PERSONAL COOLING USING THERMAL CONDUCTION ON THE DESK

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ABSTRACT

In order to reduce the energy load on buildings, the indoor climate will not be maintained within narrow boundaries in the future. With the application of local conditioning systems that offer individual building occupants the possibility to increase their personal comfort level, a narrow boundary is no longer necessary. In uniform conditions, the comfort level is directly related to the heat balance of a person. However, even before the heat balance is restored from a slightly uncomfortable environment, a thermal stimulus in the right direction can give a person a pleasant feeling. This effect is called alliesthesia. In this study positive alliesthesia in a warm environment was tested by offering cooling via a plate on top of a desk.

Tests were conducted in the climate chamber in a slightly warm environment (PMV = 1.0, operative temperature of 28°C, clo = 0.6). Six subjects were recruited to test the three cooling settings. The plate temperature was maintained by running water through the integrated water pipes. The first ('passive') test was conducted without cooling water. The second test was 'cold' with a water temperature of 26 °C, in the third ('warm') test, the water temperature was maintained at 28 °C.

Alliesthesia was found in all tests. The alliesthesia in the 'passive' and the 'warm' tests were positive, in the 'cold' test, two groups formed. People who initially felt comfortable with the cooling and people who felt uncomfortable. People who voted neutral in the beginning of the test, moved to either comfortable or uncomfortable. The comfort level in the 'passive' test was maintained, unlike the level in the 'warm' tests, because of the increasing temperature of the plate. The cooling plate was unable to effect the heat balance and improve the overall thermal sensation (TS).

Keywords: personal cooling, alliesthesia, thermal comfort

INTRODUCTION

Currently, building indoor environment are maintained within a narrow boundary. Two setpoints are used in building operations, one for heating in winter, and a higher setpoint for cooling in summer. The setpoints can be found in standards [1] and are different depending on the quality class of the building. However, in previous studies [2] it was shown that applying a narrow boundary does not increase the comfort level of the building occupants, even though this is what could be expected based on the relation between predicted mean vote (PMV) and predicted percentage dissatisfied (PPD).

Maintaining the indoor temperatures within these narrow boundaries needs a big energy consumption. This means that there is a large opportunity to reduce the energy demand of a building when a more flexible temperature control strategy can be applied [3]. The application of a localised conditioning systems such as a personal heating or cooling system comes naturally to a less strictly controlled indoor environment [4][5]. A personal conditioning system (PCS) offers individuals the possibility to increase their personal comfort level above that in traditional buildings. Alliesthesia is the effect that a thermal stimulus has on the body. Small thermal stimuli can cause a pleasant or unpleasant feeling in people who are near the border of their comfort zone. A stimulus in the right direction (so a warm stimulus when near the cold side) will feel pleasant, while a cold stimulus (a breeze for example) will feel unpleasant. [6] [7] [8]. Understanding the phenomenon of alliesthesia is therefore essential to control PCS in dynamic temperature regimes. Understanding the alliesthesia effect in relation to thermal comfort will enable us to design a better, active and stimulating indoor environment and help us to apply personal conditioning systems in an effective and energy efficient manner.

We studied positive alliesthesia in a slightly warm environment with the application of local cooling. The study is performed using human subject experiments in the climate chamber. The cooling effect is reached by using a cooling plate that cools the subject locally when he touches the plate with his hands and forearms.

METHOD

The cooling plate that was used in this experiment is 0.6 m by 1.0 m. It's an aluminium plate integrated with water channels. Figure 1 shows the plate with the positions of temperature sensors indicated. The temperature sensors were placed on the bottom side of the plate, in between the water channels.

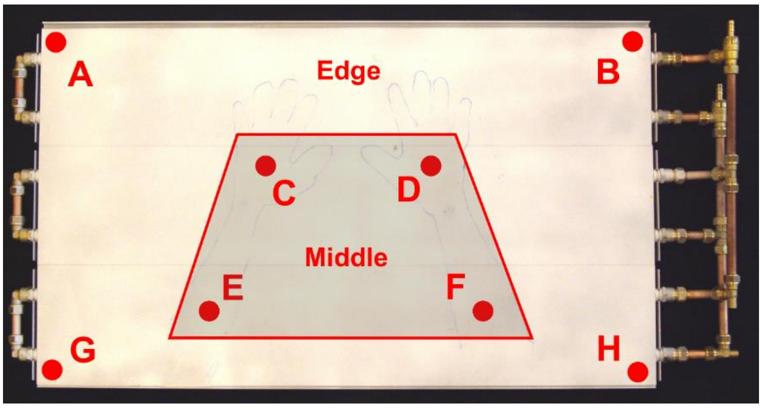

Figure 1: Position of the temperature sensors underneath the aluminium plate. The sensors in the middle are in the area where the subjects would place their forearms.

The tests were performed in the climate chamber at Eindhoven University of Technology. During the tests, the air temperature, speed and humidity of the air in the climate chamber were controlled. The environmental conditions during all tests were selected to reflect a PMV of 1.0 operative temperature of 28°C and an airspeed below 0.15 m/s. The subjects were instructed to wear clothes to a level of 0.6 clo.

During the tests, the subjects were exposed to three different levels of local cooling. In the first series of tests, the aluminium plate was used without water. The cooling effect during these 'passive' tests relies totally on the effusivity of the aluminium. During the second series of tests, the plate is actively cooled to 26°C. These tests are called the 'cold' tests. In the third series, the plate was kept at 28°C. In this 'warm' series, the plate temperature is the same as the wall and air temperature, and the same as in the passive tests initially. In the passive test, the temperature slowly increases. There is still a net cooling effect in both cases because of the effusivity of the aluminium and the plate temperature that is lower than the skin temperature.

For the experiment, six male, college-age students were recruited. Their physical characteristics are listed in Table 1. All three series of tests were performed with all six subjects, making a total of eighteen.

Before the start of a test, a short (five minutes) explanation was given and the subject would enter the climate chamber to acclimatize for 20 minutes. After that, the test would start and the subject would place their hands and forearms on the cooling plate. The subject was asked not to take their arms off the plate, except for filling out the questionnaires. The test would last for 30 minutes and is followed by a short interview.

Subject	Age [yr]	Height [m]	Weight [kg]	BMI [kg/m²]	Skin area [m²]
A	24	1.87	84	24	2.09
B	27	1.97	75	19	2.07
C	24	1.88	72	20	1.97
D	24	1.86	78	23	2.02
E	23	1.72	67	23	1.79
F	24	1.78	78	25	1.95

Table 1: Physical characteristics of the test subjects

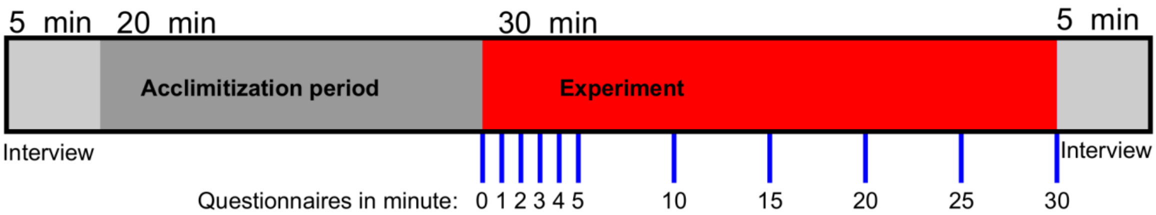

Figure 2: Schedule for the experiments: After the initial interview and acclimatization the 30 minute test started in which eleven questionnaires were done at the indicated times

Questionnaires were used to determine the thermal sensation (TS) and comfort level of the subjects during the tests. To capture the alliesthesia effect, especially in the beginning of the test, a high frequency was chosen. The first five minutes, the subject was asked to fill out the questions every minute. During the remainder of the test this was reduced to every five minutes. In the questionnaires, we asked for the TS of the hands, arms and the head specifically and for the TS and comfort of the whole body. To ensure that the subject would not spend too much time filling out the questionnaires, he only had to indicate the TS per body part on a continuous line from -3 (Cold) to +3 (Hot) in correspondence with the ASHRAE 7-point scale and indicate the comfort level by selecting the most appropriate smiley. A part of the questionnaire is shown in Figure 4.

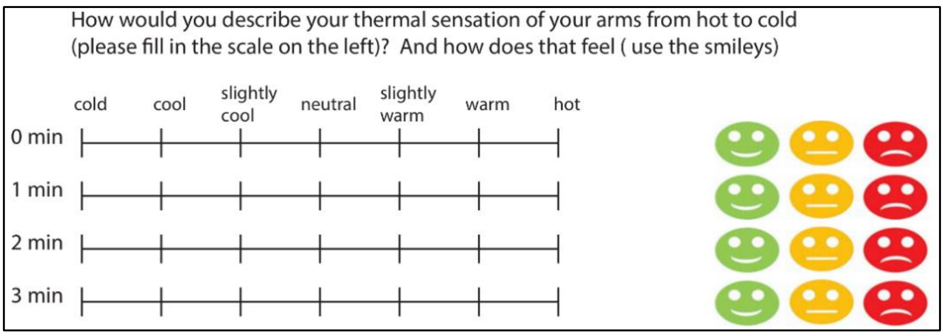

Figure 3: Part of the questionnaire used in the experiments.

The skin temperature was measured on the top side of the ring finger, the hand, the wrist and the forearm, both on the left and the right arm.

RESULTS

The test was started after the subject has acclimatized to the warm environment. This means that the TS overall is close to the PMV. During the test, this remains the same on average as can be seen in Figure 6, 8 and 10. In these figures, the TS votes from all tests within one series are combined with the average PMV calculated from the environmental conditions, not taking into account the local cooling. The TS of the body parts that were exposed to the aluminium is much lower.

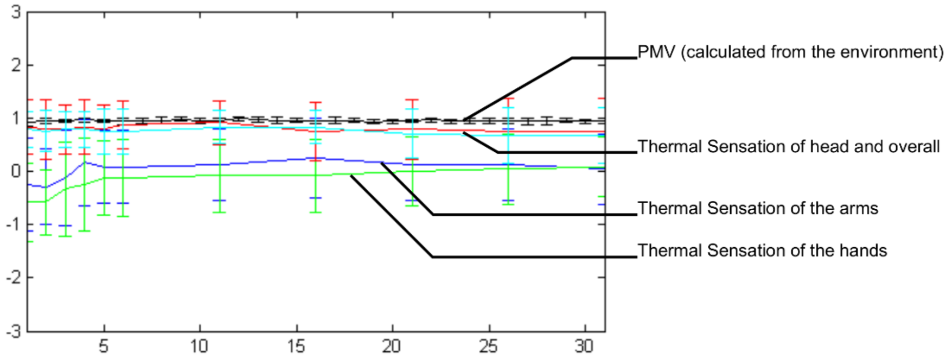

Figure 4: TS of the different body parts compared to the calculated PMV from the environmental conditions in the climate chamber during the 'passive' tests. The error bars mark the standard deviation.

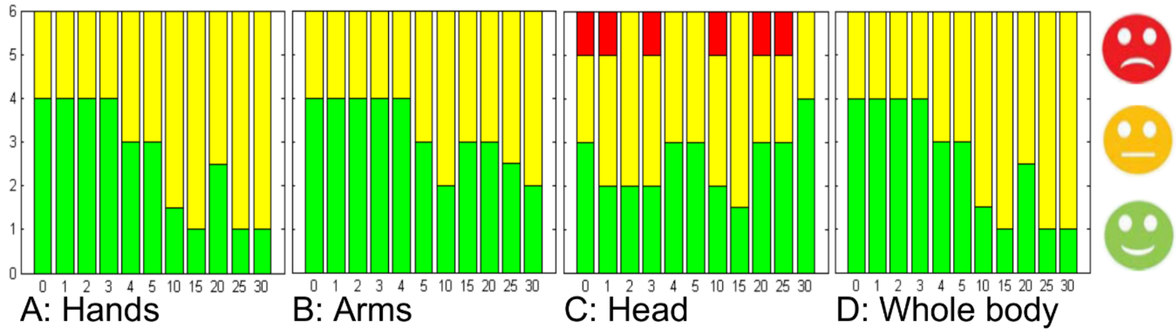

Figure 5: Comfort votes of the subjects in the 'passive' test, separated in three body parts and an overall vote. The height of the bar shows the number of votes per questionnaire. The time of the questionnaire is shown on the horizontal axis.

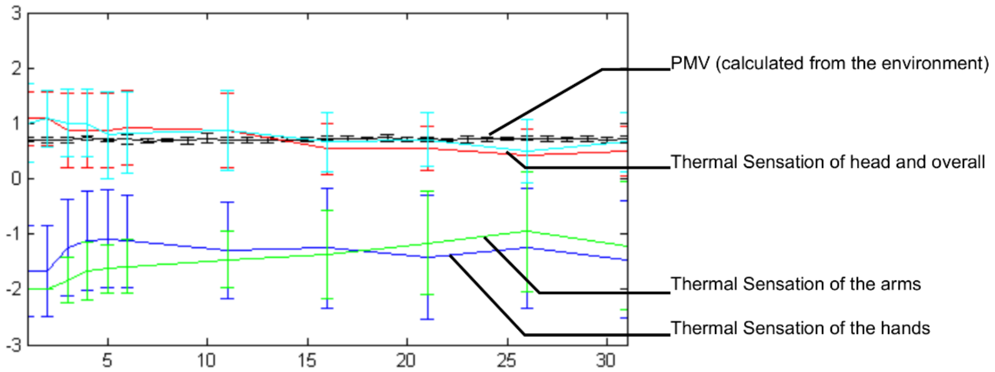

Figure 6: TS of the different body parts compared to the calculated PMV from the environmental conditions in the climate chamber during the 'cold' tests. The error bars mark the standard deviation.

In Figure 8 and 10, a similar trend can be seen, the TS overall and the TS of the head are close to the PMV, but the TS of the hands and arms are significantly lower compared within the series. During the 'cold' tests, the TS of the arms and hands are lower than in the other two series, showing the effect of a 2 degree lower surface temperature. The TS and comfort levels of the ‘passive’ (Figure 6 and 7) and the ‘warm’ tests (Figure 10 and 11) are comparable for the exposed areas in the beginning of the test. However, when the test progresses, the comfort level of both the exposed areas and overall in the ‘passive’ series goes to neutral, some of the subjects get uncomfortable in the ‘warm’ series. The difference between the ‘passive’ and the ‘warm’ series is that the plate temperature increased during the ‘passive’ tests, reducing the cooling effect.

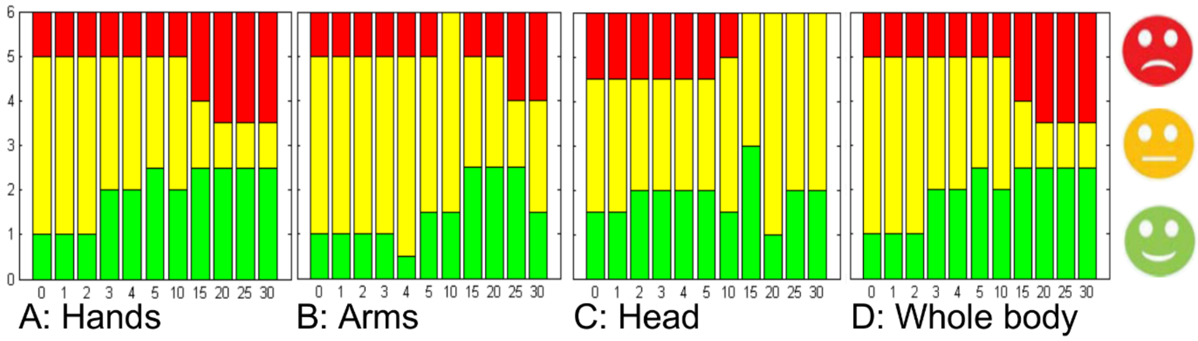

Figure 7: Comfort votes of the subjects in the ‘cold’ test, separated in three body parts and an overall vote. The height of the bar shows the number of votes per questionnaire. The time of the questionnaire is shown on the horizontal axis.

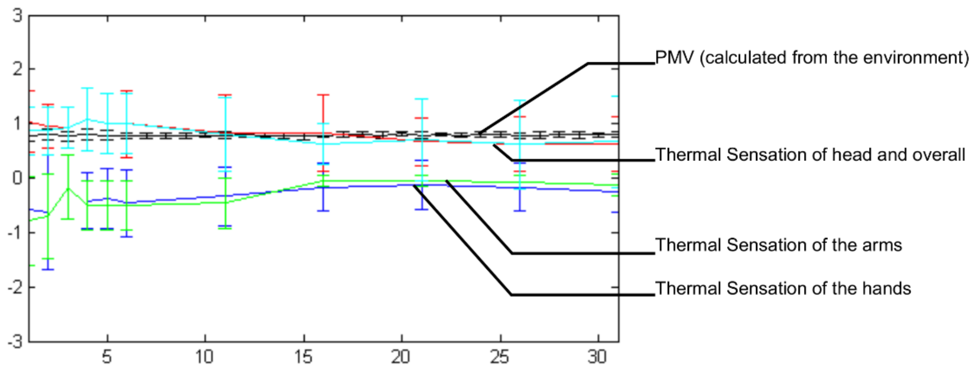

Figure 8: TS of the different body parts compared to the calculated PMV from the environmental conditions in the climate chamber during the ‘warm’ tests. The error bars mark the standard deviation.

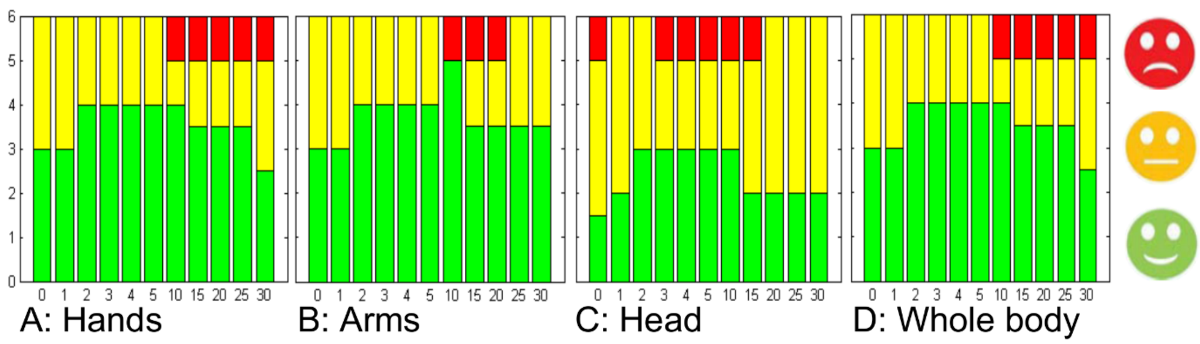

Figure 9: Comfort votes of the subjects in the ‘warm’ test, separated in three body parts and an overall vote. The height of the bar shows the number of votes per questionnaire. The time of the questionnaire is shown on the horizontal axis.

The comfort level of the test subjects during the ‘cold’ test is clearly divided in two sides and when the test progresses, both sides increase in size. Closer inspection of the individual votes show that no subjects crossed over from uncomfortable to comfortable and vice versa. The increase of both sides come from the people that initially votes neutral.

DISCUSSION

The alliesthesia effect can be seen in the development of both the TS and comfort votes for the exposed body parts during the test. Initially, the TS is lower than later on while the comfort votes show a reverse trend: comfortable at first and more neutral towards the end. The comfort level of the head is lower than on the other regions, this is in line with the findings of Arens et al. [9], that the head is the most sensitive body part in a warm environment.

The trend in the 'cold' test is different. The low temperature caused a much larger cooling effect, divided the subjects. This division could be a similar trend as found by Parkinson [8]. The initial state of discomfort determines how the stimulus effects the person. Habituation later in the test causes more people to vote either uncomfortable or comfortable rather than neutral.

In none of the tests, the heat balance of the subject could be changed. The overall TS remained close to the PMV. The effect of the plate on the comfort level, especially in the 'cold' series suggests that the cooling effect cannot be increased much further. This makes the cooling plate insufficient to provide locally thermal comfort. However, a combination with other local cooling systems such as personal ventilation might be suitable as a local cooling system.

The six subjects were all male and quite similar, this caused the small deviations between the tests. This number however is not sufficient to show significant results, the trend described in this paper is a starting point for future research.

CONCLUSION

The alliesthesia effect could be seen in the tests by looking at the TS and the comfort levels at the body areas exposed to the local cooling.

The cooling system however was not able to effect the heat balance of the person, making it hard to apply alone as a long term solution.

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