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EVALUATING THE NEED FOR A NEW DESIGNING PROCEDURE FOR THE DEFINITION OF COMBINED LOCAL DISCOMFORT PARAMETERS

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Abstract: The paper outlines the difficulties that are faced when designing indoor environments according to the requirements set by standards. The effect of warm/cold floors is not considered directly when calculating temperature radiation asymmetry in closed spaces. Furthermore, the simultaneous presence of warm floor and cold wall/window surfaces is not included in the calculation methods; no data is available about the percentage of dissatisfied in such environments. Through the description of thermal manikin, human subject experiments and computer simulation the methodology for obtaining new mathematical relationship is introduced for multiple exposures to warm floors and cold wall surfaces.

Keywords: *combined effect, local discomfort, radiant asymmetry, warm floor*

1. INTRODUCTION

Thermal comfort is that condition of mind, which expresses satisfaction with the indoor thermal environment. Thus, by nature it is a subjective, individual matter. The task of the building service engineer is to provide the occupants with such thermal environments that would result in least number of dissatisfied people. Since 1970s, extensive research work was conducted in Scandinavia and North-America in order to create the relationship between human subjective thermal comfort and the objective temperature conditions. Human subject experiments were conducted by Fanger, his colleagues and other researchers to obtain statistically significant number of human opinions (votes) with which the prediction of thermal comfort votes and dissatisfied could be done accurately for indoor spaces that are only at a design stage. Later these findings were inserted in several standards that are in force in most EU countries, e.g. in Hungary.

The main thermal comfort standard is the ISO 7730 [1] that is based on the indices worked out by Fanger (1970) [2], i.e. the predicted mean vote (PMV) – predicted percentage of dissatisfied (PPD). These indices express the cold and warm discomfort for the body as a whole (general, whole-body thermal comfort). The model is mostly applicable for sedentary people carrying out office work. Field studies summarized by de Dear and Brager [3] showed that PMV-PPD model closely approximates occupant thermal comfort in buildings that have central HVAC systems installed.

Persons with light sedentary activity may be dissatisfied not only because of cold/warm discomfort for the body as a whole, but by unwanted cooling/heating of one particular part of the body. This effect is called local thermal discomfort. Four parameters can be distinguished, namely draught, vertical air temperature difference, radiant temperature asymmetry and warm/cold floors. The criteria for these parameters regarding comfort are set in another internationally accepted standard, the CEN CR 1752 [4]. Studies that were carried out in order to create the criteria set in the standard were conducted with thermally neutral subjects who were only exposed to the parameter in question. This shows the lack of information on simultaneous exposure to several local discomfort parameters (Toftum, 2002 [5]). Furthermore, currently there is no method for calculating the combined percentages dissatisfied when two or more parameters are present. It is unknown if the percentages of dissatisfied due to general thermal discomfort and local discomfort are additive or another operation would be necessary (Olesen et al., 2002 [6]).

2. RADIANT TEMPERATURE ASYMMETRY AND WARM FLOOR

By definition radiant temperature asymmetry is the temperature difference between the plane radiant temperature of the two opposite sides of a small plane element (CEN CR 1752). In Eq. 1 Δt_{pr} represents the radiant temperature asymmetry, while t_{pr1}, t_{pr2} are the plane radiant temperatures on the two sides of the small plane element:

$$\Delta t_{pr} = t_{pr1} - t_{pr2} \tag{1}$$

According to the standard, people are most sensitive to asymmetry caused by warm ceilings and cold walls (windows), however, radiant asymmetry is seldom a problem in air-conditioned spaces, only if big window surfaces are present. Direct sunshine should also be avoided in the occupied zone in order to reduce asymmetry.

The effect of radiant temperature asymmetry on local discomfort is described as a function of percentage of dissatisfied people on Figure 1. The curves have been worked out by using results of numerous human subject experiments.

The standard categorizes the requirements for different qualities regarding local discomfort. Three categories exist; A, B and C, and the permitted asymmetries for each can be seen in Table 1.

It has to be noted for the figure and table that no direct requirement is set for the radiation effect of the warm/cooled floor; it is only indirectly present in the plane radiant temperatures.

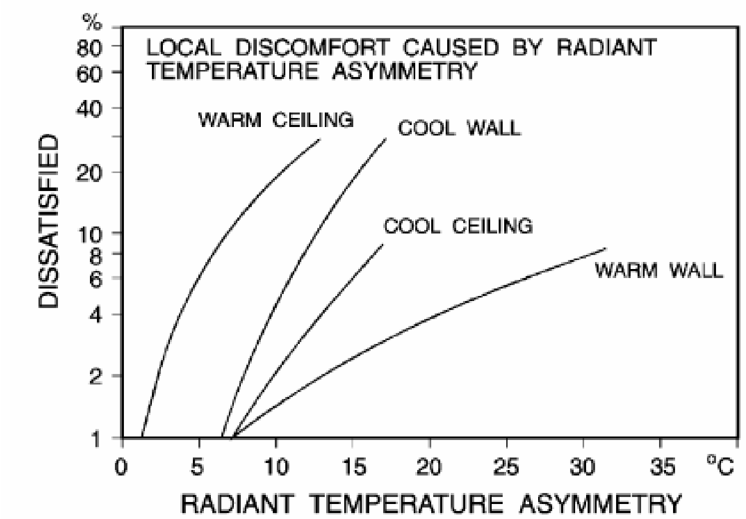

Fig.1. Local thermal discomfort caused by radiant asymmetry

Category	Radiant temperature asymmetry [°C]			
	Warm ceiling	Cold wall	Cold ceiling	Warm wall
A	<5	<10	<14	<23
B	<5	<10	<14	<23
C	<7	<13	<18	<35

Table.1. Permissible radiant temperature asymmetries for three categories

Standard CEN CR 1752 sets the requirements for floor temperatures as well. Figure 2. shows the relationship between warm/cool floor temperatures and the predicted percentage of dissatisfied.

Table 2. contains the permissible floor temperature ranges for the three categories, furthermore, includes the maximum percentage of dissatisfied allowed in each category.

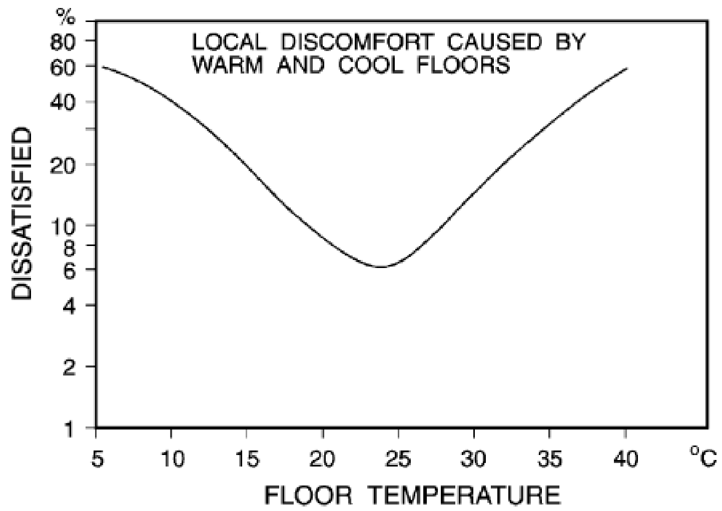

Fig.2. Local thermal discomfort caused by warm/cool floors

Category	Permissible floor temperature ranges (°C)	PPD caused by warm and cold floors (%)
A	19-29	<10
B	19-29	<10
C	17-31	<15

Table.2. Permissible floor temperatures and limits of PPD for three categories

The standard has the following remarks regarding the effect of floor temperature on human thermal comfort:

- Too warm and too cold floor may cause the occupants to feel uncomfortable due to warm or cold feet.
- In case occupants are wearing light indoor shoes, it is the temperature and not the material of the flooring that is of importance.
- When applying displacement ventilation floor surfaces may cool down that can cause discomfort.
- Warm floors seldom cause discomfort problems in the case o fair-conditioned spaces.

- Floor temperature higher than 26°C should be avoided in most cases.

After the review of both discomfort parameters it is important to note the standard gives guideline values for the calculation of radiant temperature asymmetry due to cold/warm walls or ceilings, but the effect of radiation caused by the floor on asymmetry is not considered.

Furthermore, little data is available on how the relationship between floor temperatures and predicted percentage of dissatisfied have been worked out. It is also yet unknown how the presence of these discomfort parameters affects human thermal comfort.

For this reason extensive research is conducted about the combined effect of radiant temperature asymmetry due to cold walls and warm floors on human thermal comfort. The aim is to create the mathematical relationship between the two local discomfort parameters and the predicted percentage of dissatisfied which later could be used for more accurate sizing of indoor spaces.

3. HOW TO OBTAIN NEW DESIGN VALUES

Creating new relationship between two local discomfort parameters and percentage of dissatisfied people consists of three distinct steps in this research.

First, objective heat loss data are collected via the use of a thermal manikin in a climatic chamber. Secondly, subjective data (thermal comfort and sensation votes) are collected in the same climatic chamber for the same conditions from human subjects. Thirdly, obtained heat loss values are verified through computational fluid dynamics modelling. After these three steps, a mathematical model is created for the evaluation of subjective comfort in a given space where the two local discomfort parameters in question are present.

The thermal manikin and human subject measurements are carried out in a 3,8 m (L) x 3,1 m (W) x 2,5 m (H) climatic chamber (Figure 3.) that is located within a room, thus being sealed from outdoor conditions. The chamber's walls and floor can be heated by circulating water. The circulating water temperature can be controlled in order to provide the required surface temperatures. Throughout the experiments one of the walls is cooled and the floor is heated to certain temperature combinations. Numerous thermocouples fixed on the surfaces measure surface temperatures that are registered in a data logger. Air temperatures are registered as well.

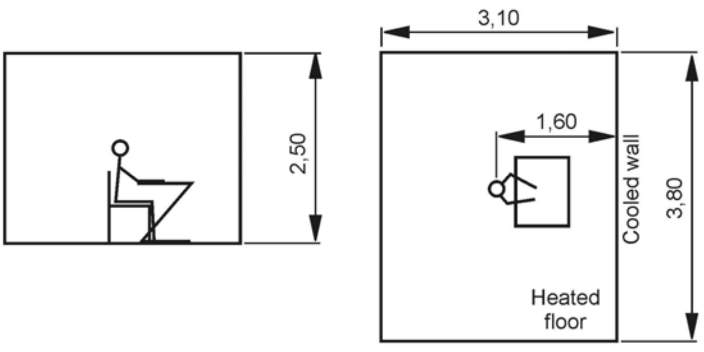

Fig.3. Parameters of the chamber and the position of the thermal manikin facing the cooled wall

The thermal manikin is seated within this chamber (Figure 4.) at a desk, facing the cooled wall. It is dressed so that the clothing insulation of the garments is as required for the experiment. The manikin is an average-sized male with 18841 cm^2 of total surface area. It is divided into 18 segments; the segments cannot be controlled separately and the manikin's software can only work in 'heating to a fixed set point' mode. Throughout exposures the heat loss and the equivalent homogenous temperature (EHT) of each body segment is registered. Data from the manikin are logged every two minutes.

From the received data the difference between the heat loss values of segments can be observed for different surface temperature combinations and the most affected areas can be located.

Fig.4. Thermal manikin seated in the climatic chamber

Thermal manikin experiments have already been conducted for this current research. Two comfort environments with uniform temperatures (air and surface temperatures being equal) and eight different surface temperature combinations were tested with a thermal manikin (Table 1). Throughout condition 1 to 8 air temperature was tried to be kept close to 23°C, so that comparison to the uniform 23°C environment would be possible.

	Cond. 1	Cond. 2	Cond. 3	Cond. 4	Cond. 5	Cond. 6	Cond. 7	Cond. 8	Base 1	Base 2
Cooled wall temp. (°C)	16	16	16	16	18	18	18	18	20	23
Heated floor temperature (°C)	20	23	26	29	20	23	26	29	20	23

Table.3. Examined surface temperature conditions

Results from the manikin experiment helped to select the body parts that are most probably affected by the asymmetric environment by obtaining heat loss values for each body section. These are the hands, head, lower leg and feet. The most extreme conditions (e.g. Condition 4), clearly showed the combined effect of cold wall and warm floor. Even though air temperatures were higher compared to the base air temperature, the heat loss of the left and right hand remained higher. This could only be due to the cold wall surface. Furthermore, the heat loss values of the lower leg and feet were lower compared to the base. The magnitude of this heat loss difference mainly was caused by the 29°C floor temperature.

By examining different temperature conditions with the manikin results, temperatures could be selected that should be examined by a human subject experiment for possible cause of dissatisfaction with the environment. Sensation and comfort votes of human subjects can be used to create the relationship between the objectively measured heat losses and human sensation of comfort [7].

Human subject experiments are to be conducted with 20 participants in order to be able to receive statistically significant results and so that obtained results could be generalized for a greater population. The 20 subjects are collage age students, healthy, not suffering from any illnesses that would affect their thermal sensation. During the experiment two environmental conditions are tested that are the same as for the manikin measurements.

Two subjects are seated in the climatic chamber for one session that lasts for 3 hours. During the session subjects are asked to fill in subjective perception, evaluation and preference scales, as well as acceptability scales. In addition they are asked about their local thermal sensation for each body part. In addition to the subjective questions objective physiological measurements are carried out. Skin surface temperature is measured at several points of the body and blood pressure is also registered. These two measurements may be linked to the sensation votes of the subjects afterwards. So that the session in the chamber would not be much different to real life office environment, subjects are asked to carry out simulated office work that consists of proof reading and addition.

After the evaluation of the subjective and objective physiological results with statistical analysis, the effect of combined exposure to two local discomfort parameters can be studied. Based on the results the effect of local discomfort parameters can be described mathematically.

In order to verify obtained data from the manikin and human subject experiments computer simulations have to be made via the use of computational fluid dynamics. The model of the chamber is created in the program environment and numerical equations are used for the description of heat exchange due to radiation between the surfaces and the manikin/human body. Results are then compared with the results of actual measurements. In addition, based on the mathematical description of thermal sensation votes for the combined exposure, simulation can be made for general indoor spaces.

4. CONCLUSION

Combined effect of two local discomfort parameters has to be studied as currently no data is available about acceptability of such comfort spaces. It is not known whether the two parameters strengthen the sensation of discomfort or they suppress each other. New sizing values may be obtained by following the described experimental methodology: measurements with thermal manikin for obtaining heat loss values for different body parts, experiments with human subjects in order to acquire subjective sensation and acceptability votes and computer simulations for the verification of obtained results. Finally, creating mathematical relationship for the calculation of predicted percentage of dissatisfied for general utilisation in practice.

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