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Assessment of Exposure to Particulate and Microbiological Contaminants in a Lecture Room

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ABSTRACT

The purpose of this study was to determine the amount of particulate and microbial contaminants, i.e. bacteria and fungi found in indoor air in a lecture hall in one of Lublin's universities and their classification. In the research part, the amount of particulate and microbial pollutants was measured. Bioaerosols were investigated using an Andersen cascade impactor, which was located in the central part of the room at a height of 1–1.5 m, and single-level impactors. Identification of the microorganisms present in indoor air was carried out. The air in the room was sampled before the start of class to determine the "background," i.e. the concentration level of microbial contaminants in the classroom without the presence of students. Subsequent measurements were taken during teaching activities in the presence of students and the teacher. The study shows that the air condition in the classroom during its operation met the requirements in terms of PM2.5, PM10 and microorganisms. The highest risk was recorded for carbon dioxide. Moreover, the highest recorded readings of this pollutant coincided with the maximum concentrations of the other monitored quantities. Therefore, it can be unequivocally stated that in the case of the analyzed room, monitoring carbon dioxide and adjusting the size of the ventilation airflow to maintain its concentration within the limit of 1000 ppm would guarantee the maintenance of adequate indoor air quality. The study showed no correlation between CO_2 concentration and measured concentrations of microbial contaminants.

Keywords: Indoor air quality, carbon dioxide, PM2.5, PM10, sick building syndrome, biological contaminants.

INTRODUCTION

Air pollution is a serious problem affecting both indoor spaces and outdoor areas. People are spending increasingly longer time indoors, often with inadequate ventilation. According to the World Health Organization (WHO), people spend about 90% of their time indoors, including 70% at work or school and 20% at home.

In recent years, indoor air quality has become such an issue that it is increasingly being considered in the design of air treatment systems and even the building itself. Almost all students are exposed to indoor air in school buildings while studying. In these environments, pollutants can adversely affect health, productivity, memory and concentration, especially in the case of students with learning disabilities.

Classroom and school environments are highly polluted for the following reasons: crowded classrooms, short breaks, inadequate ventilation (mostly gravity), outdoor pollution, windows that are too tight (interfering with gravity ventilation by lack of fresh air from the outside) and high radon levels. Groundwater and building materials containing radon are responsible for the presence of this type of indoor pollution. Radon gas enters rooms through cracks and fissures or leaking holes prepared for sanitary installations. The amount and its concentration indoors depend on several factors, such as the substrate on which the building is founded, among others, the porosity and permeability of the soil.

Therefore, it is essential to monitor the indoor environment especially in rooms where the presence of children or the elderly is anticipated.

Quality of air and indoor environment

Indoor air often contains a large amount of air pollutants that can affect human well-being and health. These pollutants can be in the form of particulate matter or volatile organic compounds, among others (Ranson et al., 2020). Another definition of indoor air quality is that it is "a state of air cleanliness that meets human expectations." Air quality varies from building to building, place to place, or time to time, and in response to user's actions (Fanger et al., 2003).

The term perceived air quality (PAQ) is used to assess air quality based on people's sensory perception. The study of perceived indoor air quality mainly uses psychophysical methods. Perceived indoor air quality is determined by the type and amount of odorous chemical pollutants, as well as thermo-humidity parameters of the air (Fang et al., 1998; Toftum et al., 1998). It has been shown that users prefer cooler and drier indoor air. To achieve the desired perceived air quality, it is best to keep indoor air temperature and relative humidity at moderate levels (Popiolek, 2005).

Two units are used to describe perceived air quality: the olf, originating from the Latin word *olfactus* (smell), is the total amount of odor impurities that people smell, which is emitted by one model person. A model person is a middle-aged adult with a hygiene standard of 0.7 baths/day. The standard olf unit is used when human senses are used to assess the indoor air quality. The second unit is decipol, from the Latin word *pollutino* (pollution), is the concentration of indoor air pollutants associated with the presence of one standard person (one olf) at a ventilation rate of 10 dm/s of fresh air under steady-state conditions. In buildings with poor health conditions, pollutant concentrations can exceed 10 decipoles (Polednik, 2013).

Sick building syndrome

In 1982, the World Health Organization (WHO) defined syndromes that occurs in enclosed spaces, the so-called 'sick building syndrome' (SBS). These are facilities in which 20% of occupants experience malaise, chronic headaches, irritation of the mucous membranes of the eyes, nose, throat, and skin allergies. Buildings with SBS currently cover between 10 and 30% of office buildings (Kronenberg and Berger, 2010).

Parameters of indoor air

Room conditions can be easily described and measured. Several basic parameters determine whether the air is healthy and comfortable for people.

- Temperature – provides so-called thermal comfort as well as determines the well-being and performance of the occupants. The optimal temperature for a person depends on the season and the level of physical activity.
  - at low metabolic rate (e.g., sewing, billing, typing), the room temperature in winter should be 20–22°C, and 23–26°C in summer,
  - at an average metabolic rate (e.g., nailing, plastering), the room temperature in winter should be 18–20°C, and 20–23°C in summer
  - at high metabolic rate (e.g., working with an axe, carrying heavy objects), the temperature should be 15–18°C in winter and 18–21°C in summer.
- Relative humidity, or the amount of water vapor in the air, should be between 40% and 60%. Too low humidity can lead to dry mucous membranes and respiratory problems, while too high humidity can lead to fatigue, lack of oxygen and distraction. In addition, excessive humidity promotes mold growth.
- Air circulation speed should not exceed 0.2 m/s. Larger values can lead to draught effects, while too low can lead to the formation of so-called "cavities" of carbon dioxide.
- Air ionization, electric climate in the air – positive ions, produced by electromagnetic radiation from office equipment, may be harmful to the health of room users. Negative ions, on the other hand, characteristic of the natural environment, have a positive effect on the human body.
- Oxygen concentration – The appropriate concentration is necessary to maintain good health, but too low or too high oxygen concentration negatively affects the performance of the human body.

- Amount of organic substances in the air – they are toxic to humans (e.g., formaldehyde). Their small amounts in the air can cause fatigue, lethargy and general disorientation, while large amounts can be dangerous to health.
- Allergens and microorganisms – mites, fungal and mold spores, pollen, viruses, algae and various bacteria pose a threat not only to people suffering from allergies, but to perfectly healthy people as well (Wolkoff et al., 2022).

Biological contaminants

Biological contaminants in the form of bioaerosols are common in indoor air. They account for between 5% and 34% of all pollutants in indoor air (Gaska and Dudzinska, 2012).

The reasons for increased indoor biofouling are changes in construction technology and the use of sealed plastic windows as well as ventilation and air conditioning systems.

A bioaerosol is a dispersive system in which the dispersing phase is air and the dispersed phase is microorganisms and their metabolites and particles consisting of organic and inorganic substances. Microorganisms include viruses, protozoa, bacterial cells, cell fragments, mycelial fragments and fungal spores (Polednik, 2013). Products of microbial metabolism are endotoxins, enterotoxins, enzymes and mycotoxins. These are often chemically very complex substances. Some microorganisms also produce microbial volatile organic compounds (MVOCs – Microbial Volatile Organic Compounds), which include alcohols, ketones, terpenes and aromatic compounds. These substances contribute to a characteristic odor of indoor air that indicates the presence of microorganisms (Dudzinska, 2013).

Particles of plant, animal and mineral origin are found among the bioaerosol particles in indoor air. Examples include pollen and plant debris, particles from human and animal exfoliation, and particles that enter indoor air as a result of soil erosion (Maus et al., 2001; Golfit-Szymczak and Skowron, 2005). Indoor bioaerosol contaminants can come from both external and internal sources.

Microorganisms in outdoor air can enter a room through doors and windows, as well as enter through cracks, crevices and various leaks in the building structure. Despite many studies, objective data on the quantitative relationship between indoor and outdoor levels of bioaerosols is still sparse. Although external bioaerosols clearly affect the concentration and quality of indoor bioaerosols, the mechanisms of these interactions are not fully understood. One of the main sources of household bioaerosols corresponds to their users. Domestic animals are also an important source of bioaerosols (Jo and Kang, 2006). It is now known that bioaerosols can consist of pathogenic bacteria and viruses, and the presence of ornamental plants can affect the level of these pollutants in a room (Gaska, 2012).

Microbial contamination can occur in building and finishing materials. Various fibrous insulation materials, drywall and wallpaper, are ideal places for microbial growth, similarly to ventilation systems (Raynor et al., 2008).

The air containing bioaerosol contaminants can cause various respiratory diseases, infections, inflammation and allergic reactions, including asthma. Bioaerosols found in indoor air are particularly harmful to people with respiratory diseases, asthma and allergies (Zabiegala et al., 2003).

The development of specific diseases caused by bioaerosol particles depends not only on the type of microbial pathogen, but also on its concentration in indoor air and depth of penetration into the respiratory system. Biological particles larger than 5 μm can only enter the upper respiratory tract. Smaller particles can penetrate deep into the alveoli and settle there, causing allergic alveolitis and other serious lung diseases. This is especially true for bioallergens with ultrafine particles, smaller than 1 μm. The carriers of this allergen can also be fine abiotic particles, such as mineral particulate matter particles and aerosol particles suspended in indoor air, which are formed by the combustion of various fuels (Hargreaves et al., 2003). The formation of bioaerosol by some microorganisms can have teratogenic, mutagenic and carcinogenic effects. The interaction of biotic and abiotic indoor air pollutants can also affect the health of indoor users. An example of this interaction is the symptoms and ailments associated with SBS. The microbiological purity of indoor air can be maintained by ensuring adequate temperature and humidity, as well as adequate ventilation of the room. In this regard, frequent cleaning, vacuuming and regular disinfection are also important (Polednik, 2013).

Types of problems associated with the presence of microbial contamination

Fungi and bacteria isolated from heating, ventilation and air-conditioning systems and other parts of a building can cause problems for people susceptible to infection in two ways: through infection or allergic reaction (Aston et al., 1981). In the case of infection, living organisms penetrate the body's defense system and actively colonize tissues such as the conjunctiva or respiratory tract. Symptoms can range from mild irritation of the eyes, nose and throat to acute pneumonia leading to many deaths, as occurred in Philadelphia in 1976 (Spendlove et al., 1983) due to Legionnaires' disease. In the case of allergic reactions, susceptible individuals become sensitized to antigenic material and suffer from mild "hay fever-type" symptoms, as in the case of allergic rhinitis, to much more severe reactions that can occur with allergic asthma, or pneumonia. Sensitization can be caused by the presence of live microorganisms, protozoan cells, the remains of dead cells or the toxic "waste" they produce. Affected individuals usually experience acute symptoms such as fever, shortness of breath, dizziness, cough, rhinitis and muscle aches and pains, which subside a few days after leaving the building and reappear upon return (Zhong-Can and Helfrich, 1987).

Bacteria – proposals for the criterion of permissible microbiological concentration in rooms

Issues related to the control of microbiological purity of air in world and Polish legislation are still unregulated today, despite the fact that the first attempts were made more than a century ago by Odon Bujawid, who proposed a criterion of acceptable microbiological contamination for living quarters at 50 bacteria in 1 liter of air. Further proposals had to wait until 1970s (Chmiel et al., 2015).

Nowadays in many countries there are already quantitative standards, or acceptable numerical values to help interpret the measurement data obtained. Standards for residential and non-industrial spaces for bacteria, for example, can be found in a 1993 report issued by the Commission of the European Communities – CEC (Table 1).

Similarly to other types of air pollution, there are many more regulations of workplaces. Currently in Poland, the Regulation of the Minister of Health of April 22, 2005 on biological agents harmful to health in the work environment and the protection of the health of workers occupationally exposed to these agents is legally binding (Journal of Laws No. 81, item 716). It is intended to meet the requirements of Directive 2000/54/EC of the European Parliament and of the European Council of September 18, 2000 concerning the protection of workers from risks related to exposure to biological agents at work.

In Poland, there are no recommendations related to the criterion for assessing the exposure to biological agents, reference values or recommendations for indoor air in residential buildings (Gorny et al., 2007).

Due to unregulated national legislation, in order to assess the indoor environment, it is necessary to refer to arbitrary normative values, which are mostly determined based on the analysis of studies available in the literature conducted by researchers over several years. They determine the permissible levels of pollutants in given environments. Table 2 summarizes the values proposed by some world government agencies regarding the level of bacterial concentrations in selected rooms.

Proposals for limit values were also made by individual groups of researchers, including Wells (1955), who proposed a breakdown of permissible concentrations for different seasons of the

Table 1. Acceptable amount of bacteria according to the Commission of the European Communities Report – CEC (1993)

cfu/m^3	Homes	Non-industrial premises
Very low pollution	$<1.0 \cdot 10^2$	$<5.0 \cdot 10^1$
Low pollution	$<5.0 \cdot 10^2$	$<1.0 \cdot 10^2$
Moderate/increased pollution	$<2.5 \cdot 10^3$	$<5.0 \cdot 10^2$
High pollution	$<1.0 \cdot 10^4$	$<2.0 \cdot 10^3$
Very high pollution	$>1.0 \cdot 10^4$	$>2.0 \cdot 10^3$

Table 2. Bacterial concentration limits for selected rooms (Gorny, 2004)

Normative values (reference values cfu/m3)	Document	Organization/institution or country
0 cfu/m^3 – no safe level for pathogenic microorganisms < 1.0·10^2 (homes) and < 5.0·10^1 (non-industrial premises) – very low pollution < 5.0·10^2 (homes) and < 1.0·10^2 (non-industrial premises) – low pollution < 2.5·10^3 (homes) and < 5.0·10^2 (non-industrial premises) – moderate /increased pollution < 1.0·10^4 (homes) and < 2.0·10^3 (non-industrial premises) – high pollution > 1.0·10^4 (homes) and > 2.0·10^3 (non-industrial premises) – very high pollution 4.0·10^3 cfu/m^3 – limit value for classrooms (GB9668–1996) (GB9668–1996)	Biohazards reference manual 1986 Biological particles in indoor environment Report No. 12 1993 Chinese National Standards 1996	AIHA (American Industrial Hygiene Association) CEC (Commission of the European Communities) China

year. Thus, for summer the permissible sum of bacteria and fungi <1.5·10^3 cfu/m^3, while for winter <4.5·10^3 cfu/m^3.

Proposals for limit values were also made by individual groups of researchers, including Wells (1955), who proposed a breakdown of permissible concentrations for different seasons of the year. Thus, for summer the permissible sum of bacteria and fungi is <1.5·10^3 cfu/m^3, while for winter <4.5·10^3 cfu/m^3.

In Poland in the 1970s, the permissible degree of indoor air contamination with microorganisms was determined, which for school rooms was set at 1.5–3.0·10^3 cfu/m^3 for bacteria and 2.0–3.0·10^2 cfu/m^3 for fungi – see Table 3 (Krzysztofik, 1992).

In the case of standards for determining the content of fungi in the air, a number of proposals for permissible concentrations of this group of microorganisms have emerged around the world. Table 4 shows the proposals of some of them.

As the cleanliness of indoor air and the working environment, which should include school facilities, is increasingly important, research is being conducted around the world to determine the existing state of indoor air quality, as well as seeking to improve it. Research in schools has focused mainly on measurements of carbon dioxide, temperature and humidity. Microbiological contaminants have been studied in many types of rooms, but few in schools.

The amount of bacteria and fungi in the air ranges from a few to 1.8·10^9 cfu/m^3 (CFU – colony forming units), depending on the type of room. The saprophytic microflora predominates among the indoor air pollutants. The most common are bacteria belonging to the genera *Micrococcus* (over 42%), Staphylococcus (38.8%), Bacillus (10%), which represent 68–80% of all microorganisms in this environment. Other types of bacteria are also present, such as: *Ochrobactrum,*

Table 3. Permissible degree of microbiological air pollution of utility rooms (Krzysztofik, 1992)

Type of utility room	Permissible number of microorganisms in 1 m^3 of air		
	Total number of microorganisms on MPA medium	Number of hemolytic microorganisms on blood agar	Total number of fungi on Sabouraud medium
Outdoor air	3.0·10^3	1.0·10^2	1.0·10^3
Health care rooms:			
- operating room	1.0·10^2	0	0
- dressing room	1.5·10^2	0	5.0·10^1
- patient room	1.0·10^3	5.0·10^1	2.0·10^2
Residential house rooms:			
- kitchen and dining room	2.0·10^3	1.0·10^2	3.0·10^2
- living room	1.5·10^3	5.0·10^1	2.0·10^2
- bedroom	1.0·10^3	5.0·10^1	1.0·10^2
Classrooms:			
- lecture rooms	1.5·10^3	5.0·10^1	2.0·10^2
- practical exercise rooms	2.0·10^3	1.0·10^2	2.0·10^2
- gymnasiums	3.0·10^3	1.5·10^2	3.0·10^2

Table 4. Fungal concentration limits (Gorny, 2004)

Normative values (reference values)	Document	Organization/institution
$3.0 \cdot 10^2$ cfu/m^3 – highest permissible concentration for common fungi (e.g., for *Cladosporium*) $2.0 \cdot 10^2$ cfu/m^3 – highest permissible concentration for the total fungal flora $2.0 \cdot 10^2$ cfu/m^3 – recommended indoor/outdoor concentration comparison > $2.0 \cdot 10^2$ cfu/m^3 – if various species other than *Alternaria* and *Cladosporium* are present, testing should be carried out > $5.0 \cdot 10^2$ cfu/m^3 – if various species, including *Alternaria* and *Cladosporium,* are present, studies should be undertaken Indoor air quality update.	Indoor air quality update Biocontaminants in indoor environments 1994 Testing of older houses for microbiological pollutants 1991	Cutter Information Corp. Bowser Technical Inc.

Pseudomonans, Aeromora, Xartonans, Pasteurella, Sphingomous. In air with high relative humidity (above 70%), pro-proliferation may be present in the range of 7 to $5.3 \cdot 10^4$ cfu/m^3 of air. The most common species are genera: *Streptomyaj, Nocordia*. Actinomycetes can make up to 25–40% of the total number of bacteria in the air (Libudzisz, 2009).

MATERIALS AND METHODS

The indoor air quality study was conducted in a gravity-ventilated teaching room, located on the 2nd floor of a building, at one of Lublin's universities. Samples were taken during the heating period with and without the presence of students. Temperature, CO_2, PM2.5, PM10, humidity, bacterial and fungal concentrations were measured.

Air samples for measuring the concentration of microbial contaminants were taken using single-stage impactors and a 6-stage Andersen MAS-6 cascade impactor – see Figure 4.1 (level 6 0.65–1.1 µm, level 5:1.1–2.1 µm, level 4: 2.1–3.3, level 3: 3.3–4.7 µm, level 2: 4.7–7 µm and level 1:7 µm and below) – which was located in the central part of the room at a height of 1–1.5 meters. Sampling time was 10 min. Microorganisms were collected on Petri dishes with the appropriate microbiological medium. For fungi, Sabourand agar with chloramphenicol was used as the medium, while for bacteria, soy agar was used. Petri plates were incubated for 48h at 36±1°C for bacteria and for 14 days at 27±1°C for fungi. After the incubation period was completed, quantitative analysis of bacteria and fungi was performed by counting and correcting based on Andersen correlation tables. Subsequently, the concentration of microorganisms was counted in colony-forming units (CFU) on solid medium in 1 m^3 of sampled air (cfu/m^3).

In order to obtain accurate information on the existing state of the air inside the classroom, selected bacterial and fungal colonies were subjected to a thorough qualitative analysis. The qualitative analysis consisted of tests to identify the microbial species present in the air. The identification process consisted of determining the morphological characteristics, cell wall structure (in the case of bacteria) as well as biochemical characteristics of the bacteria and fungi tested.

Other measurements of temperature, humidity, CO_2, and particulate matter were carried out using a sensor designed and manufactured by employees of the Faculty of Environmental Engineering at Lublin University of Technology, allowing continuous measurement and recording, sequentially every 15 seconds. In addition, the number of users and possible activities that could affect the results were written down, among others, opening windows. The measurement was conducted continuously from 9:10 a.m. to 1:12 p.m. In order not to disrupt the teaching process, it was carried out at a single point in the room. The measurement point was located in the central part of the room.

RESULTS

Microclimate parameters

The results of the measurements of CO_2, temperature, PM2.5 and PM10, and relative humidity from the selected week are shown in Figures 1–5.

The changes in carbon dioxide concentration along with the permissible level of carbon dioxide concentration over time and taking into account class attendance are presented in Figure 1.

Carbon dioxide concentrations exceeded the permissible limit of 1,000 ppm several times and varied from 470 ppm to 3,300 ppm.

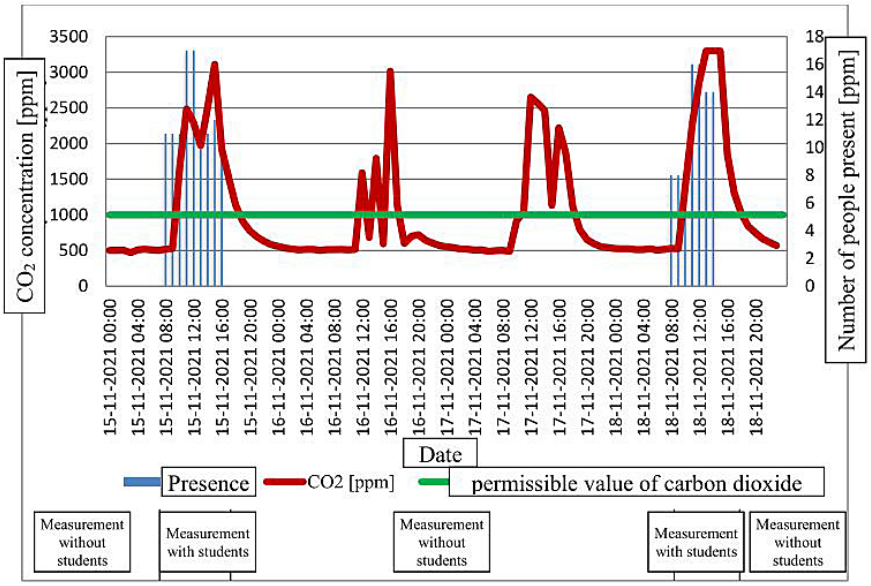

Figure 1. Concentration of carbon dioxide in the indoor air of the teaching room at each measurement hour, taking into account attendance

The recorded maximum concentrations of carbon dioxide pose dangers to human health causing, i.a. a decrease in concentration, drowsiness, and headaches. The temperature change in the room on selected measurement days is shown in Figure 2.

The temperature ranged from 19.8°C to 25.9°C, the room was overheating, possibly due to lack of control with thermostatic valves or weather control in the heating system. The change in concentration of PM2.5 and PM10 in the room on each measurement day is shown in Figures 3 and 4.

The content of particulate matter was higher during the evening hours, the highest PM2.5 content was recorded on the night of November 16–17th, it amounted to 126.1 µg/m^3. The WHO recommended PM2.5 concentration level of 25 µg/m^3 was not exceeded throughout the measurement period. The particulate matter content varied from 16.4 µg/m^3 to 126.1 µg/m^3.

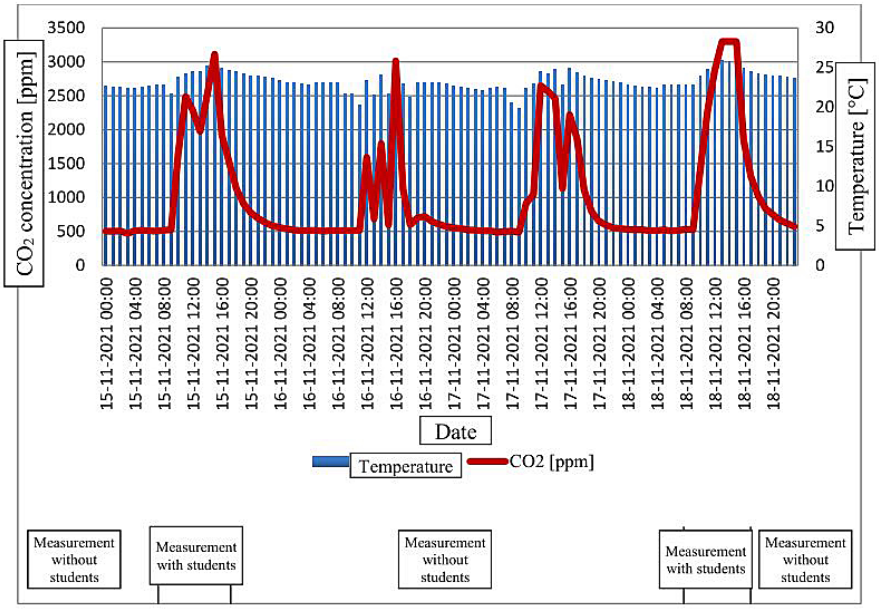

Figure 2. Temperature change

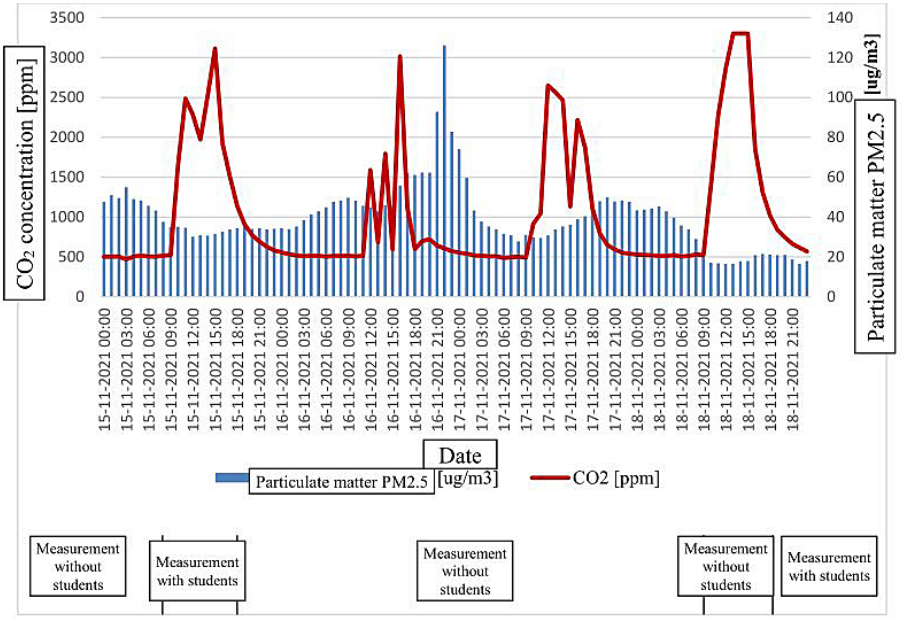

Figure 3. Concentration of particulate matter PM 2.5

The concentration of PM10 as well as the concentration of PM2.5 was higher during the evening hours, the highest content of PM2.5 was recorded on the night of November 16–17th and amounted to 135 µg/m^3, which is below the WHO recommended level of PM10 concentration of 40000 µg/m^3. The dust content varied from 17.7 ug/m^3 to 135.7 µg/m^3.

Elevated concentrations of particulate matter are recorded when coal and wood are burned. Excessive PM2.5 and PM10 emissions also occur when fuels of questionable quality are used. Poor technical condition of the heating system also has a major impact on the increase in emissions, resulting in low combustion efficiency, so regular maintenance and inspection of equipment efficiency is required. Another reason is low chimneys, which can cause pollutants to accumulate near buildings and then penetrate into the premises. To minimize the presence of particulate pollutants in larger buildings, mechanical ventilation with an anti-smog filter is required, which consists of a fine filter and a carbon filter.

Due to the vicinity of solid-fuel-fired single-family houses, it is assumed that the latter reason (chimneys below the window line) may have been the cause of the evening increases in particulate matter concentrations.

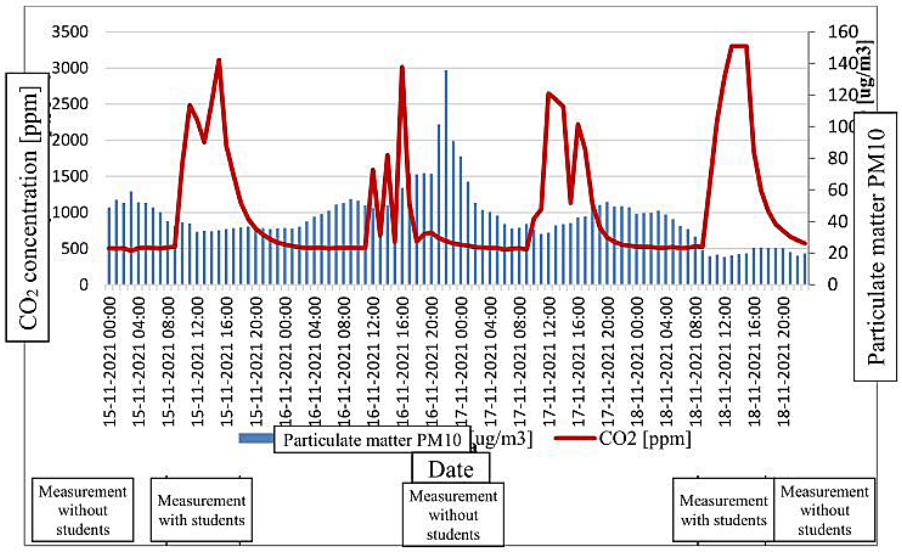

Figure 4. Concentration of particulate matter PM 10

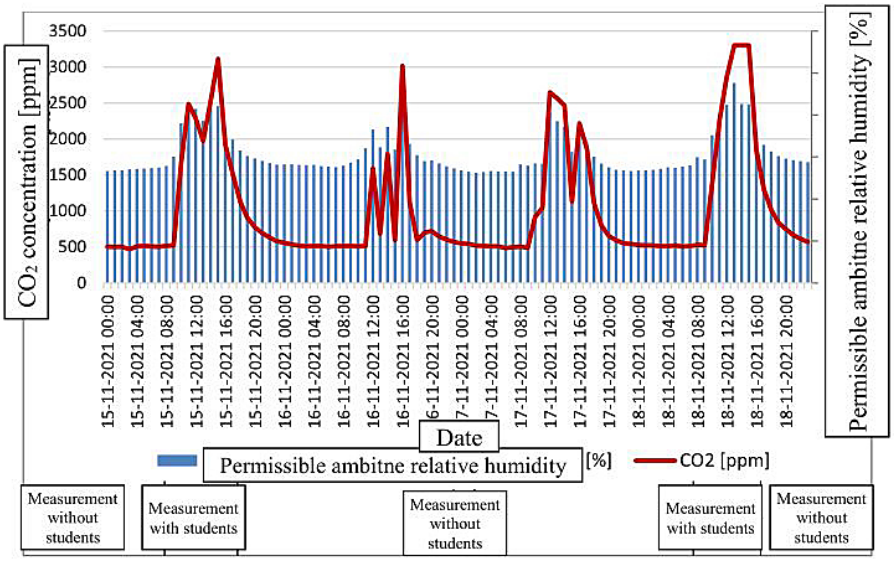

Figure 5. Room humidity on particular days

Graphs of the change in humidity in the project room on each day of measurement are shown in Figure 5.

The recommended indoor relative humidity should be between 30–60%. The recorded relative humidity was in the range of 30–60% from 8:00 a.m. to 8:00 p.m., during the other hours the humidity was less than 30%. Excessively dry air in the room causes a feeling of dryness in the mouth and nose. Furthermore, individuals may experience a sensation of throat irritation and respiratory distress. The relative humidity in the study room varied from 26% to 48%.

Microbiological parametes

Diagrams of the change in the concentration of bacteria in the project room on each measurement day are shown in Figures 6 and 7. The figures compare the bacterial concentration with the CO_2 measurement, which was taken continuously. Due to the use of impactors

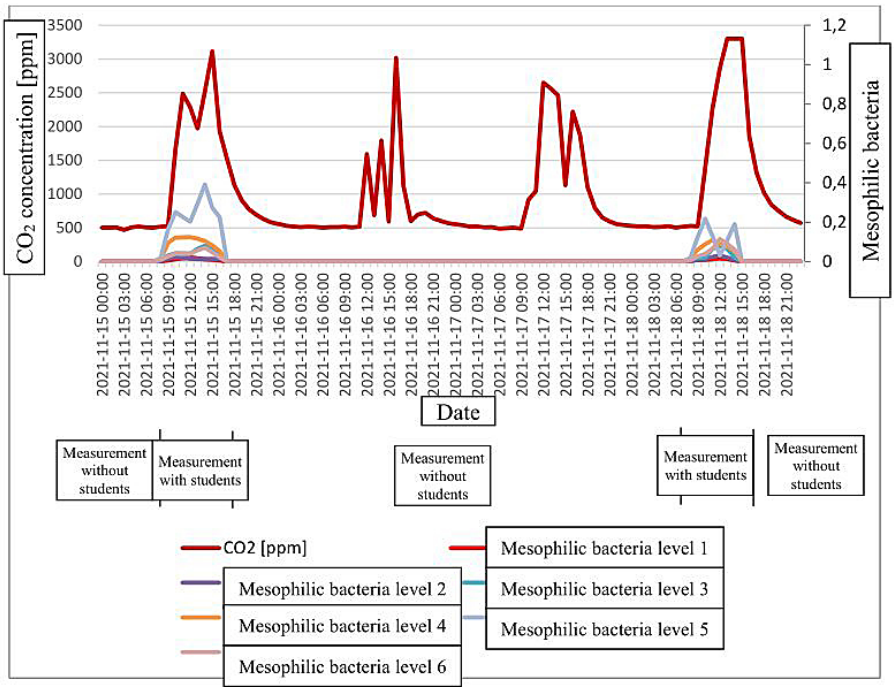

Figure 6. Content of mesophilic bacteria on each measurement day

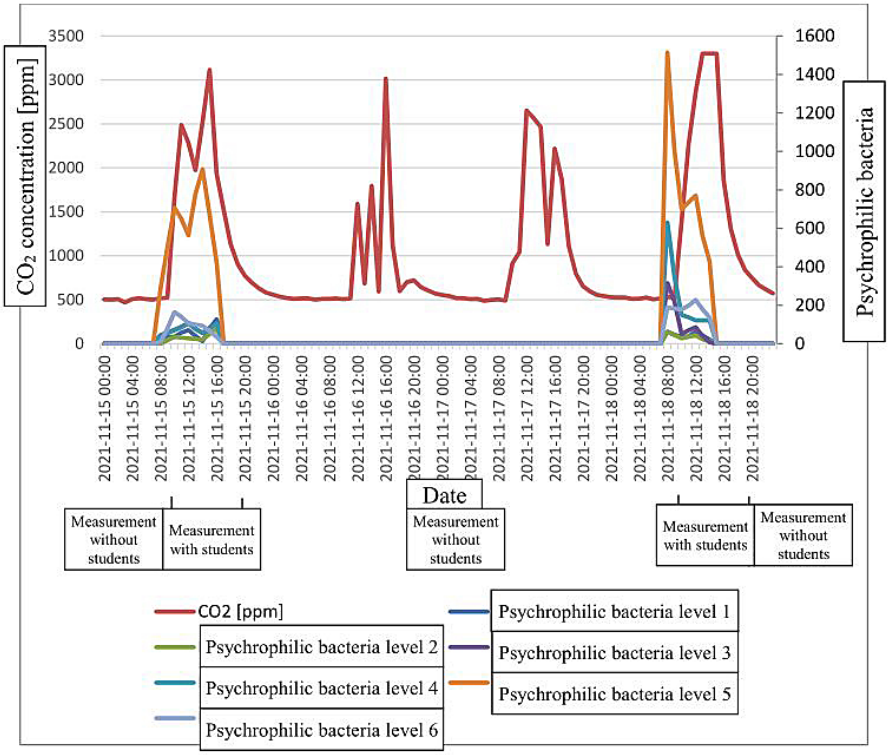

Figure 7. Psychrophilic bacteria content on each measurement day

in the bacterial studies, it was not possible to measure in real time. Microbial contamination tests were repeated at the beginning and end of each lesson to check whether high CO_2 concentrations coincided with the reported elevated bacterial concentrations. There was no correlation over the range of concentrations measured.

The content of mesophilic bacteria for each level was:

- level 1 from 0 cfu/m^3 to 64 cfu/m^3,
- level 2 from 0 cfu/m^3 to 93 cfu/m^3,
- level 3 from 0 cfu/m^3 to 236 cfu/m^3,
- level 4 from 0 cfu/m^3 to 354 cfu/m^3,
- level 5 from 0 cfu/m^3 to 1143 cfu/m^3,
- level 6 from 0 cfu/m^3 to 336 cfu/m^3.

The content of psychrophilic bacteria for each level was:

- level 1 from 0 cfu/m^3 to 128 cfu/m^3,
- level 2 from 0 cfu/m^3 to 78 cfu/m^3,
- level 3 from 0 cfu/m^3 to 316 cfu/m^3,
- level 4 from 0 cfu/m^3 to 631 cfu/m^3,
- level 5 from 0 cfu/m^3 to 1515 cfu/m^3,
- level 6 from 0 cfu/m^3 to 228 cfu/m^3.

The highest concentration of bacteria was recorded at level 5 for mesophilic bacteria and amounts to 1143 cfu/m^3, whereas for psychrophilic bacteria it is 1515 cfu/m^3. Referring to Krzystofik's assumptions (Table 3), according to which the concentration of bacteria in a classroom should not exceed $1.5 \cdot 10^3$ cfu/m^3, only in the case of psychrophilic bacteria a slight exceedance of the concentration level of these bacteria was recorded. The change in the concentration of fungi in the room on each day of measurement is shown in Figure 8.

When analyzing the results, it can be stated that the content of psychrophilic bacteria for each level was:

- level 1 from 0 cfu/m^3 to 21 cfu/m^3,
- level 2 from 0 cfu/m^3 to 14 cfu/m^3,
- level 3 from 0 cfu/m^3 to 28 cfu/m^3,
- level 4 from 0 cfu/m^3 to 100 cfu/m^3,
- level 5 from 0 cfu/m^3 to 85 cfu/m^3,
- level 6 from 0 cfu/m^3 to 14 cfu/m^3.

Figure 8 shows that the highest fungal concentration was recorded at level 4 and equals 100 cfu/m^3. The remaining concentrations are in the range of 0–85 cfu/m^3. The permissible concentration of this pollutant, which is $2.0 \cdot 10^2$ cfu/m^3 according to Krzysztofik (Table 3), was not exceeded at any level.

The dominant bacteria and moulds isolated from the air samples tested are: *Bacillus lentus, Bacillus licheniformis, Bacillus pumilus, Bacillus cereus, Pseudomonas stutzeri, Micrococcus*

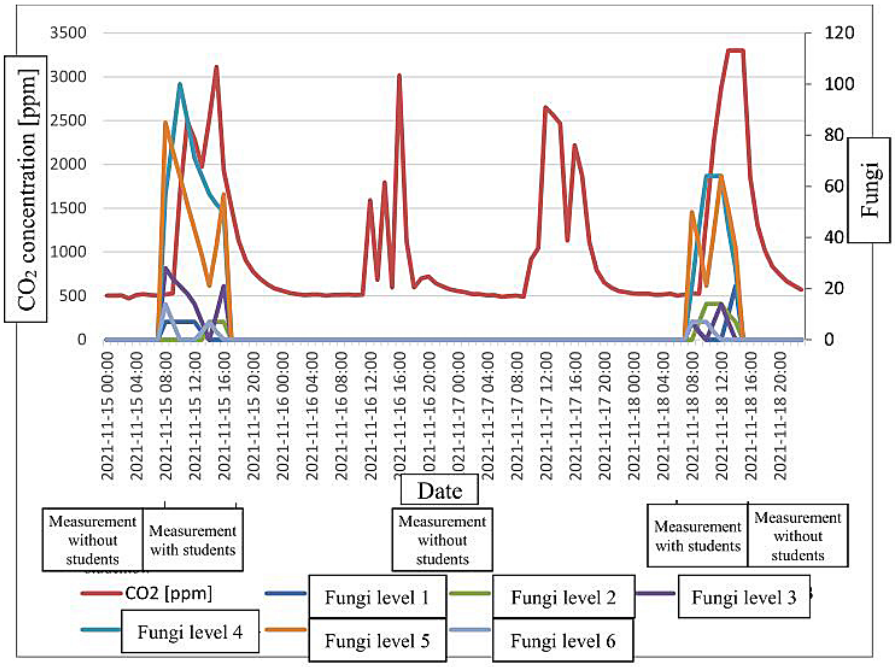

Figure 8. The content of fungi on each measurement day

ssp., Staphylococcus xylosus, Staphylococcus saprophyticus, Staphylococcus haemolyticus, Acremonium, Aerobasidium, Aspergillus, Aspergillus niger, Alternaria, Cladosporium, Epicocum, Mucor, Penicilinium.

CONCLUSIONS

The study shows that the air condition in the classroom during its operation met the requirements in terms of PM2.5, PM10 and microorganisms. The highest risk was recorded for carbon dioxide. Moreover, the highest recorded readings of this pollutant coincided with the maximum concentrations of the other monitored quantities. Therefore, it can be unequivocally stated that in the case of the analyzed room, monitoring carbon dioxide and adjusting the size of the ventilation airflow to maintain its concentration within the limit of 1000 ppm would guarantee the maintenance of adequate indoor air quality. Thermal comfort (temp., humidity) can only be provided by a system equipped with a heater, cooler and humidifier.

The study showed no correlation between CO_2 concentration and measured concentrations of microbial contaminants. This may be because the microorganisms were not measured continuously. It is recommended that the tests are repeated in other schools to measure bioaerosols in real time or to use measuring instruments.

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