Thermal Comfort of Neutral Ventilated Buildings in Different Cities[1]

Xiaojiang Ye, Zhaoxiao Zhou, Zhiwei Lian, Yuangao Wen, Zhengping Zhou, Chunxiao Jiang

PH.D, Associate Prof., PH.D Prof., Prof., Postgraduate, Postgraduate

Wuhan Institute of Technology
Wuhan P.R.China, 430073
xjye@sogou.com

Shanghai JiaoTong University
Shanghai P.R.China, 200030
zwlian@sjtu.edu.cn

Abstract: Although the ASHRAE 55-1992 and ISO 7730 Standards are used all over the world, many researchers have pointed out that it is impossible to maintain a uniform thermal comfort standard worldwide because of differing climate conditions. Two field thermal comfort investigations were carried out in Shanghai and Changsha. In the hot season the neutral temperature in Changsha and Shanghai is 27.5℃ ET* and 26.5℃ ET*, respectively. Compared with other cities' studies, in Beijing and Tianjin, this paper discusses thermal comfort conditions in China. The results show that thermal neutral temperature in these Chinese cities is higher than that in the ASHRAE standard. Therefore, thermal comfort temperature in China cannot directly correlate with the ASHRAE standard. This difference should be considered when designing air conditioning designing to save energy.

Key words: thermal sensation, thermal comfort, natural ventilation

1. INTRODUCTION

The Standards of ASHRAE 55-1992 and ISO 7730 have been used all over the world for the determination of optimum 'design' temperatures in buildings[1,2]. Current sizing recommendations for HVAC systems in China are also based on ASHRAE standards. However, Analysis of international field studies shows that people adapt to the temperatures they experience and are comfortable over a greater range of temperatures than current standards suggest[3,4]. Therefore, many researches examined the comfort criteria of ASHRAE Standard 55 for their applicability in hot and humid climates in recent decades[5]. Field studies of thermal comfort have suggested that design temperatures derived from this standard would require more heating and cooling energy to achieve thermal comfort than was indicated from the survey results [6,7]. There are lots of energy could be saved when the thermal neutral temperature obtained from field study was used to be design indoor temperature. For example, the overall cooling load reduction in Islamabad and in Karachi is 23% and 20% respectively if using this 'new' design indoor temperature[8,9].

There is a wide range of climatic conditions in China. The northern parts of China, such as Beijing and Tianjin can be cool. In these cold regions, the temperature drops well below zero in the winter. The centre part of China, such as Changsha, is extremely hot in summer. The southern part and coastal strip of China, such as Shanghai, is warm and humid. Therefore, it is worthy to study thermal neutral temperature in Chinese cities.

The aim of the research described in this paper is to study thermal neutral temperature in Changsha and Shanghai. Compared with other cities' studies, in Beijing and Tianjin, this paper discusses thermal comfort condition in China. And study the deference between comfortable indoor temperatures for buildings in Chinese cities and ASHRAE Standards.

2. METHODS AND BACKGROUND DESCRIPTIONS

2.1 Questionnaire

The questionnaire was divided into two parts, background and sensation vote. The background

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included demography and health. The sensation vote questionnaire mainly included thermal sensation and personal comfort. The scope and format of the questionnaire was based on the references[10-12]. Metabolic rates and clothing insulation were estimated in accordance with ASHRAE Standard 55-1992. The thermal sensation scale was the ASHRAE seven-point scale of warmth ranging from cold (-3) to hot (+3) with neutral (0) in the middle.

2.2 Instruments

Air temperature, globe temperature, air velocity and relative humidity were measured in this study. Spot measurements were conducted at representative points in the building. The measurement instrument is shown in Table 1 and the height is 1.1m.

Tab. 1 Measurement instrument and height

Measurement Item	Measurement Instrument
Air Temperature	TESTO 110
Globe Temperature	Black-bulb (150 mm)
Air Velocity	EY3-2A
Humidity	Dry and Wet bulb Thermometer

The accuracy of the instrument followed that prescribed in ASHRAE Standard 55-1992 and ISO 7726[13]. Measurements of the environmental data were taken while the subjects were completing their questionnaires.

2.3 Data analysis

The field investigations were carried out in Changsha and Shanghai from August to September in 2004. Total of 98 subjects (42 females and 56 males) in Changsha and 554 subjects (375 female and 179 males) in Shanghai attended this investigation. Subjective data were collected during the test. The subjects included university students, office clerks and residents. The subjects were between 12 to 62 years old having an average age of 29.4 years. They were in good health. The detail data of subjects in this investigation was shown in Table 2. The activity level was office activities and the metabolic rates of the subjects in this study could be taken as 1.0 met (55 W/m^2)[14]. Subjects in the study could freely adjust their clothing according to the changes of climate.

3. RESULTS AND DISCUSSIONS

In thermal comfort study, the relationship between thermal sensation and effective temperature (ET*) is the basic of researching thermal neutral temperature. The ET* is the temperature at 50% relative humidity that yields the same total heat loss from the skin as for the actual environment. One recognized method to predict the subjective comfort which results from a given temperature is regression analysis. Fig.1 and Fig.2 demonstrate the influence of indoor ET* on thermal sensation vote (TSV). When regressive analyzing the data we gathered in the thermal comfort investigation, we can get the results that the neutral temperature in Changsha and in Shanghai is 27.5°C ET^*(see Fig.1) and 26.5°C ET^* (see Fig.2), respectively. That is to say, the difference of neutral temperature between these two cities is 1°C ET^*. On the base of short-term study on thermal comfort in summer, some other studies have also got the similar conclusions as follows: the neutral temperature in Beijing[15] is 26.7℃ ET^*, and it is 27.5 ℃ ET^* in Tianjin[16]. As is shown in Table 3, the difference of the neutral temperature in Shanghai, Beijing and Tianjin is small (the maximum difference is 0.2℃ ET^*). On the contrary, the difference of neutral temperature between Changsha and Beijing is 0.8℃ ET^* and it's 1.1℃ ET^*between Changsha and Tianjin .Beijing and Tianjin lie to the north of china which is south temperate zone and inferior moist climate, while Changsha and Shanghai lie to the south of china which is north subtropical zone and moist climate. The average temperature of the hottest month in Changsha is higher than in Shanghai, Beijing and Tianjin. As a result, the neutral temperature in Changsha is higher than that in Shanghai, Beijing and Tianjin 1℃ ET^*, 0.8℃ ET^* and 1.1℃ ET^*, respectively. It is to say that to the residents live in the environment with hotter summer, the neutral temperature could be litter higher than those live with cooler summer. The perhaps reason is they have used to the hotter environment they live.

Furthermore, compared the neutral temperature in Changsha, Shanghai, Beijing, and Tianjin with the range of neutral temperature given in ASHRAE 55-1992, it is obviously that the neutral temperature in these cities are all beyond than the range of ASHRAE standard that is from 22.8℃ ET* to 26.1℃ ET*. Thermal neutral temperatures in other field studies are also not uniform. Busch carried out a field study and found the thermal neutral temperature was 28.5℃ ET in office buildings in Bangkok[17]. The margins of the acceptable zones in naturally ventilated campus classrooms is 21.1~29.8℃ ET* and the thermal neutral temperature is 26.3℃ ET*. It is distinct different from the 23.0~26.0℃ ET* criterion of ASHRAE Standard 55, especially in the upper boundary[5]. In comparison of other studies, the neutral temperatures in this study are lower than those found in Hawaii and Singapore in naturally ventilated buildings. The neutral operative temperatures in Singapore and Hawaii is 28.5℃ and 27.4℃, respectively[18,19]. The range of accepted temperature in Shanghai is between 14.7 and 29.8℃ T_{op} in the adaptive thermal comfort study[20].

Moreover, as is shown in our study, there are visible difference of neutral temperature between china and foreign country. Consequently the standard of heating and air-conditioning in china should be differing from the corresponding in ASHRAE Standard to adapt to its own characters. With the use of the field thermal neutral temperature analysis, it is possible to reduce temperature shock and the thermal comfort dissatisfaction rate of occupants. So that not only thermal comfort of subjects can be improved, but large numbers of energy could be saved.

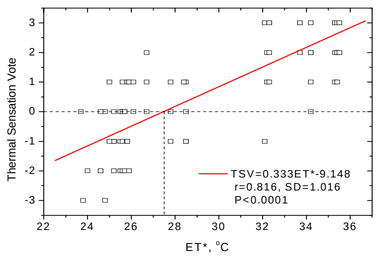

Fig.1 the relationship between thermal sensation vote and ET * in Changsha

Tab. 2 Data of subjects in Changsha and Shanghai

Items		Min	Max	Mean	S D
Chagsha	Age, year	12.0	62.0	31.8	12.0
	S_h, cm	120.0	186.0	164.2	8.7
	A_w, kg	34.0	84.0	58.7	10.5
	S_a, m^2	1.01	1.93	1.60	0.18
Shanghai	Age, year	22.0	40.0	28.2	4.2
	S_h, cm	158.0	187.0	168.7	7.7
	A_w, kg	42.0	75.0	59.7	7.4
	S_a, m^2	1.36	1.89	1.64	0.13

Tab. 3 Climate condition and thermal neutral temperature in each city

	Location	Shanghai	Changsha	Beijing[15]	Tianjin[16]
Climate Normal Value	North Latitude	31°24'N	28°13'N	39°56'N	39°06'N
	East Longitude	121°29'E	112°55'E	116°17'E	117°10'E
	Height above Sea Level, m	8.3	65.5	54.7	5.2
	Average Temp in Hottest Month	27.8	29.3	25.8	26.4
	Average Temp in Whole Year	16.6	17.1	12.3	12.6
	Extremity maximum Temp in Whole Year	37.8	39	41.9	40.5
	Extremity Minimum Temp in Whole Year	-7.7	-10.3	-18.3	-17.8
	Average Relative Humidity in Whole Year	76	82	57	62
	Average Air Velocity in Whole Year	3.2	2.2	2.5	2.4
	Thermal Neutral Temp, ET^*, ℃	26.5	27.5	26.7	26.4

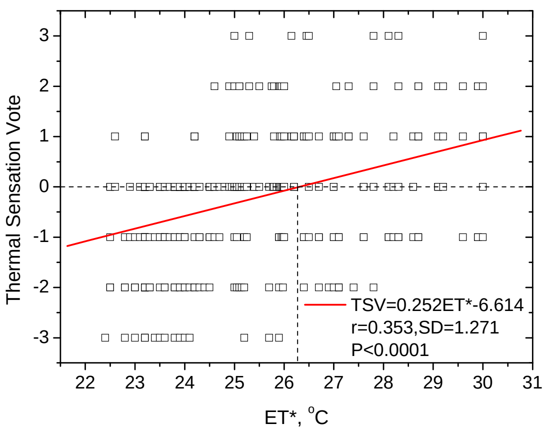

Fig.2 The relationship between thermal sensation vote and ET* in Shanghai

4. CONCLUSIONS

On the results of a short-term investigate in shanghai and Changsha and compared with other studies, this study researches the difference of thermal neutral temperature in Chinese cities or areas and in other country areas. The main conclusions are as follows:

As the regression analysis on the data of investigations shows, the neutral temperature in Changsha and in Shanghai is 27.5℃ ET* and 26.5℃ ET*, respectively. As is shown above, it is obviously that the neutral temperature in cities of China are all beyond the range of ASHRAE standard (23.0~26.0℃ ET*), which is also proved by other studies in different cities such as Beijing and Tianjin. Consequently the standard of heating and air-conditioning in china should be differing from the corresponding in ASHRAE standard to adapt to its own climate characters and living styles.

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