Indoor Environmental Quality Determinants in the Buildings

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Abstract. The presented aim of this study is to establish or reject the correlation (relationship) between the individual indoor environmental quality indicators and the total satisfaction with the indoor environment. The subjective satisfactory survey has been performed in 10 standardized university classrooms (Czechia) to evaluate the indoor environmental quality (IEQ). The IBSM SPPS Software Statistics ver. 25.0 was used to assess the Kendall non-parametric correlation analysis. Seven individual different indoor environmental quality indicators evaluating by subjective perceptions of the users were reviewed: air acceptability, thermal comfort, humidity comfort, odor comfort, acoustic comfort, visual comfort, and color comfort. The user’s subjective perceptions of the indoor environment were collected by questionnaires. Minimizing the ability to adapt and acclimatize was desirable. The statistically significant correlation (P < 0.01) were observed between the air acceptability ($\tau_b = 0.249$), the odor comfort ($\tau_b = 0.260$), the acoustic ($\tau_b = -0.244$), the visual comfort ($\tau_b = 0.203$), and the color comfort ($\tau_b = 0.192$) and total satisfaction with the indoor environment. The thermal comfort and the humidity comfort are not statistically correlated with the total satisfaction of the indoor environment (P > 0.01).

1. Introduction
The achieving of a high level of indoor environmental quality (IEQ) is a key factor of healthy buildings according to the principles of sustainable development. Poor indoor quality is associated with a variety of diseases and symptoms, collectively referred to as Sick Building Syndrome - a combination of nonspecific symptoms such as headache, dizziness, nausea, eye irritation, irritation of nose or throat, dry cough, dry skin and itching, difficulty concentrating, fatigue, sensitivity to odors, voice hoarseness, various allergies, personality changes and reduced productivity.

The state of the indoor environment of buildings is formed in the process of heat and mass exchanges that take place between components with different energy potentials. There are many parameters, which define indoor environmental quality in the buildings. Generally, these parameters can be physical, chemical or biological. There is a great number of studies about indoor pollutants and their impacts on health, well-being and productivity of the users of the buildings [1-5]. Indoor environmental quality (IEQ) could be represented by four environmental categories: thermal comfort, indoor air quality, lighting, and acoustics [6].

Achieving an optimal indoor environment requires a comprehensive approach. Adaptability is also closely related to health, comfort and productivity. Adaptation can be described as a continuous...
dynamic interaction of building users and indoor environment indicators that co-creates the final state of the user. Generally, 3 categories of adaptation are defined: behavioral adaptation, physiological adaptation and psychological adaptation.

2. Methods

Methods for assessing the quality of the indoor environment can generally be divided into subjective methods and objective evaluation methods. Figure 1 shows a scheme of indoor environment quality (IEQ) assessment. The quality of the indoor environment is defined by total satisfaction (TS). Total satisfaction consists of a number of indoor environmental factors. In this study, seven essential parameters of the indoor environment are evaluated. These are air acceptability (AA), thermal comfort (CC), humidity comfort (HC), odor comfort (OC), acoustic comfort (AC), visual comfort (VC), and color comfort (CC).

![Figure 1. Assessment scheme of indoor environmental quality (IEQ)](image)

In this study, a total of 299 students in 10 standardized university classrooms were included this questionnaire analysis. The user’s subjective perceptions of the indoor environment were collected by questionnaires. Questionnaire surveys were carried out in different university classrooms in the first 10 minutes after the start of the lesson. The reason was to minimize the effects of acclimatization and adaptation in the indoor environment of the building. Figure 2 illustrates the detailed Indoor Environmental Quality (IEQ) questionnaire. Seven individual different indoor environmental quality indicators evaluating by subjective perceptions of the users were review: air acceptability, thermal comfort, humidity comfort, odor comfort, acoustic comfort, visual comfort, and color comfort. The standardized quantification of the indoor environment used a scale model range. Figure 2 shows the Indoor Environmental Quality (IEQ) questionnaire. The detailed results of indoor environmental assessments in these university classrooms are presented in [7-9]. The questionnaire was explained in detail before testing.
Data are examined by correlation analysis. The correlation analysis is one of the most common statistical tools. The correlation summarizes the strength of the association between two random continuous variables. In this study, the non-parametric correlation Kendall's Tau_b is used. This type of correlation is suitable for ordinal or ranked variables that take ties into account.

3. Results and discussions
Table 1 shows the results of the Kolmogorov-Smirnov and Shapiro-Wilk normality test from IBM SPSS Statistics ver. 25. The appropriate test depends on the sample size: Shapiro-Wilk normality test is used for n < 50. In another way, the Kolmogorov-Smirnov is preferred. In all cases of monitored indoor environment indicators, the expressed p-values (Sig.) are significantly lower than the significance level $\alpha$. The null hypothesis that the random sample of a variable comes from a normal distribution is rejected in favor of an alternative hypothesis. The sample comes from a non-normal distribution.
Table 1. Verification of the normality (IBM SPSS Statistics ver. 25).

|                  | Kolmogorov-Smirnov | Shapiro-Wilk |
|------------------|--------------------|-------------|
|                  | Statistic | df | Sig. | Statistic | df | Sig. |
| Air Acceptability| 0.296     | 299 | 0.000 | 0.820     | 299 | 0.000 |
| Thermal Comfort  | 0.174     | 299 | 0.000 | 0.920     | 299 | 0.000 |
| Humidity Comfort | 0.402     | 299 | 0.000 | 0.677     | 299 | 0.000 |
| Odor Comfort     | 0.193     | 299 | 0.000 | 0.836     | 299 | 0.000 |
| Acoustic Comfort | 0.222     | 299 | 0.000 | 0.870     | 299 | 0.000 |
| Visual Comfort   | 0.236     | 299 | 0.000 | 0.880     | 299 | 0.000 |
| Color Comfort    | 0.318     | 299 | 0.000 | 0.819     | 299 | 0.000 |
| Total Satisfaction| 0.338     | 299 | 0.000 | 0.791     | 299 | 0.000 |

*a Lilliefors Significance Correction

A Kendall's Tau_b correlation is run to determine the relationship between indoor environmental parameters and total satisfaction with the indoor environment amongst 299 participants. According to Table 2 for the indoor environmental quality parameters, the air acceptability (AA) is positively correlated with the total satisfaction (TS) of indoor environmental quality ($\tau_b = 0.249$, $P < 0.01$), the odor comfort (OC) is also positively correlated with the total satisfaction quality ($\tau_b = 0.260$, $P < 0.01$), the acoustic comfort (AC) is negatively correlated with the TS ($\tau_b = -0.244$, $P < 0.01$), the visual comfort is positively correlated with TS ($\tau_b = 0.203$, $P < 0.01$), and the color comfort (CC) is also positively correlated ($\tau_b = 0.192$, $P < 0.01$). The thermal comfort (TC) and the humidity comfort (HC) are not correlated with the total satisfaction of the indoor environment ($\tau_b = 0.036$ and $0.039$, $P > 0.01$).

Table 2. Nonparametric correlations – Kendall's Tau_b (IBM SPSS Statistics ver. 25)

|                  | Correlation Coefficient | Sig. (2-tailed) | N  |
|------------------|-------------------------|----------------|----|
| Air Acceptability| 0.249**                 | 0.000          | 299|
| Thermal Comfort  | 0.036                   | 0.581          | 299|
| Humidity Comfort | 0.039                   | 0.460          | 299|
| Odor Comfort     | 0.260**                 | 0.000          | 299|
| Acoustic Comfort | -0.244**                | 0.000          | 299|
| Visual Comfort   | 0.203**                 | 0.000          | 299|
| Color Comfort    | 0.192**                 | 0.000          | 299|

**Correlation is significant at the 0.01 level (2-tailed).
In mathematical statistics, the coefficient of Determination (R²) reflects the quality of the regression model which expresses the proportion of the variability of the dependent variable model. The coefficient of determination can be at most 1.0, which means the perfect prediction of the values of the dependent variable. Determination coefficients of the indoor environment are set out in Table 3.

| Significant Correlation at the 0.01 level | Correlation Coefficient | Determination Coefficient |
|-----------------------------------------|-------------------------|---------------------------|
| Air Acceptability                       | Yes                     | 0.249                     | 6.20 %                     |
| Thermal Comfort                         | No                      | 0.036                     | 0.13 %                     |
| Humidity Comfort                        | No                      | 0.039                     | 0.15 %                     |
| Odor Comfort                            | Yes                     | 0.260                     | 6.76 %                     |
| Acoustic Comfort                        | Yes                     | -0.271                    | 7.34 %                     |
| Visual Comfort                          | Yes                     | 0.203                     | 4.12 %                     |
| Color Comfort                           | Yes                     | 0.192                     | 3.69 %                     |

Figure 3 shows the determinants of the indoor environment. Acoustic comfort has the greatest influence (7.34 %) on the satisfaction and well-being of the indoor environment. Another important component of the internal environment is the odor microclimate. Odors influence on overall satisfaction is almost 7%. Air quality characterized by air acceptability has an impact rate of more than 6%. The influence of light and color conditions influences the resulting impression of the indoor environment by about 4%. Temperature comfort and humidity comfort have no statistically significant effect on the satisfaction of the indoor environment. The effect of both parameters is very low, only 0.13%. The insufficient correlation between thermal and humidity conditions does not mean it is not important to maintain the thermal-humidity microclimate in university classrooms. This phenomenon can be an explanation so that the temperature and humidity in the indoor environment of the classrooms are kept stable over the long term and do not affect the overall condition.

The monitored indoors parameters influence the quality of the indoor environment to approximately 28%. The internal environment is created by other undefined components of 72%. Indoor environmental quality could be impacted by outdoor climate conditions and weather, building operation and human factors.

**Figure 3.** Determinants of the indoor environmental quality (IEQ) in Buildings
4. Conclusions
In this study, the subjective survey was conducted to comprehensively evaluate the users' overall experience of the indoor environment in university classrooms. Ten standardized university classrooms were investigated. Ensuring suitable indoor quality is a cornerstone of the health, well-being and productivity of building users. The hygienic routines and ventilation conditions are key to ensure a stable indoor environment. This is becoming increasingly important as the energy performance of buildings increases and associated airtightness of the building envelope increases. In conclusion, the results of correlation analysis have shown the statistically significant correlation between total satisfaction and air acceptability, odor, visual, acoustic and light conditions.

References
[1] H. H. Ali, and R. Al-Hashlamun, “Assessment of indoor thermal environment in different prototypical school buildings in Jordan,” Alexandria Engineering Journal, vol. 58, issue 2, pp. 699-711, 2019.
[2] L. Schibuola, and Ch. Tambani, “Indoor environmental quality classification of school environments by monitoring PM and CO2 concentration levels,” Atmospheric Pollution Research, vol. 11, issue 2, pp. 332-342, 2020.
[3] Y. Geng, B. Lin, J. Yu, H. Zhou, W. Ji, H. Chen, Z. Zhang, and Y. Zhu, “Indoor environmental quality of green office buildings in China: Large-scale and long-term measurement,” Building and Environment, vol. 150, pp. 266-280, 2019.
[4] S. Zuhaib, R. Manton, C. Griffin, M. Hajdukiewicz, M. M. Keane, and J. Goggins, “An Indoor Environmental Quality (IEQ) assessment of a partially-retrofitted university building,” Building and Environment, vol. 139, pp. 68-85, 2018.
[5] L. T. Wong, K W. Mui, and P. S. Hui, “A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices,” Building and Environment, vol. 43, issue 1, pp. 1-6, 2008.
[6] D. Khovalyg, O. B. Kazanci, H. Halvorsen, I. Gundlach., W. P. Bahnfleth, J. Toftum, and B. W. Olesen, “Critical Review of Standards for Indoor Thermal Environment and Air Quality,” Energy and Buildings, in press, 109819, 2020.
[7] M. Kraus, and P. Novakova, “Assessment of indoor air quality in university classrooms,” MATEC Web Conf., vol. 279, 03012, 2019.
[8] M. Kraus, and P. Novakova, “Gender Differences in Perception of Indoor Environmental Quality (IEQ),” IOP Conference Series: Materials Science and Engineering, vol. 603, 052084, 2019.
[9] M. Kraus, and P. Novakova, “Assessment of the Indoor Environment for Education,” IOP Conference Series: Earth and Environmental Science, vol. 290, 012144, 2019.