Investigation of air pollutants in rural nursery school – a case study

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Abstract. Children's exposure to air pollutants is an important public health challenge. Indoor air quality (IAQ) in nursery school is believed to be different from elementary school. Moreover, younger children are more vulnerable to air pollution than higher grade children because they spend more time indoors, and their immune systems and bodies are less mature. The purpose of this study was to evaluate the indoor air quality (IAQ) at naturally ventilated rural nursery schools located in Upper Silesia, Poland. We investigated the concentrations of volatile organic compounds (VOCs), particulate matter (PM), bacterial and fungal bioaerosols, as well as carbon dioxide (CO_2) concentrations in younger and older children's classrooms during the winter and spring seasons. The concentration of the investigated pollutants in indoor environments was higher than those in outdoor air. The results indicate the problem of elevated concentrations of $PM_{2.5}$ and PM_{10} inside the examined classrooms, as well as that of high levels of CO_2 exceeding 1,000 ppm in relation to outdoor air. The characteristics of PM and CO_2 levels were significantly different, both in terms of classroom occupation (younger or older children) and of season (winter or spring).

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 [1]. 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. There, they are exposed to unknown levels of indoor pollutants. Children are particularly vulnerable to air pollutants, because they spend more time indoors than active, healthy adults, moreover they breath higher volumes of air relative to their body weights and their tissue and organs are growing [2].

Many research that consider children underline the relation between IAQ (indoor air quality) and health effects [3].

Among indoor pollutants researchers point out volatile organic compounds (VOCs), 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), bioaerosols as well as

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temperature and relative humidity to provide thermal comfort [4]. Carbon dioxide (CO_2), although not defined as an air pollutant, is an indicator of low ventilation rates [5]. Increased levels of CO_2 led to a decrease in pupils' learning abilities of approximately 5% and communicate with respiratory illnesses [6].

In addition to air pollutants emitted indoors and penetrating from outdoors, ASHRAE Standard [7] 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 [8].

The aim of the present study is to characterize IAQ in rural nursery school located near Gliwice, in southern Poland. The study carried out simultaneous measurements of:

- VOCs (particularly benzene, toluene, ethylbenzene and xylenes - BTEX),
- PM (indoor: PM_1, $PM_{2.5}$, PM_{10} and total - TSP; outdoor: $PM_{2.5}$ and PM_{10}),
- bioaerosols (culturable bacterial and fungal aerosols),
- CO_2 concentration (outdoors and indoor in two classrooms) with physical parameters (temperature and relative humidity)

in naturally ventilated classrooms occupied by younger and older children classrooms during winter and spring seasons. The emphasis of this article will be on the difference between winter and spring seasons as well as younger and older children classrooms.

2 Materials and methods

The study was carried out rural nursery school situated about 10 km north of the city of Gliwice (Figure 1), which is located in the west district of the industrial region of Upper Silesia, Poland. The major activities influencing the ambient air quality of this site are agricultural activities (during non-heating periods) and burning of biomass and fossil fuels for domestic needs (during heating periods).

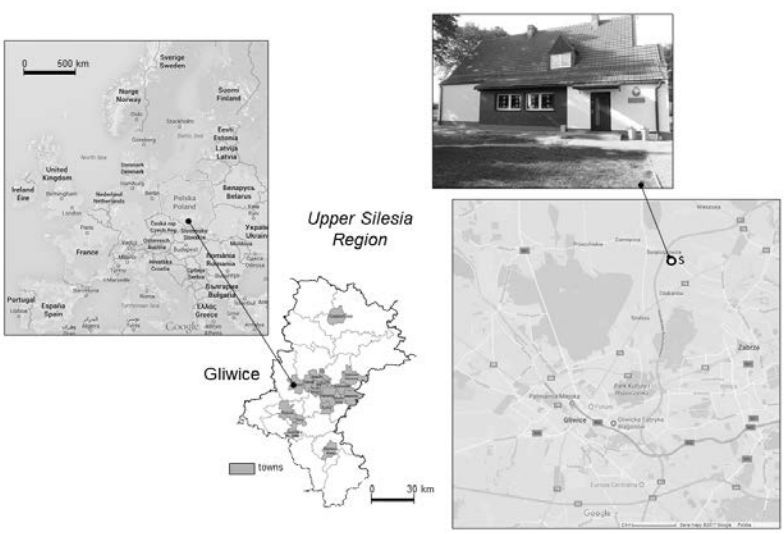

Fig. 1. Location of the investigated nursery school (Map data: 2017© Google, ORION-ME).

The building is located 50 m from the A1 highway. It is separated from the highway by highway screens. It is a detached building (Figure 1) that underwent thermal efficiency

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improvement processes, completed in the summer of 2013. During the thermal insulation process, natural ventilation using the buildings' air duct systems was left unchanged. Consequently, the IAQ is primarily ensured by means of stack ventilation and airing through open and unsealed windows. The measurements were conducted in both the classrooms of older (five- to six-year-old, I) and younger (three- to four-year-old, II) children. Table 1 summarizes the specification of the two sampling sites, including basic IAQ parameters and the occupancy of each classroom during the winter and spring seasons.

Table 1. Summary of the occupancy and IAQ parameter characteristics for each studied classroom, as well as for the outdoor air.

Parameters	**Classroom of Children**	
	Older (I)	**Younger (II)**
Children's Age, Years	5–6	3–4
Floor	Ground floor	Ground floor
Volume, m^3	169.7	118.6
Period of Occupation	6:30–16:00	8:00–12:30
Number of children in group	24	21
Median occupancy of children - winter	16	14
Median occupancy of children - spring	18	14
Indoor temperature, °C - winter	27.8±3.6	26.2±2.7
Indoor temperature, °C - spring	23.6±2.7	24.2±1.9
Indoor relative humidity (RH), % - winter	24.5±6.7	26.0±6.6
Indoor relative humidity (RH), % - spring	46.5±5.6	42.5±4.8
Indoor CO_2 concentration, ppm - winter	1122.7±571.0	1265.4±652.6
Indoor CO_2 concentration, ppm - spring	1374.5±825.5	1090.8±630.8
Outdoor parameters, mean ± SD		
Season	winter	spring
Temperature, °C	13.4±9.2	24.4±11.6
Relative humidity (RH), %	47.0±28.8	54.3±34.0
CO_2 concentration, ppm	374.0±17.1	353.5±16.2

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 building. The sampling position in classrooms was set at the height of an average child's head (i.e., about 0.8 to 1.0 m above the floor) and away from the door, thus avoiding disturbances resulting from air currents.

Sixteen VOCs (benzene, toluene, ethylbenzene, m-xylene, p-xylene, o-xylene, styrene, isopropylbenzene, n-propylbenzene, 1,3,5-trimethylbenzene, tert-butylbenzene, 1,2,4-trimethylbenzene, sec-butylbenzene, 4-isopropyltoluene, n-butylbenzene and naphthalene) were actively sampled using Perkin Elmer stainless steel tube samplers containing Tenax GR according to the US EPA TO-17 method [9]. Indoor and outdoor fractions of PM were actively sampled and determined following the reference procedure PN-EN 12341 standard [10]. Bioaerosols, defined as bacterial and fungal colony-forming units per cubic metre of air (CFU/m^3), were collected using a six-stage Andersen cascade impactor (with aerodynamic cut-size diameters of 7.0, 4.7, 3.3, 2.1, 1.1 and 0.65 μm). Continuous measurements of CO_2 concentrations both inside classrooms and outside the building were performed using automatic portable monitors (model 77535, Az Instruments). A detail procedures concerning determination of selected air pollutants has been presented in our previous articles [8,11–13].

Statistical analyses were performed using the statistical package Statistica 13 (StatSoft). The non-parametric Mann–Whitney *U* and Wilcoxon matched-pairs tests for VOCs, PM fractions, and bioaerosols were performed in order to test whether outdoor and indoor concentrations differed significantly, as well as whether the concentrations of compounds in older (I) and younger (II) children's classrooms differed significantly from one another. While for CO_2 levels the parametric t-test was used. A statistical significance level of α = 0.05 was used throughout the study.

3 Results and discussion

3.1 Volatile organic compounds

The average concentrations of 16 determined VOCs outdoors 2.39 and 1.14 μg/m^3 during winter and spring, respectively, as well as average ΣVOC_{16} indoors was 10.6±4.9 μg/m^3 point to low concentrations of VOCs in the selected site. Analogically to outdoor concentration levels, indoors higher concentrations were observed in winter 16.1 μg/m^3 (I) and 14.3 μg/m^3 (II), with correspondence to 1.1 μg/m^3 (I) and 1.5 μg/m^3 (II) in spring. Figure 2 to presents the average indoor and outdoor concentrations of BTEX in older (I) and younger (II) children's classrooms as well as outside the building.

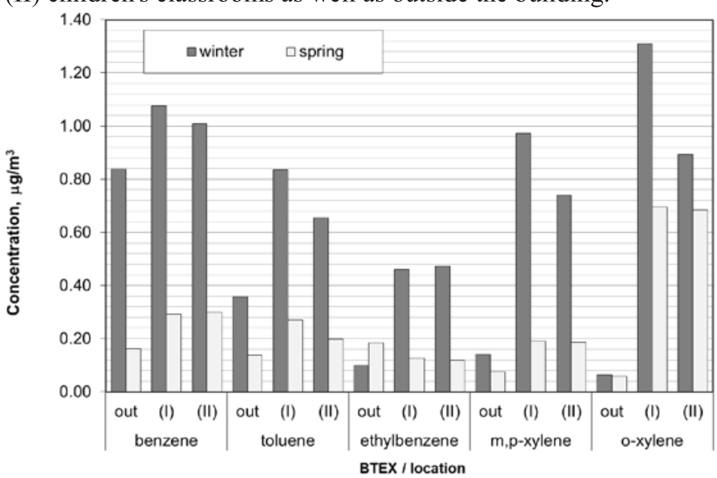

Fig. 2. The average concentrations of BTEX (μg/m^3) during winter and spring campaigns

The concentrations of BTEX found inside the classrooms were higher than outdoor concentrations. The levels of many VOCs are typically higher inside the residences compared to outdoors because indoor VOC source emissions are stronger than the infiltration of outdoor air [14]. As shown in Figure 2, during winter season the concentrations of xylenes were significantly different ($p > 0.05$) between older (I) and younger (II) children classrooms. During the spring season indoor levels of BTEX in both classrooms are on the similar levels except toluene ($p < 0.05$).

Additionally toluene and xylenes are well correlated R^2>0.7, which point to common emission sources. Toluene and xylenes are strong compounds that are used in many household and industrial products. In the nursery schools children may breathe air contaminated with toluene and xylenes by use of glues, paints, rubbers and plastic-modelling cements. The other source of toluene and xylenes might be cleaning solvents used by nursery staff. Along with other solvents, common sources of ethylbenzene and o-xylene might be paints, varnishes and to a lesser extent plastics, and synthetic fibre products e.g. in the coating of fabrics and papers [15].

3.2. Particulate matter

Polish legislation [16] specifies a 24-hour mean concentration of PM_{10} in ambient air, which is 50 μg/m^3. For $PM_{2.5}$, there is no corresponding short term (24-hour) limit, but there is an annual level of 25 μg/m^3. The World Health Organization (WHO) is more strict in this regard; for $PM_{2.5}$, it recommends a 24-hour average standard of 25 μg/m^3 [17] and recommends applying to indoor spaces the same guidelines as for ambient air.
Simultaneously with indoor samples, outdoor samples of $PM_{2.5}$ and PM_{10} were collected on playground areas. The average concentrations of $PM_{2.5}$ and PM_{10} were 19.37 μg/m^3 and 22.73 μg/m^3 during spring, and did not exceeded WHO guidelines. While the concentrations during winter were 49.40 μg/m^3 and 59.00 μg/m^3, and exceeded WHO guidelines at 98% and 18% for $PM_{2.5}$ and PM_{10}, respectively.
The concentrations were significantly different between seasons as well as between older (I) and younger (II) children classrooms (Wilcoxon test, $p<0.05$). PM concentrations were higher in older children's classrooms (Table 2). The TSP, PM_{10} and $PM_{2.5}$ levels were significantly higher in older children classrooms ($p < 0.05$), while the PM_1 levels were higher but only in winter. Other research reported an analogous relationship between the classrooms of younger and older children [18], and indicated a potential reason for this being the cumulative effect of three major conditions: high occupancy, poor ventilation and the intensive activities of children resulting in the PM resuspension phenomenon [19].

Table 2. Average levels of PM fractions (μg/m^3) measured during occupancy periods inside the classrooms of younger and older children, as well as indoor/outdoor ratios.

PM fraction	Winter				Spring			
	(I)	(II)	Indoor/Outdoor $(I/O)_I$	$(I/O)_{II}$	(I)	(II)	Indoor/Outdoor $(I/O)_I$	$(I/O)_{II}$
PM_1	102.11	49.04	—		45.62	49.04	—	
$PM_{2.5}$	125.69	67.65	3.30	1.11	69.31	67.65	4.78	3.85
PM_{10}	166.12	81.49	3.79	1.10	112.26	81.49	6.85	4.10
TSP	184.24	91.19	—		131.38	91.19	—	

The concentrations of $PM_{2.5}$ (67.65 to 125.69 μg/m^3) and PM_{10} (81.49 to 166.12 μg/m^3) in all classrooms exceeded WHO guidelines, indicating the low quality of air in all classrooms (Table 2).

The average outdoor concentrations of $PM_{2.5}$ and PM_{10} were typical for the Upper Silesia region [20–23]. Indoor mean concentrations of samples collected in Portuguese preschools were found to be at a similar level, e.g., PM_1, $PM_{2.5}$, PM_{10} and TSP were 33.08, 34.69, 50.94 and 85.81 μg/m^3, respectively [4].

The I/O ratios were higher for larger fractions of PM_{10}. The larger the particles are in optical diameter, the heavier they are and the more easily they are able to be deposited on floors and furnishing. Consequently, the influence of re-suspension on indoor particle concentrations increases with particle size. To understand the effect of size distribution on the measured PM concentrations, three different PM size ratios were used to characterize indoor air: $PM_1/PM_{2.5}$, $PM_{2.5}/PM_{10}$ and PM_{10}/TSP. The ratios calculated for each classroom were 0.72, 0.75 and 0.88 for $PM_1/PM_{2.5}$, $PM_{2.5}/PM_{10}$ and PM_{10}/TSP, respectively. All these ratios are high, showing high contribution of small particles.

3.3 Bioaerosols

Table 3 presents the average concentrations of bacterial and fungal aerosols collected in the indoor and outdoor air of rural nursery schools during the analysed winter and spring seasons. Bacteria levels (751-2588 CFU/m^3) were higher than fungi levels (156-1549

CFU/m^3). The total concentrations of bacterial aerosols obtained in indoor air during the spring season were of a comparable level to those of the previous study conducted in urban nursery schools, which found levels of between 2545 and 2890 CFU/m^3. However, the concentrations recorded inside the urban classrooms during the winter season were in some cases almost five times higher [12] than the results obtained in the rural nursery school. Other studies [24] concerning IAQ in two nursery schools in Bydgoszcz, conducted between April and February 2014, reported higher average concentrations of bacteria in the indoor air (3697 CFU/m^3, range: 1520-7780 CFU/m^3) and lower average concentrations in the outdoor air (137 CFU/m^3, range: 100-180 CFU/m^3). Research performed in Ankara, Turkey, underlined that, among indoor urban environments, the highest concentrations of total bacteria aerosols were observed in kindergartens, at 649 and 1462 CFU/m^3 in the winter and summer seasons, respectively [25].

Table 3. Average concentrations of total bacterial and fungal colony-forming units per cubic metre in winter and spring season, as well as indoor/outdoor ratios.

Season		Winter			Spring		
Aerosol	**Location**	**Average concentration**	**SD**	**I/O ratio**	**Average concentration**	**SD**	**I/O ratio**
Bacterial aerosol, CFU/m^3	OUT	751	223.4	-	1428	138.7	-
	(I)	1990	301.9	2.65	2588	85.8	1.81
	(II)	1596	288.8	2.12	2223	291	1.56
Fungal aerosol, CFU/m^3	OUT	156	28.6	-	1549	222.4	-
	(I)	172	34.7	1.1	670	93.7	0.43
	(II)	241	21.5	1.55	707	119.5	0.46

The calculated average I/O ratios of bacterial and fungal aerosol levels according to groups of children for both winter and spring seasons, representing parallel indoor and outdoor samples collected for each sampling day, are given in Table 3. As can be seen from Table 3, the results indicate between two and four times higher indoor concentrations of bacterial aerosols than outdoor samples. The average I/O ratio calculated for all indoor and outdoor bacteria concentrations for the winter season was >1 so it can be concluded that the major sources of these bioaerosols are likely internal, such as building occupants (in this case children and their activities) as well as building materials that host microbiological growth (especially carpets).

According to Mann–Whitney U test results, a non-significant relationship was found between sample types (i.e., indoor (I) and (II) as well as outdoor bacteria levels) measured in both seasons ($p>0.05$).

3.4 Carbon dioxide

Based on the general guidelines concerning the quality of air inside non-residential buildings [5], the increase in CO_2 concentrations in relation to CO_2 concentration in outdoor air (ΔCO_2) was measured during the children's occupation of both classrooms of each of the studied building. Figure 3 depicts the classification of IAQ in each nursery school building during the children's occupation during compulsory care/teaching hours (8:00–13:00). The indoor concentrations of CO_2 revealed inadequate classroom air exchange rates. Most worryingly, during compulsory care/teaching hours, the air in the classrooms was often of low quality (IDA4). The highest contribution of IDA4 (60.0% of compulsory care/teaching time) prevailed in the younger children's classroom (II).

Our research confirmed the enumerated conditions, moreover, our results point out differences between older (I) and younger (II) children's classrooms, which can become more significant if we link inadequate ventilation with the various patterns of children's activities.

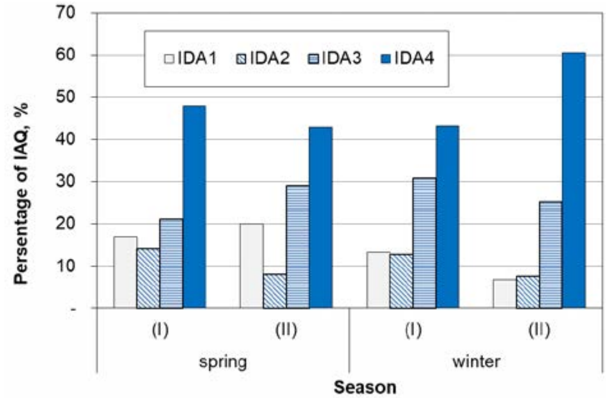

Fig. 3. Classification of IAQ (IDA) in nursery school building according to growth of CO_2 concentration (ΔCO_2).

4 Conclusions

Based on the results from this study, we draw some general conclusions here. The mean values of indoor VOC, PM, bacterial and fungal aerosol samples, as well as CO_2 concentrations, were higher than in outdoor samples. The conclusion can therefore be drawn that indoor sources are the main contributors of IAQ in nursery schools. The results clearly indicate the problem of high $PM_{2.5}$ and PM_{10} concentrations inside classrooms, exceeding the WHO short-term guidance values. Frequently monitored high levels of CO_2 exceeding 1000 ppm in relation to outdoor air (IDA4) also confirmed low indoor air quality inside classrooms, which is concerning in terms of the potential exposure effects on children's health.

The relationship between IAQ in older and younger children's classrooms was the most significant in PM (PM_1, $PM_{2.5}$, PM_{10} and TSP) and CO_2 concentrations. Compared to younger children, older children are more physically active, thus increasing PM re-suspension. The highest CO_2 concentration was observed in the classroom of younger children, who slept during the afternoon. In addition to the highest contribution of low IAQ – during 60% of teaching hours – the role of the afternoon nap seems significant.

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