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Field survey of indoor thermal comfort in rural housing of northern China in heating season

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Abstract: This paper introduces a field measurement of an indoor thermal environment in rural housing in suburban Beijing from December 2008 to March 2009. The indoor environment parameters such as air temperature, mean radiant temperature (MRT), airflow velocity and relative humidity are measured. A questionnaire survey of the occupants' thermal sensations in these surveyed houses is conducted and their daily activities and clothing conditions are recorded. The results show that the thermal neutral temperature of rural housing is 18.4 ℃, and the lower limit of acceptable temperature range can be extended to 10.9 ℃. The comfortable indoor temperature is affected by the occupants' clothing and lifestyle. Therefore, the indoor temperature standards of space heating for suburban housing cannot be simply duplicated from that for urban housing. Compared with occupants in suburban Beijing, it is found that the occupants in rural Hunan province feel colder at the same operative temperature due to the high relative humidity in Hunan province.

Key words: rural housing; thermal comfort; field survey; space heating

In recent years, many researchers in China have studied thermal environment and occupant comfort in residential buildings in large cities[1-5], and the national standards for indoor thermal environment in different climate zones in China have been constituted based on the thermal comfort of urban residences in China and the ASHRAE standard. A field survey in rural housing in Hunan province, China was taken in the winter of 2006[6]. The results of this survey show that the neutral operative temperature is 11.5 ℃ in the rural Hunan residences and the acceptable indoor temperature is much lower than the standard value for the urban residence in that area. In fact, there are very few studies focused on indoor thermal environment in rural areas.

Rebuilding the existing rural residences for building energy efficiency and better indoor environmental quality is one of the most important tasks in China today. The indoor temperature standard is a base when we consider what kind of technical measures should be adopted. Therefore, the comfortable indoor thermal environment for rural residences is what should be studied. A field survey of indoor thermal comfort for space heating in rural residences in suburban Beijing, China was conducted by Tsinghua University. Furthermore, the survey results[6] are compared with those in Hunan to find out the differences between rural housing in cold climate zones and summer-hot and winter-cold climate zones, and the reasons for the differences are analyzed.

1 Method

1.1 Time and location

The surveys were conducted in rural housing in suburban Beijing during a period from December 2008 to March 2009.

1.2 Interviewees

Totally 30 occupants from seven residences were interviewed, and they were almost evenly divided between men and women. Their average age was 53.8 years old.

1.3 Building types and ways of space heating

All residences are single-storey buildings. A typical house plan with three bedrooms is shown in Fig. 1. It includes living room, bedrooms, kitchen, toilet, storage and spaces for domestic animals. Different from urban residences, rural residences have one or more yards and most of the functional zones are disconnected. An occupant has to go across the yard if he/she wants to go from one zone to another. Besides, working and some other activities in the yard are also parts of their lives. So the occupants have to go in and out of rooms frequently in their daytime. Hot water boilers are used to supply heat to the radiators installed in living rooms and bedrooms in most rural residences. There are a few families still using coal stoves for space heating.

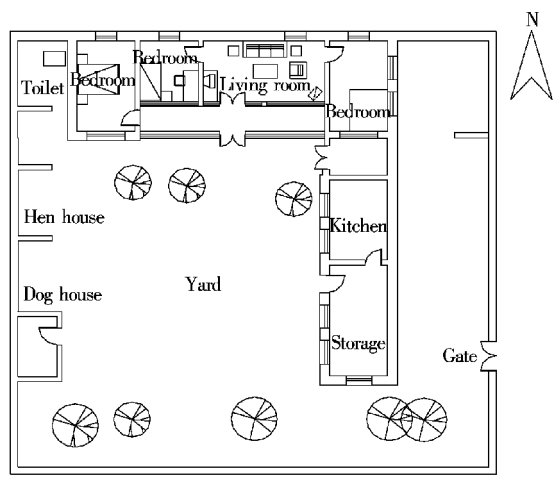

Fig. 1 The typical house plan

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1.4 Investigation method

The survey includes the measurements of indoor and outdoor environmental parameters and the inquires of the interviewees' subjective sensations. The two parts are conducted synchronously. The indoor environmental parameters measured are air temperature, mean radiant temperature, relative humidity and airflow velocity. The interviewees' clothing and activity conditions are recorded. PMV (predicted mean vote) is calculated by using these six recorded parameters. Meanwhile, the interviewees' thermal sensations are acquired by their votes. According to GB/T 18977—2003[7] and ISO 7730—2005[8], subjects' thermal sensation votes are acquired by questionnaires in which ASHRAE thermal sensation scale with seven levels is used. See Fig. 2.

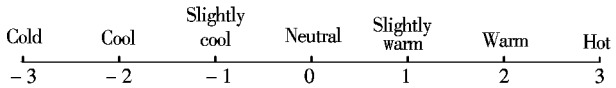

Fig. 2 TSV index

2 Results and Discussion

2.1 Environmental parameters

Daily average outdoor air temperatures are calculated from the hourly outdoor air temperatures recorded during the survey period. Daily average outdoor temperatures range from −1.7 to 10.8 ℃. The operative temperature is used as the indoor temperature index since it comprises the factors of both convection and radiation. The operative temperature ranges from 6.1 to 22.3 ℃, of which 83% is below 18 ℃ and 49% is within 15 to 17 ℃. Indoor air velocity ranges from 0.02 to 1.1 m/s, of which 52% is below 0.2 m/s. Relative humidity ranges from 20% to 77.6%, of which 82% is within 40% to 69%.

2.2 Thermal resistance of clothing

The interviewees' thermal resistances of clothing are in the range of 1.2 to 2.3 clo, of which 50.6% are in the range of 1.5 to 1.9 clo, which is equivalent to a set of long underwear top, long underwear bottom, thick long sleeved sweater, thick sweat pants, thick jacket, thick trousers, thick socks and boots.

2.3 Comparison between TSV and PMV

Fig. 3 shows the investigated TSVs (thermal sensation votes) and the regression lines as well as the PMV values. The cloth resistance of each interviewee is used in the PMV calculation, while the average metabolic rate, 1.4 met, is used. Each data point in Fig. 3 is the average value of all the interviewees' data at the same operative temperature (T_o). From Fig. 3, it is found that when indoor temperature gets low, the linear regression of PMV goes below that of TSV; and the deviation of TSV from PMV becomes greater as the temperature goes lower. It means that occupants do not feel as cold as PMV predicts. But when the indoor temperature is higher, TSV is lower than PMV, i. e., people feel cooler than PMV predicts. This difference may be caused by two reasons. First, when the indoor temperature is higher, the occupant may be resting, so the metabolic rate is lower than 1.4 met. Secondly, the occupant may have just come in from the outside, and the temperature of the body core as well as TSV is low.

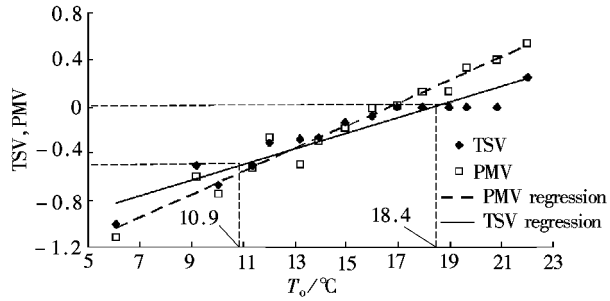

Fig. 3 Relationship between PMV/TSV and operative temperature

The formulae of linear regressive PMV and TSV are shown as follows:

$$\mathrm{PMV} = 0.097\,6T_o - 1.629\,3 \quad (1)$$

$$\mathrm{TSV} = 0.066\,7T_o - 1.223\,9 \quad (2)$$

From Eq. (2), it is found that when TSV = 0, the subjective thermal neutral temperature is 18.4 ℃.

The slope of the TSV regression line shows occupants' sensitivity towards the change in temperature. As it is lower than that of PMV, it means that the occupants are not so sensitive as PMV predicts.

From the regressive TSV, it can be concluded that when TSV = −0.5 (acceptable by 90% of the occupants), the lower limit of acceptable temperature can be as low as 10.9 ℃.

2.4 Indoor thermal environment standard of rural housing

The acceptable range of temperature in rural residences is lower than the national standard of space heating for urban housing, 18 ℃. One of the most important reasons is that the occupants in rural residences wear more clothes than those in urban residences when they stay at home.

Fig. 4 shows the results of field surveys on the relationship between clothing and indoor thermal environment of both urban and rural residences. Compared with the occupants in urban areas, it is found that the occupants in rural areas wear more and their indoor temperatures are lower. What is the reason? Is it only due to lower family income or economic levels in rural areas?

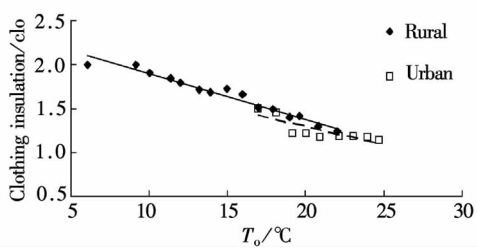

Fig. 4 Thermal resistance of clothing of rural/urban areas to operative temperature

In order to answer these two questions, the occupants' daily activities from 08:00 to 19:00 are recorded in detail. The time distribution of occupants spent in different func-

tional zones during the daytime is shown in Fig. 5. Although the occupants spend 70% of their daytime in the living room, but they go in and away from the living room more than 15 times per day. For example, an occupant goes to the kitchen twice for cooking, three times for dining, the toilet three to four times, the kitchen three times for getting boiled water, the yard three times for cleaning and feeding chickens, and the boiler room for fuelling. Each stay is about 2 to 20 min while each cooking costs 40 to 60 min.

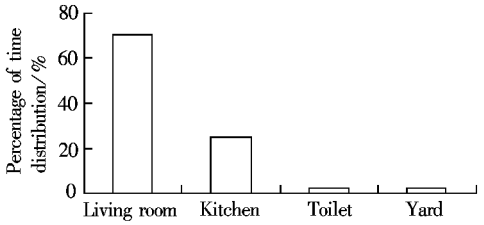

Fig. 5 Time distribution of occupants spent during daytime

Fig. 6 shows the recorded daily air temperatures of different functional zones of a typical family. It is shown that the temperatures in the yard, the toilet and the kitchen are much lower than those in the living room.

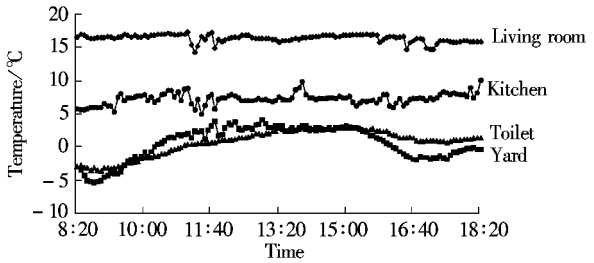

Fig. 6 Recorded temperatures in different functional zones in a typical family home

An important fact is that the occupants never put on or take off clothes when they go in and away from the living room. Therefore, their clothing should make them neither too warm in the living room nor too cold when they are outside for a short time. According to the clothing condition, the indoor temperature of the residences should not be too high, so most occupants choose 15 to 17 ℃ as their comfortable indoor temperature according to their intensity of activities.

2.5 Comparison of rural thermal comfort in Beijing and Hunan

Researchers in Hunan University took a field study of occupants' thermal comfort and residential thermal environment in a rural area in Hunan province in the cold winter of 2006[6]. 30 naturally ventilated rural residences were investigated and occupants warmed themselves using basins in which charcoal was burnt. Although the results of this survey show that the acceptable indoor temperature is lower than the standard value for an urban residence, it is still different from the results of this research. Trying to find more unrevealed facts, a comparative analysis is performed on results from Beijing and Hunan.

Tab. 1 shows the comparison of parameters relevant to thermal comfort in rural housing in Beijing and Hunan. It shows that the mean clothing insulation of Hunan is 2.15 clo, which is higher than that of Beijing, 1.6 clo. The mean metabolic rate, which is 1.53 met, is also higher than that of Beijing, 1.4 met.

Tab. 1 Summary of indoor parameters relevant to thermal comfort

Parameters		Operative temperature/℃	Relative humidity/%	Air velocity/(m·s^{-1})	Clothing insulation/clo	Mean metabolic rate/met
Beijing	Mean	14.9	46.9	0.29	1.6	1.4
	Max	22.0	59.7	0.56	1.9	
	Min	6.1	36.4	0.07	1.1	
Hunan	Mean	8.57	78.79	0.05	2.15	1.53
	Max	11.24	85.57	0.17	2.89	
	Min	6.06	68.04	0	1.16	

A new PMV of Beijing is derived with Hunan's clothing resistance and mean metabolic rate, i.e. 2.15 clo and 1.55 met, and the environmental conditions used are still Beijing's data. The deviation of the new PMV from the original PMV of Beijing is added to the TSV of Beijing, and then the new modified Beijing TSV is obtained and shown in Fig. 7.

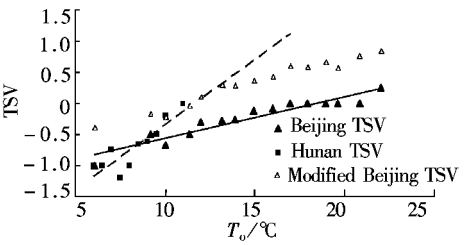

Fig. 7 Relationship between TSV and operative temperature in suburban Beijing and Hunan

Removing the effects of both clothing and metabolic rates as mentioned above, occupant thermal sensation votes in Hunan are lower than those in Beijing at the same operative temperature, which is shown in Fig. 7. The reason may be that high relative humidity, 70% to 80%, causes the increase of the heat diffusion of clothing, and then causes the low thermal sensation. However, the impact of high humidity in a cold climate on clothing has not been well studied quantificationally yet. Further research on this topic is necessary.

3 Conclusions

1) In cold regions, the thermal sensation of occupants of rural residences in winter is higher than the PMV value. Occupants are not so sensitive to lower indoor air temperature as PMV predicts.

2) The subjective thermal neutral temperature of rural housing is 18.4 ℃, while the lower limit of acceptable temperature is extended to 10.9 ℃ (TSV > −0.5). It is why more than 80% of the occupants choose the temperature lower than 18 ℃ as their acceptable temperature in their space heating room.

3) The indoor temperature standard of space heating for rural housing should not be simply duplicated from that for urban residences due to the unique lifestyle and house design in rural areas. According to the results of the field survey introduced in this paper, 14 to 15 ℃ can be suggested as the indoor temperature standard for space heating in rural residences, because it is the median of the acceptable temperature range chosen by the occupants.

4) Occupants' thermal sensation votes in Hunan are lower than those in Beijing at the same operative temperature. The reason may be that high relative humidity in Hunan province decreases the clothing insulation and then makes people feel cold.

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中国北方地区采暖季农宅室内热舒适调查

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摘要:介绍了在2008 年12 月至2009 年3 月对北京近郊的农宅室内热环境进行的现场调查. 对空气温度、平均辐射温度、风速、相对湿度等室内环境参数进行了测量,以问卷方式调查记录了居民的热感觉,并考察了农民的衣着和生活习惯. 调查结果表明,农宅中性温度为 18.4 ℃,可接受温度区间下限为 10.9 ℃. 舒适温度受到农民的衣着习惯和生活方式影响. 因此北方农宅的采暖温度标准不能照搬城镇单元式住宅楼的采暖标准. 通过与北京近郊农宅的比较,发现在相同的操作温度下,湖南农宅居民感觉更冷,原因可能是湖南农宅有较高的相对湿度.

关键词:农宅;热舒适;现场调查;采暖

中图分类号:TU241.4;TU111.3