IMPROVING INDOOR THERMAL ENVIRONMENT OF RESIDENTIAL BUILDINGS UNDER TYPICAL SPACE HEATING METHODS IN XINJIANG, CHINA

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Abstract. In order to improve the thermal environment of residential buildings in winter for Xinjiang, this research conducted a field test and a survey of residential buildings under typical heating methods. The results show that the indoor temperature and humidity are dynamically changing, and the variation of central heating and gas wall-mounted furnace fluctuated less than that of coal heating. Furthermore, the thermal environment evaluation shows that the thermal comfort level under gas wall-mounted furnace heating are the highest, which belongs to category I. For the central heating and coal stove, only 12% and 26% of buildings achieve to category II. Moreover, it is found that the acceptable temperature range of coal furnace heating residents can be as low as 19.5°C, while that of central heating and gas wall-mounted furnace heating is 20.3°C~25.7°C, which relate to the clothing insulation of residents under different heating methods. In addition, all residents almost have the same habit of window opening behaviour during heating period, and 72% of residents open windows for ventilation. Correspondingly, 62% of residents feel dry during heating season, which induce xerosis cutis, dry mouth and other uncomfortable symptom, and can be improved by using humidifier, planting plants and so on.

1 Introduction

Heating energy consumption in northern China accounts for more than 65% of the total building energy consumption, and even up to 90% in some areas [1]. Xinjiang is located in the northwest of China. It is a typical cold/severe cold region, with the longest heating period of 190 days and the lowest outdoor temperature of -40°C in winter.

For residential buildings, different heating methods bring different indoor thermal environment. Some researchers conducted field investigations and comparative studies on human thermal comfort in typical public buildings in Beijing, Harbin, Shanghai and other regions, and found that residents in northern China have low adaptability to cold environment, and people's psychological expectation of indoor environment is affected by outdoor temperature, thus affecting people's thermal sensation evaluation. In addition, the lower the outdoor temperature is, the higher the expectation of indoor neutral state is, and the stronger the acceptance degree of indoor cold environment is [2]. When people have higher ability to control the environment, their thermal sensation tends to be neutral and they are more comfortable [3]. When the heating room temperature is too high, people's adaptability to the cold environment is gradually weakened, which will increase the heating energy consumption and is not good for human health [4]. People exposed to higher heating temperature for a long time are more sensitive to the decrease of indoor temperature, and higher heating temperature promotes the formation of higher thermal comfort zone [5]. People's adaptation to indoor hot and humid environment is mainly related to indoor temperature, followed by people's behavioural adjustment, psychological expectations, etc. On the one hand, too high indoor temperature reduces people's ability to adapt to cold environment. On the other hand, it increases the energy consumption of heating in residential buildings and affects human health. Most of the researchers conducted thermal comfort studies in Beijing, Harbin, Tianjin and other cities. The climate of different cities varies greatly, and the research of the above cities cannot account for all the cold/severe cold regions. In addition, residents' response to indoor thermal and humid environment in winter varies, so in-depth investigation of thermal environment in Xinjiang is needed.

Therefore, this paper gives a research on the thermal environment of Residential buildings under different space heating methods in Xinjiang. The field test and questionnaire survey were conducted, the clothing state, window opening behaviour and the improving method of thermal comfort was investigated and analysed.

2 Methods

2.1 Questionnaire survey

The questionnaire survey was conducted from January 2021 to February 2021, and 486 questionnaires were collected. The location distribution of questionnaire survey is shown in Fig.1. Among them, the Percentage of males and female was 55% and 45%, respectively. According to the survey, the activity state of people in residential buildings are mostly study, work and walk, which belong to very light labour and mild labour. The typical space heating methods are central heating-floor heating, central heating-radiator, gas wall-mounted furnace, electric wall hanging furnace, coal stove and other heating methods (electric heater, electric heat film/electric heat resistance wire, renewable

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energy), and the percentage are accounted for 47%, 30%, 11%, 1%, 9% and 2%, respectively.

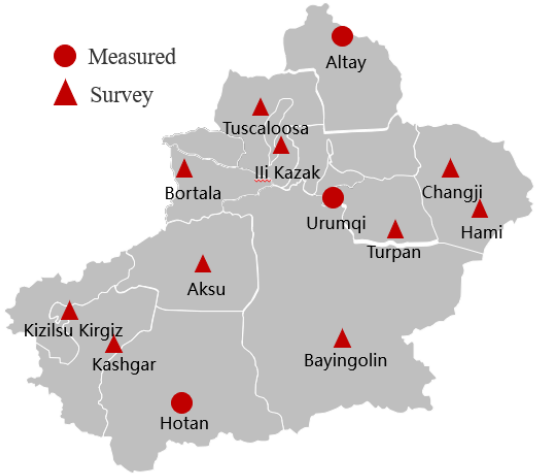

Fig. 1. Location distribution of questionnaire survey and field test

2.2 Field test

In this study, the thermal environment of typical residential buildings in Urumqi (cold zone C), Hotan (cold zone A) and Altay (cold zone B) were experimentally measured, and the location distribution of field test is shown in Fig.1. Table 1 shows the characteristics of winter meteorological parameters in the three areas.

Table 1. Meteorological characteristic parameters of the field test region in winter

Area	Calculated temperature outside (°C)	Space heating period days (d)	Average outdoor wind speed (m/s)	Extreme temperature (°C)
Urumqi	-19.7	180	1.6	-32.8
Hotan	-8.7	132	1.4	-20.1
Altay	-24.5	190	1.2	-41.6

The selected buildings were single-family houses and the residential area was 80~120 m^2. Heating methods are central heating-floor heating, gas wall-mounted furnace, and coal stove. The male and female ratio was nearly 1:1, and the age was ranging from 15 to 70 years old. Continuous tests were conducted in the living room, bathroom, bedroom, kitchen, and outside.

The instrument for field test were listed in table 2. The indoor dry bulb temperature, black bulb temperature and relative humidity were measured for 48h continuously. The instrument was calibrated before the test and the data was recorded every 30s. According to the Evaluation Standard (GB/T50785-2012), the recorder of temperature and humidity was placed 1.1 m above the ground, and the black bulb thermometer was placed 0.6 m above the ground.

Table 2. Measuring instrument

Name	Model	Parameters	Range	Accuracy
Temperature and humidity recorder	88162	Air temperature	30~70°C	±0.5°C
		Relative humidity	0~100%	±3%
Black bulb thermometer	AZ8778	Black bulb temperature	0~50°C	±1~2°C

3 Results and discussion

3.1 General evaluation of thermal environment

The average indoor temperature and humidity of different rooms under central heating, gas wall-mounted furnace and coal stove are shown in Figure 2. The indoor temperature of residential buildings under central heating was stable, and the indoor temperature was kept above 20°C, which meets the requirements of indoor heating temperature in winter. The indoor temperature under coal stove heating fluctuated from 15°C to 27°C. For space heating under gas wall-mounted furnace, residents can adjust the temperature independently. And the indoor temperature was about 23°C, and the humidity varies in a small range of 32%~57%.

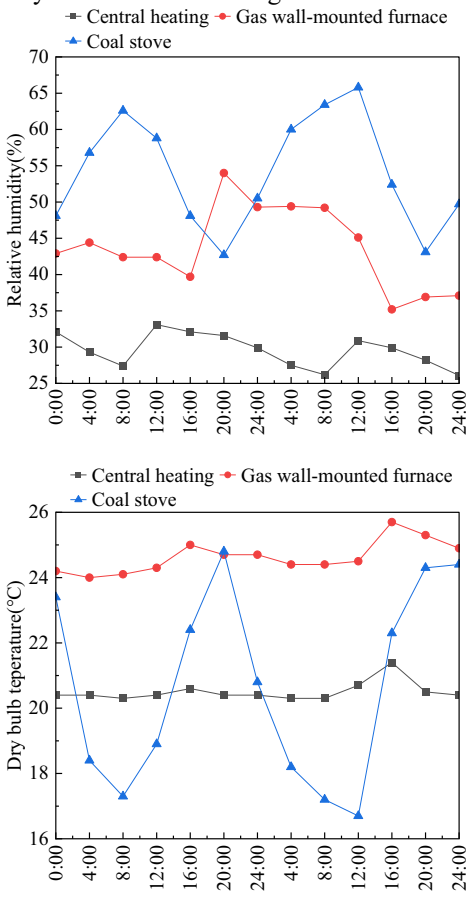

Fig. 2. Temperature and humidity changes under different heating methods

According to the experimental test, the distribution of thermal comfort zone under different heating methods was obtained. As shown in Figure 3, the area surrounded by dotted lines is the area where PMV=±1, indicating that all the temperature and humidity residents in this area consider thermal comfort. The temperature and humidity in the coal furnace space heating room was beyond the standard area partly. The indoor comfort humidity under central heating was relatively low, and the indoor comfort level under gas wall-mounted furnace is within the standard comfort range. and the indoor comfort level of coal stove is wider than the standard comfort area.

Moreover, the acceptable temperature ranges to residents under central heating is wider than that of residents under gas wall-mounted furnace heating. Residents using coal stove for space heating can accept a wider range of indoor temperature under thermal comfort.

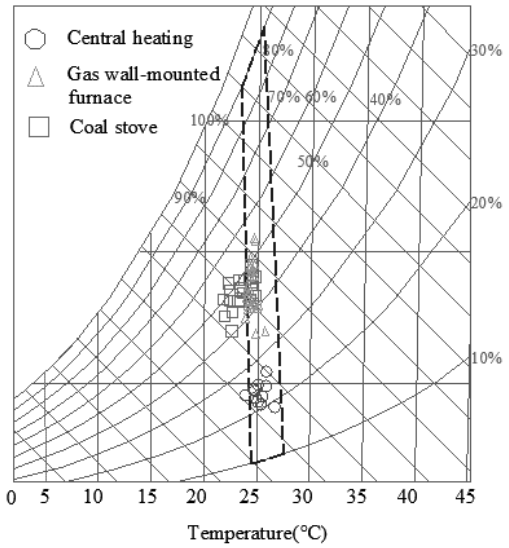

Fig. 3. PMV thermal comfort distribution of the three heating modes

According to GB/T 50785-2012 (Table 3), the thermal comfort evaluation of the three heating methods is carried out., 12% of rooms under central heating are category I, 68% are category II and 20% are category III. For coal stove heating, 26% of rooms reached category I, 22% reached category II and 52% were category III. Particularly worth mentioning is that all rooms under gas wall-mounted furnace heating reached category I.

Table 3. Evaluation index of indoor thermal environment

Level	Heated and cooled buildings	
Category I	PPD≤10%	-0.5≤PMV≤0.5
Category II	10＜PPD≤25%	-1≤PMV＜-0.5 or +0.5＜PMV≤+1
Category III	PPD＞25%	PMV＜-1 or PMV＞+1

3.2 Clothing condition and improving the thermal comfort

According to the clothing survey and the list of thermal resistance values of individual clothing in ASHRAE55-2013 and ISO7730-2005, the clothing insulation was calculated as formula below.

$$I_{cl}=0.161+0.835\sum I_{comp} \quad (1)$$

Where:

I_{cl}——Thermal resistance of a single suit (clo);

I_{comp}——Thermal resistance of single garment (clo).

The calculation results show that the average clothing insulation of residents in winter for central heating and gas wall-mounted furnace heating was 0.7 Clo, and that for coal stove heating is 1.1 Clo. It shows that the residents of central heating and gas wall-mounted furnace in winter wear relatively thin, and the residents under coal stove heating wear thick clothes.

For the thermal sensation, 48% of residents felt moderate, 32% felt slightly hot, hot or very hot, and 20% felt slightly cold, cold or very cold. As for the indoor humidity of residential buildings, 34% of residents think moderate, 61% of residents feel dryness, and 3% of residents felt a little damp. Therefore, the problem of indoor thermal environment in Xinxiang is generally dry. According to the survey, the percentage of dry mouth and xerosis cutis occur in residents are about 57%.

To improve the thermal environment, especially for the dry feeling, residents use humidifier and plants to raise the relative humidity, accounting for 33% and 27% respectively. In addition, 12% and 10% of residents raise fish or splash water, and 18% of residents do not take any measure.

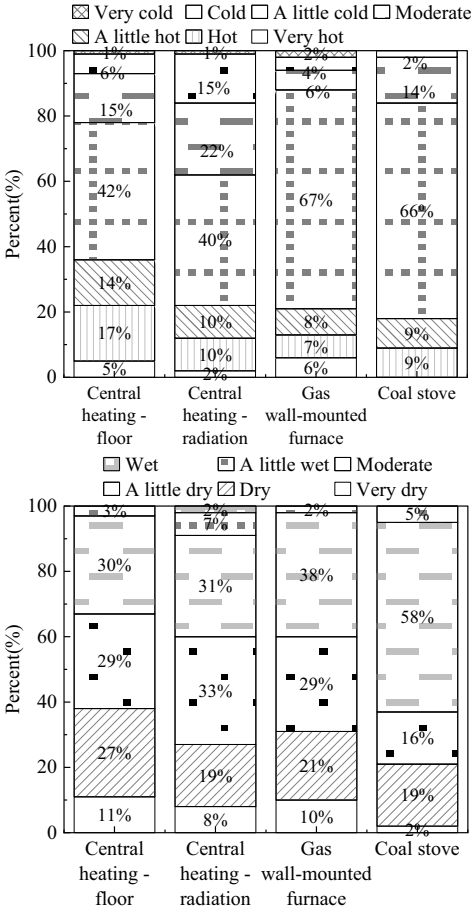

Fig. 4. Thermal sensation under different heating methods

3.3 Window opening behaviour

During space heating time in winter, 57% of residents would open their windows. As shown in Figure 5, the window opening frequency to more than one or three times a day, one time every three days, one time a week and all the time accounted for 72%, 19%, 2% and 7%, respectively. For the window opening time, less than 5min, 5-10 min, 10-30min and more than 30min, were accounted for 20%, 40%, 28% and 12%, respectively. The degree of window opening was divided into slightly open, half open and full open, accounting for 46%, 36% and 18%, respectively. Moreover, the cold air coming into the room played a role in indoor ventilation, and alleviated the indoor dryness.

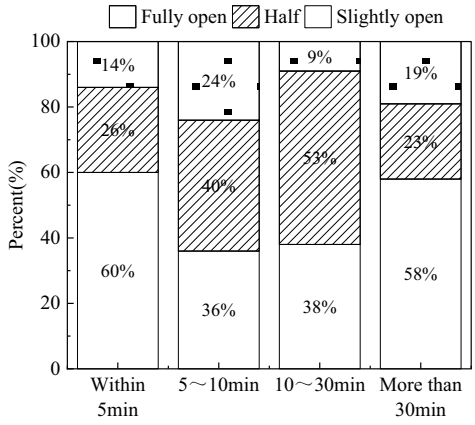

Fig. 5. Window opening time and degree

The main reason for residents to open windows was ventilation, accounting for 72%, followed by cooling and preventing strange smells from floor drains, accounting for 16% and 12%. Moreover, 43% of residents choose not to open windows in the heating season, mainly due to the fear of cold wind and low indoor temperature, accounting for 36% and 33% respectively, followed by the habit of not opening windows in winter, serious outdoor air pollution (haze, etc.) and indoor humidity and other reasons. Accounting for 72%, followed by cooling and preventing strange smells from floor drains, accounting for 16% and 12%. 43% of residents choose not to open windows in the heating season, mainly due to the fear of cold wind and low indoor temperature, accounting for 36% and 33% respectively, followed by the habit of not opening windows in winter, serious outdoor air pollution (haze, etc.) and indoor humidity and other reasons.

4 Conclusion

This paper conducted the field test and questionnaire survey to study the thermal environment in Xinjiang, the findings are listed below.

(1) Central heating is more popular in Xinjiang. Residents are highly satisfied with the thermal environment. The temperature of central heating room was above 20°C, the suitable indoor temperature under gas wall-mounted furnace heating was about 24°C, and the indoor comfortable temperature range under coal stove heating was wider.

(2) According to the PMV, the comfortable temperature accepted by residents under coal stove heating is lower than that of gas wall-mounted furnace and central heating.

(3) Residents under central heating and gas wall-mounted furnace wearing thinner clothes, the average clothing insulation was 0.7 clo. The temperature and humidity range of coal stove heating is large, and residents wore thick clothes, averaging 1.1 clo.

(4) 62% of residents felt different degree dryness, and had the symptom of xerosis cutis, dry mouth and other discomfort. The main measures were to place humidifiers and raise plants.

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