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Occurrence of Indoor VOCs in Nursery School - Case Study

Ingrid Juhasova Senitkova[1]

[1] Department of Civil Engineering, Institute of Technology and Business in České Budějovice, Okružní 517/10, České Budějovice, 370 01, Czech Republic

14667@mail.vstecb.cz

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 concentrations of volatile organic compounds (VOCs) as well as carbon dioxide (CO_2) concentrations in younger and older children's classrooms during the winter season were studied. An electronic nose based on gas chromatography was used for the analysis of individual VOCs and a photoionization detector with a UV lamp was used for the determination of total volatile organic compounds (TVOC) concentration. Continuous measurements of CO_2 concentrations both inside classrooms and outside each building were performed using automatic portable monitors. Improving ventilation, decreasing the occupancy per room and completing cleaning activities following occupancy periods can contribute to alleviating high CO2 and VOC_s occurrence levels.

1. Introduction

Recent developments in indoor materials have resulted in the use of more synthetics and composites, which can affect air quality. These potentially adverse effects are further complicated by the fact that children are spending more time than ever indoors, up to 90% according to estimates by the U.S. Environmental Protection Agency (EPA). It is easy to understand why there is a growing concern about the quality of the air we breathe. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Comparing numerous recent studies regarding indoor air quality (IAQ) and the health of school children relatively few examples of research focusing on younger children were found [1,2,3,4,5]. 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. The several main reasons for studies on indoor air parameters in nursery schools are known. 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 [6, 7]. The 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 [1, 5]. As a result of these and other factors, totally new terminology has come into use and the topic is gaining more attention every day. Some examples include: Sick Building Syndrome (SBS), Building Related Illness (BRI), and Multiple Chemical Sensitivity (MCS) or Environmental Illness (EI). Sick Building Syndrome (SBS): where more than 30 per cent of occupants experience adverse effects while in the building, but no clinically diagnosed disease is found. Building Related Illness (BRI): general term for a medically diagnosable illness caused by, or related to, building occupancy. Multiple Chemical Sensitivity (MCS) or Environmental Illness (EI): a controversial condition where an individual has or develops sensitivity to even low levels of certain chemicals due to extended exposure.After first paragraph, other paragraphs are indented as you can see in this paragraph. After Introduction, divide your article into clearly defined and numbered sections.

A major pollutant in indoor air are volatile organic compounds (VOCs) emitted from materials and building products [8]. Definition by U.S. EPA is: VOC means a hydrocarbon or derivative of hydrocarbon that has a vapor pressure greater than 0.01 kPa (0.002 psi) at a temperature of 20°C and pressure of 102.9 kPa (14.7 psi). Excluded compounds are methane, ethane, methylene chloride, 1,1,1-trichloroethane (methyl chloroform), trichlorofluoromethane, dichlorodifluoromethane (CFC-12), chlorodifluoromethane (CFC-22), trifluoromethane (FC-23), trichlorotrifluoroethane (CFC-113), dichlorotetrafluoroethane (CFC-114), and chloropentafluoroethane (CFC-115) [9]. Indoor air pollution by VOCs is a particularly variable phenomenon: type and concentration of VOCs may change from one indoor space to another and concentrations may vary between different locations within the same space.

In addition, there are short and long term variations of VOC concentrations with time. The obvious dynamics of indoor pollution by VOCs are mainly caused by two factors: (a) the large variety of VOC sources in the indoor environment and the diversity of their emission characteristics, and (b) the wide range of ventilation conditions and air circulation patterns [10].

Among indoor pollutants researchers 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 [11,12]. Carbon dioxide (CO2) 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% [13]. CO_2 concentration is an indicator of low ventilation rates, which increase communicable respiratory illnesses [14]. In addition to air pollutants emitted indoors and penetrating from outdoors, ASHRAE Standard points that some materials act as sinks for emissions and then become secondary sources of VOCs and PM as they reemit adsorbed pollutants [15]. 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.

2. Methods and sampling

Children attending the nursery schools range from two to six years old, divided by age into four different classrooms (2-3 year old children, 3-4 years old children, 4-5 years old children, 5-6 years old children). In order to evaluate discrepancies between IAQ in the classrooms of two-three years old (A) and five-six years old children (B) measurements were performed in each classroom simultaneously using outdoor measurements. The classrooms were approximately the same volume: 200 m3. Daytime schedules in every classrooms of nursery school are generally similar. An essential difference between the groups is that the younger groups of children have an afternoon nap which lasts 2 hours. They dressed in sleeping suit sleep or rest and micro ventilation by unsealed windows was provided. The resting time children of the oldest group usually watch TV or listen to fairy tales. The indoor and outdoor concentrations of selected VOCs, as well as CO_2 concentrations were measured in the classrooms of the youngest group of children and the oldest one. The sampling position in classrooms was set at the height of an average child's head 1 m above the floor and away from the door, thus avoiding disturbances resulting from air currents. The measurements were realized in morning 1 hour before the children's occupancy (1), every hour during the care time (2) and at the end of day care time (3).

The air temperature and relative humidity was set with data logger Testo 175-H2 (measurement accuracy: ±3% RH, ±0.5°C). Concentration of total volatile organic compounds (TVOC) expressed as concentration of toluene was measured with ppbRAE 3000, which is a photoionization detector (PID) with UV lamp. This device has a measuring range of 1 ppb to 10000 ppm and measurement accuracy ±3%. Three-second response time allows real-time monitoring with this instrument. Ultra-fast electronic nose called zNose®, which is based on combination of gas chromatography and surface acoustic wave detector was used for sampling and analysis of individual VOCs. Manufacturer of this device specifies the standard deviation < 2%. The used method includes the following settings: sensor temperature of 10°C, column temperature of 40–200°C, valve temperature of 165°C, inlet temperature of 200°C, pump time of 60 seconds (0.5 ml of air/s), and analysis time of 20 seconds. Capillary column DB-5 with 1 m length, film thickness 0.25µm, and internal diameter 0.5 mm was used for measurement. All instruments were placed in the center of the rooms and each measurement in each room lasted 30 minutes. The measuring time was sufficient, because both devices for determining of VOCs work quickly and allow users to see the results directly on the spot. Continuous measurements of CO_2 concentrations both inside classrooms and outside each building were performed using automatic portable monitors. Each monitor, equipped with a non-dispersive infrared sensor, was connected to a PC with RS232software installed. The precision of measurements ranged between 0 and 10 000 ppm CO_2: ±100 ppm CO_2 or±3% at a concentration below 100 ppm. The monitors display and record measurements in real time, allowing for logged data to be downloaded for analysis. The selected sampling interval was 60 s.

3. Results and discussion

The results of measured concentrations of CO_2 and TVOC as well as the indoor air temperature and relative humidity are summarised within the Table 1. The difference between the youngest (A) and the oldest (B) children's classrooms (i.e., flooring materials, variety of toys, the activities of children, and cleaning practices) resulted in different indoor TVOCs concentrations, and different CO2 concentrations.

Table 1. VOC concentration in nursery school classrooms (A), (B)

	A / 1	A / 2*	A / 3	B / 1	B / 2*	B / 3	Out
CO_2 [ppm]	380	1270	2850	380	1520	3420	380
TVOC [µg/m^3]	58,36	72	93,4	52,13	67,14	89,11	4,38
Rh [%]	39,6	49,8	62,7	37,2	61,4	58,3	42,8
Temperature[°C]	22,1	23,8	24,1	22,2	24,2	23,7	18,6

* average value of care hours

Carbon dioxide concentrations are often used as a surrogate for the rate of outside supply air per occupant. Permissible concentrations of carbon dioxide in confined spaces equal 1000 ppm. This minimum sanitary requirement is recommended by the European Office of the WHO and by ASHRAE [15, 16]. Based on the above mentioned regulations, the increase of CO_2 concentration in relation to CO_2 concentration in outdoor air was measured in both studied classrooms.

The indoor concentrations of CO_2 showed inadequate classroom air exchange rates. The variation of indoor CO_2 concentrations during a typical working day at both classrooms occurred. A strong correlation was observed regarding the CO_2 level and children's activities, especially in the oldest children's classrooms (B). For example, during meals or when entering into and exercising and dance classes. The highest CO_2 concentration (3420 ppm) was observed in the oldest children's classroom (B). Generally, during children's occupancy of the classrooms, the air was of low quality. The concentration of the investigated pollutants in indoor environments was higher than those in outdoor air. 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 CO_2. It can be said that in the youngest children's classrooms it was 80.0% of care hours, while in the oldest children's classrooms this was 70.0% of care hours. Numerous scientific studies highlight that CO_2 levels often exceed the recommended standards. Its concentrations vary according to the length and level of occupancy in the classrooms, the type and quality of ventilation and room design [5,13,17,18,19] . Presented research confirmed enumerated conditions; moreover, our results point out differences between older and younger children's classrooms, which can become more significant if we link inadequate ventilation with the various activities of children.

Table 2. Measured VOCs [μg/m^3] concentration in studied nursery school classrooms (A), (B)

	A / 1	A / 2*	A / 3	B / 1	B / 2*	B / 3	out
Benzene	2.13	2.91	3.66	1.62	2.58	3.16	1.35 – 1.83
Toluene	1.26	3.74	4.52	1.10	2.66	3.54	0.61 – 0.83
Styrene	0.97	3.41	5.14	0.87	3.24	5.19	0.17 – 0.45
Ethylbenzene	0.48	5.99	7.09	0.54	7.15	8.83	0.22 – 0. 37
n-butylbenzene	0.60	1.48	2.73	0.53	1.79	2.11	0.08 – 0.11
o-xylene	0.65	8.92	10.98	0.76	9.92	11.65	0.26 – 0.41
m,p-xylene	0.56	1.94	2.51	0.66	1.71	2.23	0.21 – 0.39
1-butanol	0.47	7.29	9.93	0.41	8.11	10.72	0.68 – 0.97
1-butylacetate	0.69	9.09	11.26	0.58	9.54	11.88	0.89 – 1.17
Metylacetate	0.82	4.57	7.44	0.73	4.14	7.16	0. 21 – 0.34
Etylacetate	0.21	3.12	4.27	0.33	3.42	5.43	0. 18 – 0.44
Naphthalene	1.15	1.49	2.07	0.57	0.83	2.17	0.32 – 0.38

* average value measured during the care hours in studied classrooms

In general, indoor VOC concentrations were found to be similar and were higher than outdoor concentrations. The highest average concentrations in both classrooms, for the youngest and oldest children, were reported for 1-butylacetate, 1-butanol, o-xylene and ethylbenzene. Indoor levels of toluene, m- and p-xylene, styrene and n-butylbenzene were significantly higher than outdoor levels for both studied classrooms. Previous research studies reported higher indoor concentrations of benzene (20 μg/m^3) and toluene (50 μg/m^3), while ethylbenzene, xylenes, styrene and naphthalene were measured at a similar level to that of this study [20, 21]. The most abundant and frequently found VOCs in school air were benzene, toluene, ethylbenzene, m- and p-xylene and o-xylene. Another study presents for these VOCs, respectively, the mean values of 1.6, 26.2, 0.7, 1.1 and 0.81 mg/m3. A higher level of toluene indicates the effect of traffic on measured concentrations [22].

4. Conclusions

Although indoor air quality in nursery schools are similar poor to other schools, it can be assumed that preschool children are more perceptive and vulnerable than other school children, due to their activities in preschool being of a more diverse nature and their immune systems and bodies being less matured. Some of the compounds such as benzene, styrene, formaldehyde, and toluene, may be irritating, toxic, or even carcinogenic.

Volatile organic compounds, or VOCs, are among the most complex and troubling indoor air pollutants. Manufactured and synthesized products often release large quantities of VOCs, some of the compounds they release, such as benzene, styrene, formaldehyde, and toluene, may be irritating, toxic, or even carcinogenic. VOCs emitted can become attached to other surfaces in the space, especially fabrics, and then be re-emitted over time. Flooring especially carpet installations can be among the most significant sources of VOCs in nursery school buildings. Consider alternatives to wall-to-wall carpeting like hardwood flooring, tile, slate, natural linoleum, or natural cork. If considering such flooring alternatives, carefully examine the adhesives, sealers and cleaning agents that could result in VOC emissions during installation and maintenance. For wood-floor finishes, waterborne polyurethane is suggested. Waterborne finishes have been tested for durability, and many wear comparably to solvent-based ones.

Finally, it should be emphasized that, even with the most complete investigations of indoor air quality, it may be impossible to establish a clear relationship between the characteristics and composition of the indoor air and the health and comfort of the occupants of the building under study. Only the accumulation of experience on the one hand, and the rational design of ventilation, occupation and compartmentalization of buildings on the other, are possible guarantees from the outset of obtaining indoor air quality that is adequate for the majority of the occupants of a building.

Studies have been done to ascertain both the causes of air quality problems and their possible solutions. In recent years, knowledge of the contaminants present in indoor air and the factors contributing to a decline in indoor air quality has increased considerably, although there is a long way to go. The quality of indoor air can and does impact personal comfort, building maintenance costs and even health and safety, either positively or negatively depending on how air quality is managed.

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References

[1] P.T.B.S. Branco, et al., “Indoor air quality in urban nurseries at Porto city: particulate matter assessment”. *Atmos.Environ.* 84, pp. 133-143, 2014.
[2] A. Mainka, et al., “Indoor air quality in urban nursery school in Gliwice, Poland: Analysis of the case study”. *Atmospheric Pollution Research* 6, pp. 1098-1104, 2015.
[3] K. Gładyszewska-Fiedoruk, „Correlations of air humidity and carbon dioxide concentration in the kindergarten“. *Energy Build.* 62, pp. 45-50, 2013.
[4] I. Senitkova, I., “Impact of Indoor Surface Material on Perceived air quality“. *Material Science and Engineering C,* Volume 36, pp.1-6, 2014.
[5] C. Yoon, K. Lee, D. Park, „Indoor air quality differences between urban and rural preschools in Korea,“ *Environ. Sci. Pollut.* Res. 18, 333-345, 2011.
[6] S. Salvi, „Health effects of ambient air pollution in children,“ *Paediatr. Respir. Rev. 8,* 275-280, 2007.
[7] M. Santamouris, et al., “Experimental investigation of the air flow and indoor carbon dioxide concentration in classrooms with intermittent natural ventilation,” *Energy Build. 40*, 1833-1843, 2008.
[8] O. Wilke, O. Jann,D. Brödner, „ VOC- and SVOC-emissions from adhesives, floor coverings and complete floor structures,“ *Indoor Air, 14(8)*, pp. 98-107, 2004.
[9] United States Environmental Protection Agency. SIP – NWAPA580, http://yosemite.epa.gov Open Document
[10] ECA-IAQ (European Collaborative Action “Indoor Air Quality and its Impact on Man”) Sampling Strategies for Volatile Organic Compounds (VOCs) in Indoor Air, Office for Official Publications of the European Communities: Luxemburg (Report No. 14, EUR 16051 EN), 1994
[11] M. J. Mendell, G. A. Heath, „Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature“ *Indoor Air 15*, 27-52, 2005.
[12] P. N. Pegas, et al., “Outdoor/indoor air quality in primary schools in Lisbon: a preliminary study,” *Quimica Nova 33*, 1145-1149, 2010.
[13] M. Griffiths, M. Eftekhari, “Control of CO2 in a naturally ventilated classroom,” *Energy Build.*

40, 556-560, 2008.

[14] EN (European Standard) EN 13779 Ventilation for Nonresidential Buildings. Performance Requirements for Ventilation and Room conditioning systems, 2008.

[15] ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers). Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality, 2013.

[16] WHO (World Health Organization), 2000. Air Quality Guidelines for Europe. World Health Organization, Regional Office for Europe.

[17] A. Mendes, et al., " Environmental and ventilation assessment in child day care centers in Porto: the envirh project," *Toxicol. Environ. Health Part A* Curr. Issues 77, 931-943, 2014.

[18] D. Mumovic, et al., „ Winter indoorair quality, thermal comfort and acoustic performance of newly built secondary schools in England," *Build. Environ. 44*, 1466-477, 2009.

[19] S. M. Dumała, M. R. Dudzinska, „Microbiological indoor air quality in Polish schools," *Annu. Set Environ.* Prot. 15, 231-244, 2013.

[20] S. C. Sofuoglu, et al.," An assessment of indoor air concentrations and health risks of volatile organic compounds in three primary schools," *Int. J. Hyg. Environ. Health* 214, pp. 36-46, 2011.

[21] I. Senitkova, „Environmental sustainability of building materials and perceived air quality – interior surfaces," *Chem. lists*, vol. 110, 4, pp. 289-294, 2016.

[22] G. Demirel, et al., "Personal exposure of primary school children to BTEX, NO2 and ozone in Eskisehir, Turkey: relationship with indoor/outdoor concentrations and risk assessment," *Sci. Total Environ.* pp. 473-474, 537-548, 2014.