CLIMATE COOLING FOR COMFORT: CONVECTIVE OR RADIATIVE CHOICE

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INTRODUCTION

Many studies have shown that thermal comfort is related to mean thermal sensation (Fanger, 1970). In addition, it was shown that preferred skin temperatures are independent of clothing (Gagge *et al.*, 1938), but this applies only to light clothing (≤0.6 Clo). Olesen and Fanger (1973) have suspected the changes in skin temperatures to be detrimental to thermal comfort in heavy clothing, since in such a condition, the operative temperature for thermoneutrality is low and the skin temperatures then tend to non-uniformity, the unclothed parts being colder.

We showed more recently (Candas *et al.*, 1994) that even at thermoneutrality, the local heat losses of a thermal mannikin are fundamentally different under convective heating compared to radiative heating, although the average overall heat fluxes could be equal in both cases.

To try to confirm the observations which we had previously made from conditions implying some heating (by analogy with the winter conditions), we decided to investigate the summer comfort conditions, implying body cooling in order to reach neutral thermal sensation.

METHODS

Six groups of 10 young male subjects underwent one unique exposure, while wearing light clothing: short-sleeve shirt, summer trousers, briefs, light socks and sandals. The Clo value determined by using a thermal mannikin was 0.5 Clo.

Firstly, the subject, instrumented with local skin temperature probes, sat for 30 minutes in a slightly warm environment (PMV = 1.2, see Table 1). He then filled in the first questionnaire, elaborated according to the ISO 11399 (1995) recommendations. This questionnaire contains items on global and local (6 body parts) thermal sensations (9 point-scale), associated global and local pleasantness (7 point-scale from very unpleasant to very pleasant) and global preference (7 point-scale, from much cooler to much warmer).

Subsequently, the condition was changed so as to simulate air conditioning in summer. The refreshment of the chamber was expressed in terms of Equivalent and for a warmer one in Tf (p<0.01) although Teq was even slightly higher in Tf (26.7 °C).

	Tski °C	Tskf °C	ΔTsk °C	OMV a.u.	PREF a.u.	DISC %
Ta	34.7 (0.1)	33.9 (0.1)	-0.7 (0.1)	0 (0.2)	-0.3 (0.1)	5
Tf	34.4 (0.1)	33.9 (0.1)	-0.5 (0.1)	0.0 (0.3)	0.7 (0.2)	40
T2w	34.5 (0.1)	33.7 (0.1)	-0.8 (0.1)	0.7 (0.1)	-0.8 (0.2)	40
Tfc	34.4 (0.2)	34.0 (0.1)	-0.4 (0.1)	0.3 (0.2)	-0.4 (0.1)	20
T4w	34.5 (0.1)	33.8 (0.1)	-0.7 (0.1)	0.1 (0.2)	-0.2 (0.2)	15

Table 2: Initial (i) and final (f) of mean skin temperature (Tsk), (and SD); Tsk variations (ΔTsk); final mean values (and SD) of overall thermal sensation (OMV) and preference (PREF); final percentage of discomfort (DISC).

To try to explain these observations, local skin temperatures were examined for each of the main body segments: head, trunk, arms, hands, legs and feet. Figure 1 shows the results when local skin temperatures are expressed as differences to what was observed under the comfortable Ta condition.

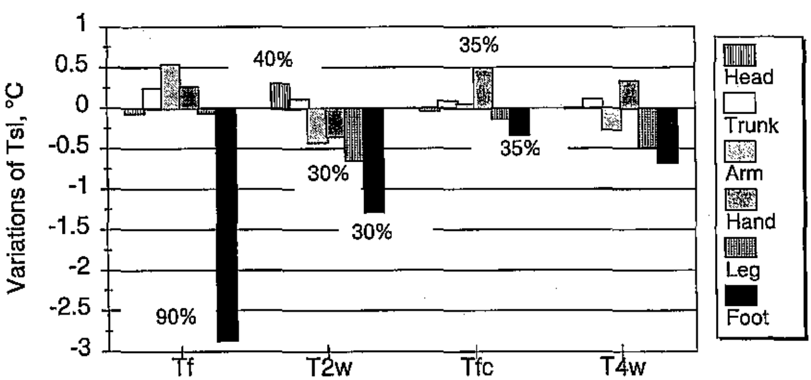

Figure 1: Variations of local skin temperatures expressed as differences from those observed under the Ta condition. Percentages (>30%) of local discomfort are also given.

Temperature (Table 1) assessed from the heat flux obtained with the Heatman® mannikin. The chamber environment was cooled in a linear manner from Teq = 29.6 °C to 26.5 °C in 20 min (the changes are given in thick characters in the table). Each condition was then maintained constant for 2 hours during which subjects were given questionnaires every 30 min.

	Initial climate	Conditions				
		Ta	Tf	T2w	Tfc	T4w
Tair, °C	30	**25.5**	30	30	30	30
Tfloor, °C	25	25	**7**	25	**17**	**22**
Tceiling, °C	30	30	30	30	**17**	**22**
Tlateral walls, °C	30	30	30	**17**	30	**22**
Tdp, °C	15	15	**6**	15	15	15
Va, $m.s^{-1}$	0.1	0.1	0.1	0.1	0.1	0.1
Flux, $W.m^{-2}$	23	41	38	41	37	38
Teq, °C	29.6	26.1	26.7	26.1	26.8	26.7

Table 1: Values of ambient parameters in the 5 conditions, starting from an initial slightly warm climate.

Initial and final data, corresponding respectively to the first and the mean values of the 2 last questionnaires, were analysed. Skin temperatures collected at the same time were treated using an ANOVA followed by a Dunnett's test with Ta condition as a control. Thermal sensations and preference assessments were compared to the Ta condition using a Mann-Whitney procedure. Discomfort was calculated from the unpleasantness ratings in the questionnaires, and compared to Ta values with the Chi-squarred method.

RESULTS

The initial thermal warm climate led to an observed thermal sensation (OMV) of +1.3 ±0.6 (mean ± SD). Table 2 reveals that initial mean skin temperature (Tski) in this warm condition was not different between the various subject groups before cooling occurred. In addition, final mean skin temperatures (Tskf) were not statistically different in any of the 5 climates tested.

OMV was compared to that observed under the Ta condition (which produced the smallest percentage of dissatisfied) and was higher in T2w ($p<0.01$) indicating that cooling 2 vertical walls was not as efficient as air cooling. However, discomfort (DISC) was significantly higher ($p<0.01$) under both T2w and Tf. At the same time, thermal preference (PREF) for a cooler environment was expressed in T2w ($p<0.05$)

Minimal skin temperature variations were observed under both Tfc and T4w (right part of the figure) whereas larger changes were found under Tf and T2w (left part), which were both estimated as uncomfortable.

In the Tf condition, local discomfort appeared to be concentrated on the feet, and was rated as unpleasantly cold in 90% of the cases. Under T2w, global discomfort probably originates from an opposition between warm head and cold legs and feet (local discomfort ≥30% of the cases). Tfc induced discomfort only of the extremities (35%).

CONCLUSIONS

The five conditions which were tested in this paper corresponded to PMV + 0.5 and should normally not generate discomfort, according to Fanger (1970). In fact, we observed global discomfort under two of them despite equal mean skin temperatures. While air conditioning at low air velocity is best appreciated, only homogeneous radiant cooling proved to be satisfactory. In the other radiative conditions, global discomfort originated from local discomfort. These local discomfort judgments are related to local variations of skin temperature or to spatial distribution changes. Until now, the usual tools such as PMV index or Teq cannot predict such kinds of discomfort. Therefore, we concluded that a computer model, taking into account the local skin temperature distribution, could predict the risks of discomfort. We propose the use of a revised Stolwijk model which includes a better assessment of all local radiant heat exchanges and predicts the local skin temperature changes. Our predictive model is in agreement with the responses of human subjects in the conditions tested.

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