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Quality of human functioning in study areas and workplaces in terms of the condition of the indoor environment

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Abstract

Due to necessity, people spend most of their lives in enclosed spaces. This creates the need to shape the indoor environment so as to form a state of satisfaction with their surrounding conditions. When shaping or assessing the quality of the indoor environment in buildings, we should primarily focus on its impact on the quality of life of users. Study and work environments are particularly important because attention needs to be paid to, among others, the significant relationship between the inappropriate quality of this environment and psychomotor skills, academic results, work efficiency, or increasing sickness absence and the associated high economic cost of these factors. This article presents the results of research on the condition of the study and work environment. It determines the factors influencing the shaping of indoor environmental conditions and presents the impact of the indoor environment on the quality of the people working there. The relationship between the basic parameters of the indoor microclimate and the level of satisfaction with the environmental conditions and its impact on the comfort of study and work is examined. Attention is paid to the impact of green solutions in buildings in order to improve the quality of life and efficiency in study areas and workplaces.

Introduction

Providing the users of buildings with appropriate air quality, cognitive performance, and maintaining thermal and work comfort are the key goals of managing the thermal environment in closed premises. The surroundings, in which a person lives, should allow them to achieve a state of satisfaction with the conditions prevailing there and fully satisfy their physical and mental needs. European Union guidelines (European Parliament, 2024) indicate the need to maintain appropriate hygienic conditions in rooms that affect the health and well-being of people staying there. Member States are obliged to implement appropriate indoor-environment quality standards to guarantee a healthy indoor climate and appropriately comfortable conditions. According to Polish legislation, a building must be designed and built to ensure that basic hygiene, health, and environmental requirements are met (Journal of Laws, 2022, 2024), and employers are obliged to provide employees with safe and hygienic working conditions (Journal of Laws, 2018, 2023).

Since people spend a significant amount of time indoors, buildings should be structures that will not negatively impact them. The long-term impact of unfavorable environmental conditions may cause or intensify symptoms related to the improper functioning of the body, lead to reduced mental and physical performance and, consequently, to weakness or disease (Wargocki & Wyon, 2017; Telejko, Majewski & Kotrys-Działak, 2022;

Zhang, Du & Chow, 2023; Mansor et al., 2024). The World Health Organization has stated that many of the ailments that people complain about are related to the quality of the indoor microenvironment. This phenomenon is called sick building syndrome (SBS), and its symptoms appear to be closely related to the time spent in the building, which decreases or disappears after leaving the building. Symptoms of the syndrome are primarily irritation of the eyes, nose or throat, itching and dry skin, hoarseness and dry coughing, cold and flu-like symptoms, dizziness and headache, nausea and sensitivity to unpleasant odors, allergies and increased frequency of asthma attacks or fatigue, and irritability and difficulty in concentration (Mansor et al., 2024; Niza et al., 2024; Obi, 2024). The WHO has stated that non-communicable diseases account for 70 % of the total burden of disease attributable to occupational hazards (Felgueiras et al., 2022). Therefore, to avoid occupational hazards, minimum requirements for health protection at work are established at international and national levels. Since 2009, the WHO has also issued a separate series of guidelines on indoor air quality.

Indoor air quality is recognized as an important health risk factor, but this issue was not taken completely seriously until attention was paid to the economic aspect of increasing sickness absence and its clear link with the quality of the working environment (Al Horr et al., 2016; Arata et al., 2023). It was estimated that the potential annual economic effects related to the elimination of the syndrome and the increase in production would be in the range of 25–60 % in relation to the use of other activities aimed at improving the quality of work, which is not directly related to improving the quality of the indoor environment (Figure 1).

A significant percentage of the world's population are students and workers, who spend approximately one-third of their time at school and work. The base goal is to ensure thermal comfort, which is primarily influenced by the thermal parameters of the microclimate, i.e., air temperature, air relative humidity, airflow speed, and ambient radiation temperature (Wargocki & Wyon, 2017; Du et al., 2020; Kosiń, 2022; Tran et al., 2023). Personal parameters of the microclimate, i.e., thermal insulation of the clothes worn and physical activity, are also an important element. Maintaining the desired values of microclimate parameters and appropriate air quality affects the energy needs of the building (Gabrielyan et al., 2024). The implementation of the energy efficiency program led to a significant sealing of the building structure and a reduction in the amount of air exchanged in the ventilation process, which constitutes the main share of losses in the heat balance of an energy-efficient building and, thus, to a deterioration of the indoor environment. Meanwhile, ensuring appropriate microclimate conditions and air quality in rooms may, in the case of study and work environments, affect not only the health safety of their users, but also the effectiveness of activities performed and their cognitive performance (Al Horr et al., 2016; Lis & Vranayova, 2019; Kapalo et al., 2023; Tran et al., 2023; Shi et al., 2023; Zhang, Du & Chow, 2023; Saniuk, Grabowska & Thibbotuwawa, 2024). The quality of the internal environment is believed to have a greater impact on work performance than the influence of the social environment or personal factors (Felgueiras et al., 2022; Li et al., 2023). Significant correlations have been found between environmental quality and performance, allergies, and SBS symptoms (Li et al., 2023; Niza et al., 2024).

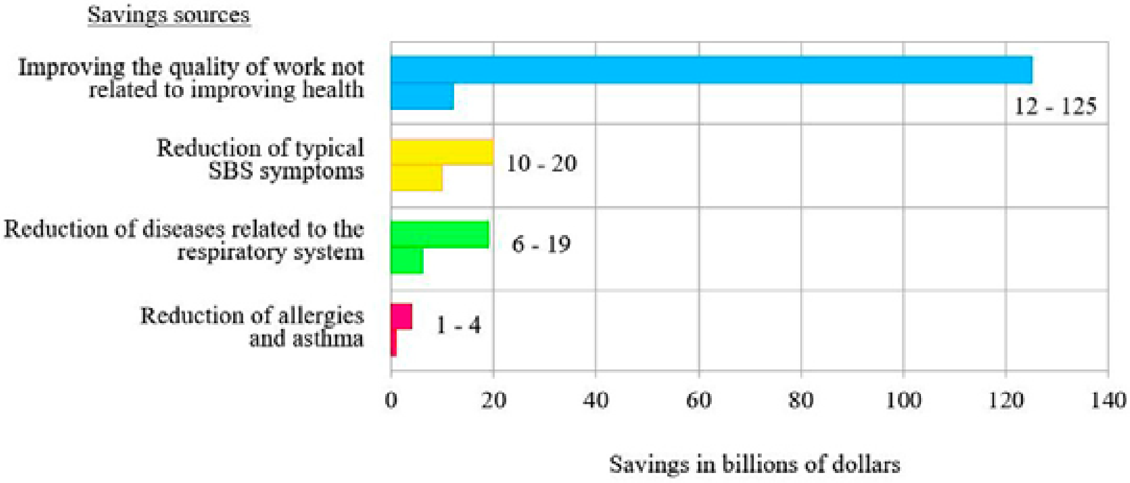

Figure 1. Annual savings from syndrome reduction (performed on the basis of Al Horr et al. (2016) and Arata et al. (2023))

Significant difficulties in ensuring proper air quality in rooms are particularly visible in the case of gravity ventilation systems commonly used in educational buildings (Kapalo et al., 2018; Wargocki, 2022; Tran et al., 2023). These are buildings characterized by a high density of people in rooms where it is extremely important to properly focus both students and teachers (employees) on the educational process, so the effectiveness of ventilation is extremely important here (Kapalo et al., 2019; Wargocki et al., 2020; Kabirikopaei et al., 2021). However, high carbon dioxide concentrations are recorded in these types of buildings, often exceeding 3,000 ppm. Air quality is improved by airing, but during periods of low external temperatures, this causes significant cooling of the rooms, which leads to increased heat loss from the building and discomfort for the people staying there. Although carbon dioxide is not generally considered a poisonous air pollutant, high levels of its concentration inside buildings can negatively affect users, their cognitive functions, and mental and physical performance (Petersen et al., 2016; Azuma et al., 2018; Mishra et al., 2020; Fan et al., 2023). The most frequently described health problems include fatigue, drowsiness, headaches, malaise, and trouble with concentration (Figure 2).

Carbon dioxide is the main human metabolite, so its indoor concentration depends on the number of people and the ventilation efficiency of the room. Using mechanical ventilation systems, it is possible to ensure a controlled inflow of the appropriate amount of air, its appropriate circulation, and more precise removal of pollutants, which allows for the maintaining of carbon dioxide concentrations at the required level of up to 1000 ppm (Pettenkofer index). Air-conditioned rooms ensure thermal comfort when they overheat and, thus, increase work efficiency. Modern air conditioners not only cool or heat rooms but also clean them of microorganisms and dust. However, research shows that people working in air-conditioned environments may experience chronic headaches, fatigue, annoyance, irritation, nasal congestion, and difficulty breathing. Paradoxically, air-conditioning equipment, if not properly maintained, can spread pollen, mold spores, fungi, mites, bacteria, and viruses. The additional humidification of polluted rooms exasperates allergies and asthma, and frequently setting the temperature too low worsens existing health problems.

An important element of study areas and work environments is ensuring proper lighting (Niciejewska & Mlakar Kač, 2019). Legally compliant workplace lighting is crucial to promoting work safety and comfort. The Labor Code and standards regarding lighting in the workplace specify the minimum amounts of light and lighting parameters for various types of work (Journal of Laws, 2022). The intensity and color of lighting are extremely important, as well as the even distribution of light sources and the absence of reflections and shadows. The legislation also regulates the direction of light incidence. It cannot cause glare, poorly outlined contours of objects, or blind the user. Properly selected lighting affects eyesight, concentration, and efficiency, which enables proper performance of tasks and minimizes the risk of errors. The negative effects of improper lighting can lead to eye fatigue, headaches, and stress.

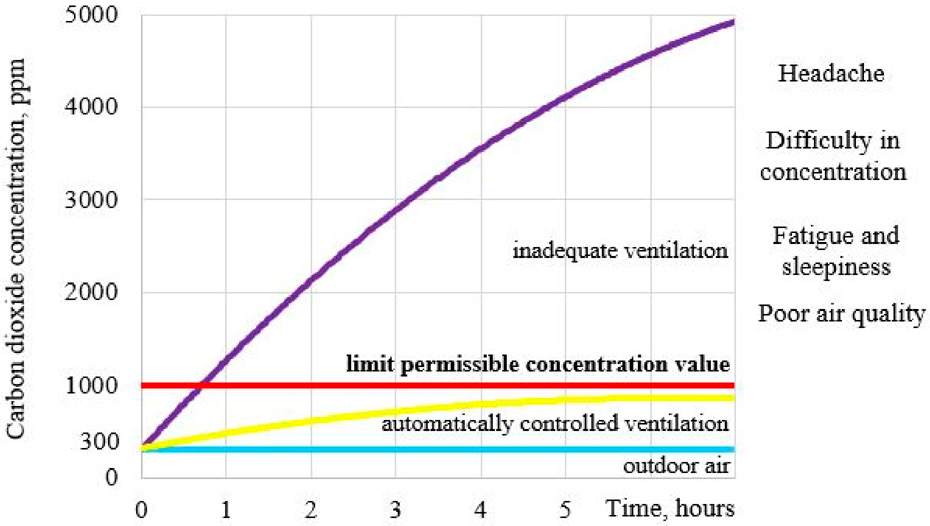

Figure 2. Ventilation level, CO_2 concentration, and user's feelings (performed on the basis of Azuma et al. (2018), Mishra et al. (2020), and instalacjebudowlane.pl (2024))

Nature-based solutions improve the quality of human functioning in the outdoor environment, making it healthier and safer while promoting green construction (Čákyová et al., 2023; Fonseca, Paschoalino & Silva, 2023; Ghazalli & Brack, 2023). Increasingly more attention has also been placed on the positive impact of nature indoors, not only on the quality of life or mental well-being but also on work comfort, efficiency, and productivity (van den Bogerd et al., 2020; Tkachenko & Mileikovskyi, 2020; Poorova & Vranayova, 2021; Rhee, Schermer & Cha, 2023).

Scope and method of analysis

The aim of this paper is to assess the quality of study and work environments and analyze their impact on the quality of the functioning of room users. The introduction outlines the issues relevant to the subject of the paper concerning microclimate, thermal comfort, sick building syndrome, and guidelines for maintaining the quality of the indoor environment. Important study and work environments are laboratories where concentration and precision are required. The results of a study conducted at the Building Physics Laboratory of the Faculty of Civil Engineering at Czestochowa University of Technology are presented. Reference is also made to the results of research previously conducted in other educational buildings.

The Building Physics Laboratory (Figure 3) is located on the first floor in the southeastern part of the building. The dimensions of the room are a height of 3 m, a width of 5.3 m, and a length of 11.3 m. The area is nearly 60 m^2, and the cubature is nearly 180 m^3. The windows face east.

Air temperature, air relative humidity, and airflow velocity, as well as lighting intensity and carbon dioxide concentration, were measured at a laboratory station using stationary sensors integrated with a recorder. Measurements were completed using a portable Fluke 975 AirMeter air quality meter, a Testo 845 thermohygrometer with accessories, and a KIMO VT110 thermoanemometer with a thermocouple probe. The ambient radiation temperature was measured using a TP3276.2 spherical thermometer probe. Outdoor climate parameters were measured using a weather station located on the roof of the building. Thermal insulation of a clothing ensemble and metabolic rates of room users were estimated using tabular summaries and formulas included in the PN-EN ISO 9920 and PN-EN ISO 8996 standards. Thermal comfort indicators, the predicted mean vote (PMV), and the predicted percentage dissatisfied (PPD) were measured with a Brüel & Kjær thermal comfort meter, and the assessment of people's thermal comfort was completed using thermal sensation questionnaires applying the thermal sensation scale presented in Table 1.

Table 1. Thermal sensation scale (PN-EN ISO 7730, 2006; ANSI/ASHRAE Standard 55, 2020)

+3	+2	+1	0	−1	−2	−3
Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold

The method is applied to premises where the users' activity level provides an average metabolic rate of 1.0 to 2.0 met and where worn clothing provides thermal insulation of 1.5 clo or less. The PMV model uses the principle of heat balance by linking key factors of thermal comfort to people's average response from the scale above. People indicating +2, +3, −2, or −3 on the scale are dissatisfied with existing thermal conditions. The other ratings on the scale are within the comfort zone. Based on the specified PMV value, the PPD index can be determined using the following equation (PN EN-ISO 7730);

$$\mathrm{PPD} = 100 + -95\exp\left(-0.03353\mathrm{PMV}^4 - 0.2179\mathrm{PMV}^2\right) \quad (1)$$

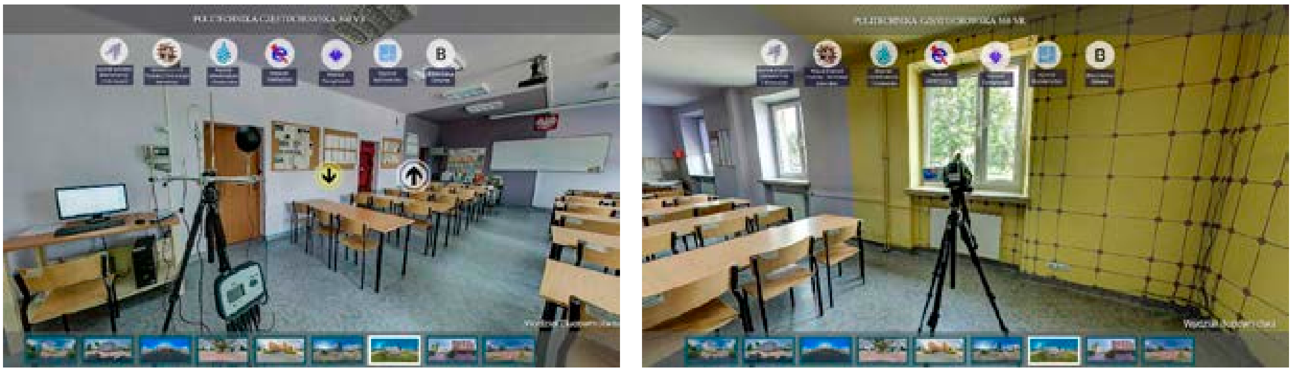

Figure 3. Laboratory of Building Physics (Politechnika Częstochowska, 2024)

The PPD index is symmetrically distributed around the PMV, from 5 % of dissatisfied people at PMV = 0 to 100 % at PMV = ±3. The analysis of the impact of the state of the indoor environment on the quality of functioning of its users was based on questionnaires and tests. The focus was on the impact of the quality of the environment on thermal comfort, study and work comfort, and results, as well as on well-being and health. The presented results were obtained on the basis of 236 studies of people conducted during the 2018/2019 academic year. The average age of the full-time and part-time students is 23 and 29 years old, respectively. The length of stay of individual groups of students in the room ranged from 90–135 minutes.

The indoor environment condition and quality of users' functioning

Figures 4–8 present the course of the outdoor temperature and the course of the basic thermal parameters of the microclimate in the room, as well

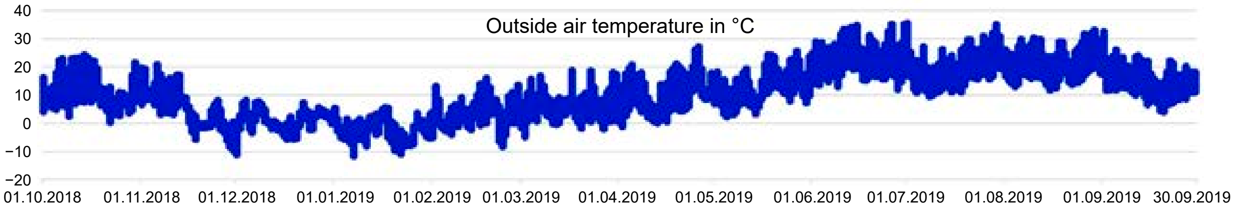

Figure 4. Outside air temperature

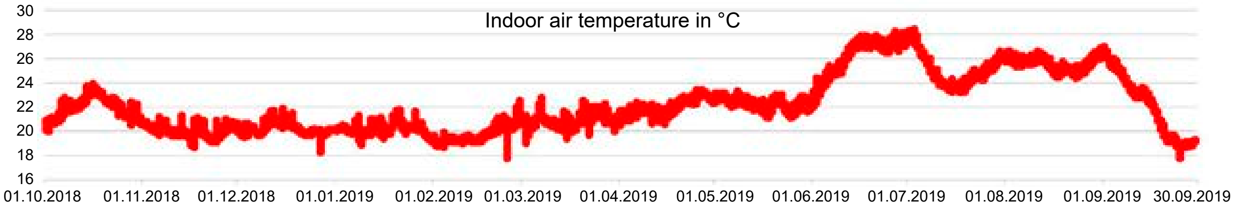

Figure 5. Indoor air temperature

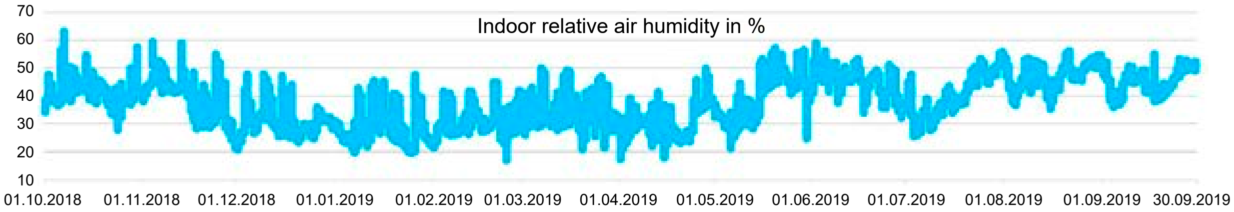

Figure 6. Indoor relative air humidity

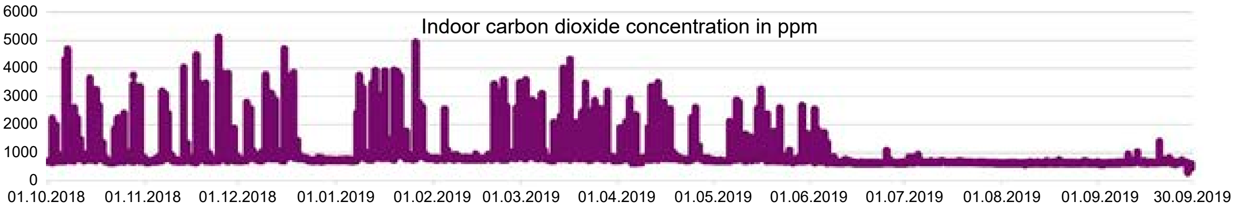

Figure 7. Indoor carbon dioxide concentration

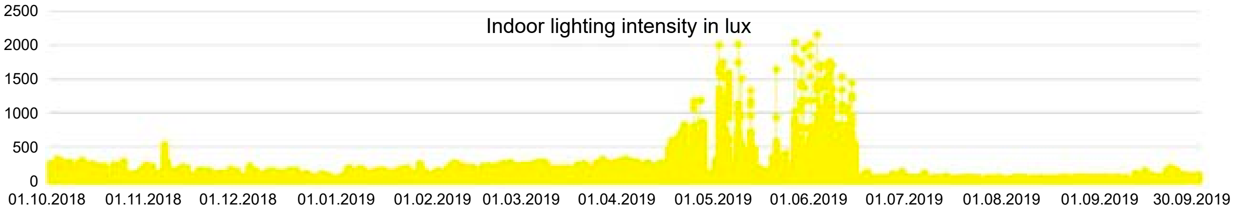

Figure 8. Indoor lighting intensit

as the level of carbon dioxide concentration and lighting intensity in the discussed period.

The selected period did not differ significantly in terms of the values of external climate parameters from the average values recorded in the long-term periods. The values of thermal microclimate parameters outside the heating season were mainly influenced by the values of external climate parameters, while during the heating season, the key factor was the heating system. Temperature requirements, which should be maintained in individual rooms during the heating season, are included in the technical conditions (Journal of Laws, 2022). Maintaining a sufficiently lower temperature is, of course, beneficial for energy efficiency, but it is not beneficial for people working in a sitting position. During the heating season, temperatures that remained in the range of 19–21 °C on average were positively received by users. Outside the heating season, higher temperatures were recorded, but this was not the main reason for discomfort. The roller blinds reduced the transmittance of solar radiation energy and, thus, limited overheating in the room. However, this had a negative impact on the daylight intensity of interior lighting and forced the use of artificial lighting, which is contrary to energy efficiency. The ambient radiation temperature is related to the temperature of the surrounding partitions, which is influenced by their thermal insulation. During the heating season, the ambient radiation temperature was, on average, about 0.5 °C higher than the air temperature, while, outside the heating season, it was about 1 °C higher on average. Similar temperature conditions were recorded during investigations in other educational buildings. However, with large glazing on sunny days, the rooms overheated, and the users' dissatisfaction with the existing environmental conditions increased.

In perfectly clean air, low relative humidity is not bothersome for room users. The health problems reported at low relative humidity are related to indoor air pollution. High humidity, however, is unfavorable due to energy savings and the possibility of mold and fungi growth. During the heating season, lower relative humidity values were recorded on average (at the level of 40 %) and, outside the heating season, the relative humidity value increased significantly to 60 %. During investigations in other educational buildings, the average relative humidity was 30 % with a standard deviation of 10 % during the heating season, and an average of 50 % with a standard deviation of 9 % outside the heating season.

At an air temperature of 20 °C, the recommended airflow velocity is in the range of 0.15–0.20 m/s for people working in a sitting position. However, studies carried out in other educational buildings have shown that these values are slightly too high, especially when close to windows in the case of large glazing, which is typical for this type of building. About 20 % of respondents were dissatisfied with this situation. The airflow speed in the laboratory room was maintained at 0.1 m/s and did not cause user dissatisfaction.

Personal microclimate factors were tracked. The thermal insulation of the clothing worn was 0.52 clo with a standard deviation of 0.17 clo outside the heating season, and 0.89 clo with a standard deviation of 0.12 clo during the heating season. The level of metabolic rates was estimated at 1.4 met with a standard deviation of 0.2 met during the academic year.

The formation of the values of microclimate elements, mainly the value of temperature, thermal insulation of clothing, and metabolic rates, has a significant impact on thermal sensations. Table 2 shows the averaged results (avg.) of PMV and PPD values and standard deviation (s). The measurements were supplemented with an assessment of users' thermal sensations based on questionnaires (Table 3).

Table 2. Thermal comfort indicators estimated based on measurement

Indicators	PMV		PPD, %	
Period	avg.	s	avg.	s
Heating season	−0.7	0.4	15.8	8.1
Off the heating season	+0.8	0.5	17.7	10.4
Whole period	+0.3	0.6	7.3	13.7

Table 3. Thermal sensations estimated on the basis of questionnaires

Indicators	Assessment		% of dissatisfied	
Period	avg.	s	avg.	s
Heating season	−0.6	0.5	13.7	10.5
Off the heating season	+0.9	0.3	23.5	7.3
Whole period	+0.4	0.4	8.1	8.2

During the heating season, the majority of users were satisfied with the existing thermal conditions. In contrast, outside the heating season, the number of dissatisfied people was higher. Overall, the evaluation of the thermal environment remained in the comfort zone. In the period preceding the heating season and just after the end of the heating season, the number of people dissatisfied with the thermal

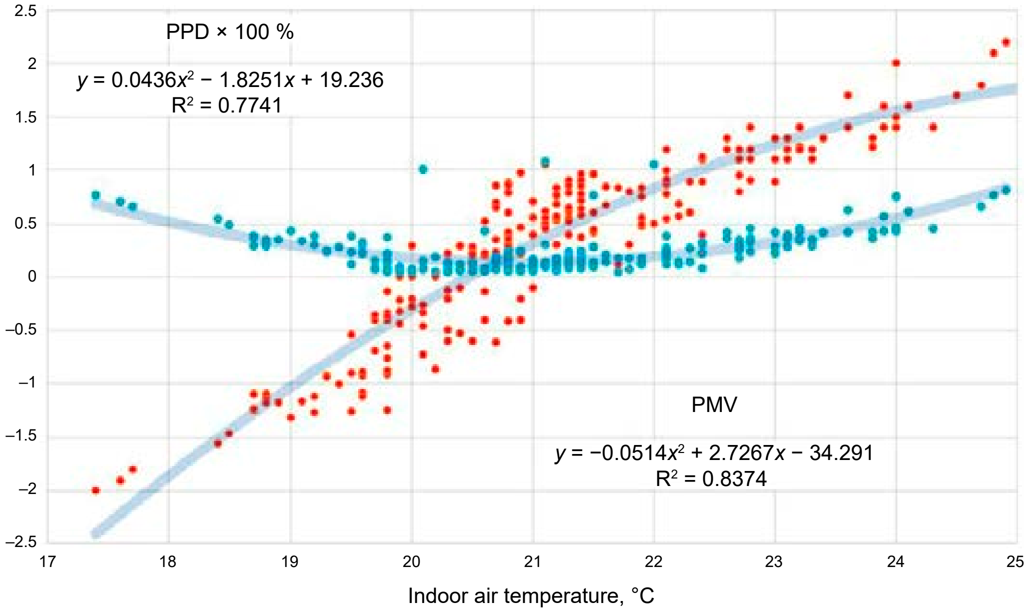

Figure 9. Influence of air temperature on the development of PMV and PPD values

conditions of the environment increased, and the rating then approached the value of −2. The number of dissatisfied people also increased in the summer, with intense solar radiation. Users' ratings then approached +2.

The deviation of PMV values from the comfort zone in specific time intervals was mainly due to changes in the values of microclimate parameters, primarily temperature. Figure 9 shows the changes in PMV and PPD values due to changes in air temperature.

Changes in air temperature, also in the average temperature of ambient radiation, significantly affected the thermal comfort conditions of the people in the study. Determination coefficients in both cases remained on average at the level of 0.8. With certain physical activity, going outside the thermal comfort zone can be, to some extent, regulated by an increase or decrease in the thermal insulation of clothing. An increase in the physical activity of indoor users resulted in a decrease in the temperature value considered comfortable. The air relative humidity and the airflow velocity in the room remained at an acceptable level and had no significant effect on the thermal sensations of the users.

Indoor lighting intensity was at 281 lux with a standard deviation of 65 lux. A computer workstation requires a lighting intensity of no less than 500 lux. Indoor lighting intensity on work surfaces (e.g., laboratory workstations and tables) remained slightly too low for indoor lighting with daylight. This may have been one of the causes of slowed mental performance. Artificial light illumination was required, especially when working on a computer or taking measurements. For artificial lighting, white or neutral light is preferred, which does not cause, for example, color deformation on the computer screen and measurement equipment display.

During the course of the study, indoor residents reported experiencing certain complaints from the sick building syndrome symptom group, which they identified with being in a particular environment. The main complaints reported were fatigue and sleepiness, difficulty in concentration, headache, and nose irritation (Table 4).

Table 4. Sick building syndrome symptoms

SBS symptoms	% of occurrence	
	avg.	s
Throat irritation	15.7	4.6
Nose irritation	22.5	4.7
Eyes irritation	16.8	2.4
Headache	25.1	8.6
Fatigue and sleepiness	41.5	18.4
Irritability	6.9	1.2
Difficulty in concentration	33.6	17.2

During the classes, a rapid increase in carbon dioxide concentration was noted, from 600–800 ppm to 2500–3500 ppm. The limit of CO_2 concentration reached even 5000 ppm. Only after airing the room the previous day after the classes ended was the room not aired immediately before or during the experiment. European (ISO) and American (ASHRAE) standards, as well as WHO guidelines, indicate a value of 1000 ppm as the limit value of CO_2 concentration inside rooms where there are people. Subsequent levels of this concentration are considered a measure of air quality. At 2000 ppm levels, poor air quality and sleepiness are observed, and headaches are possible at 2000–5000 ppm levels. Levels above 5000 ppm lead to pronounced discomfort and increased heart rate, while increases above 15,000 ppm lead to breathing problems. Levels above 30,000 ppm lead to dizziness and indisposition (Azuma et al., 2018; Mishra et al., 2020). High concentrations of carbon dioxide are included in the table of toxic substances in the regulation on the highest permissible concentrations and intensities of factors harmful to health in the work environment (Journal of Laws, 2018). The highest allowable concentration of CO_2 in the workplace is 9000 mg/m^3 (i.e., about 5000 ppm), but this seems to be too high, especially for long-term exposure.

Students completed questionnaires about experiencing SBS symptoms at different CO_2 levels. As the concentration of carbon dioxide in the air increased, some SBS symptoms became more severe. This particularly concerned fatigue and sleepiness (increase in symptoms up to 78 %), difficulty in concentration (up to 69 %), or headaches (up to 57 %). In other previously studied educational rooms, high levels of carbon dioxide concentration were also recorded during most of the classes, reaching nearly 3500 ppm, with the natural gravity ventilation system commonly used in this type of building. In the case of rooms intended for study and work, the ventilation air volume flow (according to the regulations) should be 20 m^3/h for each person in the room. The high tightness of windows, which is maintained for energy efficiency reasons, is contrary to the principles of gravity ventilation and is the cause of high CO_2 concentrations and intensification of SBS symptoms. If windows with an infiltration coefficient of less than 0.3 m^3/(m h daPa$^{2/3}$) are used, it is necessary to use air vents. With gravity ventilation, the air stream flowing through a fully opened air vent, with a pressure difference of 10 Pa on both sides, should be within the range of 20–50 m^3/h, and, when it is closed, it should remain at the level of 20–30 % of this value.

An equally important aspect of environmental quality, guaranteeing thermal comfort, was ensuring appropriate conditions for mental work. Interior conditions influence not only the ability or willingness to study and work but also its efficiency and quality, as well as the final results achieved. Among various environmental factors, air temperature, relative humidity (at very low or high values), and the degree of ventilation affecting the level of CO_2 concentration should be considered as factors significantly affecting the quality and efficiency of work.

The experiment conducted in the Building Physics Laboratory included three categories: a knowledge test, a test on remembering the information provided, and the efficiency of performing a selected measurement. The knowledge test included logical and computational tasks. Attention was paid to the time taken to complete the test and the number of errors made. The next test concerned cognitive abilities, which involved remembering a certain amount of information and then restoring it. The efficiency and correctness of the measurement were carried out on a stand for measuring the temperature and heat flux density inside the wall (Figure 10).

Figure 10. Station for measurement of temperature and heat flux density inside the wall

The station can automatically record measurements using specialized software. It is also possible to read the temperature and heat flow density values directly from the recorder screen. The students had to perform four complete measurement series. What mattered was the timing of the measurements and the correctness of their recording and interpretation.

Research carried out in other educational buildings also found that an increase or decrease in air temperature impairs the ability to perform work efficiently (Figure 11).

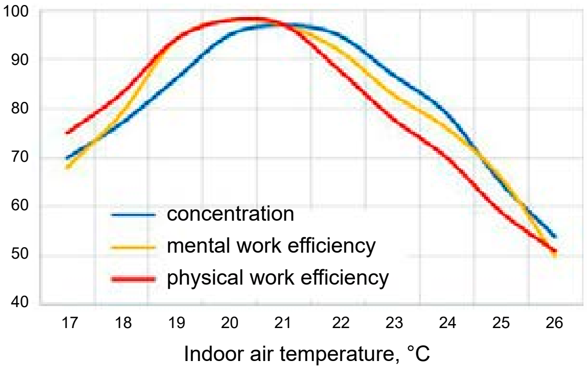

Figure 11. Physical and mental effectiveness as a function of indoor air temperature

Tests and measurements were conducted at increasing values of CO_2 concentration. The initial value of CO_2 concentration was about 600 ppm and gradually increased to a value of 2500–3500 ppm. A significant impact of carbon dioxide concentration above 3000 ppm on mental performance was found. This was especially true for cognitive functions. Students remembered and recalled approximately 15–20 % less information than at CO_2 concentrations of up to 1000 ppm. They also made approximately 17–23 % more errors in the tests, and the time taken to complete them was longer. The time needed to conduct all four of the measurement series also increased. Students showed a lower level of concentration on the assigned task, indicating drowsiness and fatigue. At a level above 4000 ppm, they performed three measurement series instead of four at the same time as at a CO_2 concentration of up to 1000 ppm.

During previously conducted research on the state of the environment in other educational buildings, it was noticed that interaction with greenery is beneficial in terms of improving the emotional state and general well-being of users, which also seems to have a positive impact on cognitive functions. Living greenery seems to be a valued element of the study and work environment, but not only this. In premises where wall coverings were used, such as painted decorations or posters with green elements, the users found the premises more acceptable even without elements of natural or artificial greenery.

Conclusions

The quality of the indoor environment is inextricably linked to the quality of people's lives in closed spaces. Prolonged exposure to unfavorable environmental conditions can cause or aggravate many symptoms associated with abnormal functioning of the body. When specifying the requirements or assessing the quality of the indoor environment in buildings, it is necessary to consider, first of all, the values of the parameters of the interior microclimate and air quality. Proper shaping of the interior microclimate is a basic condition for people in a given environment to achieve a state of thermal comfort and general well-being and health, as well as the efficient and effective performance of mental and physical work.

The average assessment of thermal comfort in the considered environment was within the acceptable comfort zone; among the analyzed thermal microclimate parameters, air temperature and average ambient radiation temperature had a significant impact on thermal sensations. The intensity of interior lighting by daylight was insufficient for the efficient performance of assigned tasks. In many cases, it was necessary to use artificial lighting.

Occupants of the laboratory reported experiencing symptoms of SBS, which mainly included headache, fatigue, and sleepiness, as well as difficulty in concentration. These symptoms were primarily linked to high CO_2 concentrations in the room. An increase in CO_2 concentrations above 3000 ppm clearly contributed to occupant discomfort, an increase in SBS symptoms, and a depletion of their mental performance and work productivity. Setting the maximum concentration of CO_2 in the workplace at 5000 ppm seems to be in contradiction with the results obtained from studies during which concentrations of 2000–3000 ppm did not provide adequate quality of functioning in such an environment.

From the carbon dioxide concentration curve, it could be inferred that the effectiveness of gravity ventilation was low despite the air vents installed in each window. The need to ventilate by opening windows to improve air quality was the cause of increased heat loss and temporary deterioration of thermal comfort conditions during the heating season. While increasing the amount of air exchanged in the ventilation process would increase the operating costs of heating buildings, it would generate clear benefits for the well-being and health of the occupants of the premises as well as for the quality of learning and work and would contribute to reducing sickness absenteeism and related economic losses in the workplace. The introduction of an automatically controlled ventilation system with CO_2 concentration sensors in educational buildings would ensure a constant, gradual supply of fresh air in the amount necessary to guarantee adequate hygiene and health conditions.

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