



Validation of the Fanger Model and Assessment of SBS Symptoms in the Lecture Room

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Abstract: The indoor environment of buildings significantly affects the well-being and health of room users. Experiencing thermal discomfort reduces concentration and productivity during study or work, causing drowsiness, fatigue or deterioration in general well-being. The study focuses on presenting the results of the questionnaire study on the symptoms of sick building syndromes (SBS), namely: dizziness, nausea, eye pain and nasal mucosa, experienced by 69 students during a lecture in a large and modern auditorium of Kielce University of Technology. The results show that many students experienced SBS symptoms, which seem to have affected their concentration during the class. The article also discusses the thermal sensations of the students with a focus on comparing the obtained results with the Fanger model of thermal comfort. The discrepancy between the model calculation results and the experimental data has been observed and discussed.

Keywords: indoor environment, sick building syndrome, thermal comfort

1. Introduction

We spend most of our time indoors, namely in offices, schools and living quarters. Thus, the indoor environment has a considerable influence on us. It is possible that due to poor ventilation or thermal discomfort, people tend to feel tired or sleepy. Concentration and productivity can also deteriorate. Excessive cold or heat also affects our health and well-being. Unsuitable indoor air conditions can have certain consequences, such as runny nose, watery eyes or dizziness, which are examples of sick building syndrome (SBS) symptoms. A study (Suzuki et al. 2021) conducted on nearly 5000 Japanese participants that focused on sick building syndrome and its risk factors showed that young people and women, above all, are more sensitive to SBS. The test results obtained in 24 air-conditioned and 27 naturally ventilated university classrooms on 2110 students (Hu et al. 2022) reveal that men felt comfortable in cooler climates and had a lower incidence of SBS than women. In (Mentese et al. 2020), research in Turkish residential buildings was described. It focused on sick building syndrome as well as the lung function of the subjects. The research has shown that internal and external factors influenced the quality of indoor air. Consequently, the subjects felt tired, had difficulty concentrating, and had flu-like symptoms. Additionally, the authors investigated the relationship between indoor pollution, SBS symptoms and other parameters. The experimental research (Fan & Ding 2022) was carried out in China, and almost 30000 questionnaires from 2370 buildings were collected for the analysis. It was also confirmed that the indoor environment influences the occurrence of symptoms of sick building syndrome. Another study from China (Sun et al. 2013), which covered almost 4000 students of the same age, indicates the occurrence of various symptoms of SBS, including skin and mucosa problems. It needs to be added that women experienced more symptoms, such as dry air or the smell of mould. In (Licina & Yildirim 2021), productivity and symptoms of SBS before and after moving into office buildings were tested. The SBS symptoms were reported mostly below 20% of the cases; the most common symptom was fatigue.



The problem of the sick building syndrome is closely related to poor indoor air quality. In (Dharmasastha et al. 2022), the authors researched the influence of internal heat load and natural ventilation on the thermal efficiency of the building roof. The results showed that natural ventilation lowers the level of carbon dioxide but reduces the level of thermal comfort. Similarly, the test results obtained in educational buildings (Chena et al. 2022) confirmed that the fresh air ventilation system lowers the CO₂ concentration in the rooms, translating to better air quality and, thus, improved health conditions indoors. The paper (Aguilar et al. 2022) assessed the ventilation rates for educational buildings in Portugal and Spain. Research shows that proper ventilation can guarantee adequate air exchange and, thus, keep the risk of infection low.

Sick building syndrome can be considered an even more severe problem if it affects room users' well-being. Naturally, it is a complicated issue and involves the heating systems' operation (Wojtkowiak & Amanowicz 2020, Amanowicz & Wojtkowiak 2021) and ventilation air filtering processes (Dąbek et al. 2002, Dąbek et al. 2012). It might also be directly or indirectly linked with heat transfer problems, e.g.: (Koshlak & Pavlenko 2020, Pafcuga et al. 2021, Orman 2014, Hečko et al. 2021, Pavlenko 2020, Pavlenko & Koshlak 2021) and especially phase – change phenomena (Chatys & Orman 2017, Orman & Chatys 2011).

From the above-presented literature review, it is worth noting how common the symptoms of SBS are; however, a combined assessment of SBS problems and thermal comfort in Polish conditions has not been found in the literature (although in Poland, studies on the indoor environment can be found, e.g.: (Dudkiewicz & Jeżowiecki 2009, Maliszewska et al. 2019). The article focuses on the sensations of a large group of students in one Kielce University of Technology lecture theatre. Four ailments are discussed and analysed: dizziness, nasal mucosa, nausea and eye pain. The validation of the Fanger model will also be made.

2. Experimental Setup and Testing Method

The study was conducted in the large lecture hall of Kielce University of Technology in the Central-Eastern part of Poland. The environmental measurement was made with an Italian microclimate meter BA-BUC-A, which collected data on the current air temperature, carbon dioxide content, relative humidity, and airflow velocity. Measurements were recorded manually, and the measurement time was about 1 hour. While the meter was collecting microclimate data, at the same time, questionnaires were distributed to sixty-nine students, who voluntarily answered questions about the indoor environment, particularly about possible sick building syndrome symptoms that they might have experienced. Figure 1 presents the lecture room after the measurement with the questionnaires located on the desks, marking the location of the respondents during the test.



Fig. 1. Lecture room with the completed questionnaires on the desks

There were 135 seats in the lecture room, of which 51% were taken during the testing. The surface area is 107.1 m², while the cubature is 344.3 m³. One large window facing South had a surface area of 2.64 m². In terms of the HVAC system, the room is equipped with mechanical ventilation and cooling (with the basic parameters set by the room users). The vents that provide fresh air into the room are located on the wall, and the vents that remove the exhaust air – are on the ceiling (both types can be seen in Figure 1). The study was

performed in June; thus, no heating was on. However, air heating is the room's thermal energy source during the heating season.

The measuring station consisted of the BABUC-A microclimate meter with adequate probes. It was located in the middle of the room. Table 1 presents the basic technical features of the measuring device.

Table 1. Accuracy and maximal range of the parameters measured in the study

Parameter	Maximal range	Accuracy level
Air temperature	45°C	0.5°C
Relative humidity	100%	3%
Globe temperature	70°C	1°C
Carbon dioxide level	5000 ppm	20 ppm + 3% of the value
Air velocity	30 m/s	3% (at 25°C)

During the measurements, the indoor air parameters fluctuated and ranged from 26.1 to 27.7°C for air temperature, 48.5-53.3% for relative humidity and 937-1223 ppm for carbon dioxide concentration. Airflow velocity was almost constant and amounted to 0.04-0.06 m/s. The volunteers were 20 to 25 years old. Their mean height and weight were 1.76 m and 74.5 kg, respectively. For analysis related to thermal comfort, it is more important to know the Body Mass Index of each participant. Its average value was calculated for each person individually and ranged from 17.71 to 38.16 kg/m². The smokers constituted 17.4% of the group, while 13% of the students indicated they were ill within the last seven days, and some (8.7%) had a fever. The recent sleep duration of the respondents ranged from 1h to 2h: 11.9% slept four hours or less, while 10.4% slept nine hours or more. The average sleep duration for the whole group was 6.5h, which is quite low and can be explained by the examination period at the university.

3. Results and Discussion

The study was performed in June. Sixty-nine students took part in the survey. At the moment of filling in the forms, the microclimate parameters in the tested room were as follows: air temperature: 26.2°C, carbon dioxide level: 1223 ppm, relative humidity: 53.3%. It should be noted that the temperature was quite high in the room (due to the lack of air conditioning). Moreover, a high concentration of CO₂ could also contribute to the results obtained in the present study. Relative humidity was in the optimal range and could not have impacted the students' sensations.

Four symptoms of sick building syndrome will be considered and discussed: dizziness, eye pain, nausea and nasal mucosa (frequent sneezing, itching, nasal congestion). Regarding each of the above-mentioned health problems, the students could choose from the following possible answers: "definitely do not feel it" (-2), "rather do not feel it" (-1), "rather feel it" (+1) and "definitely feel it" (+2).

The first SBS symptom to consider is dizziness. Figure 2 shows the test results as a frequency count of each answer to the question "Do you feel dizziness and to what extent?" separately for women and men.

Dizziness was mostly felt by women – about 15% of the combined answers (+1) and (+2) and slightly fewer men (11%). The rest of the group did not feel the stated discomfort. However, a worrying phenomenon is that almost 5% of women definitely felt dizziness when occupying the room. Dizziness could be caused by the high temperature during the lecture and a relatively high level of carbon dioxide in the room.

The next question in the questionnaire was focused on eye pain. As before, the students were asked if they felt it and to what extent. Figure 3 shows the results from the questionnaire survey as the frequency count.

9.5% of women in the analysed lecture room definitely experienced eye pain. Moreover, the same number of women indicated that they also rather experienced eye pain (while the share of men was almost identical and amounted to 9.1%). This value is quite large and should call for attention, not only because of the health issues but because it might affect the clear vision of the material being taught during the lecture. Maybe poor lighting conditions in the room were responsible for such a large number of complaints. The illuminance value was not measured, and this issue cannot be addressed in detail; however, the questionnaire contained a question about the assessment of lighting conditions, and 8.7% of the respondents considered lighting in the room as being poor (while 36.3% thought the room was bright and 55% that it was bright enough). It might explain the eye pain of those who might have had poor lighting at their sitting location in the room. Nevertheless, over 80% of women and over 90% of men did not report this ailment during the measurements.

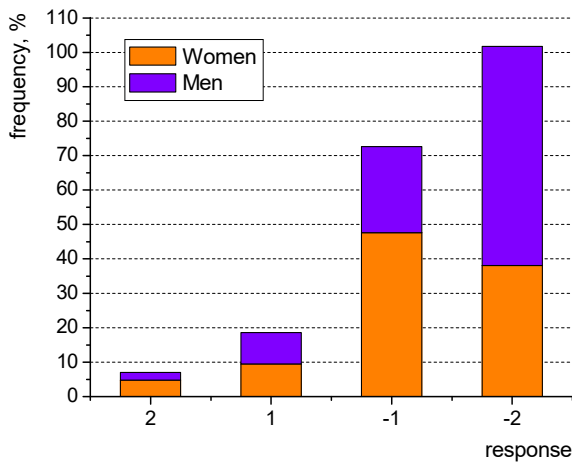


Fig. 2. Responses of the students regarding dizziness

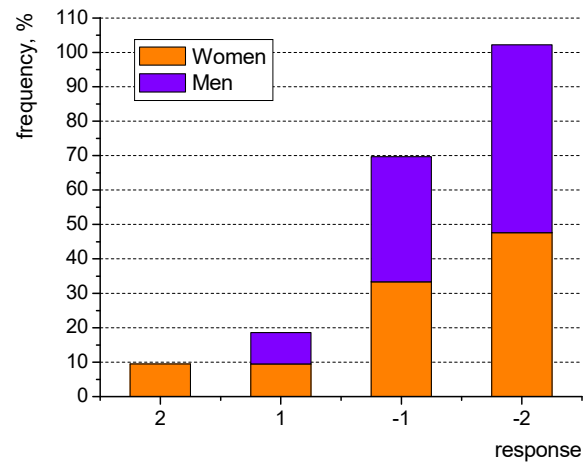


Fig. 3. Responses of the students regarding eye pain

Another health aspect investigated by the present questionnaire study is nausea. Figure 4 presents the test results as the frequency count of the answers provided by women and men.

Figure 4 provides information about the appearance of nausea after a prolonged stay indoors – namely in the lecture hall. It turned out that no women experienced nausea (thus, 100% of them marked (-1) and (-2)). However, three men (6.8% of men in the room) confessed that they experienced or rather experienced nausea. If this health problem had not been caused by something else (e.g. unfresh food, some medication taken by these people, hunger, etc.), the indoor environments (e.g. elevated temperature or air quality) could have contributed to this state and such a response in the questionnaire.

The last ailment is the appearance of irritation of the nasal mucosa (including frequent sneezing, itching, burning around the nose and nasal congestion). The survey results regarding this health problem are shown below in Figure 5.

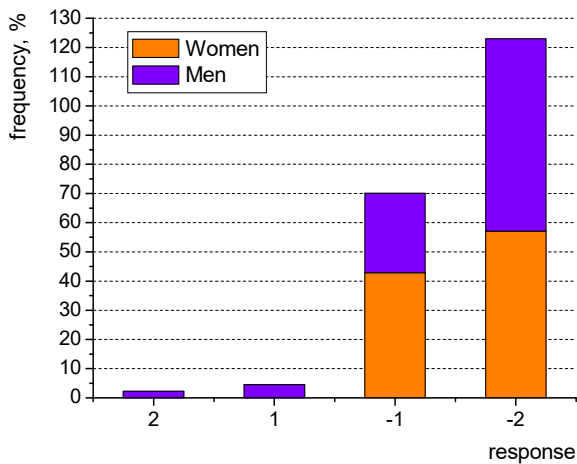


Fig. 4. Responses of the students regarding nausea

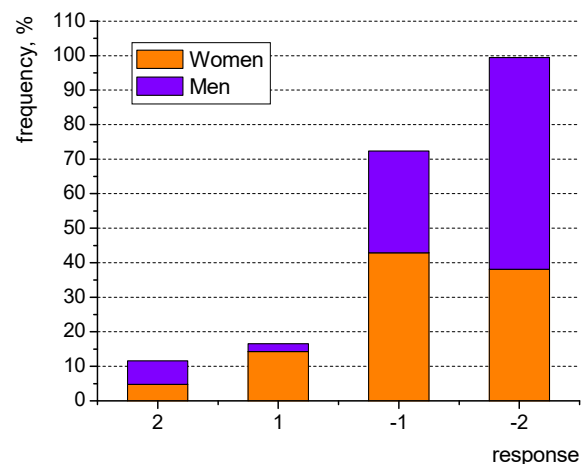


Fig. 5. Responses of the students regarding nasal mucosa

As can be seen, ca. 19% of women and ca. 9% of men marked the answers (+2) and (+1), confirming the occurrence or a possible occurrence of this problem. The rest of the group answered (-1) and (-2). The reason for the appearance of a runny nose, and at the same time, other nasal ailments, could be the presence of solid particles in the air or allergens (which is quite probable considering the fact that the tests were conducted in June). However, these were not measured in the present study. Also, other elements of the indoor environment could have contributed to the occurrence of this symptom. The tests would need to be repeated in winter to verify the possible influence of allergens.

The occurrence of the symptoms mentioned above is undoubtedly unfavourable. However, dizziness, eye pain, nausea and nasal mucosa could also influence the concentration of the students during the classes and, consequently, their learning performance. Relations between the rating of each symptom and the self-reported concentration have been analysed to verify this thesis. The students were asked if they experienced any concentration issues and answered that they either: definitely had such problems (+2), rather yes (+1),

rather not (-1) or definitely not (-2). Figure 6 shows the obtained data for 4 x 69 data points (overlapping each other) and the linear fittings of the generated data points for each considered symptom.

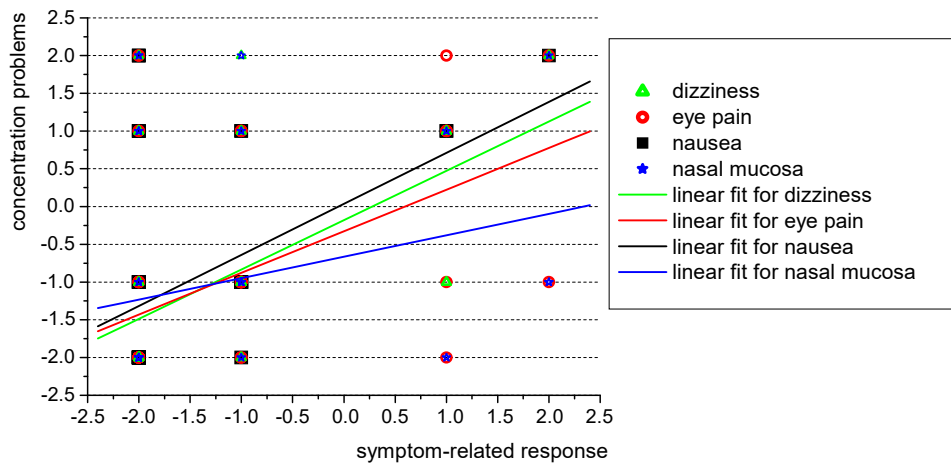


Fig. 6. Ailment responses vs. concentration problems

There seems to be a clear dependence between the occurrence of the sick building syndrome symptoms and concentration problems reported by the respondents. The graph shows that generally, people who marked a certain ailment response – namely, that they definitely experienced it: (+2) on the x-axis, they also had concentration problems (and marked (+2), which appears on the y-axis). Similarly, if they were fine and had no health problems in the analysed room and marked (-2) for the ailment occurrence, they did not have any concentration issues and marked (-2) or (-1). The linear fitting lines for all the ailments show the same upward trend; however, the relation between nasal mucosa and concentration problems is weaker than in the case of the remaining three SBS symptoms. It is evident that the relationship between concentration and dizziness, eye pain and nausea is almost the same for such a large number of people in the room. The linear fit equations related to the impact of dizziness (DI), eye pain (EP), nausea (NA) and nasal mucosa (NM) on concentration problems (CS) take the following forms:

$$CP = 0.6536DI - 0.1808; R^2 = 0.32 \quad (1)$$

$$CP = 0.5517EP - 0.3279; R^2 = 0.23 \quad (2)$$

$$CP = 0.6761NA + 0.0352; R^2 = 0.19 \quad (3)$$

$$CP = 0.2845NM - 0.6652; R^2 = 0.07 \quad (4)$$

The ailments and concentration problems can be related to the indoor environment in the room, especially thermal and humidity parameters and air quality. The best measure of indoor air quality is the level of carbon dioxide, which has been determined in the study. Its value ranged from 937 ppm at the beginning of the lecture to 1223 ppm at the end and could be considered quite high; however, the authors recorded higher concentrations at educational buildings. The questionnaire contained two questions regarding the subjective assessment of indoor air. The students were asked to assess the air's quality and the smell's presence. The results have shown that 7.2% considered the air as "very fresh" and 82.7% as "quite fresh", while the rest (10.1%) called it "not fresh". It indicates that quite a large number of people were unsatisfied with the air quality. At the same time, 24.6% of the students did not detect any smell, while 69.6% felt weak or moderate smell. Thus, it seems that the air in the room might not be of high quality.

The overall assessment of the indoor environment has also been conducted in the present study. The respondents were asked about how they generally felt in the room. They could choose from the following answers: "very good" (+2), "good" (+1), "neutral" (0), "bad" (-1) and "very bad" (-2). The subjective assessment of well-being is vital. It has been analysed concerning each student's individual rating of the thermal environment, subjective air quality assessment and four ailments (dizziness, eye pain, nausea and nasal mucosa). Figure 7 presents the influence of these factors on well-being. The thermal environment has been considered as the subjective assessment called the 'thermal sensation vote' (TSV). Each participant marked one of the following answers on their rating of the thermal state: "too hot" (+3), "too warm" (+2), "pleasantly warm" (+1), "neutral" (0), "pleasantly cool" (-1), "too cool" (-2), "too cold" (-3). The air quality rating ranged from "very fresh" (+2), "quite fresh" (+1) to "not fresh" (-1). All the ailments mentioned above have been considered together as the average value of the four marks (given for each ailment) in the range from (-2) to (+2).

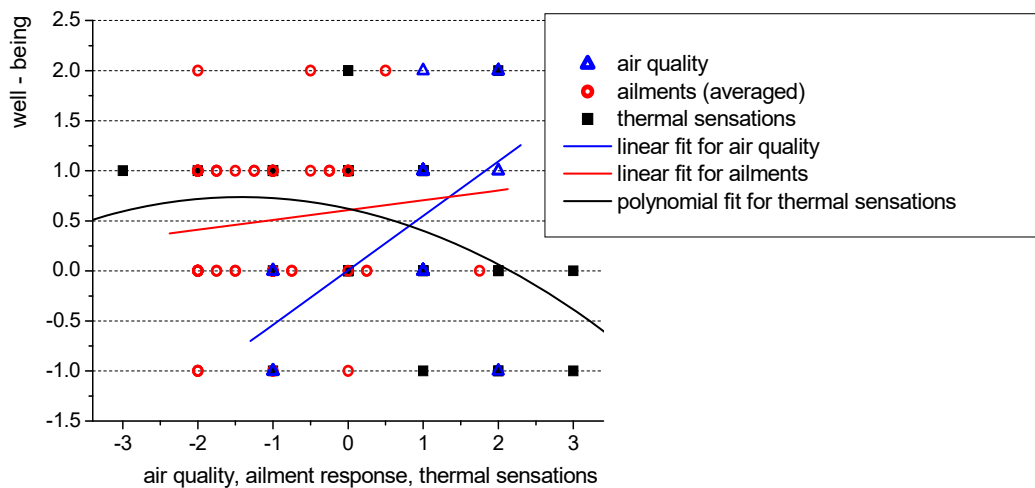


Fig. 7. Influence of subjective air quality, the occurrence of ailments and thermal sensation vote on the well-being of the respondents

As the subjective rating of air quality increases, the well-being of the respondents also rises. This correlation is quite clear, contrary to the influence of the occurrence of ailments (as an average rating of four of them). In this case, they might not impact human well-being, although the opposite seems to be true (when people feel ill, they poorly assess their well-being). The explanation of this phenomenon might be that the students were not quite responsive to the occurrence of ailment because a small number of the people only experienced these problems. Thus, their assessment was not large enough to make a difference for the whole group, who was overwhelmingly not reporting any health-related problems. The most favourable state for the thermal environment assessment is neutral (0). Both positive and negative values, such as (-3) "too cold" or (+3) "too hot", describe negative sensations. However, the study has shown that the most preferable (the one that produces the highest well-being rating) is the thermal sensation value of about -1.5. It can be attributed to the high indoor and outdoor temperatures at the time of measurements and the preference of the respondents to reduce the surrounding temperature. It must be explained that the students rated their thermal environment within a wide range of votes: from -3 to +3, even though the indoor air temperature was uniform within the lecture room. It can stem from their individual thermal preferences, small differences in clothing level, and health conditions, but also (at least to some extent) from locally different environment conditions at locations where the students were actually situated (for example, some sat close to the door, while some might have been directly irradiated by the sun through the windows). The obtained equations related to the impact of air quality (AQ), averaged ailments (AA) and thermal sensations (TS) on well-being (WB) take the following forms:

$$WB = 0.5437AQ + 0.0055; R^2 = 0.28 \quad (5)$$

$$WB = 0.0981AA + 0.6072; R^2 = 0.02 \quad (6)$$

$$WB = -0.0575TS^2 - 0.1635TS + 0.6212; R^2 = 0.13 \quad (7)$$

It also needs to be mentioned that 20% of the respondents indicated in the questionnaires that they were hungry during the study. Even a larger share (33% of students) indicated that they were thirsty at the time of measurement, which might be understandable in such high temperature environment. These factors could also have had some influence on the obtained results.

The thermal environment largely determines the well-being of room users. Thus, maintaining thermal comfort conditions for all the people indoors is crucial. The common way to analyse this phenomenon is the experimental questionnaire survey, which enables us to obtain actual human responses. However, equally important is the proper determination of thermal comfort based on the indoor air parameters. In this way, the thermal responses of room users can be predicted even before the building is built. They can also be used when the building is finished and operational – for proper settings of indoor air parameters (mostly air temperature) in order to provide adequate conditions there for all the people. The thermal comfort assessment is carried out according to the methodology presented in the international standard (ISO Standard 7730 2005), which originated from the works of O.Fanger from the 60s and 70s (Fanger 1974) and, thus, will now be validated. The equations provided there lead to the calculation of the indices: PMV (predicted mean vote) and PPD (predicted percentage dissatisfied). PMV takes values in the range of (-3) to (+3) and relates directly to the thermal sensation vote (TSV) described earlier, with (-3) meaning "too cold" and (+3) "too hot",

while (0) is the neutral and most favourable thermal state. PPD predicts a share of room users dissatisfied with their indoor environment. It relates to the questionnaire survey in such a way that it is a share of the respondents who marked (-3), (-2), (+2) or (+3) when assessing their thermal sensation. Below, a comparison of the experimental results (based on the collected questionnaires) and the calculation results according to the methodology (ISO Standard 7730 2005) has been presented in Figures 8 and 9.

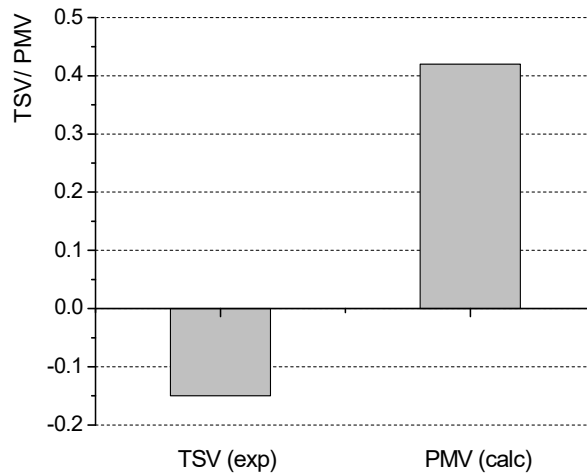


Fig. 8. Comparison of thermal sensation vote (TSV) and predicted mean vote (PMV)

The mean value of thermal sensation vote according to 69 questionnaires was: $TSV(\text{exp}) = -0.15$, while the calculation results carried out with the Fanger model (based on the indoor air parameters recorded with the microclimate meter as well as clothing thermal resistance and activity level of the students) amounted to $PMV(\text{calc}) = 0.42$. The difference between these two values is 0.57; however, they both fall into the favourable and acceptable range of thermal sensations of ± 0.5 according to (ISO Standard 7730 2005). Because TSV and PMV take the values from -3 to +3, the discrepancy between the model and the experimental results is not very large; however, it exists, and the model failed to determine thermal sensations in the considered lecture room correctly. It must be emphasised that data available in the literature – for example, the results of the tests performed in India (Indraganti et. al 2013, Manu et al. 2016) – confirm that the model might not properly determine the actual thermal sensations of room users.

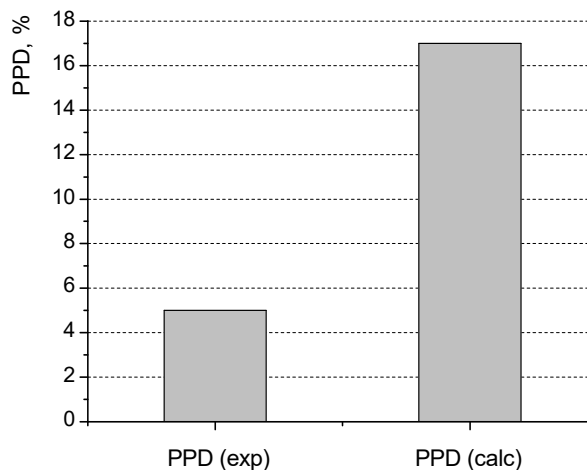


Fig. 9. Comparison of experimental and calculated results on the share of the dissatisfied (PPD) in the room

The actual share of the people who were dissatisfied with the thermal conditions in the room (determined based on their opinions expressed in the questionnaires) amounted to 5% (Figure 9). On the other hand, the calculations conducted according to the Fanger model generated a value of 17%, which is the predicted percentage of the dissatisfied. The discrepancy is quite significant and can be explained by the fact that the model was originally developed in the 60s based on experimental studies, while the modern buildings – such as the one where the tests took place – might generate different indoor environment conditions due to

the modern strategies of operation and control of heating, ventilation and air conditioning systems as well as the kind of building materials, air supply system design and other factors. Moreover, human expectations regarding their most favourable thermal environment conditions might have changed throughout the decades and can now be quite different compared to when experimental thermal comfort studies with the view of model development were carried out.

Due to the importance of the problem of the occurrence of sick building syndromes, the study should be extended in the future to include more SBS symptoms and their influence on the learning performance of the students measured both subjectively (with questionnaires) and objectively (assessing the actual learning outcomes).

4. Summary and Conclusions

4.1. Summary

The indoor environment should be designed appropriately so that sick building syndrome symptoms would not occur. Similarly, the thermal environment ought to be adequately controlled, too. The present study revealed that members of the large group of students (69 people in total) experienced eye pain, dizziness, nausea or nasal mucosa and the number of such responses was quite high for almost all the symptoms (except for nausea). Dizziness was experienced by 11% of men and 15% of women, eye pain by 19% of women and 9.1% of men, nasal mucosa by ca. 19% of women and ca. 9% of men, while nausea was observed only in 6.8% of men.

The thermal environment in the lecture room seems to have impacted the respondents' well-being, and it was observed that the most favourable conditions were reported by those who felt cool in the lecture room. It might have been caused by high indoor air temperature during the measurements ranging from 26.1 to 27.7°C.

The validation of the Fanger model in the considered room showed differences between the model calculations and experimental data. The values of the predicted mean vote and thermal sensation vote differed by 0.57. The percentage of the dissatisfied calculated according to the model was 17%, while the actual measurements provided the value of 5%.

4.2. Conclusions

Probably proper management of microclimate in the room (e.g. by increased fresh air flow or better filtering) and providing more acceptable thermal conditions could help reduce sick building syndrome symptoms. It is especially vital at educational facilities because concentration problems might occur and, consequently, the students' learning potential could be reduced.

The discrepancies between the Fanger model calculations and experimental data confirm the findings of various researchers from other regions of the world that the analysed model might not be quite precise in the predictions of thermal sensations of room users.

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