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Thermal adaptation and thermal environment in university classrooms and offices in Harbin

Zhaojun Wang*, Aixue Li, Jing Ren, Yanan He

School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, China

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ABSTRACT

To study the influences of indoor and outdoor climate on thermal adaptation, a field study was conducted in classrooms and offices in winter and spring. The thermal environment parameters in the classrooms and offices were tested during the survey, while the subjects were interviewed on their thermal responses. The results showed that human thermal sensations were related to both indoor and outdoor climates.

The neutral temperatures were not the same under different indoor temperature conditions in winter. The indoor microclimates had influences on human adaptability; the thermal neutral temperature was close to the indoor mean air temperature in thermal comfort environments. However, people felt hot when the indoor temperature was high and beyond the comfort zone in winter. Because the winter is long and outdoor temperature is low in Harbin, people have adapted to the cold environment. The indoor temperature should be kept at the lower limit of the comfort range in winter to keep human comfort and save energy.

The neutral temperatures were different in winter and spring which proved that the outdoor climate influenced human adaptation. The indoor temperature in winter is suggested lower than that in spring, which is a comfortable and energy efficient regulation strategy. According to the regulation strategy, about 9.6% energy for centralized heating system can be saved.

1. Introduction

Harbin is located in northeast China and the centralized heating period lasts for 6 months, from October 20 to April 20 next year. The energy consumption for space heating accounts for a big proportion of the total building energy consumption in Harbin. The indoor design heating temperature is 18 °C during the heating period according to Chinese standard. However, the real indoor temperatures are generally higher than 24 °C in some buildings, also going beyond the upper limits in ASHRAE 55-2010 [1] and ISO 7730 [2] standards. Occupants often feel hot and have to open windows to lower the indoor temperatures, which has increased building energy consumption.

In a “real world”, a person is no longer a passive recipient of the given thermal environment, but instead of an active agent getting accustomed to the environment by adaptive behaviors to enhance his health, performance, efficiency and comfort living or working there. Brager and De Dear proposed an adaptive model of thermal comfort in naturally ventilated buildings in 1998, which stated that the person interacted with the thermal environment and the past thermal history might have influences on their thermal responses. On the other hand, people could actively adapt to the environmental variation by physiological acclimatization, behavioral adjustment and psychological habituation or expectation [3].

A great amount of field studies on thermal comfort in built environments have been conducted all over the world, such as in the US, Australia, Canada, China etc., and the investigated buildings are mainly office and residential buildings. The results showed that the neutral temperatures in tropical area were higher than those in cold climate zones and the neutral temperature in winter was lower than that in summer [4–15] in the same region, which proved that people might adapt to climates.

Cao et al. [11] indicated that the lower the outdoor air temperature in winter, the worse thermal adaptability to warm environment, while the adaptability to cool environment would be stronger. Therefore, maintaining a high indoor temperature during the winter will not only waste energy, but also make occupants uncomfortable.

A field study on thermal environment and thermal comfort was done in university classrooms and offices in Harbin during the heating period in winter and spring. Through this study, the relationships between thermal adaptation and indoor or outdoor

* Corresponding author.
E-mail address: wangzhaojun@hit.edu.cn (Z. Wang).

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Table 1
Age distribution of the subjects in the classrooms and offices.

		Classrooms in winter	Classrooms in spring	Offices in winter
Sample size		200	200	88
Gender	Male	146	138	61
	Female	54	62	27
Age (year)	Mean	19.7	19.8	35.5
	Standard deviation	1.87	1.34	13.1
	Maximum	25	25	76
	Minimum	18	17	21

climates are analyzed, and the strategy of changing indoor temperature with climate is presented to maintain thermal comfort and save energy.

2. Research method

2.1. Objectives

The aims of this field study are as follows:

(1) To obtain the thermal neutral temperatures under different thermal exposures.
(2) To investigate the relationship between indoor thermal environment and thermal adaptation in winter.
(3) To research the relationship between outdoor climate and human adaptability in winter and spring.
(4) To give the strategy of changing indoor temperature with climate.

2.2. Samples selection

The random sampling method was used. To study the influence of indoor microclimate on thermal adaptation in winter, the field study was carried out in classrooms and offices under different indoor temperature conditions simultaneously. To analyze the seasonal impact on human adaptability, the offices and classrooms with almost same indoor temperatures were chosen in winter and spring. The classrooms surveyed were in the same building in winter and spring during the field study. Orientation, storey and gender were taken into consideration of the selection.

The classrooms were heated by radiators and the offices were heated by radiant floor in winter. There was neither mechanical ventilation nor any temperature control in the rooms. Occupants could open windows to regulate indoor temperatures.

200 healthy college students in 18 classrooms in a building in winter and 200 college students in 21 classrooms in the same building in spring were surveyed. 88 healthy graduate students and teachers in 28 offices in an office building were interviewed. The subjects only voted once during the study.

The age distribution of the participants in the classrooms and the offices are listed in Table 1. It is seen that the average ages of the students were 19.7 and 19.8 years in the classroom surveys in winter and spring, respectively. And it was 35.5 years of the subjects in the office survey in winter.

2.3. Data collection

The study was conducted in winter and spring during the heating period. The winter study was conducted from December 15, 2010 to January 21, 2011. The spring study was performed from April 4 to April 14, 2011.

The thermal environment parameters in the classrooms were tested during the heating period from winter to spring, and the test in the offices was conducted in winter. The subjective thermal sensations and thermal comforts were investigated simultaneously.

2.4. Measurement of environment parameters

The subjects were seated working or learning during the tests. The air temperature and air speed were measured near the subjects at three heights of 0.1, 0.6 and 1.1 m. The mean air temperature is the average of the three heights. So is the air speed. The relative humidity was measured at the 1.1 m level in the room center.

The air temperature and air speed were recorded by a hot-wire anemometer (Testo425). The relative humidity was measured by a hygrothermograph (TES1360). The temperatures of surfaces were measured with thermocouples.

The mean radiant temperature was the spatial average of the surface temperature of each wall, window and the floor, weighted by the areas.

Surface temperatures of the window and external wall were tested at five points on each surface. The temperatures of the internal walls and floor were measured at the center on each surface. The temperatures of surfaces were measured with thermocouples, but the roof temperature was inconvenient to measure. Therefore, the surface temperature of the roof was not tested, using the floor temperature instead.

The accuracy of air temperature transducer is within 0.5 °C. For air speed, the accuracy is ±0.03 m/s. The accuracy of humidity transducer is ±2%. The accuracy of the thermocouple is within 0.2 °C.

2.5. Questionnaires

The questionnaires include: Backgrounds survey, such as gender, age, length of time living in Harbin etc.; Clothing and activity checklists; Thermal sensation survey, which is on the ASHRAE thermal sensation scale [1,2]: cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly warm (+1), warm (+2), hot (+3); Thermal comfort and thermal acceptability survey; Improvement measures taken by the occupants, such as opening windows, changing clothes etc.

488 subjects including the students and teachers were asked to fill in the questionnaires and evaluate the thermal environment in the classrooms and offices. Everyone took part in the survey only once. 200 questionnaires were collected from the classroom study in winter and spring, respectively. 88 questionnaires were collected from the office study in winter.

3. Results of thermal environment investigation

3.1. Outdoor climates

During the heating period in winter, the outdoor air temperature ranged between −24.3 °C and −15.1 °C, with an average of −19.7 °C. The relative humidity (RH) fell within 56% and 87%, with a mean of 74.1%. The air speed ranged from 0.7 m/s to 3.5 m/s, with a mean of 1.79 m/s.

During the heating period in spring, the outdoor temperature ranged between 4 °C and 20 °C, with an average of 12.2 °C. And it was about 32 °C higher than that in winter. The relative humidity (RH) fell within 29% and 59%, with a mean of 39%. The air speed ranged from 0.8 m/s to 3.6 m/s, with a mean of 1.92 m/s.

3.2. Indoor climates

The indoor environmental parameters are shown in Tables 2–4, where t_a, t, t_r, t_o, φ, v, I_{cl} are air temperature, surface temperature of