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Determination on Carbon Dioxide Levels in School Buildings: the Effect of Thermal Efficiency Improvement

Badanie stężeń ditlenku węgla w pomieszczeniach szkolnych z uwzględnieniem wpływu termomodernizacji budynku

Indoor air quality (IAQ) in schools is an important public health concern. Particular attention should be paid to children, because they are more vulnerable to air pollution than adults. Although carbon dioxide is not considered a toxic air pollutant, its concentrations inside buildings may have a negative impact on users. The most commonly described health problems include tiredness and its effects (headaches, bad mood, poor attentiveness). Carbon dioxide concentrations are often used as a surrogate for the rate of outside supply air per occupant. Permissible concentration of carbon dioxide in confined spaces is 1,000 ppm. This minimum sanitary requirement is recommended by the European Office of the WHO and ASHRAE. The Polish Committee for Standardization has established general guidelines concerning the quality of air inside non-residential buildings. This standard was drawn up based on EU directives, through classification of IAQ, as it is influenced by the CO_2 concentrations above the outdoor level (ΔCO_2). Based on the above regulations, the increase in indoor CO_2 concentrations in relation to CO_2 concentrations in outdoor air (ΔCO_2) were measured along with physical parameters (temperature and relative humidity) to evaluate IAQ in the classrooms of two primary schools built in the nineteenth century in Poland. More than 100-year-old buildings built of bricks before World War II are a frequent occurrence in rural schools in the area of Upper Silesia, Poland. One of the school buildings underwent thermal effectiveness improvement while the other has not been modernized in these terms yet. The aim of the research was to check the extent to which thermal modernization of an old public building influences indoor air quality in the context of concentrations of carbon dioxide. The measurement period was chosen for late spring in order to avoid the impact of municipal emissions (so-called low emissions) common in rural areas. The average concentration of carbon dioxide in school rooms after thermal modernization (WTM) were higher than the concentrations observed in the school not subjected to thermal modernization (NTM). The CO_2 concentrations ranged from 1,287 ±333 ppm to 2,146 ±386 ppm and from 936 ±196 ppm to 1,878 ±567 ppm in WTM and NTM school buildings, respectively. The results clearly indicate a higher occurrence of poor air quality (up to 70% of time during the school days) in the thermally improved school building compared to the one without thermal improvement (up to 52% of the time). The measurements also showed that the exposure of school children to elevated carbon dioxide concentrations during classes was higher in thermally improved primary school buildings, which in turn may represent a health concern.

Keywords: **carbon dioxide, schools, school children's exposure, thermal modernization**

Introduction

Carbon dioxide (CO_2) is a gas which, with water steam, belongs to the most important greenhouse gases. In nature, it occurs in free forms and as part of other compounds and mixtures. Natural sources of CO_2 include respiration and distribution and combustion of biomass during forest fires and reservoirs in oceans and photosynthesis processes. Among the anthropogenic sources of CO_2 are processes of fossil fuel combustion and clearing and burning forests [1].

Carbon dioxide should be also mentioned as one of the most frequent indoor air pollutants. It is not considered a toxic air pollutant, but in closed rooms, carbon dioxide replaces oxygen, thus deteriorating indoor air quality [2]. This may lead to tiredness, sleepiness, headaches or problems with concentration. Therefore, the problem of exposure to CO_2 in closed buildings should be addressed as people spend 80 to 90% of their time in such places [3-6]. The concentration of CO_2 has been commonly used as an indicator of the efficiency of ventilation systems [7]. In Poland, the permissible concentrations of carbon dioxide in the indoor air of rooms intended for permanent residence of people, including classrooms, are not standardized. According to the Pettenkofer's scale accepted by the World Health Organization (WHO), poor office room air quality is characterized by CO_2 concentrations of over 1,000 ppm i.e. ca. 1,800 mg/m^3. The concentration of 2,500 ppm is considered hazardous to human health. Indoor air quality in public rooms, such as classrooms, has been of particular interest of researchers and public opinion. Concentrations in the range of 3,000 to 5,000 ppm are typical of unaired classrooms after ca. 1 hour.

A high concentration of CO_2 in classrooms has a negative effect on learning performance and student's health. The study [8] found that the increase in CO_2 levels leads to a decline in students' attention by 5%, similar to the effect evoked by not eating the breakfast. Shendell et al. [9] indicated correlations between short-term elevated concentration of CO_2 (> 1,000 ppm) in classrooms and increased absence from school (from 10 to 20%). Authors of the study [10] emphasized that large number of students remaining in classrooms with low cubic volume and, consequently, increased CO_2 concentrations, should lead to the correction of guidelines that take into consideration these indices and threshold environmental doses during design of cubic volume of classrooms.

The aim of the study was to verify the degree to which thermal modernization of a public utility building impacts on indoor air quality in the context of carbon dioxide concentrations. According to the Ordinance of the Minister of Health, educational buildings intended for permanent occupation by children and young people belong to the A category [11], which leads to high requirements concerning indoor air quality (IAQ). In Poland, indoor air quality in non-residential buildings is evaluated using the ΔCO_2 index, which denotes an increment of the concentration of carbon dioxide in the room to the level of over carbon dioxide concentration in the outdoor air. According to the standard PN-EN 13779:2008 [12]: *Ventilation for non-residential buildings. Performance requirements for ventilation and room-conditioning systems*, four categories are used for indoor air as presented in Table 1.

Table 1. **General classification of indoor air quality (IAQ)**

Category	Description	Increase of CO_2 concentration compared to CO_2 in the external air
IDA 1	High indoor air quality	below 400
IDA 2	Medium indoor air quality	400÷600
IDA 3	Moderate indoor air quality	600÷1000
IDA 4	Low indoor air quality	over 1000

1. Characterization of examinations

Two school buildings were chosen for the examinations. Both schools are located in over 100-year-old building. The primary school in Ziemięcice was accepted for the use in 1874, whereas the school in Przezchlebie - in 1884. Both buildings have been used as schools. They are typical of rural schools from the Upper Silesia region, built of bricks before World War II.

Thermal efficiency improvement in the School in Ziemięcice was performed in 2011 (it was denoted in the text as WTM - with thermal modernization). The modernization consisted in the replacement of the old heating system (exchange of boiler into gas boiler and installation of high-performance heaters), installation of plastic windows and warming the external walls of the building (10 cm Styrofoam).

In the school in Przezchlebie, thermal modernization has not been performed yet (this was denoted as NTM - without thermal modernization).

Air exchange in both buildings was ensured by natural ventilation. Due to a low efficiency of such systems, air quality has to be improved by airing classrooms during breaks. Furthermore, depending on weather conditions, windows remain slightly ajar during classes.

The WTM school was attended by 67 children who spent their breaks in the school canteen or in the corridors, with exception of first grade students, who spent their breaks in classrooms. Furthermore, there were 53 children in the NTM school, spending their breaks in school corridors. The number of children in classes in both schools did not exceed 14.

Concentrations of CO_2 with such physical parameters as temperature and air humidity were measured by means of the CO_2 sensor, model 77535 (AZ Instruments). The device senses absorption of infrared radiation and allows for the measurement of CO_2 concentration over the range from 0 to 10,000 ppm (accuracy of ±5%), temperature measurements ranging from –10 to +60°C (accuracy of ±0.6°C) and measurement of humidity with Rotronic sensor in the range of 0 to 99% (accuracy of ±3%) [13]. The sensor has a calibration certificate.

2. Discussion

Measurements of internal air parameters (temperature, humidity) with concentration of CO_2 were performed during two measurement series from April to June 2016.

Late spring was chosen as the best measurement period in order to avoid the effect of low emissions. The first series of determinations included constant measurements of the listed parameters (every 1 minute) from 7:30 a.m. to 1:30 p.m., with classes in the WTM school taking place from 8:00 a.m. to 1:20 p.m. and from 7:55 a.m. to 1:10 p.m. in the NTM school. The second series consisted in the measurements of the above mentioned indoor parameters, which were performed simultaneously in the rooms with the highest CO_2 concentrations. These measurements were performed continuously every minute over the entire school week (from Monday to Friday).

During the first session, the measurements were performed for each of the six classrooms, the changing room and the gym. Results of these measurements are presented in Tables 2 and 3.

Table 2. **CO_2 concentrations and physical parameters defining comfort conditions inside the rooms in the primary school after thermal modernization**

Room type		Outside	Classroom						Changing room	Gym
			1	2	3	4	5	6*		
Cubic volume, m^3		–	136	92	136	184	72	144	17	184
CO_2 ppm	Min	707	1515	866	767	824	887	848	837	854
	Max	786	2817	2289	2590	2786	2221	3235	2557	2930
	Mean	725	2146	1287	1348	1327	1657	1946	1466	1506
	SD	13	386	333	581	519	340	619	362	492
t °C	Min	17.6	21.7	22.1	23.0	22.5	21.5	25.5	17.1	17.8
	Max	26.7	26.3	25.4	27.3	25.0	26.5	28.0	23.8	22.6
	Mean	23.5	25.3	23.7	25.3	23.6	24.7	27.0	22.2	19.4
	SD	2.4	0.8	0.8	1.1	0.8	1.0	0.5	1.0	0.9
Humidity %	Min	34.6	21.6	41.9	22.5	21.7	30.3	20.8	25.0	65.7
	Max	66.0	42.4	51.2	32.2	38.2	42.7	32.2	43.7	77.2
	Mean	44.8	26.9	45.9	28.8	26.8	36.4	27.1	32.0	70.5
	SD	7.0	3.0	1.5	2.3	3.7	2.4	2.7	2.8	1.7

SD - standard deviation
* - IT classroom

Mean values of the carbon dioxide concentrations in the building of the school after thermal modernization ranged from 1,287 ±333 to 2,146 ±386 ppm. Furthermore, in the school without thermal modernization, mean CO_2 concentrations ranged from 936 ±196 to 1,878 ±567 ppm. For comparison, mean concentration of CO_2 in the old kindergarten building after thermal modernization was in the spring season 1,375 ±826 and 1,091 ±631 ppm, for older and younger children, respectively [14]. The ratio of mean indoor and outdoor carbon dioxide concentrations in the WTM (I/O) reached values from 1.8 to 3.0, whereas in NTM, this value ranged from 1.1 to 2.2.

The CO_2 levels were compared with classification of indoor air quality according to the PN-EN 13779:2008 standard [12], with division of indoor air quality into four categories according to Table 1.

Table 3. **CO_2 concentrations and physical parameters defining comfort conditions inside the rooms in the primary school without thermal modernization**

Room type		Outside	Classroom						Changing room	Gym
			1	2	3	4	5*	6*		
Cubic volume, m^3		–	106	150	69	53	60	150	49	154
CO_2 ppm	Min	773	757	707	732	971	857	791	817	777
	Max	863	1527	1464	2697	2921	3358	1976	1651	1821
	Mean	820	936	1001	1425	1878	1789	1259	1296	1331
	SD	28	196	188	524	567	668	292	198	329
t °C	Min	24.7	21.10	20.5	23.7	20.8	21.6	22.8	17.8	21.3
	Max	27.1	24.80	25.0	29.7	23.5	24.5	27.5	18.7	27.6
	Mean	25.7	23.00	22.5	27.1	22.3	23.0	26.0	18.3	24.8
	SD	0.7	0.90	1.0	1.7	0.7	0.9	1.2	0.1	1.4
Humidity %	Min	42.5	45.10	37.1	31.7	43.0	37.2	34.4	46.9	41.2
	Max	45.1	53.50	52.1	48.0	51.7	46.2	45.6	52.1	49.0
	Mean	44.1	48.60	41.6	34.3	47.0	40.7	40.3	49.7	45.6
	SD	0.8	1.90	1.9	1.6	1.8	2.2	2.3	1.2	1.5

SD - standard deviation
* - IT classroom

Figures 1 and 2 present characterization of air quality with division into indoor air quality classes.

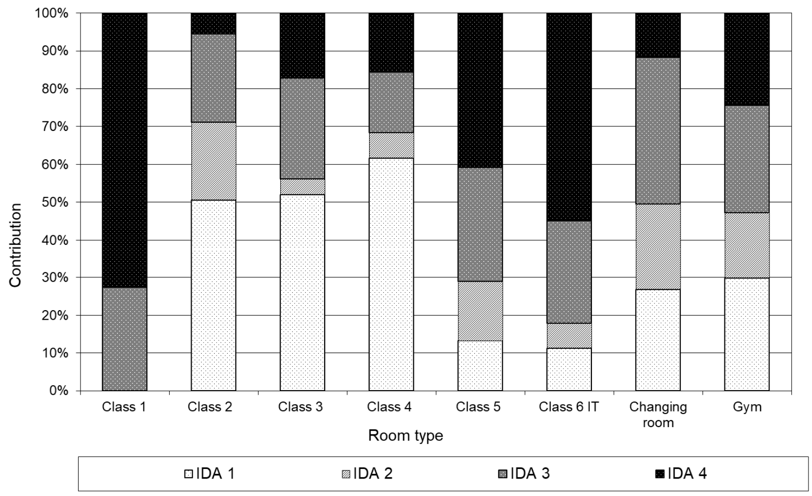

Fig. 1. Frequency of CO_2 concentrations with levels that may influence the health of children in the school building after thermal modernization

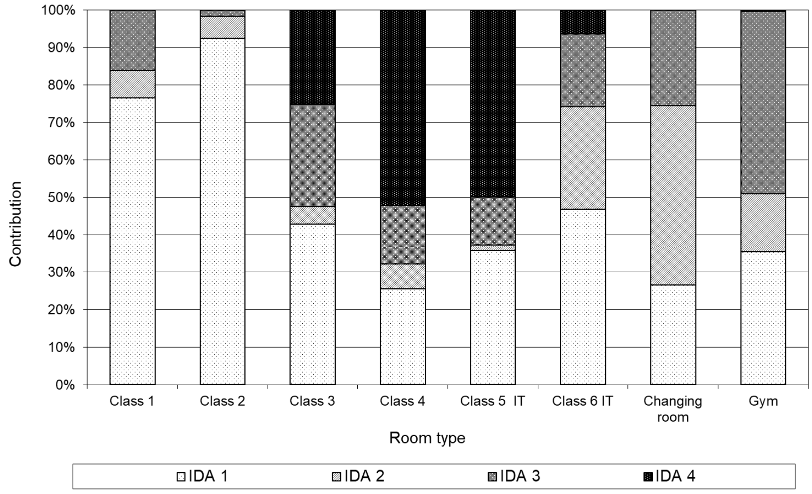

Fig. 2. Frequency of CO_2 concentrations with levels that may influence the health of children in the school building without thermal modernization

Comparison of individual rooms in both schools (without and after thermal modernization) revealed low indoor air quality in all rooms after thermal modernization (IDA 4). For the WTM school, low indoor air quality was dominant in class 1 (> 70%), where students didn't go to corridors during breaks. For comparison, in the examinations conducted in an old nursery school low indoor air quality (IDA 4) was observed in 40÷60% [15]. In the NTM school, low indoor air quality was recorded in classes 3-6. These were classes with the lowest cubic volume and computer rooms. In other rooms of the NTM school, indoor air quality ranged from high (IDA 1) to moderate (IDA 3).

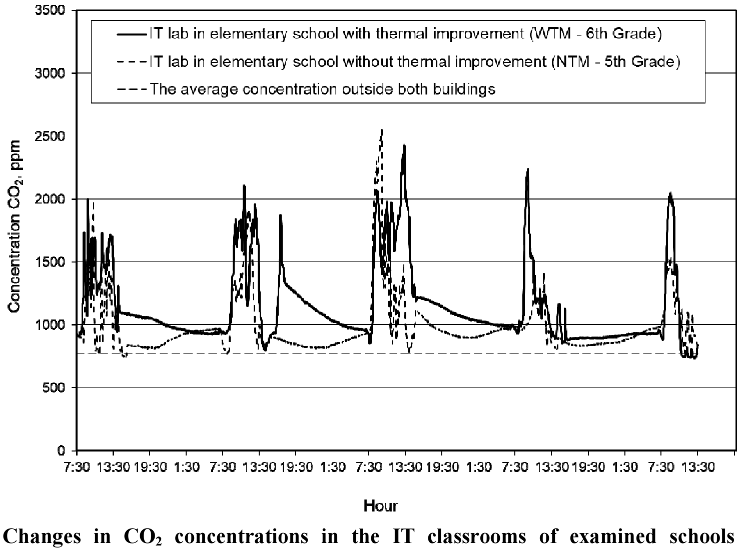

Fig. 3. Changes in CO_2 concentrations in the IT classrooms of examined schools during a school week

The second series of the examinations involved the measurements of the parameters outside and inside the buildings over the school week (from Monday to Friday). IT classrooms, which are characterized by a high percentage of low quality air, were chosen for the determinations. As presented in Figure 3, a similar pattern of changes in CO_2 was found during measurements in both classrooms. Despite a twice smaller cubic volume of the IT classroom in the NTM school with similar number of students in both schools, better air exchange was ensured in the NTM.

Conclusions

Thermal modernization of a building has a substantial effect on its air exchange rate, which is closely related to the level of indoor CO_2 concentration. Depending on the characteristics of the internal environment of buildings, air quality may vary in the range from high (IDA 1) to low (IDA 4).

As demonstrated in the study, low indoor air quality leads to students' feeling discomfort, which makes it difficult to focus attention. The students may experience problems with concentration and be sleepy, which leads to deteriorated learning efficiency.

The results obtained in the study showed that thermal modernization of old buildings leads to deteriorated indoor air quality, which was confirmed by high CO_2 concentrations. In the context of reduction of low emissions and STOP-smog actions, a number of information campaigns have been performed recently while tools for financing thermal modernization projects have been implemented. Striving for high level of building tightening ensures, on the one hand, good thermal insulation, but on the other hand, it reduces access to fresh air. It should be emphasized that thermal modernization of buildings without improving ventilation efficiency through replacement from natural into mechanical ventilation may lead to deterioration of air quality and thus worse health status of building users.

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Streszczenie

Pomimo iż ditlenek węgla nie jest uważany za trujące zanieczyszczenie powietrza, poziomy jego stężeń wewnątrz budynków mogą skutkować negatywnym wpływem na użytkowników danych pomieszczeń. Wśród najczęściej opisywanych problemów zdrowotnych wymienia się uczucie zmęczenia i jego konsekwencje (bóle głowy, złe samopoczucie, kłopoty z koncentracją). W celu oceny potencjalnych skutków zdrowotnych dokonano pomiarów stężeń ditlenku węgla wraz z parametrami fizycznymi (temperaturą i wilgotnością względną) w pomieszczeniach dwóch szkół podstawowych zbudowanych w XIX wieku. Budynek jednej z nich został poddany termomodernizacji, w drugim jej nie przeprowadzono. Uzyskane wyniki wskazują na częstsze występowanie niskiej jakości powietrza w szkole poddanej termomodernizacji (do 70% czasu w ciągu dnia nauki) w porównaniu do szkoły bez termomodernizacji (do 52% czasu). Przeprowadzone badania wskazują, iż uczniowie budynku szkoły podstawowej poddanego termomodernizacji są częściej narażeni na podwyższone stężenia ditlenku węgla w czasie lekcji aniżeli uczniowie budynku szkoły niepoddanego termomodernizacji, co w konsekwencji może dla nich stanowić zagrożenie zdrowotne.

Słowa kluczowe: **ditlenek węgla, szkoły, narażenie uczniów, termomodernizacja**