Atmospheric Pollution Research 6 (2015) 1098–1104

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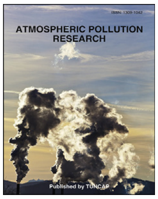
Atmospheric Pollution Research

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



Original article

Indoor air quality in urban nursery schools in Gliwice, Poland: Analysis of the case study

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ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form
30 April 2015
Accepted 12 June 2015
Available online 21 October 2015

Keywords:
Children
VOCs
PM
Bioaerosols
CO_2

ABSTRACT

Children's exposure to air pollutants is an important public health challenge. Particular attention should be paid to preschools because younger children are more vulnerable to air pollution than higher grade children and spend more time indoors. The purpose of this study was to compare the indoor air quality (IAQ) at nursery schools located in Gliwice, Poland.

We investigated the concentrations of volatile organic compounds (VOCs), particulate matter (PM) and bacterial and fungal bioaerosols, as well as carbon dioxide (CO_2) concentrations in younger and older children's classrooms during the winter season at two urban nursery schools, located within traffic and residential areas. The concentration of the investigated pollutants in indoor environments was higher than those in outdoor air. The results clearly indicate the problem of elevated concentrations of $PM_{2.5}$ and PM_{10} inside the classrooms. High levels of CO_2 exceeding 1000 ppm in relation to outdoor air also confirmed the low indoor air quality of classrooms. This is concerning in terms of the exposure effects on the health of children. The relation between IAQ in older and younger children's classrooms was also statistically significant in the case of PM and CO_2.

Improving ventilation, decreasing the occupancy per room and completing cleaning activities following occupancy periods can contribute to alleviating high CO_2 and particle levels.

1. Introduction

One of the five EU benchmarks for Education and Training (ET 2020) is that by 2020, at least 95% of children between the ages of four and starting compulsory primary education should participate in early childhood education (EU, 2011). In the context of expanding early childhood education, the EU should be active in reviewing research pertaining to the quality of care afforded to the system's youngest participants, which is linked in particular with the microenvironment of nursery schools. Comparing numerous recent studies regarding indoor air quality (IAQ) and the health of school children (Almeida et al., 2011; Sofuoglu et al., 2011; Dumała and Dudzińska, 2013; de Gennaro et al., 2013; Zwoździak et al., 2013a, 2013b; Alves et al., 2014; Demirel et al., 2014; Krugly et al., 2014; Mazaheri et al., 2014; Turunen et al., 2014), we found relatively few examples of research focussing on younger children (Yoon et al., 2011; Cyprowski et al., 2013; Gładyszewska-Fiedoruk, 2013; Branco et al., 2014; Latif et al., 2014). Researchers often encounter problems in gaining access to such institutions as nursery schools. As well as installing the necessary measuring equipment in the way to avoid disturbances during the measurement process and to limit children's curiosity.

Studies on indoor air parameters in nursery schools are interesting for three main reasons:

- children are particularly vulnerable to the harmful effects of air pollution because of immature lung defences, narrower airways, higher inhalation rates and higher metabolic rate of oxygen consumption per unit of body weight (Salvi, 2007; Santamouris et al., 2008)
- younger children spend more time in preschools than in any other indoor environments besides the home
- indoor air quality in preschools is different from primary or higher schools (Yoon et al., 2011; Branco et al., 2014).

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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.2015.06.007

Consequently, the exposure of preschool children is different from older children and need to be studied.

Most of the research that consider schoolchildren underline the negative influence of biological, chemical or particulate pollutants and thermal conditions (temperature and humidity) on the quality of indoor environments, which might influence building occupants in direct and indirect ways.

Among indoor pollutants researchers Mendell and Heath (2005) and Pegas et al. (2010) point out volatile organic compounds (VOCs), NO_2, biologicals and higher temperatures as statistically significant in decreasing the attendance of school children and adults in offices or laboratories. Branco et al. (2014) underlined the health significance of particulate matter (PM), especially finer particles (particles with an aerodynamic diameter smaller than 2.5 μm, $PM_{2.5}$ and smaller than 1 μm, PM_1). Pastuszka et al. (2000) focus on bioaerosols, which can cause a variety of health effects (illness and allergic reactions) as a result of inhaling both living and dead cells of biological aerosols.

Carbon dioxide (CO_2) levels, although not defined as an air pollutant, showed a statistically significant association to school children being absent from school. Increased levels of CO_2 led to a decrease in pupils' learning abilities of approximately 5% (Griffiths and Eftekhari, 2008). CO_2 concentration is an indicator of low ventilation rates PN-EN 13779 (2008), which increase communicable respiratory illnesses.

In addition to air pollutants emitted indoors and penetrating from outdoors, ASHRAE Standard (ASHRAE, 2013) points that some materials act as sinks for emissions and then become secondary sources of VOCs and PM as they reemit adsorbed pollutants. The sink materials include fabric partitions and other fleecy materials. The specific sorptive properties of soft materials are particularly relevant in the case of nursery schools, especially in younger children's classrooms, where except for carpets, there are many sorptive toys and additional materials such as bedcovers for the duration of an afternoon nap.

In Poland, as far as is known, there have been no studies on VOCs, PM, bioaerosols and CO_2 levels in terms of highlighting the discrepancies between IAQ in the classrooms of younger and older children attending the same nursery school. To reduce this gap in the research, the major objectives of the current study are: (a) to evaluate indoor and outdoor concentrations of selected VOCs, different fractions of PM and bioaerosols, as well as CO_2 concentrations in selected urban nursery schools; (b) to analyse the influence of activities of younger and older children on air pollutant concentrations.

2. Materials and methods

Gliwice is a typical city in the industrial region of Upper Silesia (4.5 million people in the region). The city is home to 36 nursery schools, 72.2% of which are public. The study was carried out on two nursery schools located in residential and traffic area during the winter season of 2013/2014.

2.1. Sampling sites and buildings

The first building, engraved with SU-1 (Sikornik district Urban area 1), is located in the residential area on the southwest of the city centre, next to an air quality station. The second is located in an urban traffic area, engraved with PU-2 (Pszczyńska street Urban area 2). The front facade of the PU-2 building is located/sited 50 m from the street with heavy traffic reaching 2400–2800 vehicles per hour (Kozielska, 2013). Between the building and the street there is parking space available, which enables the flow of air from the traffic in the street.

Both nursery schools are located in detached buildings with two floors they were constructed in the 1970s (Fig. S1). This kind of location is typical for many nursery schools in Poland. The buildings underwent the process of thermal efficiency improvement, which was completed in 2008 (SU-1) and 2007 (PU-2), however the natural ventilation systems were left unchanged. Consequently, the indoor air quality is mostly ensured by means of stack ventilation and airing through open and unsealed windows. The buildings have kitchens, which use gas stoves, located on the first (SU-1) or ground floor (PU-2).

Children attending the nursery schools range from three- to six-years-old, divided by age into four (SU-1) and six different classrooms (PU-2). Daytime schedules in both nursery schools are generally similar. An essential difference between the groups is that the younger children have an afternoon nap from 12:00 to 14:00. In the SU-1 nursery school, children dressed in pyjamas sleep, while in the PU-2 during the resting time children usually watch TV. For the duration of an afternoon nap, one or two windows are usually unsealed.

Both nursery schools have a spacious outdoor playground; however, these were rarely used during the winter measurement campaign.

In order to evaluate discrepancies between IAQ in the classrooms of five–six years old (I) and three years old children (II), measurements were performed in each classroom simultaneously using outdoor measurements. The classrooms were of the same volume: 180 m^3 in SU-1 and 210 m^3 in PU-2. In the SU-1 nursery school, the classroom for younger children (II) is situated above the classroom for older children (I). In the PU-2 nursery school, the classrooms are located in the opposite manner, with the younger children's classroom (II) on the first floor.

2.2. Sampling and analytical methods

The indoor and outdoor concentrations of selected VOCs, different fractions of PM (indoor: PM_1, $PM_{2.5}$, PM_{10} and TSP; outdoor: $PM_{2.5}$ and PM_{10}) and bioaerosols, as well as CO_2 concentrations, were measured in the classrooms of younger and older children in the selected buildings. The measurements were carried out from 9 to 20 December 2013 (SU-1) and from 7 to 17 January 2014 (PU-2). The sampling position in classrooms was set at the height of an average child's head (i.e., about 0.8–1.0 m above the floor) and away from the door, thus avoiding disturbances resulting from air currents (Fig. S2). Table S1 presents detailed characteristic of sampling methods of each compound.

Sixteen VOCs (were actively sampled according to the US EPA TO-17 method (van de Wiel and Molhave, 1993; SKC, 2012). Prior to sampling, tube samplers were conditioned at a temperature of 280 °C.

The samples were analysed using a thermal desorber TurboMatrix 100 connected to a gas chromatograph Clarus 500 (PerkinElmer, Inc., Waltham, MA, USA) with a flame ionization detector (FID). Each sample tube was thermally desorbed for 3 min at 280 °C, focused on a cold trap at −5 °C and desorbed at a maximum temperature of 280 °C for GC injection. An RTX-5 (Restek Corp., Bellefonte, PA, USA) capillary column 30 m × 0.32 mm × 3.00 μm, was applied for separating sample components. Flow of the carrier gas, i.e., helium was equal to 2 cm^3/min. The temperature of the detector was 260 °C. The initial temperature of the GC oven was 50 °C, which was maintained for 2 min, then increased by 8 °C/min until it reached 220 °C. The total time of the analysis was 23 min. The detector was provided with hydrogen (45 cm^3/min) and air (450 cm^3/min).

The quantitative analysis was completed based on the calibration curves prepared for VOCs samples The linear correlation