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Analysis of Carbon Dioxide in Kindergartens in Poland

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Abstract. Children in kindergartens spend between five and ten hours a day, the quality of air inside is very important. Kindergartens are public buildings. Kindergartens in Poland do not have mechanical ventilation, most often use stack ventilation, which is frequently aided by airing. The three considered buildings were located in eastern Europe. The main objective of the research was to evaluate the interior conditions, especially with regard to carbon dioxide concentration.

In the afternoon, the permissible level of carbon dioxide concentration was substantially exceeded (by 190% at the most in first series of measurement).

The present research has resulted in considerable improvement of indoor conditions in the analyzed kindergartens (less than 140% in third series of measurement).

The presence of children and ventilation habits seemed to be the main determinants of IAQ and carbon dioxide.

Keywords: natural ventilation, indoor air quality, carbon dioxide concentration.

Conference topic: Environmental protection.

Introduction

Policy makers and researchers develop methods for improving and monitoring acceptable indoor air quality for a healthy environment (St-Jean *et al.* 2012).

In kindergartens none of the IAQ parameters has been measured earlier because scientists often have trouble getting access to these institutions (Mainka, Zajusz-Zubek 2015). The first studies of air quality in kindergartens have been published in 2015. Nunes (Nunes *et al.* 2015) examined the levels of particulate matter in kindergartens. Until now estimate values of the parameters in kindergartens have been extrapolated from research carried out in schools. Although the age of the children is similar, classes taught in kindergartens differ from these taught at schools in significant way. While in the kindergartens children take part in games involving physical movement, in schools intellectual effort takes precedence.

To avoid headache, fatigue, loss of concentration and absenteeism, it is highly recommended to implement measures to alleviate the critical situations regarding IAQ (St-Jean *et al.* 2012). More efficient ventilation habits could be implemented to improve IAQ in kindergartens and in other buildings where there is no mechanical ventilation.

Room microclimate

The optimal parameters of indoor air are proposed in the report (Report WHO 2000; PN-EN ISO 7730:2006) and in the paper (Ramalho *et al.* 2015).

In order to breathe freely, an adult needs between 20 and 25 m^3/h of air (ASHRAE Standard 62-1989). One could assume, that on average a child requires between 15 and 20 m^3/h of breathing air (75% of flow of air for an adult), yet children's needs are so varied that they evade categorisation because they depend on the child's activity and age, as well as on the temperature and humidity in the room.

Although CO_2 concentration may easily be considered a factor contributing to air purity (Naumov *et al.* 2015; Fabbri, Boeri 2014), without proper measuring equipment no one is able to define this type of air pollution.

Carbon dioxide

The air exhaled by humans differs in composition from the air they breathe in. Nitrogen is 78%, and the percentage is not significantly changed in the process of respiration; other gases also remain at 1%. What changes is the proportion of oxygen (from 21% to 17%) and carbon dioxide (from 1% to 4%) (Bogdan, Chludzinska 2010). Level of concentration of carbon dioxide in the room should be max 1000 ppm; such is the minimum sanitary requirement established by the European branch of WHO [9] and ASHRAE (ASHRAE Standard 62-1989).

Indoor air quality classification that has been adopted in many other EU countries is described in PN-EN 13779: 2008 (PN-EN 13779: 2008). The document introduces four major categories of indoor air quality with corresponding levels of carbon dioxide concentration. The standard also defines the minimum air flow rate of ventilation air per person. Table 1 shows the values of air flow rate per person in spaces where smoking is banned and where pollution emission is low. The values take into account human metabolism, hence they suitably describe places such as kindergartens.

Table 1. Indoor air quality classification (PN-EN 13779: 2008)

Class	Quality of indoor air	Increase of CO_2 concentration in relation to CO_2 concentration in outdoor air	Airstream volume	
			Typical	Standard
		ppm	m³/h per person	
IDA 1	high	below 400	above 54	above 72
IDA 2	medium	400–600	36–54	45
IDA 3	moderate	600–1000	22–36	29
IDA 4	low	above 1000	below 22	below 18

Reaserch methods

Description of the analyzed kindergartens

Although kindergartens face a variety of difficulties, this paper focuses solely on the problems related to ventilation systems.

The issue that is brought up most often is the parents' concern with open windows. Airing involves opening all windows in a given classroom for 5 to 10 minutes while the children are taken for a stroll around the building (the windows are closed 5 minutes before the children's return). Sometimes children visit another classroom, while their classroom is being aired. It has also been observed that kindergarten premises are often aired when the children are outside the building, i.e. in the playground or on a walk. With regard to airing, it has to be admitted that keeping windows unsealed all the time should be advocated, because such practice lets outdoor air penetrate into classrooms, which, in turn, makes the stack ventilation system work properly. This is because letting the used air out is not enough; a proper amount of fresh air should be delivered back into a given room.

Negative gauge pressure (under pressure) that sometimes appears in public building (for example through the work of extraction in the kitchen or in the toilet) must be aligned. If there is no inflow of outside air into the rooms, drafts appear whenever the doors are open. The worst is, if the stack ventilation draws in cold air into the room.

This study was to observe the quality of indoor air in the halls of a kindergarten and to suggest how to improve it. The analyzed kindergartens characteristics are shown in Table 2.

Table 2. The kindergartens characteristics

	1st kindergarten	2nd kindergarten	3rd kindergarten
Year of construction	1950	1985	1980
Year thermo-modernization	no	2008	2007
Scope of thermo-modernization	re-plastering	re-plastering	re-plastering
Windows	double-pane	triple-pane	triple-pane
Modernization of ventilation system	no	yes	no
Size of the kindergarten	very small	small one	large
Picture of the kindergarten	Fig. 1	Fig. 2	Fig. 3

Fig. 1. Kindergarten No. 1.

Fig. 2. Kindergarten No. 2.

Fig. 3. Kindergarten No. 3.

Table 3 presents relevant data as to the size of rooms and windows in the surveyed kindergartens and the number of children therein. Each new window in the kindergartens is double-glazed (description shown in Table 3). In the first kindergarten the windows have two different sizes, while in the second and third kindergartens there are three different sizes.

Table 3. The description of windows in the investigated kindergartens.

	unit	1st kindergarten	2nd kindergarten	3rd kindergarten
Total window area	m^2	40.4	163.78	311.87
Total building area	m^2	170	654	845
Ratio of window area to the area of the building	m^2/m^2	0.31–0.39	0.30–0.41	0.29–0.49
Heat transfer coefficient U	W/m^2K	2.2	1.5	1.7
The number of children in the kindergarten	items	45	100	250
The number of children in one group	items	15	20	30
The area of the room	m^2	50	70	80
The volume of the room	m^3	150	210	240
The area of the room relative to one child	m^2/child	3.33	3.5	2.67
The volume of the room relative to one child	m^3/child	10.00	10.5	8.00

Measurements and methodology

The analyzed kindergartens is in Białystok, in north-eastern Poland in the temperate climate zone.

The level of children' activity in a kindergarten depends on the time of the day; thus indoor air parameters cannot be accurately determined to hold in all circumstances. In Białystok (in Poland) classes in all kindergartens are conducted in a similar way. Children come to the kindergarten (7–8 am) and until breakfast they engage in rather peaceful activities. Having finished their breakfast (8.30 am), the children start playing more intensively and their activity level grows; however, if after breakfast learning time is planned, the activity level decreases. About noon classrooms are ventilated. After lunch (1.00 pm), small children take a nap and older children go to the playground, learn, or play quietly not to wake the younger ones. Activity levels drop significantly in all groups at that time. Once the children have had their afternoon snack (3.00 pm), they engage in a variety of activities: since it is not a time for learning, the games children play may be either steady or intensive depending on their individual needs. It becomes clear then that the level of children's activity can be accurately determined only before breakfast and during the nap. Although children's activity frequently does not directly correspond to teachers' activity, a correlation between the two is often observed. The research took place in autumn: in September, in November and in February. In September the central heating was switched of, in November the central heating was switched on and the windows were opened for 15–20 minutes daily. In February the central heating was switched on and the windows were opened rather infrequently 2–5 minutes. The choice of these particular months was determined by the fact that in summer (May–August) the windows are open all the time and the indoor air is the same as outdoor air. In Poland, weather conditions in spring are the same as in autumn. In winter, the weather is different. It is a lot colder than in spring and autumn and this is why the rooms are rarely aired. In the selected months, the measurements were taken 3 times a week. The paper presents selected results of the measurements.

The measurements in all kindergartens, in all classrooms and in other rooms were made at the height of an child's head, at a height of 1.00–1.10 m from the floor level in the center of the classroom. The experiment accounted for such air parameters as CO2 concentration, temperature and relative humidity using a measuring instrument Testo 435-4 and probe air quality (Table 4). The reading of the values took place every 30 seconds.

Table 4. Description of measuring equipment Testo 435-4.

Using spot	Measuring items	Measuring range	Resolution	Accuracy
Outdoor	Temperature	–20°C to +50°C	0.1°C	±0.3°C
	Humidity	+2 to +98% RH	0.1% RH	±2 %RH
	Carbon dioxide concentration	+0 to +5000 ppm CO_2	50 ppm CO_2	±2%
	Atmospheric pressure	+600 to +1150 hPa	0.5 hPa	±5 hPa
Indoor	Temperature	0 and +50°C	0.1°C	±0.3°C
	Humidity	+10 to +98% RH	0.1% RH	±1 %RH
	Carbon dioxide concentration	+0 to +5000 ppm CO_2	50 ppm CO_2	±2%

In this article we discuss only the CO2 concentration. The temperature in all kindergartens was consistent with the recommendations; in the kindergartens that underwent thermo-modernization the air was dry.

Discussion of the obtained measuremen results

The outdoor parameters in first season of measurement presented in Table 5. The charts (Fig. 4–6) show carbon dioxide concentration in the afternoon, considering all three months the measurements were taken. Figures 4–6 also feature measurement errors, which have been calculated with a confidence level of 95% (Moffat 1988; Almeida, de Freitas 2014; Sulewska 2010).

Table 5. Outdoor parameters in first season of measurement.

Parameters	Unit	September		November		February	
		morning	afternoon	morning	afternoon	morning	afternoon
Temperature	°C	8.4	13.6	3.1	2.6	–0.5	0.2
Humidity	% RH	89.50	70.30	86.4	83.5	88.3	86.2
Carbon dioxide concentration	ppmv	408	403	444	450	480	460
Atmospheric pressure	hPa	1006	1006	972.3	970.9	1006.4	1007.2

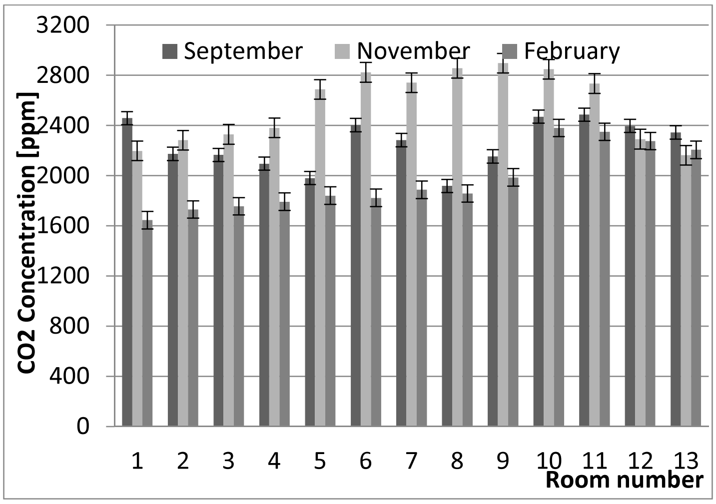

Fig. 4. CO_2 concentration in rooms in kindergarten No. 1

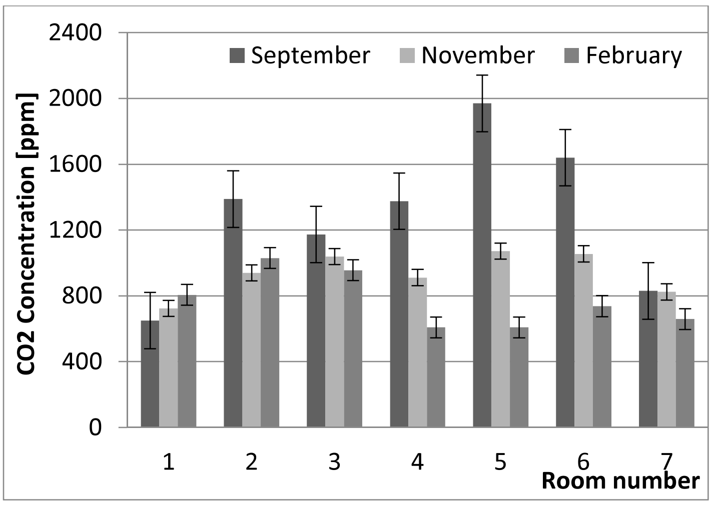

Fig. 5. CO_2 concentration in rooms in kindergarten No. 2

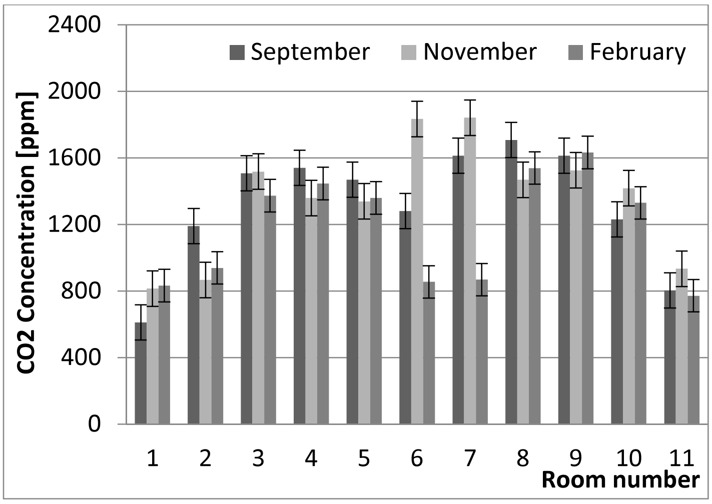

Fig. 6. CO_2 concentration in rooms in kindergarten No. 3

Outdoor relative humidity is high in months of measurement (Table 5) and should be affect the indoor air quality.

In kindergarten No. 2 carbon dioxide concentration exceeded the permissible norm by 97% at most during the first series of measurements (in September); by 7.2% during the second series (November); and only by 3% during the third series (3% was exactly the precision of measurements; Fig. 5 February). In the afternoon, in two of the kindergartens carbon dioxide concentration exceeded the norm significantly (by as much as almost 190%; Fig. 4) and ranged between 608 and 2896 ppm.

Although the number of children in kindergartens No. 1 and No. 2 is roughly the same, the reason for the high concentration of CO_2 in kindergarten No. 1 is poor ventilation.

It has to be admitted that the present research has resulted in considerable improvement of indoor conditions in the said kindergartens (Fig. 4–6). The management and staff have considered ventilating the rooms all day long by means of unsealed windows. Air quality in the rooms either improved or remained stable which could be observed with each consecutive measurement; even when weather conditions hardly favour natural ventilation, the windows are kept unsealed (micro-ventilation) during most of the day.

The number of children in a room is a very important factor. In Poland, there is no legislation as to how many children may stay in a room of a given size (surface and/or volume). As evidenced by Branco *et al.* (2015), this is not an exclusively Polish problem.

In all buildings indoor air temperature was in the range between 19.2 and 22.0 ^{o}C and so met recommended level. Relative humidity values in kindergarten No. 1 were acceptable during all test periods, whereas in kindergartens No. 2 and 3 they were lower in some cases; even though outdoor relative humidity was high. Most of the time, however, they stayed at the recommended level.

As the first measurement set had been completed, the staff of the kindergartens were informed about the indoor air quality. Instead of temporary airing with fully opened windows, continuous micro-ventilation was suggested.

After this research had been completed, headmasters confirmed that central heating costs have not risen and the number of children and staff absent because of illness decreased by about 20%.

The analysis of research results has confirmed the worries about the inferior quality of indoor air in kindergartens in Poland. In autumn, winter, and spring indoor air quality is bad and it does not meet any of the recommended standards. IAQ in kindergartens in Poland is similar to that which can be observed in schools in other countries of the EU (Ramalho *et al.* 2015) and in the USA, but not in schools in Poland. The CO_2 concentration in Polish schools is much higher than in the kindergartens. Therefore, we suppose that analogical results could be obtained in other countries.

In Portuguese schools in winter, when there is no mechanical ventilation and opening windows is cumbersome, carbon dioxide concentration rose up to 2500 ppm (Almeida, de Freitas 2014; Branco *et al.* 2015). The author's other research (Krawczyk *et al.* 2017; Krawczyk *et al.* 2016; Gładyszewska-Fiedoruk, Krawczyk 2013) proved that CO_2 levels in classrooms in Universities in Białystok does not exceed 1800 ppm. In the kindergartens which were examined in this study, this concentration exceeded 2500 ppm only once. If we dismissed it as an exception, we could summarize that the maximum measured CO_2 concentration in Polish kindergartens is between 1600 and 2000 ppm.

The results clearly point to kindergarten No. 2 as the one with a properly operating ventilation system and decent indoor air parameters. In the afternoon in September, the quality of indoor air dropped, but it still could be classified as IDA3 – IDA4 (Table 1), normal IAQ is IDA1 – IDA2. It has to be added that the permissible norms were exceeded only once in one measurement series in one room. In the kindergarten, ventilation occurred with only minimum active participation of the personnel: windows did not need to be opened on a regular basis, as air could freely penetrate inside the building through the installed ventilation valves.

Conclusion

Summing up, three kindergartens of various size and different insulation properties of exterior walls were investigated. Their air exchange systems were also organized differently. Overall, the research concerned 31 rooms in the kindergartens.

- Kindergarten No. 1 was located in a building which had not undergone thermal efficiency improvement, and accordingly had the worst interior conditions.
- Kindergarten No. 2 was located in a building which had benefited from full thermal efficiency improvement, along with the modernization of its ventilation system; the interior conditions were the best of the analyzed kindergartens.
- Finally, kindergarten No. 3 was located in a building in which only a partial thermal efficiency improvement had been conducted (i.e. the ventilation system had not been modernized); the interior conditions turned out to be rather uncomfortable.

Research results showed that CO_2 concentration changes during normal usage of kindergarten space. To avoid headaches, fatigue, loss of concentration and other health symptoms among the children attending these kindergartens, a new method of room ventilation was suggested to keep good IAQ.

This study allowed for a better understanding of the distribution of CO_2 concentrations in kindergartens. In fact, the presence of children and ventilation habits seemed to be the main determinants of IAQ. It was also found that CO_2 concentrations were high and exceeded the European standards (about 190%).

It might also be necessary to review the Polish legislation on the number of children per classroom, accounting for IAQ and children's health issues.

The presented results are based on experiments conducted solely in Polish kindergartens in Białystok. Analogical results from other countries might also be interesting.

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