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# ANALYSIS OF PARAMETERS INFLUENCING THE INDOOR AIR QUALITY

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**Abstract**

In modern society, when people spend most of their time in indoor environment, it is very important to ensure the best possible indoor climate in order to achieve general satisfaction with the users of the space. The paper provides an overview and description of the key parameters required for achieving a quality indoor climate. Also, the measurement of indoor air quality (IAQ) parameters was performed in one of the classrooms in the building of the Faculty of Mechanical Engineering in Sarajevo in the period from May 7 2019 till May 24 2019. The results obtained by measurement are compared with the values prescribed according to EN 15251, EN 16798, EN 13779 and ASHRAE 62.1 standards in order to determine the level of air quality in the room.

**Keywords:** indoor air quality; european standards; thermal comfort; ASHRAE standard

## 1. Introduction

The concept of quality indoor air is quite broad and there are many parameters that affect the achievement of thermal comfort. However, indoor air quality (IAQ) is most often determined using three key parameters: carbon dioxide ($CO_2$) concentration, indoor air temperature and relative humidity. In modern society, people spend 90% of their time indoors, which is why it is very important to achieve the appropriate microclimate and air quality in those spaces. [1]. A lot of research that has been conducted has shown that all aspects of comfort affect the overall satisfaction of occupants, including the subjective feeling of comfort, health and on-the-job performance. The research has also shown that the concentration of carbon dioxide depends on the level of activity and the number of people present inside. The analyses have revealed that a lower level of activity causes the concentration of $CO_2$ to decrease and scale back to night-time outdoor concentration levels [2]. The $CO_2$ level rises in poorly ventilated and oxygen-deficient spaces, therefore people staying or working in closed spaces with poor air quality commonly suffer from headaches, drowsiness, a drop in energy and concentration levels [3], [4], [5]. The comfort associated with spending time indoors is also closely related to energy consumption because unfavourable micro-climate conditions adversely affect people's mental and physical condition and in many cases act as a motivating factor for occupants to take steps to increase the level of comfort, which in turn can lead to higher energy consumption levels. Authors in their work [6] have used a dynamic building simulation tool to compared the energy use of two classrooms designed to meet various indoor environmental quality (IEQ) standards. Simulations were performed using the criteria for heating and cooling setpoints, ventilation rates, humidity levels and illuminances for each category in the EN, ISO, ASHRAE and ISHRAE standards in order to identify how the criteria from each standard affect energy use and IEQ. In their research, they came to the conclusion that it is less energy expensive to improve IEQ parameters by moving from setpoints of the Category III to Category II than from Category II to Category I. The group of authors in their research [7] gave a critical review of standards for indoor thermal environment and air quality. Increasing the building's energy efficiency very often leads to poor comfort conditions in buildings. Therefore, future standards and regulations for defining energy performance should be focused on indoor comfort and air quality in the space, in addition to reducing energy consumption in the building. If the standards are focused only on the reduction of energy consumption in the building, it can lead to problems for the users and their poor productivity related to the disturbed indoor comfort. The most common problems occur due to the restrictive requirements of the standard for the minimum number of air changes in the room.

A number of international standards provide for recommended parameters for indoor air quality. This paper will consider BAS EN ISO 7730:2010, EN 15251:2007 which was modified with the standard EN 16789-1:2019 and ASHRAE 62.1 standards, and the results obtained by measurement will be matched against the values recommended in those standards.

## 2. Assessment of thermal comfort using BAS EN ISO 7730:2010

The BAS EN ISO 7730:2010 standard serves to analytically determine and interpret thermal comfort using the calculation of PMV (*PMV - Predicted Mean Vote*) and PPD indices (*PPD - Predicted Percentage of Dissatisfied*) and local thermal criteria. The standard determines the PMV and PPD indices depending on the level of activity and clothing. The PMV index is derived from the human heat balance equation and is expressed as (1) [8]:

$$PMV = (0{,}028 + 0{,}303 \cdot e^{-0{,}036 \cdot M})[(M - W) - H - E_c - C_{res} - E_{res}] \quad (1)$$

where: $M$ – metabolic rate, $W$ – effective mechanical power, $H$ – sensitive heat exchange (dry heat loses), $E_c$ – heat exchange by evaporation on the skin (wet heat losses), $C_{res}$ – heat exchange by convection in breathing, $E_{res}$ - evaporative heat exchange in breathing.

Expression (1) shows that the PMV index can be calculated for different values of the metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity and humidity [8], [9]. The PMV index has a seven-point thermal sensation scale, from -3 (too cold) to +3 (too hot), with 0 translating as thermal neutrality. Even when the PMV index is 0 dissatisfaction with thermal comfort will still be expressed by some people, because even if all the occupants are dressed in a similar fashion and engage in similar activity levels the comfort sensation varies from one person to another. Once the PMV index is known, the PPD index that predicts the percentage of thermally dissatisfied occupants, i.e. feeling too cold or too hot, can be determined. The PPD index is determined by means of the mathematical expression (2) as a function of the PMV index [8], [10]:

$$PPD = 100 - 95 \cdot e^{-(0{,}03353 \cdot PMV^4 + 0{,}2179 \cdot PMV^2)} \quad (2)$$

Expression (2) shows that in case of thermal neutrality the minimal percentage of dissatisfied respondents is 5%, whereas for the maximum 10% of dissatisfied respondents, which is acceptable under the ISO 7730 standard, PMV can range from -0.5 to +0.5, which is regarded as an acceptable thermal environment. The predicted number of dissatisfied respondents is also illustrated in the diagram shown in Fig. 1 [3], [8], [9], [10].

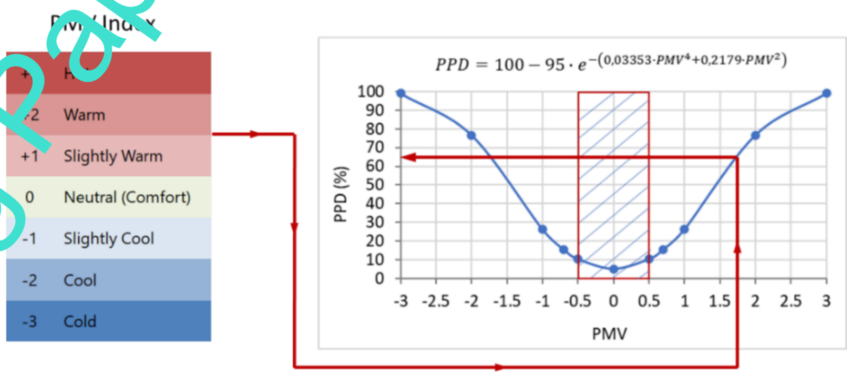


Fig. 1. Predicted percentage of dissatisfied as a function of predicted mean vote [3],[8],[9],[10]

PMV and PPD indices can be directly used as a criterion for the assessment of indoor thermal comfort. This is because they take into account the impact of key parameters determining the indoor thermal condition as well as those that are descriptive of a person (their physical activity and clothing) [8], [10].

In educational buildings where occupants (students and teachers) were an important source of air contamination, it was recommended to calculate the percentage of occupants dissatisfied with IAQ, as a function of pollutant concentrations. For the main representative pollutant, which is $CO_2$, the PD = f($cCO_2$ ) function is expressed by equation [11]:

$$PD_{CO_2} = 407 \cdot e^{\left(-15{,}05 \cdot c_{CO_2}{}^{-0{,}25}\right)} \tag{3}$$

## 3. Recommended values of indoor air quality parameters according to EN 15251, EN 16789, EN 13779 and ASHRAE 62.1 standards

The European standard for indoor environment EN 15251:2007 sets permitted carbon dioxide concentration levels for indoor air compared to outdoor carbon dioxide concentrations for different categories of buildings, as shown in Table 1 [12].

| Category | $CO_2$ concentration above outdoor concentration (ppm) | Fresh air per person (l/s/person) | Relative humidity | Air flow for pollution emission in buildings (l/s/m²) | | |
|---|---|---|---|---|---|---|
| | | | | Very low polluted buildings | Low polluted buildings | Polluted buildings |
| **I** | 350 | 10 | 30 – 50 | 0.5 | 1.00 | 2.00 |
| **II** | **500** | **7** | **25 – 60** | **0.35** | **0.70** | **1.40** |
| **III** | 800 | <4 | 20 – 70 | 0.2 | 0.40 | 0.80 |
| **IV** | >800 | - | - | - | - | - |

Table 1. Permitted carbon dioxide concentrations according to EN 15251 [12]

According to the EN 15251 standard, the recommended carbon dioxide concentration in educational institutions is assigned Category II, which means that $CO_2$ concentrations should not exceed the upper limit of 500 ppm relative to outdoor $CO_2$ concentrations. For non-residential buildings ISO 17772, EN 16798 and EN 15251 have similar requirements for ventilation rates, but EN 15251 does not specify any values for Category IV. Moreover, recommended indoor air temperature in educational institutions according to EN 15251 (Category II) is 20°C in the winter period and 26°C in summer [12].

Standard EN 16789-1 published in 2019, is update of the EN 15251 from 2007, covering indoor environmental criteria for the design of buildings, room conditioning systems, and lighting systems. The major change from EN 15251 is that the standard is split into a normative part EN 16798-1, and a technical report part EN 16798-2 TR. The standard establishes three, or sometimes four categories of thermal comfort. Category I is recommended for users with less thermal adaptation (e.g. the elderly, sick, or children), while categories II and III are recommended for new and existing buildings, respectively. Category IV is with poor quality air and unacceptable regarding health. The listed $CO_2$ values can also be used for demand controlled ventilation according to standard EN 16789, as shown in Table 2 [13].

| Category | $CO_2$ concentration above outdoor concentration (ppm) | Fresh air per person (l/s/person) | Relative humidity | Air flow for pollution emission in buildings (l/s/m²) | | |
|---|---|---|---|---|---|---|
| | | | | Very low polluted buildings | Low polluted buildings | Polluted buildings |
| **I** | 550 | 10 | 30 – 50 | 0.5 | 1.00 | 2.00 |
| **II** | **800** | **7** | **25 – 60** | **0.35** | **0.70** | **1.40** |
| **III** | 1350 | 4 | 20 – 70 | 0.3 | 0.40 | 0.80 |
| **IV** | >1350 | <4 | <20, >70 | 0.25 | 0.3 | 0.6 |

Table 2. Default design $CO_2$ concentrations above outdoor concentration assuming a standard $CO_2$ emission of 20 L/(h per person) according to EN 16789 [13]

The acceptable level for the Category I according to EN 16798 is 550 ppm, which is 200 ppm higher than in EN 15251 standard and Category II is the same as Category III in above mentioned standard. According to EN 16789 standard, II category is recommended for educational buildings with corresponding value of 800 ppm $CO_2$ above outdoors for energy calculation.

The European standard EN 13779 classifies indoor air quality into four categories (Table 3) ranging from IDA 1 to IDA 4 to indicate high and low indoor air quality respectively. Also, according to the EU, the typical $CO_2$ indoor air concentration ranges from 600 to 1000 ppm relative to outdoor $CO_2$ concentrations.

| Category | Quality of indoor air | $CO_2$ concentration above outdoor concentration (ppm) | | Fresh air rate (l/s/person) |
|---|---|---|---|---|
| | | Typical range | Default value (ppm) | |
| **IDA 1** | High | ≤400 | 350 | >15 |
| **IDA 2** | Medium | 400-600 | 500 | 10-15 |
| **IDA 3** | Moderate | 600-1000 | 800 | 6-10 |
| **IDA 4** | Low | >1000 | 1200 | <6 |

Table 3. Indoor air quality classification according to EN 13779 [14]

According to ASHRAE 62.1, the permitted upper limit concentration of $CO_2$ in the office space is 700 ppm relative to outdoor $CO_2$ concentrations [15]. Since outdoor $CO_2$ concentrations typically range from 300 ppm to 500 ppm (as the typical outdoor concentration of CO2 were taken 400 ppm value.), the recommended $CO_2$ concentration for business premises should be in range from 1000 ppm to 1200 ppm. Also, according to the ASHRAE 62.1 standard, the relative air humidity in educational buildings should be between 30% and 60%, and the indoor air temperature between 20 and 24°C in the winter period, and between 23 and 26°C in the summer period [15]. EN 16798 and EN 15251 require relative humidity to be maintained within 30-50% for Category I, 25-60% for Category II, and 20-70% for Category III. No criteria for the relative humidity for Category IV are stated meaning that any values beyond limits of the Category III are unacceptable [12], [13].

## 4. Description of the measuring instrument and analysis of indoor air quality parameters

The goal of this paper is to analyse of $CO_2$, indoor air temperature and relative humidity level and their variability during analysed period. The instrument used for the measurement of indoor air parameters is the OPUS 20-TCO data logger, manufactured by Lufft, Fig. 2. It consists of three internal sensors for recording air temperature (°C), relative humidity (%) and carbon dioxide concentration (ppm). The measuring range for carbon dioxide concentration is 0-5000 ppm, with ±50 ppm accuracy, for air temperature it is from -20 to +50°C with 0.3°C accuracy and for relative humidity the measuring range is 10-95%, with 0.2% accuracy. The measuring range is set to do measurements every 10 seconds, with values being recorded every 30 minutes. The sensor is placed inside a room, 1 meter above the floor and at a 1-meter distance from the user, as illustrated in Fig. 3.


Fig. 2. Instrument for measuring air quality

Fig. 3. Positioning of the instrument

Measuring indoor air quality parameters was performed in one of the 2nd floor classrooms at the Faculty of Mechanical Engineering in Sarajevo. The classroom has 148.6 $m^2$ and the volume of 498.8 $m^3$. The glazing faces south and east. The classroom is equipped with sunscreen vertical blinds that can be moved according to need. There is no mechanical ventilation in the classroom, and the classrom is naturally ventilated. Carbon dioxide concentration, relative humidity and air temperature measurements were performed outside the heating season, from 7 May 2019 to 24 May 2019. Fig. 4 shows $CO_2$ values recorded in one of the 2nd floor classrooms in the analysed period.

The results have shown that during each working day the $CO_2$ concentration rises from the start of the lectures and reaches its maximum values at the end of the day, that is, when students leave the classroom. At the end of the working day the indoor $CO_2$ concentration begins to decrease until its value becomes approximately equal to the value of the external $CO_2$ concentration, which usually ranges from 300 ppm to 500 ppm. Fig. 4 shows that for some parts of the day $CO_2$ concentrations do not comply with the prescribed ASHRAE and EN 15251/EN 16789 standards. Higher $CO_2$ concentrations were particularly pronounced from 13 May 2009 to 17 May 2019. On those days, according to class schedule, teaching was performed from 9 a.m. to 3 p.m. or even 5 p.m.

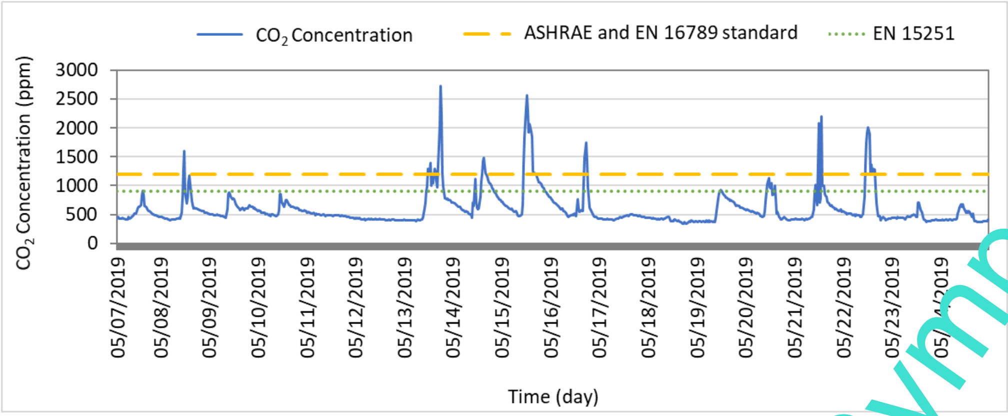


Fig 4. Change of carbon dioxide concentration in one of the classrooms at the Faculty of Mechanical Engineering in Sarajevo in the analysed period

Also, Fig. 4 indicates that the highest $CO_2$ concentration was recorded on 13 May 2019 at 6:00 p.m. (2729 ppm) and on 15 May 2019 at 12:30 p.m. (2560 ppm), both cases being 56% above the average values recommended by standards. The measurement results obtained for 13 May 2019 and 15 May 2019 show that the quality of air belongs to IDA 4 Category (concentration over 1000 ppm) according to EN 13779 standard. This category is used in reference to buildings with poor or low indoor air quality. When the values obtained by measurement are compared with the values set in the ASHRAE and EN 16789 standard, the mean daily concentration of $CO_2$ for 13 May 2019 and 15 May 2019 falls within the 1000 ppm - 2000 ppm range, the real-time $CO_2$ concentration at different parts of the day even exceeding 2000 ppm, which means that air quality is inadequate, causing people to experience pronounced lack of focus and sleepiness. It is common knowledge that $CO_2$ concentration levels and the amount of fresh air in indoor environments depend on the number of the people present, their activity level and the way the analysed space is ventilated. When the measurements were carried out in analysed classroom the number of students attending the lectures exceeded 50, which, in addition to inadequate classroom ventilation, represents a leading cause behind higher $CO_2$ concentration levels. Table 4 shows the overall measured values of IAQ parameters in one of the classroom during it full occupancy for the analyzed period.

| **Date** | **$CO_2$ max (ppm)** | **$CO_2$ min (ppm)** | **$CO_2$ average (ppm)** | **Indoor air temperature (°C)** | **Relative humidity (%)** |
|---|---|---|---|---|---|
| **May-07** | 911 | 428 | 605 | 23.3 | 32.2 |
| **May-08** | 1604 | 431 | 857 | 24.6 | 29.3 |
| **May-09** | 1857 | 586 | 733 | 23 | 36.8 |
| **May-13** | 2729 | 414 | 1153 | 22.9 | 49.4 |
| **May-14** | 1483 | 449 | 914 | 21.7 | 44.3 |
| **May-15** | 2560 | 502 | 1614 | 23.5 | 42.5 |
| **May-16** | 765 | 455 | 535 | 22.5 | 41.7 |
| **May-20** | 1127 | 414 | 738 | 21.9 | 40.9 |
| **May-21** | 2207 | 457 | 945 | 21.9 | 42.9 |
| **May-22** | 2014 | 504 | 1258 | 23.2 | 47 |
| **May-23** | 703 | 450 | 529 | 23.5 | 43.8 |
| **Analysed period** | **2729** | **414** | **898** | **22.9** | **41.0** |

Table 4. Measured IAQ values in one of the classrooms at the Faculty of Mechanical Engineering in Sarajevo in the analysed period

During most period of time when students were in the classroom the $CO_2$ concentration was slightly higher than the recommended one by standards. The average temperature during occupied period was 22,9°C, with a minimum of 20,6°C and a maximum 25,7°C. Average humidity during classes was around 41%, with a minimum value of 26,3% and a maximum of 55,9%, which is the highest value measured on May 13, at the same time when the highest $CO_2$ concentration of 2729 ppm was measured. The percentage of occupants dissatisfied with indoor air quality, as a function of average CO2 concentrations according to expression (3) would be 24,8%. Also, based on the obtained measurement results, a correlation analysis of the $CO_2$ concentration with relative humidity and indoor air temperature have been performed.

Since the measurements were carried out outside the heating season the indoor $CO_2$ concentrations are strongly influenced by the outdoor $CO_2$ due the fact that windows are opened more frequently than in heating period. Consequently, the correlation was performed only for two days during the analyzed period when the classroom was fully occupied and outdoor air temperature was low in order to reduce the possibility of opening the window for a longer period of time because in case of naturally ventilated educational buildings many indoor air parameters depend significantly on outdoor air conditions. As it can be seen from Figures 5 and 6, high correlation was observed for these days, i.e. temperature and relative humidity values follow the change in $CO_2$ concentration. The similar investigation had been done by group of authors in [5].

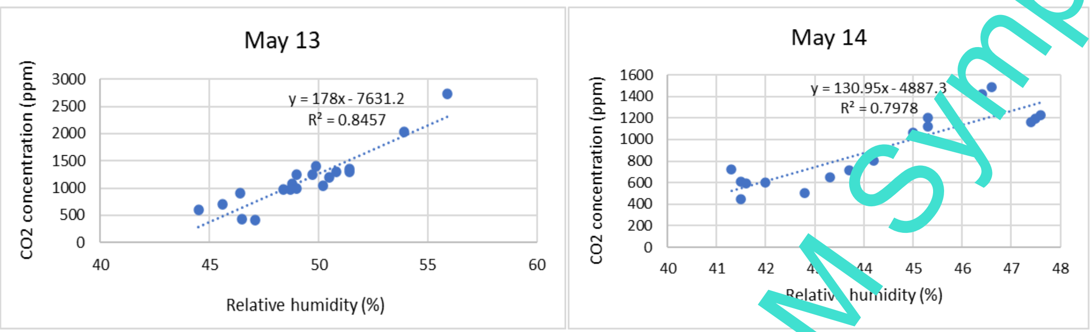


Fig. 5 Correlation coefficient between relative humidity and $CO_2$ during two occupied days

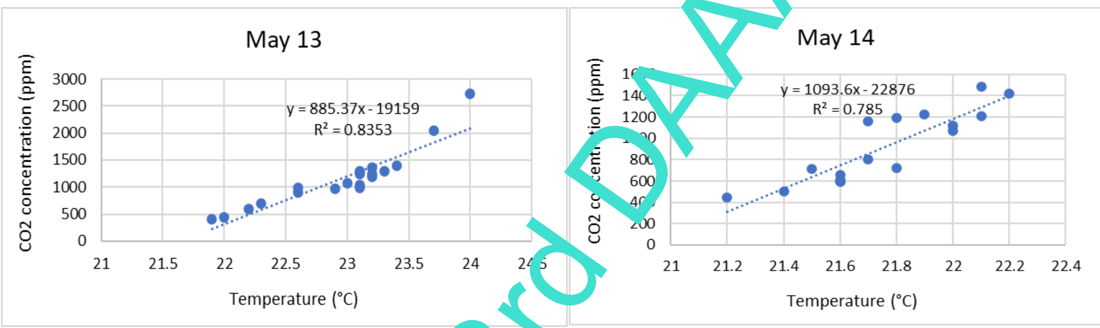


Fig. 6 Correlation coefficient between indoor air temperature and $CO_2$ during two occupied days

The level of relative humidity of indoor air also represents one of the key parameters that bears upon the quality of indoor air. Moisture in the building envelope often causes many problems, including low indoor air quality. Similarly, people endure high indoor temperatures more easily when humidity is low, because sweating regulates the body's temperature and in that way helps the body cool down. If indoor air is saturated with water vapour it cannot hold the extra vapour from sweating, which can lead to heat stroke. Likewise, low air humidity levels are not good as they can cause discomfort, respiratory problems and increase the risk of infections. Fig. 7 shows the change of temperature and relative humidity in one of the classrooms in the analysed period.

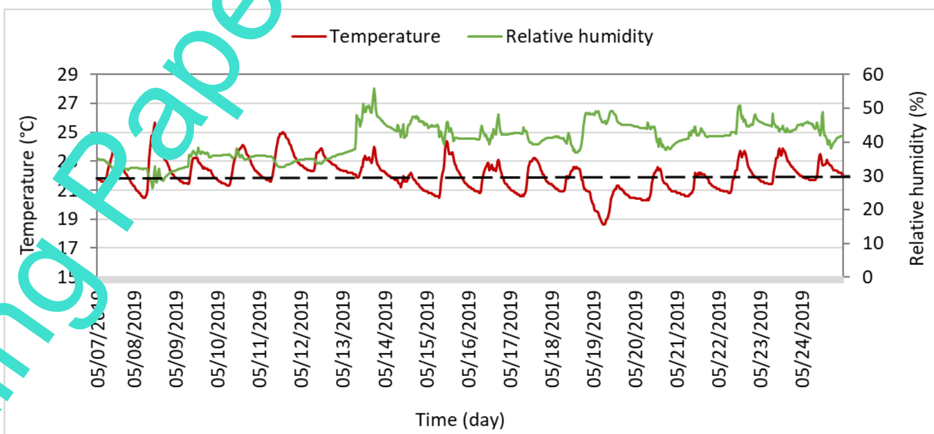


Fig. 7 Change of temperature and relative humidity in one of the classrooms at the Faculty of Mechanical Engineering in Sarajevo in the analysed period

Fig. 7 indicates that humidity concentration levels reached their peak of 55.9% on 13 May 2019 at 6:00 p.m. However, the relative humidity never registered levels above the Category II upper limit of 60% nor below lower limit of 25%, as defined by EN 16798-1:2019. After matching the relative humidity levels recorded in analysed classroom against the recommended values, relative humidity can be said to fall within the limit of recommended values. The lowest temperature levels were recorded over the weekend, namely on Sunday, 19 May 2016, at 6:00 a.m., when the temperature was 18.6°C, while the maximum temperature (25.7°C) was recorded on Wednesday, 8 May 2019. During working days, the indoor air temperature ranged from 20.5°C in the early morning hours to 25.7°C in the afternoon. Since the measurements were performed in May, outside the heating season, the results were compared using the summer season values. According to EN 16798-1:2019, the recommended indoor air temperature in educational facilities in summer is 26°C, while ASHRAE 62.1 recommends that indoor air temperature values be in the range between 23°C and 26°C. Bearing in mind the recommended values it can be concluded that the indoor air temperature in the analysed period remained within the permitted limits.

## 5. Conclusion

This paper cites the parameters necessary for achieving a quality climate in indoor environments, describes the impact these parameters have on human health, and gives their limit values as recommended under EN 15251, EN 16798, EN 13779 and ASHRAE 62.1 standards. The values recorded in one of the classrooms at the Faculty of Mechanical Engineering in Sarajevo indicate the presence of a high concentration of carbon dioxide, which at different parts of the day exceeds by 56% the levels recommended under the standards governing permissible concentrations in educational institutions. Inadequate ventilation is the main cause of high $CO_2$ concentration levels in educational institutions. Furthermore, the measurements performed lead to the conclusion that air temperature rises and air humidity decreases on working days and when people stay indoors. The results of this research indicate the need to make a plan and find solutions to control $CO_2$ concentration levels, as well as the need for additional ventilation to ensure a sufficient number of air exchanges in the form of mechanical ventilation as a complement to natural ventilation. Therefore, installing $CO_2$ sensors, implementing night cooling and ventilation arrangements in buildings in the summer period and using mixed mode or hybrid ventilation are some of the possible solutions for raising the level of indoor air quality.

In this paper, it was analyzed indoor air quality, however indoor environmental quality (IEQ) is characterized by four environmental categories such as thermal comfort, indoor air quality, lighting, and acoustics whereby equirements for each category are often split up in different standards. Since it is very important to consider all IEQ factors next research steps would be providing and implementing an IAQ model which can be used to determine the value of the overall indoor environmental quality index (IEQ) including these components: thermal comfort, indoor air quality, acoustic comfort and lighting quality. Also, it would be interest to evaluate the influence of different ventilation systems, air rates and schedules on the thermal comfort and indoor air quality of a refurbished educational building compared with unrefurbished one through measurement of IAQ parameters.

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