Indoor Air Quality Evaluation of guests' rooms in hotel building: a Case Study of Turówka Hotel

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Abstract. The advancement of civilizations and the development of society increase the amount of time that a person spends indoors. Currently, people spend up to 80-90% of their lives in buildings, which is why it is so important to ensure proper thermal conditions and high indoor air quality. Air exchange in the rooms is a necessary process for comfort due to the concentration of oxygen and carbon dioxide and the removal of heat and pollutants. The presence of users is a source of pollution in the form of carbon dioxide and heat emitted. An insufficient supply of fresh air may lead to the increase of dioxide concentration to levels that disturb the proper functioning of the body. Installations in hotel buildings must be designed and operated in such a way as to ensure high comfort and meet the high requirements of customers in terms of the internal environment, safety, and reliability of the system. The study aimed to analyse air quality and thermal comfort in hotel rooms. The research was conducted in a historic hotel located in southern Poland. The building consists of four above-ground stories and the basement. The building has 50 double rooms, a conference room for 40 people, and a restaurant with 90 seats for guests. Temperature, humidity, and carbon dioxide concentrations were measured in the rooms. The analysis was conducted based on data from the daily and weekly cycles and included the influence of external factors. Measurements in hotel rooms were carried out continuously with a sampling period of 1 minute, both in the presence and absence of guests. The paper presents an analysis of the variability of air parameters in a daily and weekly cycle and the influence of external factors on the measured values. On this basis, it will be possible to assess the air quality inside hotel rooms and propose solutions to improve internal conditions.

Keywords. Indoor air quality, comfort assessment, carbon dioxide concentration, hotel building.
DOI: https://doi.org/10.34641/clima.2022.67

1. Introduction

Indoor air quality (IAQ) refers to the environmental characteristics inside buildings that may influence the health and comfort of residents. Physical and chemical properties affect it in various ways and on various scales. Air temperature and relative humidity are the fundamental parameters of the assessment of indoor conditions. ASHRAE [1] recommends that relative humidity be maintained below 65%. There is no requirement for a minimum level of relative humidity. Although, low values can cause discomfort to users, including reduced resistance to infection, skin problems, xerosis and dry mucous membranes. The relative humidity should be greater than 30%. The operating temperature depends on thermal insulation and humidity. It should be in the range of about 19-26°C for clothing insulation of 1.0 clo and 23.5-28°C for 0.5 clo [2]. Carbon dioxide is also one of the most popular indicators of air quality and ventilation system performance. The CO_2 concentration increases over time, depending on the building's tightness, the number of occupants, and the type of ventilation. Carbon dioxide at high levels indoors can cause drowsiness, headaches, reduced work efficiency, and impaired concentration. The concept of "Pettenkofer number" can be found in the literature [3]. It is the hygienically acceptable concentration of carbon dioxide in a room. Pettenkofer assumed that air with a concentration of carbon dioxide above 1000 ppm is not suitable for users. In rooms intended for a permanent human residence, this concentration should not exceed 700 ppm. ASHRAE Standard 62.1 [1] also highlights the risk to human health from high concentrations of carbon dioxide. The document assumes that a carbon dioxide concentration of no more than 700 ppm above the outdoor CO_2 concentration will satisfy the vast majority of the population.

Air quality in hotel rooms is crucial for the comfort of users, which consequently also translates into the popularity of the facility. Customer complaints and dissatisfaction can directly affect the financial losses of the hotel. The comfort of the hotel's customers is strictly related to the parameters of the air in the rooms. It is essential to maintain the thermal and humidity parameters while ensuring a low concentration of carbon dioxide in the room. Hotel facilities are very complex cases to analyze air quality. There are many factors that directly affect indoor parameters in guestrooms. Particularly difficult in the analysis is to consider factors such as irregular use of rooms and users' preferences or habits.

In the literature, many papers [4-7] focus on the assessment of indoor air quality. However, only a small number of them consider the hotel buildings. Asadi et al. [5] presented the results of air measurements in a hotel building, including temperature, humidity, and indoor pollutants, including particulate matter, carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (HCHO), and total volatile organic compounds (TVOCs). The results indicate, among other things, inadequate ventilation and significant indoor air pollution. A similar study for newly opened hotels was conducted by Chan et al. [6]. The authors studied both the physical parameters of the air and the pollutants in it. The results showed that most of the studied hotels were not able to provide a completely comfortable indoor environment. Shen et al. [7] instead focused on indoor environmental quality as assessed by guests in Chinese budget hotels. Authors considered user comfort in four categories: acoustic environment, luminous environment, indoor air quality (IAQ), and thermal environment. Of all air quality problems, acoustic environment problems were the most common. The authors also noted the significant impact of the season and climate region of the hotel in reducing occupant quality. For example, the indoor air quality complaint rate drops significantly in winter, and the thermal environment complaint rate is much higher in regions with lower temperatures. Moreover, differences in the perception and evaluation by different customer groups were also noted.

The paper presents an analysis of the parameters inside the hotel rooms. The hotel is located in southern Poland. Variability of internal parameters in the daily and weekly cycles is presented. The analysis includes temperature, relative air humidity, and carbon dioxide concentration. The dependences of these parameters on external conditions, including air temperature, wind speed, precipitation, and insolation, were also checked.

2. Research Methods

2.1 Case of the study

The measurements were carried out in a hotel located in a town within the Kraków metropolitan area in Poland. The building is a reconstruction of a historic salt store from 1812. The five-story hotel has been entered to the register of monuments. The building consists of four floors above ground and underground. Figure 1 shows the hotel's appearance.

Fig. 1 - The appearance of the analyzed hotel.

The hotel has 49 double rooms, one single room, and a suite. There is also a restaurant, a hotel bar, a drink bar, a conference room, and a swimming pool. During the measurements, a constant airflow was supplied to the guest rooms.

2.2 Data collection

The measurements included both conditions inside the rooms and external conditions directly on the premises of the analyzed facility. The tests were conducted continuously with a reading period of 1 minute and during normal hotel operations. Measurements inside the guests' rooms include air temperature, air relative humidity, and carbon dioxide concentration. Figure 2 presents the appearance of the room with the location of the measuring sensor.

Fig. 2 - View of a hotel room with location of measuring sensor.

The outdoor air parameters measured during the study are temperature, wind speed, rainfall occurrence (on a scale of 0 - no rain, 1 - rain), and insolation.

Data from two double guest rooms located on the second floor were used for analysis. Room R1, with an area of 31.3 m^2, is located on the northwest side of the building. Room R2 (21.7 m^2) is located almost on the other side of the corridor (south-east side). The floor plan with the indicated rooms is presented in Figure 3.

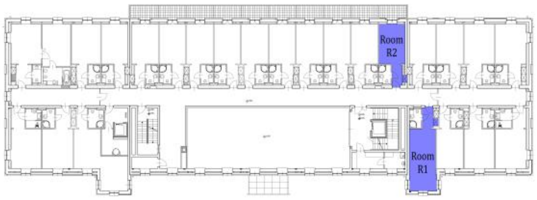

Fig. 3 - Floor plan with room locations.

The measurements have been carried out in 2020. However, due to the pandemic, restrictions in Poland, temporary closure of the hotel, and reduced tourist traffic, not all of the collected data fully reflect the characteristics of the facility and indoor air quality. The months with the low outdoor temperatures were chosen. The two months, November and December of 2020, were adopted as the analyzed period. In the summer, users are much more likely to leave the windows open, which in turn affects the assessment of air quality and ventilation efficiency in the facility. Therefore, the authors deliberately chose months with low temperatures when the opening of windows and balconies is limited. Figure 4 shows the variation in outdoor temperature over the analyzed period, highlighting the periods included in the detailed analysis.

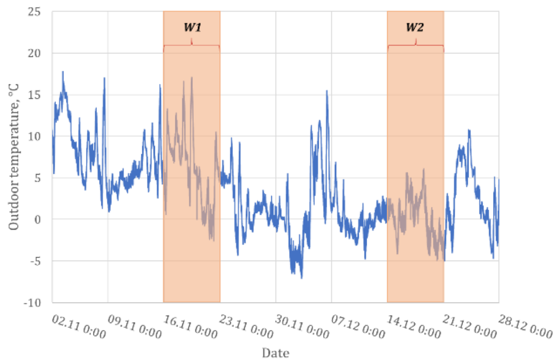

Fig. 4 - Outside temperature distribution of November-December 2020 period highlighting the analyzed periods.

The weeks covered by a more detailed analysis are marked in orange in figure 4. The first week, including a period from 16 to 23 November, is referred to as "W1". As can be seen, this period is characterized by large temperature amplitudes and high maximum readings reaching over 15 °C. The second of the selected periods is referred to as "W2" in further analysis and covers the week from 14 to 21 December. During this period, lower outside temperatures are observed. Moreover, the daily and weekly temperature variations are less than during the W1 week.

2.3 Analysis methods

The obtained data were averaged to 5-minute periods to facilitate further analysis and to eliminate the influence of momentary signal outages or extreme readings. The prepared dataset was further analyzed in both daily and weekly cycles. Additionally, the dependence between indoor conditions and outdoor parameters was checked. For this purpose, correlation coefficients and correlation charts were used.

3. Results and discussion

This chapter presents the main results and their discussion. As described in Section 2.3, this part of the study is divided into four sections.

3.1 Preliminary data analysis

Firstly, the initial analysis of the collected data from both study weeks was conducted. For this purpose, the minimum, maximum and average values of each measured parameter were determined. Table 1 presents a statistical summary of the outdoor air parameters for the two weeks analyzed. The table does not include the parameter determining the occurrence of precipitation. This parameter was measured on a two-level scale, where 0 means no precipitation and 1 indicates the rainy period.

Tab. 1 – Statistical summary of external conditions data.

Parameter	Min	Max	Avg
	Week W1		
Sunlight, lux	1.00	999.00	357.37
Temp, °C	-2.50	16.78	6.09
Wind, m/s	0.00	4.46	1.02
	Week W2		
Sunlight, lux	1.00	999.00	306.61
Temp, °C	-4.80	5.74	0.05
Wind, m/s	0.00	2.66	0.47

Similarly, a summary of internal parameters was prepared. Due to the analysis of two separate rooms, the data were prepared individually for rooms R1 and R2. The obtained values are summarized in Table 2 and Table 3, respectively.

Tab. 2 – Statistical summary for data from room R1 for both analyzed periods.

Parameter	Min	Max	Avg
	Week W1		
Temp, °C	22.3	23.6	23.1
RH, %	30.0	42.0	38.2
CO_2, ppm	400.0	914.0	493.1
	Week W2		
Temp, °C	20.2	22.5	22.0
RH, %	28.0	39.0	31.7
CO_2, ppm	400.0	1126.0	595.9

Tab. 3 – Statistical summary for data from room R2 for both analyzed periods.

Parameter	Min	Max	Avg
	Week W1		
Temp, °C	16.8	24.8	23.0
RH, %	25.0	45.0	34.4
CO_2, ppm	400.0	3296.0	626.3
	Week W2		
Temp, °C	21.8	25.0	23.3
RH, %	24.0	35.0	28.3
CO_2, ppm	400.0	4079.0	703.5

Already on the preliminary stage of the analysis, it was noticed that the rooms have different characteristics and the range of the obtained values of parameters vary greatly. Both air temperature, relative humidity, and CO_2 concentrations vary in a wide range in room R2. Moreover, low temperatures below 17°C and very high concentrations of carbon dioxide above 3000 ppm were recorded in room R2 during the measurement period.

3.2 Weekly analysis

In the next step, analysis was performed based on the data from tested weeks. Results were examined separately for both rooms. Figure 5 presents the variation of air parameters inside room R1 for the first test week.

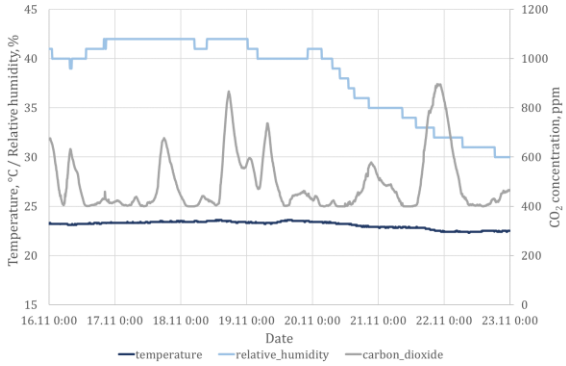

Fig. 5 - Variability of internal parameters of air in room R1 for the first measuring week W1.

The graph shows variations in carbon dioxide concentrations ranging from 400 to over 900 ppm, with no clear trend of variability in the week cycle. On some days, there is a visible increase in concentration in the evening hours and then its slow decline into the morning hours. This decrease may be the effect of the daily sleeping timetable of the average user. Human emits a much smaller stream of carbon dioxide during sleep. The temperature inside the room is kept relatively constant. On the other hand, the relative air humidity significantly decreases at the end of the week from over 40% to 30%. The fluctuations in the values of these parameters for the R2 week are presented similarly. The graph is given in Figure 6.

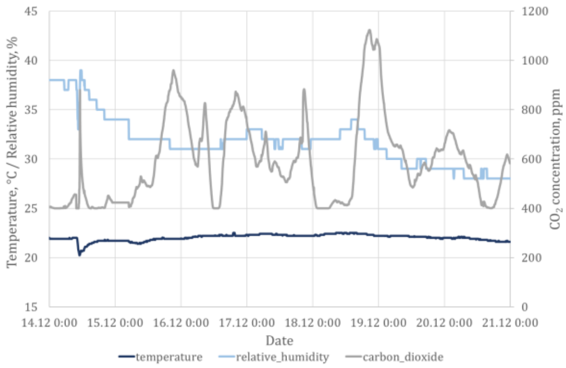

Fig. 6 - Variability of internal parameters of air in room R1 for the second measuring week W2.

Similar to the first week, there is also a trend of increasing carbon dioxide concentration during the evening. The concentration during this period exceeds 1000 ppm but does not rise above 1200 ppm, which can be considered correct conditions for use. On 14 December, a decrease in temperature to 20 °C is noticeable. Given the suddenness of the drop, it may be the result of opening a window. The rapid decrease of the carbon dioxide concentration also confirms this theory. Similar to the first week, the relative humidity also decreases during the week.

An analogous procedure was carried out for the second in hotel rooms. Figure 7 shows a plot of the variation in indoor conditions in room R2 during week W1.

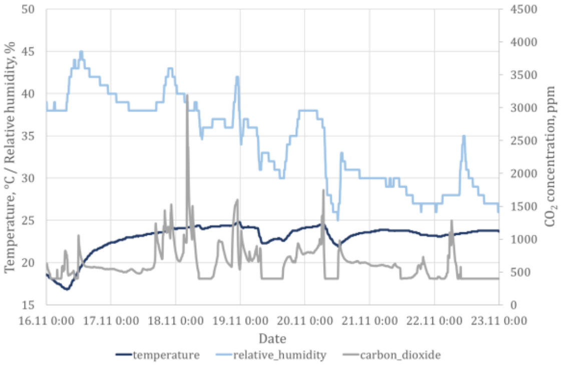

Fig. 7 - Variability of internal parameters of air in room R2 for the first measuring week W1.

In this case, significant variability is noted for each parameter. The decrease in temperature on the first of the analyzed days may be due to the guests' preference for low air temperatures or to the absence of users. However, a temperature of 17°C, as observed on 16 December, is associated with a high probability of feeling cold among users. As can be seen, carbon dioxide concentrations as high as 1000 ppm were recorded at the same time, so we assume that users were nevertheless present in the room. As in the previous examples, there is also a decrease in relative humidity values. Figure 8 shows the variation of these parameters for week W2.

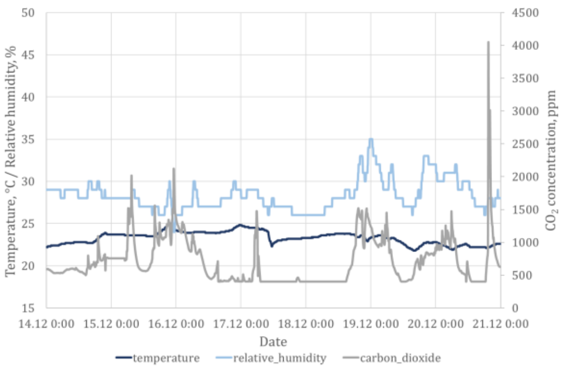

Fig. 8 - Variability of internal parameters of air in room R2 for the second measuring week W2.

It is noticeable in the figure that the temperature varies from 22 to 25°C during the week. On 17 December, the temperature drops quickly by about 2 degrees. No other sudden temperature changes were noted. However, significant fluctuations can be observed in the case of carbon dioxide concentration. The concentration increases several times to the level of about 1500 ppm. On 21 December a sudden increase to the level of 4000 ppm is noticed. Such indications significantly exceed the level considered as comfortable.

3.3 Daily analysis

The next step focused on the variability of indoor parameters in the analyzed rooms over a daily cycle. From the research period, one day from each of the rooms was selected for the detailed analysis. The selection was based on the high variability of parameters. At the same time, periods with CO_2 concentrations observed above 500 ppm were selected, which may indicate the presence of indoor users. Figure 9 shows the distribution of indoor parameter variability in room R1 on 17 December (Thursday).

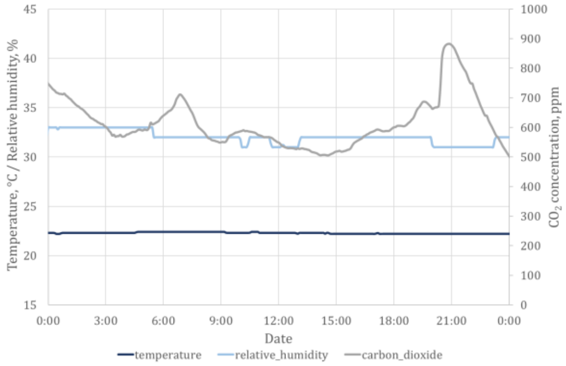

Fig. 9 - Variability of internal air parameters in room R1 on the example of December 17.

As can be seen in the graph above, the concentration of carbon dioxide varies from 500 to just under 900 ppm, which can be considered an acceptable level for comfortable use. Temperature and relative humidity fluctuate within a small range and are maintained at a comfortable level. Figure 10 shows the distribution of indoor parameter variability in room R2 on 15 December (Tuesday).

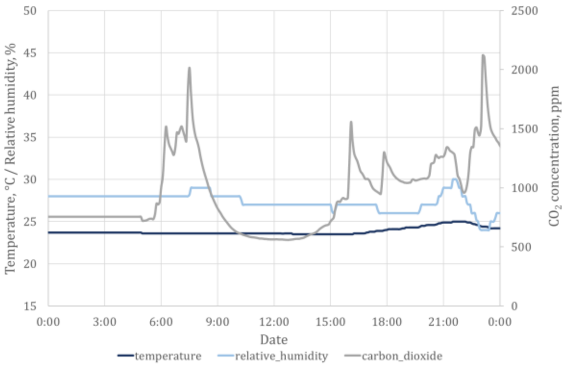

Fig. 10 - Variability of internal air parameters in room R2 on the example of December 15.

In the case of room R2, we see significantly higher variability in all measured parameters. The concentration of carbon dioxide varies from over 500 to over 2200 ppm. An increase in temperature and humidity is also noticed after 20:00. The decrease in these two values after 22:00, and the subsequent decrease in carbon dioxide concentration, may indicate that a window was opened in the room.

3.3 Analysis of the external factors

In the next stage, the authors decided to check the relationship between the values of individual indoor air parameters and the values measured outside the building. Further analysis was conducted jointly for both measurement weeks to get a more general view of the relationship between the parameters.

Tab. 4 – Correlation coefficients of room R1.

Outdoor conditions	Temp, °C	RH, %	CO_2, ppm
Rain	-0.008	0.093	-0.144
Sun	0.042	0.031	-0.291
Temp	0.761	0.757	-0.336
Wind	0.318	0.280	-0.431

The determined correlation coefficients show a clear relationship between the individual values inside the room and the temperature measured outside the facility. For the relationships of two parameters: air temperature and relative humidity and the outside air temperature, the values of the coefficients are above 0.75. Moreover, for room R1, the influence of wind speed on the concentration of carbon dioxide was noticed, and the determined correlation coefficient was -0.431. The above-mentioned dependencies with the highest correlation coefficients are presented on graphs. Figure 11 shows the relationship between the temperature inside room R1 and the outdoor temperature. In addition, the graph shows the trend line as a second-order polynomial and the coefficient R2.

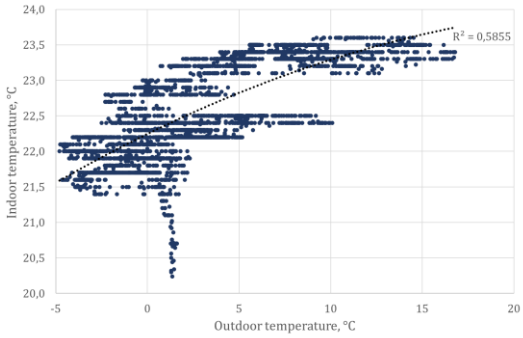

Fig. 11 - Relationship of indoor temperature to outdoor temperature for room R1 in both weeks.

As can be seen, several measurements' points do not fit into the trend noted. These records were obtained at outdoor air temperatures around 1-2 °C. Likely, this is the result of the periodic ventilation of the room by opening the window. Similar to previous charts, Figure 12 shows the relationship between indoor relative humidity and outdoor temperature.

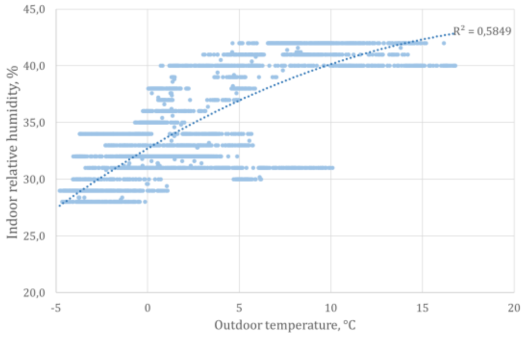

Fig. 12 - Relationship of indoor relative humidity to outdoor temperature for room R1 in both weeks.

As in the case of the previous chart, a group of values deviates from the determined trend. Nonetheless, the relationship is noticeable. As mentioned before, an interesting relation between the concentration of carbon dioxide in room R1 and the wind speed was noticed. The results in the form of a graph are presented together with the trend line in Figure 13. As above, a second-order polynomial relationship was used.

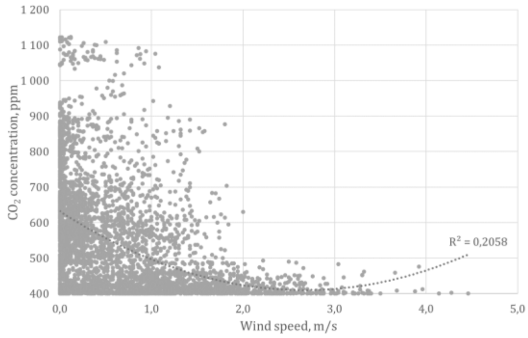

Fig. 13 - Relationship of indoor CO_2 concentration to wind speed for room R1 in both weeks.

The presented dependence is much weaker than the previous two relations. Nevertheless, there is a noticeable tendency for the concentration of carbon dioxide to decrease at high wind speeds. Of course, the presence of users and their activities are the key factors that affect changes in carbon dioxide concentration. However, it was noted that the increased windiness, and hence air infiltration, may dilute indoor air pollutants. This fact may be related to the leakage of window frames and the location of the room on the west side because, in the Polish climate, the winds blow from the west direction most often. This analysis does not include the direction of the wind. It may result in a weaker relationship between these quantities. Likewise, the dependence coefficients were also estimated for room R2. The results are summarized in Table 5.

Tab. 5 - Correlation coefficients of room R2.

Outdoor conditions	Temp, °C	RH, %	CO_2, ppm
Rain	-0.076	0.018	-0.051
Sun	-0.124	-0.018	-0.267
Temp	-0.045	0.634	-0.231
Wind	0.018	0.167	-0.158

In this case, the highest values of the coefficient were obtained for the relation between indoor air humidity and external temperature. The remaining values for the R2 room take low values, not exceeding the level of 0.3 in absolute terms. As can be seen, the dependence of carbon dioxide concentration on wind speed, in the case of this room, is characterized by a much lower correlation coefficient. As mentioned above, it may result from the location of the rooms on both sides of the corridor, where room R1 is on the north-west side, and room R2 is on the south-east side. The relationship that obtained the best result with the trend line is shown in Figure 14. As in the above cases, a second-order polynomial function was used.

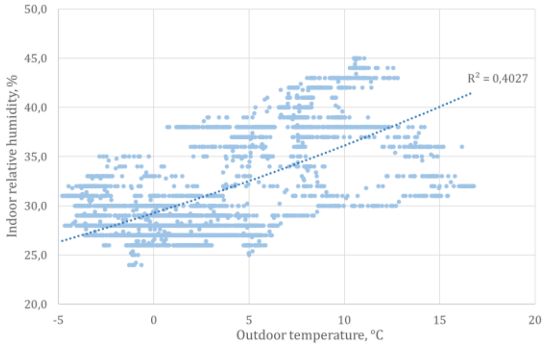

Fig. 14 - Relationship of indoor relative humidity to outdoor temperature for room R2.

Among the analyzed relationships, only the relationship between indoor relative humidity and outdoor temperature is noticeable for both of the analyzed rooms. Hence, the relationship between these two parameters for both rooms is shown in Figure 15.

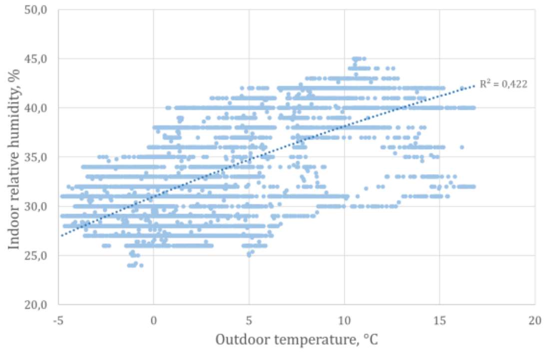

Fig. 15 - Relationship of indoor relative humidity to outdoor temperature for both rooms.

4. Conclusion

Analysis of indoor environmental quality is crucial, particularly in rooms where users spend a significant part of their day. The measurements were carried out in two guest rooms located on the first floor of a hotel in southern Poland. The conducted analysis showed that the conditions inside the rooms are highly variable with time. Moreover, the levels of carbon dioxide are many times higher than the recommended values, especially for room R2. An increase in the ventilation flow rate for room R2 should be considered to improve indoor air quality. As can be seen, both rooms, despite their location in the same building, have quite different characteristics and dynamics of air parameters changes. Room R1 is over 30% larger, therefore with the same number of users, the increased concentration of carbon dioxide is not surprising. However, the level of the CO_2 concentration is significantly high, temporarily reaching values that threaten the health and comfort of the users. Periodic air humidification would also be appropriate, as a drop in humidity below 30% may cause discomfort to users.

There are several problems noted in the measurements and analysis of indoor air quality in hotel buildings. The most important of them include individual preferences of users and irregular periods of actual hotel guests' presence. At the stage of further analyses, the conducted research should be supplemented with the measurements of user presence in the examined room.

During the analysis, clear relations between the indoor air parameters and the external conditions were noticed. Especially for room R1, the determined correlation coefficients took high values, considering that the correlations were checked individually for the relationships of each parameter. Once the data were supplemented with the occupant presence factor, the developed dependencies could provide an excellent basis for further multi-parametric analysis. For example, authors could implement artificial intelligence to develop a prediction model. In this way, ventilation and heating systems could automatically respond before indoor conditions deteriorate.

5. Acknowledgement

The research was carried out in the project entitled „Opracowanie zintegrowanego systemu umożliwiającego precyzyjną kontrolę mikroklimatu w dużych obiektach użytkowych w celu spełnienia wymagań dotyczących budynków o niemal zerowym zapotrzebowaniu na energię (nZEB)" no. POIR.01.01.01-00-0720 / 16 co-financed by the EU European Union from the Regional Development Fund under the Intelligent Development Operational Program for 2014-2020.

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Data Statement

The datasets generated during and analysed during the current study are not publicly available due to privacy restrictions but are available on request from the corresponding author.