

Indoor Air Quality in Schools Located in Poland, Lublin Province

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ABSTRACT

The quality of indoor air in educational institutions is a critical determinant of the health and well-being of students. The purpose of the study was indoor air quality monitoring carried out for different age groups of students in grades IV–VIII or college classrooms (students used the classroom according to the schedule, the same group uses the room for up to 2 classes), I–III (students stay in the classroom for all classes, leaving only during breaks), kindergarten “0” (students are practically in one and the same room all day). The individual measurements included measurement of CO₂ concentration, concentration of PM_{2.5} and PM₁₀ particles, formaldehyde, volatile organic compounds (VOCs), along with monitoring of changes in temperature and humidity in the classroom. The results indicate that children are exposed to elevated levels of these pollutants for a significant portion of their school day, which can have implications for their health and well-being. The findings reveal significant deviations from the recommended levels, emphasizing the need for improved ventilation and monitoring practices.

Keywords: indoor air quality, CO₂, PM_{2.5}, PM₁₀, formaldehyde, volatile organic compounds, Polish schools.

INTRODUCTION

According to the World Health Organization (WHO), indoor air has a greater impact on human health and well-being than outdoor air. On the one hand, this is due to the amount of time spent by people indoors (almost 90% of their lives), and on the other hand, the concentration of pollutants in a confined space. Since much has been done to reduce the emission of harmful substances into the atmosphere, the indoor concentrations of many pollutants are now higher than in outdoor air (WHO, 2010; Cichowicz et al., 2014; Cichowicz et al., 2015; Sowa et al., 2017; Sowa, 2002).

The exposure to harmful substances is particularly important for young organisms, and schoolchildren often spend more than eight hours a day (one-third of their time) in classrooms. Many years of research have proven that indoor air quality has a significant impact not only on the health of users, but also on the ease of learning, memorization and overall well-being (Zander-Swiercz, 2019; Mainka A. et al., 2015; Mainka A. et al., 2018). In Poland, the majority of educational

facilities are buildings from the 1960s and 1970s, which have undergone various types of renovations in recent years. As part of these, measures were often taken to reduce energy consumption, mainly through the modernization of central heating systems and heat substations, insulating the building envelope and replacing window frames.

Reduction of energy consumption is also enforced by current legislation. Since January 2017, the values of permissible energy consumption indicators EP for newly constructed buildings and certain heat transfer coefficients U for the building envelope have changed, in accordance with the amendment of the regulation on technical conditions to which buildings and their location should conform, which came into force on January 1st, 2014. This solution is aimed at fulfilling the provisions of Article 9(1) of the Energy Performance of Buildings Directive, according to which by December 31st, 2020, all new buildings should be near-zero energy buildings, and after December 31st, 2018, new buildings occupied and owned by public authorities (including schools) were near-zero energy buildings (nZEB). Referring to

Article 2(2) of the EPBD Recast, an nZEB building should be understood as a building with a low demand for non-renewable primary energy and a high degree of use of renewable energy. For example, in Poland, an nZEB school building should have an EP ratio of 45 kWh/(m²·year) and the heat transfer coefficients of the building envelope according to the data compiled under the technical conditions.

In addition, in accordance with Article 39(2) of the Law on the Energy Performance of Buildings and Article 9(3) of the Directive, Annex 1 to the Resolution also includes the government actions taken to promote low-energy buildings, including the design, construction and remodeling of buildings in an energy-efficient manner. Unfortunately, very often the remedial actions taken result in deterioration of indoor air parameters.

Most schools in Poland are two-story buildings with gravity ventilation and a traditional heating system based on panel radiators. The height of the gravitational ventilation ducts, especially for the upper floor, is very small (1–2 m) which means that during windless periods, the value of the active pressure causing air flow is low and prevents the inflow of air into the room. In addition, it is often impossible to reconstruct the ventilation system without significant interference with the building structure (Gładyszewska-Fiedoruk, 2011; Połednik, 2013; Krawczyk et al., 2016).

AIR QUALITY AND USERS' HEALTH

Medical reports show a steady increase in the number of people suffering from allergies. It is estimated that today one in five people has hay fever, one in five school-aged children has asthma, one in six suffers from allergic skin lesions, and one in 20 people has urticaria attacks. Indoor air quality depends on the properties of aerosols present indoors. Indoor air quality can be affected by the quantitative and mass concentration, granulometric composition, as well as chemical and biological composition of aerosol particles. The physical properties of aerosols also determine the dynamics of aerosol dispersion indoors, in addition to the location where aerosol particles are deposited in the human respiratory system (Chmielewski, 2011; Chmielewski 2012; Fisk, 2013; Murkowski and Skórska, 2016). With every breath, people are exposed to the inhaled aerosols, as they can account for between 5 and

34% of indoor air pollution. The particles with size which does not exceed 7 µm, i.e. those included in the inhaled fraction, are a particular threat. The particles with a diameter of 4.7–7 µm are deposited in the throat, 3.3–4.7 µm reach the trachea and primary bronchi, 1.1–3.3 µm can enter the secondary and terminal bronchi, and those under 1.1 µm reach the bronchioles of the lungs. The particles smaller than 2.5 µm are considered to be particularly dangerous. According to PN:EN, the following fractions of aerosol particles can be distinguished:

- Extra-tracheal fraction – mass share of particles of inhaled fraction not penetrating beyond the larynx (PN-EN481:1998);
- Tracheal fraction – mass share of particles of inhaled fraction penetrating beyond the larynx (PN-EN 12792:2006);
- Tracheobronchial fraction – mass share of particles of fractions penetrating deeper through the larynx, but not entering the laryngeal airways (PN-EN 12792:2006);
- Respirable fraction – the fraction of aerosol penetrating the respiratory tract that poses a health risk when deposited in the gas exchange area (PN-EN 12792:2006);
- Thoracic fraction – the fraction of aerosol that enters the respiratory tract in the thoracic region, which poses a health risk when deposited in the tracheobronchial area and gas exchange area (PN-EN 12792:2006);
- Inhalable fraction of particles – the inhalable fraction, which is the mass fraction of all airborne particles, inhaled through the nose and mouth (EN 14031:2006).

Regulations, standards and ordinances in force or recommended in various countries identify carbon dioxide as an indicator of indoor air quality. It is generally recognized that controlling and diluting CO₂ will maintain an adequate microclimate free of excessive gaseous or particulate pollutants. CO₂ concentration is considered an indicator of ventilation intensity. Its value indoors depends on its value in the external environment and CO₂ emissions from internal sources. In addition, it is important information in determining the quality of indoor air.

Studies show that the existing solutions of gravity ventilation systems in schools are unsuitable for their structure and use. The performance of ventilation ducts is variable and largely dependent on weather conditions as well as the tightness

of windows. The widespread conversion to windows with high tightness results in minimal airflows and near-zero air exchange, which is one of the main reasons for the occurrence of excessive indoor concentrations of various pollutants, as well as the negative perception of indoor conditions by users. The situation is concerning, as the studies conducted so far confirm the unsatisfactory air quality in educational buildings (Simoni et al., 2010; Telejko, 2017; Basińska et al., 2019; Bartyzel et al., 2020).

Children spend a significant portion of their day in school environments. The quality of the air they breathe during this time can have a profound impact on their health, cognitive abilities, and overall well-being (Ferdyn-Grygierek, 2008; Mijakowski and Sowa, 2017; Johnson et al., 2018). This study seeks to understand the indoor air quality in schools in the Lublin Province, with a particular focus on CO₂, formaldehyde, and PM_{2.5} concentrations, as well as temperature variations.

While there have been numerous studies on indoor air quality in various settings, there is a noticeable gap in the literature regarding the specific conditions in schools in the Lublin Province. This study aimed to bridge this gap by providing a comprehensive analysis of the indoor air quality in these schools. The primary objective of this study was to assess the indoor air quality in schools located in the Lublin Province, focusing on CO₂,

formaldehyde, PM_{2.5} concentrations, and temperature variations. The study also aimed to understand the impact of certain behaviors, such as ventilation habits, on the observed concentrations.

RESEARCH METHOD

Measurements were carried out using IAQmeter meters (Figure 1), which allow continuous measurement and recording. The devices were installed in classrooms and in the school corridor, in the users' breathing zone. A portable pSENSE meter was used to measure the CO₂ concentration in outdoor air.

In addition, the number of users and any activities that might affect the result were written down (including opening windows). Teachers were asked to keep a log of activity and use of the room. The information was used to verify the results obtained, eliminate possible measurement errors, and thus correctly formulate conclusions.

The IAQmeter has the ability to continuously record the following air quality parameters:

- air temperature,
- relative air humidity,
- formaldehyde concentration,
- CO₂ concentration,
- VOC concentration,
- concentration of PM₁₀, PM_{2.5} particles.



Fig. 1. IAQmeter meter

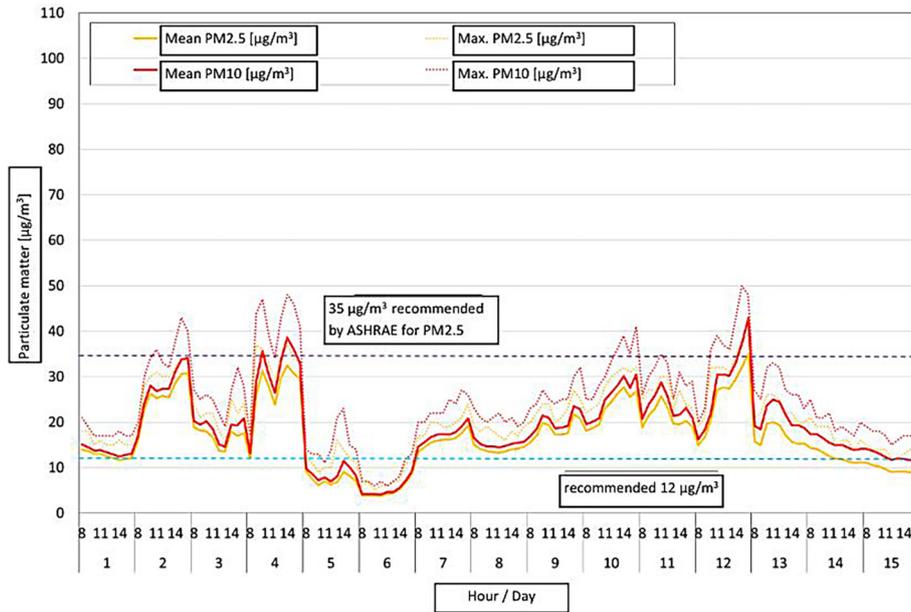


Fig. 3. Concentration distribution of PM2.5 and PM10 particles in ROOM A

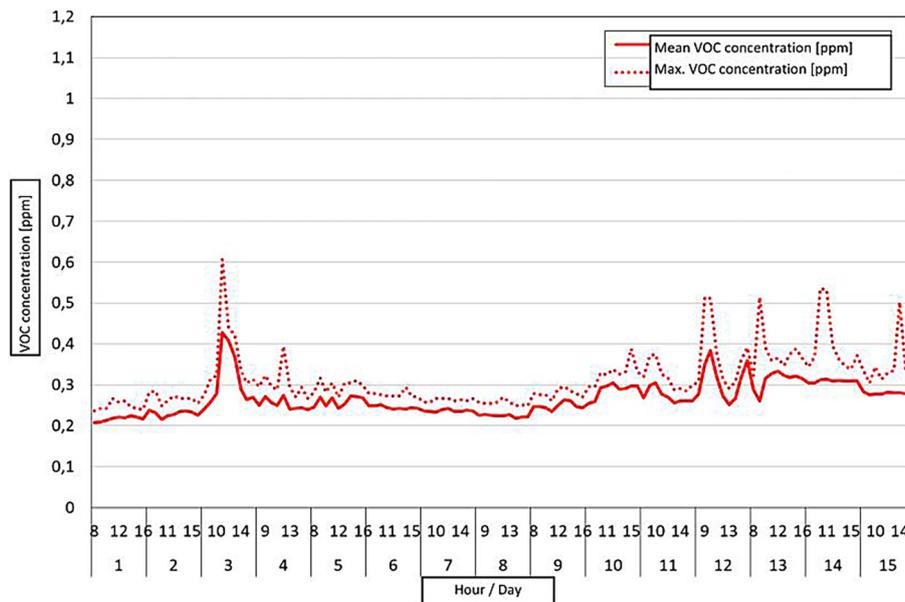


Fig. 4. Change in VOC concentration in ROOM A

of exposure to particulate pollutants would be significantly worse. Despite frequent ventilation, average temperatures above 20 degrees (mostly above 21, 22°C, Table 3) were recorded in every room studied. In ROOM A, the temperature reached 25°C. Studies have shown that during breaks, in the corridor, students are often under worse conditions than recorded in the classroom.

It should be noted that during the measurements, teachers ventilated the room not only during breaks, but also left the windows temporarily ajar during classes. This situation applied to

more than 95% of the compiled results. The information about the length of ventilation would further help interpret the differences in the CO₂ concentrations obtained. Therefore, it is recommended to repeat the study with close monitoring of the behaviors related to the duration of window opening/tilting. For a majority of the school day, children are exposed to CO₂ concentrations above the recommended 1000 ppm. The lowest CO₂ and formaldehyde concentrations were observed in the room with the largest volume. The renovation activities in adjacent areas significantly impacted the

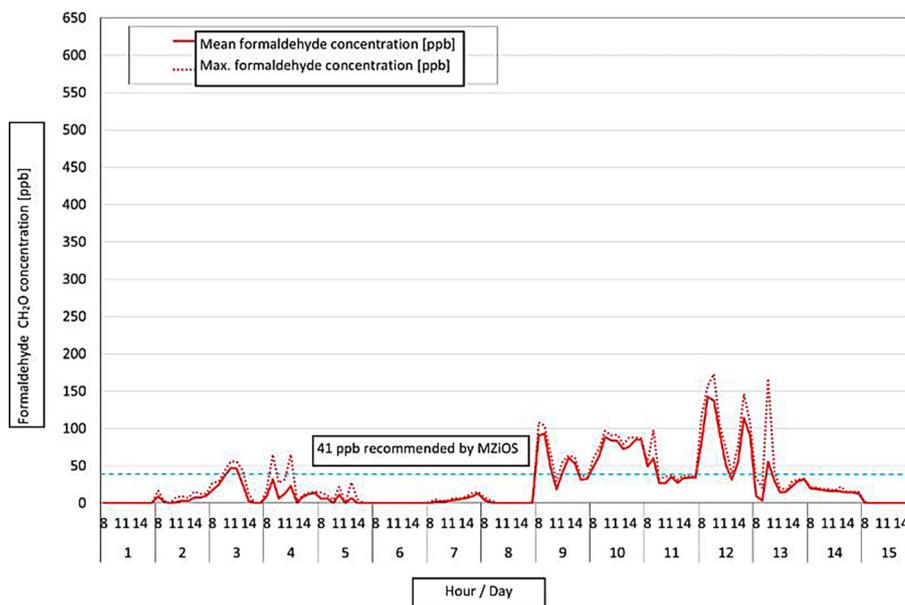


Fig. 5. Change in formaldehyde concentration in ROOM A

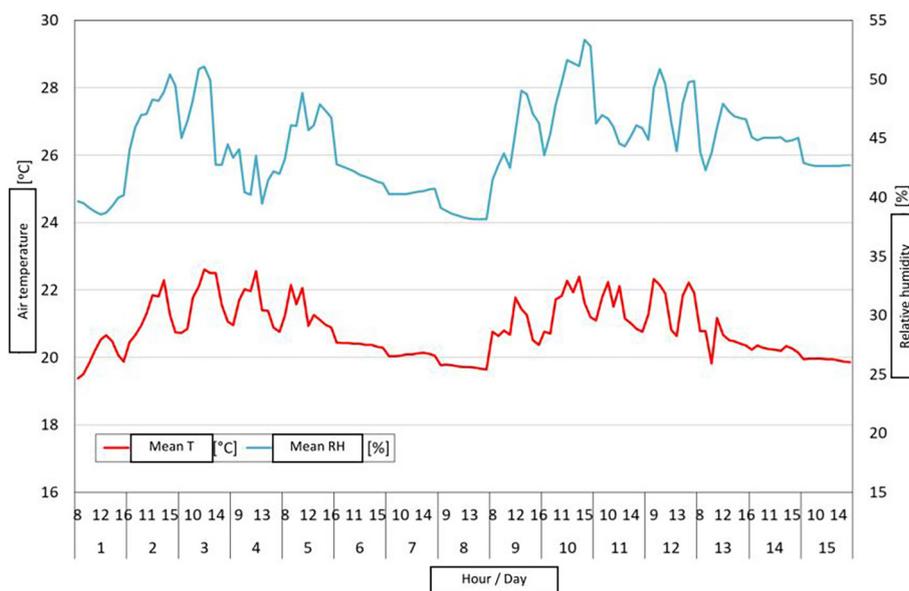


Fig. 6. Changes in temperature and humidity in ROOM A

formaldehyde concentrations, especially in Room C and the corridor. The PM_{2.5} concentrations in Room C exceeded the recommended limit of 12 $\mu\text{g}/\text{m}^3$, reaching values greater than 35 $\mu\text{g}/\text{m}^3$. Despite regular ventilation, temperatures in all rooms studied exceeded 20°C, with Room A reaching up to 25°C. The corridor conditions during breaks were often worse than those in the classrooms.

The elevated levels of CO₂, formaldehyde, and PM_{2.5} observed in the study are concerning. These pollutants can have various health implications, including respiratory problems, cognitive

impairments, and other health issues. The fact that children are exposed to these conditions for a significant portion of their day is alarming. The impact of room volume on pollutant concentration suggests that larger spaces may offer better air quality. However, the influence of external factors, such as renovation activities, can significantly alter these conditions. The findings related to temperature indicate that, despite the ventilation efforts, maintaining a comfortable temperature is a challenge in these schools. Referring to the work by Sadrizadeh et al. (2022), it was noted that the

Table 1. Assessment of the exposure to CO₂ concentrations

Measured CO ₂ concentration	Number of hours [h]	Time spent in a given concentration [%]
Room A; V = 188 m ³		
>1000 ppm	66.18	91.9
>1500 ppm	52.67	73.2
>2000 ppm	25.22	35.0
Room B; V = 236.6 m ³		
>1000 ppm	67.49	93.7
>1500 ppm	46.82	65.0
>2000 ppm	11.33	15.7
Room C; V = 132 m ³		
>1000 ppm	71.02	98.6
>1500 ppm	61.42	85.3
>2000 ppm	43.71	60.7

Table 2. Assessment of the exposure to PM_{2.5} concentrations

Measured concentration of PM particles	Number of hours [h]	Time spent in a given concentration [%]
Room A; V = 188 m ³		
PM 2.5 ≥35 µg/m ³	0.51	0.7
Room B; V = 236.6 m ³		
PM 2.5 ≥35 µg/m ³	1.8	2.5
Room C; V = 132 m ³		
PM 2.5 ≥35 µg/m ³	35.69	49.6

Table 3. Assessment of overheating exposure in classrooms

Measured air parameters	Number of hours [h]	Time spent at elevated temperatures [%]
Room A; V = 188 m ³		
Temperature ≥21°C	48.82	67.8
Room B; V = 236.6 m ³		
Temperature ≥21°C	64.49	89.6
Room C; V = 132 m ³		
Temperature ≥21°C	68.51	95.0

problem of poor air quality in schools is not only an issue in Poland, but also in the countries of the European Union and beyond. In most school environments around the world, CO₂ concentrations are high because natural ventilation is the main solution used to improve the quality of air (Canha et al., 2016; Schibuola et al., 2018; Schibuola et al., 2018a). The WHO does not treat CO₂ as a pollutant. However, its concentration affects the assessment of indoor air quality (IAQ) (Schibuola, Tambani, 2020); HVAC industry often misrepresents this fact, even though efforts are made to correct this inconsistency in technical reports, standards, conference proceedings, etc. (ASHRAE, 2022).

Pupils' physical activity, the way rooms are used (opening windows, doors) and ventilation efficiency affect the CO₂ levels in classrooms (Heebøll et al., 2018; Stabile et al., 2019; Kapalo et al., 2019). In Kuwait, Al-Awadi (2018) et al. studied the effect of CO₂ concentration on students' health in 3 schools. The obtained results showed the effect of elevated CO₂ concentrations in classrooms on reduced academic performance. In turn, Madureira et al. (2015) investigated the relationship between levels of this pollution in primary schools in Portugal and health problems such as allergies and asthma. Their measurements showed that CO₂ concentrations exceeded 1,000 ppm in classrooms

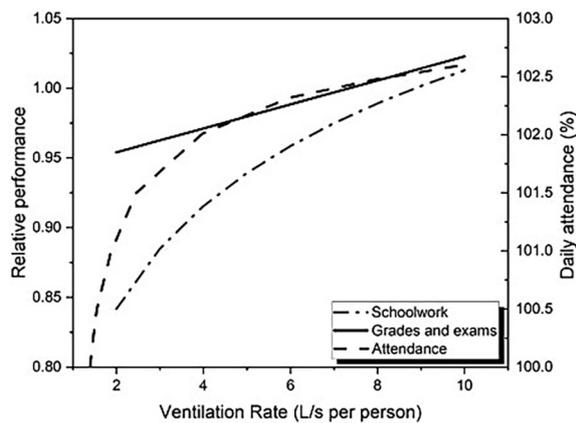


Fig. 7. Speed of completing school assignments, national tests and exams, learning along with daily student attendance in relation to ventilation (Wargocki et al., 2020)

with high occupancy rates, resulting in poor quality of indoor air. The data regarding carbon dioxide were also used in United Kingdom to assess the increase in airborne diseases in 45 classrooms in 11 schools (Vouriot et al., 2021). The study linked the variability of CO₂ concentration and ventilation rate to the risk of infection depending on the season; January was the month that corresponded to the greatest risk. Kalimeri et al. (2016) conducted measurements of formaldehyde, temperature, relative humidity, and CO₂ concentration, in school environments in Greece. They showed that inappropriate ventilation constituted the main cause of poor quality of indoor air. Turunen et al. (2013) studied IAQ as well as health status of sixth grade students in Finnish schools. They observed a significant statistical correlation between the reported poor quality of indoor air and temperature. They also found that higher the temperature and the lower the ventilation efficiency, the more students reported poor air quality (CAQ – Class Air Quality). Smedje et al. (Sweden) (1997) found no significant association between asthma symptoms and correctly measured IAQ parameters, such as CO₂ concentration and humidity. Simoni et al. (2010) studied the respiratory system of schoolchildren in Norway and found that the children who spent more time indoors with high CO₂ concentrations (above 1000 ppm) were more likely to have a dry cough. A similar situation was observed for PM10 and the symptoms related to upper airway patency (mainly nasal). Wargocki et al. (2020) published studies on the effects of CAQ that reported the results of CO₂ measurements (an approximate indicator of classroom ventilation) together with

students' cognitive performance. Their aim was to determine the influence of indoor environmental parameters on the performance of students as well as determine the minimum requirements of air quality necessary to ensure adequate learning conditions. They separately analyzed the results of the study, which assessed school work, exams, grades, and absenteeism rates. With the lack of an air quality index, CO₂ was used as a benchmark for IAQ (ventilation) assessment. Figure 7 presents the dependencies resulting from the analysis. Wargocki et al. stated that if the rate of ventilation within classrooms was increased to 10 l/s per person, significant benefits would be achieved, contributing to improved learning and reduced absenteeism. A conclusion was drawn that CO₂ concentrations should be maintained at a level of 900 ppm or below. There is no data on the possible benefits of keeping the levels of CO₂ below 900 ppm or maintaining ventilation rates at more than 10 l/s for each person. Nevertheless, since the relation between operating efficiency and ventilation is log-linear, improvements in ventilation would likely contribute to additional benefits, presented in Figure 7. Given the observed conditions, it is imperative to:

- Implement more effective ventilation strategies, possibly including mechanical ventilation systems.
- Monitor and control renovation activities to minimize the release of pollutants.
- Educate staff on the importance of regular and effective ventilation.
- Repeat the study with a focus on monitoring ventilation behaviors to better understand their impact on indoor air quality.

CONCLUSIONS

The study highlighted the need for improved indoor air quality in schools in the Lublin Province. Addressing these issues will not only enhance the health and well-being of the students but also provide conducive environment for learning and development.

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