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Relationship between Human Thermal Comfort and Indoor Thermal Environment Parameters in Various Climatic Regions of China

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Abstract

Architectural design is based on the reliability and rationality of construction standards. The thermal comfort standard is a very important part of construction standards. In this study, Chinese researches about the field survey of various areas were summarized. The distribution range of thermal comfort temperature and neutral temperature were obtained by using the PMV evaluation index. The neutral temperature of different types of buildings in different seasons was summarized. Its relationship with indoor parameters was analyzed in detail. These findings provide a basis for the formulation of building specifications and architectural design in future.

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Keywords: The building standards, Thermal comfort, Temperature, Climatic region;

1. Introduction

The specifications of building thermal comfort include the temperature, humidity, wind speed and others, which can directly affect the thermal environment and building energy consumption. With the improvement of living standards of people, people paid more attention to the comfort of the living environment. how to make the building thermal comfort standards meet the needs of human body becomes more and more important [1].

Due to the difference of the geographical location, architectural function, living environment, personnel status, the thermal comfort specifications are different, the impact of different parameters is different [2]. The main purpose of

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this paper is to give some suggestions about the thermal comfort in a more reasonable and energy efficient way without reducing the indoor comfort level.

In this paper, 71 papers about thermal comfort investigation in China in the past 21 years from 1995 to now are introduced, and the thermal comfort range and thermal neutral temperature of different climate zones and different types of buildings are systematically summarized. The relationship between the statistical results of the thermal neutral temperature and the measured temperature is analyzed in detail, which provides a reference for the future design of the building and the building specifications.

2. Methods

The climate in China is divided into severe cold areas, cold areas, hot summer and cold winter areas, hot summer and warm winter areas and warm areas, while China is divided into North and south by the Qinling and Huaihe. The research of this paper involves all seasons and different populations in china.

In order to illustrate the representativeness of the samples, the paper summarizes the geographical distribution of the literature as shown in Figure1, in which the circle represents the summer, the triangle represents the transition season, and the box represents the winter. According to Figure1, we can see that these samples mainly distribute in northeast China, north China, the central and western regions and the southern coastal areas.

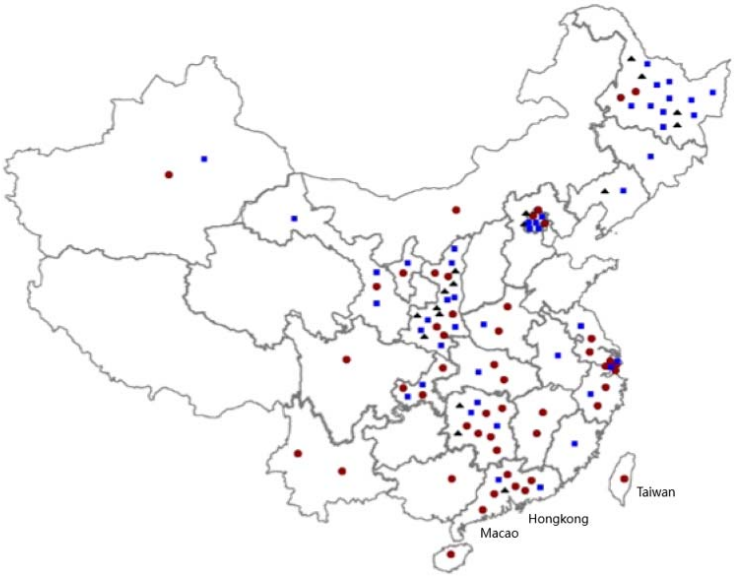

Fig. 1. Geographical distribution of the sample

In this paper, the type of the buildings contains a wide range, as shown in Figure 2. The proportion of residential buildings and schools are more, and other types of buildings are less. The ventilation and heating ways of these buildings are shown in Figure3. For rural areas, the majority of rural buildings use natural ventilation in summer and self-heating in winter. Urban buildings mostly use natural ventilation combined with mechanical ventilation, and mostly use central heating in winter, use natural ventilation in transition season. As for schools and other places, they mostly use natural ventilation in summer and central heating in winter. Shopping malls, subways, railway stations and other public buildings, mostly adopt mechanical ventilation and central heating.

In this paper, the majority of people's activities is sedentary or mild activity, more than 80% of the literature set the human metabolic rate between 1.0met and 1.3met, most of the research set the data to 1.2met.

In different literatures, there are some differences in indoor temperature and humidity. There are a great relationship between the indoor temperature and the building's cooling or heating way. People's living habits also related to the indoor temperature, so the data is irregular. Most of the data is within the scope of human thermal comfort, but in several buildings people feel uncomfortable at the current temperature of the room.

The distribution of indoor humidity and wind speed is more discrete. In general, the humidity in winter is much smaller than it in summer. The wind speed in summer is generally higher than it in winter, which is due to the need for keeping warm in winter.

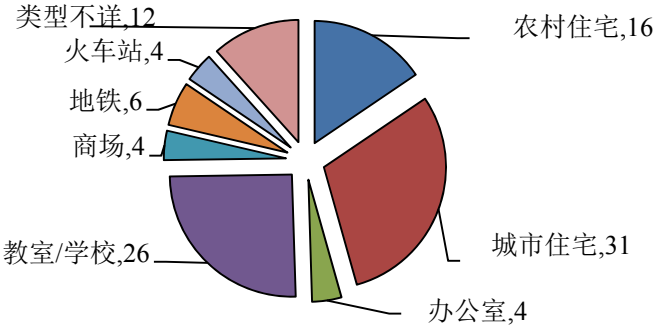

Fig. 2. Distribution of building types

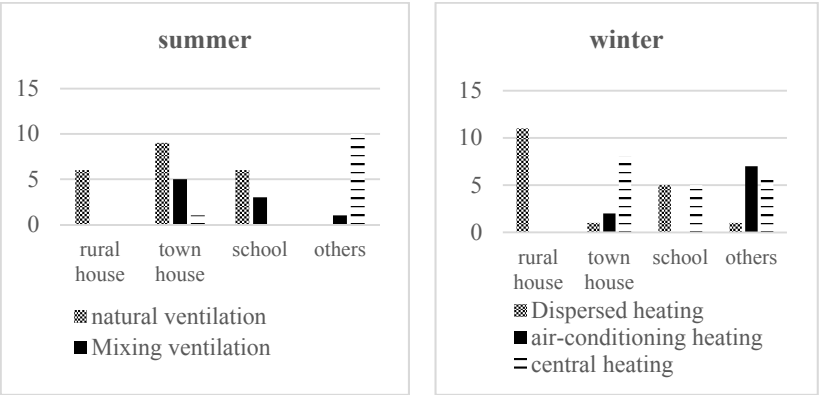

Fig. 3. Sample distribution of ventilation mode and heating mode

3. Results

3.1. Thermal comfort temperature contrast

Table 1 and table 2 shows the thermal comfort temperature range in different cities.

Thermal comfort range is according to 80% or 90% satisfaction rate of the PMV evaluation index [3], PMV index is almost the same in the current study, the climate zone and heating mode is the main difference.

Table 1. Temperature range of thermal comfort in transition season

City	Comfort temperature range（℃）	City	Comfort temperature range（℃）
	Urban housing	Harbing[70]	21~24.5
Harbing[35]	18.7~25.9	Beijing[39]	20.8~26.3
Xian[36]	≥14.5	Beijing[39]	20.7~26.3
Xian[37]	≥11.4,neutral21.3	Xian[71]	neutral :17.1
Xian[38]	neutral:20.76	Xian[71]	neutral :20.1
	Public building	Changsha[72]	15.1~22.4
Harbing[69]	21~27	Shenyang[73]	15.5~22.4

In table1, the transition season building all adopts natural ventilation (except Guangdong). The specific range of thermal comfort is related to the body's clothing, lifestyle and local climate. The thermal comfort temperature distribution in the same climate zone in the transition season is also the same, which can provide a reference for architectural design.

In table 2, rural people have a stronger ability to resist cold and they have a wider range of thermal comfort than city people in winter. The reason is that most of rural regions have no air-conditioning and central heating, and a majority of people engaged in manual labor. Although the weather is cold in the north, the thermal comfort temperature is not lower than that in the south because of the central heating. Most of crowded public buildings adopt the mechanical ventilation and centralized heating, this is because that people with big traffic need more fresh air, and mechanical ventilation can ensure the need of the fresh air. Mechanical ventilation can maintain the temperature in a stable range, therefore, people's thermal comfort range generally narrower.

Table 2. Temperature range of thermal comfort

summer		winter	
City	Comfort temperature range（℃）	City	Comfort temperature range（℃）
Rural residential in summer		Rural residential in winter	
Xian[4]	20.7~29.5	Harbing[10]	15~18
Hanzhong[5]	22.6~26.6	Haerbing[11]	≥8.8,neutral 14.4
Jiangzhe[6]	≤30	Harbing[12]	4.4~21.3
Liuyang[7]	21.8~31.6	Yanbian[13]	15~17
Xiangbei[8]	15.65~30.14	Yingchuan[14]	≥16
Yuedong[9]	23.8~29.0	Xian[4]	9.0~15.8
City residential in summer		Guanzhong[15]	neutral 12.7
Haerbing[17]	21.5~31.0	Guanzhong[15]	≥8
Jiaozuo[18]	20.7~29.2	Beijing[16]	≥10.9,neutral 18.4
Baotou[19]	23.8~26.9	Xiangbei[8]	8.4 ~ 15.65
Yingchuan[20]	≤28.5	City residential in winter	
Xian[4]	26.0~30.7	Harbing[27]	18.0~25.5
Beijing[21]	≤30	Harbing[28]	18.5~26.5
Chongqing[22]	22.6~30.5	Harbing[12]	19.3~28.6
	22.5~28.7	Harbing[29]	neutral 22.9
Jiangzhe[6]	≤30	Xian[4]	9.0~15.8
Changsha .etc [23]	25.1~30.3	Jiaozuo[30]	11.6~24.2
Changsha .etc[23]	25.0~31.6	Nanyang[31]	11.2~16.8
Kunming[24]	20.8~25.1	Hangzhou[32]	12.6~18.6
Nanning[25]	25.8~28.9	Chengdu .etc[33]	14.35~16.53
Shenzhen[26]	≤29.5	Hefei[32]	13.22~23.22
public architecture in summer		Shanghai[34]	≥14.6
Beijing[39]	neutral 26.9	public architecture in winter	
Beijing[40]	neutral 25.7	Harbing[57]	19.6~24.4
Beijing[41]	24.1~29.7	Harbing[58]	21~24.5
Shanghai[42]	neutral 23.61	Guanzhong[59]	12.7~16.9
Chongqing[43]	25.5~29.8	Beijing[39]	19.9~25.8
Chongqing[44]	24.8~28.3	Beijing[40]	17.6~24.6
Haikou[45]	23.34 ~ 27.82	Beijing[41]	neutral 21.8
Nanning[46]	25.8~28.9	Lanzhou[60]	18.2~22.2
Nanning[47]	17.8~24.8	Shanghai[42]	neutral 16.60
Xian[48]	24.45~30.6	Chongqing[61]	14.04~24.2
Jiayuguan[49]	24.9~29.5	Chongqing[44]	17.5~23.0
Shanghai[50]	≤23.2	Wuhan[62]	neutral 21.7
Chengdu[51]	24.25~30.5	Xiamen[63]	15.6~16.0
Xian[52]	22.0~27.8	Harbing[64]	10~16.4
Changsha[53]	25.5~29.4	Shengyang[65]	16.6~21.3
Changsha[54]	22.6~26.5	Beijing[64]	10~20.5
Guangzhou[55]	21.6~29.3	Lanzhou[66]	13~17
Guangzhou[56]	23~27	Xian[67]	13.8~23.8
		Xian[68]	14.3~23.3
		Nanjing[64]	10~22.3
		Guangzhou[64]	15.8~25.2

3.2. Calculation and analysis of thermal neutral temperature

The thermal neutral temperature and the measured temperature data of all the samples were collected and analyzed, as shown in figure 4. In order to verify that the average temperature to be considered as ideal thermal comfort temperature is reliable, we get the deviation and variation coefficient to indicate the degree of discrete data. The variation coefficient is the ratio of the standard deviation of the mean. When the variation coefficient is less than 15%, the data is reliable. The calculation of the dispersion degree about using the average neutral temperature as the thermal neutral temperature is shown in table 3.

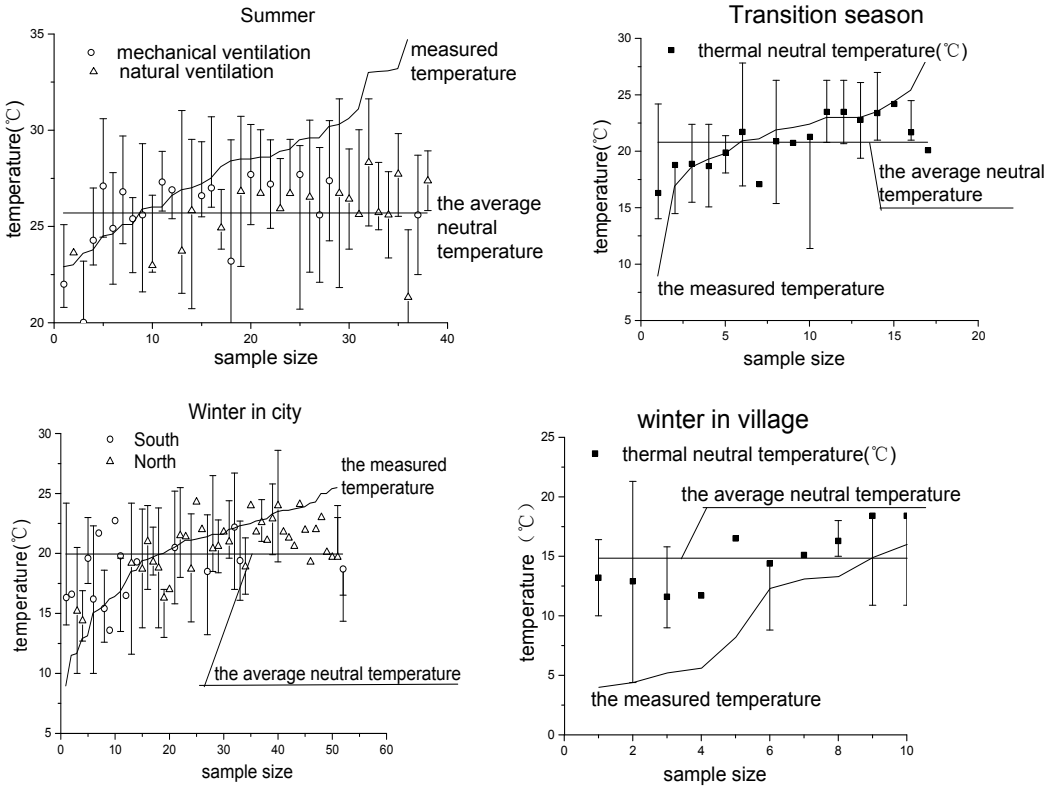

Fig. 4. Measured temperature and thermal comfort temperature distribution

Figure 4 shows that the measured temperature nearly has no effect on the thermal comfort temperature in summer, and the average value of the thermal neutral temperature is 25.7℃.

In transition season, buildings mostly use natural ventilation and the average of thermal neutral temperature is 20.8℃. During the transition period, with the increase of the measured room temperature, the thermal neutral temperature is on the rise (except for small part of the data). It shows that the measured room temperature can affect the thermal neutral temperature.

Table 3. Calculation of the dispersion degree

Season	Summer	Transition	Winter(village)	Winter(city)
The average neutral temperature(℃)	25.7	20.8	15.4	20.0
Mean absolute deviation(℃)	1.416	1.648	2.210	2.064
Standard deviation (℃)	1.893	2.034	2.660	2.590
Variation coefficient (%)	7.37	9.77	17.26	12.98

The average of urban thermal neutral temperature in winter is about 20.0℃. With the increase of the measured

temperature, the thermal neutral temperature is on the rise. The distribution range of thermal comfort temperature is wide, which is related to the location of the building and the ways of heating, lifestyle, etc. In winter, because there is no central heating in the south, the mean thermal neutral temperature in the south and north will be calculated respectively. The average temperature is 18.6℃ in the south and 20.3℃ in the north. Due to the lack of central heating in winter in the south, the thermal adaptability of human body is strong, the average of the thermal neutral temperature in the south is lower than that in the north.

The average of thermal neutral temperature is 15.4℃ in rural winter, which is significantly lower than that in the city building. The distribution range of thermal comfort temperature is wide, which is because most of rural buildings have no central heating and people have a stronger cold tolerance. The thermal neutral temperature is between 11.6℃~18.4℃.

4. Conclusions

The research systematically summed up investigations on thermal comfort in China, including natural ventilation and mechanical ventilation; Human body is basically in a meditation state. Most indoor temperature of the building meet the human thermal comfort needs, but there are also a part of the buildings does not meet the human thermal comfort. The indoor wind speed is small, the humidity distribution scope is broad from 19% to 87%. Most of the literature is based on PMV, and thermal comfort satisfaction rate range is 80% to 90% of the PMV evaluation index by the actual investigation. The following conclusions are drawn.

- The results show that different geographical location can affect human thermal adaptation. In Shanxi, Guangdong, Beijing and other research areas with many samples, they have greater reference value. In addition, for buildings using natural ventilation, we should take the human body's thermal adaptability into account, and it will have a wider thermal comfort range.
- The thermal comfort temperature is not completely related to the climate zone, which also can be affected by the actual insulation measures and the way of cooling and heating.
- The average neutral temperature are summarized as follows: the summer: 25.7℃; winter city construction: 20.0℃ (South: 18.6℃, North: 20.3℃); winter rural construction: 15.4℃; transition season: 20.8℃.
- The results show that the thermal comfort temperature will increase with the increase of the measured room temperature, that is to say, the long-term living environment can affect human thermal adaptation. Indoor temperature can affect the human's thermal comfort range, which is particularly evident in winter.

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