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RESEARCH ARTICLE

Human subject experiments for investigating the combined effects of two local discomfort parameters

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Abstract

The purpose of HVAC systems is to provide a comfortable environment and set the conditions for efficient work. The enhancement of buildings' energy performance puts emphasis on meeting the comfort requirements indoors, as the acceptable environments have to be provided from less energy. The comfort of occupants is determined by the heat exchange between his body and his indoor environment. Even if whole body thermal comfort is accomplished there may be local areas on the body where sensation of discomfort may arise. The paper contains the results of a human subject experiment that was carried out to study the combined effect of two, simultaneously present local discomfort parameters, namely radiant temperature asymmetry and warm feet. Results showed that local discomfort caused by warm feet was not present or was out ruled by the radiation from the cold wall surface.

Keywords

Human subject experiment · local discomfort · thermal sensation · skin temperature

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1 Introduction

The purpose of HVAC systems, along with the construction of the building is to provide a comfortable environment and set the conditions for efficient work. The systems have to fulfil this requirement by using less energy and emitting fewer pollutants to the environment.

In Europe, the energy demand of building operation takes 40% of the primary energy use. As a result, EU has put emphasis on reducing the energy use of buildings, and set requirements that member countries have to accomplish [1].

It is important that while energy consumption should be reduced desired indoor comfort is maintained. This principle requires further investigation and modelling of comfort conditions.

2 Problem formulation

According to the current knowledge comfort parameters that affect the comfort and efficiency in the indoor environment are the following:

- the temperature and distribution of air indoors,
- the mean radiant temperature of the building envelope's surfaces,
- the relative velocity,
- the partial pressure of water vapor in the air, and relative humidity of air,
- metabolic heat produced by the human body that has a specific activity level,
- the insulation of clothing,
- indoor air quality [2].

The standard (CEN CR 1752) that is applied for the determination of comfort conditions [2], contains the term of overall, whole body thermal comfort that is described by two indexes PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied). Furthermore, it includes four local discomfort parameters that may cause discomfort on certain body parts even if whole body thermal comfort conditions are met. These are:

– Radiant temperature asymmetry,

– Warm and cold floors,

– Vertical air temperature difference,

– Draught.

Based on the range of PMV value and the PPD and due to local discomfort parameters, indoor spaces are categorized by the standard into categories A, B and C. The newer standard that aims at increasing the energy efficiency of buildings [3] applies four categories and gives the PMV-PPD values for those.

Even though the sizing diagrams and values are results of extensive laboratory investigations, they do not apply to cases when the different local discomfort parameters are simultaneously present in the indoor space. This gave a reason for the herein described experiments.

Until recently only very few research studies dealt with multiple short-term exposures, e.g. combined effect of temperature, indoor air quality and noise were studied by Balazova et al. [4]. Berglund et al. [5] evaluated the subjective human response to low-level air currents and asymmetric radiation. Olesen et al. [6] and Toftum [7] outlined in their papers the need for further investigations regarding combined effects of local discomfort parameters.

Because of the aforementioned reasons the Department of Building Services and Process Engineering decided to investigate the effect of simultaneously present local discomfort parameters via different experimental methods [8] [9].

In this paper a project is described in detail that was run in the fall of 2008 with the participation of 20 subjects, to show the methodological approach taken for the investigation of combined effects and to introduce results gained from experiments. The two local discomfort parameters studied were radiant temperature asymmetry and warm floor.

Experiments with human subjects were conducted in a climate chamber, where one of the walls was cooled (to produce radiant asymmetry) and the floor was heated.

The hypothesis behind the investigation was as follows. In an office environment, change (increase) in comfort is expected when the quality of an outside wall, or glass facade is increased so that its inside surface temperature is changed from 16°C to 18°C. The occupants are seated facing the cold surface. It was hypothesized as well that radiant temperature asymmetry caused by the cold wall surface will overrule the sensation of warm feet caused by floor heating. Dissatisfaction due to warm feet was thought to appear only when no cold wall was present.

3 Facilities and methods

3.1 Climate Chamber

The climate chamber, used for the experiment, is located within a room, thus it is unaffected by outdoor conditions. The chamber has the following dimensions: 3.8 m (L) × 3.1 m (W) × 2.5 m (H). The volume of the space equals to 29.5 m^3. Fig. 1 shows the layout and side view of the chamber. The chamber does not have windows, only artificial lighting is available.

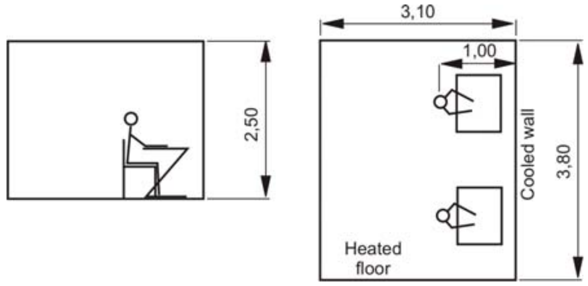

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Fig. 1. Layout and side view of the chamber

The chamber's walls and floor are equipped with embedded surface heating or cooling systems. The surfaces can be cooled or heated by circulating water in any desired combinations. The water temperatures are controlled through a computer program, commonly used for building operation, in order to provide the required surface temperatures. In the current experiment, one of the walls (wall C) was cooled and the floor was heated simultaneously.

The chamber's air is served by an air handling unit, which heats and supplies outdoor air. The temperature can be controlled by a thermostat. The supply air enters the chamber through the perforated ceiling panels on the ceiling, resulting in very low air velocity (0.1 m/s), and it is removed through the grills on the sidewalls of the chamber. During the experiment the unit was set to provide the minimum required fresh air for two persons.

Two desks and chairs were placed in the chamber; distances from the surfaces are indicated in Fig. 1.

3.2 Physical measurements

The chamber is equipped with temperature sensors; Fe-CO thermocouples. Twelve sensors are distributed evenly and fixed on wall C (the cooled surface) and sixteen are mounted on the heated floor. The surface temperatures of the other walls are measured as well by 4 (wall D), 3 (wall A) and 3 (wall B) sensors. Air temperature is measured at heights 0.1 m, 0.6 m, 1 m and 1.7 m at two points respectively. All measured data are collected in an Almemo 5690 measuring instrument in 30 second intervals.

Outside air temperature is measured with two Testo temperature loggers placed outside the laboratory room of the chamber. The outdoor air temperature is measured to be able to see whether different outside air temperatures affected overall thermal sensation of subjects.

Radiant temperature asymmetry is measured with an Innova 1221 Thermal Comfort Datalogger, by using the MM0036 transducer. The transducer is placed in line with the body of the subjects at head height; one side of the sensor faces the cooled wall's half-space, while the other measures on the opposite side.

3.3 Experimental plan

The experimental plan for the investigation carried out during the fall of 2008 with two groups of subjects is shown in Table 1.

Tab. 1. Experimental plan

Week	Dates	Group No. (2prs/day)	Conditions wall / floor
1	27/10 – 31/10	1	16˚C /28˚C
2	03/11 – 07/11	2	18˚C /28˚C
3	10/11 – 14/11	1	18˚C /28˚C
4	17/11 – 21/11	2	16˚C /28˚C
5	24/11 – 28/11	1	– / 28˚C
6	01/12 – 05/12	2	– / 28˚C

The conditions followed a balanced order of presentation. Table 2 refers to the set parameters and the condition numbers.

Tab. 2. Set conditions for the experiment

Condition No.	Temperatures
1	16˚C wall – 28˚C floor
2	18˚C wall – 28˚C floor
3	No wall cooling – 28˚C floor

Subjects attended their three sessions on the same day of the week with two weeks difference always in the morning hours.

Other physical quantity controlled was the temperature of indoor air. The temperature was aimed to be between 23-24˚C for the two conditions when a cooled wall was present. For the third condition temperatures between 22-23˚C were set. The reason for having different air temperatures was to acquire neutral overall thermal comfort sensation, so that local discomfort parameters caused by radiation could be observed more easily.

3.4 Subjects

All together 20 subjects (10 males and 10 females) were recruited for the investigation. They were college age subjects between 20 and 28. Participants were divided into two groups. Two subjects were exposed per session. Sessions that were held always in the mornings lasted for three hours.

The 20 subjects selected were healthy, not suffering from any illnesses that would affect their thermal sensation according to the background questionnaire they completed before the experiment.

Subjects participating in the investigation were completely blind to the parameters investigated; no information or clues were given at any time about the surface temperatures that were applied.

Subjects were asked to wear t-shirts and trousers throughout the experiment (approx. 0.7 clo). They received a pair of socks and slippers after arrival. (Slippers had rubber soles and were made of a thicker textile). Participants were allowed to modify their clothing as desired, however were asked to indicate the time and action on a paper.

3.5 Subjective assessments

Upon arriving to the session, in the ante-room, subjects were asked when and what they had for a meal, whether they drank coffee, whether they smoked, if they had a good nights rest or not and if anything stressful occurred before coming. They also had to complete a questionnaire about their general state (ability to concentrate, freshness, tiredness).

Three times during each session, after entering the chamber, 1.5 h, and 3h of exposure, subjects were asked to complete a questionnaire, marking visual analog scales (VAS) to indicate their assessment of thermal comfort. The applied scales are internationally accepted and frequently used in thermal comfort studies.

The VAS that were used in the investigation and the summary of the questionnaires are shown on Fig. 2 and Table 3.

3.6 Objective physiological measurements

Three times, 0.1 h, 1.5 h and 3 h of exposure the skin temperature and blood pressure of the subjects were measured.

The experimenter entered the chamber and with the help of a surface thermometer (Testo 905-T2) the following points were measured: forehead, nose, faces, ears, upper arms, lower arms, hands, proximal phalanges of the 4th fingers, distal phalanges of the 4th fingers, chest, lower legs, ankles, feet and the back of the head. After this the blood pressures of the subjects were measured.

3.7 Experimental procedure

The three hour long sessions were run according to the schedule shown in Table 4. Subjects were seated on office chairs by two desks. They carried out simulated office work, proof reading and two-digit addition, to restrict them to remain close to their "workstations". Subjects could only leave the chamber if needed to go to the toilet. When not working they were allowed to read, study or talk.

3.8 Data processing and statistical analysis

The physical measurements were recorded automatically for subsequent computer analysis. The subjective votes marked on the VAS in the questionnaires were transcribed manually so that they could be further analyzed. Subjective assessments, except for the local sensation votes, and physical data were assumed to be normally distributed and they were analyzed by paired sample t-tests. Within sessions, repeated measures were used for variance. For the analysis of local sensation votes the non-parametric Wilcoxon-test was used. For significance p-value was <0.05 indicating the tendency for the variable to differ between the conditions and sessions. Pearson-Bivariate correlation was applied to see whether subjective votes correlated with the measured skin temperature values.

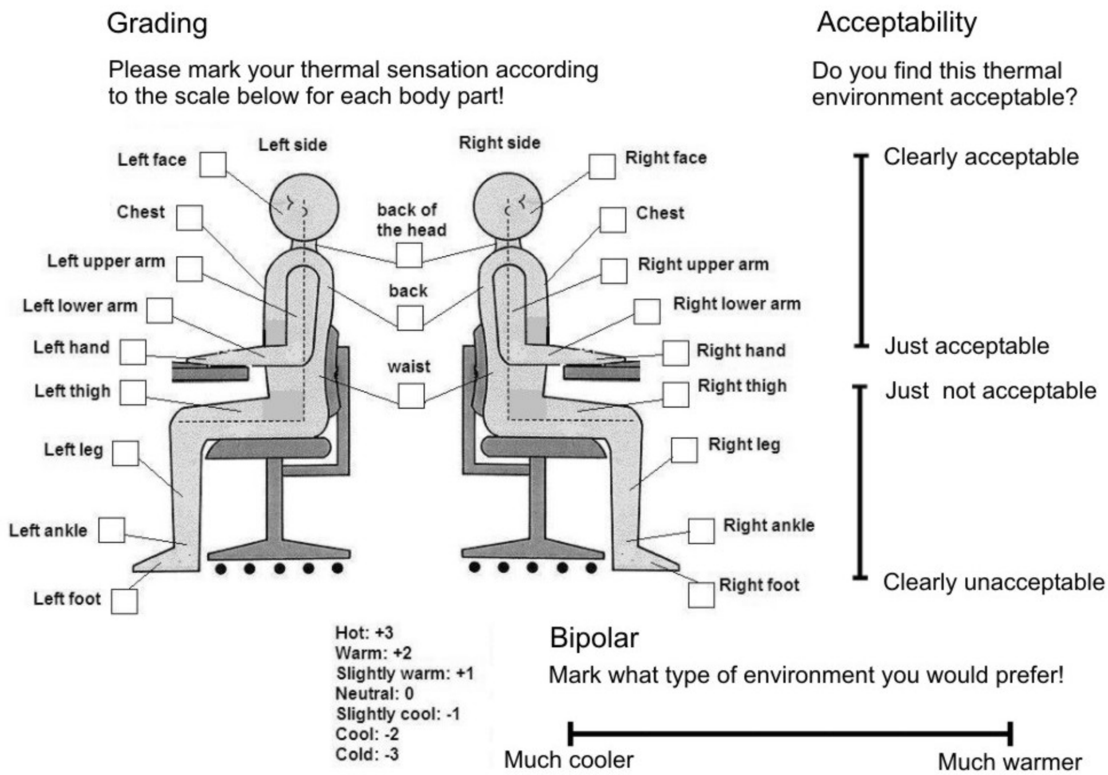

Fig. 2. Examples for the applied scales

Tab. 3. Summary of questionnaires and VAS

Variable	Type of scale	Low value	High value
		General state:	
Mental state	Bipolar	Interested	Bored
Mental tension	Bipolar	Relaxed, content	Upright, frustrated
Fatigue	Bipolar	Rested	Tired
Concentration	Bipolar	Easy to concentrate	Hard to Concentrate
		Thermal comfort:	
Thermal sensation	Thermal (7-point)	Cold	Hot
Thermal evaluation	Bipolar	Comfortable	Uncomfortable
Thermal preference	Bipolar	Much cooler	Much warmer
Thermal environment	Accept-ability	Clearly Acceptable	Clearly unacceptable
Local sensation	Thermal - discrete	Cold	Hot

Tab. 4. Schedule for the simulated office work

Clock time	Relative time	Event
08:30	-30 min	Arrival, 10 minutes of calm walking, afterwards general state and fatigue questionnaire
09:00	0 min	Enter chamber, thermal comfort questionnaire 1
09:05	5 min	Measure skin temperature and blood pressure
09:20	20 min	Start own activity
09:35	35 min	Start proof reading
10:10	70 min	Start addition
10:20	80 min	Thermal comfort questionnaire 2
10:25	85 min	Measure skin temperature and blood pressure
10:40	100 min	Start own activity
10:55	115 min	Start proof reading
11:30	150 min	Start addition
11:40	160 min	Thermal comfort questionnaire 3, general state and fatigue questionnaire
11:45	165 min	Measure skin temperature and blood pressure
12:00	180 min =3 h	Finish

4 Results from objective physiological measurements and from subjective assessments

4.1 Results of overall, mean skin temperature analysis

The measured local skin temperatures after entering the chamber, 1.5h and 3h of exposure were collected and their mean values were analyzed statistically using paired-sample t-test and repeated measures linear model.

Fig. 3 shows the comparison of overall body temperatures for each condition. The results of statistical analysis are indicated as well session-by-session. Note: e.g. 21 = 2nd measurement of

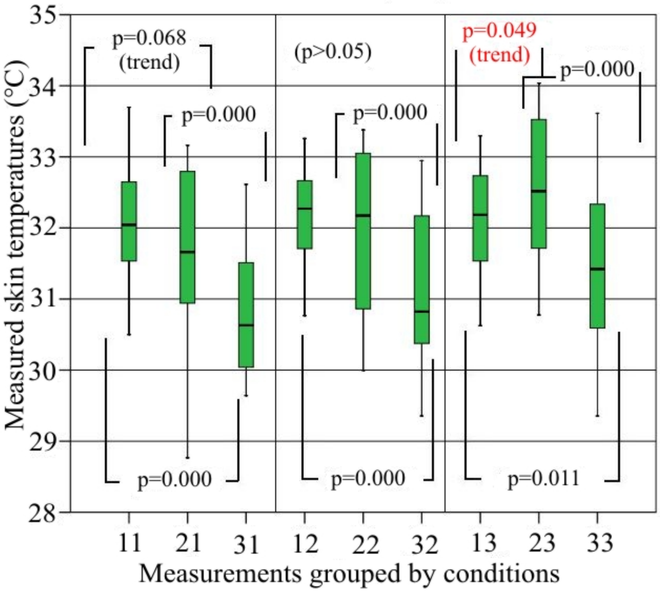

Fig. 3. Comparison of body temperature by sessions

Condition 1 (first digit (2): measurement number, second digit (1): number of condition/session). P-value in gray: overall body temperature significantly increased.

Significant cooling could be observed for each condition. As for Condition 1 a trend could be seen for cooling between the 1st and the 2nd measurement and significant cooling occurred only by the end of the session. For Condition 2 there was no trend for cooling between the 1st and the 2nd measurement and significant cooling occurred only by the end of the session. Results for Condition 3 show a trend of overall skin temperature increase by the time of the 2nd measurement and afterwards a significant cooling occurs. The final overall mean skin temperature was the lowest for Condition 1 and highest for Condition 3.

Measurement results were compared between conditions as well. Fig. 4 shows the results of the comparison. There were no significant differences between the 1st measurements of each condition. On the other hand significant difference was found between the 2nd measurements of conditions. The difference was less significant between Condition 1 and 2. As for the 3rd measurements it was found that between Condition 1 and 2 and Condition 1 and 3 significant differences exist, however Condition 2 and 3 did not show significant differences.

Heat loss of subjects was greatest when a 16˚C wall was present. The overall body temperature dropped regardless of

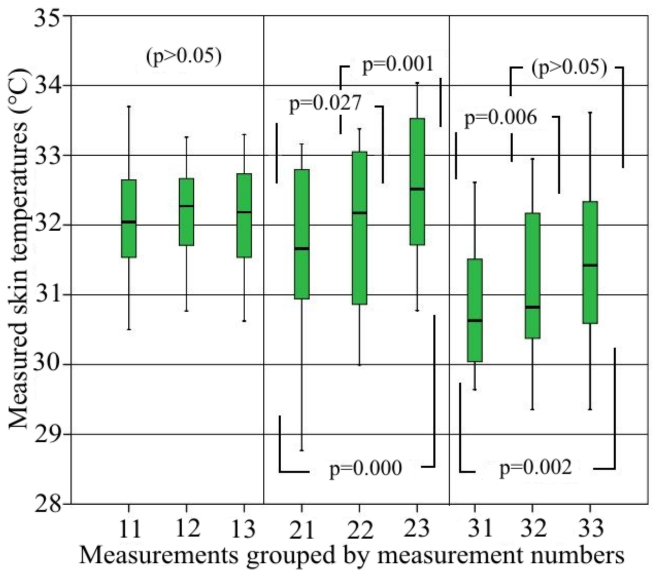

Fig. 4. Comparison of body temperature by conditions

the high floor temperature in Condition 3.

4.2 Results of local body part temperature analysis

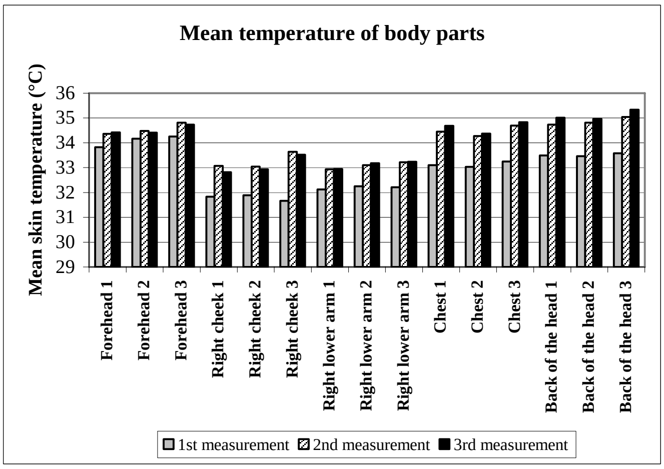

Fig. 5. Temperature of body parts by conditions

Note: "Bodypart" 1, 2, 3 stands for Condition 1, 2 and 3 respectively.

The presented figure contains a few examples for those body parts that generally have temperatures close to the core temperature of the body (like chest, forehead etc.) or their temperature change follows the same manner as the chest or forehead. The body parts all acted similarly for all three conditions, namely:

- by the end of the sessions the temperature of body parts increased compared to the beginning.
- the temperature of body parts increased the most for Condition 3.

The following table contains the results of t-tests for the above described body parts.

Note: Middle gray marks cases when significant temperature changes occur by the 2nd measurement, but afterwards no significant change can be observed. Light gray marks cases when

Tab. 5. Results of t-tests during sessions for each condition

Body parts	Between Measures.:	Condition 1	Condition 2	Condition 3
		Sign.	Sign.	Sign.
Forehead	1.-2	*0.040*	*0.012*	**0.000**
	1.-3.	*0.021*	*0.019*	**0.001**
	2.-3.	0.526	0.405	0.317
Right cheek	1.-2.	**0.000**	**0.001**	**0.000**
	1.-3.	**0.002**	**0.009**	**0.000**
	2.-3.	0.098	0.473	0.344
Right lower arm	1.-2.	**0.005**	**0.002**	**0.002**
	1.-3.	**0.002**	**0.000**	**0.000**
	2.-3.	0.967	0.612	0.933
Chest	1.-2.	**0.000**	**0.000**	**0.000**
	1.-3.	**0.000**	**0.000**	**0.000**
	2.-3.	0.112	0.54	0.213
Back of the head	1.-2.	**0.000**	**0.000**	**0.000**
	1.-3.	**0.000**	**0.000**	**0.000**
	2.-3.	*0.013*	0.101	**0.008**

significance occurs only between 2nd and 3rd measurements. Dark gray marks cases when significant changes occur between each measurement within sessions. Italic marks significance levels where 0.009 < p-value < 0.05, and bold marks when significance levels are p-value < 0.009

Body parts listed in Table 5 had temperatures that had increased over the period of a session. In the following those body parts are presented that had decreasing temperatures during sessions (see Fig. 6).

Fig. 6 contains the temperature of some of the extremities (hands and feet etc.) and of the nose. These body parts all acted similarly for all three conditions, namely:

- by the end of the sessions the temperature of body parts decreased compared to the beginning.
- the temperature of body parts decreased the most for Condition 1 and least for Condition 3.
- Finger temperatures decreased the most during sessions.

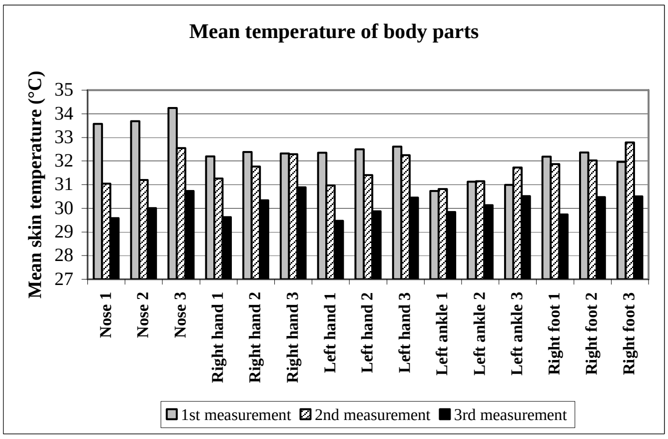

Fig. 6. Temperature of body parts by conditions

Table 6 contains the results of t-tests for body parts descibed in Fig. 6.

Tab. 6. Results of t-tests during sessions for each condition

Body parts	Between Measures:	Condition 1	Condition 2	Condition 3
		Sign.	Sign.	Sign.
Nose	1.-2.	**0.000**	**0.000**	**0.003**
	1.-3.	**0.000**	**0.000**	**0.000**
	2.-3.	**0.001**	**0.003**	**0.000**
Right hand	1.-2.	*0.026*	0.196	0.947
	1.-3.	**0.000**	**0.002**	**0.006**
	2.-3.	**0.000**	**0.001**	**0.000**
Left hand	1.-2.	**0.000**	**0.008**	0.223
	1.-3.	**0.000**	**0.000**	**0.000**
	2.-3.	**0.000**	**0.000**	**0.000**
Left ankle	1.-2.	0.808	0.943	*0.031*
	1.-3.	**0.005**	**0.002**	0.221
	2.-3.	**0.000**	**0.000**	**0.000**
Right foot	1.-2.	0.434	0.411	0.091
	1.-3.	**0.000**	**0.000**	**0.012**
	2.-3.	**0.000**	**0.000**	**0.000**

Note: Light gray marks cases when significance occurs only between 2nd and 3rd measurements. Dark gray marks cases when significant changes occur between each measurement within sessions. Italic marks significance levels where 0.009 < p-value < 0.05, and bold marks when significance levels are p-value < 0.009.

4.3 Results of overall thermal comfort vote analysis

The assessment of the 4 visual analogue scales in the questionnaires obtained after entering the chamber, 1.5h and 3h of exposure were analysed statistically using paired-sample t-test and repeated measures linear model.

The following figures (Figs. 7-9) show the mean value of votes.

Thermal sensation scales:

Within sessions significant differences were found in the following cases:

Thermal sensation scale			
Voting numbers:	1. - 2.	1. - 3.	2. - 3.
Condition 1	0.000	0.000	–
Condition 2	–	–	–
Condition 3	0.000	0.009	0.000

Between conditions significant differences were found in the

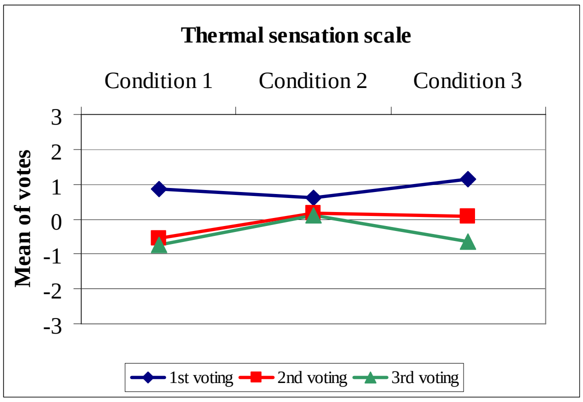

Fig. 7. Thermal sensation scale

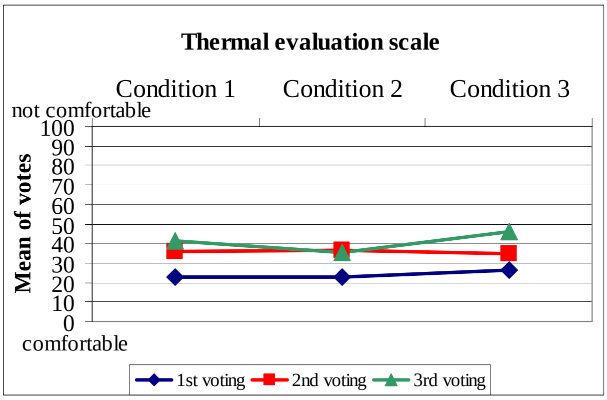

Fig. 8. Thermal evaluation scale

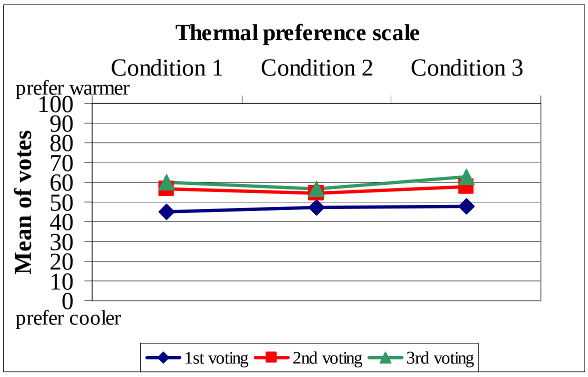

Fig. 9. Thermal preference scale

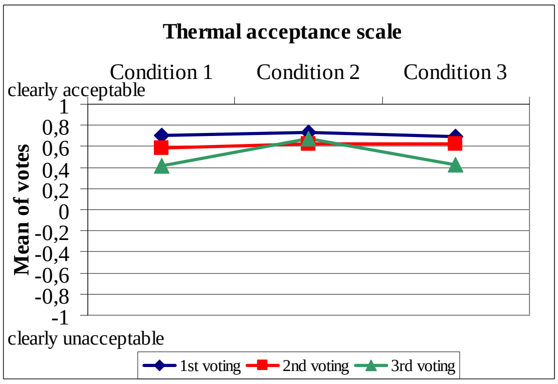

Fig. 10. Thermal acceptance scale

following cases:

Thermal sensation scale			
Conditions:	1. - 2.	1. - 3.	2. - 3.
1st voting	–	–	0.013
2nd voting	0.004	0.005	–
3rd voting	0.005	–	0.008

Thermal evaluation scales:

Within sessions significant differences were found in the following cases:

Thermal evaluation scale			
Voting numbers:	1. - 2.	1. - 3.	2. - 3.
Condition 1	–	0.002	–
Condition 2	–	–	–
Condition 3	–	0.006	–

No significant differences could be observed between conditions for the thermal evaluation scale.

Thermal preference scales:

Within sessions significant differences were found in the following cases:

Thermal preference scale			
Voting numbers:	1. - 2.	1. - 3.	2. - 3.
0 Condition 1	0.000	0.000	–
Condition 2	0.009	0.000	–
Condition 3	0.001	0.000	–

Between conditions the only significant difference could be observed between the 3rd measurements of Condition 2 and 3: sig=0.007. Subjects would have preferred warmer thermal environment in Condition 3.

Thermal acceptance scales:

Within sessions significant differences were found in the following cases:

Thermal acceptance scale			
Voting numbers:	1. - 2.	1. - 3.	2. - 3.
Condition 1	–	0.002	–
Condition 2	–	–	–
Condition 3	–	0.015	–

Between conditions the only significant differences could be observed between the 3rd measurements of Condition 1 and 2: sig=0.011 and the 3rd measurements of Condition 2 and 3: sig=0.014.

4.4 Results of local thermal comfort vote analysis

The votes given on grading scales in the questionnaires obtained after entering the chamber, 1.5h and 3h of exposure were analysed statistically using non-parametric Wilcoxon test.

Local thermal sensation votes have decreased by the end of the sessions for all three conditions. The mean of local votes varied between slightly warm and slightly cool. The 1st votes for Condition 3 have been the highest (approx. 1 – slightly warm) and showed the greatest decrease compared to the other conditions.

The following table (Table 7) shows the significant results within the sessions of each condition for some of the body parts under study.

Tab. 7. Significant differences between subjective local thermal sensation votes within sessions

Body parts	Between Votes:	Condition 1	Condition 2	Condition 3
		Sign.	Sign.	Sign.
Right cheek	1.-2.	0.011	–	–
	1.-3.	0.027	–	0.011
	2.-3.	–	–	**0.003**
Right lower arm	1.-2.	**0.006**	**0.001**	**0.002**
	1.-3.	0.010	0.022	**0.000**
	2.-3.	–	–	**0.006**
Right hand	1.-2.	0.012	**0.002**	–
	1.-3.	**0.000**	**0.002**	**0.000**
	2.-3.	0.021	–	**0.000**
Chest	1.-2.	**0.006**	0.033	**0.003**
	1.-3.	**0.000**	–	**0.001**
	2.-3.	–	–	**0.007**
Left ankle	1.-2.	0.014	0.016	**0.001**
	1.-3.	**0.000**	**0.002**	**0.000**
	2.-3.	–	–	0.014
Right foot	1.-2.	0.026	–	0.013
	1.-3.	**0.000**	0.013	**0.002**
	2.-3.	0.025	–	0.018

From the table above it can be seen that for the examined body parts significant decrease occurred between the 1st and 3rd votes of Condition 1 and Condition 3.

Condition 2 gave the least significant differences for the votes within session.

Comparing conditions significant differences were present mostly for the 3rd votes of Condition 2 and Condition 3. The mean value of 3rd votes was lower for Condition 3 than for Condition 2.

4.5 Results of correlations between measured data and votes

Correlations were done for both overall body temperatures and general thermal comfort votes and for local measured temperatures and thermal sensation votes.

Mean skin temperature correlated with the thermal sensation votes only for Condition 3, for the 1st and 2nd measurements/votes.

As for the mean skin temperature - thermal preference vote correlation was found for the 2nd and 3rd measurement/vote of Condition 1. Furthermore, the 2nd measurement of Condition 3 showed correlation between the mean values and votes.

Correlation between locally measured values and votes was present only in a few cases.

- Right hand:
Condition 1 – 2nd, 3rd measurement/vote
Condition 2 – 2nd measurement/vote
Condition 3 – 1st, 3rd measurement/vote
- Left hand:
Condition 1 – 2nd, 3rd measurement/vote
Condition 2 – 2nd, 3rd measurement/vote
Condition 3 – 3rd measurement/vote
- Right foot:
Condition 2 – 1st, 2nd measurement/vote
Condition 3 – 1st, 2nd measurement/vote
- Left foot:
Condition 1 – 2nd measurement/vote
Condition 2 – 1st measurement/vote
Condition 3 – 1st, 2nd measurement/vote

4.6 Results of objective temperature measurements

The surface and air temperature data were collected in figures for the periods when skin temperatures had been recorded (beginning, 1.5h and 3h of exposure). The following three figures show the temperatures for the period of the 3rd skin temperature measurements (after 3h of exposure) for each condition.

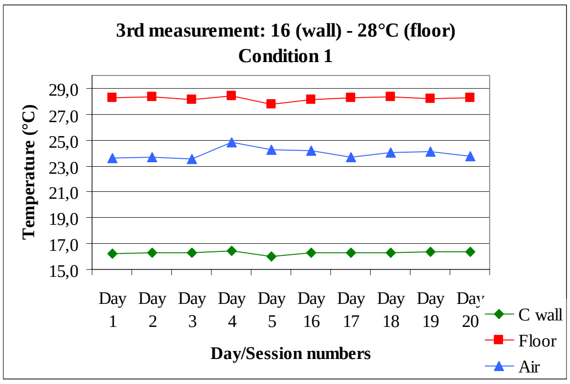

Fig. 11. Measured environmental parameters for Condition 1

The figures (Figs. 11-13) show that the desired surface temperatures for this experiment were accomplished. Air temperature showed minor fluctuations day-by-day, however it remained between 23-25°C.

5 Discussion

It was hypothesized in this study that radiant temperature asymmetry caused by the cold wall surface will overrule the sensation of warm feet caused by floor heating. Dissatisfaction

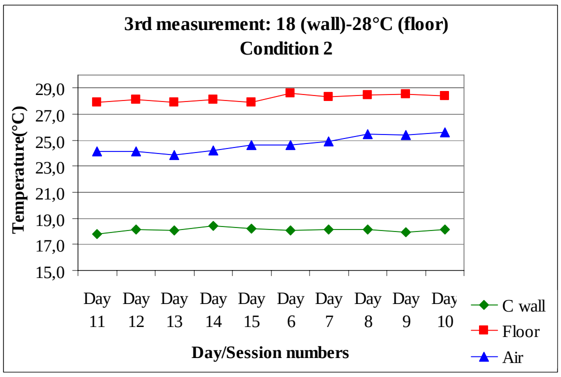

Fig. 12. Measured environmental parameters for Condition 2

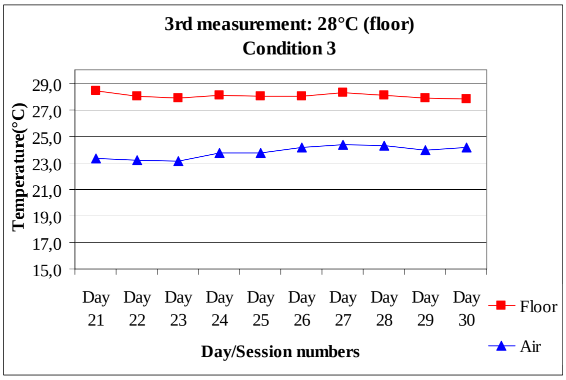

Fig. 13. Measured environmental parameters for Condition 3

due to warm feet was thought to appear only when no cold wall was present. It was also hypothesized that significant increase in comfort is expected when the quality of an outside wall, or glass facade is increased so that its inside surface temperature is changed from 16˚C to 18˚C.

5.1 Skin temperature measurements

There was no significant difference between overall skin temperatures for the 1st measurement of each condition that is due to the walking activity that was carried out by each subject before sessions. This gives a proper ground to see the differences between conditions. From the results indicated in subsection 4.1 and 4.2 it can be said that the presence of a cold surface had an effect on overall temperature as well as on local skin temperature. The significant results obtained between measurements within sessions are on one hand caused by the natural behaviour of the human body, while on the other hand are due to the set environmental effects. It is natural that the temperature of subjects' chests, faces, ears etc. increased as they had to make decisions, carry out tasks and think. It is also natural that the sedentary activity would result in decreasing temperatures at the extremities. These physiological effects are present in the results of Condition 3 that can be considered as a control condition from this point of view. From the results it can be clearly seen that the least favourable condition is Condition 1, while the control Condition 3 gives the smallest changes regarding skin temperature. For Condition 3 less people showed decreasing, while more people had increasing skin temperatures.

It has to be noted that contrary to the hypothesis no discomfort could have occurred due to the presence of warm floor as the temperature of the feet decreased during sessions. This can be explained on one hand with the physical operation of the human body i.e. continuous sedentary activity. On the other hand the fact that air temperature was controlled throughout measurements could have affected the change in skin temperature and thus local discomfort. If the air temperature wouldn't have been controlled, in time the 28˚C floor would have increased the temperature of the air enough to be able increase the temperature of feet. From the radiation point of view it seems that the floor has smaller impact on skin temperature than the cold vertical surface. This finding supports the idea that increasing the quality of the wall (or window) will cause less cooling/discomfort in the body parts.

5.2 Subjective assessments

During the experiment subjects filled out questionnaires with VAS (see Fig. 2) about their general thermal comfort and local thermal sensation three times.

From the votes for general thermal sensation the following can be observed: subjects found Condition 1 to be the coldest which was followed by Condition 3, and Condition 2 that was thought to be the warmest. Votes varied between slightly warm and slightly cool. No significant differences could be found between Conditions 1 and 3, but both conditions were significantly different to Condition 2. This may be due to the effect of air temperature to thermal sensation. Even though the same air temperature was set for Conditions 1 and 2, the actual air temperature increased compared to the set value for Condition 2. It is possible that the slight increase in the air temperature may have caused the better votes for Condition 2 compared to Conditions 1 and 3. It appears that subjective votes are more affected by air temperature than by radiant temperature.

In general, subjects felt comfortable in all three thermal environments. They would have preferred warmer environment that is somewhat unexpected, as air temperatures were set higher compared to the design air temperature used in practice. Nevertheless, they found the thermal environment to be acceptable regarding overall thermal comfort.

The only exception is in the acceptability. Subjects found Condition 2 significantly more acceptable at the end of the session than Condition 1. It has to be noted that subject did not find these conditions unacceptable; the mean values were not negative.

As it can be seen in subsection 4.4 local thermal sensation votes decreased for all body parts within conditions, even though in reality some of them had increasing temperatures. This may be explained once more with that air temperature has bigger impact on thermal sensation than radiation from the floor. The higher air temperature that appeared for Condition 2 supports this idea. Between conditions, significant results were only found for a few body parts and only between Condition 2 and 3.

Regarding the body parts, the fact that Condition 3 was considered worse than Condition 2 may be due on one hand to the fact that air temperature was lower when only the floor was heated and on the other hand to that the thermal sensation at the beginning of sessions was higher for Condition 3 and from which point a greater drop occurred. The modification of clothing may have had an impact on this result as well. Nine people have modified their clothing for Condition 1, 8 people for Condition 2 and 7 for Condition 3. People were not cold enough in Condition 3 to modify clothing, but felt cooler than in Condition 2 or 1 where they had already altered their clothing ensemble.

6 Conclusions

The paper presents the results of an experimental measurement designed to describe the comfort/discomfort conditions that may be present in an office environment.

The laboratory experiment described in the paper was carried out to observe how the temperature and thermal sensation of subjects change when the quality of a badly insulated wall or glass facade is increased and the floor temperature is high.

The possibility for the presence of two local discomfort parameters has been examined, namely radiant temperature asymmetry caused by the cold wall surface and warm feet caused by floor heating.

The hypothesis said that radiant temperature asymmetry caused by the cold wall surface will overrule the sensation of warm feet caused by floor heating.

Results showed that the presence of a cold surface had an effect on measured whole body temperature as well as on local skin temperature. It was found that the temperature of the extremities (hands and feet!) decreased more when a cold surface was present. It was observed that contrary to the hypothesis no warm feet discomfort occurred due to the presence of warm floor. This may be so as the temperature of the air has been controlled.

From the point of view of measurements, it may be possible that the floor has smaller impact on skin temperature than the cold vertical surface. This finding supports the idea that increasing the quality of the wall (or window) will cause less cooling/discomfort in the body parts, however further investigation is necessary, e.g. studying the difference of convective and radiative heat exchange between the body and its surroundings.

From the point of view of subjective votes it may be possible that thermal sensation is more affected by the temperature of air than temperature radiation in designed office comfort environments.

According to the hypothesis, dissatisfaction due to warm feet was thought to appear only when no cold wall was present.

Both the temperature of the feet and the local thermal sensation showed decreasing values for the control condition, when only a warm floor was present. Thus, the hypothesis could be rejected; however the question of mechanical ventilation and the control of air temperature (like in an office environment) should be considered.

It was also hypothesized that significant increase in comfort is expected when the quality of an outside wall, or glass facade is increased so that its inside surface temperature is changed from 16˚C to 18˚C.

Result proved this hypothesis right as the measured skin temperatures and subjective votes showed significant differences between Conditions 1 and 2. The case where the temperature of the wall was set higher (18˚C) can be considered significantly more comfortable than for the colder condition. Nevertheless the effect of the air temperature on the subjective vote should be taken into account as well.

For the thermal conditions set in this experiment it can be said that overall thermal comfort only varied between slightly warm and slightly cool. For the applied thermal situation (surface temperatures, controlled air temperatures) the two local discomfort parameters tend to decrease each other's effects, i.e. the warm floor helps to reduce the effect of the cold wall (only to a limited extent) and the cold surface may reduce the chance of warm feet discomfort.

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