A winter case study on synergy effect of temporal and spatial alliesthesia in temporarily occupied spaces

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Abstract. Temporarily occupied space (TOS) is defined as a conditioned space in which most of occupants stay for less than a certain period (e.g., 40 min). Based on the concept of TOS, specific application scenarios for transient and non-uniform thermal environments were explored by chamber tests. In the study, human subjective assessments were obtained from 16 subjects (8 males and 8 females). The synergy effect of temporal and spatial alliesthesia in TOS was quantitatively analyzed, which could achieve energy efficient thermal comfort. The synergy effect extended human thermal comfort under lower neutral temperature.

Keywords: Temporal alliesthesia, Spatial alliesthesia, Temporarily occupied space (TOS), Thermal comfort, Energy efficiency

1 Introduction

Temporarily occupied space (TOS), such as waiting areas of banks, post offices, railway stations, was defined as indoor spaces in which most of occupants stay for less than a certain period (about 40 minutes) [1]. The concept of TOS provides a specific application case for the study of temporal alliesthesia and spatial alliesthesia thermal environments. Temporal alliesthesia mainly refers to thermal overshoot caused by temperature sudden changes [2-4]. Spatial alliesthesia mainly refers to thermal stimulation to sensitive body segments [2,5-7]. Although temporal alliesthesia and spatial alliesthesia were well studied [8-12], the synergy effects of temporal alliesthesia and spatial alliesthesia were seldom explored. One of the reasons is that practical application cases were not clearly presented before the concept of temporarily occupied spaces. In this paper, the method of target and perimeter is used to study the transient and non-uniform thermal environment of TOS in winter. It puts forward a new idea for improving human thermal comfort and reducing energy consumption.

2 Methods

The experiment was performed in a climate chamber in winter. This chamber is located in Xi’an (latitude: 33°42′ to 34°45′N, longitude: 107°40′ to 109°49′E), China. During the experiment, the outdoor temperature (mean ± standard deviation [SD]) was 2.8 ± 1.1 °C. The dimensions of the climate chamber are 3.8 m (length) × 3.8 m (width) × 2.6 m (height) (volume = 37.5 m³) (Fig. 1). The chamber is used as TOS in this study. In this experiment, the process of entering indoor environment from outdoor environment with lower temperature creates temporal alliesthesia. Four adjustable heated chairs created spatial alliesthesia. The heated chair is shown in Fig. 2. In this study, heating power of the back and seat cushion was set to 10 W/m² and 5 W/m², respectively.

Fig. 1. Climate chamber and the measurement point of environmental parameters.

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2.1 Measuring parameters

Air velocity was measured with hotwire anemometers (SWEMA03, Swema Corp., Sweden, accuracy ±0.05 m/s). The air velocity is measured before the experiment. Air temperature/relative humidity was measured using sensors HOBO U12-012 (Onset Corp., USA, temperature accuracy ± 0.35 °C, RH accuracy ± 2.5%). Globe temperature was measured using sensors HQZY-1 (TianJianhuayi Co., Ltd, China, accuracy ± 0.3 °C). CO₂ level was measured using sensors RTR-576 (T&D Corp., Japan, CO₂ accuracy ± 50ppm). These physical parameters were measured at 0.6 m height at the room center. In this study, the CO₂ concentration was less than 700ppm throughout the tests. Air speed was kept below 0.15 m/s and mean radiant temperature was maintained close to air dry-bulb temperature for all experimental conditions. The details of experimental parameters are summarized in Table 1.

| case | Target air temperature (°C) | Measure air temperature (°C) | Target relative humidity (%) | Measure relative humidity (%) |
|------|-----------------------------|-----------------------------|----------------------------|----------------------------|
| 1    | 12                          | 11.8 ± 0.1                  | 50                         | 49.8 ± 3.2                  |
| 2    | 14                          | 13.9 ± 0.1                  | 50                         | 48.3 ± 2.1                  |
| 3    | 16                          | 15.9 ± 0.1                  | 50                         | 47.3 ± 1.8                  |
| 4    | 18                          | 18.0 ± 0.1                  | 50                         | 47.0 ± 1.8                  |

2.2 Participants and experimental design

Sixteen healthy volunteers (8 male, 8 female) were recruited for the study. Their age, height, weight and body mass index (mean ± [SD]) were 22.4 ± 1.5 years, 1.69 ±0.08 m, 60.2 ± 8.1 kg and 21.0 ± 1.8 kg/m², respectively. Drugs and alcohol uses were not allowed at least 24 hours before experiments. They received an honorarium once completed all trials. The experiment was divided into two stages including 30 min outdoor exposure and 60 min indoor exposure. The subjects started the outdoor exposure at -30th minute. They filled out the questionnaire at the -20th minute. The subjects enter the chamber at the 0th minute. The experimental procedure is shown in Fig. 3. A standardized questionnaire was used. The thermal sensation vote (TSV) and neutral temperature was studied.

2.3 Statistical analysis

Shapiro–Wilk normality test was used to examine whether the data were normally distributed. The homogeneity of variance between data was conducted by Levene’s test. When the data were not normally distributed and have uncertain distribution status, the Wilcoxon signed–rank test was used to verify whether there was a significant difference in the overall distribution. For normally distributed data with similar variance, the paired t–test was applied. Results are considered to be statistically significant when p<.05.

3 Results

3.1 Neutral temperature

TSVs for all four test cases were not in normal distribution (Shapiro–Wilk, p<.05). There are significant differences in TSVs between any two out of the four test cases (Wilcoxon signed–rank test, all p<.05). As shown in Fig.4, the neutral temperature of the 5th, 10th, 15th, 20th, 25th, 30th, 40th, 50th and 60th minutes after entering the TOS was calculated by linear regression. The neutral temperature is 14.9°C, 14.5°C, 14.2°C, 14.0°C, 14.4°C, 14.8°C, 15.4°C, 16.0°C and 16.4°C, respectively. Figure 5 depicts temporal variations in the neutral temperature. The minimum neutral temperature is 20th minutes after entering TOS. It is 14°C. At 33th minutes after entering TOS, the neutral temperature increased as the same as at 5th minutes.
3.2 Neutral temperature difference

In this study, the neutral temperature difference was calculated by regression of indoor and outdoor temperature difference and the 5th minutes of thermal sensation vote after the subjects entered the TOS. As shown in Fig. 6, by linear regression calculation, the neutral temperature difference of 5th minutes after entering the TOS in Xi’an is 12℃.

4 Discussion

A previous study on temporal alliesthesia in TOS [1] showed the big temperature differences and different experimental conditions could be two key factors for reaching a thermal sensation steady state. TSV in the lower temperature condition can be improved by temporal alliesthesia. In addition, the time for reaching a thermal sensation steady state is about 10 minutes. Parkinson et al. [5,6] divided the spatial alliesthesia into air movement and contact heating. It should be
mentioned that the concept of a one-size-fits-all approach to the provision of thermal comfort for a given population is fundamentally flawed in transient and non-uniform thermal environments [5-8]. The individual free control is very important to achieve individual thermal comfort in built environments. Meanwhile, the local thermal discomfort can be coherently interpreted within the theoretical framework of spatial alliesthesia. Documented studies of spatial alliesthesia [11,12] showed that the heated chair or footwarmer can reduce the heating temperature in winter while maintaining neutral thermal comfort. This provided the possibility for the synergy effects of temporal alliesthesia and spatial alliesthesia in TOS.

As shown in Fig. 4, the neutral temperature increased after entering TOS at the 20th minutes. After entering the chamber, the temporal alliesthesia began to weaken after heating overshoot. Spatial alliesthesia was generated by the heating chair. The pressure controlled heating chair need a slow heating process. The neutral temperature was tugged at by an invisible force. There was no decline as before. It went up slightly. This stage took at the 20th minutes. At 33th minutes after entering TOS, the neutral temperature increased as the same as at 5th minutes. Temporal alliesthesia may be superimposed over spatial alliesthesia during the time course. They are reflected through the combined effects. The synergy effect of temporal and spatial alliesthesia extended the duration of alliesthesia-based thermal comfort.

5 Conclusions

The best synergy effects of temporal alliesthesia and spatial alliesthesia are 20th minutes after entering the TOS. The heated chairs extend the comfort of the occupants by 33 minutes. The neutral temperature of 14 °C can be regarded as the minimum temperature in TOS. This study provides a scenario for practical application of synergy effect of temporal and spatial alliesthesia. The non-adjustable heated chair (3W) was used to induce the contact heating spatial alliesthesia.

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