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Combined effect of the local discomfort parameters – research methodology

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Abstract:
The relation between human beings and buildings is continuously re-evaluated, due to the continuous evolution and new findings in ergonomics, psychology and other research fields, as well as due to the high number of influencing parameters. One of the main conditions of human comfort is the achievement of the thermal comfort. The most widely used mathematical model describing the human thermal comfort is the PMV model. The local discomfort parameters are complementary to the PMV model. The separate effect of the discomfort parameters are known, but their combined effect is unknown. The purpose of this paper is to present the preliminary findings of a research which analyses the human response to the combined effect of the draught and the hot wall. The measurements were conducted at the Budapest University of Technology and Economics

Department of Building Services and Process Engineering in the Macskásy thermal comfort chamber. The results of the paper are as follows: the presentation of the measured parameter groups which influence the thermal comfort; the evaluation of the thermal comfort under various draught and hot wall conditions; the presentation of the methodology for evaluating the human response on the combined effect of the hot wall and the draught.

Keywords: *Thermal comfort, Draught, Radiant thermal asymmetry, Local discomfort parameters*

1 Introduction

Public buildings make up a considerable part of the Hungarian building stock and the rate of these buildings has significantly increased in the last years (office buildings, for example). These buildings are often light-structured. In these cases, the two basic requirements of the interior spaces – the thermal comfort and the reduction of the energy consumption – are hard to combine because of their opposite character.

The most widely used model for the evaluation of the thermal comfort in indoor spaces is the PMV-PPD method, which is included in most of the thermal comfort standards (ISO 7730, CR 1752, EN 15251). The addition of the method consists in the local discomfort parameters. Evaluation methods and diagrams showing the separate effect of these local discomfort parameters on the thermal comfort are available (L. Kajtár, 2000), but in reality their effects appear simultaneously.

This paper presents the preliminary findings of an ongoing research during which we intend to evaluate the combined effect of the draught and the radiant thermal asymmetry in office buildings. The workers' productivity can be greatly affected by the unpleasant combined effect of the local discomfort parameters.

A research project in this field was conducted by Edit Barna (Barna E., 2012), whereby she analyzed the combined effect of the hot floor and the radiant thermal asymmetry. However, in the whole research field there is no mathematical equation which would help evaluate the combined effect of the radiant thermal asymmetry and the draught. In order to find such an equation, human experiments are absolutely necessary.

This paper sets the following goals: determining which parameter groups should be examined with human experiments, presenting the evaluation of the thermal comfort and the distributions of the parameters which influence and characterize the thermal comfort in the comfort chamber, as well as presenting the methodology of the human measurement which will link the measured data to the thermal comfort values.

2 Methods

The measurements were conducted at the Budapest University of Technology and Economics, in the Building Service Engineering and Process Engineering Department's comfort chamber. Our goal was to establish situations where the DR in the specific point of the space, where the people who participate on the human experiments will sit, is 15%, 20%, respectively 25%.

2.1 Determination of the Thermal Asymmetries

We have examined the comfort parameters of public buildings with one outside wall with 100 glazing, in winter case. In the examined cases, the heat flux from the inside air to the cold window is compensated by a heated wall, which is situated on the opposite side, as well as by the heat flux from the human body to the indoor air.

We have examined the thermal asymmetry caused by five different window types, characterised by five different heat transfer coefficients. Among the window types we have examined the effect of the windows specified in standards curently compulsory in Hungary (Utype3=1,6 W/m^{2}K), the ones stated in standards which will be compulsory after 2020 (Utype1=1,15 W/m^{2}K) and the ones characterising old building stock (Utype5=2,5 W/m^2 K).

The thermal asymmetry is present between the wall of the comfort chamber which stands for the outside window and the opposite, heated wall.

2.2 Methods for Evaluating the Thermal Comfort

For the evaluation of the thermal comfort in the comfort chamber we used the PMV and PPD comfort indices. For the determination of the dissatisfaction rate regarding the draught we used the DR (Draught Rate) indice.

We have measured the air temperature, velocity and humidity respectively the surface temperature of the walls, the ceiling and the floor.

The purpose of the research is to create a model of office buildings in winter case so we made the following assumptions: the metabolic rate we calculated with was 1,2 met, the insulation of the clothing was 1 clo. The following parameters were calculated using the measured data: Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), intensity of turbulence (Tu), Draught rate (DR).

We have measured the air velocity for 3 minutes in 125 positions, 5 different heights in the comfort chamber with a measurement frequency of 1 sec, so the turbulence intensity and the draught rate were calculated by taking into account 180 samples for every measured position.

The calculation of the PMV and PPD indices was made with a self-developed software.

2.3 Linking Measured Data to Thermal Comfort Values

In order to determine the human response to the comfort environments generated by the measured distributions of the influencing parameters, human experiments are required. In the planning phase of the measurement we analysed and answered among others the following questions and criteria (Wyon, 2003): gender and age of the subjects: male or female, old or young; number of subjects; naive or fully informed; inactive or hard-working subjects; highly motivated or unmotivated subjects; well-practiced or unfamiliar tasks; speed or errors; exposure time; necessity of physiological tests.

3. Results

3.1 Determination of the Measured Parameter Groups

The inside temperature of the windows with different heat transfer coefficients can be determined by calculating the heat flux through the window (*Equation 1*). From this value the inside surface temperature of the construction element can be determined (as shown in *Equation 2*).

$$\dot{q} = U \cdot (t_i - t_e)\left[\frac{W}{m^2}\right] \qquad (1) \qquad\qquad t_{wi} = t_i - \frac{q}{\alpha_i}\left[{}^{o}C\right] \qquad (2)$$

where q is the specific feat flux in W/m^2, t_i and t_e are the inside and outside tempeartures in ^{o}C, t_{wi} is the inside surface temperature of the wall in ^{o}C.

Table 1 shows the heat teansfer coefficient (U value), the inside surface temperature of the window, the heat flux form the inside air to the window, the necessary wall temperature of the opposite, heated wall and the resulted radiant thermal asymmetry for the analysed window types.

Table 1.

Parameters of the analysed window types

Parameter	U value, W/m2K	T_{swin}, °C	Heat flux, W/m^2	T_{swall}, °C	Asymmetry, °C
Window, type 1	1,15	17	43	26	9
Window, type 2	1,30	16	48	27	11
Window, type 3	1,60	15	59	28	13
Window, type 4	2,00	13	74	30	17
Window, type 5	2,50	10,5	92,5	32,5	22

Taking into account the human pending parameters presented in chapter 2.2. (*Iclo*=1 clo, *M/FDU*=1,2 met), we have established the parameter groups that has to be further analysed with human experiments. These parameter groups are presented in *Table 2*.

Table 2.

Calculated parameter groups

Asymmetry, °C Draught rate,%	Asym=9 °C	Asym=11 °C	Asym=13 °C	Asym=17 °C	Asym=22 °C
DR=15%	Case 1	Case 2	Case 3	Case 4	Case 5
DR=20%	Case 6	Case 7	Case 8	Case 9	Case 10
DR=25%	Case 11	Case 12	Case 13	Case 14	Case 15

3.2. Evaluation of the Thermal Comfort

We analysed the distributions of the parameters that influence the thermal comfort in the comfort chamber in all of the 15 cases presented in *Table 2*. The patterns of the resulted distributions in the case of different parameter groups (case 1…case 15) were showing strong similarities. The following conclusions can be made regarding the differences between the parameter groups: bigger thermal asymmetry caused bigger deviations in the parameter distribution; higher air flow rate caused higher air velocity values in the chamber; and resulted in higher draught rate.

Due to the similar character of the distribution of the parameters influencing the thermal comfort, this paper will only present the distribution of the parameters belonging to the parameter group presented in the *Table 2* as case 13.

Case 13 shows the following properties: surface temperature of the wall that represents the outside window: 15 °C; surface temperature of the wall that represents the heated wall: 28 ºC, inlet air temperature: 22 °C.

The heat flux introduced by the heated wall represents the energy deficit between the energy released from the human subject and the energy loss through the window.

Figures 4 to *9* show the distributions of the parameters mentioned in Chapter 2.2. The measurements were executed in 5 different heights (10 cm, 45 cm, 110 cm, 170 cm, 200 cm). The current results show the distributions of the parameters influencing the thermal comfort at 110 cm.

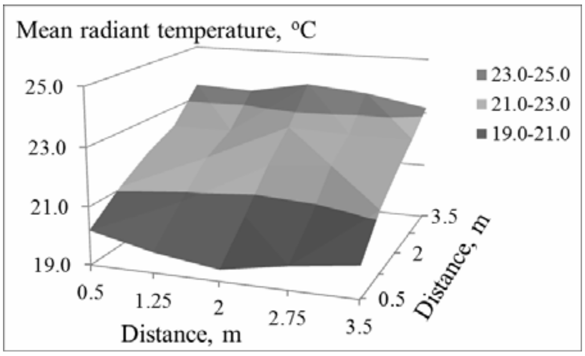


Figure 4. Mean radiant temperature distribution

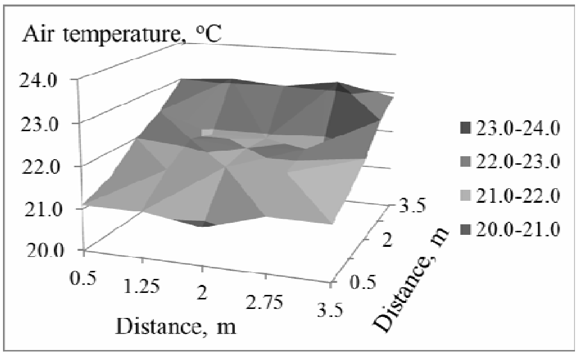


Figure 5. Air temperature distribution

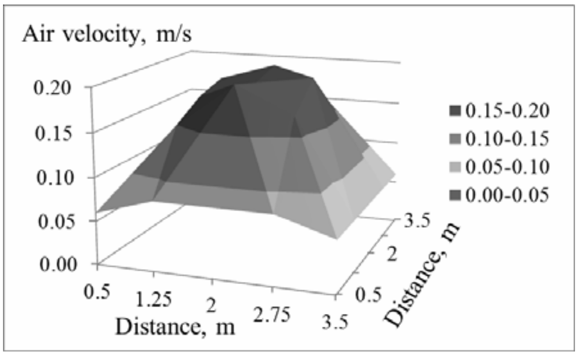


Figure 6. Air velocity distribution

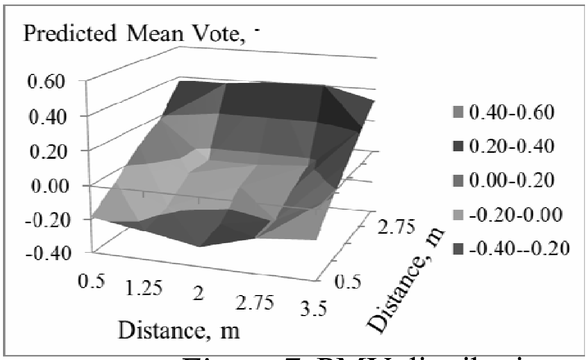


Figure 7. PMV distribution

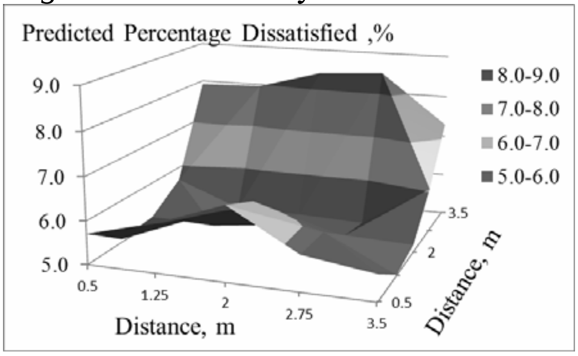


Figure 8. PPD distribution

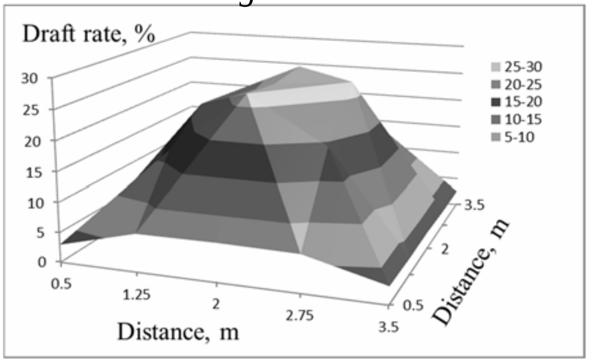


Figure 9. DR distribution

Fig. 4 shows the mean radiant temperature distribution in the comfort chamber. Due to the generated radiant thermal asymmetry, the mean radiant temperature has an increasing tendency towards the hot wall.

Fig. 5 shows the air temperature distribution. The character of the distribution differs from the previous because the air temperature field is influenced by the air flow introduced through the air diffuser placed in the centre of the comfort chamber. The air is introduced through the ceiling unit at 22 °C.

Fig. 6 shows the air velocity distribution. The velocity distribution shows a concentric character. The values of the velocity vectors are bigger in the centre of the chamber. The minimum value of the air velocity field is next to the walls of the comfort chamber.

In order to analyse the combined effect of the draught and the thermal asymmetry in winter case, the thermal comfort in the specific location of the space where the participants of the human experiment will sit, should be ideal according to the PMV model. Due to this boundary condition, the parameters influencing the thermal comfort were adjusted in a way that the Predicted Mean Vote is between -0,2 and 0,2 in the centre of the chamber as shown in *Fig. 7*.

The distribution of the Draught Rate in the comfort chamber shows the influences of the previously presented air velocity distribution and air temperature distributions. Our goal was to create a comfort environment where the PMV value is ideal in the centre of the comfort chamber and the draught rate is close to 15, 20 or 25 % depending on the situation we wanted to analyse. This case shows a distribution of the DR when the purpose was to achieve the DR=25%.

3.2. Subjective Thermal Comfort Tests

The goal of these measurements is to translate the objective data to subjective, thermal comfort parameters. After determining and calculating the parameter groups that have to be analysed and after measuring the distributions of the parameters influencing and describing thermal comfort, we created a research methodology for the human experiments.

20 young adults were selected, male and female subjects in equal number. The subjects were not fully informed, they did not know which thermal comfort conditions were established.

In order to determine the influence of the combined effect of the draught and the thermal asymmetry on the productivity of the office work, the subjects were doing well- practiced tasks, for example proof-reading. According to Wyon (Wyon, 2003) these types of tasks have been found to be more sensitive than unfamiliar tasks, as they are similar to normal work and thus the learning effect is minimized.

The subjects of the experiment were paid, thus motivated, and during the experiment we recorded the speed of their work and also the errors. This is important because higher work speed can generate more errors and vice versa.

The length of the human experiments was four hours and very limited physiological measurements were conducted, because the created parameter field generated a low level of physiological stress.

Table 3 presents the subjective scales for the general state and thermal comfort state utilized during the human experiments.

4. Discussion

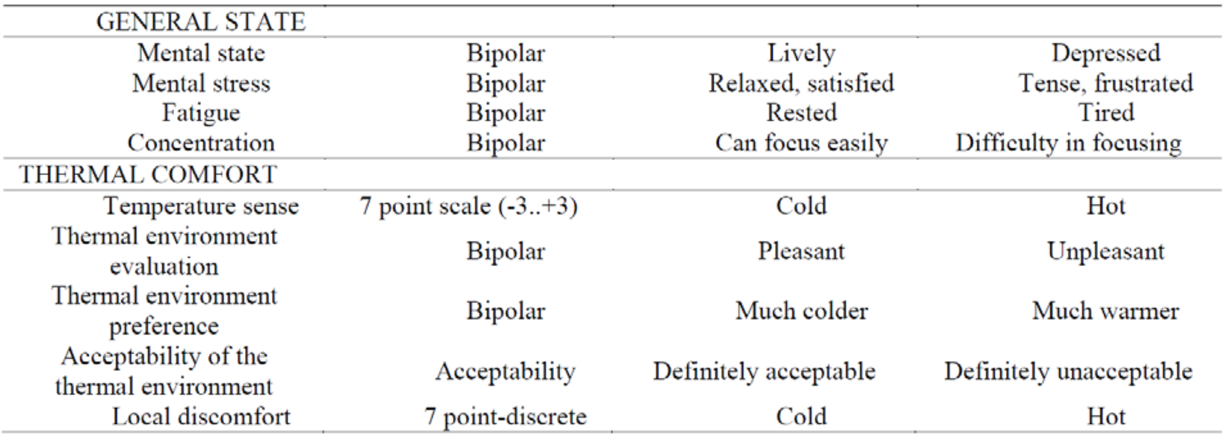
The results presented in this paper are intermediate results from an ongoing research. The main result is the presentation of the distribution of the parameters influencing the local discomfort parameters. These distributions were determined with a combination of numerical and empirical methods. They show similarities regardless of the magnitude of the inlet air velocity and the thermal asymmetry. They showed a pattern which depend on the two local discomfort parameters.

The paper also shows the way the before mentioned distributions can be converted into human comfort response. Further on, it presents the methodology we used in determining the combined way of action of the draught and the radiant thermal asymmetry.

Once the research will be completed, it will result in a mathematical method for the determination of the combined effect of the before-mentioned local discomfort parameters. This will have relevance in the health and productivity of the occupants and the economic run of the buildings. All the measured temperature values presented in the paper are random variables (air temperature, surface temperatures). They show a normal distribution, the error in the values presented never exceeded 7%.

Table 3.

Subjective scale for the general state and thermal comfort state



GENERAL STATE			
Mental state	Bipolar	Lively	Depressed
Mental stress	Bipolar	Relaxed, satisfied	Tense, frustrated
Fatigue	Bipolar	Rested	Tired
Concentration	Bipolar	Can focus easily	Difficulty in focusing
THERMAL COMFORT			
Temperature sense	7 point scale (-3..+3)	Cold	Hot
Thermal environment evaluation	Bipolar	Pleasant	Unpleasant
Thermal environment preference	Bipolar	Much colder	Much warmer
Acceptability of the thermal environment	Acceptability	Definitely acceptable	Definitely unacceptable
Local discomfort	7 point-discrete	Cold	Hot

5. Conclusions

The relevance of the research lies in the fact that the way of action of the combined effects of the local discomfort parameters is unknown. By knowing that, a more precise description of the phenomenon can be done. Furthermore, it is possible to reach an optimization between the energy use and the optimal thermal comfort, thus assuring a healthy thermal environment. In other words, the topic has its relevance in the comfort, health and economical field.

The other important aspect of the research is the determination of the link between the productivity of the office work and the combined effect of the local discomfort parameters. The method will be a useful tool for building operators, owners and planning engineers, but will also be relevant for the researchers doing comfort researches.

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