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OBJECTIVE AND SUBJECTIVE EXPERIMENTS FOR THE INVESTIGATION OF COMBINED EFFECT OF TWO LOCAL DISCOMFORT PARAMETERS

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***Abstract**:*
Today’s requirements for energy saving and energy efficiency lead to the development and spreading of low temperature heating and high temperature cooling systems that affect the occupant’s heat exchange with his surroundings via radiation. With regards to such systems, the combined effect of two local discomfort parameters is studied in this paper, namely radiation temperature asymmetry and warm floors. Currently available standards deal with these parameters separately and no data are available on how many people are dissatisfied due to multiple exposures. The paper summarizes the results of two separate climate chamber experiments: one with a thermal manikin and an other with human subjects that are simultaneously exposed to cold wall and warm floor.

1. Introduction

Energy efficiency is becoming a concern of the building industry lately. Energy efficiency has to be reached for different types of buildings: for new commercial and office buildings, which often have extensive glass facades, for family houses and for buildings that are under renovation processes. Recently, low temperature heating and cooling systems are becoming more and more popular in the case of newly built buildings. These systems should use as much renewable energy (solar, heat gains from room equipment and from occupants) as possible, thus satisfying the demand for energy saving. These systems all work via radiation, and it is a question whether local discomfort parameters will be of concern or not.

The terminology of thermal comfort and local discomfort is only around since the middle of the 1900’s. It has been most extensively investigated and described by Fanger et al. By definition thermal comfort is that condition of mind, which expresses satisfaction with the indoor thermal environment (CEN CR 1752). 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.

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 an internationally accepted standard, the CEN CR 1752. 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). Furthermore, currently there is no method for calculating the combined percentages dissatisfied when two or more parameters are present.

The aim of this paper is to present the methodology and results of two climate chamber experiments in which the simultaneous exposure to two local discomfort parameters, namely warm floor and a cooled wall, was studied. In the first set of measurements, the heat loss data of a thermal manikin have been collected, while in the second set of experiments human subjects were exposed to the thermally asymmetric environment.

2. Methods

Measurements were carried out in a 3,8 m (L) x 3,1 m (W) x 2,5 m (H) climatic chamber that is located in 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. One of the walls was cooled and the floor was heated during the experiments.

Surface temperatures were registered on each wall and the floor by using Fe-Co thermocouples. Twelve thermocouples were fixed on the cooled wall; sixteen on the heated floor and the temperature of the other walls were measured in three points respectively. Data were collected and saved in a data logger. The air temperature was also measured at three heights (0.1 m, 0.6 m and 1.0 m) by thermocouples.

2.1 Thermal manikin experiments

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. The manikin was seated in front of a desk facing the cooled wall, in the middle of the chamber (Figure 1.). (Barna E, Bánhidi, 2008a)

Table 1. *Examined surface temperature conditions*

	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

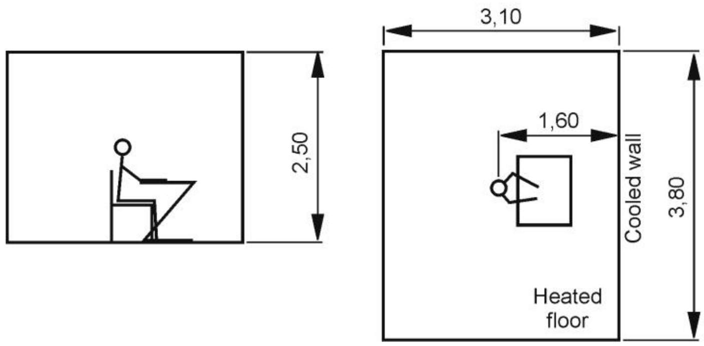

Figure 1. Experimental setup (side view – top view);

position of the manikin compared to the cooled wall

The manikin used in the experiment 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 could be registered. The manikin was wearing a clothing ensemble that had a clo value equal to 1.

Data were collected from the manikin every 2 minutes after steady-state condition was reached, and average heat-loss and EHT was calculated from 30 to 45 data (covering 60 to 90 minute periods).

For the present study, heat loss data from the manikin’s different body parts were used. The measured values for condition 1 - condition 8 were compared with the values of base measurement 1 and 2.

2.2 Human subject experiments

Two asymmetric environments were tested with the human subject experiment (Table 2.). Air temperature was maintained at 23°C The experiment was 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 conditions and participants had balance order of presentation. The 20 subjects were collage age students, healthy, not suffering from any illnesses that would affect their thermal sensation. (Barna E, Bánhidi, 2008b)

Table 2. Human subject experiment's design

Week 1	Week 2	Week 3	Week 4
15°C wall	18°C wall	18°C wall	15°C wall
28°C floor	28°C floor	28°C floor	28°C floor
10 prs (1-10)	10 prs (11-20)	10 prs (1-10)	10 prs (11-20)

Two subjects were seated in the climatic chamber for one session that lasted for 3 hours. During the session subjects were asked to fill in subjective perception, evaluation and preference scales, as well as acceptability scales (Figure 2.). In addition, they were asked about their local thermal sensation for each body part. Besides the subjective questions, objective physiological measurements were carried out. Skin surface temperature was measured at 18 points of the body and blood pressure was also registered three times throughout the session. Based on earlier findings, the two physiological 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 were asked to carry out simulated office work that consisted of proof reading and two-digit addition.

Data was analysed by using SPSS software.

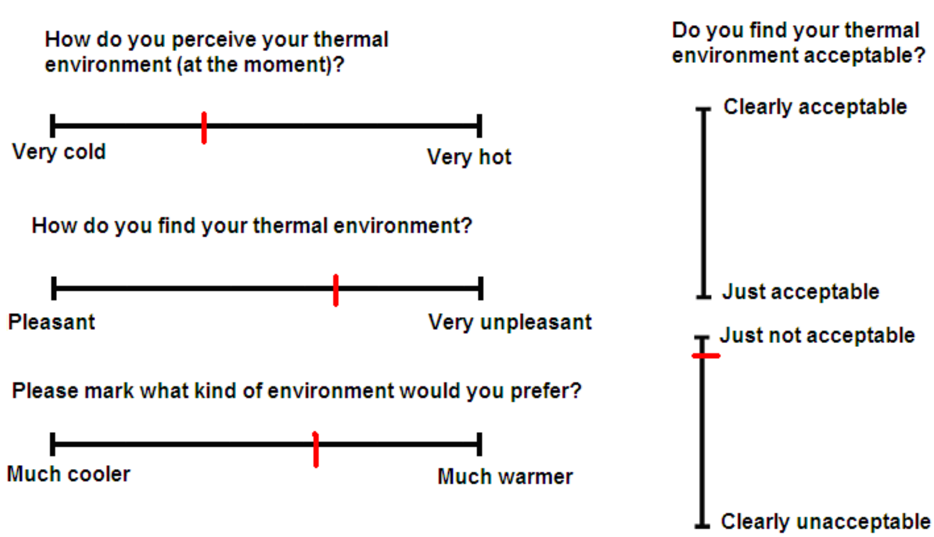

Figure 2. Applied subjective scales

3. Results and discussion

Comparisons were made for the heat losses of body sections between Base 1, 2 (uniform environments) and the 8 different asymmetric conditions (See Table 1).

Figure 3. summarizes measurement results for cases when the floor temperature was kept 23°C and wall temperatures were set to 16°C and 18°C (Condition 2 and 6). The measured heat losses were compared to the uniform 23°C environment. Heat loss values were highest, between 70-90 W/m^2, for the following body parts: Face, Head, Left and Right hands. Compared to the heat losses in the uniform environment, in the case of 18°C wall, a 10 W/m^2 increase could be observed, while for the 16°C wall an approximately 15-20 W/m^2 increase could be registered for the head and hand regions. The lower leg region had higher, between 50-70 W/m2 heat loss values compared to the upper body parts.

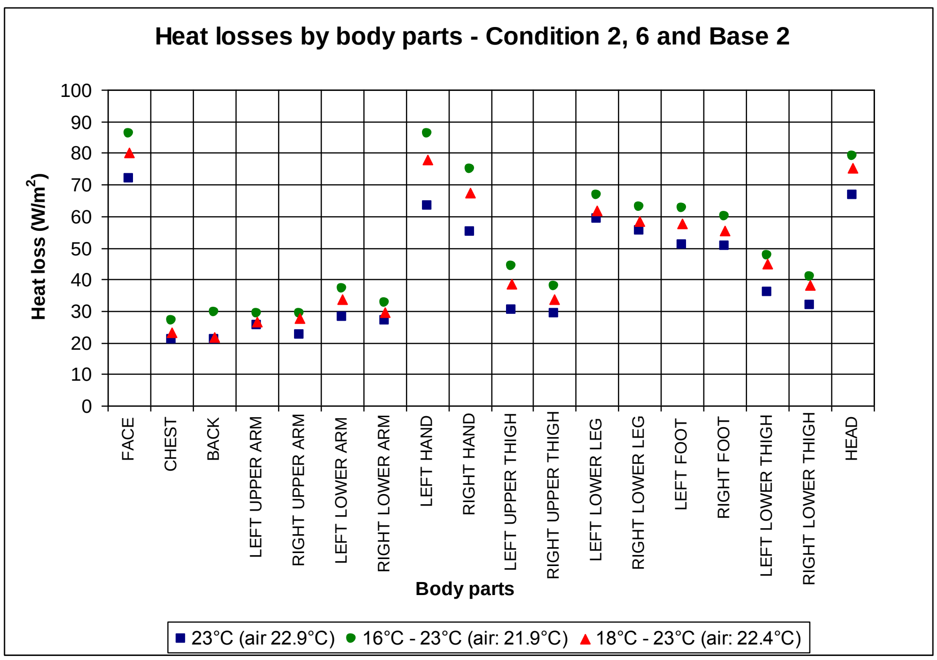

Figure 3. Comparison of body section heat loss values between uniform environment (Base 2), and Condition 2 and 6

Figure 4. shows an example for the investigation of the effect of different floor temperatures. Heat losses, when the wall temperature was set to 16°C, were compared with the 23°C uniform environment.

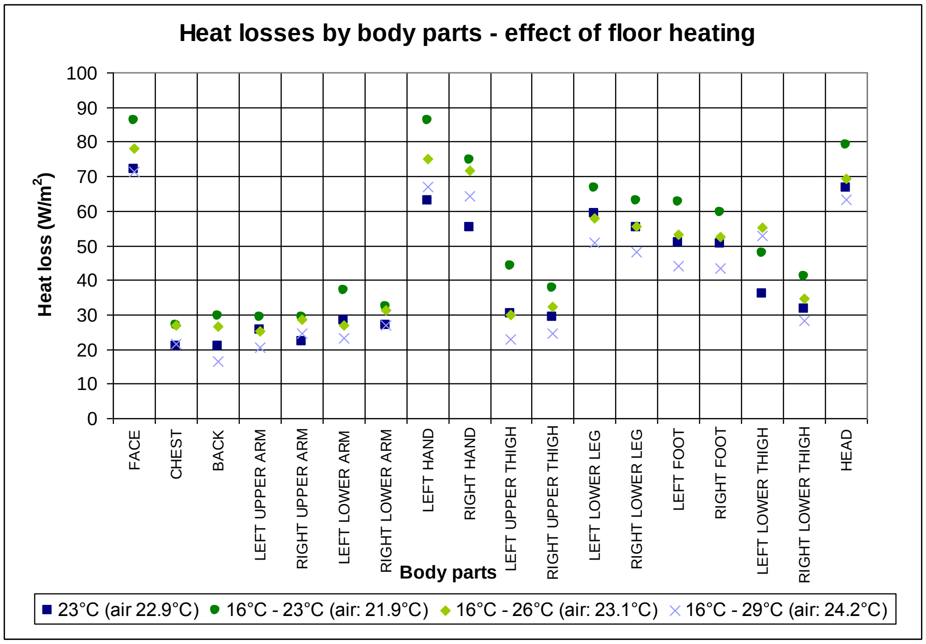

Figure 4. Comparison of body section heat loss values between uniform environment (Base 2), and Condition 2, 3 and 4

Findings of the thermal manikin experiments 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. Furthermore, the investigation helped in finding those temperature combinations that were worth testing for unacceptability or comfort in the human subject experiments: 16°C – 18°C wall temperatures, 28°C floor temperature.

Results of the statistical analysis show that there were no significant differences between the examined temperature combinations, namely 16°C wall – 28°C floor and 18°C wall – 28°C floor. As only these two conditions have been tested no comparison can be made to a more uniform e.g. 23°C operative temperature.

However, it was found that the condition with 16°C wall had a trend showing lower measured skin temperatures compared to the 18°C condition. Figure 5. gives an example for the trend behaviour: the figures show the measured skin temperatures of subjects' right foot for the colder condition (left picture) and the condition with 18°C (right picture). The three-three columns stand for the three measurements throughout the session (before, during and after session).

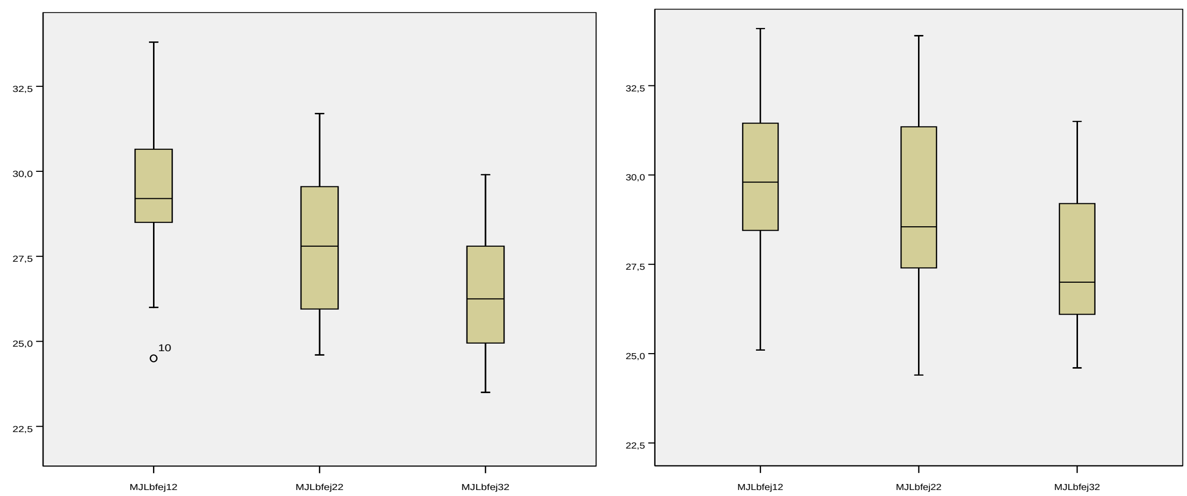

Figure 5. Example for the trend behaviour of the conditions with 16°C (left) and 18°C (right) wall temperatures

It can be seen from the previous figures that the change of skin temperatures were significant between the beginning and the end of the sessions. This was true for both temperature conditions, however changes were bigger in the case of 16°C wall and 28°C floor temperature.

Between the beginning and the end of the sessions the temperature of the following body parts significantly decreased: left-right lower leg, left-right ankle, left-right feet. At the same time the following body parts showed significantly increased temperatures: left-right cheek, left and right ears, chest and the back of the neck.

It is interesting that in spite of the floor heating 28°C how the temperatures of the lower body parts decreased. This can be due on one hand to the radiation effect of the wall as it was less than 1 m away from the subjects and on the other hand to the sitting posture. The body tried to concentrate the heat it produced to the chest and head area. It also has to be mentioned that the hands' temperature hasn't decreased significantly.

As for the subjective votes the following body parts (Table 3.) showed significant decrease in the sensation votes for both conditions: In all cases the votes decrease to (-1) – slightly cool.

Table 3. Significant subjective thermal sensation votes

16°C wall – 28°C floor	18°C wall – 28°C floor
left-right hands	left-right hands
left-right ankles	left-right ankles
left foot	left foot

left-right upper arms	right foot
Left-right lower arms	Chest
Left-right feet	

It was found that there are no good correlations between the measured skin temperatures and the subjective thermal sensation votes. Mostly the sessions' first measurements and votes showed strongest correlations.

4. Conclusions

The paper introduces two approaches that were applied for the investigation of combined effects of two local discomfort parameters, namely thermal manikin measurements and human subject experiments. Manikin measurements resulted in obtaining heat loss values for various body parts. With the help of the measurement the most sensitive body parts and temperature combinations that should be investigated could be chosen. Human subject experiments showed that floor heating have not got impact on skin temperature and thermal sensation when a cool wall is present.

5. Future work

The obtained results show that further work is needed so that the heat loss values from the manikin could be related to the human subject experimental results. Besides, computer simulations are planned for the verification of results and for creating a new mathematical relationship between combined effect of two local discomfort parameters and percentage of dissatisfied people.

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