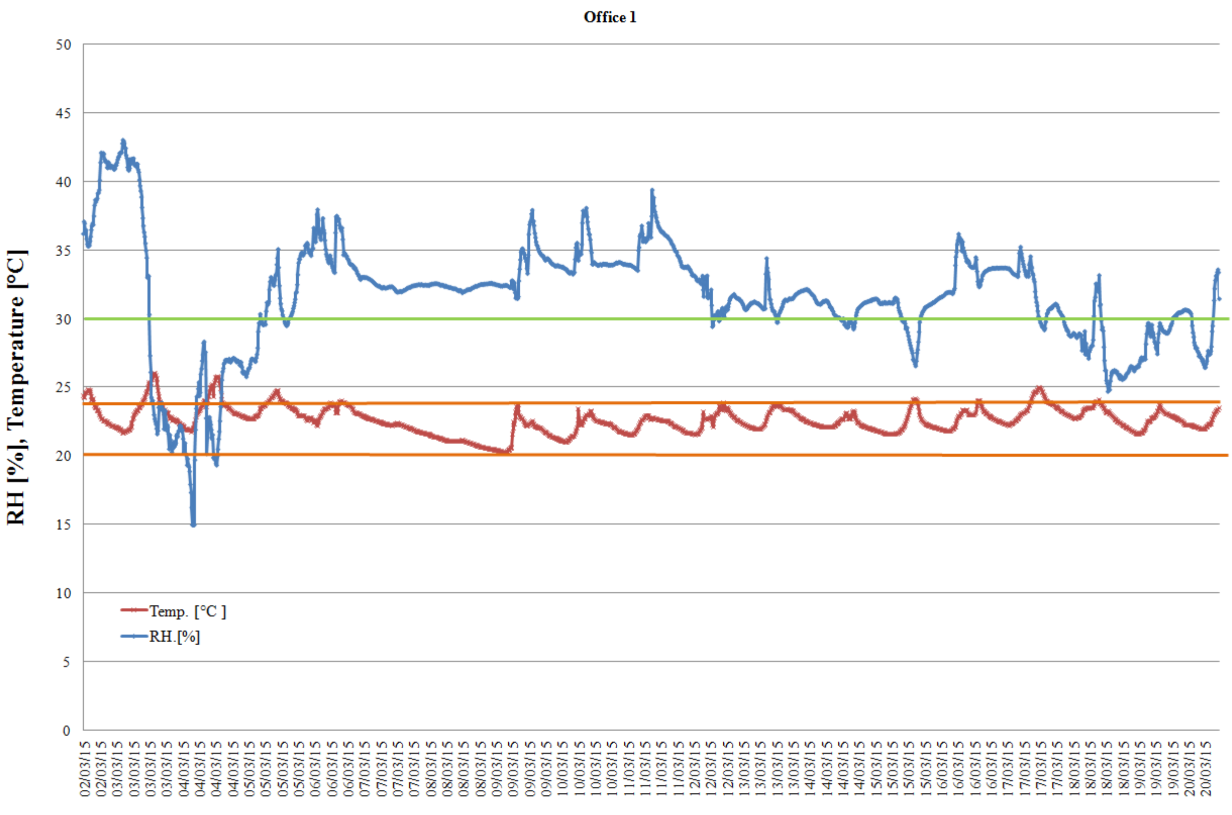

Figure 3. Temperature and humidity measured in Office 1

The green line represents the lowest criteria for relative humidity that is considered to be comfortable for occupants (recommended values are from 30% to 70%, according to ISO 7730 [11]). The orange lines represent the range of recommended temperatures according to ISO 7730 [11] (recommended values are from 20 to 24°C). In office 1, the temperatures are in between the desired range in more than 92% of the time. Minimal recorded value is 20,27°C, and maximal value is 26°C. Du to that, only 8% of the time, the temperature was higher than 24, and lower than 26°C. The average temperature during the working hours was 23°C.

Looking at the relative humidity, the situation in Office 1 is much better than in the Office 2; the relative humidity was in desired range in 75% of the time. During the working hours, the average value of relative humidity was RH=32%, and in the 76% of the time it was equal or higher than RH=30%. Minimal recorded value was RH=15%, and maximal RH=43%.

5. Conclusions

This study is a part of a bigger, ongoing research on indoor environmental quality and the energy performance of buildings aiming at distinguishing the correlation between IAQ and optimal working performances in office buildings and classrooms. However, the work presented in this paper is interesting, in that it depicts the difficulties in assessing IEQ in naturally ventilated office buildings, but also in drawing some first conclusions. On this line of approach, the key problem in offices with natural ventilation in the winter period is low relative humidity and high CO_2 concentration levels, a rather limited ventilation. This was shown, as the relative humidity in Office 2, that is North-East oriented, is significantly below the desired range during the 92% of working hours. The situation in South-West orientated office 1 is better, but still not satisfactory during the 25% of the working hours. These differences can be connected to the slightly higher temperature in office 2, which had been recorded in 18,5% of the time, than in office 1, where the temperature higher than 24°C had been recorded during only 8% of the time.

The situation with temperature is much better in comparison with relative humidity, looking at desirable values, due to the thermostatic valves that had been installed.

The control of IAQ indicators and appropriate ventilation is crucial for occupants' health and productivity and naturally also for conserving energy and reducing operational expenses having in mind the expenses of treatment and workers' absences. The decision about the appropriate ventilation rates should always take into account the anticipated benefits for occupants' health, rather than choosing the minimal rates for energy savings.

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