Atmospheric Pollution Research xxx (2016) 1–15

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Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Original article

Indoor air quality investigation of the school environment and estimated health risks: Two-season measurements in primary schools in Kozani, Greece

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A R T I C L E I N F O

Article history:
Received 26 February 2016
Received in revised form
4 July 2016
Accepted 4 July 2016
Available online xxx

Keywords:
School buildings
Indoor air quality
Exposure
Children
Building material emissions
Ventilation

A B S T R A C T

Two primary schools and one kindergarten were selected in the city of Kozani, Greece in order to investigate the school environment, the indoor air pollutants that children are exposed to and possible health risks at school. In each school three classrooms and one outdoor position were monitored from Monday to Friday, in both non-heating (26/09/2011–14/10/2011) and heating (23/01/2012–10/02/2012) period. Temperature, relative humidity and CO_2, were continuously monitored. Formaldehyde, benzene, trichloroethylene, pinene, limonene, NO_2 and O_3 were measured with diffusive samplers. CO was monitored every day (30 min/day). Radon was measured for four weeks with short term radon detectors. $PM_{2.5}$ was gravimetrically determined while $PM_{2.5}$ and PM_{10} fractions were measured using the optical light scattering technique. Building material emission testing for VOCs was performed using the Field and Laboratory Emission Cell (FLEC). The ventilation rate for each classroom was calculated based on the CO_2 measurements.

Results indicated that indoor air concentrations of the measured pollutants were within accepted limits with indicative ranges 1.5–9.4 μg/m^3 for benzene, 2.3–28.5 μg/m^3 for formaldehyde, 4.6–43 μg/m^3 for NO_2 and 0.1–15.6 μg/m^3 for O_3. Emissions from building materials seem to have a significant contribution to the indoor air quality. Very low ventilation rates (0.1–3.7 L/s per person) were observed, indicating inadequate ventilation and possible indoor air quality problems requiring intervention measures. The estimated average lifetime cancer risks for benzene, formaldehyde and trichloroethylene were very low.

1. Introduction

Indoor air quality (IAQ) attracts the scientific interest especially when it concerns the health of vulnerable populations such as children. School environments comprise a special case of indoor environments. In 2000 the European Federation of Allergies (EFA) through the "Indoor Air Pollution in Schools" Project (Carrer et al., 2002), highlighted the need for a multidisciplinary EU program aiming to provide a healthy school environment. The multidisciplinary SINPHONIE Project (Csobod et al., 2014) covering the areas of health, environment, transport and climate change, aimed to survey schools and establish an observatory network in Europe on school indoor pollution and health.

School children spend almost 30% of their day at school, 70% of which in classrooms. Due to their higher rates of breathing, their developing lungs and immune system, children are more vulnerable to air contaminants compared to adults (American Thoracic Society, 1996; Chaudhuri and Fruchtengarten, 2005; U.S. EPA,

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2016.07.002

2012). Lung development continues through childhood and lung function grows at least through adolescence. Chemical exposure during developmental windows may produce lifelong structural and functional alterations, and some may become apparent only later in life (Miller and Marty, 2010). Therefore air quality in classrooms is of major concern (Kim et al., 2006; Madureira et al., 2015; Mi et al., 2006; Shaughnessy et al., 2006; Shendell et al., 2004; Sofuoglu et al., 2011). Both health problems and poor building maintenance (Earthman et al., 1995) increase absenteeism which can decrease children's learning performance and teachers' productivity (Celano and Geller, 1993; Moonie et al., 2008; Taras and Potts-Datema, 2005; U.S. EPA, 2012). On the other hand, adequate airing in the classrooms may reduce absences, prevent the transmission of infectious diseases (Nazaroff, 2011) and improve health and performance of both students and teachers in completing mental tasks (Haverin-Shaughnessy et al., 2012; Seppänen et al., 1999; Shaughnessy et al., 2006; Shendell et al., 2004; Sundell et al., 2011).

Investigation of the air quality in schools helps the assessment of the pollution level and the application of corrective measures if necessary. In a school study in Hong Kong (Lee and Chang, 2000), the two most important air quality problems found concerned PM_{10} and CO_2 levels. Rovelli et al. (2014) revealed a general situation of poor IAQ in seven schools and confirmed that PM represents a significant concern in school classrooms, especially for particle fractions affected by indoor resuspension phenomena. Daisey et al. (2003) in their review on IAQ, ventilation and health symptoms in schools indicated that many schools are not adequately ventilated. A French pilot monitoring survey of 160 schools and day-care centers (Michelot et al., 2013) targeted on formaldehyde (HCHO), benzene and air stuffiness (based on CO_2 measurements) found that IAQ was satisfactory only in 26% of the investigated premises. Shaughnessy et al. (2006) and Bakó-Biró et al. (2012) reported significant connection between the classroom ventilation rates and school performance of the children, while Shendell et al. (2004) found an association between the increase in CO_2 concentration and the decrease in annual average daily attendance. Mendell and Heath (2005) in their review concluded that poor Indoor Environmental Quality (IEQ) in schools is common and adversely influences the performance and attendance of pupils, primarily through health effects from indoor pollutants. Yang et al. (2009) in their IAQ investigation regarding the age of the school buildings, reported indoor sources of HCHO and suggested the use of mechanical ventilation and low-emitting furnishing.

In Belgium, Stranger et al. (2008) assessed the indoor and outdoor IAQ of primary schools in Antwerp, where they indicated different elemental composition of classroom $PM_{2.5}$ and local outdoor $PM_{2.5}$, and increased benzene concentrations for classrooms located at lower levels. A more recent study (Rivas et al., 2014) in 39 schools in Barcelona, detected high levels of $PM_{2.5}$, NO_2, equivalent black carbon (EBC), ultrafine particle (UFP) number concentration and road traffic related trace metals, in school playgrounds and indoor environment. The concentrations of indoor particle number during school hours were found mainly influenced by the concentrations of outdoor particle number in a six classroom study in Italy (Fuoco et al., 2015). The same study reports lower CO_2 levels and greater radon concentrations reduction during spring due to longer airing periods performed by the occupants. Chaloulakou and Mavroidis (2002) who measured indoor and outdoor CO concentrations at a school near the center of Athens, indicated that indoor CO concentrations were in general lower than the respective outdoor levels, presenting seasonal variation. An IAQ study regarding particulate matter in 64 schools in Munich (Fromme et al., 2007) revealed that exposure to PM in schools is high. High PM concentrations were correlated with high CO_2 concentrations and with low class level, i.e. higher PM values in primary schools than in secondary schools. Another PM study (Almeida et al., 2011) showed that inside classrooms, there are significantly higher coarse particle concentrations than the ambient levels, high levels of CO_2 (implying inadequate ventilation) and high contribution of the pupils' physical activity to the re-suspension of particles.

Despite the various IAQ studies performed at school buildings around the world, no studies have been performed including simultaneous measurement of various physical and chemical parameters, as well as, on -site measurements of building material emissions. The present study aims to provide an insight to the school environment, knowledge on the indoor air pollutants that children are exposed to and possible health risks at school, for the three primary schools in the city of Kozani, by determining a wide number of physicochemical parameters and studying their interrelations and their possible sources.

2. Materials and methods

2.1. School location and description

This study was conducted in the city of Kozani (northern Greece, 40°18′00″ N-21°47′20″ E) during two sampling campaigns. Three public primary schools, hereinafter school 1 (S1), school 2 (S2), school 3 (S3), were selected based on their location, their building structure properties, their availability and their willingness to participate to the research. Each school was studied for one school week, i.e. each campaign lasted for three weeks (one week per school). The location of each school was carefully examined regarding the influence of the surroundings; urban/rural area, green zone/heavy traffic/industry, north/south/east/west. Regarding their building structure, the selected schools were representative of the building stock of the country in terms of typology, construction techniques and age.

Fig. 1 shows the sites of the three schools. S1 is a primary school located at a residential suburban area next to a busy road and a bus stop. S2 is a kindergarten located at a mixed commercial and residential area next to a busy road. S3 is a primary school located in a residential area near the city park, with a small parking site nearby. All schools are naturally ventilated and use central district heating, called teleheating (hot water generated by the lignite power plants of the area, Fig. 1). All schools were equipped with heating radiators operating during the cold season. The first sampling campaign (September–October 2011) was carried out during the non-heating season in Kozani, when heating systems were not in use at schools, public buildings and residencies. During the second sampling campaign (January–February 2012) the heating system was in operation in all buildings (heating season in Kozani). Detailed building characteristics and exact sampling dates are given in Table 1. The abbreviations "NHP" and "HP" mentioned from now on refer to the non-heating and heating periods respectively.

The weather conditions collected by the fixed monitoring station (latitude: 40.29, longitude: 21.84, altitude: 621 m) of the Hellenic National Meteorological Service (HNMS) during the same weeks over which the two measurement campaigns were performed, are outlined in Table 2. The wind rose diagram (Fig. 2) indicates the predominant wind directions during NHP and HP.

2.2. Methodology

Indoor and outdoor measurements were performed in three schools during two sampling campaigns (during the heating and non-heating season, respectively), (Table 1). Indoor and outdoor air was measured simultaneously in three classrooms and at an

Please cite this article in press as: Kalimeri, K.K., et al., Indoor air quality investigation of the school environment and estimated health risks: Two-season measurements in primary schools in Kozani, Greece, Atmospheric Pollution Research (2016), http://dx.doi.org/10.1016/j.apr.2016.07.002