ASSESSMENT OF RISK OF DISCOMFORT DUE TO THERMAL TRANSIENTS BASED ON A COMPUTER MODEL OF THERMOREGULATION

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INTRODUCTION

Thermal comfort is based on the thermosensory estimates of people exposed to steady-state conditions, and comfort is predicted from the human heat balance equation, which is quite easy to calculate when ambient parameters are stable. The Stolwijk computer model makes it possible to quantify the physiological responses to the ambient condition, and from it, we have derived a psychophysiological model (1) predicting the risk of discomfort originating from changes in the local skin temperature distribution (2). To check whether this model could also predict, with good accuracy, the discomfort risk under thermal transients, we carried out experiments in which subjects were exposed to climates leading them progressively from a slightly warm to a slightly cool sensation (and vice-versa) in 30 or 60 minutes.

METHODS

Forty-eight subjects volunteered for these experiments, and each of them participated only once, after having signed an informed consent about the conditions approved by the ethics committee. Four groups of 6 males and 6 females were exposed to thermal ramps in a climatic chamber. Mean skin temperature (T_{sk}) was calculated from 10 local sensors. Observed mean votes and discomfort were deduced from responses to standard questionnaires that had been filled in by subjects before, during and after the thermal transients. The protocols (see Table 1 below for ambient parameters) were as follows: (1) for P1 and P2, after 30 minutes of a 21°C uniform climate (predicted mean vote: PMV = −1), the thermal environment was linearly increased to PMV = +0.5 in either 30 (P1) or 60 (P2) minutes; (2) for P3 and P4, after 30 minutes of the PMV = +0.5 climate,

Table 1. Ambient Conditions

Condition PMV = −1	*Conditions PMV = +0.5*	
Start of P1 − P2 End of P3 − P4	P1 - P3	P2 - P4
Ta = Tr = 21°C	Ta = 28.5°C Tfloor = Twalls = 21°C	Ta = Tfloor = 27,1°C Twalls = 21°C
Air velocity = 0.12 m.s^{-1} ; Dewpoint temperature = 14°C		

the thermal environment was linearly decreased to PMV = −1 in either 30 (P3) or 60 (P4) minutes.

After these transients, the climate was constant for 90 min. The physical parameters of these conditions (given in the table) were chosen to mimic either a thermal change by convection (only T_a was modified) or an indoor solar effect (resulting in a change in floor temperature associated with an air thermal rise).

RESULTS

Left upper part of Figure 1 shows the T_{sk} as a function of time. T_{sk} showed the same pattern under both positive and negative thermal changes. However T_{sk} decreased faster under P3 since T_{sk} was found lower at min 75. T_{sk} decreased more (−2 °C) during negative transients than it increased (+0.5°C) during the positive ones, for the same PMV. This is mainly due to lesser increases in the skin temperatures of the lower part of the body (legs and feet). Right upper part of the figure shows the changes with time in the whole-body thermosensory judgements. In opposition to what was observed on T_{sk}, the thermal votes associated with negative transients did not differ, whereas they did differ during the positive thermal ramps: the increase in the mean thermal vote was greater under the 30-min thermal ramp compared to the 60-min ramp.

Left lower part of the figure illustrates the results of the variation in the percentages of dissatisfied people. Considering a threshold of 30%, as necessary for

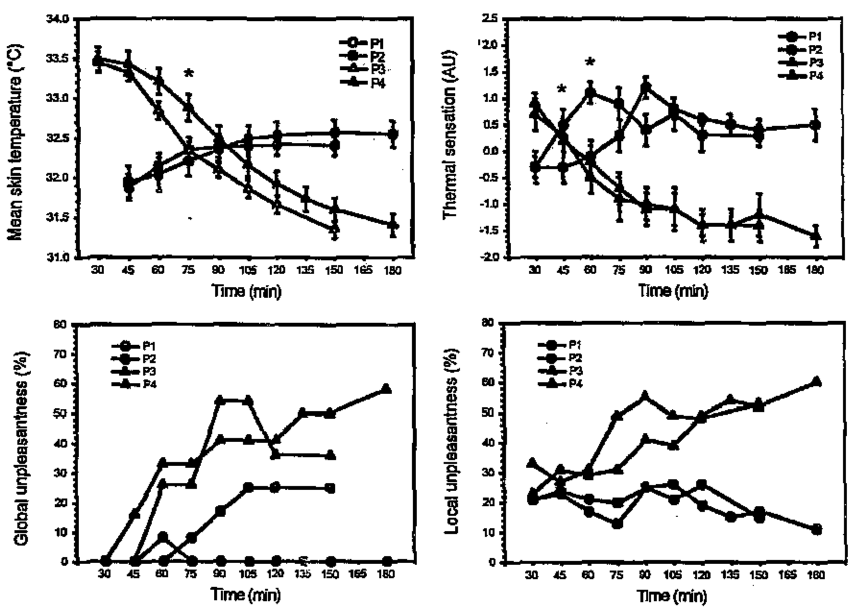

Figure 1. Top: mean skin temperatures and average whole body thermal sensations (both with SEM). Bottom: percentages of dissatisfied people and of local unpleasantness.

a pronounced discomfort, leads to the conclusion that the cool conditions were judged as uncomfortable while no discomfort was ever observed in the warm environment. It is worthwhile to note that the 30% (5%) were only passed at min 90 under both negative thermal transients.

Right lower part of the figure illustrates the same results in relation to discomfort, but based on local estimates. The values presented here are the sums of all the local discomfort estimates, expressed by the subjects on a schematic human drawing, seen from front and back (13 zones): these are percentages of possible responses. When considering again a 30% threshold as a value above which discomfort is obviously expressed, it can be stated from the figure that no discomfort was found during and after the warm transients, while discomfort was clearly expressed when the thermal transients led to a cool climate (P3, P4).

DISCUSSION

The PMV index is a good index for the prediction of the mean thermosensory judgement: the present study confirms that a PMV of -1 corresponding to a whole-body cool thermal sensation provokes discomfort, while a slightly warm PMV of +0.5 does not. But the associated PPD appears largely underestimated. Our experience confirms that a level of 30% (in the case of a small number of subjects) is generally a threshold that can be considered for discomfort certainty. In addition, our results show a good concordance between overall discomfort and local unpleasantness. This is an interesting point since whole-body discomfort is obtained from a unique judgement (which can sometimes be altered for some unknown reason), while local unpleasantness estimates are obtained from many possible answers proposed to the subjects (in our case, 13 zones represented on a human-like shape). However, the same threshold value of 30% has to be considered before whole-body discomfort can be ascertained.

To predict the risk of discomfort, we elaborated a computer model, which calculates the degree of likely dissatisfaction, based on an integration of the thermal changes in all local body segments. It takes into account the following:– the T_{sk} changes; the large-body segments thermal state (hand, torso, back, arm, hands, legs and feet); the thermal differences between the extremities, as well as the thermal state of these extremities (head, hands and feet); and the differences between right and left side and/or upper and lower part and/or front and back of the body. Our model uses a formula that integrates all of these components, some of them having an additive effect, some others a multiplicative one. The left part of Figure 2, below, shows the prediction of the T_{sk} under the 4 thermal conditions; the right part illustrates what is called the discomfort risk (IRI) resulting from the integration of all local thermal inputs calculated by the computer. An arbitrary value of 80% predicts some discomfort probability, while a value of 100% or more reflects pronounced discomfort.

The results obtained from the computer model are in good agreement with those found during the experiments. No discomfort is predicted during and after the positive ramp (P1 and P2) and no discomfort was observed in reality. In opposition to this, both negative transients towards PMV $= -1$ should induce discomfort: under the 30 min ramp (P3), computer predicts discomfort at time 80 min, while real discomfort was found at time 90 min in the experiments. A small difference is found for the P4 simulation (60 min ramp) since discomfort is predicted by the model at time 110 min, while it was found earlier (at time 90 min) in the experiments; nevertheless, prediction of unpleasantness was obtained as really observed. In conclusion, if it is well known that discomfort in humans originates from thermal imbalance, it can also be the result of the local variations from a theoretical thermal distribution required for comfort. Our computer model, based on negative effects of changes in the optimal skin temperature distribution, appears as a good tool for predicting these discomfort risks, even during or after thermal transients.

REFERENCES

1. Candas, V. and Herrmann, C. 1995, Les bases physiologiques de l'inconfort, in F. Penot et J.B. Saulnier (eds.), *La thermique de l'Homme et de son proche environnement* (Paris: Elsevier), 111-122.
2. Candas, V., Herrmann, C., Bothorel, B., Sari, H. and Gonord, M. 1996, Climate cooling for comfort: convective or radiative choice, in Y. Shapiro, D.S. Moran and Y. Epstein (eds.), *Environmental Ergonomics. Recent Progress and New Frontiers (ICEE 96)* (London and Tel Aviv: Freund Publishing House), 174-178.

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