Impact of the indoor environmental quality on employee well-being in a LEED-certified office building

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ABSTRACT

This paper deals with the assessment of the indoor environmental quality (IEQ) in two selected offices of the newly built green administrative building, which has achieved the second highest level of evaluation within the international LEED certification. The assessment of the IEQ was performed through real measurements of IEQ factors and a questionnaire survey. In each office, the total measurement time was set at 24 hours. The data recorded during the 8-hour working time were evaluated separately. During working hours, five employees were present in the first office (larger in area) and two in the second. Measurements were performed under natural conditions. For comparison, 24-hour measurements were repeated in the second office but without the presence of occupants. The results of IEQ monitoring showed that the legislative and LEED limits were not exceeded in any of the offices (either within 24 hours or during working hours). Exceeding the recommended LEED limit for TVOC concentrations in the second office by 34% during 8-hour working hours was related to the presence of people in this office. The measured daylight intensities in both offices met the minimum legislative requirement. The subjective evaluation shows that the occupants of the building themselves perceive IEQ positively. Although more than 50% of respondents said they feel fatigue, lethargy and have a headache while working in the office, given previous IEQ perception results, these symptoms may be related to the type of work performed rather than IEQ. Based on the results obtained from real measurements and a questionnaire survey, it can be stated that the monitored office spaces of the selected green certified building provide a quality, healthy and comfortable indoor environment that does not significantly interfere with their work performance.

INTRODUCTION

Nowadays, the construction of green buildings is popular. Green buildings represent a trend towards sustainable and environmentally friendly construction. These buildings combine lower operating costs, a healthier working environment and environmental friendliness (He & Kvan, 2018). In the last two decades, countries around the world have developed a large number of Green Building Rating Systems (GBRS) in order to rate and certify green buildings (Shan & Hwang, 2018). Indoor environmental quality is included in all the green building certifications as a fundamental factor for assessing the health risk for indoor occupants and the contribution of IEQ in green building certification is almost the same in all the analyzed certification tools (Mattoni & Guattari, 2018). The most commonly used international green building certification systems include LEED and BREEAM (Lee, 2019). In the LEED certification system, the IEQ is evaluated in the Indoor Environment Quality category, and in the BREEAM system, the IEQ is included in the Health and Well-being section. Part of the IEQ assessment in both certification systems is the regular testing and evaluation of IEQ risk factors through real measurements or subjective assessment by the building occupants themselves. Factors that most commonly contribute to IEQ include thermal comfort, indoor air quality (IAQ), sound quality, and lighting (Wei & Wargocki, 2020).

Up to now, only a few studies have been published that have addressed the assessment of IEQ in green certified buildings. Most of them deal with the subjective assessment of IEQ in certified buildings, but there are missing those that also deal with the real measurement of IEQ risk factors (Lee & Wargocki, 2019). In a study by Altomonte & Schiavon (2019) was found that the achievement of a specific IEQ credit did not substantively increase satisfaction with the corresponding IEQ factor, while the rating level, and the product and version under which certification had been awarded, did not affect workplace satisfaction. According to a study by Lee & Kim (2008), LEED-certified office buildings showed higher occupant satisfaction with IAQ than non-LEED-certified buildings. In addition, LEED-certified buildings had higher occupant performance in office furnishings quality, thermal comfort quality, IAQ, and cleanliness and maintenance quality than non-LEED-certified buildings. Results from cross-sectional questionnaires according to Altomonte & Saadouni (2017) showed that BREEAM certification per se did not seem to substantively influence building and workspace satisfaction. Conversely, occupants of BREEAM offices tended to be less satisfied with air quality and visual privacy than users of non-BREEAM buildings. The results of a study by Jin & Wallbaum (2020) show that occupant satisfaction with IEQ in a newly renovated office BREEAM certified building has not well achieved and in the office environment occupants prefer warmer temperature, more fresh air, less noise, and more daylight.

The aim of the study is to assess the state of the indoor environmental quality in selected offices of a green certified office building through determination of IEQ risk factors and subjective evaluation (questionnaires).

OBJECT DESCRIPTION

The newly built office building, in which IEQ monitoring was performed, is situated in the center of Košice (eastern Slovakia). This building belongs to the so-called green buildings awarded the LEED certificate. The building consists of a monolithic reinforced concrete foundation. The vertical load-bearing structure comprise of a reinforced concrete skeleton, which is filled with brick masonry around the perimeter. The horizontal load-bearing structure consists of reinforced concrete ceiling slabs. Dividing partitions are plasterboard with a thickness of 125 mm and surface treated with white paint. The surface of floors in offices is made of anhydrite screed. The perimeter cladding consists of a glass facade aluminum system. The windows are openable with insulating 3-glass. The interior doors are glazed in an aluminum frame. The building uses large radiant floor heating/cooling. Part of the extra standard is that the building has built-in ceiling cooling/cassette air conditioning. The building has a total of five floors. The above-standard quality of the working environment in the building is ensured by the most modern technologies, including humidifiers and built-in temperature, relative humidity, particulate matter and CO_2 sensors. The air supplied to the building is freed of impurities by effective filtration, so-called plasma effect – using ionizers. Energy-saving LED lights with intelligent lighting intensity control are installed in the building.

The monitoring itself took place in two selected offices located on the fourth floor. The first office (Office 1) with an area of 55 m^2 is used by six employees. The second office (Office 2) with an area of 25 m^2 is used by two employees. During the monitoring, there were five employees in Office 1 and two employees in Office 2. Both offices are equipped with standard office furniture and technology. There is a carpet in each office. While Office 1 is illuminated bilaterally, Office 2 is illuminated unilateral. All measurements took place under natural conditions in October 2020. During working hours, there was a constant exchange of air in the Office 1 alternately in a natural way or by activating mechanical systems. In the second office, only mechanical air exchange during working hours was provided. For comparison, in the absence of employees, another measurement was performed in the second office (Office 2*). Measurements in the Office 2* took place without air exchange in it. The entire monitoring was performed only four months after the users moved into the building.

METHODS

The parameters of the thermal-humidity microclimate (air temperature, relative humidity and air velocity), CO_2 concentrations and illuminance levels were determined using a TESTO 435-4 multifunction device with appropriate probes (Testo, Inc.; Germany). The particulate matter (PM) concentrations of the two representative fractions (2.5 and 10 µm) were determined using a HANDHELD 3016 IAQ instrument (Lighthouse Worldwide Solutions, Inc., USA), which uses a laser-diode light source and collecting optics for particle detection. Total volatile organic compound (TVOC) concentrations were determined with a ppbRAE 3000 UV photoionization detector (RAE Systems, Inc.; USA). A two-point calibration, zero and standard reference gas (isobutylene), was performed before the measurement itself. All measured concentrations are expressed in toluene equivalents (correction factor of 0.5). The probes and measuring instruments were placed approximately in the middle of the room at a height of 1.1 m from the floor. The parameters of the thermal-humidity microclimate, particulate matter and total volatile organic compounds were recorded at one minute intervals. Illuminance levels were measured within the lighting network. The mean radiant temperature was measured at three heights using a Vernon-Jokl spherical thermometer (sphere diameter d = 0.1 m) according to ISO 7726 (1998), on the basis of which the operative temperature was also calculated. The mean radiant temperature was recorded only during working hours in Offices 1 and 2. Detailed information on the measuring devices used in this study is summarized in Table 1.

Table 1. Technical data on measuring instruments

Measuring instruments	Technical data
Multifunctional device Testo 435-4	**Air temperature – NTC** measuring range: from 0 to +50 °C; accuracy: ±0.3 °C
	Relative humidity – Humidity capacitive sensor measuring range: from 0 to 100 %rH; accuracy: ±2 %rH
	Ambient CO2 measuring range: from 0 to +10,000 ppm; accuracy: ±2 %rH; accuracy: ±(75 ppm ±3 % of mv) (0 to +5000 ppm) ±(150 ppm ±5 % of mv) (+5001 to +10000 ppm)
	Air velocity measuring range: 0–20 m/s; accuracy: ±(0.03 m/s + 4% of mv)
	Lux probe – for measuring illuminance measuring range: from 0 to 100000 lx
Handheld 3016 IAQ	measuring range: from 0.3 to 25 µm
ppbRAE 3000	measuring range: 1 ppb – 10,000 ppm; accuracy from 10 to 2,000 ppm: ±3% at calibration point

Active sampling of the target volatile organic compounds was performed for six hours. Air samples were collected onto an Anasorb CSC sorption tube using a SKC PocketPump TOUCH sampling pump. After sampling, the samples were further analyzed in an external authorized laboratory by gas chromatography.

A modified questionnaire based on previous studies by Cheung & Schiavon (2021) and Lee & Wargocki (2020) was used to subjectively assess the indoor environmental quality. The questionnaire contained questions related to basic information about the respondent and questions focused on the perception of thermal comfort, CO_2 concentration, odor (TVOC concentration), the presence of PM and the perception of the overall IEQ. In the next part, the questionnaire deals with the subjective evaluation of occupant comfort and work performance.

Thermal comfort was assessed using Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices. Both indices were calculated using the CBE Thermal Comfort Tool, which is described in more detail by Tartarini & Schiavon (2020). The PMV indicator takes into account six parameters (metabolic rate, clothing level, air velocity, mean radiant temperature, air temperature and relative humidity). From the PMV index, it is possible to calculate the percentage of people who would not be satisfied with a particular thermal environment, the so-called PPD index. In the autumn, the level of clothing insulation was expected to be 0.61 clo (trousers, long-sleeved T-shirt) and the metabolic rate for sitting activities was chosen to be 1.0 in the CBE Thermal Comfort Tool. The calculation of PMV indices included average values of air temperature, relative humidity and air velocity obtained from measurements during the 8-hour working period.

RESULTS AND DISCUSSION

The examination of the indoor environmental quality consisted in the monitoring of IEQ risk factors and in the subjective evaluation of these factors by the occupants themselves.

Results of real measurements

In each of the offices, the total monitoring time was 24 hours. From the data obtained during the 24-hour monitoring, the data recorded during the 8-hour working time were evaluated separately. The statistically processed results were compared with the requirements for the thermal-humidity microclimate and the limit values of harmful substances in the indoor air given in Decree no. 210/2016 Coll. Simultaneously, the results were compared with LEED v4.1 requirements for the assessment of indoor air quality in a newly built buildings and interiors.

Results of 24-hour monitoring

Table 2 shows the statistically processed results of IEQ parameters evaluated in selected office spaces during 24-hour monitoring.

Table 2. Evaluation of results from 24-hour monitoring

	Statistics	Temperature [°C]	Relative humidity [%]	Air velocity [m/s]	$PM_{2.5}$ [μg/m³]	PM_{10} [μg/m³]	CO_2 [ppm]	TVOC [μg/m³]
Office 1	Average	23.2	46.0	0.02	1.52	6.18	576	389
	Min [1]	21.4	41.6	0.00	0.53	0.54	442	173
	Max [2]	25.8	50.9	0.26	4.08	31.39	829	465
	SD [3]	0.96	1.84	0.02	1.01	6.88	120.62	39.89
Office 2	Average	23.27	45.18	0.02	0.54	4.49	556	849
	Min [1]	22.50	40.70	0.01	0.28	0.37	431	396
	Max [2]	23.80	49.40	0.09	2.66	95.05	870	3192
	SD [3]	0.24	2.92	0.01	0.26	8.55	135.42	401.31
Office 2*	Average	23.57	45.08	0.02	1.08	2.58	479	425
	Min [1]	23.00	42.80	0.01	0.45	0.72	429	343
	Max [2]	24.80	48.60	0.07	1.83	13.84	652	647
	SD [3]	0.49	1.26	0.00	0.42	1.95	40.89	54.23

[1] Minimum value, [2] Maximum value, [3] Standard deviation

The results of the thermal-humidity microclimate indicate that there are only minimal differences between monitored offices. Requirements of Decree no. 210/2016 Coll. for relative humidity (30–70%) and air velocity (≤ 0.2 m/s) were met in both occupied offices, including Office 2*. The legislative requirement for PM_{10} concentrations (50 μg/m³) for 24-hour exposure was also not exceeded. The LEED v4.1 certification system for new construction gives limit values for concentrations of $PM_{2.5}$ (≤ 12 μg/m³), PM_{10} (≤ 50 μg/m³) and TVOC (≤ 500 μg/m³). These limit values were not exceeded in any of the monitored offices. The only exception is Office 2, where the LEED limit for TVOC concentrations was exceeded by 41%.

The presence of TVOC in Office 2 was found to be 54% higher than in Office 1. The course of TVOC concentrations in individual offices during the total 24-hour monitoring period is shown in Figure 1. A sharp increase in TVOC concentrations was recorded in Office 2 after working hours between 5.05 p.m. and 5.35 p.m. due to cleaning activities.

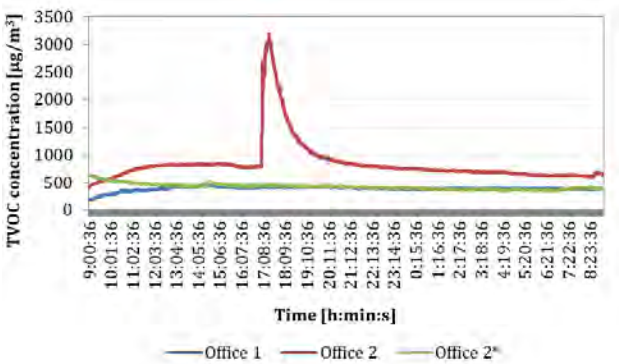

Figure 1. The course of TVOC concentrations during 24-hour monitoring in each office

The recommended limit value for CO_2 concentrations according to Pettenkofer (< 1000 ppm) was not exceeded in any of the occupied offices. The highest CO_2 concentrations were recorded during working hours when there were employees in the offices, as shown in Figure 2. In the absence of employees, the CO_2 concentration ranged from 400 to 600 ppm.

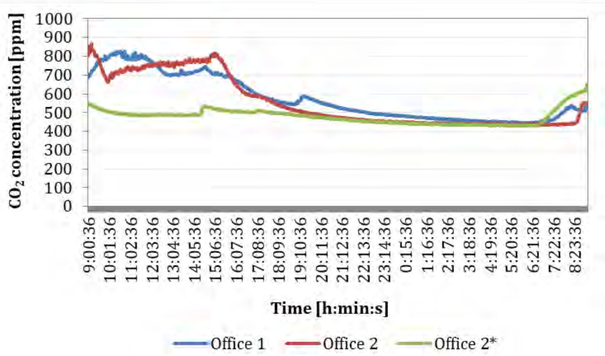

Figure 2. The course of CO_2 concentrations during 24-hour monitoring in each office

It can be seen from Figure 3 that the cleaning activities in Office 2 affected not only the TVOC concentrations but also the particulate matter concentrations. The presence of a cleaner in the Office 2 during cleaning was also reflected by a slight increase in CO_2 concentrations (indicated by an arrow).

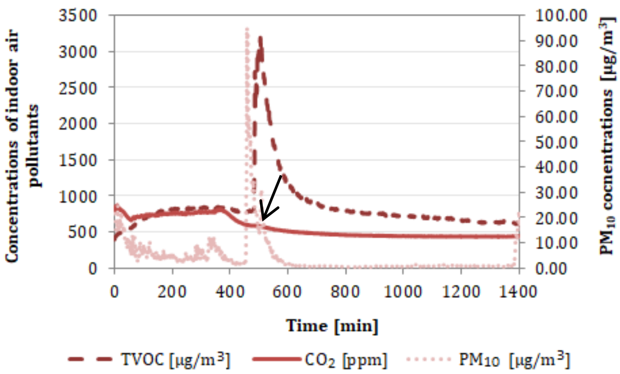

Figure 3. Concentrations of indoor air pollutants recorded in the Office 2 within 24 hours

Results obtained during 8-hour working period

During working hours from 9.00 a.m. to 5.00 p.m., the indoor air temperature in Office 1 ranged from 21.4 °C to 25.8 °C and the relative humidity values from 41.6% to 50.9%. The maximum air velocity reached 0.26 m/s. The average values were 24.2 °C for air temperature, 45.9% for relative humidity and 0.00 m/s for air velocity. In Office 2, during 8-hour working hours, the indoor air temperature ranged from 22.50 °C to 23.80 °C, the relative humidity values from 40.70% to 45.20% and the air velocity values from 0.01 m/s to 0.09 m/s. The average values were 23.50 °C for indoor air temperature, 41.73% for relative humidity and 0.02 m/s for air velocity. During a typical working interval (9.00 a.m.–5.00 p.m.), when no employees were present in this office, the indoor air temperature varied from 23.40 °C to 24.80 °C, the relative humidity values from 42.80% to 48.60% and the relative humidity from 0.02 m/s to 0.07 m/s. The average value was 24.17 °C for indoor air temperature, 45.24% for relative humidity and 0.02 m/s for air velocity. The operative temperature values were 24.3 °C for Office 1 and 23.2 °C for Office 2.

Particulate matter concentrations in fraction 2.5 µm ranged from 1.25 µg/m^3 to 4.08 µg/m^3 during the eight hours of occupancy of Office 1, while PM_{10} concentrations ranged from 2.01 µg/m^3 to 26.57 µg/m^3. The average particulate matter concentration was 2.74 µg/m^3 for $PM_{2.5}$ and 14.09 µg/m^3 for PM_{10}. During the occupation of Office 2 by its employees, the average concentration of $PM_{2.5}$ reached the value of 0.45 µg/m^3. The average concentration of PM_{10} was 6.16 µg/m^3. $PM_{2.5}$ concentrations ranged from 0.28 µg/m^3 to 0.78 µg/m^3 and PM_{10} concentrations from 1.12 µg/m^3 to 24.69 µg/m^3. In the absence of employees during standard working hours, $PM_{2.5}$ concentrations ranged from 0.45 µg/m^3 to 0.85 µg/m^3 and PM_{10} concentrations from 0.72 µg/m^3 to 13.84 µg/m^3. The average concentration of $PM_{2.5}$ was 0.60 µg/m^3. In the case of PM_{10}, the average concentration was 2.68 µg/m^3.

Concentrations of carbon dioxide (CO_2) and total volatile organic compounds (TVOC) were also monitored in all offices during the 8-hour working period. In Office 1, CO_2 concentrations ranged from 604 ppm to 829 ppm and TVOC concentrations from 173 µg/m^3 to 465 µg/m^3. The average CO_2 concentration was 733 ppm, while the TVOC concentration averaged 378 µg/m^3. In contrast, in Office 2, the lowest recorded CO_2 concentration was 585 ppm and the highest was 870 ppm. The lowest TVOC concentration reached 396 µg/m^3 and the highest 851 µg/m^3. The average CO_2 concentration in this office was 736 ppm and the average TVOC concentration was 752 µg/m^3. Without the presence of employees in Office 2, CO_2 concentrations ranged from 482 to 550 ppm with an average concentration of 501 ppm. On average, the concentration of TVOC in Office 2* was 481 µg/m^3, while the lowest recorded concentration of TVOC was 420 µg/m^3 and the highest 647 µg/m^3.

Even during the 8-hour working time, the average values of the thermal-humidity microclimate parameters did not differ significantly from each other. In addition, the mean radiant temperature was recorded during working hours, from which the operative temperature was calculated. As a result, the operative temperatures for Offices 1 and 2 were within the optimal (20–24 °C) and permissible (18–26 °C) legislative limits. CO_2 concentrations were kept at the same levels in both occupied offices (Office 1 and 2). As the measurements took place under natural conditions (with active ventilation), these values were also below the recommended limit value of 1000 ppm. The average TVOC concentration found in Office 2 between 9.00 a.m. and 5.00 p.m. was 50% higher than that observed in Office 1 and 36% higher than in Office 2*. The LEED limit value was exceeded by 34% in Office 2. During this period, Office 2 has not yet been cleaned and the increased concentration of TVOC is rather related to the presence of employees and the reduced air exchange in this room. From the results of TVOC in Office 2*, it can be stated that the amount of TVOC present in Offices 1 and 2 comes from office equipment and technology, or is still released from the materials used during construction. Particulate matter concentrations ($PM_{2.5}$ and PM_{10}) reached the highest levels in Office 1, which is related to its higher occupancy. Fluctuations in the concentration of PM in individual offices occurred mainly when users moved around the office. Nevertheless, the concentrations of $PM_{2.5}$ and PM_{10} during the entire period of use of the office, whether in Office 1 or 2, were below the required legislative (only for PM_{10}) and LEED limits. In addition to TVOC concentrations, air samples were collected at each office for analysis of target VOCs. Target VOCs include compounds such as toluene, xylenes, styrene and tetrachlorethylene listed not only in the Decree of the Ministry of Health of the Slovak Republic 210/2016 Coll., but also on the list of LEED criteria. The results of the laboratory analysis showed that all the listed compounds were below the detection limits, and thus their presence was not confirmed in any of the monitored offices.

Illumination levels were recorded between 9.00 a.m. to 10.00 a.m. in both offices (1 and 2), immediately after monitoring the parameters of the thermal-humidity microclimate and IAQ. In Office 1, the measured illumination level was 963 lx and in Office 2, 301 lx. Both values were above the required minimum legislative limit (200 lx).

Subjective evaluation of IEQ

A total of 12 employees (8 women and 4 men) were involved in the questionnaire study. These employees spend 40–50 hours a week at their workplace, which is approximately 8–9 hours a day. Most respondents were under the age of 40, except for two men who fell into the age category of 41–50 years. Of all respondents, only two were smokers. The two assessed offices were occupied by non-smokers. All employees performed the administrative type of work.

In the subjective evaluation of thermal-humidity microclimate, 67% of respondents were satisfied with the temperature in the indoor environment and up to 83% of respondents stated that they were satisfied with the humidity of the environment. Fifty percent of respondents did not perceive any draft, the rest of the respondents perceive light to mild draft. A complete subjective assessment of thermal comfort by building users is shown in Figure 4.

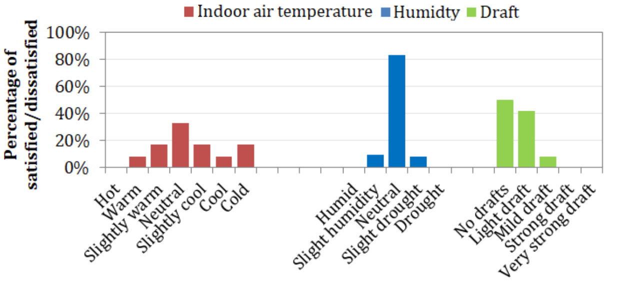

Figure 4. Subjective evaluation of thermal-humidity microclimate

The PMV and PPD indices calculated for Offices 1 and 2 using CBE Thermal Comfort Tool are summarized in Table 3. According to ISO 7730 (2005), the indoor environment can be considered comfortable if the calculated PMV index is in the range of -0.5 to +0.5, which represents approximately 10% of dissatisfied. The results show that, in contrast to Office 2 (Category IV – lower level of expectation), the conditions of the thermal comfort in Office 1 (Category II – medium level of expectation) can be considered comfortable. Pursuant to EN 16798-1 (2019), a lower level of expectation will not pose any health risk to occupants, but may decrease their comfort.

Table 3. Results of PMV and PPD indices

	Office 1	Office 2
Mean radiant temperature [°C]	24.5	22.8
PMV	-0.37	-0.81
PPD [%]	8	19
Category	II	IV

Figure 5 shows the percentage of people satisfied and dissatisfied with indoor air quality. Of the total number of respondents, 34% stated that they perceive indoor air as fresh in terms of CO_2 concentrations and up to 58% as slightly fresh. Regarding the odor, most users did not perceive any odor in the indoor air (67%), or perceived only a faint odor. Out of the total number of respondents, 59% of them answered that they do not perceive dust (particulate matter) in the indoor environment of their workplace. The rest perceived the amount of dust in the indoor environment as low or acceptable.

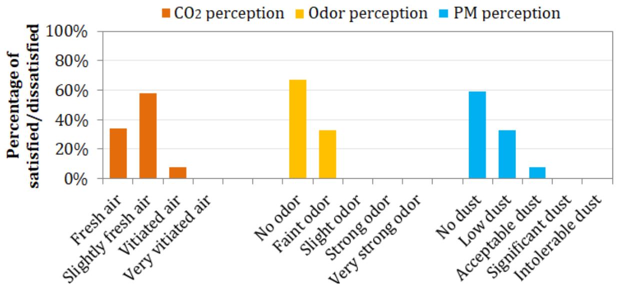

Figure 5. Subjective evaluation of indoor air quality

According to the results in Figure 6, up to 45% of users consider the level of office lighting to be very high and the remaining 58% to be high to acceptable.

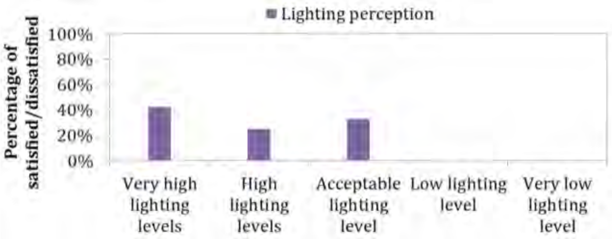

Figure 6. Subjective evaluation of illumination

In general, users have expressed satisfaction with the IEQ in their workplace. All users agreed that, in terms of their personal preferences, they assessed the indoor environment as acceptable rather than unacceptable.

The influence of IEQ on subjective performance of occupants is summarized in Figure 7. Up to 41% of respondents said that indoor air temperature slightly increases their performance; 67% stated that they considered humidity to be neutral in relation to their perceived performance; a total of 59% of users stated that drafts did not affect their performance or reduced their performance only slightly. Exactly 50% of respondents stated that they consider IAQ (CO_2 and odor perception) to be neutral in terms of their performance. 58% of respondents said that perceived dust (presence of PM) in the workplace did not affect their performance. A quarter of respondents consider workplace lighting to be neutral in relation to their performance. A total of 50% of respondents stated that illumination significantly to slightly increases their performance.

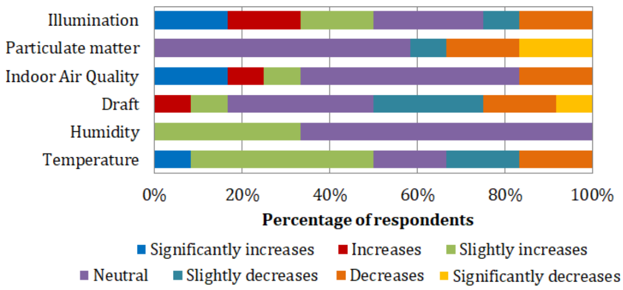

Figure 7. Influence of the IEQ parameters on the subjective performance of occupants

The results of the subjective assessment of occupant comfort are shown in Figure 8. The majority of respondents rated the indoor temperature, humidity, perception of drafts, indoor air quality (particulate matter separately) and illuminance levels as very comfortable and comfortable.

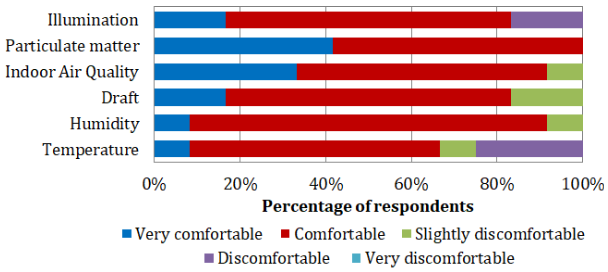

Figure 8. Results of subjective evaluation of occupant comfort

The most common SBS symptoms experienced by employees during their work included fatigue and lethargy, as well as headaches. Exactly 50% of respondents said they felt heavy-headedness, have concentration problems or eyes itching, burning or irritation. A detailed evaluation of SBS symptoms is shown in Figure 9.

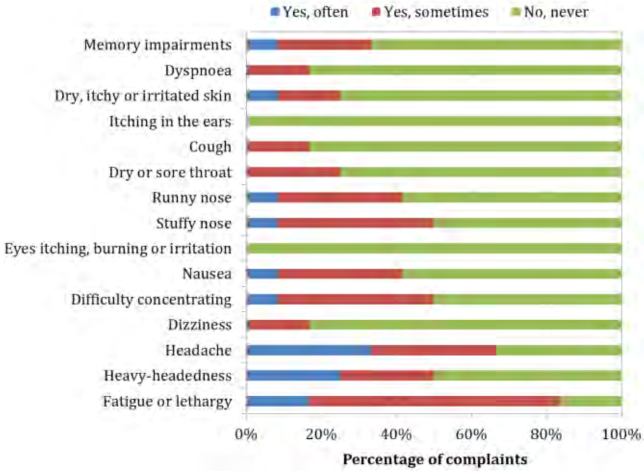

Figure 9. Assessment of SBS symptoms

Taking into account previous answers regarding the perception of IEQ, it can be argued that the symptoms of most respondents are related to the type of work performed rather than to IEQ.

CONCLUSIONS

In this study, the indoor environmental quality in the newly built LEED-certified office building was evaluated. As part of the evaluation of the indoor environmental quality in this administrative building, IEQ risk factors were monitored in two selected offices under natural conditions. These two offices differed in area and number of users. In addition to real measurements, a questionnaire survey was conducted, which focused on the perception of IEQ risk factors by users themselves and the impact of these factors on their comfort and performance in a given work environment.

The results of real measurements show that both offices meet the required legislative and LEED limits. The LEED limit was exceeded only in the case of TVOC concentrations in a smaller office during working hours. For comparison, measurements of IEQ parameters were repeated in this office, but in the absence of occupants. This comparison demonstrates that TVOC concentrations exceeded the recommended LEED limit, mainly due to the presence of occupants in this office. In both monitored offices, the minimum legislative requirement for daylight intensity was met. The questionnaire survey showed that respondents perceive IEQ in a green building positively and consider this environment to be comfortable to very comfortable. Most respondents stated that the influence of IEQ parameters increases their performance or that they perceive the influence of these factors as neutral. In view of these answers, it can be said that headaches, fatigue or lethargy, which occurred in more than half of the respondents during their stay at the workplace, are more related to the type of work performed than to IEQ.

Overall, it can be stated that the assessed offices of the selected certified building provide a healthy and comfortable environment that does not significantly affect the performance of the users themselves.

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REFERENCES

Altomonte, S., Schiavon, S., Kent, M. G. and G. Brager (2019). Indoor environmental quality and occupant satisfaction in green-certified buildings. *Building Research & Information*, 47(3), 255-274. https://doi.org/10.1080/09613218.2018.1383715

Altomonte, S., Saadouni, S., Kent, M. G. and S. Schiavon (2017). Satisfaction with indoor environmental quality in BREEAM and non-BREEAM certified office buildings. *Architectural Science Review*, 60(4), 343-355. https://doi.org/10.1080/00038628.2017.1336983

Decree of the Ministry of Health, Slovak Republic no 210/2016 Coll on detailed requirements for indoor environment of buildings and minimum requirements for low-standard flats and accommodation facilities.

European Standards (2018). Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6 (EN 16798-1).

He, Y., Kvan, T., Liu, M. and B.Li (2018). How green building rating systems affect designing green. *Building and Environment*, 133, 19-31. https://doi.org/10.1016/j.buildenv.2018.02.007

Cheung, T., Schiavon, S., Graham, L. T. and K.W.Tham (2021). Occupant satisfaction with the indoor environment in seven commercial buildings in Singapore. *Building and Environment*, 188, 107443. https://doi.org/10.1016/j.buildenv.2020.107443

International Organisation for Standardisation (2005). *Ergonomics of the thermal environment – analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria* (ISO 7730).

International Organisation for Standardisation (1998). Ergonomics of the thermal environment — Instruments for measuring physical quantities (ISO 7726).

Jin, Q. and H. Wallbaum (2020). Improving indoor environmental quality (IEQ) for occupant health and well-being: A case study of Swedish office building. *In IOP Conference Series: Earth and Environmental Science* (Vol. 588, No. 3, p. 032072). IOP Publishing.

Lee, E. (2019). Indoor environmental quality (IEQ) of LEED-certified home: Importance-performance analysis (IPA). *Building and Environment*, 149, 571-581. https://doi.org/10.1016/j.buildenv.2018.12.038

Lee, J. Y., Wargocki, P., Chan, Y. H., Chen, L. and K. W. Tham, (2019). Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings. *Indoor air*, 29(1), 112-129. https://doi.org/10.1111/ina.12515

Lee, J. Y., Wargocki, P., Chan, Y. H., Chen, L. and K.W.Tham (2020). How does indoor environmental quality in green refurbished office buildings compare with the one in new certified buildings?. *Building and Environment*, 171, 106677. https://doi.org/10.1016/j.buildenv.2020.106677

Lee, Y. S. and S. K. Kim (2008). Indoor environmental quality in LEED-certified buildings in the US. *Journal of Asian Architecture and Building Engineering*, 7(2), 293-300. https://doi.org/10.3130/jaabe.7.293

Mattoni, B., Guattari, C., Evangelisti, L., Bisegna, F., Gori, P. and F. Asdrubali (2018). Critical review and methodological approach to evaluate the differences among international green building rating tools. Renewable and Sustainable Energy Reviews, 82, 950-960. https://doi.org/10.1016/j.rser.2017.09.105

Shan, M. and B. G. Hwang (2018). Green building rating systems: Global reviews of practices and research efforts. *Sustainable cities and society*, 39, 172-180. https://doi.org/10.1016/j.scs.2018.02.034

Tartarini, F., Schiavon, S., Cheung, T. and T. Hoyt (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX*, 12, 100563. https://doi.org/10.1016/j.softx.2020.100563

USGB, LEED v4.1 Building Design and Construction Beta Guide, Washington. 2019. Available on: https://www.usgbc.org/resources/leed-v41-building-design-and-construction-beta-guide-january-2019.

USGB, LEED v4.1 Interior Design and construction Beta Guide, Washington. 2019. Available on: https://www.usgbc.org/resources/leed-v41-interior-design-and-construction-rating-system-january-2019.

Von Pettenkofer M. (1858) Über den Luftwechsel in Wohngebäuden. Der J.G. München: Cotta'schen Buchhandlung.

Wei, W., Wargocki, P., Zirngibl, J., Bendžalová, J. and Mandin, C (2020). Review of parameters used to assess the quality of the indoor environment in Green Building certification schemes for offices and hotels. *Energy and Buildings*, *209*, 109683. https://doi.org/10.1016/j.enbuild.2019.109683