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Indoor thermal comfort survey in campus buildings (classrooms) in Beijing for a long time

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Abstract

Beijing is in the Cold Climate Zone of China. This study carries out a long-term survey of indoor environmental parameters, the clothing of occupants, and the metabolic rate of occupants as well as people's voting of their sensation in classrooms in Beijing. The study was conducted in 2011 and 2012, trying to explore people's requirement of indoor thermal environment. Relationships between thermal parameters and people's sensations are found. The acceptable temperature range can meet the requirements of most of users. Also the clothing is an important factor influencing the occupants' sensation. A narrower range will make it more sensitive.

Keywords: Thermal comfort, Field study, Whole year, Classrooms, Adaption

1 Introduction

In recent years, as Chinese government has announced a series of strategies and policies of greatly promoting the environmental protection and energy conservation, building energy conservation is getting seriously attention. In such a situation, many universities want to make their campus "greener", so campus construction energy conservation work develops rapidly. For universities, it is important to make sure the campus construction can meet the requirements of teachers and students: learning, working or living comfortable and healthy. Meanwhile, universities need to play a leading and exemplary role in energy conservation and emissions reduction. For this purpose, it is very important to do the research which can find out what indoor environment conditions can meet the requirements of comfort and save much energy.

Previous field investigation for thermal comfort mostly aimed at a particular season (Wang et al, 2005; Cao et al, 2012; Lou et al, 2005; Li et al, 2007). In fact, human requirements for indoor thermal environment may vary in different seasons. The study of the relationship between the requirements and indoor environments in different seasons is more important. There are some annual field investigations in the cold region (Wang et al, 2007), hot summer and cold winter region (Liu, 2007; Mao, 2007), hot summer and warm winter region (Chen et al, 2010; Zhang et al, 2010). Never less in the vast area of cold region, it is still rare.

To solve the above-mentioned two problems, we choose the classrooms and dormitories to carry out the thermal comfort field investigation work for a whole year. This article will mainly analyze the research results of campus buildings. The research about the dormitories will be discussed in another article.

2 Methodologies

2.1 Time and Place

The field study was conducted from September 2011 to August 2012, for 30 weeks (paused in holidays). The investigated places are classrooms in a university. There are four different rooms in this study which are similar designed for 30 users, shown in Fig. 1. Windows can be opened or shut down freely by the users. During autumn and spring, the classrooms are cooled down by the natural ventilation; in summer, there is no electric fan in the rooms, the rooms are cooled down by the central air-conditioning system; in winter, the rooms are warmed by the central air-conditioning system too. There are two controllers of the system in each room, the teacher or the administrator will set them before the classes. Respondents in classrooms were undergraduates.

Figure 1. Classrooms in this study

2.2 Information of Respondents

In order to avoid the effect of thermal adaptation caused by different regions, the respondents were all people who had lived in Beijing for long time and had adapted to the climate of Beijing well.

There are 66 respondents from two classes. The basic information of the respondents is in Table 1.

Table 1. Basic information of the respondents

Gender	Number	Age	Height(cm)	Weight(kg)
Male	31	21±3	173±10	64±11
Female	35	21±3	163±9	55±10

2.3 Instruments and Questionnaire

During each investigation, the environmental parameters were recorded while the respondents filled out all the contents of the questionnaires. The respondents were asked to fill the questionnaires at least once a week.

The indoor environment parameters including air temperature, mean radiant temperature, relative humidity and air velocity were measured by using the AM-101 PMV and PPD indices meter (Fig. 2). The accuracy of AM-101 is shown in Table 2. The parameters of the height of 1.1m were recorded. 1.1m is the height of head when people sit.

Figure 2. AM-101 PMV and PPD indices meter

Table 2. Accuracy of the AM-101 PMV and PPD indices meter

Parameter	Accuracy (Valid Range)
Temperature	±0.5°C （15-35°C）
Relative Humidity	±3% （20-80%）
Air Velocity	±0.1m/s （0-1m/s）
	±0.5m/s （1-5m/s）

The questionnaire consists of two parts: the basic information of respondents and their thermal votes. The basic information is about the activity and clothing of the respondents; thermal sensation is voted using ASHRAE seven-point scale, as shown in Fig. 3. In the research, 969 questionnaires are effective.

Your current thermal sensation is:
-3 clod; -2 cool; -1 slightly cool; 0 neutral; +1 slightly warm; +2 warm; +3 hot

Figure 3. The thermal sensation vote in the questionnaire

3 Results

3.1 Indoor Environment Parameters

The indoor environment parameters during this study are shown in table 3. There are the minimum, the maximum and the average value in the table. Indoor air velocity is very low. In most of the cases, it is lower than the human sensory threshold of 0.2 m/s. The average temperature and humidity in autumn, winter and spring are similar, while the ranges are different; temperature in summer is a little higher, ranges of temperature and humidity are smaller.

Table 3. Indoor environment parameters

Season	Research period		Min.	Max.	Avg.
Autumn	2011-9-28~ 2011-10-28	Air Temperature(° C)	20.6	26.7	23.0
		Radiant Temperature(° C)	22.3	26.5	23.8
		Relative Humidity (%)	26.7	53.2	42.4
		Air Velocity (m/s)	0	0.2	0.1
Winter	2011-11-2~ 2012-3-31	Air Temperature(° C)	17.2	26.7	23.3
		Radiant Temperature(° C)	19.4	23.7	21.7
		Relative Humidity (%)	9.0	63.0	30.2
		Air Velocity (m/s)	0	0.2	0.1
Spring	2012-4-2~ 2012-4-27	Air Temperature(° C)	20.3	25.5	23.0
		Radiant Temperature(° C)	22.1	24.3	21.8
		Relative Humidity (%)	9.1	52.7	24.2
		Air Velocity (m/s)	0	0.4	0.1
Summer	2012-8-7~ 2012-8-13	Air Temperature(° C)	25.5	27.7	26.6
		Radiant Temperature(° C)	25.3	27.3	26.3
		Relative Humidity (%)	59.3	69.3	65.2
		Air Velocity (m/s)	0.1	0.2	0.2

3.2 Metabolic Rate and Clothing Insulation

In each survey, environmental parameters measurement lasted for a whole class (contains two section classes, 45 minutes each, 5 minutes break down in the middle). Respondents filled the questionnaires during the break, thus, we can ensure that the respondents had kept sitting for 45 minutes without eating before the questionnaires. According to the ASHRAE Handbook (ASHRAE, 2012), the metabolic rate of respondents was about 1.1 met.

During autumn and winter, clothing insulation of the respondents is between 0.5 clo to 1.3 clo. Difference between indoor and outdoor temperature is small in autumn, people reduce their dress when the indoor temperature is higher. Outdoor temperature is very low in winter, the respondents dress in long underwear, sweaters, trousers and etc. Some respondents still dress much indoor when the temperature indoor is higher. The temperature rise in spring, people no longer wearing a thick coat, clothing insulation reduced to 0.5 clo to 1.0 clo. In summer, both indoor and outdoor temperature is higher; respondents wear short sleeves, shorts or thin coat only, clothing insulation is 0.3 clo to 0.9 clo.

3.3 Relationships between Environment Parameters and Thermal Sensation Votes (TSV)

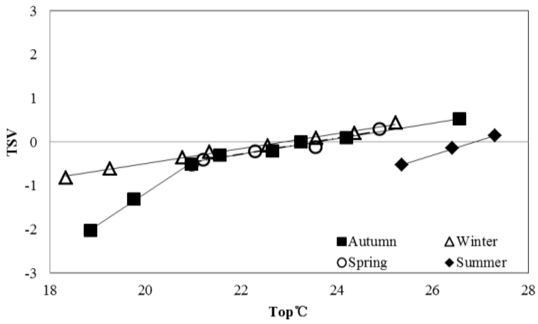


Figure 4. Relationships between operative temperature and TSV in different seasons

The relationships between operative temperature and TSV (average value) are shown in Fig. 4. According to GB/T 5701-2008 "indoor thermal environment conditions", for the persons who engaged in activities in sit conditions, no direct sunlight and surrounding air velocity is not more than 0.2 m/s, the operative temperature equals to the average value of the air temperature and the radiant temperature. The regression function of the average TSV is as follows:

Autumn： top<21^o C： $TSV = 0.7246t_{op} - 15.659 (R^2 = 0.9969)$

top≥21^o C： $TSV = 0.1775t_{op} - 4.176 (R^2 = 0.9846)$

Winter： $TSV = 0.172t_{op} - 3.9298 (R^2 = 0.9941)$

Spring： $TSV = 0.1838t_{op} - 4.3257 (R^2 = 0.9571)$

Summer： $TSV = 0.3416t_{op} - 9.1759 (R^2 = 0.999)$

The slopes of the regression function of autumn (top≥21^o C), winter and spring are similar, when 26^o C>top≥21^o C, the function for spring and autumn are the same. The slope of the function in summer is greater than the other three seasons. This means that the respondents are more sensitive to the change of temperature in summer. The relationship between operating temperature and TSV in autumn can be divided into two segments, the turning point is the point of the operating temperature is about 21^o C. The line slope is greater when the temperature is low, means that respondents are more sensitive to temperature change in low temperature, and we can see that the TSV are lower than that in winter. Then we can get the neutral temperature and the 90% acceptable temperature range. The data are shown in Table 4. Due to that in summer the highest temperature we get is 27.7^o C, 0.5 of average TSV does not appear, so we can't get the upper limit of the acceptable temperature range, according to the function, the upper limit might be 28.3^o C.

Table 4. The neutral temperature and the 90% acceptable temperature range

Season	The neutral temperature(^{o} C)	The 90% acceptable temperature range (^{o} C) -0.5<TSV<0.5	The average value of the clothing insulation
Autumn	23.5	（20.7,26.3）	0.85
Winter	22.9	（19.9,25.8）	1.15

Season	The neutral temperature(°C)	The 90% acceptable temperature range (°C) -0.5<TSV<0.5	The average value of the clothing insulation
Spring	23.5	（20.8,26.3）	0.79
Summer	26.9	（25.4,28.3）	0.42

4 Discussions

4.1 Clothing Insulation

According to the result of Table 4, the neutral temperatures are different between different seasons. The acceptable temperature ranges are different too. In winter, the neutral temperature is the lowest, and in summer it is the highest. In autumn and spring, the neutral temperatures are the same. The main reason of the different is the clothing insulation, Fig. 5 shows the clothing insulation of different seasons in every centigrade, the maximum and minimum values are shown. It is obvious that the insulation in winter is the largest, in summer it is the smallest.

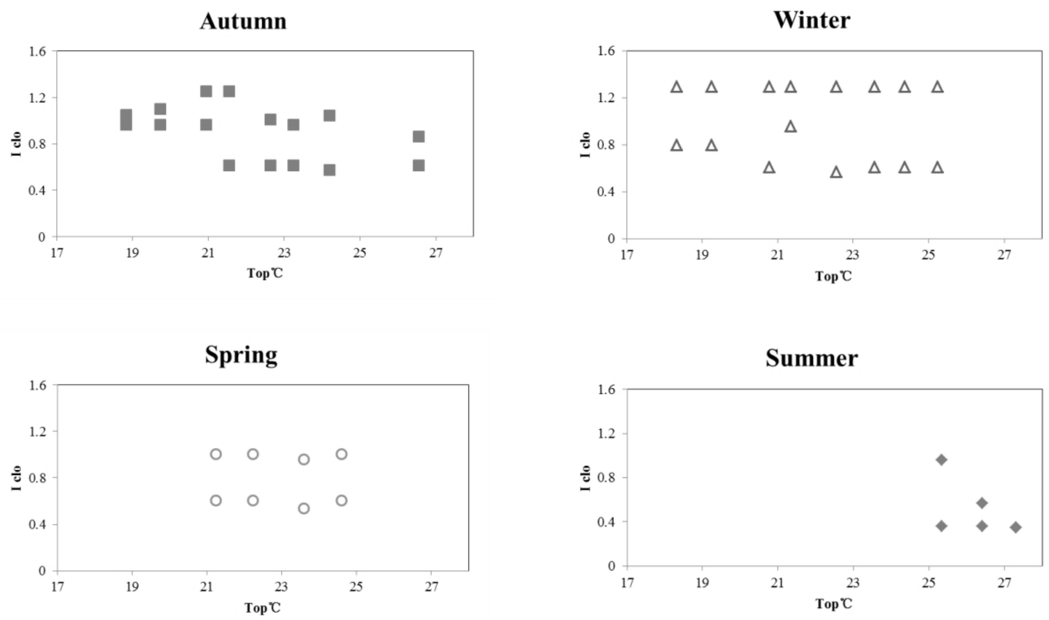


Figure 5. The Relationships between operative temperature and the clothing insulation in different seasons

The main reason for the highest neutral temperature in summer is that people dress less in summer. The adjustable range of the clothing is smaller so the respondents' ability of adapt to the temperature is weaker, so people are more sensitive to the temperature change and then the slope of the function is greater. The results also show that people are more sensitive to the temperature change when the temperature is low in autumn. Can we find the reason on clothing insulation change?

It is obvious shown in the Fig. 5, when the temperature is lower than 21°C, the clothing insulation changed in autumn. The minimum values are much larger than the ones when the temperature is higher, while the maximum values are smaller, so the ranges of the insulation become narrower. In winter, the clothing insulation changed different from that in autumn. The maximum values are still, and the minimum values are larger than the ones when the temperature is higher, but the difference is not that larger like that in autumn. So we can say that people in autumn have a weaker ability to change their cloth to adapt to the temperature change, this will be a main reason for they become more sensitive to the temperature change. In both autumn and winter, outdoor temperature is lower than that indoor. The maximum values of the clothing insulation were decided by the outdoor temperature. In winter, the outdoor temperature is lower, so the maximum values are larger; then, the minimum values will be decided by the indoor temperature, but at the same indoor temperature, respondents dress more in autumn than in winter. On the other hand, TSV in autumn are lower than that in winter, this means that the respondents feel colder in autumn than that in winter, so we can say that they have an adaption on cold in winter. Due to there is no condition of the low temperature appears in the spring, we can't ensure that whether the respondents still have the adaptation on cold in spring.

4.2 Natural Ventilation

We recorded the proportion of the opening windows (table 5), we can know that if the rooms were using natural ventilation.

Table 1. Percentage of the opening windows in different seasons

Season	Percentages of the opening windows
Autumn	33%
Winter	8%
Spring	33%
Summer	0%

As it is shown, during the spring and autumn, there was a higher percentage of opening windows, and the indoor air-conditioning system wasn’t running at the same. Compared with the indoor temperature range and acceptable temperature range in table 3 and table 4, in the spring and autumn, natural ventilation can meet the requirements of the indoor thermal environment of respondents in these two seasons.

4.3 Neutral Temperature or Acceptable Temperature Range

In winter, we use central heating indoor, due to the individual differences, only 60% of respondents feel neutral (TSV=0) when the indoor temperature equals to the neutral temperature (shown in Fig. 6), 90% of the respondents’ TSV are between -1 to 1 (acceptable temperature range means the temperature make the average TSV are between -0.5 to 0.5, but in this survey, respondents actually vote value as an integer, thus we use -1 and 1 to determine the acceptable range), the state of the indoor environment can meet the requirements of the respondents. When the temperature is extended to the acceptable temperature range, although only 53% of the respondents feel neutral, but there are still 90% of the respondents’ TSV are between -1 to 1 (shown in Fig. 7), the state of the indoor environment can meet the requirements of the respondents.

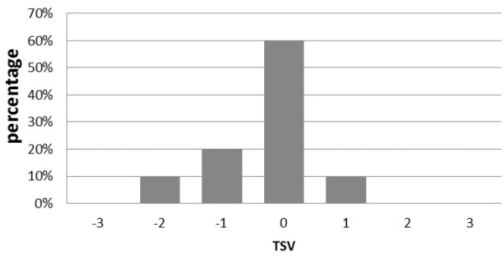


Figure 6. TSV at the neutral temperature in winter

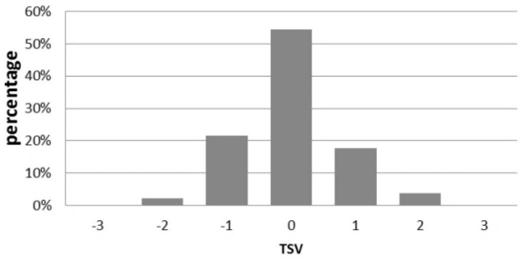


Figure 7. TSV at the acceptable temperature range in winter

The condition in summer is similar to that in winter (shown in Fig. 8 and Fig. 9). When indoor the temperature equals to the neutral temperature or between the acceptable temperature range (upper limit is the highest temperature in this research, the average TSV < 0.5), the requirements can be satisfied (more than 90% of the respondents' TSV located in [-1, 1]).

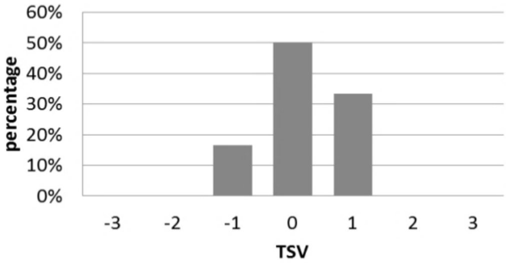


Figure 8. TSV at the neutral temperature in summer

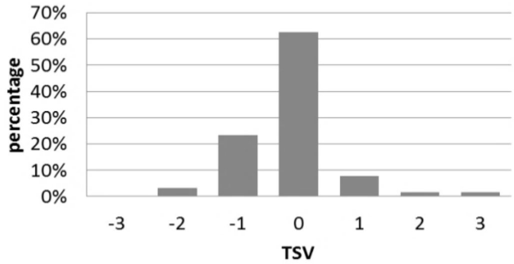
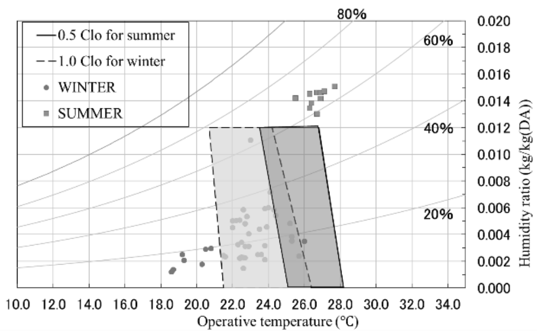


Figure 9. TSV at the acceptable temperature range in summer

Considering the demand for technology and energy to control the indoor temperature to a specific temperature point, we can consider to control the indoor temperature based on the accept temperature range, as long as the indoor temperature can be controlled in this range, the requirements can be satisfied.

4.4 The Standards

The ASHRAE standards use the PMV-PPD model and adaptive model to assess occupants' thermal comfort in the air-conditioning periods and the natural-ventilation periods. While in China, the GB standards about thermal comfort are always similar to the ASHRAE standards. Fig. 10 and Fig. 11 show the compared results we get with the standards in this survey.



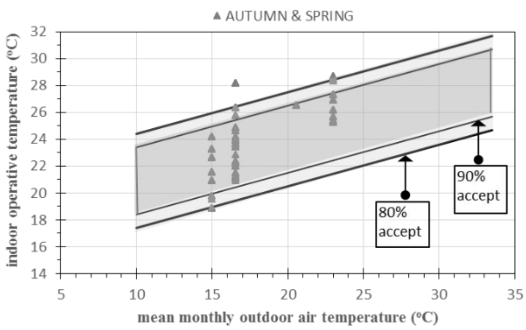


Figure 10. Indoor temperature we get in the survey. Background: ASHRAE 55 standard for air-conditioning

Figure 11. Indoor temperature we get in the survey, as a function of a monthly average of outdoor temperature. Background: ASHRAE 55 standard for natural ventilation

As shown in Fig. 10, in summer, the real environment is more warm and humid than the standard. Yet as discussed before, people won't feel uncomfortable. In winter, temperatures match the standards well in most cases, and all of the points are higher than 18 $^{\circ}C$ (the lower limit for heating in the north of China). As previously discussed, there are some people who feel cold in autumn. In Fig. 11, we can see that no point is lower than the 80% accept range. All these means that the standards do not fit the classrooms well, we need to do more research to find out the rules to the assess occupants' thermal comfort in classroom buildings.

Although we take a comparison between the results and the ASHRAE standards like this. We use the standards for air-conditioning buildings to compare to the results in summer and winter, and the standards for no mechanical cooling system buildings to compare to the results in autumn and winter, in fact it is not meet the requirements of ASHARE standards in the comparison above. ASHARE Standards can only be used in air conditioning or no mechanical cooling system buildings, but in the actual construction in China these does not see more. Most of the buildings are air conditioning in the summer and mixing ventilation in other seasons. Thus we need more standards to apply to such buildings.

5 Conclusions

(1) In the majority of the time in autumn and spring, natural ventilation can meet the requirements of respondents in the classrooms in Beijing.

(2) Thermal sensations are different in different seasons. In this research, the neutral temperature is 26.9^{o} C in summer, while it is 22.9^{o} C in winter. The main reason is the difference between the clothing insulation. Compared with the winter, respondents in autumn don't adapt to the cold, so they are more sensitive to temperature change when the temperature is low.

(3) During the seasons when the natural ventilation can't meet the requirements, individual difference should be considered when we control the air-conditioning system. Even if the indoor temperature is controlled to the neutral temperature, it can't satisfy all respondents' requirements. The proportion of respondents who feel neutral is still keeping the high level if it control to the acceptable temperature range. So considering energy consumption, the acceptable temperature range might be the control aim for the system.

6 Acknowledgement

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