INVESTIGATION OF INDOOR ENVIRONMENTAL QUALITY AND PRODUCTIVITY IN MONITORED OFFICES IN SLOVAKIA

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ABSTRACT

Laboratory and field studies show that the physical and chemical factors in the work environment may have a notable impact on the health and comfort of the occupants, and consequently on productivity. There are numerous ways to define productivity. Actually, productivity should be universally defined as the ratio of output to input. A field study was conducted during the heating season in office buildings in Slovakia. A first objective of this study was to determine occurrence level of pollutants in these buildings. A second objective was to evaluate the effect of indoor environmental quality on occupants' productivity. The quality of indoor climate was also a variable in the analysis. The procedure comprises measurements of indoor environmental parameters, including thermal parameters, concentrations of carbon dioxide, concentrations of total volatile organic compounds, concentrations of particulate matters, acoustic and lighting levels and completion of questionnaires by occupants. Productivity was assessed by method used simulated office tasks. Occupants performed text typing, addition task and symbol – letter task (learning memory test) in experimental offices to evaluate occupants´ productivity. Subjective experiments were carried out to evaluate the effects of indoor environmental quality on human comfort. The mean mass concentration of particulate matters and noise level were exceeded limit values in the investigated office room 1 (building A). The mean concentration of carbon dioxide and noise level were exceeded recommended and limit values in the office rooms 3 and 4. The mean values of total and correct productivity of all tasks were higher in the investigated building B (offices 3 and 4). Occupants indicated they were uncomfortable with the IAQ.

Keywords: indoor environmental quality, office, productivity, perceived comfort

1. Introduction

The indoor environmental quality (IEQ) is an expression which was derived from four contributing factors namely thermal comfort, indoor air quality (IAQ), acoustic comfort and lighting (Ncube and Riffat, 2012). Building occupants often react in noticeably different ways under the same indoor environment, leading to a presumption that various personal or psychosocial factors beyond environmental parameters influence occupants' perception of the quality of indoor environment (Kim *et al*., 2013). Office work performance contributes substantially to productivity gain in today's world, and recent research has focused on the impact of IEQ on office work (Lan *et al*., 2009). Numerous studies focused on individual work performance have been conducted (Koopmans *et al*., 2011). Objective measurements are usually a measure of task performance, including primary task performance (a single task is performed and the productivity is recorded as its absolute value) and comparative task performance (two or more tasks are performed consequently and the productivity variations between the tasks are recorded). The advantage of objective measurements is that quantitative results can be obtained (Jin *et al.*, 2012).

This paper presents the results from measurements of indoor environmental parameters and objective evaluated office productivity in two office buildings. Perceived comfort and satisfaction with the indoor environmental quality was determined also in this paper.

2. Methods

Experimental measurements were conducted for four days, during the heating season, each day for 8 hours from morning to afternoon. The experiments were carried out in two office buildings in city of Kosice, in Slovakia. Building A was designed and constructed in 2013 as sustainable building and certified by system of LEED (Leadership in Energy and Environmental Design) as gold. Building B was reconstructed in 2012. The selected office buildings were used by commercial organizations. The experiment was carried out in four offices, in which occupants sat at two workstations, each consisting of a table, chair and personal computer.

The following instruments for determination of indoor environmental quality were used: air velocity (anemometer Testo 425), air temperature, air humidity and concentrations of carbon dioxide (multiple-function measuring instrument Testo 435), particle size fractions (particle counter 3016, Hand Held analyzer), total volatile organic compounds – TVOC (detector ppbRAE 3000), sound pressure level (Sound Level Meter - Brüel & Kjær Type 2250, Hand Held analyzer) and illuminance level (multiple-function measuring instrument Testo 435).

The indoor climate questionnaires were performed simultaneously with the indoor climate measurements. Information collected included personal factors, such as gender, age, satisfaction with the indoor environment and comfort. Occupants were instructed on how to fill out the questionnaires used to obtain subjective responses.

During the measurements, occupants took a share in simulated office work consisting of 3 different tasks (text typing, mathematical calculation and learning memory test). The detailed description of these tests can be referred to Budaiova *et al*. (2014). Occupants of investigated offices were encouraged to perform tests as accurately and quickly as possible.

3. Results

The effect of indoor environmental quality on productivity investigated in typical office buildings is presented in this paper.

3.1. Indoor environmental quality

Limit values of physical and chemical factors are determined by Decrees of the Ministry of Health of the Slovak Republic No. 259/2008 Coll. and No. 549/2007 Coll. (Table 1) Concentrations of carbon dioxide in investigated offices were compared by recommended concentration according to von Pettenkofer (1800 $mg.m^{-3}$). Concentrations of total volatile organic compounds could be managed to be less than the no effects level of 200 $\mu g.m^{-3}$ (Molhave, 1991).

Table 1: Limit values of environmental parameters

Parameters	Limit value
Relative humidity	30 – 70 %
Air velocity	≤ 0.25 m/s
Illuminance intensity	≥ 500 lx
Sound pressure level	≤ 50 dB
Particulate mass concentration PM_{10}	≤ 50 $\mu g.m^{-3}$

Indoor air temperature, relative humidity, sound pressure level and illuminance intensity measured in investigated offices are summarized in Table 2. The mean value of air velocity was 0.02 m/s in the offices O1 and O2 and the mean value of air velocity was 0.015 m/s in the offices O3 and O4. Values of indoor relative humidity and air velocity were within allowable level in all investigated offices (Health Ministry Decree No. 259/2008). Average values of sound pressure level were exceeded limit value in investigated offices 1, 3 and 4 (according to the

Health Ministry Decree No. 549/2007 Coll.). In the office O4 were not met limit value for illuminance level (according to the Health Ministry Decree No. 259/2008).

Table 2: Mean and median values of temperature, relative humidity sound pressure level and illuminance intensity in the investigated offices

Building	Office room	Air temperature [°C]		Relative humidity [%]		Sound pressure level [dB]	Illuminance intensity [lx]
		mean	median	mean	median	mean	mean
A	O1	24.2	24.3	35.3	35.2	52.0	680
	O2	24.8	25	32.2	31.8	47.4	553
B	O3	24.5	24.6	43.2	43.2	52.2	554
	O4	22.9	23.2	42.9	43.4	54.3	473

The mean mass concentrations of particulate matters (PM) for each size fractions in the offices are presented in Table 3. $PM_{2.5}$ concentrations ranged from 8.73 to 13.94 $\mu g.m^{-3}$. The highest $PM_{2.5}$ concentrations were found in office room O1. The maximum permissible value for indoor PM_{10} concentration (50 $\mu g.m^{-3}$) was exceeded in investigated office O1. This finding might confirm the significance of the outdoor sources of PM because the windows in office room O1 were several times opened during the sampling.

Concentrations of TVOC and carbon dioxide are summarized in Table 3. In all investigated offices, the mean concentration of total volatile organic compounds (expressed as toluene) reached value of 136 $\mu g.m^{-3}$ (SD: 17). This environmental factor was within allowable limit and recommended levels. According to the recommended value, average indoor CO_2 levels should not exceed 1800 $mg.m^{-3}$ (von Pettenkofer, 1858). The mean concentration of carbon dioxide (CO_2) reached 1511 $mg.m^{-3}$ in the investigated building A (O1 and O2 with mechanical ventilation) and 2592 $mg.m^{-3}$ in the investigated building B (O3 and O4 with natural ventilation). The concentration of CO_2 exceeded recommended value in the offices with natural ventilation. CO_2 in those concentrations is not generally thought to be harmful and so is often accorded little significance (Health and Safety Commission, 1992).

Table 3: Particulate mass concentrations in monitored office rooms during the experiment

Building	Office room	Particulate mass concentrations [$\mu g.m^{-3}$]			TVOC [$\mu g.m^{-3}$]	Concentration of carbon dioxide [$mg.m^{-3}$]
		$PM_{2.5}$	$PM_{10.0}$	Total PM		
A	O1	13.94	81.35	90.87	145.4	1582
	O2	8.73	39.22	44.43	113.4	1439
B	O3	10.45	38.67	47.59	153.8	2492
	O4	12.56	42.30	56.62	134.1	2694

3.2. Comfort

Occupants assessed the perceived comfort in the investigated offices during the experiments. Comfort votes were cast on 4-point numerical scales - comfort (0), slightly discomfort (1), discomfort (2) and very discomfort (3).

In office building A: indoor air temperature was rated as slight discomfort (25%) and discomfort state (75%); air humidity was rated as comfort (50%) and slight discomfort state (50%); IAQ was rated as slight discomfort (25%) and discomfort state (75%); the noise levels and illuminance levels were rated as comfort state.

In office building B: indoor air temperature, air humidity and IAQ were rated as comfort (50%) and slight discomfort state (50%); the noise levels and illuminance levels were evaluated as comfort (75%) and slight discomfort state (25%).

3.3. Productivity

Objective productivity was evaluated using the following indicators:

- Total productivity (%) – expressed as the ratio of total number of solved answers to the maximum number of answers.
- Correct productivity (%) – expressed as the ratio of correctly solved answers to the maximum number of answers.

The average values of occupants´s productivity of individual tasks and all tasks are summarized in Table 4. The mean value of productivity of all tasks was higher in building B (offices 3 and 4). The highest total productivity was in mathematical calculation in all investigated offices, on the other hand occupants had the most mistakes in this task (mathematical calculation) in both building.

Table 4: Productivity of occupants in investigated office rooms

Office tasks	Building A (office room 1 and office room 2)		Building B (office room 3 and office room 4)	
	Total productivity	Correct productivity	Total productivity	Correct productivity
Text typing	93.2%	92.9%	100%	99.5%
Mathematical calculation	100%	95.7%	100%	97.1%
Learning memory test	85%	85%	97.5%	96.7%
All tasks	92.7%	91.2%	99.2%	97.8%

4. Conclusions

This study has discussed the satisfaction of occupants with their environment in a modern buildings and objective evaluated performance in this buildings. The maximum permissible value for indoor concentration of PM_{10} (50 $\mu g.m^{-3}$) was exceeded by 62.7% in investigated office O1. Average values of sound pressure level were exceeded limit value (50 dB) by 3% in all investigated offices. The concentration of CO_2 exceeded recommended value by 44.2% in the offices with natural ventilation (O3 and O4). Occupants evaluated perceived IAQ as discomfort state. An increased ventilation rates may increase satisfaction with perceived air quality by lowering indoor CO_2 levels. The mean value of total productivity was higher than 92% in investigated offices 1 and 2, and higher than 99% in offices 3 and 4. Further research will focus on better understanding of the relations between IEQ, productivity, and occupants' responses.

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