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A STUDY OF THERMAL COMFORT AT KIELCE UNIVERSITY OF TECHNOLOGY

BADANIE KOMFORTU CIEPLNEGO NA POLITECHNICE ŚWIĘTOKRZYSKIEJ

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Abstract

The article presents the research of thermal comfort based on the Fanger model. The research was conducted in three educational rooms. The study involved 98 people whose age is between 19 and 23 years old. The study consisted in measuring the parameters of the thermal environment. During the research, students completed surveys regarding the thermal sensation. On the basis of the research, the predicted mean vote PMV score and the predicted percentage of dissatisfied PPDs were determined. This made it possible to compare the assessment of respondents with those indicated according to the standard, which showed that the Fanger model does not reflect the results of the respondents. The best solution will be to modify the Fanger model.

Keywords: thermal comfort, thermal sensation, room air quality

Streszczenie

W artykule przedstawiono badania komfortu cieplnego na podstawie modelu Fangera. Badania prowadzono w trzech pomieszczeniach edukacyjnych. Wzięło w nich udział 98 osób, których wiek zawiera się w przedziale od 19 do 23 lat. Badanie polegało na zmierzeniu parametrów środowiska termicznego. Podczas wykonywanych badań studenci wypełniali ankiety dotyczące odczucia cieplnego. Na podstawie przeprowadzonych badań określono przewidywaną średnią ocenę PMV oraz przewidywany odsetek osób niezadowolonych PPD. Pozwoliło to na porównanie oceny ankietowanych ze wskazanymi według normy, co pokazało, że model Fangera nie odzwierciedla wyników ankietowanych. Najlepszym rozwiązaniem będzie modyfikacja wzoru Fangera.

Słowa kluczowe: komfort cieplny, odczucia termiczne, jakość powietrza w pomieszczeniu

1. INTRODUCTION

Ensuring adequate thermal comfort is one of the main reasons why we spend most of our time inside buildings. Adequate thermal conditions are key elements for our well-being, health and productivity. Not providing the right conditions can adversely affect our immune system and we start to feel tired. Our efficiency of performed activities will also decrease, which will make us less efficient regardless of whether the work is mental or physical. That is why it is so important to ensure adequate parameters of the air in the room and try to keep them at an appropriate, as far as possible unchanging level.

Thermal comfort is important when designing heating and air conditioning systems. The main purpose of air-conditioning devices is to maintain air parameters within set limits. These include air temperature, air speed, humidity, pressure. Modern available technologies make it possible to construct buildings that ensure precise compliance with these parameters. Well-designed air conditioning improves the comfort of living and also provides friendly working conditions for people staying in a given room.

The key element of feeling thermal comfort is the air temperature. The human body adapts itself at a given moment to the prevailing climatic conditions. It has a wide range of functionality under given conditions, but only in a small climatic range it feels thermal comfort [1]. The adaptation of the air temperature in the room is calculated on the basis of the model developed by Fanger [2]. There is a model in which the thermal comfort is expressed using the Predicted Mean Vote (*PMV*). *PMV* determines the average voting rating in the category on a seven-grade rating scale [3]. The *PMV* index is a function of environmental conditions, which include air temperature, air velocity, humidity, average radiation temperature, metabolic rate and clothing insulation. The Fanger's comfort equation is also associated with the PPD index – the predicted percentage of people dissatisfied with the existing conditions [3]. International standards concerning thermal comfort have also been developed, e.g. ASHRAE 55 [4] and PN EN 16798 [5].

Farraj [6] conducted research on thermal comfort in air-conditioned residential buildings. He compared the Actual Mean Vote – *AMV* with the Predicted Mean Vote – *PMV*. He stated that the ISO 7730 standard for calculating *PMV* does not assess the actual thermal sensation of the person tested in a desert climate. According to Siewa et al. [7], the thermal comfort model should be improved to provide reliable guidance for designers. A similar study was conducted by Ricardo et al. [8], who examined the relationship between *PMV* and Mean Thermal Sensation (MTS) and operating temperature, and found a significant relationship. Arslanoglu and Yigit [9] conducted research in the climate chamber and studied the effect of radiation heat flux on human thermal comfort. They concluded that the respondents felt thermal discomfort because the heat stream caused differences in skin temperatures. They proved that the head is most affected by radiation. Similar conclusions were reached by Atmaca [10], who examined the differences between body segments caused by high radiation temperature and the temperature for the construction of walls and ceiling structures with an impact on thermal comfort. The issues of thermal comfort are inextricably linked to the issue of heat exchange, which was discussed inter alia in [11, 12].

Based on the presented literature review, it can be concluded that Fanger's model does not reflect the actual thermal sensations, because the *PMV* index determined by him is a function of human physical activity, thermal insulation of clothing, temperature, humidity and speed of air movement, and average temperature of ambient radiation. According to Fanger, the *PMV* model does not take into account, for example *BMI* mass index. Therefore, the article verifies this thesis for educational rooms in Kielce, and then a modification of the model will be developed in order to reproduce as accurately as possible the optimal conditions of thermal comfort obtained from the surveys.

2. MATERIAL AND METHOD

The research was conducted at the Kielce University of Technology for three groups. In February, two measurements were made in the Energis building at the Faculty of Environmental, Geomatic and Energy Engineering, and the outside temperature was 1°C. And at the beginning of March one measurement was made in building C at the Faculty of Management and Computer Modeling and the outside temperature was equal to 3°C. The test consisted of measuring parameters such as air temperature, air velocity, average

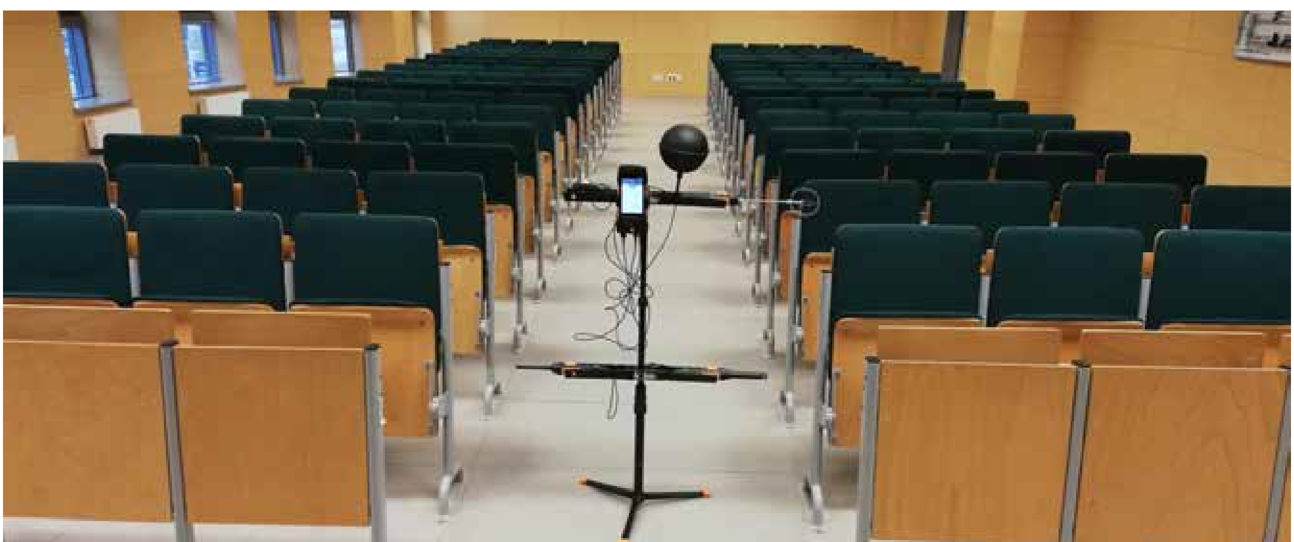

Fig. 1. Data acquisition device on the tripod

environment

radiation temperature, black sphere temperature, relative humidity of air and air velocity, and light intensity. The microclimate meter was used to measure these parameters, which is shown in Figure 1.

During the measurements, people in the room completed a survey on the characteristics of the thermal sensations of the microclimate and what outfit they are currently wearing. On this basis, the type of clothing was averaged and the clothing insulation level was determined by adding the thermal resistance of the office chair (0.1 clo). Respondents marked the type of physical activity during 30 minutes before coming to the room where the measurement was taken. If you answered: intensive effort, such a survey was rejected due to the likelihood of disturbed thermal sensations due to increased metabolism. The rest of the answers related to this question were taken into account. When asked about the current state of health, when the respondent marked the answer "yes", such a survey was canceled because the thermal sensations of the sick are not meaningful. Each survey had a record at the end, which provided information on the sex, age and weight of the person surveyed.

Based on the program on the website [13], the *PMV* and *PPD* index were determined. This made it possible to compare the assessment of respondents with those indicated according to the standard. An important element was the question about current thermal sensations on a seven-point scale (from –3 "too cold" to +3 "too hot").

3. RESULTS

98 people took part in the study, of which 39 questionnaires were rejected, 13 because of marking the "yes" answer to the question of whether they are ill, and 26 because of averaging the isolation of clothing, so 59 questionnaires were considered for further analysis, including 33 women and 26 men. The study involved young people, whose age is between 19 and 23 years old. After the analysis of the studies, the results from the questionnaires were compared with the results from the website [13].

3.1. Comparison of the Fanger model for PMV and PPD

Based on the research, graphically presented the opinions of the respondents with the Predicted Mean Vote (*PMV*), based on the standard. The results of tests for three rooms are presented below, comparing the Fanger model with the results based on surveys in Figure 2.

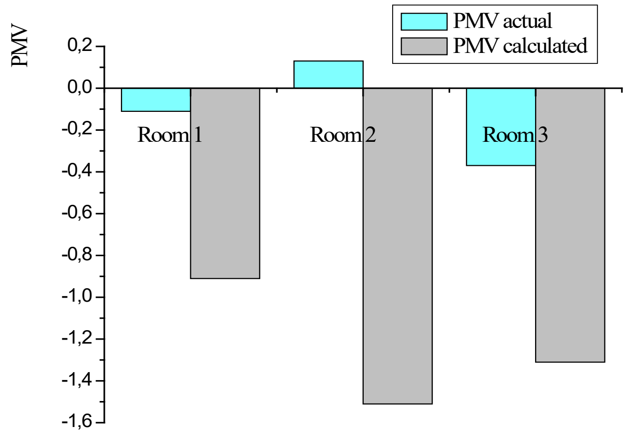

Fig. 2. Comparison of actual test results and calculations according to the Fanger model for PMV

The graph shows that there is a significant discrepancy between the calculation results according to the Fanger model and the results developed on the basis of surveys. Analyzing the figure above, it can be seen that the Fanger model does not correctly map the actual thermal sensations of the subjects. This means that when assessing the microclimate in these rooms, standard guidelines would not be meaningful. By the shape of the bars, it can be seen that on average these values differ by 1. Then the percentage of dissatisfied PPD was compared according to the opinions of the respondents and based on the Fanger model. Figure 3 presents this relationship.

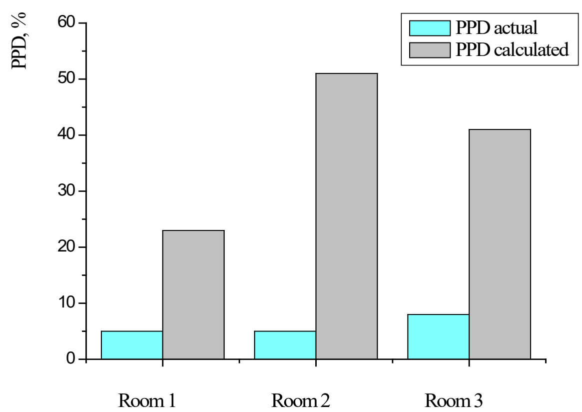

Fig. 3. Comparison of actual test results and calculations according to the Fanger model for PPD

The above figure illustrates how PPD [%] calculated on the basis of the standard [13] and determined from surveys is presented. According to this figure, it can be seen that the values of the predicted percentage of dissatisfied people do not coincide with the Fanger model.

3.2. The effect of BMI on the PMV formula

The *BMI* mass index was calculated on the basis of formula (1), which is the quotient of weight and height, which respondents entered in the metric. Figure 4 illustrates its impact on the feeling of thermal comfort in a given facility.

$$BMI = \frac{weight[kg]}{height^2[m^2]} \tag{1}$$

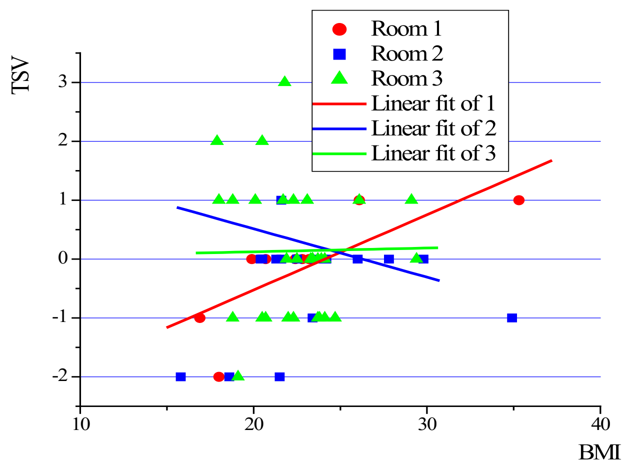

Fig. 4. Influence of BMI factor on TSV (Thermal Sensation Vote)

From Figure 4 there is no special relationship that the subjects in these conditions with a lower *BMI* prefer a higher temperature. It can be seen that the respondents did not give a clear picture of the dependence of TSV on the *BMI* mass index. To observe if *BMI* affects TSV, more tests should be performed.

3.3. Voting on the thermal impression

Figure 5 shows the thermal impression, which is expressed as TSV, with TSV values based on the seven-point ASHRAE scale [4].

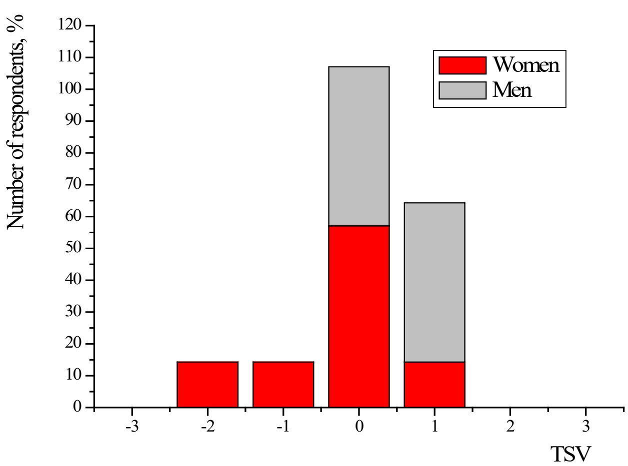

Fig. 5. Frequency distribution of Thermal Sensation Vote (TSV)

Analyzing the responses of the respondents, it can be seen that the largest percentage of people voted for a comfortable thermal sensation (0), 50% men and 57% women. Women dissatisfied with the room conditions are 15%. No man on the set scale is dissatisfied with the conditions. The room is pleasantly warm (+1) for 15% of women and 50% of men, and 15% of women think that the room is pleasantly cool. The next figure shows the dependence of thermal voting on preferences.

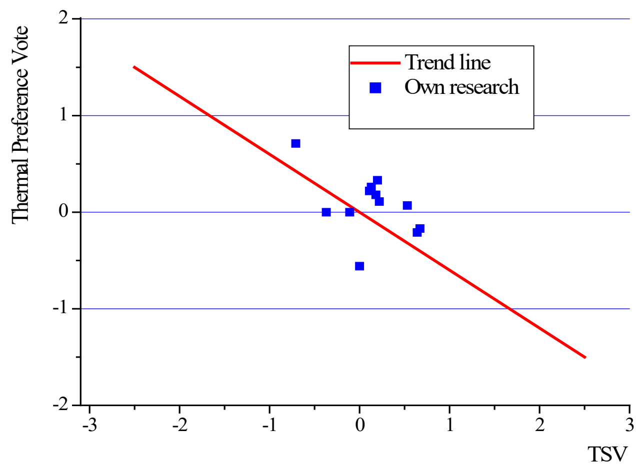

Fig. 6. TSV dependence on thermal preference vote

From the above points marked on the graph, it appears that the respondents are satisfied with the room temperature. Only individuals would like the room to be warmer.

3.4. New model

The Fanger model is expressed using the predicted mean vote (*PMV*). The *PMV* index was calculated according to the formula [3]:

$$\begin{aligned} PMV = {} & [0.303 \cdot exp \cdot (-0.036 \cdot M) + 0.028] \cdot \\ & \{(M-W) - 3.05 \cdot 10^{(-3)} \cdot [5733 - 6.99 \cdot (M-W) - \\ & p_a] - 0.42 \cdot [(M-W) - 58.15] - 1.7 \cdot 10^{(-5)} \cdot \\ & M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) - \\ & 3.96 \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - \\ & f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\} \end{aligned} \tag{2}$$

where:
M – metabolic rate [W/m^2];
W – effective mechanical power [W/m^2];
I_{cl} – thermal insulation of clothing [m^{2}K/W];
t_a – air temperature [°C];
$\bar{t}_r$ – average radiation temperature [°C];
p_a – partial pressure of water vapour [Pa];
t_{cl} – surface temperature of clothing [°C].
1 unit of metabolism = 1 met = 58.2 W/m^2,

1 clothing thermal insulation unit = 1 clo = 0.155 $m^2°C/W$.

Referring to Figure 2, it can be seen that formula (2) based on the Fanger's model does not correctly reproduce real test results. It is necessary to modify formula (2). The new formula after modification is presented below:

$$\begin{aligned} PMV = {} & [0.303 \cdot exp \cdot (-0.036 \cdot M) + \\ & 0.028] \cdot \{(M - W) - 3.05 \cdot 10^{(-3)} \cdot \\ & [5733 - 6.99 \cdot (M - W) - p_a] - \\ & 0.42 \cdot [(M - W) - 58.15] - 1.7 \cdot 10^{(-5)} \cdot \\ & M \cdot (5867 - p_a) - 0.0014 \cdot M \cdot (34 - t_a) - \\ & 3.96 \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - \\ & f_{cl} \cdot h_c \cdot (t_{cl} - t_a)\} \cdot (-0.0098) \cdot BMI \end{aligned} \quad (3)$$

Equation (2) has been extended by the product (– 0.0098) · *BMI*, which influenced the approximation of test results to the trend line. Below is Figure 7, which shows the modification of the Fanger formula taking into account the *BMI*. The green points are the test results (from surveys and calculations according to the Fanger's formula), while the black points are the results after modification of the formula (3). The red trend line means 100% compliance with the model.

From the above chart, you can see a significant improvement in pattern modification. However, you should look for another parameter, e.g. CO_2, which will improve the model, or the addition of CO_2 + *BMI* together.

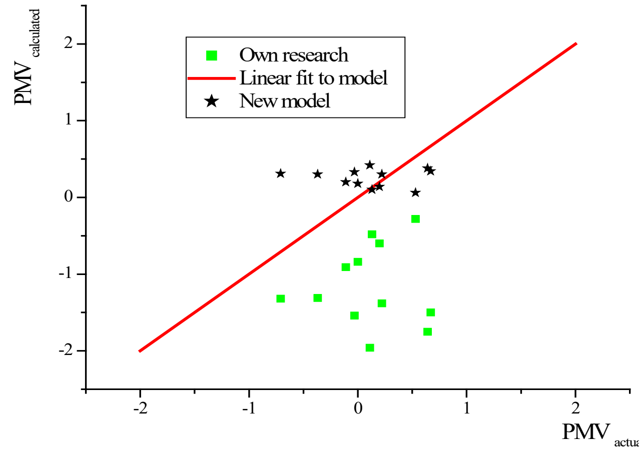

Fig. 7. Modification of the Fanger model

4. SUMMARY AND CONCLUSIONS

Based on the research, it can be concluded that the standard guidelines for the calculation of thermal comfort in terms of the predicted mean vote *PMV* and the predicted percentage of dissatisfied PPD are not reflected in the assessment of the respondents. There was also no clear correlation between the impact of *BMI* on *PMV*. The best solution is to modify the Fanger formula by finding another parameter, e.g. CO_2, or adding CO_2 + *BMI* together. It is important that in school buildings, the rooms have adequate thermal conditions, because failure to provide such conditions is tiring on the body, and thus on thought functions. Detailed analysis of thermal comfort including statistical analysis will be carried out in a separate article, after expanding the experimental base.

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