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Overall thermal sensation, acceptability and comfort

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Abstract

The relationships between overall thermal sensation, acceptability and comfort were studied experimentally under uniform and non-uniform conditions separately. Thirty subjects participated in the experiment and reported their local thermal sensation of each body part, overall thermal sensation, acceptability and comfort simultaneously. Sensation, acceptability and comfort were found to be correlated closely under uniform conditions and acceptable range ran from neutral to 1.5 (midpoint between 'Slightly Warm' and 'Warm') on thermal sensation scale and contained all comfortable and slightly uncomfortable votes on thermal comfort scale. Under non-uniform conditions overall thermal acceptability and comfort were correlated closely. However, overall thermal sensation was apart from the other two responses and non-uniformity of thermal sensation was found to be the reason for the breakage. Combining the effects of overall thermal sensation and non-uniformity of thermal sensation, a new thermal acceptability model was proposed and the model was testified to be applicable to uniform and non-uniform conditions over a wide range of whole body thermal state from neutral to warm.
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Keywords: Thermal sensation; Thermal acceptability; Thermal comfort; Non-uniform environment; Non-uniformity of thermal sensation

1. Introduction

With the requirements of energy saving, more and more attention is paid recently to the study on thermally non-uniform environment. Assessment of non-uniform environment is a highlighted problem for well-designed non-uniform environment practice in buildings.

For the assessment of uniform and steady thermal environment, the known indices, such as PMV, ET* and SET, which predict human thermal sensation by environmental parameters and personal informations, are widely accepted. However, there is no universal index to evaluate thermally non-uniform environment, and overall (whole body) thermal sensation [1–4], overall thermal acceptability [5–8] and overall thermal comfort [9–12] were used separately by different researchers. It would be useful to understand the relationship between overall thermal sensation, acceptability and comfort under non-uniform environment.

The relationship between thermal sensation and acceptability was firstly clarified by Fanger [13], who defined the dissatisfied based on the experimental results by Gagge et al. [14] as those who vote 'Cool' or 'Cold', 'Warm' or 'Hot'. This definition was confirmed by Berglund [15] through comparison with the responses obtained by directly asking subjects whether they find the thermal conditions acceptable or unacceptable. As the relationship was derived and confirmed under uniform conditions, its validity under non-uniform conditions remains untested.

The relationship between thermal comfort and acceptability was investigated by Berglund [15]. He compared the effect of temperatures that deviate from those of optimum comfort assessed by percent comfortable [16] with the one by thermal acceptability [17] and found that they were quite similar, which indicates that the thermal comfort votes falling in comfortable or slightly uncomfortable range were perceived by the subjects as acceptable. The comparison was conducted under uniform environment and the one for non-uniform environment remains vacant.

The known relationships between thermal sensation, acceptability and comfort were derived qualitatively under

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uniform environment. The purpose of the present study was to investigate quantitatively the relationships between overall thermal sensation, acceptability and comfort under uniform and non-uniform environments and to develop a new thermal acceptability model applicable to both environments.

2. Experimental methods

The experiment was carried out in the climate chamber in Tsinghua University. The chamber was used to achieve a thermally uniform environment and the ambient air temperature in the chamber was maintained with a precision of ±0.2 °C. Personalized ventilation system was used to produce non-uniform environment by supplying local cooling airflow to three sensitive segments of human body—face, chest and back—separately.

Three room temperatures, ranging from neutral to warm, were chosen and for each room temperature, three local cooling target temperatures (target temperature means the air temperature at the center of cooling body part surface), ranging from neutral to slightly cool, were studied in the present study (Table 1). Relative humidity was kept at 40%, and air velocity was less than 0.1 m/s in the room air. Air velocity at the outlet of local cooling airflow was maintained at 1 m/s.

Each test consisted of half-an-hour exposure to uniform condition and half-an-hour exposure to non-uniform condition. The ambient room temperature was maintained the same and local cooling airflow was supplied only when the exposure to non-uniform condition started. Thirty randomly selected Chinese students, with a normal range of age, height and weight, participated in the experiment of all conditions and the total duration for each subject was 27 h. All the subjects wore only shorts during the experiment to keep the same clothing insulation for the three cooling body segments. The sequence of presentation was balanced among the subjects. Three subjects participated in the test at one time and remained sedentary throughout each exposure. Conversation was permitted but the subjects were not allowed to exchange views concerning the thermal environment.

Table 1
Experimental conditions

Room temperature (°C)	28–32–35
Target temperature (°C)	22–25–28

Subjects reported their local thermal sensation of each body part, overall thermal sensation, overall thermal acceptability and overall thermal comfort simultaneously at each voting time and three times in the last 10 min for each exposure. Thermal sensations were reported on ASHRAE 7-point scale (Fig. 1a). A visual-analogue scale indicating acceptability, originally developed to evaluate indoor air quality by Gunnarsen and Fanger [18], was used in the present study (Fig. 1b). A thermal comfort scale developed by Zhang [11] was applied in the present study to force subjects to make a clear determination about whether their perceived state falls in the category of ‘Comfortable’ or ‘Uncomfortable’ (Fig. 1c).

3. Results and discussion

Shapiro–Wilk’s W test was applied and the results show that human responses obtained in all conditions were normally distributed. They were therefore analyzed using repeated-measure ANOVA. Compared with independent-measure design, repeated-measure design with balanced order of presentation is a more efficient approach, which

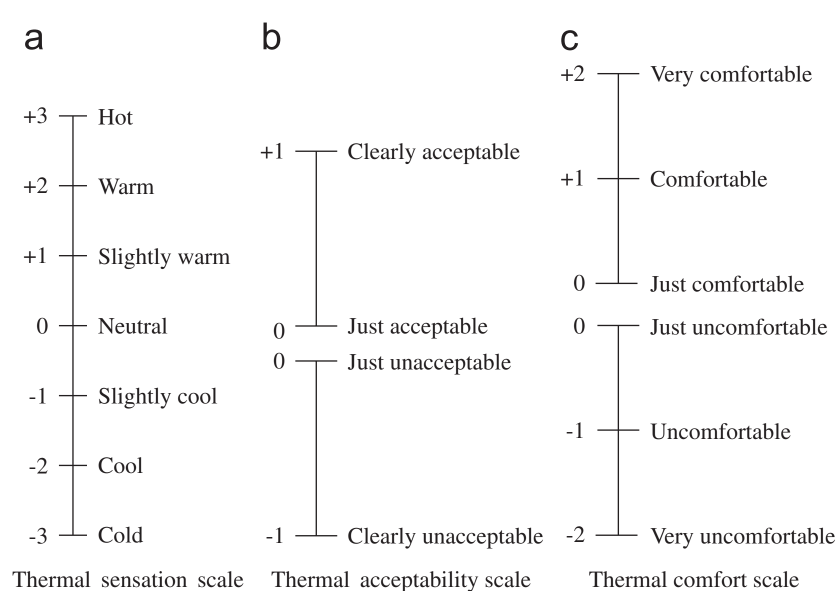

Fig. 1. Voting scales: (a) thermal sensation scale; (b) thermal acceptability scale and (c) thermal comfort scale.

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