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Investigation of indoor and outdoor air quality of the classrooms at a school in Serbia

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ABSTRACT

The air inside schools can be more polluted than the air outside. The purpose of this study was to investigate the air quality in primary school placed in town at the east of Serbia. The characterization of air pollution concentration was performed with main goal to determine relationship between indoor and outdoor air pollution within five classrooms. The measurements were conducted continuously in indoor and outdoor environment for period of 10 days. The standard sampling and analytical methods were applied (gas chromatography coupled with mass spectrometry). This paper presents and analyses concentrations of different physical and chemical pollutants in the indoor and outdoor environment: respirable particulate matter with different diameters (up to 2.5 μm and 10 μm), polycyclic aromatic hydrocarbon in particulate matters up to 10 μm, volatile organic compounds, formaldehyde, ozone, carbon-dioxide and nitric-dioxide. It was found, in one class, that the concentration of particulate matter with diameter up to 10 and 2.5 microns as well as polycyclic aromatic hydrocarbon in particulate matters up to 10 μm were higher in indoor environment than in outdoor. The average value of formaldehyde in all classrooms was significantly higher than recommended value. On the basis of received results, extensive school renovation program can be recommended.

1. Introduction

During the week, pupils were spending more time in schools (up to 87%) of their time indoors, where they were exposed to environmental influences. Insufficient and inadequate ventilation rates, the cleaning products and the chemicals emitted by building materials or furnishings can cause the problems of indoor air pollution at the schools. The parameters which may have affect on IAQ (indoor air quality) are sources of indoor air pollutants, HVAC (the heating, ventilation and the air-conditioning system), occupants and other pollutant pathways [1,2]. There are many sources in outdoor environment, such as a heavy traffic and combustion of fossil fuels in furnaces for heating, which may have affect on the indoor air pollution in schools [3–5]. IAQ, such as the level of pollutants, humidity, temperature, and so on, directly can have affect on health and working capacity of children, as well as comfortable accommodation of teachers and staff in schools. Numerous studies have shown a direct dependence of poor IAQ with health problems. Low ventilation rate and outdoor air pollution from traffic can cause asthma symptoms among pupils. It was also confirmed that the total working capacity of children decreases with illnesses and absence from school [6–8].

In schools in Republic of Serbia (RS), there are problems often linked to the indoor air quality due to pollution of the outside air, poor construction and building maintenance, poor cleaning and poor ventilation. In RS, the share of school children population (aged 7–14 years) in the total population is 7.5%, and every 10th school-aged children has asthma. Research conducted in city of Belgrade, which is middle ranked on list of towns in RS with children asthma, shows that 9% of children which attend primary school suffer from this disease [9].

To assess the most commonly pollutants in indoor school environment and pupil's exposure to inside pollution, several studies have been conducted. The paper [10] presents a review of personal exposure of school-aged children to specific pollution in Western Europe and North America. The authors have explained basic concept of measurement and modelling techniques of personal exposure assessment as an essential tool to identify health

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risks, set air quality standards and policy implementation. A paper by Pegas et al. [11] presented an investigation of inside and outside concentration of volatile organic compounds, nitric-dioxide, particulate matter up to 10 μm and bio-aerosols in school buildings in urban and suburban area. In a study [12], the IAQ was determined in different seasons in a large number of schools in Bavaria. The data of indoor air climate parameters (temperature, relative humidity), carbon-dioxide (CO_2) and particle fractions (up to 10 μm and 2.5 μm) were collected. It was found that the exposure to particulate matter in schools was high. Another goal of this study is to identify the parameters which correlated with increased concentrations of particulate matters, such as high CO_2 concentrations and low class level.

The purpose of this study is to determine the level of IAQ in school, to characterize concentration of indoor and outdoor air pollution and compare them with the recommended values. This study investigated inside and outside pollution concentrations at different measuring places in elementary school building placed in downtown. In this way, renovation program may be proposed with main goal to achieve a healthy indoor school environment.

2. Major indoor pollutants

Several indoor air pollutants common to schools include: biological contaminants (mould, dust mites, pet dander, pollen, etc.), carbon-dioxide, carbon-monoxide, dust, environmental tobacco smoke, fine particulate matter, lead, nitrogen oxides (NO, NO_2), radon, volatile organic compounds, formaldehyde, solvents and cleaning agents. The sources of the typical indoor air pollution in school buildings are different: emissions from building materials, paints, varnishes, solvents, fuel combustions products from heating, the by-product realized from the activities of the building occupants, biological sources, etc. Today it is very difficult to quantify the exposure from indoor pollutants (personally exposed from indoor pollution), especially for pollutants which can be associated with health effects (phenomenon called SBS (Sick Building Syndrome)). The major indoor air pollutants which were measured and analysed in this paper are shortly described below, across the categories of sources, standards and guidelines for indoor air quality and health effects.

Suspended PM (particulate matter) concentrations were higher in indoor environments than in outdoor, in case when the sources of particulate matter were placed in the immediate vicinity (attributed to gas and coal stoves for cooking, boilers for heating space, tobacco and smoking as well as it is shown in many studies) [4]. It was also discovered that cleaning can cause re-suspension of these particles from carpet and furniture [13–15]. Dust was made up of particles in the air and may contain lead, pesticide residues, radon, or other toxic materials. Health effects vary depending upon the characteristics of the dust and any associated toxic materials. Small particles are capable of passing through the body's defences and enter the lungs. Inhalation of fine PM has been linked to increase of respiratory health problems (asthma, bronchitis, etc.). The 2005 WHO AQGs (air quality guidelines) for PM_{10} list in outdoor air 20 μg/m^3 per hour for an annual average and 50 μg/m^3 for a 24-h average and for $PM_{2.5}$ in outdoor air, recommended value is 10 μg/m^3 as the annual limit and 25 μg/m^3 as the 24-h limit. There are currently no standards for $PM_{2.5}$ in school indoor air environments [16].

PAHs (polycyclic aromatic hydrocarbons) were produced as a result of incomplete combustion and absorption in particles. Emissions from traffic have been found to be the main outdoor source for the indoor PAH concentration in urban and suburban locations [17]. School indoor air is contaminated by PAHs which come from outside air, but also from indoor emission sources such as smoking, cooking and heating during the combustion of fossil fuels [18]. PAHs particles were considered as compounds with carcinogenic potential. They occur in indoor air as complex mixtures and their composition depends from site to site. Most single PAHs concentration in indoor air is benzoapyrene, which was considered to represent the best single indicator compound. The guideline value for PAHs in indoor air is based on epidemiological data from studies on coke-oven workers. The risk for lung cancer for PAH mixtures is estimated to be 8.7×10^{-5} ng/m^3 of benzoapyrene [19].

VOCs' (volatile organic compounds) pollutants that originate from different sources and concentrations of the individual components may be different, depending on the presence or absence of potential emission sources. The common sources of VOCs in school indoor air are: construction materials, furnishings and textiles, adhesives, paints, classroom supplies, consumer products, copy machines, cleaning products, commercial products and combustion furnaces. It was found that high indoor concentrations of trichloroethylene and 1,4-dichlorobenzene originate from furniture (such as leather) [14,15]. In accordance to the literature [7] school furniture (draperies, wood desks and chairs that use certain glues, vinyl type flooring, etc.) as well as construction materials can increase the level of formaldehyde and VOCs pollution and they present the main sources of SBS. The levels of VOCs found in schools indoor can be much higher than those found outdoor. This is because a building indoor environment is not well ventilated. The effects of VOCs on health depend on several factors including the type of VOCs, the amount of VOCs and the length of time a person was exposed. VOCs may cause irritation to the eyes, nose, and throat, headaches, and nerve problems can also occur. Some studies on animals have shown that breathing some types of VOCs over a long period of time can increase the risk of getting cancer. Most standards and guidelines consider 200–500 μg/m^3 as acceptable for total VOCs [20]. Table 1 considers measured concentration of total VOCs that is classified into five ranges [21].

Formaldehyde (HCHO) indoor concentration depends on the presence of the primary sources of emissions such as construction materials (particle-board, medium-density fibreboard, plywood, resins, adhesives and carpeting). The concentration depends on the temperature and humidity of indoor air. Common pollutant in school is HCHO which can be also emitted from furniture, ceiling tile, wood shelving, and cabinetry [20]. Formaldehyde emissions in the atmosphere originate from fuel combustion processes (power plants, traffic, etc.). Secondary HCHO formation occurs in air through the oxidation of volatile organic compounds (VOCs) and reactions between ozone (mainly from outdoors) and alkenes [22,23]. The contribution of these secondary chemical processes to the ambient and indoor concentrations is still not fully quantified. Taking into account all the indoor HCHO sources, it is difficult to identify the major ones that contribute to indoor levels. After effects exposure to formaldehyde at indoor levels include odour (which may cause discomfort), sensory irritation to the eyes, lung

Table 1
Total VOCs and proposed classification.

VOC concentration (mg/m^3)	Proposed classification	Health effects
<0.25	Low	No irritation or discomfort expected
0.25–0.5	Average	Irritation and discomfort may be possible
0.5–1	Slightly increased	
1–3	Considerably increased	
>3	Strongly increased	Discomfort expected and headache possible

effects (asthma and allergy) and eczema [24]. Formaldehyde mean concentration range in indoor air (in homes, schools and public buildings) is 0.002–0.25 mg/m^3 where concentrations varied greatly across countries [25]. In urban environments, concentrations are usually in the range of 0.001–0.02 mg/m^3 [25]. According to Table 2, the indoor concentration are usually much higher than the outdoor level. The most important way to control HCHO concentration is the air exchange rate and the use of low-emitting materials and products.

Nitrogen dioxide (NO_2) is usually formed from coal combustion processes, in furnaces gas appliances as well as smoke from cigarettes [26]. Outdoor sources, such as vehicles, also contribute to indoor NO_2 concentration. Standards list 0.053 ppm (107 μg/m^3) as the average 24-h limit for NO_2 in outdoor air (ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) and the U.S. EPA (Environmental Protection Agency) National Ambient Air Quality). WHO air quality guideline value of 200 μg/m^3 and 40 μg/m^3 for 1-h indoor NO_2 and annual average indoor NO_2, respectively, is recommended. The main health effects which occur with exposure to NO_2 in the indoor environment are respiratory symptoms, decreases in immune defence, etc.

Carbon-dioxide (CO_2) indoor concentration is formed from metabolic processes in a body of occupancy as well as in combustion processes of fossil fuel, like those in cars buses, trucks, stoves, furnaces, etc. Exhaled air is usually the largest source of CO_2 in classrooms. The ratio of indoor and outdoor concentration of CO_2 is usually in the range of 1–3. ASHRAE Standard 62-2001 recommends 700 ppm above the outdoor concentration as the upper limit for occupied classrooms (usually around 1000 ppm) [27]. The poor comfort conditions occur when level of CO_2 in air is higher than 0.2% (2000 ppm) and when the level is higher than 0.35% (3500 ppm) there is risk of long-term health effects. At concentrations above1.5% (15,000 ppm) some loss of mentalacuity has been noted [28].

Ozone (O_3) is naturally produced in the atmosphere but it can be a main part of air pollution called smog. Ozone can be released into the air from some equipment such as laser printers and copiers, from some types of 'air cleaners' and from certain industrial processes. In the upper layer of the sky, ozone is helpful in protecting from effects of the sun. In the lower layer, close to the earth, in outdoor and indoor environment, it can be harmful by inhalation. When inhaled, it can damage the lungs and irritate the throat. Ozone as reactive gas tends to occur in small concentrations in indoor environment in respect to outdoor values. It is the result of a very fast reaction between gas and the indoor surfaces [15]. Many studies have shown associations between daily mortality and ozone levels. It is recommended that the air quality guideline for ozone is set at the level of 100 μg/m^3 for an 8-h daily average. This concentration will provide adequate protection of public health, though some health effects may occur below this level.

Table 2
Mean exposure concentrations of formaldehyde in outdoor and indoor environments (sampled over several days) [19].

	Concentration (mg/m^3)
Outdoor air	
General	<0.01
Highly urbanized or industrial areas	0.02
Indoor air	
Schools/kindergartens	
General	<0.05
Range	0.002–0.05

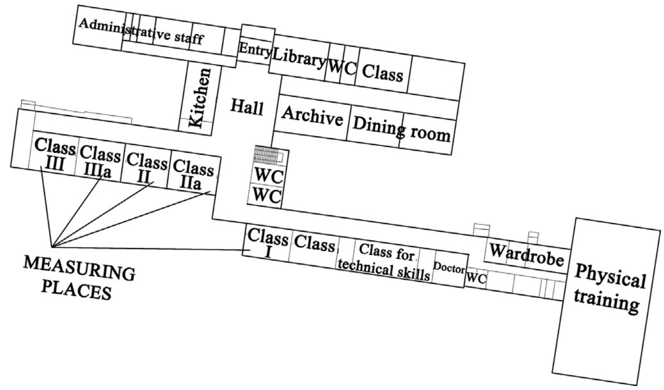

Fig. 1. The ground floor plan of the building school.

3. Measuring site description

The measurements of indoor and outdoor air pollution were conducted in a primary school located in the commercial-residential area of Zajecar, town placed at the east of Serbia. Fig. 1 shows the ground floor plan of the school building and the inside measuring points (class I, II, IIa, III and IIIa). The outside samples were obtained from one place in school garden. The school building is 40 years old, the total number of students attending the school is 750 and the number of employees is 70. Classrooms are used five days a week and 10 h per day. Each classroom has about 28 students. The potential sources of air pollution, in the vicinity, that may affect on the IAQ are: the boiler for school heating space placed in the basement of the school, the surrounding heating plants at distances up to 1 km, stored fuels (coal, wood) in the basement of the school, a nearby factory to 10 km distance, the individual furnaces in each surrounding house. It is a naturally ventilated school, and the classrooms in the school building are not air conditioned. Combustion that take a place in furnace of the boiler is incomplete and system for flue gases is not properly designed. The classrooms are in poor condition. The floor of the analysed classrooms is the concrete and is covered with old carpets or linoleum. The carpets are mouldy and in the classroom is a noticeable smell of mould. The windows are in poor condition, and in the winter usually open a one of four windows in the classroom.

The aim of this paper was to present the results of sampling of key indoor and outdoor pollutants that have affect on IAQ in school.

Fig. 2. The image for the outdoor air measuring instruments.

Table 3
The ambient and outdoor air conditions measuring instruments.

Pollutants	Measuring instrument	Accuracy	Measuring range
Suspended particulate matter (PM_{10} and $PM_{2.5}$)	Low volume sampler Sven/Leckel LVS3	0.01 m^3	Controlled flow rates 1.0–2.3 m^3/h Uncontrolled flow rates of 3.2 m^3/h
Polycycle aromatic hydrocarbons (PAHs in PM_{10})	Compendium method TO-13A (gas chromatography coupled with mass spectrometry, GS–MS)	Indicated flow rate ±10%	0.20–0.28 m^3/min
Volatile organic compounds (VOCs) (benzene, trichloroethylene, tetrachloroethylene, limonene and pinene) Nitric-dioxide (NO_2) Ozone (O_3) Formaldehyde (HCHO)	Passive/diffusive sampler Radiello for ambient and outdoor monitoring	±10%	1 μg/m^3 to 1000 mg/m^3
Indoor carbon-dioxide (CO_2)	Testo 435-4 instrument with probe IAQ 0632 1535	±50 ppm	0–5000 ppm
Outdoor carbon-dioxide (CO_2)	Testo 445 instrument with CO_2 probe	1 ppm	0–10,000 ppm
Indoor air temperature (*T*) and relative humidity (RH)	Testo 435-4 instrument with probe IAQ 0632 1535	±0.3 °C ±0.2%	0–50 °C 0–100%
Outdoor air temperature (*T*) and relative humidity (RH)	Testo 445 instrument with probe RHt	±0.4 °C (0–50) °C ±0.5 °C < 0 °C ±0.1%	−20 °C to 70 °C 0–100%

The following pollutants, as quality parameters of the internal and external air, were measured and analysed: respirable suspended particulate matter size up to 10 μm (PM_{10}), respirable suspended particulate matter less than 2.5 μm ($PM_{2.5}$), polycyclic aromatic hydrocarbons in PM_{10} (PAH in PM_{10}), volatile organic compounds (VOCs), formaldehyde (HCHO), ozone (O_3), nitric-dioxide (NO_2) and carbon-dioxide (CO_2). The samples were collected both indoor (in five classrooms) and outdoor that are indicated in Figs. 1 and 2. In this study health symptoms, which may cause by poor IAQ, are not analysed.

4. Measuring and sampling methods

The results of pollutants measurement that are presented in this paper are based on measuring which was conducted in April 2012, in period of 8 days (or 10 days for some pollutants). All the samples were collected both indoor and outdoor. Outdoor sampling was performed at one measuring site, and indoor sampling at five measuring sites (PM_{10} and $PM_{2.5}$ were measured in all classrooms; NO_2, O_3, HCHO, CO_2 and VOCs were measured in class I, class II and class III). Measuring equipments which were used for separated, identified and quantified complex mixtures of chemicals are presented in Table 3. Table 4 shows the common indoor environmental parameters, i.e. PM_{10}, $PM_{2.5}$, PAH in PM_{10}, VOCs, HCHO, O_3, NO_2, temperature and relative humidity. Also, the average indoor and outdoor pollution concentrations, with a minimum and maximum of concentration as well as ratio of indoor and outdoor concentrations were presented in Table 4.

Table 4
The concentration of indoor air pollutants and thermal comfort parameters.

Different indoor air pollutants	Average ± SD	Min	Max	I/O
PM_{10} (μg/m^3)	70.63 ± 19.8	37.32	103.14	1.01
$PM_{2.5}$ (μg/m^3)	43.58 ± 12.9	26.88	63.92	0.98
PAHs in PM_{10} (μg/m^3)	61.66 ± 61.4	10.19	198.73	1.30
VOC (μg/m^3)	48.67 ± 11.3	39.71	61.32	31.96
HCHO (μg/m^3)	63.74 ± 22.8	42.98	88.15	12.58
O_3 (μg/m^3)	15.51 ± 6.50	8.82	15.90	0.07
NO_2 (μg/m^3)	15.02 ± 7.50	7.53	22.45	1.64
CO_2 (μg/m^3)	1.11 ± 0.04	1.09	1.15	1.35
T (°C)	25.7 ± 2.13	16.6	30.9	1.56
RH (%)	33.3 ± 8.43	13.5	54.1	0.59

The low volume samples (Sven/Leckel LVS3) with size-selective inlets for PM_{10} and $PM_{2.5}$ fractions were used for particulate matter characterization. The quartz filters were used for sampling where the samples were taken in intervals of 24 h (±1 h). The concentrations of particulate matters were calculated based on the mass and flow. The average indoor and outdoor concentrations of $PM_{2.5}$ and PM_{10}, for whole sampling period of 192 h, were computed according to 24-h average concentration in classrooms and presented in Table 4.

PAHs were measured in each group of particles and from the gaseous phase. The total of 16 compounds of PAHs were measured: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)flouranthene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene. PAHs were collected, prepared and analysed according to Compendium Method TO-13A [29]. They were analysed by GC-MS (gas chromatography coupled with mass spectrometry). Fig. 4 shows average daily concentration of PAHs in PM_{10}. The average concentration of PAHs in PM_{10} for sampling period of 192 h in the classrooms I, II, IIa, III and IIIa was calculated, herein presented in Table 4.

The diffusive sampler 'Radiello' for passive air sampling was used for sampling and indoor concentration determination of gaseous compounds of VOCs, NO_2, O_3 and HCHO as well as outdoor environmental monitoring. One sampler per each pollutant was used. The average concentration of total VOCs, NO_2, O_3 and HCHO during the sampling period (from 2.04.2012 to 12.04.2012) was shown in Table 4.

The complex mixture of five individual compounds of VOCs presents the total concentration of VOCs. In this paper the following compounds of VOCs were considered: benzene, trichloroethylene, tetrachloroethylene, limonene and pinene. Fig. 5 shows the average level of individual VOCs concentrations.

The indoor CO_2 concentration was determined by the ambient air conditions measuring instrument Testo 435-4, device with the corresponding probe (IAQ 0632 1535), which has precision of ±50 ppm and measurement range of 0–5000 ppm.

Outdoor CO_2 concentration was measured using the Testo 445, device with precision of ±1 ppm and measurement range of 0–10,000 ppm. The measurements were conducted every 10 min at all measurement sites during the measurement period. The average

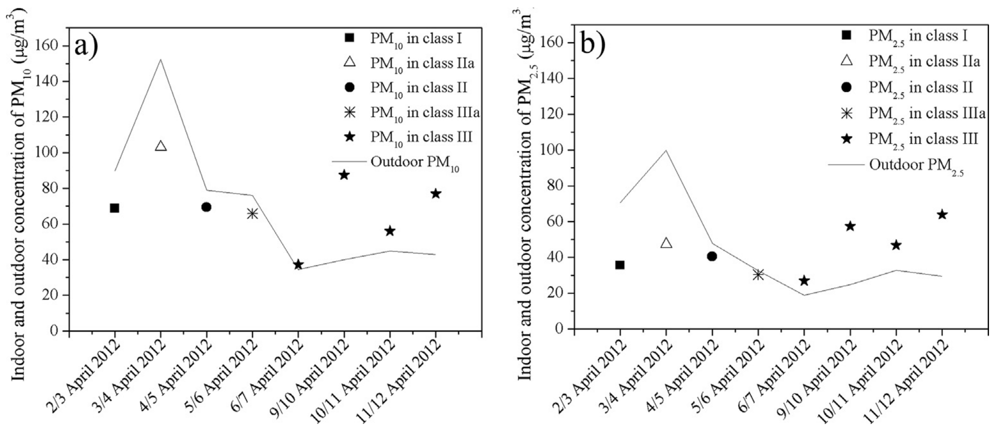

Fig. 3. Average daily concentration in indoor and outdoor environment: (a) PM_{10} and (b) $PM_{2.5}$.

daily concentrations of CO_2 are used in analysis of the results. Fig. 7 shows the daily average level of indoor and outdoor concentration of CO_2.

The indoor and outdoor temperature and relative humidity were measured using the Testo 435-4 and Testo 445, respectively. The indoor temperature and relative humidity ranged from 16.6 °C to 30.9 °C and from 13.5% to 54.1%, respectively in measurement period (Table 4). Average outdoor temperature and relative humidity ranged from 1 °C to 22 °C and from 27% to 92%, respectively (Table 4).

5. Results and discussions

The average concentration values of PM_{10} and $PM_{2.5}$ were obtained from measuring data, during the period of eight days (sampling time). Fig. 3 presents the average daily concentration of PM_{10} and $PM_{2.5}$ in indoor and outdoor environment. The average indoor concentration of PM_{10} was 70.63 μg/m^3, with a minimum of concentration of 37.32 μg/m^3 and maximum of concentration of 103.14 μg/m^3 (Table 4). The average indoor concentration of $PM_{2.5}$ was 43.58 μg/m^3 with a minimum of concentration of 26.88 μg/m^3 and maximum of concentration of 63.92 μg/m^3 (Table 4). The results showed that the average concentrations of PM_{10} and $PM_{2.5}$ in the outdoor environment were higher than the concentration of PM_{10} and $PM_{2.5}$ in the classrooms, for 20% and 32% respectively (in the classrooms: I, II, IIa and IIIa). However, based on the measured values in the classroom III, concentrations of indoor PM_{10} and $PM_{2.5}$ were higher than outdoor values as shown in Fig. 3 (average indoor concentrations of PM_{10} and $PM_{2.5}$ were 64.47 μg/m^3 and 48.75 μg/m^3 and average outdoor concentrations of PM_{10} and $PM_{2.5}$ were 40.54 μg/m^3 and 26.47 μg/m^3, respectively). According to the 2005 WHO air quality guidelines (AQGs), which give the targets related to outdoor air pollution, the guideline values for 24-h mean of PM_{10} and $PM_{2.5}$ concentrations are 50 μg/m^3 and 25 μg/m^3 respectively [16,30]. The average outdoor concentration values of PM_{10} exceed threshold limit values for outdoor air in following measuring days: 2/3; 3/4; 4/5; 5/6 of April; and they were higher than indoor concentration in classes I, II, IIa and IIIa. The average outdoor concentration values of $PM_{2.5}$ exceed threshold limit values for outdoor air for all measuring days.

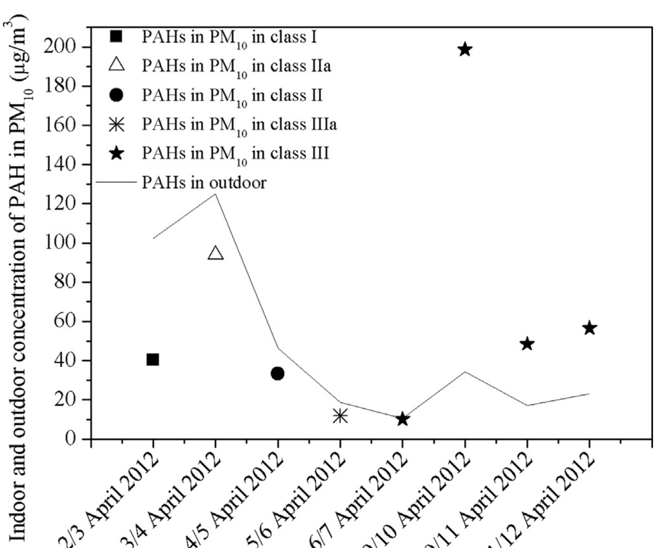

Fig. 4. Average daily concentration in indoor and outdoor environment of PAHs in PM_{10}.

When the values of PAHs in PM_{10} were analysed, on several occasions, higher concentrations were observed in indoor environments in the classroom III, compared to measured values in the outdoor environment, as it is presented in Fig. 4. On the other measuring sites (classes I, II, IIa, III and IIIa) the indoor concentration of PAHs in PM_{10} was lower, approximately 46%, than those measured in the outdoor environment. Classroom III is on the ground floor, vicinity of the boiler, which was placed in the basement of the school. Assumption can be made that increase of particulate matter of PM_{10}, $PM_{2.5}$ and PAHs in PM_{10} in classroom III, must be due to inadequate elimination of flue gases from the

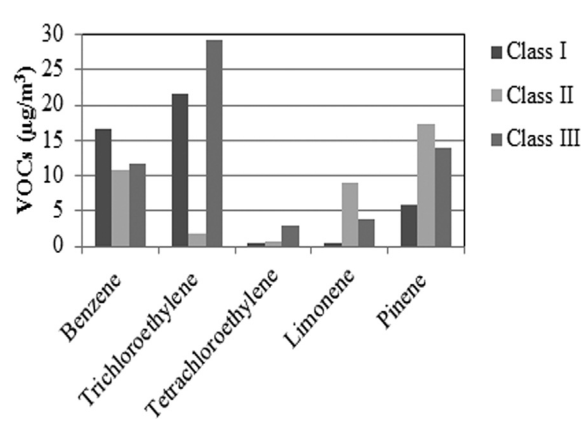

Fig. 5. Average concentration of individual VOCs.

furnace of the boiler and poor ventilation in the basement. Furthermore, walking and running children's promote re-suspension of these particulate matters.

According to measurements of VOCs, the level of 5 individual indoor VOCs ranged from 0.39 to 29.15 μg/m^3. Fig. 5 shows the average concentration of the individual VOCs in classes I, II and III. It was seen that the highest measured concentration of trichloroethylene of 29.15 μg/m^3 was in class III, then benzene of 16.54 μg/m^3 in class I, pinene of 17.36 μg/m^3 in class II, limonen of 9.13 μg/m^3 in class II and tetrachloroethylene of 2.88 μg/m^3 in class III. The average total indoor VOCs level was 48.67 μg/m^3, with the minimum of 39.71 μg/m^3 and maximum of 61.32 μg/m^3, while the outdoor VOCs value was 1.46 μg/m^3 (Table 4). The maximum concentration of total indoor VOCs was measured in the classroom III (VOCs = 61.32 μg/m^3). Most standards and guidelines consider 200–500 μg/m^3 VOCs as acceptable [20]. The total concentration of mixture of 5 individual VOCs was below recommended value.

The average values of formaldehyde in classrooms I, II and III, for the sampling time, were 63.74 μg/m^3, with the minimum of 42.98 μg/m^3 and maximum of 88.15 μg/m^3 (Table 4). Fig. 6 presents that the minimum measured concentration of 42.98 μg/m^3 was in class II, then the measured concentration of HCHO, in class I, was 60.08 μg/m^3 and maximum measured concentration of 88.15 μg/m^3 was in class II. The average HCHO outdoor concentration of 5.07 μg/m^3 was below guideline value for outdoor environment. The level found in school was significantly higher than the 30 μg/m^3 (0.022 ppm), limit recommended indoor value [19,31]. It is assumed that the cause of the increased concentration of HCHO is due to presence of internal sources, such as old furniture, wood shelving, old carpets and flooring.

The average indoor values of ozone were much less than the average outdoor ozone value (15.51 μg/m^3 and 217.71 μg/m^3 respectively, Table 4). The average concentration values of O_3 in classes I, II and III were 21.82 μg/m^3, 8.82 μg/m^3 and 15.90 μg/m^3 respectively, as shown in Fig. 6.

The indoor average concentration of NO_2 was 15.02 μg/m^3, with the minimum of concentration of 7.4 μg/m^3 in class I and maximum of concentration of 22.45 μg/m^3 in class III, Table 4. Fig. 6 shows that the outdoor concentration of NO_2 of 9.14 μg/m^3, for sampling period, was smaller. Higher concentration of NO_2 was detected in classroom III, as a consequence of incomplete combustion in the furnace of the boiler used for space heating of the school.

The indoor CO_2 in class III was higher than outdoor CO_2 concentration for all measuring days, as shown in Fig. 7. In the classrooms I and II, at the first measuring period, indoor concentrations of CO_2 were significantly higher than outside concentration of CO_2; while, at the second measuring period, indoor and outdoor concentrations were approximately similar.

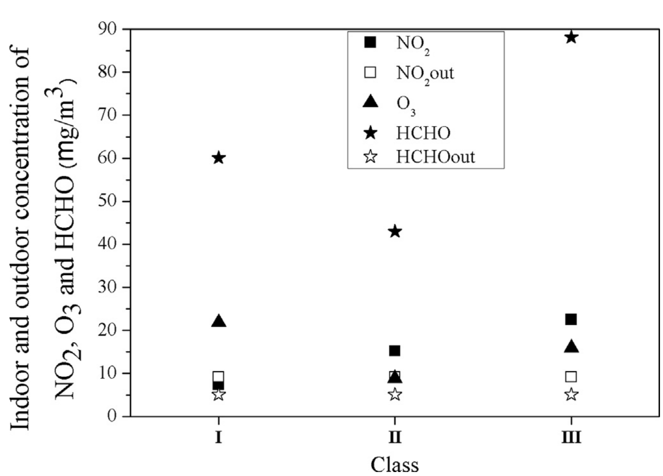

Fig. 6. Average indoor and outdoor concentration of HCHO, O_3 and NO_2 for a sampling time in classes I, II and III.

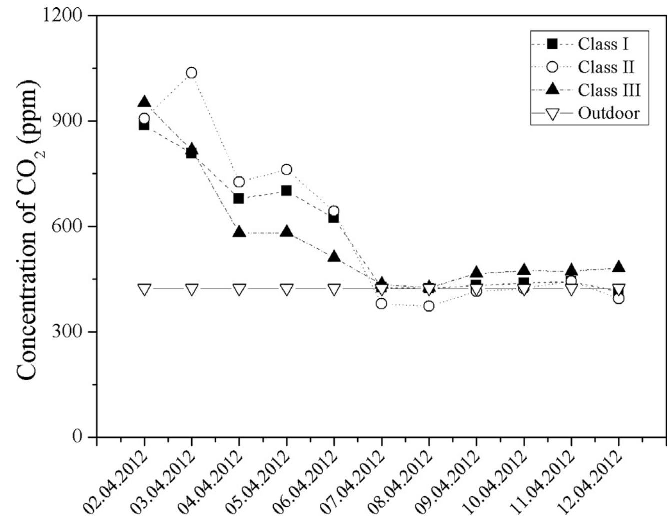

Fig. 7. Average daily level of indoor and outdoor concentration of CO_2.

The average indoor concentration of CO_2 was 575 ppm (1.11 μg/m^3) with the minimum of concentration of 562 ppm (1.09 μg/m^3) and maximum of concentration of 592 ppm (1.15 μg/m^3), Table 4. The average level of outdoor concentration of CO_2 was 424 ppm (0.82 μg/m^3). The value of 1000 ppm is a guideline value for CO_2 concentration [27]. However, it was noted that the peak of CO_2 concentration occurs in the morning hours, usually from 8 a.m. to 12:30 a.m., in classrooms (1655 ppm in class I; 1423 ppm in class II and 1453 ppm in class III). Increased concentrations of CO_2 above the recommended value can be explained by the consequence of heating only in the morning hours, hence the measurements are conducted in early April, while the windows are hardly open and the ventilation is inadequate.

6. Conclusions

This paper presents the results of research which was based on estimate of the indoor air quality with aim to point the specific air pollution in school. The most common pollutants and the ambient thermal comfort parameters, at inside and outside measuring sites, were measured and analysed. The analysis covered determination of suspended particulate matters size up to 10 μm (PM_{10}), respirable suspended particulate matter less than 2.5 μm ($PM_{2.5}$), polycyclic aromatic hydrocarbons in PM_{10} (PAH in PM_{10}), volatile organic compounds (VOCs), formaldehyde (HCHO), ozone (O_3), nitric-dioxide (NO_2) and carbon-dioxide (CO_2). The average values of outdoor concentration of PM_{10} exceed threshold limit values for outdoor air on several measuring days which were higher than indoor concentration in classes I, II, IIa and IIIa. The average outdoor concentration values of $PM_{2.5}$ exceed threshold limit values for outdoor air during all measuring days. The results showed that the concentrations of PM_{10}, $PM_{2.5}$ and PAHs in PM_{10} in class III were higher in comparison to outdoor concentration. Also, in the classroom III, the highest concentration of NO_2 was noted (three times higher than in the classroom I) as a result of poor combustion of fossil fuel (low-rank coal) [32]. It was assumed that increased indoor concentration of pollutants in school classes is a consequence of inadequate and insufficient ventilation, the incomplete combustion of coal in the furnace of the boiler, low level of eliminate of the flue gas, old carpets and flooring in the observed classrooms, and poor condition of windows. The increased concentrations of these pollutants were detected in class III because it was closest to the boiler. Also, the measurements affirm the unsatisfactory energy performance of the school building envelope [33]. The average value of formaldehyde in all classrooms was significantly higher than recommended value. It was assumed that cause of this is old furniture, wood shelving and carpets.

Performed investigation that is presented in this paper was intended to help in the making the school renovation programs. In the case herein following recommendations are presented: the reconstruction of the boiler, the replacement of coal as the primary fuel, increase boiler combustion efficiency, comprehensive school renovation program (replacing windows, furniture, and carpets), better removal of combustion products, improvement of the ventilation in the area where the boiler is placed and improvement of the natural ventilation in classrooms. A similar program of measuring and refurbishing was recommended in other schools, according to similar age, with natural ventilation system and use of coal in individual boiler for space heating.

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