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Short-term Measurements of Indoor Environmental Quality in Selected Offices – Case Study

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Abstract. Decent quality of indoor air is important for health and wellbeing of building users. We live, work and study in indoors of various types of buildings. Often people are exposed to pollutants at higher concentrations than these that occur outdoors. Continual investigation of indoor air quality is needed for ensuring comfort and healthy environment. Measuring and analysis of occurrence of physical, chemical and biological factors is the first step for suggestion of optimization measures. Inside school buildings there are often inadequate indoor climate conditions such as thermal comfort parameters or ventilation. The aim of this study was determination of indoor environmental quality in selected offices in the building of elementary school in Slovakia. The values of operative temperature were not within the optimum range of values for the warm period of the year in one of the monitored offices. The intensity of illumination was lower in the two offices. Low levels of particulate matters were measured except the one office where permissible value was exceeded by 7.6%.

Keywords: indoor environment, office, elementary school, health.

Conference topic: Energy for buildings.

Introduction

The indoor environmental quality (IEQ) covers several factors, including thermal environment, indoor air quality (IAQ), lightning and acoustic (Budaiova *et al.* 2015b). One of the fundamental human requirements is a working environment that allows people to perform their work optimally under comfortable conditions (Roelofsen 2002). Comfortable indoor environment at the workplace is important for workers' quality of life, health, and productivity (Li *et al.* 2015). The preservation of IEQ is key to the well-being and productivity of office occupants (Liang *et al.* 2014).

According to study (Vimalanathan, Babu 2014) the office workers spend 90% of the time in indoor environment. In assessing the thermal environment, one needs to consider all ambient parameters, the insulating properties of the occupants' clothing, and the activity level of the occupants by means of heat balance models of the human body. Apart from thermal parameters, air quality (measured and perceived) is also of importance for well-being and health in indoors. Pollutant levels are influenced by both outdoor concentrations and by indoor emissions. Indoor levels can thus be lower (e.g. in the case of ozone and SO_2) or higher (e.g. for CO_2 and formaldehyde) than outdoor levels (Hoppe, Martina 1998).

Study (Budaiova *et al.* 2015a) is focused on satisfaction of occupant with their environment in two modern office buildings and objectively evaluated performance in these buildings. The maximum permissible value for indoor concentration of PM_{10} (50 μg/m^3) was exceeded by 62.7% in one investigated office building. Average value of sound pressure level was exceeded limit value (50 dB(A)) by 3%. The concentration of CO_2 exceeded recommended value by 44.2% in the offices with natural ventilation. Occupants evaluated the IAQ as discomfort state. The mean value of total productivity was higher than 92% in first investigated office and higher than 99% in next investigated office. Another study (Budaiova, Vilcekova 2015) is focused on the investigation of selected office building to determine the presence of polluting agents such as volatile organic compounds, particulate matters (PM), carbon dioxide and to assess the perceived productivity by office occupants. Mean values of PM_{10} mass concentrations exceeded indoor limit value (50 μg/m^3) by 62.7% in office 1 and by 46.49% in reception. Study (Budaiova *et al.* 2015b) investigated IEQ, objectively evaluated performance, perceived performance and comfort of occupants in two office buildings. Average values of sound pressure level were exceeded limit value in both monitored offices (open space, enclosed offices). According to the measurement of physical factors and the questionnaire, the acoustical environment caused discomfort. Average performance of all tasks was higher in open space office. Total performance of occupants was higher than 84% in open space office and 92% in enclosed office. Many studies (Lan *et al.* 2010, 2011; Gruber *et al.* 2014; Song *et al.* 2016; Pei *et al.* 2015; Budaiova *et al.* 2015a; Budaiova, Vilcekova 2015) are focused on productivity and well-being office workers. Other studies (Chatoutsidou *et al.* 2015; Szigeti *et al.* 2014; Horemans, Grieken 2010) are focused on measurement of indoor/outdoor particulate matter in office buildings.

Monitoring of indoor air pollutants occurrence in selected offices of elementary school is the main goal of the presented paper.

Methodology

Screening measurements of instantaneous values of physical and chemical factors in selected rooms on the ground floor (director' office, office of special educational and pedagogical staff) and on the first floor (office of deputy) were carried out during days 05/06/2016, 05/09/2016 and 06/30/2016. There were water soluble paints on the walls and ceilings, carpets, common office furniture and equipment, and approximately 5 plants in each office. Renovation works were carried out approximately 3 years ago, (replacement of windows). Air temperature, relative humidity, carbon dioxide (CO_2) concentrations and intensity of illumination were determined using multifunctional device Testo 435-4 with relevant probes. Mean radiant temperature was measured by Vernon-Jokl spherical thermometer. Handheld noise analyser – Brüel and Kjaer Type 2250 – was used to determine the noise level. Concentrations of particulate matters (fractions from 0.5 to 10 μm) were measured using HANDHELD 3016 IAQ. The concentrations of volatile organic compounds (VOCs) expressed as concentration of the calibration compound (isobutylene) were determined with a photoionization detector with UV lamp (ppbRAE3000). Portable gas chromatograph with surface acoustic wave detector (zNose 4300) was used for qualitative determination of individual VOCs. Table 1 shows measuring ranges of used equipment.

Table 1. Information about measuring equipment

Measuring equipment	Information
Testo 435	Measuring range and accuracy: air temperature: from 0 to +50 °C; ±0.3 °C relative humidity: from 0 to 100%; ±2%RH level of CO_2: from 0 to 10,000 ppm; ±(75 ppm ±3% of mv) (0 to +5000 ppm) ±(150 ppm ±5% of mv) (+5001 to +10000 ppm) lighting intensity: from 0 to 100,000 lx; 1 lx
Brüel and Kjaer Type 2250	The dynamic range of more than 120 dB(A)
ppbRAE 3000	Accuracy from 10 to 2,000 ppm: ±3% at calibration point, measuring range: 1 ppb – 10,000 ppm
zNose 4300	Accuracy 5% RSD, 10% accuracy and sensitivity to the low ppb level for most compounds
HANDHELD 3016	Measuring range: from 0,3 to 25 μm

All measuring devices were placed in the middle of the room at height of 1.1 m above the floor. Natural ventilation through open windows was ensured for 15 minutes before the start of each measurement. Windows were opened for a further 10 minutes after starting the measurement. Subsequently, windows were closed and measurement continued with closed windows for 1 hour. At the end, the measurement was running again with open windows for another 30 minutes. Due to the findings of background values (the state of the outdoor environment) as well the dynamics of rising and decreasing the measured factors, the measurements carried out with opened and closed windows. Measurements were performed in a non-heating period. Only two persons carrying out the measurements were present in the office A (director' office) and in the office B (office of deputy). Two persons carrying out the measurements and two users were present in the office C (office of special educational and pedagogical staff) during measurement.

Results

Determined levels of selected physical and chemical factors in the indoor environment of monitored building are shown in Table 2. Requirements for selected physical and chemical factors of indoor environment provides Decree of the Ministry of Health of the Slovak Republic No. 210/2016 Coll. on detailed requirements for indoor environment of buildings and on minimum requirements for low-standard flats and accommodation facilities (2016). Requirements to ensure health protection against noise exposure provides Slovak Governmental Regulation No. 15/2006 Coll. on minimum health and safety requirements for the protection of workers against the risks relating to noise exposition (2006). The lowest mean air temperature was detected in the office C (21 °C) where was measured the highest relative humidity (51.1%). The highest mean air temperature was recorded in the office B (24.4 °C). The operational temperature was calculated according to EN ISO 7726 (1998). Optimal operational temperature for warm period of the year should be in the range from 23 °C to 27 °C and permissible operational temperature should be in the range from 20 °C to 28 °C according to Decree of the Ministry of Health of the Slovak Republic No. 210/2016 Coll. This implies that the requirement for optimal operational temperature has been satisfied in the office A and B, while in the office C has been satisfied only requirement for permissible operational temperature. However, the requirement to comply the permissible operational temperature range is for cases where it is impossible to ensure optimal operational temperature range. Further measurements of air temperature and radiant temperature are necessary in the office C. If it confirms, that the optimal operational temperature range is not ensured, it will be necessary to suggest specific optimization measures.

Table 2. Results from monitoring of indoor environmental parameters

Parameter		A	B	C	Limit/ recommended value
Air temperature [°C]	Mean	24.3	24.4	21.0	–
	Minimum	23.1	23,9	18.3	–
	Maximum	25.0	24.7	22.1	–
	S.D.	0.5	0.2	1.1	–
Operational temperature [°C]	Established by calculation	23.9	24.0	20.6	Optimal range: 23–27 °C Permissible range: 20–28 °C
Relative humidity [%]	Mean	39.5	42.2	51.1	30–70%
	Minimum	38.2	37.8	48.1	–
	Maximum	40.9	44.9	55.7	–
	S.D.	0.7	1.8	1.5	–
CO_2 [ppm]	Mean	640.3	856.7	647.7	1000 ppm
	Minimum	505	689	425	–
	Maximum	832	1081	943	–
	S.D.	90.8	116.2	152.6	–
$PM_{0.5}$ [$\mu g/m^3$]	Mean	2.8	2.7	2.8	–
	Minimum	2.7	2.2	2.2	–
	Maximum	3.0	2.9	3.8	–
	S.D.	0.1	0.2	0.4	–
PM_1 [$\mu g/m^3$]	Mean	3.6	3.4	3.4	–
	Minimum	3.5	2.8	2.6	–
	Maximum	3.8	3.7	4.6	–
	S.D.	0.1	0.2	0.4	–
$PM_{2.5}$ [$\mu g/m^3$]	Mean	5.5	5.3	4.7	–
	Minimum	5.0	4.2	3.6	–
	Maximum	5.9	6.6	5.7	–
	S.D.	0.2	0.4	0.6	–
PM_5 [$\mu g/m^3$]	Mean	23.4	19.3	17.1	–
	Minimum	18.4	14.9	10.3	–
	Maximum	30.3	37.5	28.9	–
	S.D.	2.9	2.4	4.9	–
PM_{10} [$\mu g/m^3$]	Mean	54.1	37.8	42.9	50 $\mu g/m^3$
	Minimum	38.2	30.9	18.6	–
	Maximum	72.8	76.1	86.1	–
	S.D.	8.4	5.6	16.1	–
Equivalent noise level L_{Aeq} [dB(A)]	Mean	61.3	57.0	58.6	50 dB
Illumination E [lx]	Mean	920.8	182.7	112.5	500 lx

The relative humidity should be in the range from 30 to 70%. This requirement was satisfied in all three offices. Maximum permissible concentration of particulate matter PM_{10} is 50 μg/m^3. This limit value is set for 24-hour exposure. This value was exceeded by 7.6% in the office A. According to conducted short-term measurements it is impossible to say with certainty that permissible values were not fulfilled. Therefore, it would be appropriate to carry out long-term measurements.

Minimum permissible intensity of illumination in areas with the associated lighting is 500 lux. This requirement was fulfilled only in the office A. The lighting intensity was lower by 63.5% in the office B and lower by 77.5% in the office C. In these two offices, the workplace should be rearranged.

The standard EN 13779 (2007) classifies low IAQ with CO_2 levels above level of outdoor air (typically 350 ppm) higher than 1000 ppm. This recommended value was not exceeded in selected offices. Concentrations of TVOC in offices were under detection limit of measuring device and therefore they did not exceed the recommended value of 200 μg/m^3 according to Mølhave (1990).

The equivalent noise level at the workplace should not exceed 50 dB(A) according to Slovak Governmental Regulation No. 115/2006 Coll. This value was exceeded in all monitored offices, in office A was exceeded by 18.4%, in office B by 12.3%, and in office C by 14.7%.

The dynamics of changes in particulate matter concentrations in individual rooms is shown in Figures 1–3.

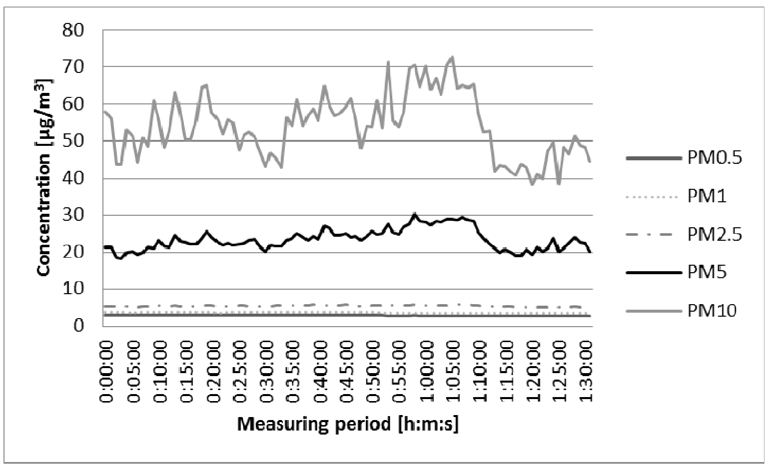

Fig. 1. The variation course of PM concentrations (office A)

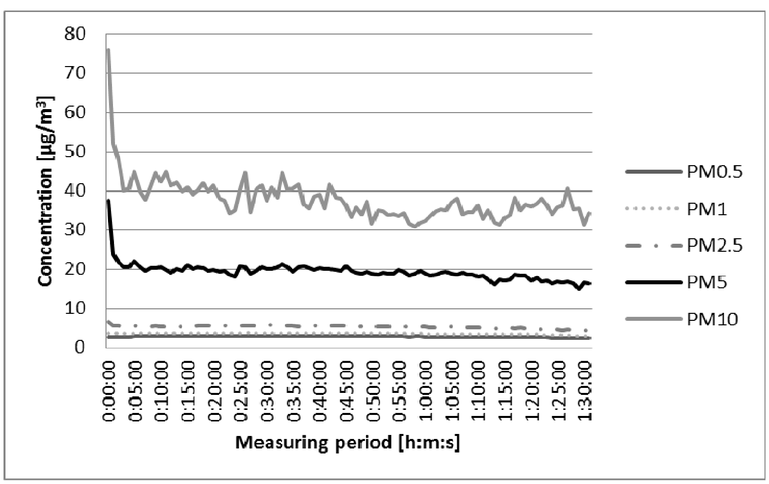

Fig. 2. The variation of PM concentrations (office B)

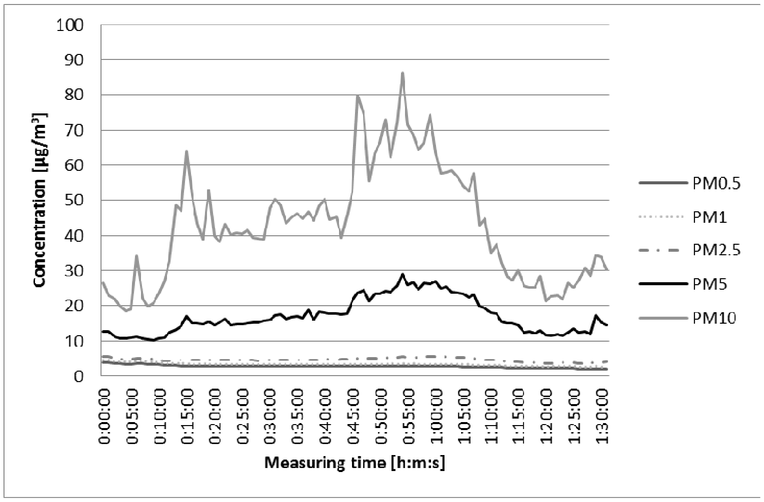

Fig. 3. The course of PM concentrations (office C)

Following VOCs were present in the indoor air in all monitored offices: aniline, *p*-cymene, and hexyl salicylate (Table 3). The source of aniline in the indoor environment of evaluated building comes from operating with paints and adhesives containing residual amounts of this substance (The center for chemical substances and preparations 2016). *P*-cymene may occur in air fresheners, cleaning agents, detergents and personal care products, however, this compound can be also released from the particle board (Pubchem 2016; Henneuse-Boxus, Pacary 2003). Hexyl salicylate is utilized in cosmetic products (Perfumer, Flavorist 2016). Nonanal is present in the ambient air and it is also widely detected in samples of indoor air (5%) in concentrations ranging from 5 to 10 μg/m^3 (Brown *et al.* 1994).

Table 3. Qualitative analysis of VOCs

CAS No.	Compound	Office A	Office B	Office C
930-60-9	2-cyclopentane-1,4-dione	✓	✓	
95-47-6	*o*-xylene			✓
62-53-3	aniline	✓	✓	✓
99-87-6	*p*-cymene	✓	✓	✓
124-19-6	nonanal	✓	✓	
–	6-dimethyloctanal-2-ol		✓	✓
1632-70-8	5-methyl undecene	✓		
90-12-0	1-methylnaphthalene			✓
629-50-5	tridecane	✓	✓	
110-42-9	methyl decanoate		✓	
122-91-8	4-methoxybenzyl formate	✓		✓
–	(E) -2-tetradecene	✓	✓	
112-17-4	decyl acetate			✓
483-75-0	α-amorphene		✓	✓
7549-33-9	4-methoxybenzyl propionate	✓		
119-61-9	benzophenone		✓	
–	(E)-10-tetradecenal	✓		✓
6259-76-3	hexyl salicylate	✓	✓	✓

Nonanal was identified in emissions from coatings used on the furniture (Salthammer 1997) and from carpets (Schaeffer *et al.* 1996). Some studies demonstrated the presence of nonanal in dust particles in the indoor environment (Nilsson *et al.* 2005). 1-methylnaphtalene can be found in dyes, although small amounts of this substance are typically in ambient air due to burning of wood and fossil fuels (ATSDR 2016). Tridecane together with *o*-xylene belongs to common organic compounds in the indoor environment. Tridecane belongs to the compounds that are emitted from building materials (e.g. vinyl flooring) (Spengler *et al.* 2001). Since there are many sources of this substance in indoor environment, it is difficult to name the source of this compound in the monitored offices. Adhesives, floor coverings, varnishes, paints, wallpapers, wax, tobacco smoke etc. are important sources of o-xylene in indoor environment (Spengler *et al.* 2001; Wilke *et al.* 2004). Benzophenone is utilized as a flavour in perfumes or as an ingredient in plastics, paints, and adhesives. It is also utilized in the manufacture of insecticides, agricultural chemicals or drugs (IARC Monographs-101 2016). Sources of other identified compounds are most likely cosmetic or cleaning products as well as outdoor air.

Conclusions

Short-term measurements of selected physical and chemical factors were carried out in the indoor environment of selected offices in elementary school in Kosice. The determined values were compared with respective limits or recommended values. The value of operative temperature is not within the optimal range of values for the warm period of the year according to Decree No. 210/2016 Coll. in one of the monitored offices (office of special educational and pedagogical staff). The intensity of illumination was lower by 63.5% in the office of deputy and by 77.5% in the office of special educational and pedagogical staff. It can be concluded in terms of the occurrence of particulate matters that low levels were measured; permissible values were exceeded by 7.6% only in the office of director. Qualitative determination of the occurrence of VOCs demonstrated their presence in monitored areas. However, based on the quantitative determination of VOCs concentrations, it can be said that they are below the detection limit and there is no prediction of their negative effect on the health of building users.

The results of measurements showed that the biggest drawback is the low lighting in the two monitored offices. Therefore, it is necessary to propose measures, namely: the use of artificial light (work area) throughout the working hours or ensure sufficient daylight by trimming the trees growing near the windows. Trimming the threes would achieve a greater direction the sunlight to the interior. This could lead also to optimal operational temperature in the office of special educational and pedagogical staff. For better evaluation of indoor environmental quality, it is necessary to carry out long-term measurements of selected physical and chemical factors of indoor environment.

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Contribution

Silvia Vilcekova had the original idea and design of the study. Eva Kridlova Burdova and Ludmila Meciarova carried out measurements, Zoran Apostoloski analysed data. Danica Kosicanova revised the paper. Silvia Vilcekova and Ludmila Meciarova interpreted the results, prepared the text, and provided the final version of the manuscript, which was revised by all authors. All authors read and approve the final manuscript.

Disclosure statement

Authors declare that not have any competing financial, professional, or personal interests from other parties.

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