Investigation of thermal and humidity conditions and air quality in the university computer laboratory

Badanie warunków cieplno-wilgotnościowych i jakości powietrza w uczelnianej pracowni komputerowej

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Educational buildings account for a significant share in the total building stock. Students and teachers spend many hours every day in classrooms. For this reason, it is crucial to ensure appropriate temperature and humidity conditions and air quality in them. This is particularly important in the case of computer laboratories, which have higher heat gains than the average classroom. The paper presents the results of long-term and short-term measurements carried out in the university computer laboratory of air parameters, i.e. temperature, relative humidity and speed, as well as CO_2 concentration level and thermal comfort indexes (Predicted Mean Vote and Predicted Percentage of Dissatisfied). The research was supplemented with a survey carried out among occupants of the laboratory. On the basis of the obtained results, it was assessed whether the natural ventilation system was efficient enough to maintain the recommended air parameters.
Keywords: thermal and humidity conditions, thermal comfort, air parameters, air quality, educational building, university, school, computer laboratory, CO_2 concentration

Budynki edukacyjne stanowią znaczny udział pośród obiektów budowlanych. Uczniowie i nauczyciele spędzają wiele godzin w ciągu dnia w salach lekcyjnych. Z tego powodu kluczowe jest zapewnienie w nich odpowiednich warunków cieplno-wilgotnościowych i jakości powietrza. Jest to szczególnie istotne w przypadku sal komputerowych, które charakteryzują się większymi zyskami ciepła od typowej sali lekcyjnej. W artykule przedstawiono wyniki długo – i krótkoterminowych pomiarów parametrów powietrza przeprowadzonych w uczelnianym laboratorium komputerowym, tj. temperatura, wilgotność względna, szybkość, jak również stężenia CO_2 i wskaźników komfortu cieplnego (przewidywana ocena średnia i przewidywany odsetek osób niezadowolonych). Badania eksperymentalne zostały uzupełnione badaniem ankietowym przeprowadzonym wśród użytkowników laboratorium. Na podstawie otrzymanych wyników oceniono, czy system wentylacji naturalnej był wystarczająco wydajny do utrzymania rekomendowanych parametrów powietrza.
Słowa kluczowe: warunki cieplno-wilgotnościowe, komfort cieplny, parametry powietrza, jakość powietrza, budynek edukacyjny, uczelnia, szkoła, laboratorium komputerowe, stężenie CO_2

Introduction

Educational buildings have a very important role in society. In the European Union, around 76 million students attend schools from early childhood education to upper secondary education [1] and around 18 million students attend tertiary education [2]. In Poland, 4.6 million students attend schools, and more than 1.2 million students attend universities [3]. Therefore, educational buildings account for a significant share in the total building stock.

Classrooms in educational buildings, such as schools and universities, are often not adequately ventilated. Due to that pupils and students are not provided with optimal air quality and thermal comfort conditions. Classrooms are characterized by a large number of students per 1 m^2, which in turn leads to high CO_2 concentration level and poor air quality.

Thermal comfort in classrooms in an education building depends on the following indoor air parameters:

- Temperature: too high value causes rapid fatigue, distraction and greater susceptibility to diseases (overheating); too low value results in lack of comfort at work and greater susceptibility to diseases (cold).
- Humidity: too low value (especially in winter) leads to nose, throat and eyes

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problems; too high value causes a feeling of breathlessness and affects the growth of mold spores.

- Speed: too high value may cause draughts; too small value (no air movement) leads to air stagnation and prevents effective ventilation.
- CO_2 concentration: too high value causes a feeling of shortness of breath and fatigue, headaches, decreased well-being, concentration, efficiency and productivity.

Various research have shown that air quality in schools is poor [4, 5], ventilation air volume flow rates are too low [6], and there are no thermal comfort conditions, e.g. due to overheating of classrooms [7, 8]. The pupils themselves also pointed out the poor quality of the indoor environment [9]. It was proved that the indoor environment can affect not only the thermal comfort, but also the health of students [10] and their studying performance [11]. Research [12] indicated that an increase in air temperature in the classroom has a negative impact on academic achievements. The increase in indoor air temperature from 20°C to 30°C resulted in a decrease in the effectiveness of school duties by 20%.

Investing in proper air quality in educational buildings can lead to long-term positive results for pupils, students and teachers through improved school and academic performance and lower health care expenses.

The type of ventilation system is largely responsible for the poor air condition in classrooms. In most Polish schools it is natural ventilation. This is due to the fact that most of the educational buildings in Poland were built decades ago and only some of them were equipped with a mechanical ventilation system.

Thermal comfort conditions in educational buildings differ from other types of buildings. Due to the high number of occupants, there is an increased risk of overheating, especially when the value of the ventilation air volume flow rate is too low. On the other hand, in the case of poorly designed air supply, high values of the ventilation air volume flow rate can lead to the phenomenon of draught. Correct design of the ventilation system is essential to avoid thermal discomfort. Different ventilation solutions can be used in the educational buildings [28, 29, 30]. The impact of the value of the ventilation air volume flow rate on the thermal comfort conditions of the school swimming pool was presented in [31].

The most important variables that influence the thermal comfort conditions are: air temperature, relative humidity and speed, as well as physical activity (metabolic rate) and clothing (clothing insulation) of the occupants. Not only proper air parameters values are important to achieve thermal comfort conditions, but also the relationship between them. When it comes to air quality, the occupants are the main source of air pollution. It is common to use an analytical method based on carbon dioxide (CO_2) concentration level in this type of indoor environment.

The body's thermal sensation can be determined by the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indexes [13]. The PMV index predicts the mean value of votes by a group of people on the P.O. Fanger 7-point scale of thermal sensation based on the heat balance of the human body [14]. The PPD index shows the percentage of people who chose values of ± 2 or ± 3 on the thermal sensation scale. The indoor environment is considered comfortable if the PMV value is between – 0.5 and +0.5.

There is no agreement in the literature regarding uniform values of indoor air parameters that should be adopted in classrooms in educational buildings. Some regulations make the values of air parameters dependent on the expected air quality in the room. Class B (good) is the air quality that should be provided in a typical educational room. Below are presented the recommendations regarding the values of indoor air parameters in classrooms in winter, according to various literature sources:

- air temperature: >20°C [15]; 22°C±3°C [16]; >18°C [22]; 20°C [17, 23];
- air relative humidity: 60% [15]; 30-70% [16]; 40-60% [24];
- air speed: <0.15 m/s [15]; <0.2 m/s [16. 17];
- CO_2 concentration level: 1000 ppm [18, 19, 20]; <1500 ppm [17, 21]; ambient + 800 ppm [15]; ambient + 500 ppm [16].

The assessment of thermal comfort conditions is particularly important in computer laboratories of educational buildings. They are equipped with a considerable number of computers, which results in higher heat gains in these laboratories than in typical classrooms. For this reason, they are also regularly ventilated between classes by opening windows. This results in a significant variability of the indoor air parameters [25]. Due to the specify of computer laboratories, achieving the appropriate indoor climate parameters in them might be difficult [26]. Ventilation and air conditioning devices might be used to make it possible to meet the requirements of air parameters in the laboratory [27].

The aim of the experimental research carried out in this paper was to verify whether the thermal comfort conditions were met and adequate air quality was ensured in the computer laboratory of an university building. The research encompassed both the long-term and short-term measurements of thermal and humidity conditions and air quality in the room. The research was carried out during Project Based Learning at the Silesian University of Technology (SUT).

Measurement diagnostics of thermal and humidity conditions and air quality in the university computer laboratory

Description of the tested computer laboratory

The tested computer laboratory was located at the Faculty of Energy and Environmental Engineering of the SUT in Gliwice, Poland (Fig. 1). The laboratory is used from Monday to Friday from 8 am to 6 pm by students and lecturers. The dimensions of the

Fig 1.
View of the tested computer laboratory (on the left), the testo 160 IAQ recorder [33] (in the middle), APAR recorder [32] (top right corner) and thermal comfort meter module [34] (bottom right corner)
Rys. 1. Widok badanego laboratorium komputerowego (po lewej), miernika testo 160 IAQ [33] (po środku), rejestratora APAR [32] (górny prawy róg) i modułu miernika mikroklimatu [34] (dolny prawy róg)

room are as follows: 5.9 × 5.5 × 3.0 m (width, length, height). In the room, there are two windows of dimensions: 2.3 × 2.0 m (height, width), located in the insulated exterior wall, facing the north-east direction. Opposite there is a wall with an interior door adjacent to the corridor. The remaining walls are adjacent to other rooms. The heat sources inside the computer laboratory are: 9 computers, 9 monitors, 6 lamps (12 fluorescent bulbs in total), a projector and occupants (maximum 17 occupants), who are also the main source of moisture and CO_2. In addition, there are 2 ribbed radiators in the room, which are part of the central heating system, located under the windows. The laboratory is ventilated by the means of the natural ventilation, the main element of which is an exhaust ventilation grille with dimensions of ~ 0.2 × 0.1 m, located in the upper part of the room (Fig. 2). The windows are not equipped with air inlets, so the air is supplied into the room only through infiltration and leaks.

Tab. 1. Technical data of the measurement devices and modules
Tab. 1. Dane techniczne przyrządów i modułów pomiarowych

		Measurement range	Measurement accuracy
Temperature and humidity recorders A236.B [32]		temperature: -30÷80°C RH: 0÷100%	for temperature: ± 0.3°C (maximum ± 0.4°C) ±2 % RH (maximum ± 2.5% RH in a range of 0÷90 % RH)
testo 160 IAQ recorder [33]		0 to 5000 ppm	±(50 ppm + 3% of a measured value) at 25°C, ±(100 ppm + 3% of a measured value) at 25°C without external power supply
Thermal comfort meter SensoData 5500 MK [34]	Air speed probe	0.05÷5 m/s	±0.02 m/s ±1.5%
	Air thermometer	-20°C÷50°C	±0.1°C
	Globe thermometer	-20°C÷120°C	±0.1°C
	Natural wet thermometer	0°C÷50°C	±0.1°C
	Relative humidity probe	0÷100% RH	±2% in a range of 10…90% RH
	Barometric pressure probe	500÷1500 hPa	±3 hPa

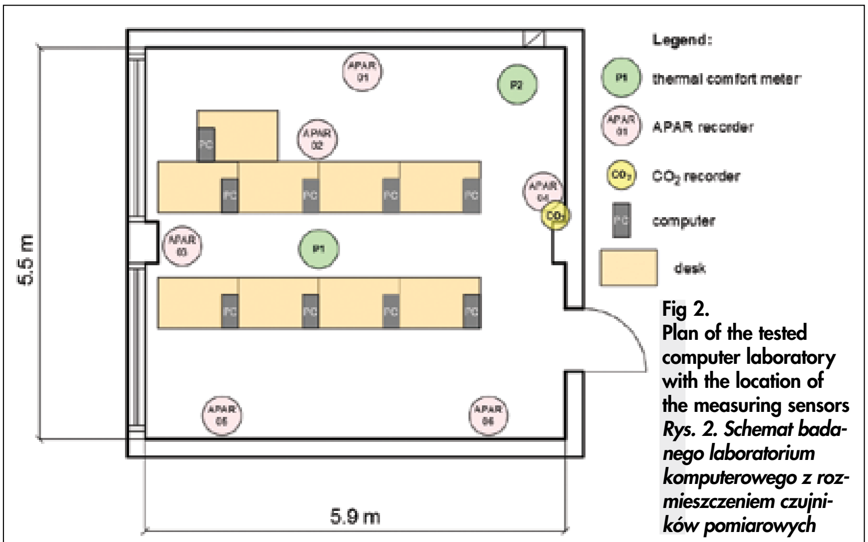

Fig 2.
Plan of the tested computer laboratory with the location of the measuring sensors
Rys. 2. Schemat badanego laboratorium komputerowego z rozmieszczeniem czujników pomiarowych

Methodology and scope of long-term and short-term measurements

The scope of thermal and humidity conditions and air quality measurements in the university's computer laboratory encompassed following air parameters: temperature, relative humidity (RH), CO_2 concentration level and thermal comfort parameters according to standards [13, 35]: Predictive Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD).

The air temperature and relative humidity were registered at 6 measuring points located near the room partitions and desks. Temperature and humidity recorders A236.B from APAR [32] were installed in these places. The location of the sensors is shown in Fig. 2. Air parameters were recorded continuously for 24 hours a day with a time step of 5 minutes for 2 months in the period from October 19 to December 19, 2021. In addition, the CO_2 concentration was monitored using the testo 160 IAQ recorder from Testo [33], with a time step of 15 minutes in a period of 1 month (from November 21 to December 20, 2021), for technical reasons. The recorder was mounted on the internal partition of the room (Fig. 2). All measuring devices were located at a height of 1.1 m. It is the height of a human head in a sitting position according to PN-EN ISO 7726 [35]. The technical data of the devices are presented in Tab. 1.

Short-term measurements of thermal comfort conditions were also carried out using the SensoData 5500 MK thermal comfort meter from Sensor Electronic [34]. The meter includes, among others measurement modules with measurement probes enabling the determination of thermal comfort indicators, a recording module, a tripod, a battery charger and a transport case. The types of measuring modules and their technical data are presented in Tab. 1. The thermal comfort meter was located in two measuring points in the tested computer laboratory (Fig. 2): in the center of the room between the rows of desks (point P1) and near the corner of the room (point P2) with the measuring modules located at three heights: 0.1; 0.6; 1.1 m, corresponding to the measurement heights for the sitting position of a person according to PN-EN ISO 7726 [35]. The Thermal Conditions software was used to operate SensoData 5500 modules to record comfort indicators (PMV, PPD). The research was carried out during the classes, with the presence of people. The duration of one measurement was 3 minutes with a parameter averaging time of 1 minute.

Results of long-term and short-term measurements with analysis

Results of air temperature and relative humidity measurements and CO_2 concentration level over the entire long-term measurement period for all sensors, as well as the value of air speed from the short-term measurements are presented in Tab. 2. All measurement results were taken into account, i.e. both during the time when occupants were present in the laboratory and when the room was unoccupied. The range of values of the respective measured parameters were compared with their recommended values. Due to the lack of uniform regulations the recommended values were adopted as mean values based on literature sources. The air temperature range was assumed as the mean range of recommended values in [15-17, 22, 23]. The air relative humidity range was assumed as the mean range of recommended values in [15, 16, 24]. The limit value of air speed was adopted in accordance with [16, 17] and its minimum value was assumed due to the risk of air stagnation. The limit value for the CO_2 concentration level was adopted in accordance with [18, 19, 20].

Tab. 2. Results of air parameters measurements in the tested computer laboratory
Tab. 2. Wyniki pomiarów parametrów powietrza w badanym laboratorium komputerowym

Measured value	Measured value range (min÷max)	Recommended/limit value
Air temperature	15.6°C÷25.1°C	19.0°C÷21.0°C acc. to the mean range from [15-17, 22, 23]
Relative air humidity	21.7%÷60.1%	40.0%÷60.0% [24]
Air speed	0.003 m/s÷0.12 m/s	0.050 m/s÷0.20 m/s [16, 17]
CO_2 concentration level	372 ppm÷2971 ppm	<1000 ppm [18, 19, 20]

The recommended value of air temperature in the tested computer laboratory was exceeded both in the lower and upper range: by 18% and 20%, respectively. The lowest recorded value of this parameter 15.6°C did not apply to the period when occupants were in the room. During their presence, the mean air temperature was 22.5°C, so it exceeded by 1.5 K the recommended value, which constitutes 7% of the limit value. In the case of air relative humidity, too low values of this parameter were observed, by 46% in relation to the minimum recommended value. The maximum recommended value of this parameter was not exceeded. Air speed values were also too low and were not within the limits of the recommended values in the lower range. Its highest recorded value 0.12 m/s, did not exceed the limit value of 0.20 m/s and constituted 60% of this value. On the other hand, too high values were obtained in the case of CO_2 concentration level, in which case the values of this parameter were exceeded by up to 200%.

Figure 3 presents the Mollier diagram on which the results of all registered air conditions in the tested computer laboratory (in blue) and the range of recommended values of air parameters (in orange) were marked. Most of the measured air conditions were outside the range of permissible values. Only 18% of the blue area covered the orange area.

The range of the measured values for respective APAR recorders are presented in Tab. 3. As before, all measurement results were taken into account, i.e. both when occupants were present and when the room was unoccupied. The lowest air temperature values were recorded for APAR 03, which was caused by the impact of external conditions as well as periodical ventilation of the room due to the location of this device on the external partition between the windows. For the remaining recorders, similar ranges of minimum, maximum and mean values of the measured air parameters were obtained. The mean values of air temperature and relative humidity in the entire room were 21.7°C and 35.3%, respectively.

In fig. 4 the mean, maximum and minimum daily air temperature and relative humidity values for all APAR recorders in the course of the long-term measurement period were collected and compared with the recommended values. The mean value of air temperature in the tested computer

Tab. 3. Summary of air temperature and relative humidity values measured by APAR recorders (minimum, maximum and mean values)
Tab. 3. Zestawienie wartości temperatury i wilgotności względnej powietrza zmierzonych rejestratorami APAR (wartości minimalne, maksymalne i średnie)

APAR recorder number	Measured value range (min÷max)		Mean value	
	Air temperature	Relative air humidity	Air temperature	Relative air humidity
APAR 01	19.6°C÷23.4°C	23.5%÷57.0%	21.9°C	35.2%
APAR 02	19.6°C÷23.4°C	23.8%÷57.3%	22.0°C	35.5%
APAR 03	15.6°C÷22.5°C	25.6%÷60.1%	19.9°C	38.5%
APAR 04	19.3°C÷25.1°C	23.4%÷51.1%	22.1°C	34.7%
APAR 05	19.9°C÷24.2°C	22.0%÷53.9%	22.1°C	33.9%
APAR 06	20.3°C÷24.1°C	21.7%÷54.0%	22.3°C	33.9%
		APAR 01÷06:	21.7°C	35.3%

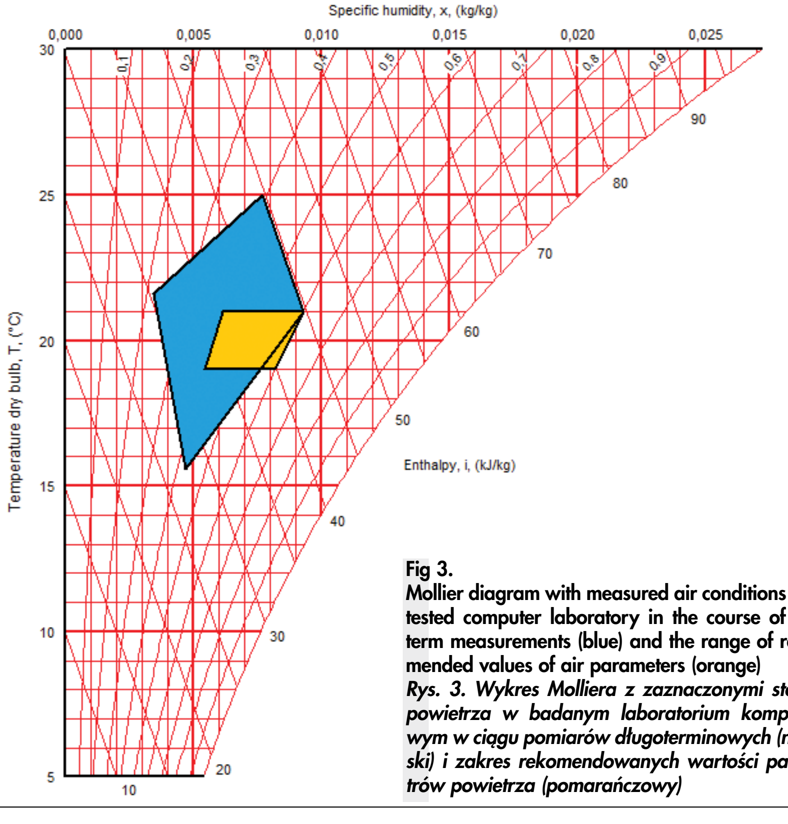

Fig 3.
Mollier diagram with measured air conditions in the tested computer laboratory in the course of long-term measurements (blue) and the range of recommended values of air parameters (orange)
Rys. 3. Wykres Molliera z zaznaczonymi stanami powietrza w badanym laboratorium komputerowym w ciągu pomiarów długoterminowych (niebieski) i zakres rekomendowanych wartości parametrów powietrza (pomarańczowy)

laboratory oscillated around the upper value in the recommended range, i.e. 21°C. The greatest fluctuations occurred in regards to minimum and maximum values: the differences were 5.7K and 3.9K, respectively. The lowest air temperature values were recorded at the beginning of November. The maximum values of this parameter exceeded the recommended values. In the case of air relative humidity, the maximum values were periodically within the recommended values on the contrary to the mean and minimum values.

The mean value of CO_2 concentration level in the tested computer laboratory was 507 ppm. Figure 5 shows the daily course of the variability of this value during the period of a month as part of long-term measurements and the variability of the minimum and maximum values of this parameter. The greatest fluctuations in the value of CO_2 concentration level occurred in the range of the maximum value: from 412 ppm to 2971 ppm. The highest values were recorded on the days when the room was used by students. Apart from those days (Tuesday, Wednesday), the CO_2 concentration level in

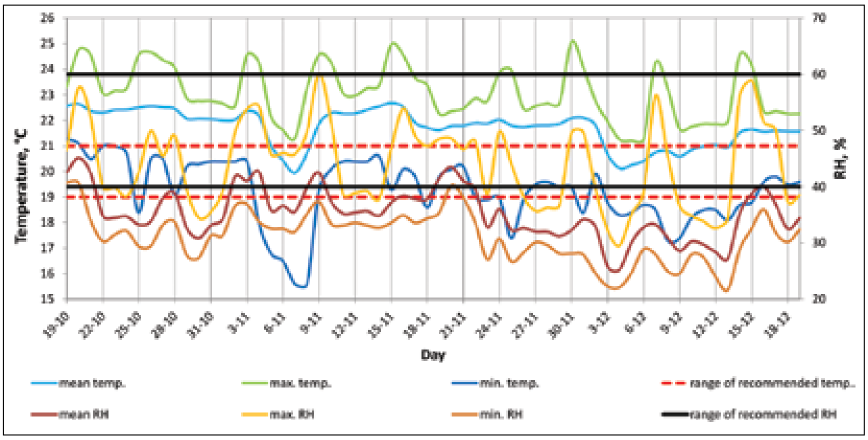

Fig 4.
Daily variability of air temperature and relative humidity in the tested computer laboratory
Rys. 4. Dzienny przebieg zmienności temperatury i wilgotności względnej powietrza w badanym laboratorium komputerowym

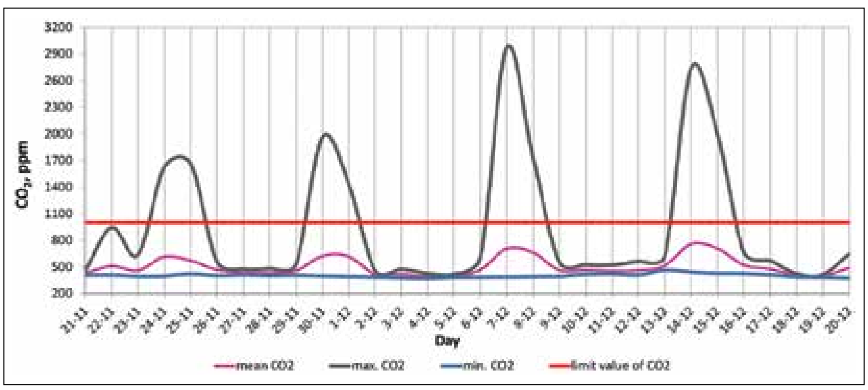

Fig 5.
Daily variability of CO_2 concentration level in the tested computer laboratory
Rys. 5. Dzienny przebieg zmienności poziomu stężenia CO_2 w badanym laboratorium komputerowym

the range of mean, minimum and maximum values fluctuated around the value of 500 ppm. During the entire measurement period, apart from the maximum value on the most occupied days, no CO_2 concentration level exceeding the permissible value 1000 ppm, was noted.

Figure 6 shows the hourly course of the CO_2 concentration level distribution for one selected day (December 7, 2021), when the laboratory was most occupied (from 9:00 to 11:00) and when the highest concentration value was recorded throughout the entire measurement period. There were 17 people in the room during the class. Already 15 minutes after the start of the class, the CO_2 concentration level doubled: from 584 ppm at 9:00 to 1118 ppm at 9:15. The increase in the concentration value was the highest at the beginning of the class and an mean increase equaled 300 ppm every 15 minutes. The highest value of CO_2 concentration, equal to 2971 ppm, was recorded at 11:00. After this time, the concentration level decreased: by 767 ppm after 15 minutes from the last occupant leaving the room, then by an mean of 200 ppm every 15 minutes until 1:00 p.m. After this time, the CO_2 concentration level continued to decrease and the stabilization of its value at the level of about 400 ppm occured at 7:00 p.m., i.e. 8 hours after the occupants had left the room.

Table 4 shows the results of measurements of thermal comfort parameters for measurement points P1 and P2. Measurements were carried out on two dates in November: measurement 1 on November 9, 2021 and measurement 2 on November 16, 2021, after the room was temporarily ventilated by opening windows. It can be concluded that thermal comfort conditions in the room were met during the short-term measurements. The PMV value was within the optimal range, i.e. – 0.5 ÷ 0.5. The mean values of the PMV and PPD indexes from all measurements were 0.18 and 5.9%, respectively.

Taking into account the mean air temperature value and its difference in relation to its spatial mean value, the room's indoor environment was homogeneous according to the standard [35]. Therefore, for the final assessment of thermal comfort conditions, the values from the abdominal height, i.e. 0.6 m for the sitting position, should be taken into account. They are marked in orange in Tab. 4. Considering this height, the thermal comfort parameters were similar in both measurement points P1 and P2 as well as in both measurements 1 and 2. The lowest PMV value, close to 0, was obtained in the center of the room at measuring point P1 in measurement 2, when the room was previously ventilated by opening windows.

As part of the research, a survey among users of the room was carried out. Both students and lecturers took part in it – a total of 96 occupants. The survey was conducted during classes on 6 different days from October 27 to November 30, 2021. Student groups of various sizes (from 5 to 17 students) took part in it. In the surveys, the occupants of the computer laboratory were asked to:

- Mark their location on the floor plan.
- Describe their clothing (to determine whether the person was lightly or heavily dressed).

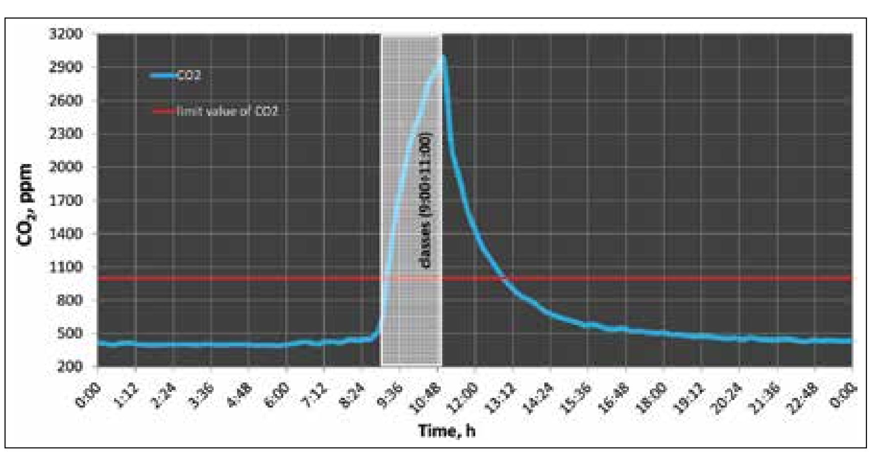

Fig 6.
Hourly variability of CO_2 concentration in the tested computer laboratory
Rys. 6. Godzinowy przebieg zmienności poziomu stężenia CO_2 w badanym laboratorium komputerowym

Tab. 4. Summary of measurement results of thermal comfort parameters
Tab. 4. Zestawienie wyników pomiarów parametrów komfortu cieplnego

Height, m	Measurment point / number of measurement	Air temperature, °C	Air speed, m/s	Relative air humidity, g/kg	PMV	PPD, %
0.1	P1 / measurement 1	22.4	0.120	9.69	-0.25	6.3
0.6		22.9	0.022		0.13	5.4
1.1		24.1	0.004		0.35	7.6
	Mean:	**23.1**	**0.049**		**0.24**	**6.4**
0.1	P2 / measurement 1	22.7	0.115	9.78	-0.23	6.1
0.6		23.7	0.055		0.17	5.6
1.1		24.4	0.053		0.33	7.3
	Mean:	**23.6**	**0.074**		**0.24**	**6.3**
0.1	P1 / measurement 2	22.8	0.027	9.29	-0.07	5.1
0.6		23.1	0.021		0.04	5.0
1.1		23.4	0.063		0.12	5.3
	Mean:	**23.1**	**0.037**		**0.08**	**5.1**
0.1	P2 / measurement 2	22.1	0.015	9.31	-0.24	6.2
0.6		22.5	0.017		-0.13	5.4
1.1		22.7	0.003		-0.07	5.1
	Mean:	**22.4**	**0.012**		**0.15**	**5.6**

- Assess the air temperature perception in the room on a 7-point ASHRAE scale: cold / cool / slightly cool / neutral / slightly warm / warm / hot.
- Assess the air humidity perception in the room on a 7-point scale – very dry / dry / slightly dry / natural / slightly humid / humid / very humid.
- Assess the air smell perception in the room on a 3-point scale – stale / neutral / fresh.

Table 5 presents the results of the survey on air temperature perception by computer laboratory occupants according to the P.O. Fanger 7-point scale of thermal sensation [14]. Only 15% of occupants described their thermal sensations as neutral. For 73% of people in the room the perception was slightly warm, warm or hot, and for 12% slightly cool. Thus, only 15% of occupants experienced the conditions of thermal comfort. Table 6 presents the results of the air humidity perception by computer laboratory occupants. 58% of the respondents described their feelings as neutral. For 12% of them, the air was slightly humid or humid, and for 30%, it was slightly dry or dry. Moreover, the occupants assessed the air quality based on the perception of air freshness in the room. 79% of them described the air smell as neutral and 21% as stale.

After analyzing the results of the survey, it was noticed that the majority of heavily dressed occupants (wearing e.g. sweatshirts or sweaters) sat in places near the windows. The perceived value of air temperature was the lowest there, which forced students to wear warmer clothes. Light dressed occupants (wearing e.g. T-shirts) sat in places farther from the windows, near the center of the room. Despite the lower thermal insulation of their clothing, they still declared their thermal sensation as slightly warm or warm. About 90% of the respondents were dressed in clothing with high thermal insulation due to the winter period and low outdoor air temperature values. In combination with the high indoor air temperature value perception, it intensified the feeling of thermal discomfort among occupants of the computer laboratory.

Tab. 5. Summary of the results of the survey on air temperature perception by computer laboratory occupants according to the P.O. Fanger 7-point scale of thermal sensation
Tab. 5. Zestawienie wyników badania ankietowego odczucia temperatury powietrza przez użytkowników laboratorium komputerowego zgodnie z 7-stopniową skalą odczuć cieplnych P.O. Fangera

Perception	Cold -3	Cool -2	Slightly cool -1	Neutral 0	Slightly warm +1	Warm +2	Hot +3
Indoor air temperature	0%	0%	12%	15%	25%	40%	8%

Tab. 6. Summary of the results of the survey on air humidity perception by computer laboratory occupants
Tab. 6. Zestawienie wyników badania ankietowego odczucia wilgotności powietrza przez użytkowników laboratorium komputerowego

Perception	Very dry	Dry	Slightly dry	Neutral	Slightly humid	Humid	Very humid
Indoor air humidity	0%	11%	19%	58%	8%	4%	0%

Conclusions

In the tested university computer laboratory, long-term measurements of thermal and humidity conditions, i.e. air temperature and relative humidity, as well as air quality in the form of CO_2 concentration level measurements were carried out. Moreover, short-term measurements of thermal comfort conditions (air temperature, relative humidity and speed as well as PMV and PPD indexes) were carried out while the occupants were present in the room during classes. The research was supplemented with a survey of the perception of thermal and humidity sensations conducted among the occupants. Based on the research, the following conclusions can be drawn:

- The mean value of air temperature in the computer laboratory during the entire measurement period (both in the presence and absence of occupants) was 21.7°C. When the occupants were present during classes the value was 22.5°C. It was 7% higher than the recommended value. The maximum value over the entire measurement period was 25.1°C, which was 20% above the recommended value. This is a confirmation of the subjective perception of the occupants, who declared in the survey that 73% of them perceived the indoor air temperature value as too high.
- The mean value of relative air humidity in the computer laboratory during the entire measurement period (both in the presence and absence of occupants) was 35.3%. The minimum value was 21.7%. It was almost twice lower than the recommended value. The subjective perception of the occupants indicated that the air humidity value was on the border of the recommended range, and 30% of them declared the air condition as dry.
- The mean value of air speed in the computer laboratory during the classes was 0.04 m/s. The minimum value was 0.003 m/s. This indicated that there was the risk of air stagnation in the room.
- The maximum value of CO_2 concentration level in the computer laboratory during the entire measurement period was 2971 ppm. This is an exceedance of the recommended value by 200%. It was observed that the CO_2 concentration level increased rapidly with the time of students occupation in the room.
- The analysis of PMV and PPD indexes was carried out only ad hoc and it was

found that during short-term measurements these values were within the recommended range. It means that the thermal comfort conditions in the room were met. It coincided with the perception of the survey respondents during the time when the short-term measurements were carried out.

- Taking into consideration the entire measurement period, the subjective results of the survey do not indicate that the thermal comfort conditions were met in the long term. Only 15% of respondents experienced thermal comfort. This means that the thermal comfort conditions in the room were only periodically optimal, but not for the longer period of time.

The results of long-term and short-term research as well as survey indicate poor thermal and humidity conditions and air quality in the computer laboratory. This is the result of inefficient natural ventilation, which is not able to provide the required value of the supply air volume flow rate. Periodic ventilation of the room by opening windows between classes only temporarily and for a short time improves the temperature-humidity conditions. In order to ensure the thermal comfort conditions and adequate air quality, it is necessary to use a properly designed ventilation system that will ensure the required number of air changes in the room. In the next stage of the research, the authors intend to carry out the numerical calculations CFD to analyze various variants of ventilation solutions in the computer laboratory to ensure the improvement of thermal and humidity conditions and the reduction of the CO_2 concentration level in the room.

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