Łukasz J. Orman, Andrej Kapjor
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EXPERIMENTAL STUDY ON THERMAL COMFORT AT UNIVERSITY BUILDINGS IN SLOVAKIA

EKSPERYMENTALNE BADANIE KOMFORTU CIEPLNEGO W BUDYNKACH UNIWERSYTECKICH NA SŁOWACJI

Łukasz J. Orman*
Kielce University of Technology, Poland
Andrej Kapjor
University of Žilina, Slovakia

Abstract

The paper discusses the issue of thermal comfort expressed by the students of the University of Žilina in anonymous questionnaires. The volunteers rated their thermal sensations, preferences as well as lighting conditions in the autumn season. The students were in favour of the prevailing thermal conditions – almost 88% of the volunteers expressed positive opinions about their environment. The comparison of the test results for a computer laboratory with the Fanger model calculation results was also made and indicated differences between the experimental data and values determined with the model.

Keywords: thermal comfort, thermal sensations, Fanger model

Streszczenie

W artykule omówiono zagadnienie komfortu cieplnego studentów Uniwersytetu w Żylinie w oparciu o anonimowe ankiety. Ochotnicy oceniali swoje odczucia termiczne, preferencje oraz warunki oświetleniowe w okresie jesiennym. Studenci wyrazili się pozytywnie w zakresie panujących warunków termicznych – blisko 88% odpowiedzi. W pracy dokonano również porównania wyników badań w laboratorium komputerowym z wynikami obliczeń wg modelu Fangera i wykazano różnice między danymi eksperymentalnymi a wartościami wyznaczonymi modelem.

Słowa kluczowe: comfort cieplny, wrażenia cieplne, model Fangera

1. INTRODUCTION

The need for maintaining thermal comfort conditions at buildings is related to the basic human needs and, thus, much attention should be paid to keep room users satisfied with their thermal environment. It is mostly related to air temperature, however a number of other factors might have an impact such as air humidity, activity level of the people and their clothing as well as air flow speed [1]. The mathematical description of thermal comfort has been proposed by Fanger [1] and is now part of the international standard ISO 7730 [2], which can be used to determine how people would rate their thermal environment.

The issue of providing thermal comfort is especially important for public utility buildings, where many people spend significant amounts of time. A study by Krawczyk and Kapjor [3] covered almost a hundred respondents up to 23 years old at two buildings of Kielce University of Technology (Poland). The measurements were made during winter. The authors

*Kielce University of Technology, Poland, e-mail: orman@tu.kielce.pl

indicated that the majority of the students positively assessed the indoor thermal environment, however the conditions for ca. 15% of women were described as "cold". Large difference were observed between the actual responses and calculation results according to the Fanger model of thermal comfort. Dębska [4] carried out tests of thermal comfort at the intelligent educational building in Kielce, during which 164 students were asked about their thermal sensations. It was reported that the indoor air temperature of 19.3-27.6°C was acceptable as well as comfortable for about eighty percent of the room users. Although the majority of the students was satisfied with the indoor conditions, there were some who considered it to be "too cold" or "too hot". The sensations regarding air humidity were also generally positive. In the paper by Dębska et al. [5] the test results collected from fourteen students in the room were the air temperature was very high (29.4°C) were presented. Despite such elevated temperature half of the respondents found the conditions as acceptable (40%) and comfortable (10%). Similarly, 40% of them assessed humidity as pleasant (with the measured value of relatively humidity of ca. 52%). In [6] a methodology of assessing both heat and mass transfer together with the related exergies between the human body and the environment was presented. Only four people (2 women, 2 men) participated in the testing. It was shown that women feel thermal comfort in higher climatic conditions. Jindal [7] provided data on thermal environment and thermal perception of 130 students. The respondents felt most favourably in the temperature range from 15.5°C to 33.7°C. A recent study [8] of indoor environment, lighting conditions and productivity conducted at four educational buildings over eleven months proves that for the measured air temperature range of 20-25.1°C and humidity of 18.16-50.9% the respondents were generally satisfied or neutral with regard to their well – being. They also assessed lighting conditions as being appropriate (about 82% of the votes). Moreover, the authors also noticed that productivity of the students was linked with the air temperature in a given room. The best results were recorded for the values of about 23-24°C. Kolkova et al. [9] performed tests in the intelligent building located at the campus of the University of Žilina. The experimental analyses covered two different positions of the blinds in the windows. It was stated in the paper that the optimum temperatures were not exceeded during the measurements. According to Jazizadeh et al. [10], who focused on thermal comfort tests in offices, air temperature is the most important parameter that impacts thermal sensation of the people in rooms. Naturally, other factors for example carbon dioxide concentration, light intensity and etc. might play a role. This role can be significant in certain rooms and the impact of the above mentioned factors might be bigger then the impact of relative humidity.

It needs to be added that the indoor environment consists of a number of elements other than air temperature and humidity. Carbon dioxide concentration, air contaminants, noise and other factors might influence people's well – being. Telejko et al. [11] focused on the issue of the sick building syndrome and analysed the health problems at a lecture room of almost seventy students. The number of respondents experiencing headaches was high, expecially in the group of women (with over 30% votes). Similarly other problems such as watery eyes, sore throat and concentration problems were reported by a number of people. This indicates the need for more detailed analysis of indoor environment due to the possibly negative influence on people there. Equally important is the need to consider thermal comfort in buildings undergoing modernization as pointed out by Kosiński and Skotnicka-Siepsiak [12]. The problem is currently especially vital in Poland, where many buildings require modernisation works.

Recently Orman and Wojtkowiak [13] presented test results of thermal comfort measurements at university buildings located in the Western part of Poland and found out that the majority of students were in favour of thermal conditions in two considered classrooms. Naturally, the indoor environment is dependent on a large number of factors such as heating or cooling systems. A significant impact can also be attributed to the design and operation of windows (as pointed out by Sadko and Piotrowski [14]) as well as the proper design of heat exchangers, which are part of heating systems (as indicated by Polacikova et al. [15]).

The present article aims to analyse the thermal sensations as well as lighting assessment of the students of the University of Žilina. The volunteers filled in the anonymous questionnaires regarding their current sensations. The study is also focused on the verification to what extend the Fanger model of thermal comfort can successfully determine the people's responses as given in the questionnaires. Studies of thermal comfort in Slovakia are rare (with the exception of e.g. [16]), thus the present paper will provide more information and data on this subject.

2. MATERIAL AND METHOD

The tests took place in Žilina, which is located in the Northern part of Slovakia – at the altitude of 347 m. Its average annual temperature is 7.8°C. February is the driest month, while in July precipitation is highest. The average monthly air temperature ranges from -3.6°C in January to 18.1°C in July [17].

The measurements consisted in completing a questionnaire containing questions on thermal sensations as well as light intensity assessment. The questions and answers within the questionnaire will be presented in the next section together with the test results. A total of one hundred and fourteen students participated, in various rooms. Figure 1 presents a computer laboratory at the University of Žilina as an example room, where the tests took place.

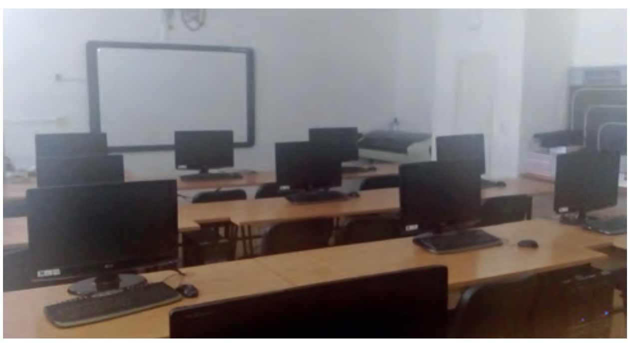

Fig. 1. An example room (computer laboratory) at the University of Žilina

Apart from collecting information about the subjective sensations of the respondents, the measurements of the indoor air parameters took place with the sensors. The measuring devices were located in the centers of the rooms, so that the gathered data could be treated as average values.

3. RESULTS AND DISCUSSION

The study was conducted in autumn, thus the respondents wore mixed clothes. They ranged from summer outfits to thick winter clothing depending on the day. However, within a given group of students occupying a certain room, the diversity in clothing was quite limited and this factor did not influence the results. Moreover, the room users adopted their clothing to the prevailing conditions in the rooms and the equipment present there that might release heat (as in the case of a computer laboratory).

The first question in the questionnaire dealt with the students' assessment on their thermal sensations at that moment of the measurements. They presented their opinions of the indoor thermal environment as "thermal sensation vote" by ticking appropriate boxes in the questionnaire ranging from "too hot" (+3), via "hot" (+2), "warm" (+1) and neutral (0) to negative values – maximally to (-3), which meant "too cold". Figure 2 presents the results of the study as a frequency count of all the answers.

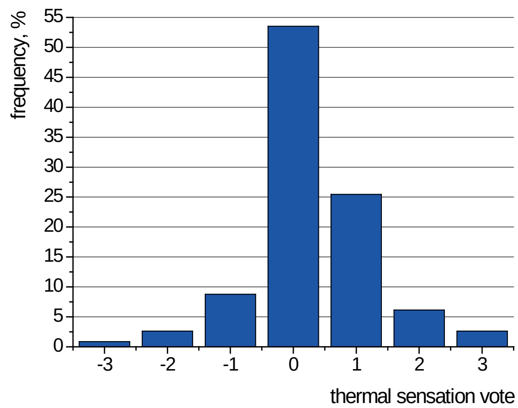

Fig. 2. Assessment of thermal sensations

53.5% of the students felt neutral, while 8.8% and 25.4% were either cool or warm, respectively. Thus, almost 88% of the respondents were generally satisfied with the environment of the rooms. It indicates a high level of satisfaction. Despite this, there were some individuals who expressed strong opinions (values of +3 and -3), however it might have been caused by health conditions, hunger or individual preferences and not necessarily by the thermal environment of the indoor space.

The next question was focused the respondents' willingness to alter the state in the rooms regarding air temperature. The students might have opted for "much warmer" (+2) via "no change" (0) to much cooler (-2) indoor environments. The obtained results have been presented in Figure 3 as the frequency count of the given "thermal preference votes".

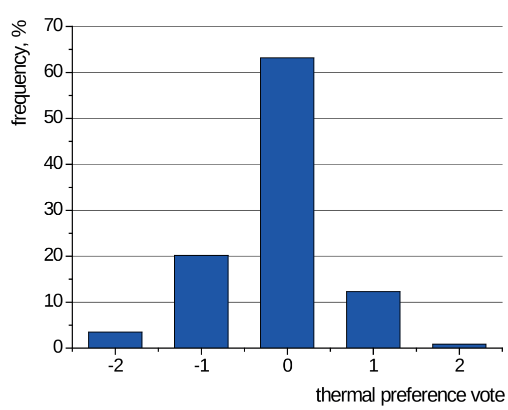

Fig. 3. Assessment of thermal preferences

63.1% of the room users wanted no change to occur in the rooms, which further backs the conclusion that the thermal environment was fine. 20.2% would like the temperature to slightly decrease, while 12.3% – to slightly increase. Both extreme responses of (+2) and (-2) did not exceed 5% of the answers.

The third question dealt with the assessment of lighting conditions. The students were asked how they rated the level of illuminance and could respond that it was acceptable (0), too strong (+1) or too weak (-1). The results have been presented in Figure 4.

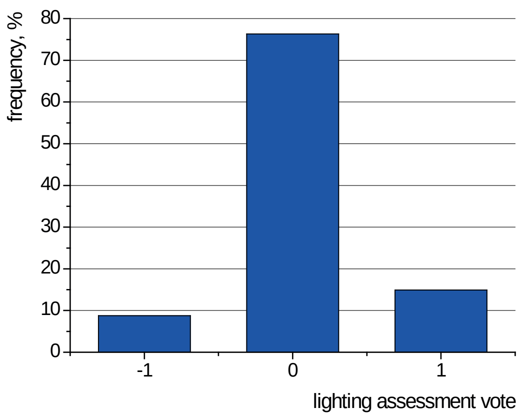

Fig. 4. Assessment of lighting conditions

76.3% of the students thought that the lighting conditions were acceptable. Naturally, it is a subjective assessment only and might be influenced by a number of factors (other than illuminance) such as the location of the light sources in the ceiling, the orientation and size of the windows in the rooms as well as part of the day, tiredness and etc. Nevertheless, this assessment is important in educational and office buildings because it might effect the productivity of the room users.

Apart from the actual testing of human thermal sensations, which is typically conducted with the use of questionnaires, it is equally important to be able to determine people's responses before the building is actually built or to be able to design heating/ventilation systems and their operation in a more user-friendly way. It is done with the view to providing room users with most preferable and comfortable conditions for living or working activities. The most common and widely accepted model of thermal comfort was developed by Fanger [1] and is used in the standard [2] throughout the world. It is able to determine the thermal sensation vote value (denoted as PMV) for a group of people in a room as well as the share of the people who are dissatisfied with the indoor environment (denoted as PPD). The value of PPD can be calculated based on the questionnaires as the ratio of the votes (+3, +2, -2, -3) to the total number of votes. The equations given in [2] have been used to calculated both PMV and PPD for a group of 10 students located in the laboratory (Fig. 1) according to the Fanger model. While the questionnaire answers provided by the students enabled to determine the experimental values of PMV (or TSV as in Figure 2) and PPD. The comparison of the experimental and calculation results has been presented in Figure 5.

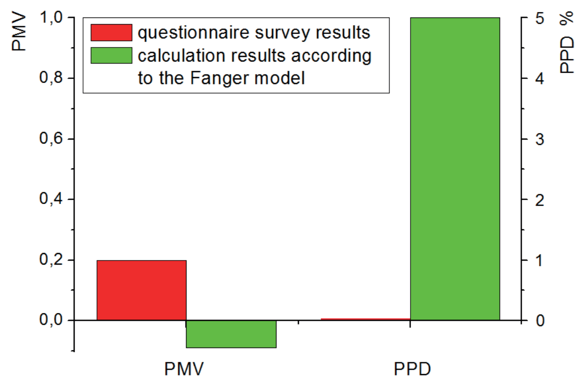

Fig. 5. Comparison of the test results for one room with the calculation results according to the Fanger model

The mean value of thermal sensation vote for the considered room was 0.2 (basing on the questionnaires), while the calculations performed with the equations constituting the Fanger model produced the value of PMV as -0.09. The difference is not significant especially that the scale ranges from -3 to +3. More significant discrepancy can be observed for PPD. The number of the students who were dissatisfied with the environment in the analysed room was 0, while the model calculations led to the value of 5%. Both of these values indicate a positive assessment of thermal comfort in the considered room. It needs to be noted that literature provides examples of much larger discrepancies, if the Fanger model is used. This fact encourages authors to developed their own modifications of the model in order to improve the accuracy of the calculations – as presented in [3, 18].

4. CONCLUSIONS

The study of thermal sensations and lighting conditions in the buildings of the University of Žilina provided new insights into the subjective assessment of the students regarding their indoor environment. It was observed that the respondents were overwhelmingly satisfied with their thermal environment (almost 88% of the responses). Thus, they were not willing to change the indoor air parameters, as indicated by 63.1% of the "no change" option with regard to the thermal preference vote. The lighting conditions were also positively assessed.

The comparison of the experimental results for a selected room (computer laboratory) with the calculation results according to the commonly accepted Fanger model showed differences. It might be related to a small number of students in a given room and the impact of other parameters – not considered in the model calculation methodology such as carbon dioxide concentration.

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