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Experimental study on the effects of climatic characteristics on people's adaptability to thermal environment

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Abstract: In order to find out how the climatic characteristics affect people's adaptability to thermal environments, experimental studies in a climate chamber are conducted on the effects of transition seasons (from spring to summer) and the occupants' native areas on indoor thermal sensations. Results reveal that people's tolerances to cool and warm indoor environments are different in the transition season. When the outdoor temperature is higher, the occupants have a weaker tolerance to a cool indoor environment, but a stronger tolerance to a warm indoor environment. Besides, it is found that the occupants' thermal sensations depend on both the climatic characteristics of the season and their native areas. The people from southern China present a greater tolerance to both warm and cool indoor environments than those from northern China. The reason can be explained according to the occupants' adaptability to the climatic characteristics and the indoor thermal environments of their native areas in different climate zones.

Key words: climatic characteristics; adaptability; thermal sensation; tolerance

The PMV (predicted mean vote) proposed by Fanger[1] is one of the most widely used thermal comfort indices. According to PMV, the human's thermal sensation and comfort is connected by six parameters: air velocity, air temperature, air humidity, mean radiant temperature, clothing thermal resistance, and metabolic rate.

Many recent studies have revealed that the PMV deviates from the TSV (thermal sensation vote) in an environment which deviates from that which is neutral. The reason may be that the person is not only a passive recipient of the given thermal environment, but also acts with the person-environment system. In some ways people adapt to the thermal environment. An adaptive model was proposed by de Dear and Brager based on results from numerous field studies[2-3]. In the model, the indoor comfortable temperature is a linear function of the monthly mean outdoor temperature:

$$T_{\mathrm{com,f}} = 0.31 T_{\mathrm{out,m}} + 17.8 \tag{1}$$

where $T_{\mathrm{com,f}}$ is the indoor comfortable temperature, and $T_{\mathrm{out,m}}$ is the monthly mean outdoor temperature. This adaptive model is today largely accepted throughout the world[4-7].

Zhou et al.[8] found in a climate chamber experiment that the outdoor temperature had effects on subjects' thermal sensations. At the same indoor operative temperature, subjects' thermal sensations are higher when the outdoor temperature is lower, and vice versa. In a field study[9] on students' thermal sensations in classrooms in Beijing during the transition season and the space heating season (winter), the outdoor temperature influenced the indoor thermal sensation when the indoor temperature was not neutral. For example, in winter a low outdoor temperature made people better adapt to a cool indoor environment and vote a higher TSV than the PMV predicted.

Thus outdoor temperature seems to affect indoor thermal sensation. However, it is still not clear how outdoor temperature affects people's thermal sensations to a cool indoor environment in a transition season. The aim of this study is to try to investigate whether people tolerate a cool indoor environment better when it is warm outdoors and whether occupants' native areas (northern or southern China) influence their indoor thermal sensation.

1 Methods

1.1 Time and place

The experiment was carried out in a climate chamber from April to May in 2009. The air temperature was controlled within 0.5 ℃, and the air relative humidity was within ±5%. The air mean velocity ranged from 0.02 to 0.05 m/s.

1.2 Subjects

A total of 29 college students (20.8 ± 3.6 years in age) are recruited to the experiment. Among those, 13 are males, 16 are females. Eleven come from southern China, and 18 come from northern China.

1.3 Instrumentation

The indoor environment parameters, including air temperature, air relative humidity, globe temperature, air velocity, are measured by the LSI hot environment monitoring station. And the mean radiant temperature t_{r} can be derived from

$$t_{\mathrm{r}} = t_{\mathrm{g}} + 2.4 v^{0.5} (t_{\mathrm{g}} - t_{\mathrm{a}}) \tag{2}$$

where t_{g} is the globe temperature; t_{a} is the air temperature; v is the air velocity.

1.4 Experimental scheme

The subjects are exposed to an indoor environment in

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which the humidity is controlled at 50%, and the temperature is controlled at 22, 25, 30 ℃, respectively. Uniform clothes are used by the subjects. Clothes A: short-sleeved shirt and shorts(0.36 clo); clothes B: short sleeved-shirt and trousers(0.57 clo); clothes C: long-sleeved shirt and trousers (0.61 clo); clothes D: suit jacket, long-sleeved shirt and trousers(0.96 clo). For 22 ℃, clothes A is sweater, long-sleeved shirt and trousers(1.00 clo).

In each experiment, there are totally four steps with four sets of clothes offered to a subject at the same indoor temperature (see Tab. 1). Each step lasts 30 min except for the first one, which lasts 60 min to avoid the effects of the temperature change from outdoors to indoors on the thermal sensation. During each step, the subjects are required to vote every 3 min. The experimental process is shown in Fig. 1.

To avoid the influence of the order of the thermal resistances of the clothes on thermal sensation, the order of the clothes is changed randomly during the experiment. The subjects are asked to be seated quietly. They are allowed to do something at a low metabolic state, such as writing, reading or surfing on the internet.

Tab. 1 Experimental conditions

Ambient temperature/℃	22	25	30
Clothing thermal resistance/clo	1.00	0.96	0.96
	0.96	0.61	0.61
	0.61	0.57	0.57
	0.57	0.36	0.36

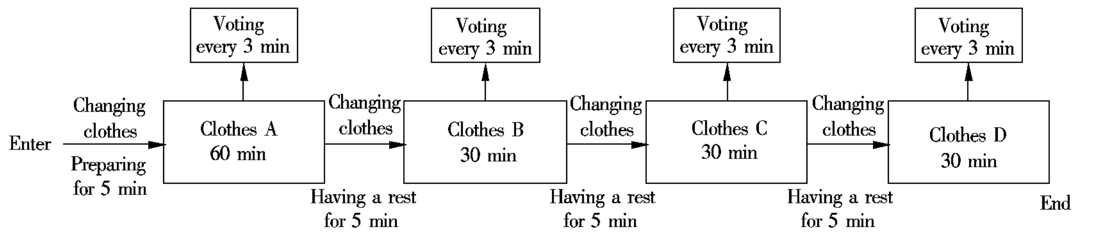

Fig. 1 Experimental process

1.5 Thermal sensation and thermal comfort

In the experiment, the subjects were asked to respond to the ASHRAE 7-point scale about their thermal sensation(see Fig. 2).

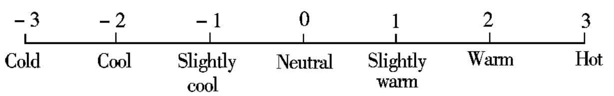

Fig. 2 ASHRAE 7-point scale for evaluation of human thermal sensation

2 Results and Discussion

2.1 Effects of daily mean outdoor temperature on thermal sensation

Fig. 3 shows the relationships between the daily mean outdoor temperature and the thermal sensation vote(TSV) and PMV for various clothes and different indoor temperatures. In this figure, the TSV is the average value of thermal sensation votes after the subjects have adapted to the indoor temperature. The experimental results reveal that:

1) In a cool indoor environment(22 ℃), the subjects generally vote lower TSV than PMV predicts when they are in clothes of low clothing insulation. When the daily mean outdoor temperature is higher, they feel even cooler. This shows that the higher the outdoor temperature, the weaker tolerance to cool environments they have.

2) In a neutral indoor environment(25 ℃), the subjects' thermal sensation is close to the PMV prediction, and does not change with the daily mean outdoor temperature, which indicates that the outdoor temperature has no influence on people's neutral thermal sensations.

3) In a warm indoor environment(30 ℃), the subjects vote lower TSV than PMV predicts. When the daily mean outdoor temperature is higher, their thermal sensation is closer to neutral. The results show that the higher the outdoor temperature, the stronger tolerance to warm environments they have.

The results are similar to that reported by Zhou et al.[8]; i. e., the higher the outdoor temperature is, the stronger tolerance to hot indoor environments people have, and people's tolerance to cool indoor environments is weaker when the outdoor temperature is higher. This phenomenon can be explained by the climatic characteristics of the transition season from spring to summer. During this period, the outdoor temperature gets higher and higher, which destroys people's adaptability to cooler environments, but engenders their adaptability to warmer environments. Therefore, when they are in cool indoor environments, people feel cooler than PMV predicts and this feeling becomes stronger when the outdoor temperature is higher. When people are in warm indoor environments, they have a stronger tolerance since they have adapted to the warm environments psychologically and physiologically; whereas when people are in neutral indoor environments, their thermal sensations are not affected by the outdoor temperature, which proves that "Only when people are in the environment, which deviates from the neutral, people's psychological and physiological adaptability to the thermal environment may play an active role for their thermal sensation"[8].

2.2 Effect of occupants' native areas on thermal sensation

In Fig. 4, TSV for persons coming from different areas in China (northern and southern) is compared with PMV for different clothes at different indoor temperatures. The subjects from southern China vote differently from the subjects from northern China. The experimental results reveal that:

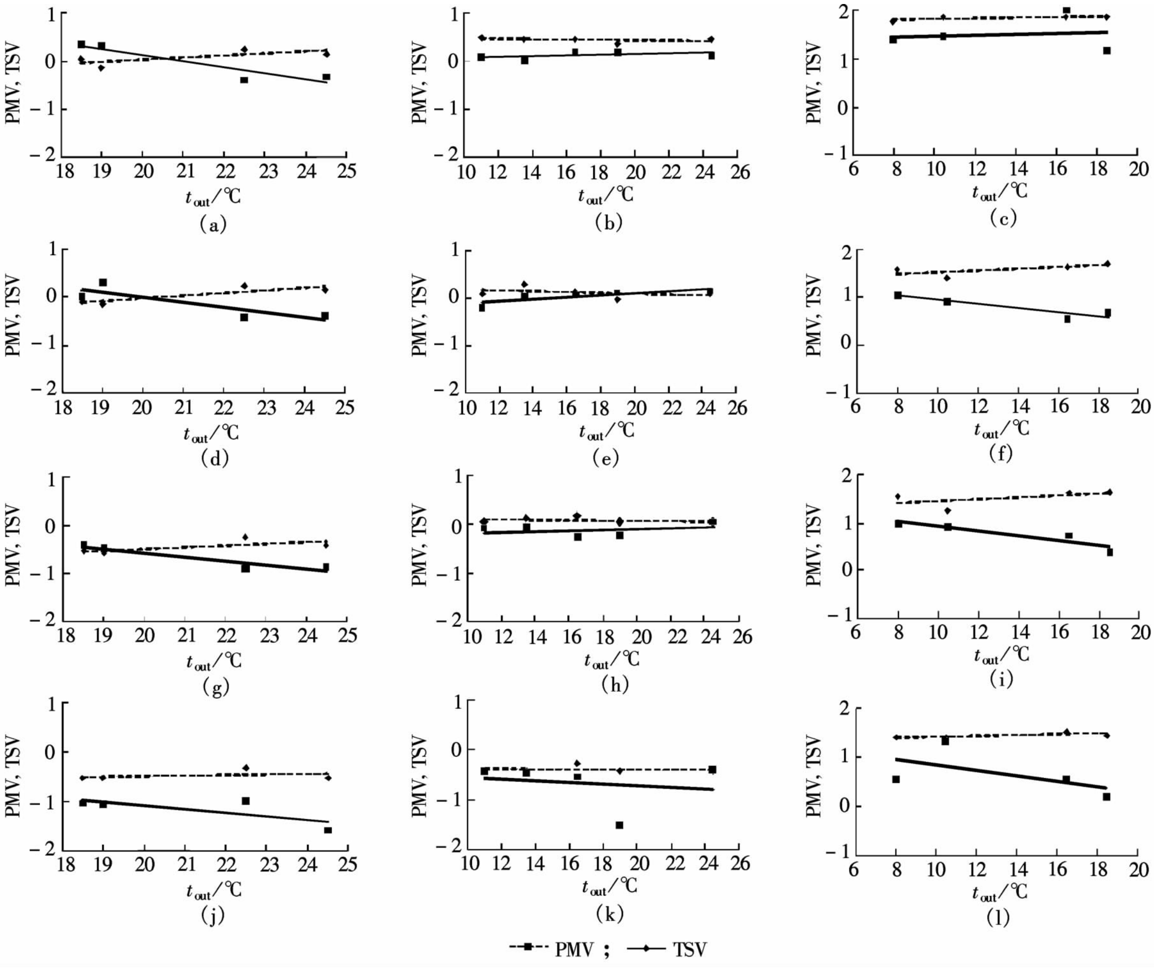

Fig. 3 Relationships between PMV, TSV and daily mean outdoor temperature for different indoor temperatures and clothing thermal resistances. (a)22 ℃, 1 clo; (b)25 ℃, 0.96 clo; (c)30 ℃, 0.96 clo; (d)22 ℃, 0.96 clo; (e) 25 ℃, 0.61 clo; (f)30 ℃, 0.61 clo; (g)22 ℃, 0.61 clo; (h)25 ℃, 0.57 clo; (i)30 ℃, 0.57 clo; (j)22 ℃, 0.57 clo; (k)25 ℃, 0.36 clo; (l)30 ℃, 0.36 clo

1) In a cool indoor environment (22 ℃), the subjects from southern China vote higher thermal sensations than those from northern China ($p < 0.05$). When the clo-value is above 0.85 clo, the subjects from southern China feel even warmer than PMV predicts, while the subjects from northern China vote lower TSV than PMV predicts during the whole experiment. This shows that the subjects from southern China have a greater tolerance to cool environments than those from northern China.

2) In a neutral indoor environment (25 ℃), the subjects from southern and northern China vote almost the same thermal sensation ($p > 0.05$), which indicates that occupants' native areas have nothing to do with their neutral thermal sensations.

3) In a warm indoor environment (30 ℃), the subjects from both southern and northern China vote a lower thermal sensation than PMV predicts. Moreover, the subjects' thermal sensations from southern China is closer to neutral than those from northern China, and the difference of TSV between southern and northern China is significant ($p < 0.001$). This shows that the subjects from southern China have a greater tolerance to the warm environments as well as to the cool environments.

The phenomenon can be explained by the different climatic characteristics of the native areas. Among all the subjects, those who are classified as the southern China group are mainly from the hot-summer and cold-winter climate zones, and generally there is no space heating in winter. And those who are classified as the northern China group are mainly from the cold or severe cold climate zones, characterized by cool summer and usually equipped with space heating facilities in winter. The persons from southern China are used to hot summer and cold indoor environments in winter, and those from northern China are used to cool summer and warm indoor environments in winter. When the indoor temperature deviates from the neutral, the differences in their thermal sensations are shown, which means that the people from southern China have a greater tolerance to both hot and cold environments than those from northern China.

3 Conclusion

During the transition season from spring to summer, the outdoor temperature gets higher and higher, which changes people' s thermal adaptation. When the indoor temperature is low, people feel cooler than PMV predicts. The higher the outdoor temperature is, the weaker the tolerance to cool environments people have. Therefore, when the indoor temperature gets high, people feel more comfortable than PMV predicts. The higher the outdoor temperature is, the stronger the tolerance to warm environments people have.

People' s thermal sensations to the thermal environment depends not only on the climatic characteristics of the local season but also on their earlier exposure to thermal climate (their native areas). The people from southern China seem to have a greater tolerance to both hot and cold environments than those from northern China.

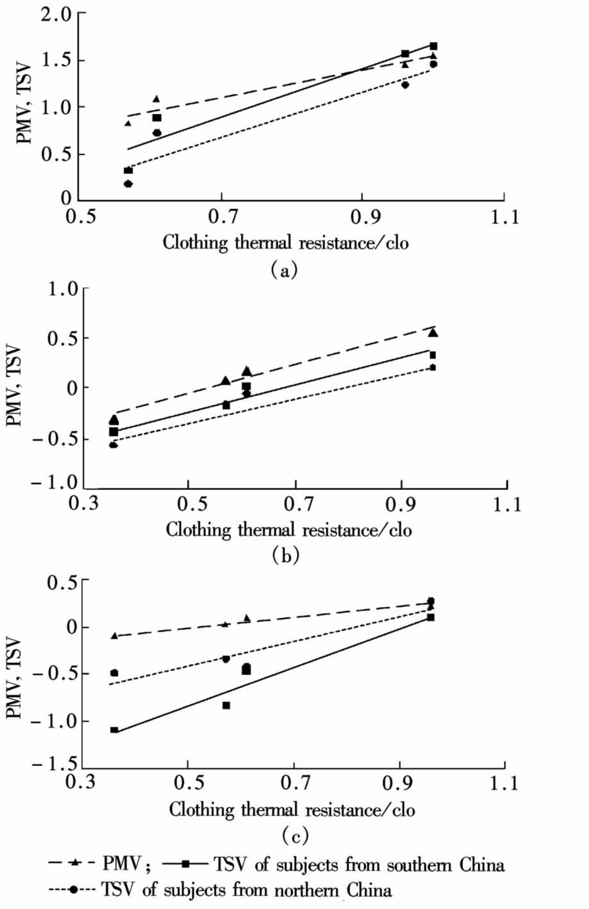

Fig. 4 Comparison of thermal sensation between subjects from southern and northern China at different indoor temperatures. (a)22 ℃; (b)25 ℃; (c)30 ℃

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气候特征对人体适应性影响的实验研究

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摘要:通过在春夏过渡季节开展人工气候室实验,研究了季节及地域气候条件与室内人体热感觉的关系,以探讨气候特征对人体热适应性的影响.研究结果表明,在春夏过渡季节人们对室内环境的冷热耐受性不同,室外温度越高,人们的冷耐受性越弱,热耐受性越强.此外,人体热感觉还受其长期居住地区的气候特征所影响.由于人们对各自居住地区的气候特征和室内环境具有适应性,在相同的室内热环境下,来自不同地区的受试者在热感觉上有一定差异,表现为南方人较北方人有更强的冷耐受性和热耐受性.

关键词:气候特征;适应性;热感觉;耐受性
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