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Energy efficient thermal comfort in temporarily occupied space – A summer case study in Tianjin

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Abstract
Temporarily occupied space is defined as an air-conditioned space in which most of occupants stay for less than a certain period (e.g., 40 minutes) such as post offices, supermarkets, bookstores and banks. After moving from a hot and humid outdoor environment to an air-conditioned temporarily occupied space in summer, thermal alliesthesia takes effect, which refers to 'thermal pleasure sensation and overshoot generated by the restoration of thermal stress toward a neutral interior condition'. Because of the overshoot, occupants' acceptable temperature ranges in temporarily occupied space are possibly elevated by less intensified air conditioning systems while they still feel comfortable. To address this issue, a human subjective response study was performed in one climatic chamber used to simulate temporarily occupied space in Tianjin. 16 healthy university students, 8 males and 8 females, were exposed to outdoor environment for 20 minutes before they stayed in the chamber for 40 minutes. Their votes on thermal sensation, comfort and preference were recorded for evaluation at different time points. The results show that, in summer, the optimal design temperature range for temporarily occupied space in Tianjin is elevated to 27 °C to 29 °C without influencing thermal comfort, enabling large amounts of cooling and dehumidification energy to be saved for air-conditioning systems. Meanwhile, thermal comfort for staffs who have long term exposure to the environment could be maintained by personal comfort systems such as desk fans or personalized ventilation in terms of spatial alliesthesia.

Keywords - temporarily occupied space; thermal transient; energy saving

1. Introduction

Non-uniform indoor environment is based on spatial concept, which could be created by intensified local conditioning and less intensified ambient conditioning [1-3]. Based on temporal concept, no definition emphasized human occupied time and thermal experience. People may spend different length of time staying in various spaces and the length of time can range from several minutes to a whole day, which influences the requirement for environmental parameters. Temporarily occupied space (TOS) is proposed considering time factors and thermal experience. It is defined as an air-conditioned space in which most of occupants stay for less than a certain period (e.g., 40 minutes). Based on the above definition of the TOS, people experience marked step changes of temperature when they enter and stay in a TOS. However, no recommendation on acceptable indoor temperature ranges under step changes when people enter a TOS has been specified [4-6]. Current thermal comfort standards do not address design temperature ranges for TOSs clearly. The study is to explore human responses to TOSs with the ultimate goal of finding the design temperature ranges in summer.

2. Methods

The experiment was performed in a climate chamber in Tianjin University during summer. The dimensions of the climate chamber are 7.0 × 4.5 × 3 m (volume = 94.5 m^3). Piston airflow is generated by ceiling supply diffusers and return air grills on the raised floor. The room was set up to simulate a TOS in this study. Objective parameters, including air dry-bulb temperature, relative humidity, globe temperature and air speed, were measured.

Five experimental conditions were selected to represent typical dry-bulb temperature levels in an air conditioned TOS in summer. Air speed was kept below 0.1 m/s and mean radiant temperature was maintained close to air dry-bulb temperature for all experimental conditions. Before the formal experiments, the test chamber was conditioned to the target dry-bulb temperature at least 2 hour ago. Steady states were kept and a 1600 W heater was used to simulate heat generation from 16 participants (8 males and 8 females). When the participants entered the chamber and started the formal experiments, the heater was switched off. The experiments were performed in the middle of July, the hottest period in summer with outdoor air temperature fluctuating around 32 °C, when human participants completely adapted to the summer season.

Before attending the formal experiments, all human participants attended one training session to be familiar with the experimental chamber, experimental procedure and survey questionnaire. The 16 human participants attended the experiments under the 5 different conditions. The experimental procedure is shown in Fig. 1. Before each experiment, the human participants were asked to arrive and stay outdoors for 20 minutes before they entered the chamber. They filled in the questionnaire for the first time after they stayed 15 minutes outdoors. When they just entered the chamber and seated, they were asked to fill in the questionnaire for the second time. After that, they were asked to fill in the questionnaire for four times. The whole experiment lasted 60 minutes and each human participant filled in the questionnaire 6 times. All the participants were required to wear clothes that have about 0.6 clo thermal insulation.

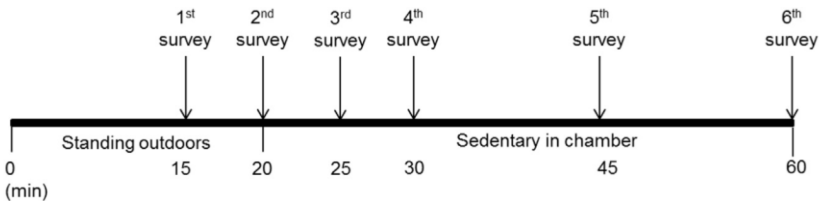

Fig. 1 Experimental procedure

A standardized questionnaire was used, which is divided into three sections. Personal information and anthropometric data are included in the first section. The second section includes a conventional scale of thermal sensation (seven-point scale: cold = -3; cool = -2; slightly cool = -1; neutral = 0; slightly warm = 1; warm = 2; hot = 3) and thermal preference (want cooler = -1; no change = 0; want warmer = 1). It also includes a scale of thermal comfort (four-point scale: very uncomfortable = -2; uncomfortable = -1; comfortable = 1; very comfortable = 2) (Fig. 2). The third section includes a garment list and current activities.

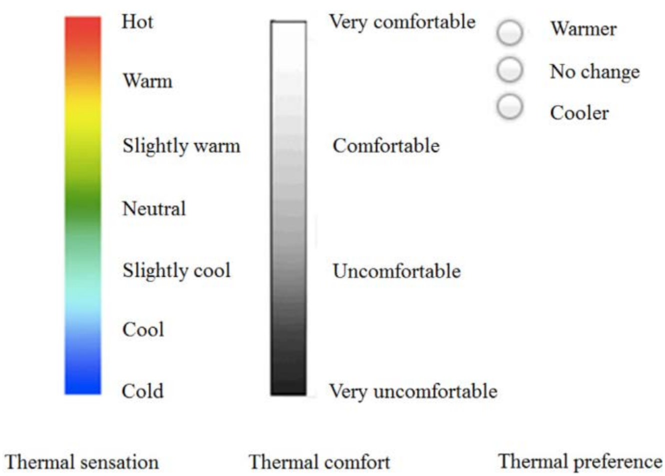

Fig. 2 Survey questions

3. Results and discussion

3.1 Thermal sensation

Thermal sensation changes of human participants in the 5 cases are shown in Fig. 3. In all these cases, cooling overshoots at 20 minutes are obviously observed. Thermal sensation reaches a relatively steady state after 10 minutes exposure to the cool environment, which demonstrates human body thermoregulation may not rapidly react to the challenge by a temperature step. For 23 °C case, thermal sensation reaches the relatively steady state after slightly longer than 10 minutes because of the big temperature step. The thermal sensation vote (TSV) difference at 60 minutes (steady state) and 20 minutes (cooling overshoot) for different cases were compared. The ΔTSV reduces from 0.81 through 0.73, 0.65, 0.6 to 0.5 when temperature increases, which demonstrates the influence of temperature difference on cooling overshoot effect. For 27 °C case, steady state thermal sensation at 60 minutes is 0.68. However, steady state thermal sensation at 60 minutes is 1.41 when temperature increases to 29 °C. There should be a threshold value, which is about 28 °C and could be used as the highest acceptable temperature in the TOS. Further case studies with smaller temperature steps are necessary to identify this threshold value. Use of different types of fans, such as ceiling fan, could elevated this threshold value to higher temeprature for saving more air conditioning energy in TOS.

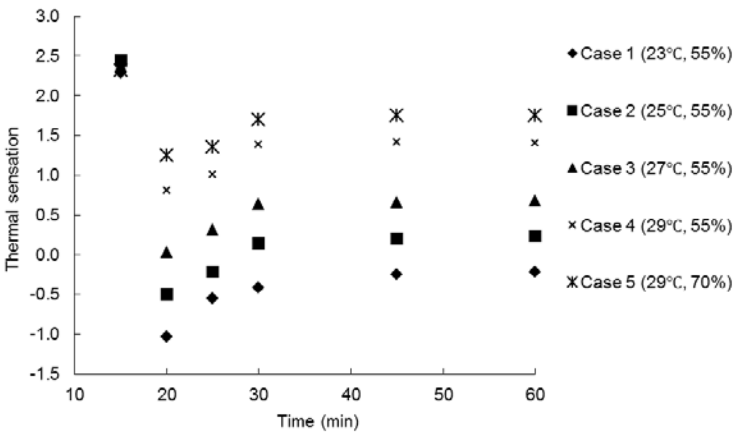

Fig. 3 Participant's thermal sensation changes during the experiment

3.2 Thermal preference

Thermal preference changes of human participants in the 5 cases are shown in Fig. 4. All human participants prefer to be cooler in the hot and humid outdoor environment. At 20 minute when the participants just entered the chamber, they prefer to be warmer in case 1, to be cooler in case 4 and 5, and to keep unchanged in case 2 and 3. From 20 to 30 minute, thermal preference values reduce in all cases. After 30 minute, thermal prefernce values reach steady state in all cases. For case 1, thermal preference moves close to keep no change after the disappearance of cooling overshoot. For case 4 and 5, human participants prefer to be much cooler after the disappearance of cooling overshoot.

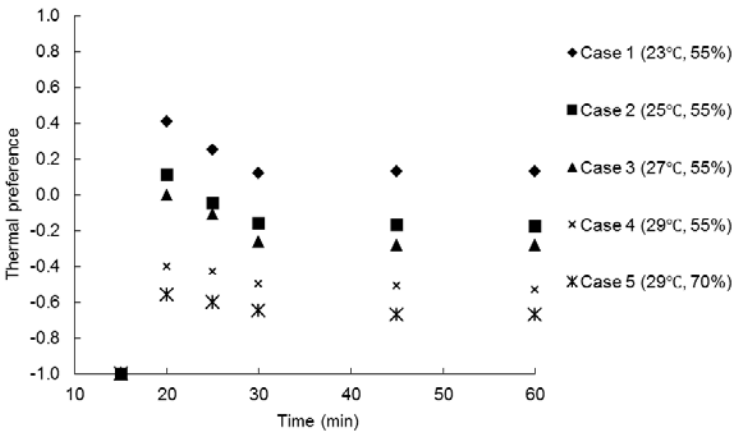

Fig. 4 Participant's thermal preference changes during the experiment

3.3 Thermal comfort

Thermal comfort changes of human participants in the 5 cases are shown in Fig. 5. All participants feel hot uncomfortable in the outdoor environment. At 20 minute, thermal comfort votes increase to postive value except case 5. At 30 minute, cooling overshot disappear and thermal comfort votes reach steady state. Maximum thermal comfort value during cooling overshoot period is 1.61 in case 1 because of about 10 °C temperature step between the outdoor temperature and the indoor temperature. At 60 minute, thermal comfort vote in case 1 reduced to 0.6, which is lower than thermal comfort vote in case 2. Overcooling is demonstrated to some extent in case 1. Thermal comfort vote in case 3 is 0.44 and thermal comfort vote in case 4 is -0.2. From thermal comfort point of view, the highest acceptable temperature exists between 27 °C and 29 °C, which is in agreement with the results in section 3.1. Elevated air movement in TOS by using fans could increase this threshold value for saving more air conditioning energy. Humidity must be controlled strictly, which was verified by case 5.

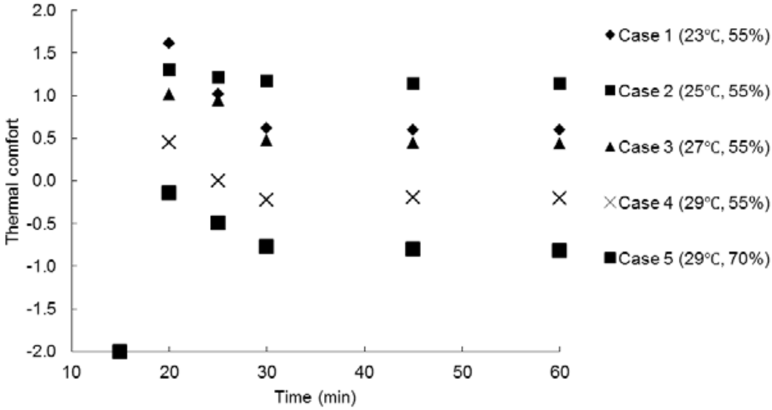

Fig. 5 Participant's thermal comfort changes during the experiment

4. Conclusions

In a TOS, cooling energy can be saved because of short term staying, which is less than 40 minutes. The indoor temperature of a TOS has impact on the TSV difference between steady state (60 minute) and cooling overshoot time (20 minute). From thermal comfort viewpoint, a temperature range between 23 °C and 27 °C is highly desirable for occupants staying in a TOS. Highest acceptable temperature exists between 27 °C and 29 °C, which demonstrates the potential of evelating setpoint temperature of a TOS in summer. More human subjects with different age ranges should be tested.

Acknowledgment

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