

AIR QUALITY AND IMPACT ON THE HEALTH OF CHILDREN

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Abstract

According to statistical data, both, preschool children and staff spend more than 90% of their time inside school buildings. The quality of physical and chemical parameters of indoor air in preschool buildings can have either a beneficial or adverse effect on children's health and may facilitate or impede effective teaching, thus contributing to or limiting the potential of young people. The aim of the present study was to analyse carbon dioxide, the primary indoor air pollutant, and assess its impact on the health and well-being of individuals occupying kindergarten classrooms. The investigated kindergarten is located in the eastern part of Lodz. Furthermore, to examine the relationship between classroom air quality and children's health and cognitive performance, a questionnaire concerning a subjective assessment of air indoor quality in the kindergarten was conducted.

Keywords: air quality, kindergarten, carbon dioxide, health

1. INTRODUCTION

Ensuring optimal air quality in the kindergarten is a prerequisite for supporting normal child development, as well as enabling effective learning and progression. Because of the long periods that children spend in preschool buildings and the specific physiological features that increase the risk of respiratory irritation, air quality in both kindergartens and schools has become an increasingly important issue that should be analysed and resolved as quickly as possible. Therefore, continuous control and monitoring of indoor air quality is, and should remain a matter of priority [1, 2, 3].

Currently, the most frequently discussed aspect concerns the assessment indoor air quality from the point of view of its impact on the effectiveness of the teaching process. High occupancy and intense human activities greatly affect indoor environment quality (IEQ) and energy consumption in buildings [4, 5]. Mental work, associated with moderate effort, results in average oxygen consumption and the release of carbon dioxide, among other by-products. Consequently, prolonged stay of children/pupils in

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a closed space results in an increase of pollution which contributes to the sensation of hypoxia (dyspnea) and, thus, attention deficit. These discomforts affect both children/pupils and teachers, and significantly impair the learning process quality [3, 6, 7, 8, 9, 10, 11].

There is evidence of the potential harmful effects of various indoor air pollutants. Poor air quality affects the general well-being and comfort and can cause negative health outcomes such as respiratory diseases and allergies. These issues have been widely addressed in scientific literature, including (guidelines on air quality and air quality management strategies) [12, 13, 14, 15, 16].

According to Stiborova, as many as 40% of children are allergic to various environmental factors, and around 20% of them take regular medications [16]. Studies show that in many cases these problems are caused by poor air quality in school buildings. Fox et al. demonstrated that CO₂ levels in heavily occupied schools correlate with levels of airborne bacterial markers, which according to Shaughnessy et al. can also negatively impact students' performance [17, 18].

In addition, prolonged exposure to poorly ventilated rooms can cause symptoms consistent with sick building syndrome (SBS). According to the World Health Organization [19] a building is referred to as "sick" *"if 20% of its users report that the cause of their poor well-being is the building itself, i.e. that symptoms appear and intensify only during their stay inside and disappear almost immediately upon leaving"*. A sick building is also characterised by its occupants' complaints of general discomfort, chronic headaches, mucous membrane irritation, nasal and throat irritation, skin sensitisation, recurrent fatigue and drowsiness, dizziness, concentration problems, as well as disorders of the respiratory system, digestive system, and, in extreme cases, the nervous system [20]. The sick building syndrome occurs mainly in air-tight buildings where energy-saving ventilation or air conditioning systems are installed [1, 3, 6, 10, 21, 22, 23].

It should be borne in mind that the overwhelming majority of individuals in educational settings are children and adolescents whose respiratory, nervous and immune systems are still developing, and therefore long-term exposure to the harmful factors is significantly more detrimental for them than for adults [3, 20, 21].

As a result, the present study focuses on determining the effects of carbon dioxide as the primary indoor air pollutant on the health and well-being of children aged 5-6 years. The kindergarten building was chosen for analysis because it represents the first collective stage of human education, which can significantly influence subsequent stages of child development. The results obtained were compared with the permissible concentrations established in current standards and regulations, and the effects were discussed in the cases when these limits were exceeded.

2. METHODS

In the 2022/2023 school year, there were 22.5 thousand officially registered pre-primary education institutions in Poland, of which 13.8 thousand were kindergartens, 7.3 thousand pre-primary classes in primary schools, 1.4 thousand preschool education teams. In the Lodz Voivodeship, there were only 1,329 preschool education establishments, of which 58% were kindergartens. Narrowing the study area exclusively to the limits of the city of Lodz, 213 kindergartens were registered in the analysed period, of which over 70% were public kindergartens. It is from group of 152 institutions, municipal kindergarten no. 93 was randomly selected as the subject of the research [24].

The kindergarten is located in the eastern part of the city, in the Stoki district (Figure 1), which is the highest region in the area surrounding the city of Lodz, known as the Lodz Hills and rise several meters above the whole city (elevations exceed 250 m). The kindergarten is surrounded by a garden of 5,300 m², which serves as a barrier against noise and traffic. The streets in the immediate vicinity are paved with cobblestones that do not allow cars to develop high speed, which promotes safety and

reduces motor traffic. In close proximity to the kindergarten building lies General Mariusz Zaruski Park with an area of 8.4 hectares, which is the largest forest complex on the edge of the Lodz Hills. Its dominant tree species include beech, fir, and spruce.

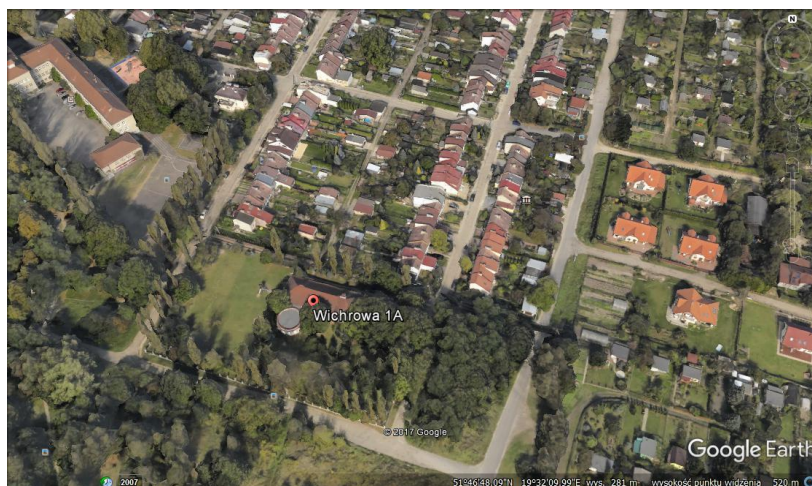


Fig. 1. Kindergarten location

The analysed building was built in 1965 in traditional technology. The one-storey building with the basement has a natural ventilation system, and in recent years underwent thermal modernisation (Figure 2), during which the windows and doors have been replaced. However, during renovation works, the ventilation system was not modernised due to high costs. As a consequence, the building repairs improved both the thermal properties and the air tightness of building. The area of the kindergarten is approximately 273 m² and the cubic volume is about 1,092 m³. The building is heated by a local bifunctional oil boiler located in the basement.



Fig. 2. Municipal kindergarten no. 93 in Lodz (Poland)

The research was carried out during the transition period, at the turn of the heating season, over three months (March–May in 2014). Three main classrooms were surveyed, where educational and play activities are conducted. The cubic volume of individual classrooms were as follows: Room A – 134

m³, Room B – 100 m³ and Room C – 86 m³. During the measurements there were 24 preschoolers and one or two teachers and one person taking the measurements. For each room, three series of measurements were carried out.

Measurements of CO₂ concentration inside the kindergarten building were performed using a VEGA-GC portable gas microchromatograph produced by Pollution S.p.A. (Fig. 3).

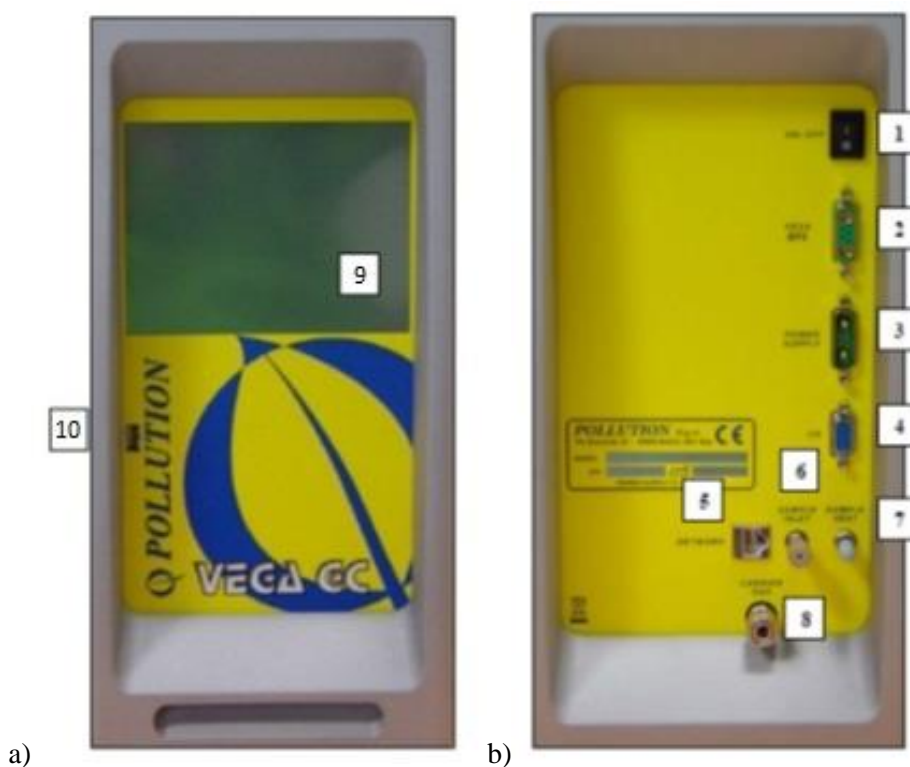


Fig. 3. VEGA-GC microchromatograph (a and b) (Data sheet of VEGA GC microchromatograph): 1 - on/off switch; 2 - port of multipoint connector of the VEGA MPS sampler (additional equipment); 3 - port of the external power connector 110-220 V AC - 12/24 V DC; 4 - RS-232 or RS-485 connector (possibility of connecting external monitor screen); 5 - LAN Ethernet port (possibility of connecting the device to local network or Internet); 6 - sample inlet; 7 - sample outlet; 8 - carrier gas connector (possibility of connecting external cylinder with carrier gas); 9 - LCD touch screen 6.5"; 10 - USB port (possibility of exporting data to external storage, connecting external keyboard/mouse and external printer)

The device is equipped with a carrier gas container (helium), a sampling pump, two batteries, and a computer module. Two columns working in parallel can be installed in the device, so a wide spectrum of gases can be analyzed during a single measurement. The thermal conductivity detector (TCD) was used to analyze samples with a minimum concentration of 500 ppb within a time range of 6 to 300 seconds, depending on the type of gas tested. Concentrations of carbon dioxide were measured using a PPQ column (Table 1) for which a calibration curve is shown in Figure 4.

Table 1. Measurement column of VEGA-GC microchromatograph (Data sheet of VEGA-GC microchromatograph)

Column name	Description	Examples of gases
PPQ	Packed column, example of application: hydrocarbons containing carbon particles from C ₁ to C ₄	N ₂ , N ₂ O, H ₂ O, CO ₂ , CH ₄ , acetylene, ethane, chloroethylene, ethanol, ethylene, propane, hydrogen sulfide and ammonia

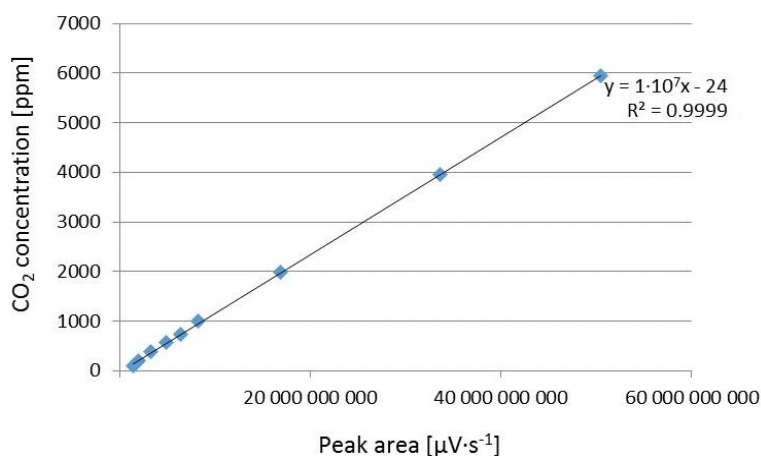


Fig. 4. Plot of the calibration curve for carbon dioxide [25]

Each measurement was performed at an interval of approx. 90 seconds. During measurements inside the room, the device was placed at a height of about 1.0-1.2 m, i.e. the average head level of children.

Parallel measurements of outdoor air parameters were also conducted. Controls were taken at a distance of 5 m in a straight line from the kindergarten. Average daily values of outdoor air parameters in the analysed period are presented in Table 2.

Table 2. Average daily values of outdoor air parameters in the analyzed period in relation to available meteorological data [26]*

Parameter	Unit	March	April	May
Temperature	°C	10/6.5*	11/10.2*	18/13.3*
Humidity	%	76	63	78
Atmospheric pressure	Pa	1018.42	1023.83	1013.113
Wind direction	-	NE	SW	SW
Wind speed	km/h	8	4	6
CO ₂ concentration	Ppm	426.47	502.43	438.70

Additionally, to determine the impact of air quality in the classroom on children's health and intellectual performance, a questionnaire concerning a subjective assessment of air quality in the kindergarten was conducted. A total of 61 children participated in the study, including, 37a girls and 30 boys. Researchers asked preschoolers three simple questions about the quality of air and their well-being during the subsequent classes (e.g. Do you feel tired and drowsy in the afternoon, etc.). Based on the children's responses and comments, the assessments were recorded in a data sheet, using a six-point scale (definitely yes, rather yes, rather no, no, definitely not). Next, the responses were analysed.

2.1. Carbon dioxide as an air quality indicator

The quality of air inside a preschool or school building is a complex system that includes many parameters which can both cause adverse health effects and affect the comfort and convenience of users of such facilities. Preschool buildings require regulation and control of environmental exposure [25, 27, 28, 29]. These facilities have a variety of uses (e.g. classrooms, canteens, gyms, changing rooms) as well as various requirements related to the type of ventilation (e.g. mechanical or natural) and heating. The level of air pollution in a preschool building depends largely on the interaction between the building and its external environment as well as the technology in which it is built, furnished and subsequently used, as well as the type and use of a ventilation system [14, 30, 31].

In preschool classrooms the activity of children varies depending on the time of day and hence the indoor air parameters cannot be permanently determined. In all kindergartens, however, a similar tendency is observed, which means that during the day the following periods can be distinguished:

- low activity, when children learn, have time for quiet play or sleep;
- high activity during intense play and sports activities.

Every human activity involves the exhalation of carbon dioxide-enriched air (2-3%). Its emission depends on the activity of the organism (Table 3) and may vary among individuals depending on diet, body weight, body condition, etc. [3, 32].

Table 3. CO₂ emissions for different activity levels [3]

Type of activity	CO ₂ emission	
	[dm ³ /s · person]	[m ³ /s · person]
Rest	0.004	4·10 ⁻⁶
Light work	0.006-0.012	(6-12)·10 ⁻⁶
Moderately heavy work	0.012-0.020	(12-20)·10 ⁻⁶
Heavy work	0.020-0.03a	(20-3a)·10 ⁻⁶
Very heavy work	0.03a-0.032	(3a-32)·10 ⁻⁶

The amount of carbon dioxide secreted in the exhaled air, depending on the type of activity, is typically reported as an average value for adults. Therefore, it should be noted that in the analysed classrooms most of the users were children for whom these values were significantly lower. Unfortunately, the available literature provides no accurate data on this subject. Regardless of the amount of CO₂ emitted by the youngest children, the effect on them will be the same (or perhaps more severe) as on adults.

It is well established that the concentration of CO₂ depends largely on the number of people in the room, the rate of air exchange and the intensity of the combustion process in the room [26, 28].

Carbon dioxide is the most common indoor gas, and although it is not considered a “toxic” air pollutant, it is the most common and most widely used indicator of indoor air quality. Its value in atmospheric air varies according to the surrounding environment. For example, in cities it is about 300-350 ppm and in industrial areas about 400 ppm. Polish legislation does not specify permissible levels of carbon dioxide either in ambient air or rooms intended for permanent residence [6, 30, 33]. Concentrations of CO₂ permitted in such facilities are usually determined on the basis of standards and recommendations of the European countries, the United States, and the World Health Organization (WHO) [19].

The concentration of CO₂ is also commonly used as an indicator of the effectiveness of ventilation systems. In Poland, air quality in non-residential premises is assessed using the Δ CO₂ index, which determines the increase in carbon dioxide concentration indoors relative to its outdoor level. According to the PN-EN 16798-3:2017-09 standard there are four categories of indoor air (Table 4) (PN-EN 16798-3:2017-09).

Table 4. Classification of indoor air quality for non-smoking rooms with low pollutant emissivity [14]

Category	Description of indoor air quality	Increase of CO ₂ concentration in relation to outdoor air [ppm]	Volume flow of outdoor air [m ³ /h]
WEW 1	High	< 400	< 54
WEW 2	Medium	400-600	36-54
WEW 3	Moderate	600-1000	22-36
WEW 4	Low	> 1000	> 22

In this context, the updated guidelines contained in EN 16798-3:2025, which comprehensively address indoor air quality and emphasise the need to control pollution levels, including CO₂ concentrations, through the appropriate selection of ventilation systems and air filtration classes, are of particular importance.

One of the key provisions of the standard is to take into account two parameters that influence the selection of the filtration level: outdoor air quality (ODA) and building function (SUP). The ODA classification is based on World Health Organisation (WHO) guidelines for safe concentrations of particulate matter, NO₂, ozone and other pollutants. Outdoor air is divided into three classes: from ODA 1 (clean) to ODA 3 (heavily polluted). Conversely, SUP classes (from SUP1 to SUP5) determine the sensitivity of a given building’s function to air quality — for example, educational and office facilities are usually classified as SUP2 or SUP3. Based on a combination of the ODA and SUP classes, the standard specifies the minimum filtration level of air supplied to the interior. Importantly, according to the new interpretation, every commercial building with human occupancy must be equipped with an ePM1 class filter, regardless of location and outdoor air quality. This approach aims to reduce the exposure of building users to harmful airborne particles and to improve indoor environmental parameters [34].

Table 5. Minimum filtration efficiency requirements according to EN 16798-3:2025 based on outdoor air quality and building function [34]

Outdoor air quality class (ODA)	SUP1	SUP2	SUP3	SUP4	SUP5
ODA 1 (clean air)	ePM1 \geq 70%	ePM1 \geq 50%	ePM2,5 \geq 50%	ePM10 \geq 50%	ePM10 \geq 50%
ODA 2 (moderately polluted)	ePM1 \geq 80%	ePM1 \geq 70%	ePM2,5 \geq 70%	ePM10 \geq 80%	ePM10 \geq 50%
ODA 3 (heavily polluted)	ePM1 \geq 90%	ePM1 \geq 80%	ePM2,5 \geq 80%	ePM10 \geq 90%	ePM10 \geq 80%

Although the concentration of carbon dioxide in respiratory secretions does not exceed the threshold of harmfulness, in closed rooms its excessive concentration may lead to a deterioration of the well-being or a decrease in the level of activity of people present in the building [10, 35]. When a person inhales contaminated air, carbon dioxide contained in it dissolves in the blood and reacts with water in the body to form carbonic acid, which in turn dissociates into hydrogen and bicarbonate ions. Increasing the amount of hydrogen ions leads to blood acidification and electrolyte imbalance, which consequently affects the health of occupants in closed spaces [36, 37]. According to the Pettenkofer scale, which is approved by the World Health Organization, carbon dioxide concentrations in indoor air above 1,000 ppm are considered as an indicator of poor air quality. At CO₂ concentrations greater than 5,000 ppm, symptoms such as fatigue, depression and general discomfort increases. This is particularly evident in children who may become drowsy, inattentive, and less inclined to intellectual and physical effort. At a concentration three times higher (15,000 ppm) breathing becomes more difficult [3, 7, 10, 11, 22]. The impact of CO₂ on the human body is shown in Table 6.

Table 6. Impact of CO₂ on the human body [7]

No.	CO ₂ concentration in the air [ppm]	Symptoms
1.	300 – 450	Dry outdoor air
2.	1000	Hygienic minimum
3.	1550 – 5000	Feeling of rising stench
4.	5000	Limit introduced in workplace
5.	15,000	Appearance of metabolic stress (disorders of acid-base balance of blood and respiration)

3. RESULTS AND DISCUSSION

The presented study has several significant limitations that should be taken into account when interpreting the results. Firstly, it was a case study conducted in a single location, which significantly limits the possibility of generalising the results to wider populations or other socio-cultural contexts. The research sample was purposeful and relatively small. Furthermore, only descriptive statistics were applied, without more in-depth statistical analysis. This was due to the exploratory nature of the study

and the assumption that the sample did not meet the conditions for the use of more advanced quantitative techniques, such as statistical significance tests or correlation analysis. The introduction of such methods could lead to overinterpretation of the data and conclusions that would not be sufficiently empirically justified.

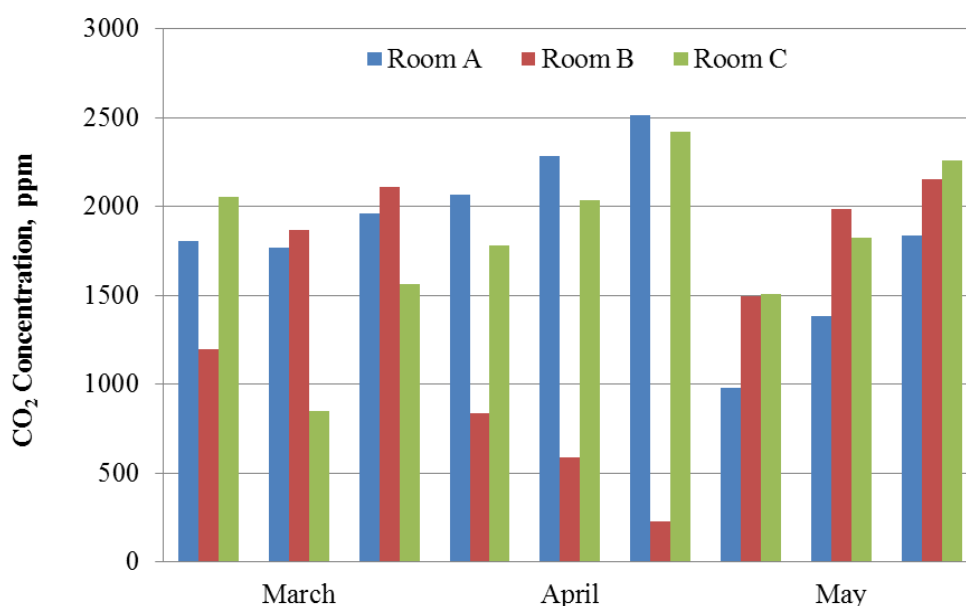


Fig. 5. Changes in CO₂ concentration measured in rooms A, B and C in subsequent months

Figure 5 shows changes in carbon dioxide concentrations measured in rooms A, B and C in selected months of 2014, during the opening hours of the kindergarten, i.e. from 6:00 to 17:00. The average carbon dioxide concentration in almost all cases exceeded 1,000 ppm, i.e. the recommended minimum hygienic value that ensures occupant comfort. It should be kept in mind that low concentrations of carbon dioxide in the air are natural and too high concentrations in the inhaled air can have negative effects on health. However, based on the surveys carried out, it appears that as many as 88% of children in the analysed classrooms experienced significant fatigue and shortness of breath during the last classes. The children unanimously stated that after dinner they were exhausted and did not want to play. Forty-four of them indicated that in the afternoon they found it harder to breathe and become fatigued more quickly during classes activities. Most children feel best in the kindergarten in the morning. They are rested, full of energy and joyful. In the morning, as many as 92% of children show high levels of interest in classes. Accordingly, it seems explicable that in children staying in the kindergarten, where carbon dioxide levels were often above 2,000 ppm, there were sometimes visible signs of fatigue, dyspnea, anxiety, respiratory distress, and increased respiratory rate. As a result, preschoolers occasionally became lethargic and less prone to physical and intellectual effort. This interpretation is also consistent with that presented by Satish and co-workers who showed an association between increased CO₂ levels and deterioration of health [22]. Due to the above analysis the direct impact of CO₂ concentrations at 600 ppm, 1,000 ppm and 2,500 ppm, respectively, on decision making ability of a group of 22 persons was examined. During the examination, participants completed a test which required decision making and filled in a questionnaire about their well-being and air quality. The group of people staying in the room with the highest carbon dioxide concentration obtained the worst results and stressed their fatigue and dizziness.

At this point, it should be emphasised that the questionnaire developed for the purposes of this study, although based on a review of the literature and expert consultations, did not undergo a full psychometric validation procedure. This may have influenced the accuracy and reliability of the results obtained. In addition, part of the dataset was subjective, based on the respondents' self-assessment, which entails the risk of cognitive and perceptual biases, interpretation errors and the influence of social factors on the answers provided.

Despite these limitations, the results obtained provide a valuable starting point for further in-depth quantitative and comparative research, which will allow the observations presented to be verified in a broader context.

A similar experiment was conducted by Fisk and coworkers [35]. During these analyses the participants took part in the decision-making test. It was found that already at a concentration of 1,000 ppm there was a decrease in intellectual capacity, and at 2,500 ppm participants' initiative and strategic thinking decreased to dysfunctional levels.

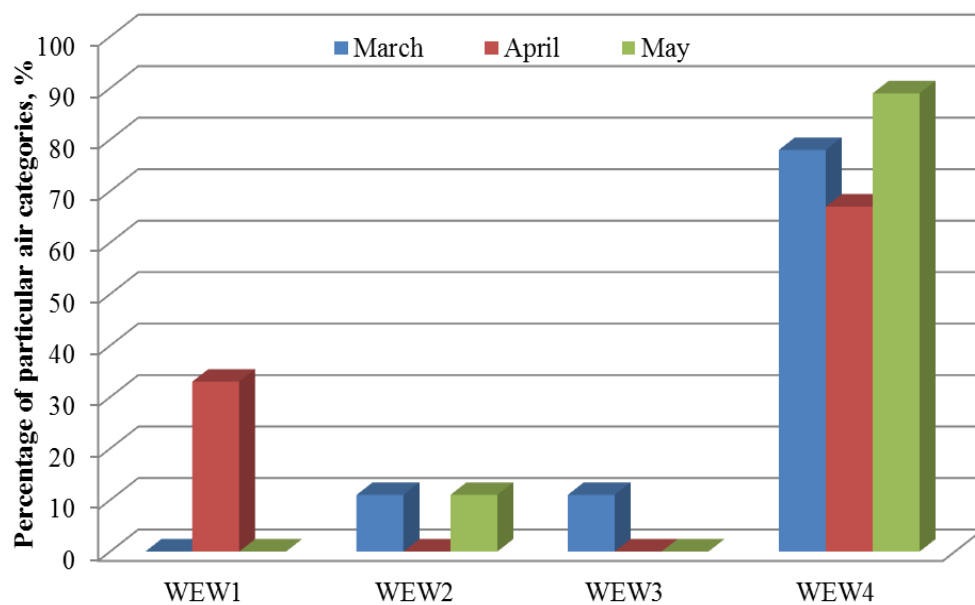


Fig. 6. Percentage of particular air categories in the kindergarten

Figure 6 shows the percentage distribution of each air quality class in the analysed months. It is not difficult to see that in all preschool classrooms analyzed, low-quality air predominated. Only in April was there a single case of deviation from this trend. In room B high quality of indoor air, specific for the WEW1 category was observed. Probably it was a result of lower activity of children and frequent ventilation of the classroom. The analyses show that natural ventilation systems traditionally used in preschool classes are not able to provide suitable conditions for effective learning. Of course, air quality can be improved by regular room ventilation during frequent breaks, but during periods of low outdoor temperatures, this leads to significant cooling of the rooms and causes drafts that adversely affect children's health. The simplest and most effective way to improve the situation in kindergartens may be the use of mechanical ventilation systems that will keep carbon dioxide concentrations at a level below 1000 ppm. Unfortunately, such recommendations are associated with considerable financial expenditures, and sometimes they are a barrier for those managing these types of facilities [38].

4. CONCLUSION

A closed room on the one hand forms an insulating barrier against unfavourable environmental factors, including varying weather conditions such as rain, snow, wind, low or extreme temperatures. On the other hand, it is a kind of “cage” in which the accumulation of toxic compounds occurs, leading to adverse health effects such as fatigue syndrome, dyspnea, pain and dizziness, irritability, reduced concentration, memory disorders, irritation of the mucous membranes of the eyes and upper respiratory tract [9, 39, 40, 41, 42].

Unfortunately, most schools and kindergartens in Poland were built in times when the notion of maintaining adequate indoor environment quality and energy efficiency were neglected during the design phase [24]. Most of the educational facilities do not use any system and equipment to help regulate the indoor environmental conditions, and the only method of air changes is gravity ventilation which operates on the basis of pressure difference. At the time of design, construction and the early use of the so-called “old buildings” outdoor air entered through cracks in the windows and doors, and also as a result of the infiltration of the buildings. Buildings that have recently undergone thermo-modernization, including window and door joinery replacement have become airtight, and consequently outdoor air flow is restricted, which significantly reduces the efficiency of gravity ventilation.

On the basis of measurements and analyses it can be clearly stated that the quality of indoor air in the kindergarten is very low. The recorded CO₂ concentrations exceeded the maximum recommended values. Although the recorded exceeded values were only temporary, they are probably cyclical throughout the whole period of using these rooms. Results of the measurements allow us to classify the examined kindergarten into the WEW 4 category of air quality according to PN-EN 16798-3:2017-09 [14]. This is a consequence of the thermo-modernization of the building without interfering with the modernization of the ventilation system and the insufficient amount of air infiltrating the room, which results in the ineffectiveness of the “old” gravity ventilation. Unfortunately, the implementation of a new mechanical ventilation system and the distribution of ventilation ducts to the rooms is more difficult in the existing buildings compared to new facilities, which is reflected in the investment costs [8, 43, 44]. As a result, investors usually leave their existing ventilation systems unmodified during the thermo-modernization regardless of the consequences.

Improper air quality in preschool buildings can cause health problems in children and teachers and it can also negatively affect comfort of learning and work. A probable effect is reduced productivity among teachers and educators, decreased engagement in learning activities due to discomfort, illness and absenteeism, and increased tension in relationships among teachers, children and parents. According to Gładyszewska-Fiedoruk, in Poland about 1% of preschool children, i.e. around 60,000 individuals, suffer from chronic respiratory diseases, including bronchial asthma [33]. These numbers indicate the urgent need to ensure adequate indoor air quality in the classrooms, which promotes better health and wellbeing among students and enhances their learning outcomes.

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