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

Marina Jovanović*, Biljana Vučićević, Valentina Turanjanin, Marija Živković, Vuk Spasojević

University of Belgrade, Institute of Nuclear Sciences 'Vinča', Laboratory for Thermal Engineering and Energy, P.O. BOX 522, 11001 Belgrade, 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

* Corresponding author. Tel.: +381 11 34 08 250; fax: +381 11 24 53 670.
E-mail addresses: marinaj@vinca.rs (M. Jovanović), bee@vinca.rs (B. Vučićević), valentin@vinca.rs (V. Turanjanin), marijaz@vinca.rs (M. Živković), vukspasojevic@vinca.rs (V. Spasojević).

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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

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