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Assessment of the Indoor Environment for Education

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Abstract. Indoor environment quality (IEQ) and its effect on well-being, productivity and performance are phenomena. Achieving suitable and comfortable indoor environment is a key factor in the creation and operation of the buildings in terms of basic principles of the sustainable development. The poor indoor environment is associated with the Sick Building Syndrome (SBS). The occurrence of pollutants in the indoor environment brings health problems to occupants as well as affects their productivity and performance. The main aim of the contribution is the study of indoor environment for educational purposes. The ordinary university classrooms located on the outskirts of the city České Budějovice (Czechia) are analysed. The classrooms are places, where the students reading, calculating, writing, and solving the assigned tasks. Achieving and satisfying the comfort in the indoor environment for education purposes is necessary for these student's activities. For example, insufficient air exchange and the CO_2 concentration above of 1000 ppm, cause fatigue and decreased concentration. The assessment of physical-chemical parameters includes analysis of indoor air temperature [°C], relative humidity [%], Carbon Dioxide (CO_2) concentration [ppm], and illumination intensity [lx] in the university classrooms. The high-quality sensor for measuring air flow, temperature, humidity, pressure, heat radiation, CO_2 concentration and illumination intensity Testo 480 with globe probe, IAQ probe, light probe and comfort level probe is used for measurement. The work is supported by the grant Specific University Research SVV 201802 Address identification and analysis of the determinants of the Indoor Environment Quality (IEQ).

1. Introduction

In addition to achieving the goal of energy saving and the reduction of greenhouse gas emissions, currently, attention is increasingly also focused on the quality of the indoor environment. People spend up to 90% of their time indoors. Indoor environment quality (IEQ) is an extremely important factor in the context of the health, comfort and performance of building users. Indoor environment quality has a significant impact on modern life around the globe. The quality of the indoor environment is the result of interaction between physical, chemical and biological parameters: temperature-humidity parameters, noise and vibrations, chemicals and odors, dust, light, electro-ion microclimate, non-ionizing radiation, and microbial contamination. Pollutants have a negative effect on the health, performance and comfort of building users at given concentrations and exposure times. The long-term unsatisfactory indoor environment is associated with the Sick Building Syndrome (SBS). Sick Building Syndrome is defined as a group of symptoms that have no clear etiology and are attributable to exposure to building variables. These symptoms include eye, nose, and throat irritation, the sensation of dry mucous membranes, dry, itching, and red skin, headaches and mental fatigue, nausea and dizziness [1]. There are a number of studies dealing with the performance and productivity in the context of the quality of

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the indoor environment [2-5]. According to the review of the literature [6], there are eight physical factors affecting satisfaction and productivity indoors: indoor air quality and ventilation, thermal comfort, lighting and daylighting, noise and acoustics, space layout, biophilia and view, look and feel, location and amenities. None of these factors acts independently, but they are constantly interacting.

University classrooms are spaces where calculating, reading, writing, working of the laptop or focusing attention on monitors takes a lot of time [7]. Moreover, the high level of Carbon Dioxide (CO_2) concentration level in the classroom has a significant effect on performance, such as lower attention and vigilance [8,9]. Indoor environment quality in the places used for education affect learning processes, concentration, and productivity of students. It also could affect the health of students and academic staff in long-term. Students are at greater risk from the reason that they spend hours of time in the educational facilities. Generally, the indoors for educational purposes are strongly affected by the synergic action of volatile organic compounds (VOCs), dust particles and microorganisms [10]. High indoor air quality (IAQ), suitable lighting and daylighting, appropriate acoustic solutions, suitable thermal-humidity conditions are crucial to the health of students and academic staff [11]. Students are more sensitive to environmental conditions than adults, especially to environmental pollutants and acoustics [12]. Users' perceptions of the indoor environment are the key parameter of sustainable buildings [13]. Sustainability in buildings could be mainly achieved by the incorporation of users' perceptions of indoor environment already in building design.

2. Method

Measurements and sensory assessments were carried out at the Institute of Technology and Business situated in the city of České Budějovice, South Bohemia, Czechia. Ten different university classrooms are selected for indoor quality research. Two of the observed university classrooms are the computer classrooms. Two classrooms serve as lecture halls for more than 200 listeners. One of them is equipped with a forced ventilation system. One classroom serves as a laboratory. The walls and ceilings are fitted with a classic internal plaster with white paint. Flooring is synthetic smooth flooring – linoleum. The windows are new, plastic with a shading system of internal blinds. The classroom equipment is classical and includes tables, chairs, whiteboard, computer and projector.

Measurements took place in October under favorable climatic conditions. During the measurements, the mean outdoor air temperature is 15,86°C the mean outdoor relative humidity is 63,74%. The mean concentration of Carbon dioxide is 645 ppm.

Before the assessment, the students were instructed on to using the scales. There is no restriction on the distribution of gender or smoking habits. The age ranged from 20 to 25 years. All panellists are university students. Overall, 289 students were interviewed. The panellists stay outdoor odors before the assessments. Before the lesson, the panellists indicated their immediate evaluation on eight continuous scales regarding air acceptability, odor intensity, thermal comfort, humidity comfort, visual comfort, color comfort, noise load and total satisfaction. Then the percentage of dissatisfied (PN) was estimated. The scale of air acceptability is divided into 2 separates scales with end-point clearly acceptable (+1) / just acceptable (0) and just unacceptable (0) /clearly unacceptable (−1). The scale of odor intensity has five levels of intensity odor: 0 no odor, 1 slight odor, 2 moderate odor, 3 strong odor, 4 very strong odor and 5 overwhelming odor. According to ASHRAE the scale of thermal comfort has 7 levels: +3 hot, +2 warm, +1 slightly warm, 0 neutral, −1 slightly cool, −2 cool, −3 cold. The humidity scale has 5 levels: 2+ too humid, +1 slightly humid, 0 just right, −1 slightly dry and −2 too dry. The range of perceived visual levels has 5 level: +2 too bright, +1 slightly bright, 0 just right, −1 slightly dark and −2 too dark. The noise load scale is divided into 5 levels: 1 no noise, 2 slight noise, 3 acceptable noise, 4 strong noise and 5 intolerable noise. The scale of perceived colors applied in the interior has 5 level: +2 too high, +1 high, 0 just right, −1 low, −2 too low. The scale of overall satisfaction includes 5 levels: +2 too high, +1 high, 0 just right, −1 low, −2 too low. The limit answers (maximum values of each scale) are regarded as discomforts in this study.

Students' self-evaluation results are compared with the measured indoor environment parameters. The high-quality sensor for measuring air flow, temperature, humidity, pressure, heat radiation, CO_2

concentration and illumination intensity Testo 480 with globe probe, IAQ probe, light probe and comfort level probe is used for measurement. Measurements and questionnaires are conducted in the first 15 minutes after the beginning of the lesson to eliminate the impact of the adaptation. Descriptive statistics such as percentages, range (minimum-maximum), or arithmetic mean are used to summarize the characteristics of the university student and their classrooms.

3. Results and discussion

Table 1 summarizes the measured values of the parameters of the indoor environment in observed classrooms. In the case of measuring the intensity of illumination is also the simultaneously measured value of the intensity of illumination outdoors. Subsequently, the daylighting factor DF [%] is expressed from both values. Occupancy [%] expresses an immediate capacity used classrooms for a total capacity of classrooms. Classroom occupancy ranges from 25 to 90%.

Table 1. Indoor Environment Quality (IEQ) in observed classrooms

Classrooms	Occupancy [%]	Indoor air temperature [°C]	Relative humidity [%]	CO_2 concentration [ppm]	DF [%]
1	25%	22.2	46.8	898	11.54
2	50%	23.1	50.1	1550	7.08
3*	48%	20.6	51.4	941	0.33
4*	60%	22.6	45.3	1039	5.43
5	57%	22.1	52.1	1422	0.76
6**	29%	24.2	44.7	611	2.05
7	25%	19.8	62.8	968	0.08
8	33%	24.1	49.8	1369	1.22
9	43%	22.7	56.7	854	1.98
10	84%	22.5	40.7	708	0.93

* computer classroom ** lecture hall with a forced ventilation system

According to the valid Czech regulations defining the requirements for classrooms, the following parameters must be met: minimal indoor air temperature 20°C, optimum indoor air temperature 22±2°C, maximum indoor air temperature 28°C, air flow rate from 0.1 to 0.2 m/s, relative humidity ranges between 30 and 65%, and air change rate ranges from 20 to 30 m^3 per student. According to Table 1, the indoor air temperature in monitored classrooms ranges from 19.8 to 24.2°C. The mean value of indoor. air temperature is 22.39°C, which meets the optimal requirements. The values of relative humidity of observed classrooms range from 44.7% to 62.8%. The mean value of RH is 50.04%. In terms of relative humidity, the conditions of the classroom's indoor environment are acceptable.

The mean outdoor CO_2 concentration is approximately 650 ppm during in České Budějovice during measures. The general requirement for indoor air quality is the concentration of carbon dioxide less than 1000 ppm. The indoor air may appear heavy and breathless at concentrations of carbon dioxide above 1000 ppm. The maximum permissible concentration is 1500 ppm. The classrooms were ventilated doors during the break, as is usual with the conventional operation. In 4 out of 10 classrooms, the 1000 ppm concentration is exceeded at the beginning of the lesson. In one case, the concentration exceeds even 1500 ppm. It is obvious that conventional ventilation by the open door during a break is insufficient in terms of indoor air quality. The main influence on increasing CO_2 concentration has the number of people, the frequency of ventilation and the size of the space. The lowest concentration of Carbon Dioxide (611 ppm) is achieved in a lecture room with a forced ventilation system.

The daylight factor (DF) is a very common and easy to use measure for the subjective daylight quality in an indoor space. It describes the ratio of outside illuminance over inside illuminance, expressed in per cent. According to valid standards (for example CSN 83 0580-1 Daylighting in buildings – Part 1: Basic Requirements), school classrooms must always have adequate daytime lighting in addition to special audiences. The daylight factor (DF) ranges between 0.33 and 11.54 %. It is also advisable to avoid glossy surfaces such as sheets, workspaces, floors that can cause reflection glare.

3.1. Thermal comfort

Thermal comfort reflects whether the user is in the room feels warm or cold depending on the actual conditions of the internal environment. The goal is to reach the maximum number of satisfied people in the room. The indoor air temperature measurements show a large range (19.8–26.2 °C). The graph (Figure 1) shows the sensory perceived component of temperature comfort, depending on the measured temperatures in the observed classrooms. The percentage of dissatisfied is 4.2%. These panellists feel cold (−3) or hot (+3). Perceived thermal comfort is rated as neutral by approximately 28.4% of panellists. Almost 60% of panellists evaluate the classroom's indoor environment on the warmer (positive) side of the scale. The mean value of perceived thermal comfort equals 0.75, reflecting thermal comfort between neutral and slightly warm.

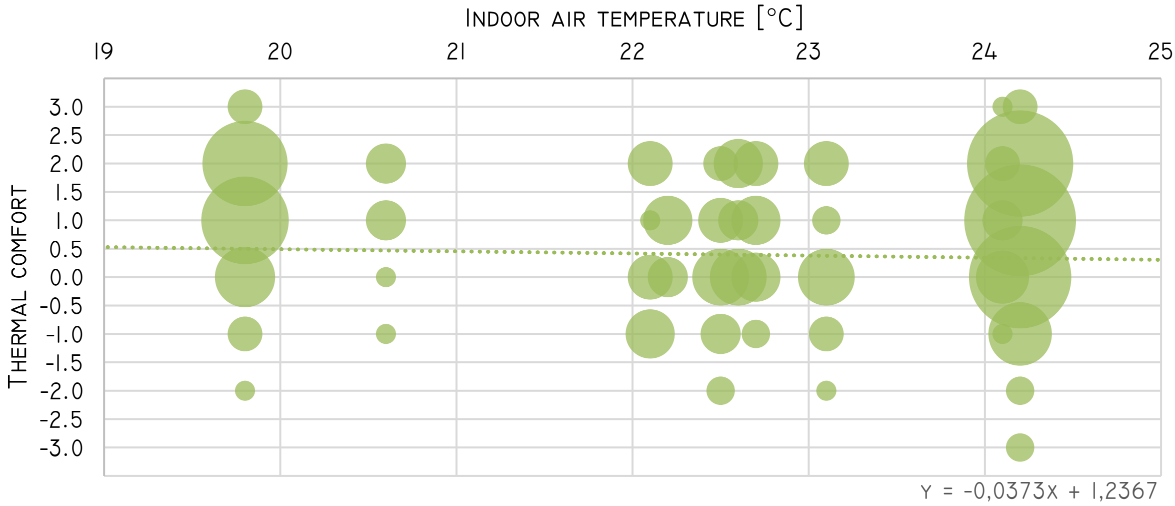

Figure 1. The relationship between perceived thermal comfort and indoor air temperature in observed classrooms of the university.

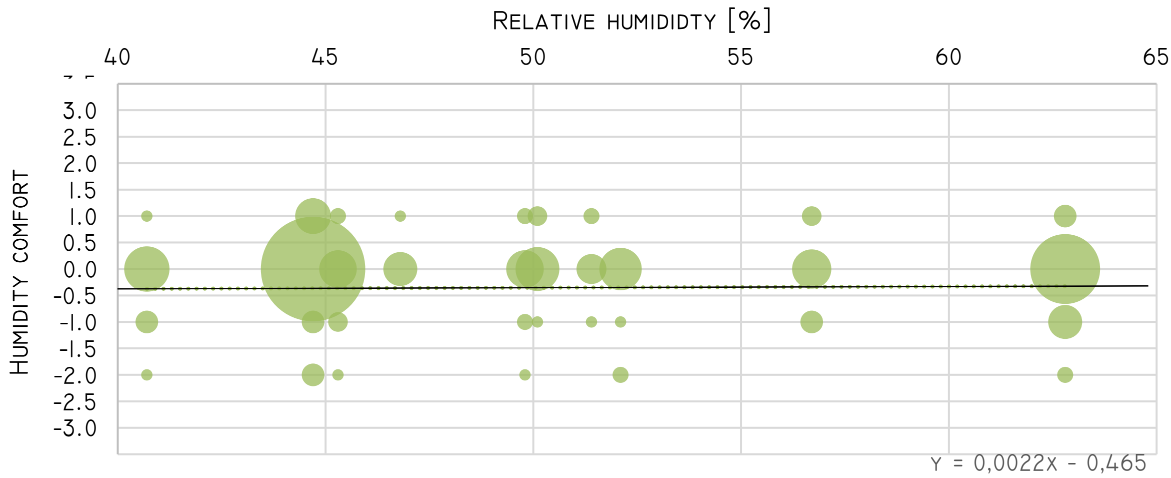

Figure 2. The relationship between perceived humidity comfort and relative humidity in observed classrooms of the university.

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Figure 2 shows relationships between perceived humidity comfort and measures values of RH in observed classrooms. The percentage of dissatisfied is 0%. The mean value of perceived humidity comfort equals −0.05. This can be expressed as neutral. The results reflect the fact that measured values of relative humidity in the monitored classrooms are within optimal limits.

3.2. Indoor air quality and odor intensity

The relationship between air quality responses (bothered by smell) and CO_2 concentration and intensity of ventilation is generally assumed. The results of the physical-chemical analysis of the environment show that the recommended concentrations of CO_2 are already exceeded at the very beginning of the lesson. Figure 3 shows the results of air acceptability related to the concentration of CO_2 in the monitored classrooms. Even before the exceeded values of the recommended carbon dioxide concentration, the percentage dissatisfied with the air acceptability is only 1.4% (clearly unacceptable). By contrast, more than 15% of questioned students assess air acceptability as clearly acceptable. The mean value of air acceptability is 0.2362, reflecting a slight positive air acceptability.

The human sense of smell is a primary factor in the sensation of comfort. Odor intensity is the perceived strength of odor sensation. None of the observed university classrooms has undergone recent refurbishment. It can be assumed that no new furniture materials were introduced into the classroom as a source of volatile organic compounds (VOCs). Besides outdoor air and classroom´s occupants, the indoor sources of odor are furniture and computers. The mean value of odor intensity for all university classes is 1.15 at the beginning of the lesson. It means a slight odor which can have represented the rising concentration of Carbon Dioxide.

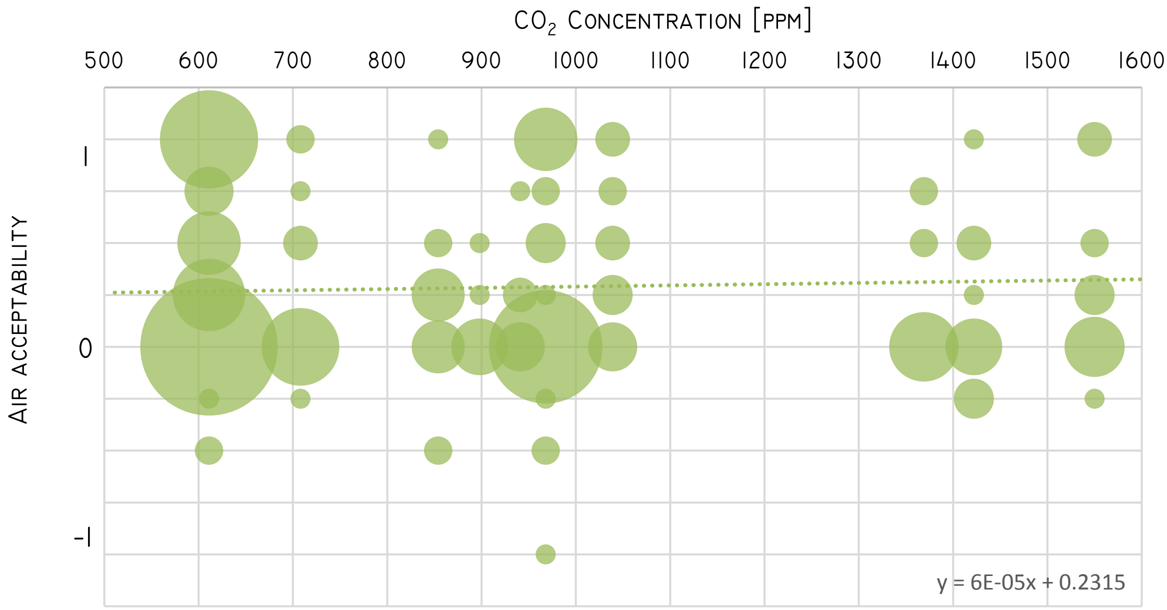

Figure 3. The relationship between perceived air acceptability and CO_2 concentration in observed classrooms of the university.

3.3. Acoustics and noise load

According to [14], one of the main effects of noise in the classroom is the reduction of speech intelligibility. An intolerable noise load of the internal environment is estimated by 0.2% of panellists. Figure 4 illustrates the perceived level of noise load in the observed university classrooms. From the point of view of noise load, the lecture hall with a forced ventilation system is the worst (classroom n. 6). The mean value of the noise load is 1.31. It corresponds to the acceptable slight noise level.

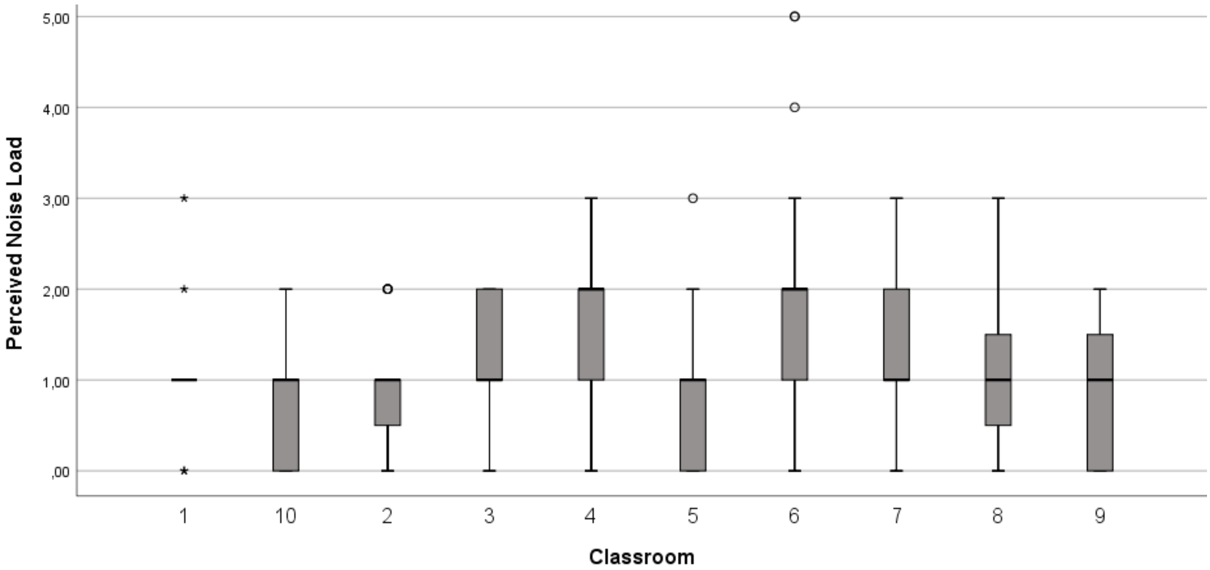

Figure 4. Perceived noise load in the observed university classrooms.

3.4. Visual comfort and applied colors in interior

Different activities require different levels of daylighting [6]. The relationship between perceived visual comfort and daylighting factor in observed classrooms of the university is shown in Figure 5. The percentage of dissatisfied is 0%. The mean value of visual comfort for all university classrooms is 0.02. The mean value is acceptable and represents the just right environment.

The questionnaire also includes questions about the perception of colors applied in classrooms. Visual comfort is largely influenced by the color of the interior. Previous studies have shown that combinations of applied colors, surface materials and lighting of indoor affect the receptivity of students and their behavior and mood [15, 16]. The percentage of dissatisfied is also 0%. The mean value of perception of color is 0.02. This mean value represents the just right quality of interior colored.

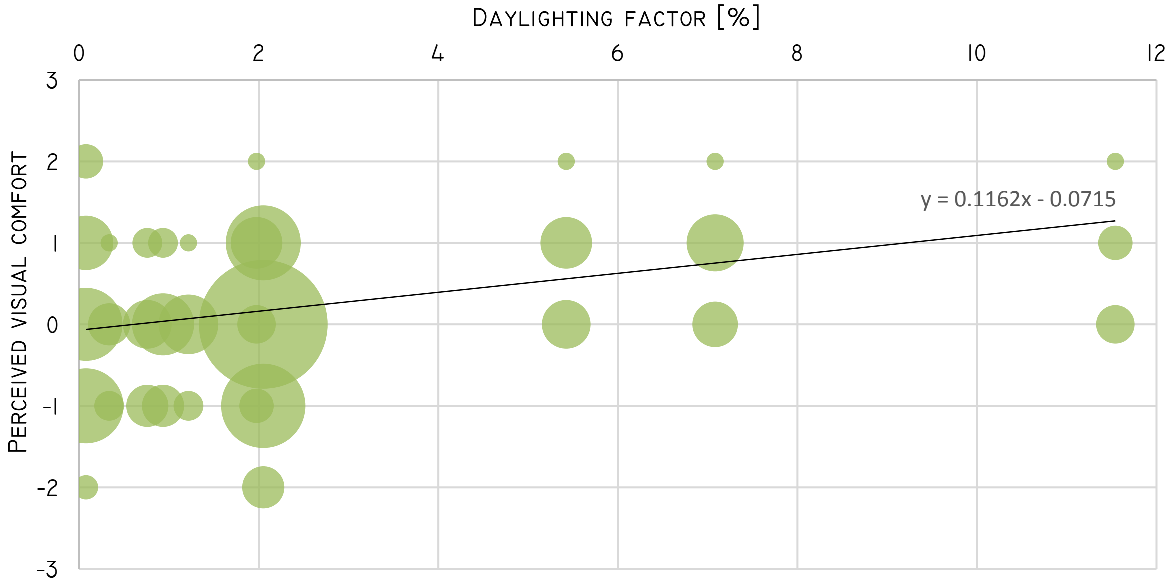

Figure 5. The relationship between perceived visual comfort and daylighting factor in observed classrooms of the university

3.5. Overall satisfaction

Figure 6 shows a histogram of perceived overall satisfaction of the indoor environment quality of observed university classrooms. The distribution of the values indicates a normal (Gaussian) distribution of values. More than 60% of panellists refer to overall quality as just right. The percentage of dissatisfied is 0%.

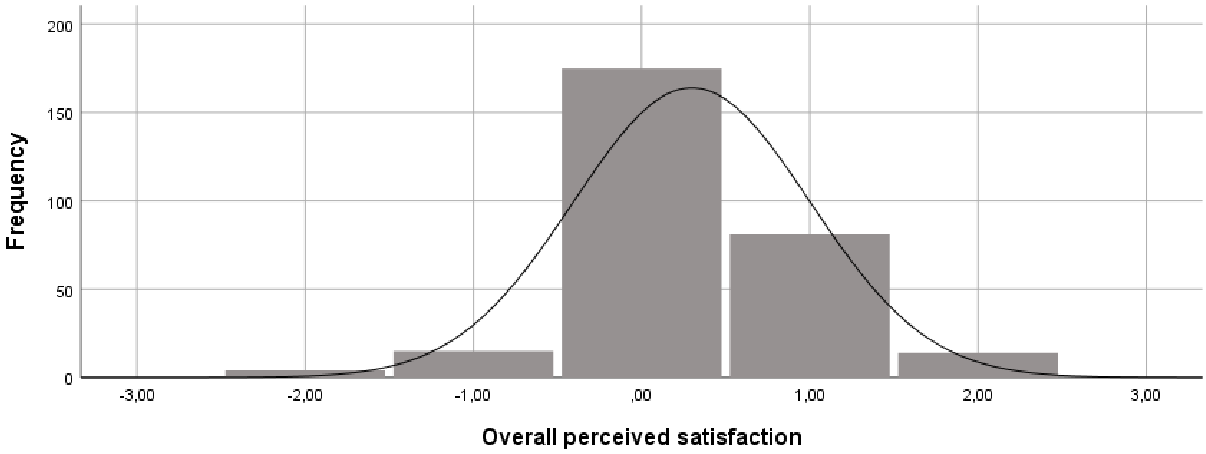

Figure 6. The distribution of the perceived overall satisfaction of the indoor environment quality of observed university classrooms.

Table 2 shows the results of perceived indoor environment quality in observed classrooms in the university. Perceived indoor environment quality is expressed by the mean value. The last column expresses the mean value for all monitored classrooms.

Table 2. Indoor Environment Quality (IEQ) in observed university classrooms.

	1	2	3	4	5	6	7	8	9	10	∅
Thermal comfort	0.60	0.37	1.10	0.89	0.29	0.80	1.11	0.75	0.74	0.14	0.75
Humidity comfort	0.10	0.11	0.10	-0.06	-0.29	0.02	-0.17	-0.13	-0.05	-0.23	-0.06
Visual comfort	0.60	0.68	-0.20	0.61	-0.18	-0,14	-0.08	-0.13	0.37	-0.14	0.03
Color comfort	-0.20	0.05	-0.10	-0.22	-0.53	-0,13	0.09	-0.44	0.00	0.05	-0.10
Odor intensity	1.10	0.84	1.40	1.17	1.24	1.24	1.32	0.81	0.74	1.05	1.15
Noise load	1.10	0.95	1.30	1.50	0.88	1.61	1.38	1.06	0.90	0.86	1.31
Overall satisfaction	0.20	0.21	0.20	0.28	0.29	0.29	0.40	0.25	0.21	0.41	0.30

4. Conclusion

There are many studies focusing on indoor air quality in primary and secondary schools. Nevertheless, studies in university classrooms are still few. The presented case study is a primary study for assessing the indoor environment quality (IEQ) of Czech university students. This paper presents the results of the investigation devoted to the quality of the indoor environment in Czech university classrooms. Understanding the perception of the quality of the inner environment by students is essential to increase the performance and productivity of not only students but also the academic staff. The long-term low indoor environment quality can lead to poor productivity, performance and ability to learn. It is also necessary to take into account the health of students and also academic staff in the context of the hygiene of the internal environment. The paper provides a concise starting point for future researchers in the field of indoor environmental quality in building for education. Although different students have different problems of IEQ in classrooms, the quality of the university's indoor environment is assessed as acceptable. Insufficient indoor environment quality in university classrooms are difficult to generalize due they differ from student to student, so to the possible measures. This knowledge is necessary and useful to develop appropriate strategies to create and maintain a sustainable internal environment for education and training. Without a proper functioning management system of the indoor environment, it is impossible to sustain a comfortable indoor environment for student occupants.

Acknowledgments
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