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Research article

Assessment of the BTEX concentrations and health risk in urban nursery schools in Gliwice, Poland

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Abstract: 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 compare the concentrations of the monoaromatic volatile benzene, toluene, ethylbenzene m,p-xylene and o-xylene (BTEX) in urban nursery schools located in Gliwice, Poland. The nursery schools were chosen to include areas with different urbanization and traffic density characteristics in order to gather a more diverse picture of exposure risks in the various regions of the city. BTEX were sampled during winter and spring seasons in older and younger children classrooms. The samples were thermally desorbed (TD) and then analyzed with use of gas chromatography (GC). In addition, outdoor measurements were carried out in the playground at each nursery school. BTEX quantification, indoor/outdoor concentration, and correlation coefficients were used to identify pollutant sources. Elevated levels of o-xylene and ethylbenzene were found in all monitored classrooms during the winter season. Outdoor concentrations were lower than indoors for each classroom. Indicators based on health risk assessment for chronic health effects associated with carcinogenic benzene or non-carcinogenic BTEX were proposed to rank sites according to their hazard level.

Keywords: children; indoor environment; risk assessment; VOC; BTEX

1. Introduction

People spend most of their time indoors. There, they are exposed to unknown levels of indoor pollutants. The exposure becomes increasingly important in the case of elder people, children and sick people, because they spend more time indoors than active, healthy adults [1,2]. Particularly susceptible to air pollutants are preschool children, because they breath higher volumes of air relative to their body weights and their tissue and organs are growing [3,4].

Many research performed in residential apartments, schools and public buildings point to relation between the concentration of indoor air pollutants and health effects of occupants [5-7].

Hazardous indoor agents include respiratory particulates, bioaerosols, toxic chemicals such as lead, asbestos, and volatile organic compounds (VOCs) e.g. aldehydes, ketones, hydrocarbons (among them benzene, ethylbenzene, toluene, xylenes). The sources of emission of these pollutants can be traced back to a variety of causes such as the use of high emitting materials for building construction and furnishing, such as carpeting, flexible flooring, paint, plastics and finishing's equipment, as well as indoor activities related to these materials, the type of heating, ventilation and air conditioning, as well as cleaning products that release chemicals into the air [7,8]. The research concerning sorption of VOCs on the surface of buildings materials [9,10] points that some materials act as sinks for pollutants and then become secondary sources of VOCs and PM as they start to reemit adsorbed pollutants. The sink materials include fabric partitions and other fleecy materials. The specific sorptive properties of soft materials is especially 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.

According to the International Agency for Research on Cancer (IARC), benzene is classified as carcinogenic to humans (Group 1), ethylbenzene is classified as possibly carcinogenic to humans (Group 2B), while toluene and xylenes are not classifiable (Group 3) [11]. Therefore, there is an international recognition of the potential health risks associated with exposure to BTEX and of the need for action to assess the exposures in the general population and to minimise these risks.

The issue of IAQ in preschool have been of particular public concern, for the following reasons:

- nursery schools, relative to other kinds of buildings, are seen as particularly likely to have environmental deficiencies because chronic shortages of funding contribute to the inadequate operation and maintenance of facilities [12],
- younger children were especially 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 [4,13],
- 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 [14,15].

Consequently, the exposure of preschool children is different from older children and adverse environmental effects could have immediate and lifelong consequences for the children and society.

In Poland, as far as is known, there have been no studies on VOCs levels determined in indoor environments occupied by children. And no studies highlighting the seasonal discrepancies between BTEX levels in nursery schools. The previous research of authors [16-18] regarded only to the winter season. To reduce this gap in the research, the major objectives of the current study are: (a) to determine winter and spring concentrations of BTEX sampled inside and outside selected urban nursery schools;

(b) to analyse exposure of older (five-six years old children) and younger (three years old children) attending the same nursery school; (c) to estimate the health risk posed by the BTEX.

2. Materials and Method

The site is located in Gliwice, 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 two seasons: winter (from 9th December 2013 to 17th January 2014) and spring (from 24th March to 17th April 2014).

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). Localization of sampling sites has been presented in supporting material (Figure S1). The front of the PU-2 building is located 50 m from the street with heavy traffic reaching 2400–2800 vehicles per hour [19]. 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. The buildings underwent the process of thermal efficiency improvement, which was completed in 2008 (SU-1) and 2007 (PU-2). The process included thermal insulation of the exterior walls and the installation of airtight windows. Inside the buildings, the heating system modernization included new radiators, pipes and in the PU-2 building the replacement of a low-class heat centre. During the thermal insulation process, the natural ventilation using the air duct systems of the buildings were left unchanged. Consequently, the indoor air quality is mostly ensured by means of stack ventilation and airing through open and unsealed windows.

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. Breakfast occurs at about 9:00, lunch at 12 o'clock and at 14:00, dessert. The classrooms are usually subjected to airing for a few minutes, with the children leaving the classrooms for toilet activities prior to and after meals. 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 undress, put on pyjamas and during the resting period, most sleep on folding beds covered with their own bedcovers. In the PU-2 nursery school, younger children rest on sleeping mats covered by nursery school blankets. During the resting time, they are usually watching fairy tale stories on television. For the duration of an afternoon nap, one or two windows are usually unsealed [16,20]. The study was conducted only in younger (3 years olds) and older (5–6 year olds) children classrooms due to the after-dinner relaxation or classes, respectively. The group of 4-year-olds was deliberately excluded because their after-dinner activity is less regular than in other groups. After dinner they have a rest or take part in physical activities, depending on their involvement and well-being.

Daily cleaning activities observed by research team are also similar in both nursery schools. Cleaning inside the classrooms occurs in the morning or at the end of the afternoon, when children are not in the classrooms, while daily cleaning in corridors and common spaces is conducted during children occupying the classrooms. Both nursery schools have a spacious outdoor playground; however, these were rarely used during the winter measurement campaign.

To evaluate discrepancies between IAQ in the classrooms of older (I) and younger (II) children, measurements were performed in each classroom simultaneously using outdoor measurements. During the sampling periods, indoor and outdoor temperature as well as relative humidity (RH), were monitored using automatic portable monitors (model 77535, Az Instruments International Ltd.). The monitors displayed and recorded measurements in real time. Each monitor was connected to a PC with RS232 software installed allowing logged data to be downloaded for analysis. The selected sampling interval was 60 s. Furthermore, every day of the school year the staff filled in the observation cards. The observations included the children's performance, behaviour (sleepy or too active) and heath condition (allergies, diseases especially airway infections). The average nursery school attendance was 72 and 84% of younger and older children, respectively.

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.

The indoor and outdoor concentrations of selected VOCs were measured in the classrooms of younger and older children in the selected buildings. The samples were actively collected using Perkin Elmer stainless steel tube samplers containing Tenax GR at a flow rate of 6 dm^3/h (air sampling pump, model 224-PCMTX8–SKC), 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.

A total of 48 sorbent sample tubes were analysed according to the US EPA TO-17 method [21] by a thermal desorber (TurboMatrix 100, Perkin Elmer) connected to a gas chromatograph (Clarus 500, Perkin Elmer) with a ionization detector (FID). Operating conditions for the thermal desorption, quality assurance and quality control (QA-QC) measures implemented in the sampling and analysis procedures as well as blanks were presented in the previous studies [16-18].

Data were analysed using the statistical package Statistica 10 (StatSoft). Outdoor and indoor (older and younger children classrooms) concentrations were characterised using descriptive analysis (i.e. arithmetic means, standard deviations, maxima, and minima). Measures of the association between outdoor, older (I) and younger (II) children classrooms were characterised with a cross-sectional regression of the different classroom concentrations with outdoor exposure. The nonparametric U Mann-Whitney test and Wilcoxon signed ranks test was used to determine whether there were significant differences in BTEX levels between nursery schools and between indoor, outdoor, and winter/spring (W/S) exposure, respectively. The relationships between indoor and outdoor exposure were characterized by the Pearson correlation coefficient. Only variables for p-values less than 0.05 are accepted as statistically significant.

3. Results

3.1. BTEX concentrations

The overall BTEX mean and range of concentrations determined in the samples collected outdoors on the playgrounds and indoors in older and younger children classrooms are reported in Table 1.

Table 1. Inside and outside classroom BTEX levels (μg/m³) in two nursery schools in Gliwice, Poland 2013–2014.

	Benzene	Toluene	Ethylbenzenee	m,p-Xylene	o-Xylene
Outdoor *(N = 16)*	1.24 ± 0.74 (n.d. to 2.16)	0.78 ± 0.60 (0.29–2.66)	0.22 ± 0.16 (n.d. to 0.69)	0.32 ± 0.21 (0.13–0.95)	0.14 ± 0.18 (0.03–0.61)
Indoor older children (I) *(N = 16)*	1.37 ± 1.06 (0.44–4.21)	1.19 ± 0.95 (0.34–2.87)	2.11 ± 4.26 (0.13–13.37)	0.72 ± 0.66 (0.17–2.19)	3.31 ± 7.49 (0.34–23.05)
Indoor younger children (II) *(N = 16)*	1.67 ± 1.25 (0.39–4.83)	1.63 ± 1.29 (0.32–3.94)	1.83 ± 3.23 (0.17–10.19)	0.87 ± 0.71 (0.16–2.30)	2.82 ± 5.99 (0.24–18.84)

Average concentration ± SD, range (min-max)

The concentrations of BTEX ranged from n.d. to 23.05 μg/m³. Outdoors the highest episode of 2.66 μg/m³ reviled toluene, while inside the classrooms o-xylene presented the maximum concentration (23.05 μg/m³). The average level of benzene found in the present study was 1.24 μg/m³, with the highest concentration reaching 2.16 μg/m³, in the area outside PU-2 building, so the concentration of benzene did not exceed the annual ambient air quality standard of 5 μg/m³ [22]. The mean concentrations measured during winter and spring campaigns (Figure 1) revealed significant differences: outdoors for benzene ($p = 0.03$) and o-xylene ($p = 0{,}04$) and indoors in both classrooms for benzene ($p< 0.003$; $p_I = 0.0018$, $p_{II} = 0.0023$), toluene ($p < 0.005$; $p_I = 0.0006$, $p_{II} = 0.0043$) and m,p-xylene ($p < 0.03$; $p_I = 0.0019$, $p_{II} = 0.022$). The detailed concentration levels of BTEX in outdoor air as well as in older (I) and younger (II) children classrooms are presented as a season-nursery school matrix in supplementary material (Figure S2). The localization of nursery schools and even a small difference between younger (I) and older (II) children classrooms (i.e., flooring materials, variety of toys, the activities of children, localization of kitchen and cleaning practices) may result in different indoor and outdoor concentrations of BTEX. Following the close location of the road with heavy traffic authors expected higher concentrations of BTEX in the environment of PU-2 nursery school. However, the outdoor air composition was not statistically different between both localizations ($p > 0.05$). As mentioned above, in the outdoor air the highest concentration had benzene and toluene. However, in both localizations, the toluene/benzene ratio was far from 2.0, which specifies the influence of sources other than nearby traffic [23,24]. This may indicate that the influence of traffic emissions is being masked by other emissions e.g. from domestic coal combustion especially during cold seasons, when heating occurs [16]. This phenomenon was also observed in studies on the surface layer of respirable particles ($PM_{2.5}$) collected in the Upper Silesia region [25].

In general, the concentrations of BTEX found inside the classrooms were similar at older (I) and younger (II) children classrooms and 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 [26]. In our study a similar indoor and outdoor relationship was observed during winter season, while during spring the role of infiltration seems significant. As shown in Figure 1, indoor levels of BTEX during winter are significantly higher than outdoor levels ($p < 0.05$), except benzene ($p > 0.05$), while they are not significantly different from indoor levels during the spring season ($p > 0.05$), except o-xylene.

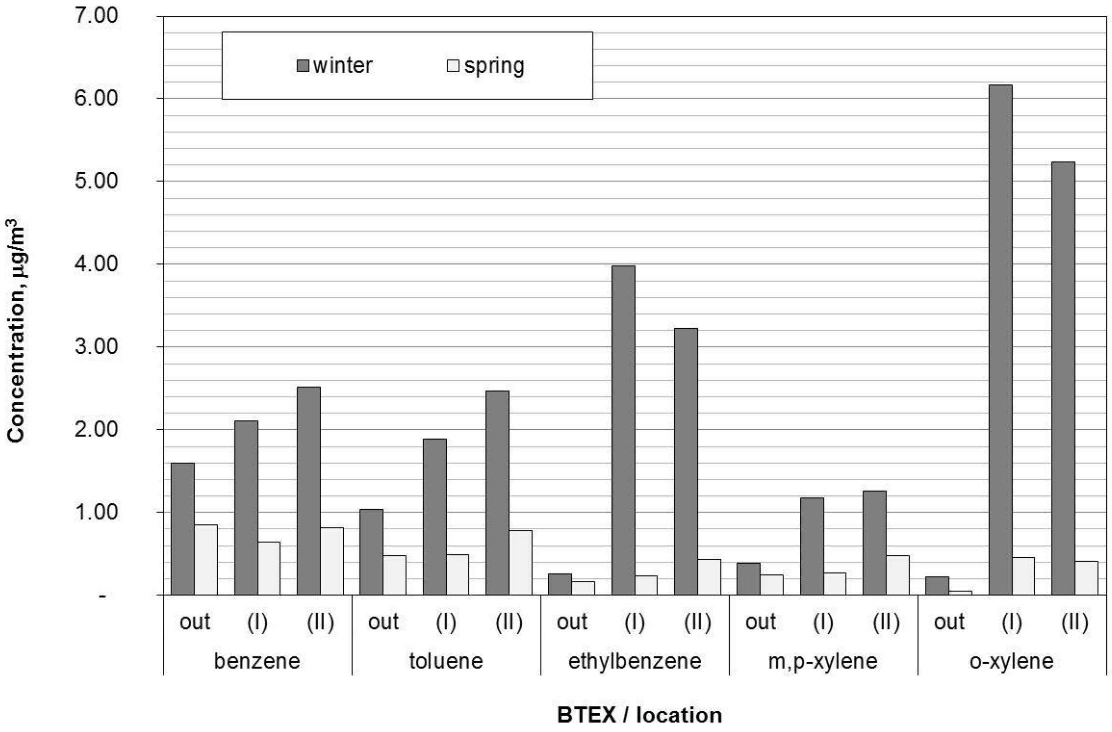

Figure 1. The average concentrations of BTEX (µg/m^3) during winter and spring campaigns. out: outdoor; (I): indoor, older children; (II): indoor, younger children.

The concentrations of measured BTEX in the present study were compared to studies carried out in the north of Poland [24], Turkey [23], Belgium [27], and as well as with the results from the UK [28]. The following outdoor levels of BTEX compounds were found in literature. For example, in 2012, the monthly (December and January) time-weighted average concentrations for benzene, toluene, ethylbenzene and xylenes (BTEX) in Gdansk (notrh of Poland) were as follows: 0.8–1.8, 0.8–1.6, 0.2–0.4 and 0.7–1.6 µg/m^3 [24]. In Turkey, the similar outdoor levels were reported for benzene (0.34–3.00 µg/m^3), ethylbenzene (0.0025–0.95 µg/m^3), m,p-xylene (0.12–1.37 µg/m^3) and o-xylene (0.02–1.19 µg/m^3), while higher concentrations revealed toluene (0.0035–23.09 µg/m^3). Buczyńska et al. [27] published the higher results for samples collected during the summer/autumn periods in heavy polluted streets of Mortsel (Belgium): benzene (1.6 ± 0.6 µg/m^3), toluene (7.0 ± 2.7 µg/m^3), ethylbenzene (0.9 ± 0.3 µg/m^3), m,p-xylene (2.3 ± 0.8 µg/m^3), and o-xylene (0.9 ± 0.3 µg/m^3). In London Eltham, Harwell and Cardiffthe (UK) the mean concentrations of BTEX were in the following range [28]: benzene (0.37–0.75 µg/m^3), toluene (0.68–1.73 µg/m^3), ethylbenzene (0.11–0.29 µg/m^3), m,p-xylene (0.31–0.85 µg/m^3), and o-xylene (0.16–0.4 µg/m^3). Indoors, during one winter session in a Turkish kindergarten, Sofuoglu et al. [6] reported higher indoor concentrations of benzene (20 µg/m^3) and toluene (50 µg/m^3), while ethylbenzene and xylenes were measured at a similar level to that of this study. Demirel et al. [23] in primary schools presents for benzene, toluene, ethylbenzene, m,p-xylene and o-xylene, the mean values of 1.6, 26.2, 0.7, 1.1 and 0.81 µg/m^3, respectively. A higher level of toluene indicates the effect of traffic on measured concentrations.

In our research, environmental parameters such as temperature and RH in both indoor and outdoor air during the sampling periods were measured. The summary of environmental parameters for both spring and winter seasons is provided in supplementary material Table S1.

3.2. Indoor/Outdoor (I/O) ratios of BTEX

The relationships between indoor and outdoor concentrations for BTEX were further evaluated by calculating indoor/outdoor (I/O) ratios, which have been used as a tool to identify sources of emissions and where I/O ratio greater than 1 is considered an indicator for substantial indoor sources. As shown in Figure 2, the mean indoor/outdoor ratios for BTEX ranged from 1.12 to 8.47 and 1.45 to 127.85 for spring and winter, respectively.

The relatively low I/O ratio for benzene in both seasons indicates that weak indoor sources for benzene and infiltration of outdoor air might be responsible for most of the benzene found in classrooms. The moderate I/O ratios observed for toluene is interpreted as a presence of indoor sources e.g. from cleaning products. On the other hand very high I/O ratios observed for ethylbenzene and xylenes can be related to strong emission from furniture [29]. The I/O ratios were found to be roughly the same in kindergartens in Catania, in Athens twice as high as outdoor concentrations and one case, approximately 10 times higher than outdoors, while in Arnhem and Nijmegen, levels were two to four times higher than outdoor concentrations [30].

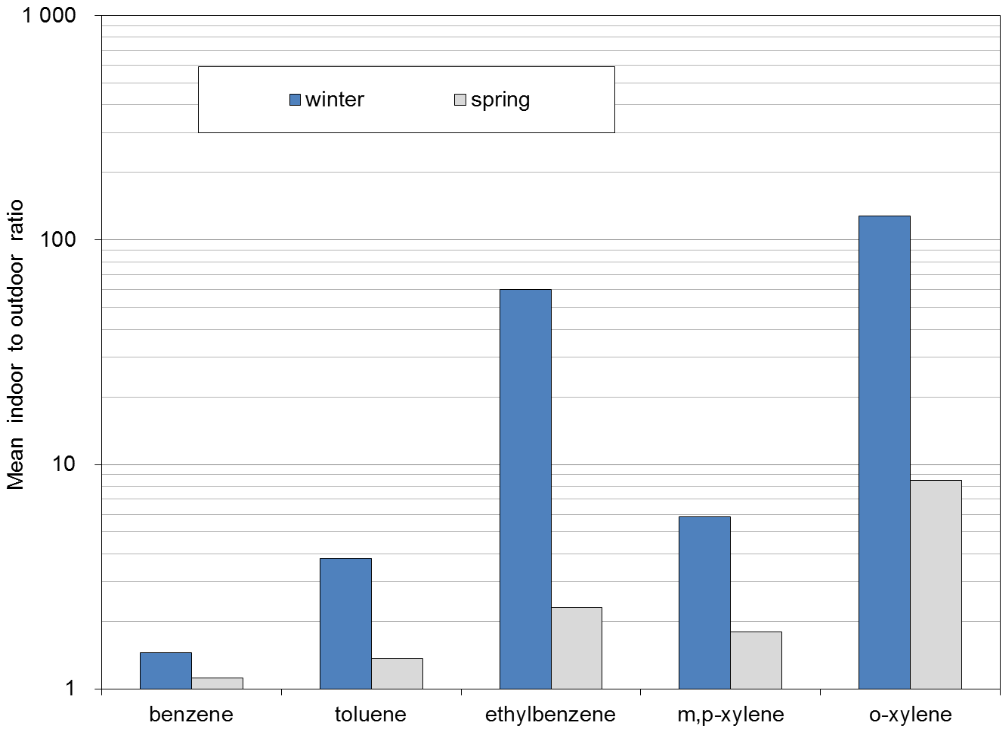

Figure 2. The mean indoor to outdoor ratios (I/O) of BTEX in spring and winter sampling seasons.

3.3. Correlation between measured BTEX

The correlation analysis can elucidate the possible source for the monoaromatic VOCs. A good mutual correlation among the species indicates that they might primarily originate from the common source (Table 2). The highest correlation coefficients were found between toluene and m,p-xylene as well as between ethylbenzene and o-xylene. 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 [31].

Table 2. Correlation matrix for the BTEX concentrations from a total of 48 samples ($p < 0.05$).

	Benzene	Toluene	Ethylbenzene	m,p-Xylene	o-Xylene
Benzene	1.00				
Toluene	0.52	1.00			
Ethylbenzene	0.48	0.65	1.00		
m,p-Xylene	0.34	**0.91**	0.51	1.00	
o-Xylene	0.49	0.59	**0.99**	0.43	1.00

A source characterization study [32] for BTEX compounds identified potential sources in different indoor environments (offices, homes, schools, shopping malls and restaurants). Among those environments, by using principal component analysis, different source factors were identified. For example in schools: one factor was characterized by high contribution of benzene, toluene, ethylbenzene, and p,m-xylene, and the other by o-xylene. In shopping malls ethylbenzene and xylenes (o-xylene and m,p-xylene) were composed in one factor suggesting food court as a common source. In restaurants, the use of natural gas for cooking purposes are significant sources for toluene and o-xylene. Also, the frequency of house cleaning is also identified to be a source of higher benzene, toluene, and m,p-xylene concentrations in homes.

In our study, o-xylene was among the relatively high concentration BTEX in kindergartens. The difference between the kindergartens and other indoor environments are in furniture, flooring materials (carpet on polymeric material vs. ceramic or stone hard flooring, respectively), the variety of materials for various activities for children (toys, art materials), having a kitchen for lunch and snacks, and every-day cleaning practices, results in a different indoor air quality in terms of BTEX. Indoors toluene and xylenes might also originate from enhanced evaporation of as industrial solvents from paints [33]. The ASHRAE standard [34] points out that the decay of elevated VOC concentrations from “wet” and “dry” emission sources can take weeks to months, depending on emission rates, the surface areas of materials and ventilation efficiency. Such a source may have developed due to renovation (painting of walls) conducted at the end of the summer holidays (August) in the SU-1 building. However, future studies oriented towards the determination of the emission rate of BTEX from these and other possible emission sources are needed.

3.4. Nursery school exposure dose (NSED) and risk indicators

The interest in exposure to BTEX has increased over the last few decades because they are associated with a broad range of health effects with major public health impacts. Among the three routes of exposure to contaminants; (inhalation, ingestion, and dermal absorption) inhalation is the major route for BTEX because of their relatively high vapour pressures [23]. Benzene is a known human carcinogen causing leukaemia. The World Health Organization (WHO) considered that an exhibition continued to benzene of 1.7 μg/m^3 might cause 10 cases of leukaemia per 10,000 inhabitants and seeing later the results of the above-mentioned concentration [35]. Toluene, ethylbenzene, and xylenes may cause brain function disturbances and are suspected carcinogens. Other potential health effects of BTEX on human health extend from throat and eye irritation to chronic asthma and even carcinogenic effects [36,37]. BTEX exposure may lead to fatigue, headache, dizziness, and vertigo [32,38].

U.S. EPA has traditionally approximated children's respiratory exposure by using adult values. However, there may be some cases where young children's greater inhalation rate per body weight or pulmonary surface area as compared to adults can result in greater exposures than adults. In our study, the nursery exposure dose (NSED) was calculated by the EPA's Child-specific Exposure Factors Handbook [39] and other publications [40-42]. The calculation procedure has been presented in supplementary material (*Exposure Indicators*).

Table S3 presents the inhaled dose of BTEX. It can be concluded that the higher dose in case of children compared to staff was attributed to the higher inhalation of air relative to body weight. It can be seen (Table S3) that both; children and staff inhaled the highest dose (*NSED*) of BTEX in winter. However, the most important is to note that younger children inhaled significantly higher *NSED* than the older ones. The BTEX dose inhaled by the staff in the studied kindergarten is 2–3 times higher than the dose absorbed by children.

Following de Gennaro [7], two integrated indicators based on inhalation risk assessment were proposed to gain a comprehensive evaluation of indoor air quality (IAQ) in the monitored classrooms. In particular, the indicators were obtained by considering the reference values used to describe chronic health effects (carcinogenic and non-carcinogenic) of BTEX: the IAQ Cancer Risk Indicator (CRI) which concerns cancer risk of benzene and the IAQ Total Hazard Ratio Indicator (THRI) relating to non-cancer risk. The calculation procedures for both indicators have been presented in supplementary material (*Exposure Indicators*).

Calculated CRI for benzene ranged from 8.4×10^{-6} to 1.2×10^{-5} during winter and spring, respectively. For carcinogens, the acceptable risk range is between 1×10^{-6} (1 in 1,000,000) and 1×10^{-4} (1 in 10,000) by US EPA's risk management, so the risk of benzene inside the nursery schools has been judged to be acceptable. Similar ranges of mean cancer risks from 0.88×10^{-5} to 1.7×10^{-5} were calculated for primary school children [23]. It is also similar to CRI for the children living with non-smoking parents 1.8×10^{-5} [43].

The second indicator: IAQ Hazard Ratio Indicator (HRI) was based on the comparison of the daily concentrations with their respective chronic non-cancer inhalation level (reference concentrations), the point at which no adverse effects are expected for a single BTEX. Non-cancer reference concentrations of BTEX detected in this study were extracted from the database provided by the IRIS (Table S4).

HRI values ≤ 1 indicate no adverse health effects and HRI values > 1 indicate long-term exposure and may result in possible adverse health effects [44]. Risk assessment can be used as a tool to identify people being impacted by the BTEX emissions and to implement risk management. According to these preliminary results HRI of BTEX are characterized by hazard ratio < 1 except o-xylene during winter. The HRI for children attending nursery schools decreased in the order of o-xylene > ethylbenzene > m,p-xylene > benzene > toluene in winter season and o-xylene > benzene > m,p-xylene > ethylbenzene > toluene in spring, showing that o-xylene was potentially highly deleterious to health. As mentioned previously, xylenes (o-xylene and m,p-xylene) and ethylbenzene were mainly attributed to furniture and food court as common sources. Therefore, considering that these two sources are important, in the study area, causing heavy health risks to preschool children. However, further research is needed to identify the extent to which the food court and furniture increased the risks of indoor exposure to BTEX.

Similar levels of hazard ratio (HRI) for BTEX, except o-xylene, for non-cancer health effects was reported in Turkish primary schools: 0.0057 (benzene), 0.043 (toluene), 0.015 (ethylbenzene), 0.0088 (m-p-xylene) and 0.0016 (o-xylene), none of the HRI was above 1 [23].

Additionally, to assess the overall potential non-carcinogenic effects posed by more than one chemical (e.g., i), the HRI calculated for each chemical is summed (assuming additive effects) and expressed as the total hazard index (THRI) [7]. The complete inhalation exposure risk for each monitored classroom is presented in Table S4.

In reference to hazard quotient (HRI), the values obtained showed that at only for o-xylene during winter season we obtained values greater than 1. Because the o-xylene concentration exceeds the benchmark concentration, it could be of nursery children health concern.

In our study, children and staff has been assumed to be exposed to measured BTEX every day, therefore exposure concentration was equal to concentration in air (*Ci*). In order to calculate the cancer risk for benzene (the only carcinogen) associated only with nursery school following [6] the NSED was multiplaied by slope factor SF $(\mu g/kg/day)^{-1}$ with the correspondance to real time exposition in nuresery school and standard lifetine of 70 years. The slope factor (potency factor) for benzene is 29 $(\mu g/kg/day)^{-1}$; a nursery school year was exactly 207 days (200 days were assumed). For younger children (II) we assumed 3 years of learning, 2 years for older children (I) and 30 years for the staff. The chronic toxic risk of benzene was from 0.10 to 0.33 for children and from 0.75 to 1.08 for staff. However, one should note that the chronic toxic risks for benzene were calculated for the specified time period (7 h indoors for children and 8 h for staff).

4. Conclusions

Although indoor air quality in preschools is similar to other schools, it can be assumed that preschool children are more vulnerable than other kids, due to their activities in preschool being of a more diverse nature and their immune systems and bodies being less mature. In Poland, to date, there have been no studies focusing on BTEX among children attending preschools.

The mean values of indoor BTEX 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 higher concentrations inside classrooms during the winter season.

Correlation coefficients point to common indoor sources of BTEX. The highest correlation coefficients revealed toluene and m,p-xylene as well as ethylbenzene and o-xylene. In the nursery schools children may breathe air contaminated with toluene and xylenes by use of glues, paints, rubbers and plastic-modelling cements, while 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.

The highest values of the dose of BTEX inhaled by the staff and the nursery's children were recorded in the winter; the older (I) and younger children (II) absorbed 46.62 and 57.77 $\mu g/kg_{body\text{-}weight}$/day, respectively. The higher NSED of younger children is connected with the higher inhalation rate relative to body weight. The level of NSED for children is up to three times higher than for the staff.

At both of these sites, there were significant indoor pollutant contributions. To rank older and younger children classrooms, based on their indoor air quality, two integrated indicators based on health risk assessment were used. The IAQ Cancer Risk Indicator (CRI) and the IAQ Total Hazard Ratio Indicator (THRI) enabled an assessment of the overall IAQ in the investigated classrooms and an estimation of the impact of the indoor activities on children frequenting these nursery schools. Results of the health risk assessment showed that benzene cancer risk levels were found to be higher for younger children and winter season. Average hazard risk index (HRI) for non-cancer health effects was found as 0.043 (benzene), 0.001 (toluene), 0.031 (ethylbenzene), 0.038 (m,p-xylene) and 0.682 (o-xylene). During spring none of the HQ was above 1, however during winter HRI for o-xylene, was > 1 it indicates long-term exposure and may result in adverse health effects.

In future, it may be important to study other nursery schools, not only in urban areas but also in rural areas. To develop effective risk assessment and management strategies aimed at reducing health risks among children, the determination of possible sources of the emission rate of other VOCs as well as the possible existence of indoor sources is highly recommended as a factor to be included in future research.

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Conflict of interest

The authors declare no conflict of interest.

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