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Human Thermal Adaptation in University Classrooms and Dormitories in Chinese Severe Cold Area in Winter

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Abstract

The heating period is very long in Harbin in China. This paper describes a field study in university classrooms and dormitories in heating period in Harbin. The survey shows that the neutral temperature in classrooms at 3 periods was 17.7℃, 19.3℃ and 19.4℃, and in dormitories the neutral thermal temperatures were 20.9℃, 21.8℃ and 21.2℃, respectively. The neutral temperatures were on the rising trend, which reflected human thermal adaptation to the heating environment. The different neutral temperatures in classrooms and dormitories were mainly caused by 2 aspects: Classrooms were warmer than dormitories, so more students could not accept classroom environment psychologically; Students have different regulative methods to the indoor environment. Clothing insulation in classrooms was bigger than in dormitories. Because of above reasons, students felt more comfortable in dormitories than in classrooms.

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Keywords: Thermal environment; Thermal adaptation; University classroom; University dormitory; Severe cold area

1. Introduction

People spent most of time indoors. Many researches show that thermal environment has great influences on peoples' comfort and efficiency of work and study. In order to create a more comfortable indoor environment, further studies of indoor thermal environment and peoples' thermal adaptation are necessary.

In China, more and more researchers focus on thermal comfort. Yao et al.[1] had a survey about occupants' adaptive responses in naturally conditioned university classrooms. She found that the adaptive comfort range was

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broader than that of the ASHRAE Standard, but in the extreme cold and hot months, the range was narrower. Cao et al.[2] found that if the indoor temperature was high, people felt uncomfortable in Beijing campus buildings in winter. Zhang[3-4] found that the neutral temperatures in naturally ventilated buildings and split air-conditioned were all higher than 24℃ based on his studies on occupants, thermal comfort in hot-humid area of China. There are several climatic regions in China, researchers should use people's adaption to different indoor and outdoor environment, built more comfortable environment.

The heating period is about 6 months in Chinese severe cold area. The outdoor temperature fluctuates greatly, and indoor temperature also has certain changes during the heating period in this area. So heating energy consumption is great in Harbin. Some field surveys have been conducted in winter in Harbin. Wang et al. pointed out the indoor temperature in heating season was higher than Chinese indoor design heating temperature (18℃) in winter[5-6], even higher than the upper limit of the ASHRAE 55 (2013)[7] standard (24 ℃). If the indoor temperature was high, people would take measures to adjust their comfort, such as opening windows and reducing their clothes. These behavioural regulations showed that there were energy wastes in Harbin.

The indoor temperature in northern universities in China is generally high in heating period. Because of the different layouts and heating conditions, thermal environments in university classrooms and dormitories are different. The personnel density in university classrooms is greater than in dormitories, and students' activities and dresses are different, and these have an impact on students' thermal sensation. So what similarities and differences are of the thermal sensation and adaptation between the two environments? Which environment is more comfortable? In this paper, the authors focus on analysing people's adaptation in university classrooms and dormitories in Harbin.

2. Methods

In October 2013 to April 2014, the authors conducted a survey about indoor environment and thermal responses of the subjects in classrooms and dormitories in a university in Harbin. Based on the outdoor temperature and heating time, the survey was divided into 3 periods: early heating period, middle heating period and late heating period.

The study was conducted at the same time in classrooms and dormitories. The distribution of subjects and their convenience were fully considered. 5 classrooms and 11 dormitories were selected. The subjective survey was longitudinal. The subjects were 30 juniors, and the ratio of male to female was 1:1. The subjects had adapted to the cold winter of Harbin, they were asked to fill in the subjective questionnaires once a week. Table 1 shows the background of the subjects.

Table 1. Background data of subjects.

	Age	Living time (*a*)
Average	20.2	5.1
Std Dev	0.94	6.89
Maximum	22	21
Minimum	18	2

Test of environmental parameters included field test and continuous monitoring. Field test parameters included air temperature, black globe temperature, air velocity, relative humidity and surface temperature of building envelopes. Table 2 shows the equipment and resolutions. Air temperature was measured at the height of 0.1 m, 0.6 m, and 1.1m. Humidity, air velocity, and black globe temperature were measured at 0.6m. A temperature and humidity logger was placed in every dormitory for continuous monitoring, and it recorded test data every 5 minutes. Figure 1 shows the measurements in the university.

Table 2. Measurement equipment and resolutions.

Equipment	Parameters	Range	Resolutions
Temperature and humidity logger(WSZY-1A)	Air temperature	-40~100℃	±0.5℃
	Relative humidity	0~100%	±3%
Black globe temperature logger(HWZY-1)	Black globe temperature	-50~100℃	±0.4℃
Hot-wire anemometer (Testo 425)	Air velocity	0~20m/s	±0.03m/s
Infrared thermometer (Testo830-T1)	Surface temperature	-30~400℃	≤2% of measured value

Fig. 1. Physical measurements in the university.

3. Results

The results of test data are listed in Tables 3 and 4, and the average indoor radiant temperature was calculated by Formula 1 (ISO 7730, 2005)[8]. The changes of indoor parameters at the early, middle and late of heating period were not obvious, and the air temperature at the early heating period was the highest. The average indoor temperatures in classrooms were all above 24.0℃, and the temperature reached or exceeded the upper limit of ASHRAE 55-2013 standard. The indoor humidity was all lower than 60%, the air speed was under 0.15m/s in the heating period, and these were conform to the thermal comfort standard.

Table 3. Indoor parameters in classrooms.

Heating period	Average air temperature (℃)	Average radiant temperature (℃)	Average humidity (%)	Average air velocity (m/s)
Early	24.8	26.1	37.1	0.04
Middle	24.2	24.7	28.6	0.03
Late	24.0	24.7	28.2	0.02

Table 4. Indoor parameters in dormitories.

Heating period	Average air temperature (℃)	Average radiant temperature (℃)	Average humidity (%)	Average air velocity (m/s)
Early	23.0	22.9	41.9	0.05
Middle	22.7	22.5	37.6	0.04
Late	23.0	23.2	36.7	0.04

$$t_r = [(t_g + 273)^4 + 2.5 \times 10^8 \times v_a^{0.6}(t_g - t_a)]^{1/4} - 273 \quad (1)$$

Where t_r is the radiant temperature, t_g is the globe temperature, v_a is the air velocity, and t_a is the air temperature.

According to the questionnaires, the students' clothing insulation was obtained, which is showed in Figure 2. The clothing insulation in classrooms was 1.01 clo, 1.02 clo and 1.01clo respectively. And in dormitories the clothing insulation was 0.90 clo, 0.99 clo and 0.85clo at 3 periods. At the middle heating period, the outdoor temperature was the lowest and thermal insulation reached the maximum. This indicated that in order to adapt to outdoor climate changes, students made initiative adjustments to feel more comfortable. There were many students in classrooms, public places; subjects were not convenient to change clothes. But subjects could freely change their clothes in dormitories, so the clothing insulation in classrooms was larger than in dormitories. Overall, subjects clothing adjustment was not only influenced by outdoor climate, but also restricted by lifestyle.

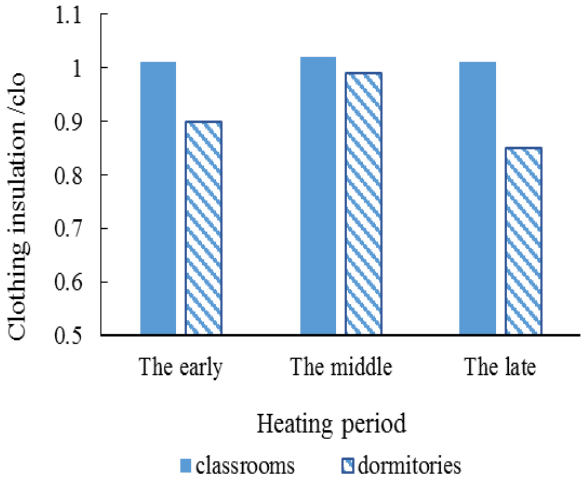

Fig. 2. Clothing insulation in classrooms and dormitories.

Figures 3 and 4 show the thermal sensation votes of subjects in classrooms and dormitories, respectively. The figures show that most of subjects felt thermal neutral in the 2 environments. More subjects voted hot side instead of cold side, which suggested that the indoor temperatures in classrooms and dormitories were still high. Especially in classrooms, more than 40% of subjects voted +1 at 3 periods. Comparing thermal sensation votes in the 2 environments, the ratio of neutral in dormitories was larger than in classrooms, and in classrooms more subjects voted hot side than in dormitories. Due to these phenomena, we get the conclusion that classrooms were hotter than dormitories, and this highly matched the air temperature in classrooms and dormitories. Obviously, indoor air temperature in the 2 environments should be decreased which not only could save energy but also be more comfortable.

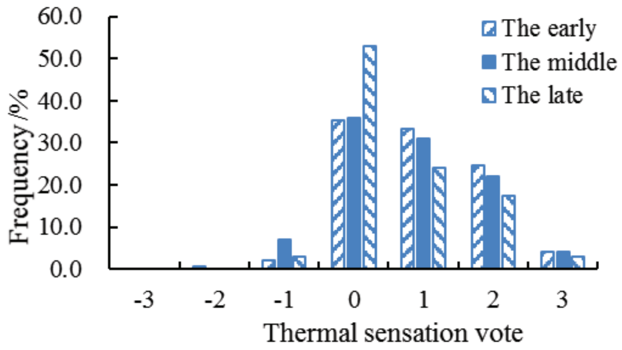

Fig. 3. Mean thermal sensation vote in classrooms.

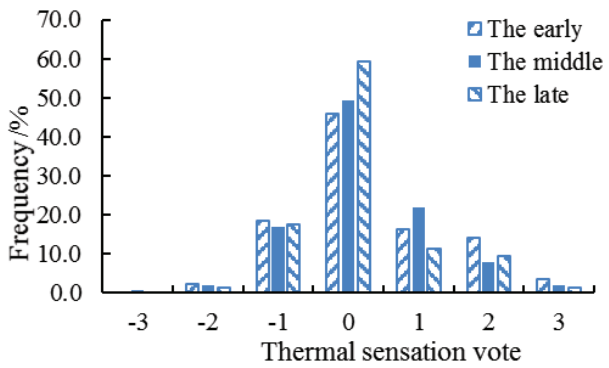

Fig. 4. Mean thermal sensation vote in dormitories.

At the early heating period, because subjects didn't adapt to high indoor temperature, many of the subjects felt hot. At the late heating period, subjects had gradually adapted to the heating environment, so when the temperature changed a little, more subjects felt thermal neutral, and the ratio of feeling overheat gradually reduced. This adaptation increased energy consumption. From the point of saving energy, we should make full use of human adaptation in winter, and reduce indoor temperature.

4. Discussion

Figure 5 shows the mean thermal sensation votes and indoor air temperature in classrooms and dormitories. The regression equations for their relationships are obtained in Tables 5 and 6.

Table 5. Regression equations in classrooms.

Heating period	Regression equations
Early heating period	y_1=0.1316x-2.3288，R^2=0.643
Middle heating period	y_2=0.1566x-3.0216，R^2=0.864
Late heating period	y_3=0.1564x-3.0357，R^2=0.7692

Table 6. Regression equations in dormitories.

Heating period	Regression equations
Early heating period	$y_{1},$=0.3402x-7.0118， R^2=0.724
Middle heating period	$y_{2},$=0.1769x-3.8674， R^2=0.5618
Late heating period	$y_{3},$=0.1320x-2,7980， R^2=0.448

Where R^2 is the correlation coefficient. From equations, we see that the thermal sensation and air temperature have a good correlation. Let y=0, the thermal neutral temperatures were 17.7℃, 19.3℃ and 19.4℃ in classrooms at the early, middle and late of heating period, respectively.

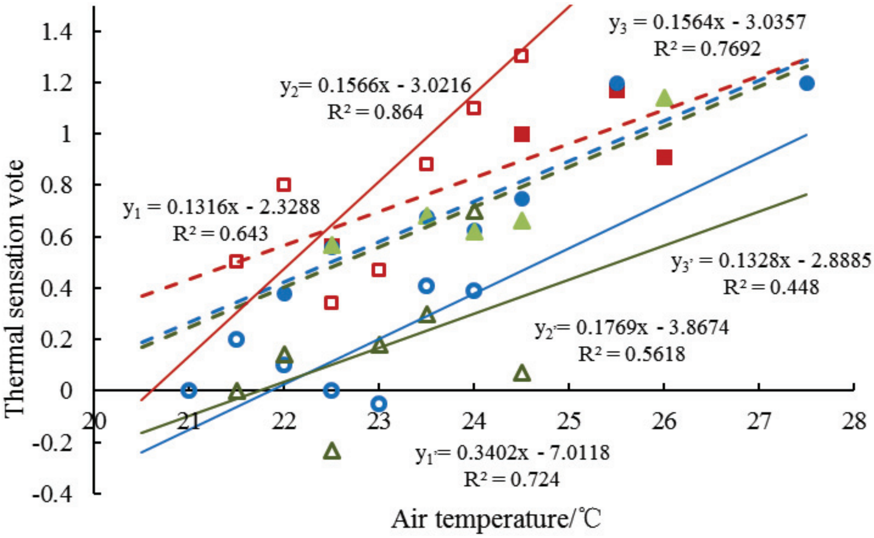

Fig. 5. Mean thermal sensation votes and indoor air temperature in classrooms and dormitories.

At the early heating period, with the decrease of outdoor temperature, university started heating. Subjects had not adapted to high indoor heating temperature in classrooms, so they felt the indoor temperature too high, and the neutral thermal temperature was lower than 18.0℃. At the middle heating period, subjects gradually adapted to the heating indoor environment in the cold winter. So the thermal neutral temperature increased significantly, reaching 19.3℃. At the late heating period, the indoor temperature reduced slightly, the neutral thermal temperature changed to 19.4℃. At the early heating period, the indoor temperature was 7℃ higher than thermal neutral temperature, which not only made subjects uncomfortable, but also wasted a lot of energy.

The thermal neutral temperatures in dormitories were 20.9℃, 21.8℃ and 21.2℃, respectively. At the early heating period, because subjects didn't adapt to indoor heating environment, so they also felt the temperature was high and the thermal neutral temperature was 2.1℃ lower than air temperature. At the middle heating period, the air temperature declined, but neutral temperature rose. This phenomenon was because the subjects had gradually adapted to indoor environment. In this period, the neutral temperature was most close to air temperature, only a difference of 0.9℃. At the late heating period, the outdoor temperature reached the highest of all 3 periods, while subjects expected the indoor temperature dropped, leading the thermal neutral temperature down to 21.2℃. From the results of 3 periods, the thermal neutral temperature changed with indoor temperature, but the thermal neutral temperature was always lower than air temperature. Therefore, the indoor temperature was high.

Comparing the results of the test, the thermal neutral temperature in classrooms was significantly higher than in dormitories. There were many students in classrooms, and the subjects were not convenient to take adjustments to release the excess heat, such as opening windows etc. Besides the clothing insulation in classrooms was higher than in dormitories. This led to subjects feeling hot, hoping to reduce indoor temperature. So the thermal neutral temperature was low in classrooms. By observing the data we know that the thermal neutral temperature was lower than indoor temperature in classrooms. However in dormitories, the two temperatures were similar, which was due to the difference of adjusting methods.

Figure 6 shows that 80% acceptable temperature ranges in classrooms and dormitories. It shows that the acceptable temperature limits in classrooms were lower than in dormitories. The upper limits in classrooms were on the rising trend at 3 periods. In dormitories the upper limits were over 24℃ at middle and late heating periods. The lower limits were all low in classrooms and dormitories, which meant that people had adaptability to cold ambient environment in winter. The change of temperature range was a little in classrooms. However, the range in dormitories was wider in heating time. The differences of the results were mainly due to the different adjustment habits. In classrooms subjects couldn't replace their clothes freely, but in dormitories they could adjust their clothes with the indoor temperature.

The thermal neutral and acceptable temperatures all showed that the indoor air temperature was too high. At the late heating period, if the air temperature changes from 24℃ to the neutral temperature 19.4℃ in classrooms, 10.1% energy can be saved. And similarly, in dormitories the air temperature also reduced to neutral temperature, 3.8% energy can be saved. At other periods, there is similar high energy saving potentials.

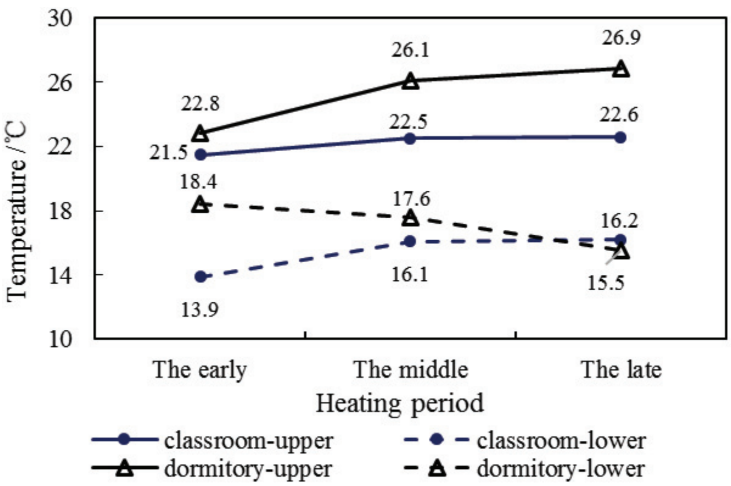

Fig. 6. 80% acceptable temperature range classrooms and dormitories.

5. Conclusion

The conclusions are as follows:

(1) Indoor environments in classrooms and dormitories were different. In classrooms, the air temperatures were higher than 24℃, and the air temperatures were close to 24℃ in dormitories.
(2) The clothing insulation in classrooms was 1.01 clo, 1.02clo and 1.01clo. In dormitories the clothing insulation was lower than in classrooms, and which was 0.90 clo, 0.99 clo and 0.85 clo, respectively. Subjects clothing adjustment was not only influenced by outdoor climate, but also restricted by lifestyle.
(3) Subjects felt hot in the two environments, especially in classrooms. This indicated that the indoor air temperature was too high.
(4) The neutral temperatures in classrooms were 17.7℃, 19.3℃ and 19.4℃ at 3 periods, and in dormitories the neutral thermal temperatures were 20.9℃, 21.8℃ and 21.2℃, respectively. The upper limits of the 80% acceptable temperature in dormitories was higher than in classrooms, and the change trends in the 2 environment were different.

(5) Because of the high indoor air temperatures, students took measures to release the excess heat, such as opening the windows, which was very wasteful. If the air temperatures dropped to neutral temperatures at the late heating period, 10.1% and 3.8% energy can be saved in classrooms and dormitories. Besides students would feel more comfortable.

Acknowledgements

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