



Study on the rural residence heating temperature based on the residents behavior pattern in South Liaoning province

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ABSTRACT

An intensive study on the heating temperature aimed to create a satisfying indoor condition that should meet the residents' thermal requirements in accordance to their daily behavior pattern. Unlike urban residents who stay indoors for a long time, rural residents constantly live in a dynamic environment: they often leave their residences and get busy with numerous labor activities. Therefore, the thermal sensation questionnaire survey performed in a steady environment is not suitable for them. To study the rural heating temperature in a dynamic environment, a three-years field investigation was performed in South Liaoning province. During the investigation, a continuous tracking method was adopted to record the residents' behavior; objective environmental parameters test and subjective thermal sensation surveys were rigorously recorded.

The results indicate that the residents behavior pattern exerts an influence on the heating temperature by influencing the residents' clothing insulation. Heating temperature in auxiliary rooms can be directly determined by the residents' thermal sensation, with the reasonable value of 11 °C. The influence of residents' behavior on clothing should be considered when determining heating temperature in the master bedroom, the reported value of which is 13 °C. The heating temperature obtained by the thermal sensation fuzzy comprehensive evaluation model in paper reflects the rural residents' real-life requirements on thermal environment, and it provides a reference for designing rural residences.

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1. Introduction

The rural regions in North China have very cold winters that last three to six months [1]. Unlike urban areas, the mode of heating in rural building is characteristically individualized; the heating temperature is controlled by the amount of coal-fuels burnt by residents themselves [2]. Due to low economic status, the rural residential indoor temperature during the winter has been relatively low. With the emphasis on rural structures/infrastructure construction, the economy and living standard have significantly improved [3]. People nowadays are no longer easily satisfied and pay more attention to comfort when it comes to indoor environment. Many rural residents blindly adopt the urban heating temperature standard. They start to burn a lot of fossil fuels, increasing indoor temperature up to 17–19 °C in the winter (the lower limit of urban heating temperature is 18 °C) [4]. However, the residents living habits, economic condition, adaptability and building heating mode between the urban and rural are significantly different, which supports an argument that the urban heating temperature

is not suitable in rural residence [5]. One of the indicators is that people easily get cold if there is a huge difference between indoor and outdoor temperature, especially if they often go in and out. In addition to the negative impact on health, maintaining the environment with high temperature by burning more coals aggravates energy demand and environmental pollution [6–7]. Rural heating is not only correlated to the residents' physical health, but also directly impacts the total energy consumption in China. Therefore, it is imperative to determine a reasonable heating temperature in rural residences.

Numerous studies in this field have indicated that the acceptable temperature in rural residences is lower than that in urban residences [2,5,8–12]. Wang et al. [8] conducted field surveys in Harbin, Northeast China where rural residences were supplied with individual heating. She reported that almost 90% of the rural residents set the lower limit of the temperature to 8.8 °C, and the neutral temperature was 14.4 °C, which are obviously lower than that in urban residences (21.5 °C). Zhu and Liu [9] proposed subjective temperature as the indoor heating temperature index, and it should not be lower than 15 °C in winter. Huang et al. [2,5] analyzed a large amount of field study data from 30 occupants in suburban Beijing. They found that the lower limit of acceptable

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Table 1
Difference in residents' behavior during the investigation and in real life.

Factors	Rural residents behavior during the investigation	Rural residents behavior in real life
Environment	Steady: stay indoors for a long time	Dynamic: go in and out often
Activity intensity	Sedentary or near-sedentary physical activity levels	Daily activity intensity
Clothing	Corresponds to sedentary or near-sedentary physical activity levels	Corresponds to the current activity

temperature among rural residents was only 10.9 °C, lower than the lower limit of heating temperature of urban residences (18 °C). They believe that rural residents' clothing and way of life significantly influence their temperature tolerance, and this is the main reason supporting the lower acceptable temperature. An increasing number of surveys have shown that the residents' living environment, heating control mode, psychological expectation and behavior pattern also influence the rural residents' tolerance for low temperature [1–2,13], which is in accordance with the Adaptive Model proposed by de Dear and Brager [14–18] in 1998. The team led by Cao et al. [2,13] found that the outdoor environment has a strong influence on the adaptability of the human body, so people who once lived in a cold indoor environment have better tolerance of winter than those who live in a hot or moderate indoor environment. Also, residents who use individual heating report higher satisfaction with indoor thermal environments compared to district heating users. Brager and de Dear [16] obtained a similar conclusion, i.e., the lower the outdoor temperature, the higher the indoor temperature, the poorer the ability to accommodate fluctuating temperatures, since the severe cold outdoor temperature was beyond residents' adjustment range.

These studies with field observation and questionnaire investigation in regard to thermal sensation represent the thermal neutral and acceptable temperatures in different rural regions, providing a theoretical guide to designing local rural buildings to some extent. Most of them refer to the 6 factors that influence a person's thermal sensation and some of them also take adaptability into account. The vast majority of the investigations were performed in a steady condition: respondents stayed in a steady indoor thermal environment for a long time and were not doing rigorous activities; they were in basal metabolism, sit or stand during the survey. Consequently, the available thermal sensation data matched the condition of people who were in sedentary or near-sedentary physical activity levels and dressed in a certain period of time, i.e., during the short survey. However, rural residents frequently go in and out throughout their daily lives. The differences in behavior of rural residents during the investigation and in real life are presented in Table 1.

The heating temperature aims to create a satisfying indoor thermal environment. It should meet the residents' thermal requirements in accordance to their daily behavior pattern. Therefore, the heating temperature trend, which was simply obtained by subjective thermal sensation questionnaire performed under a steady condition, failed to reveal the real-life requirements of rural residents.

In addition, most of the existing studies focused on the heating temperature of the master bedroom; the heating temperature of the other rooms were not within its scope for the low utilization rate. The temperature of other auxiliary rooms directly influences the heat loss from the master bedroom due to the temperature difference between adjacent rooms. Therefore, the heating temperature of each room in rural residences should also be determined.

In accordance with the above analysis, we conducted a field study with the intention of exploring the determination methods of rural residence heating temperature in a dynamic environment. Firstly, the method of continuous tracking was adopted to study rural residents behavior pattern in their daily lives. At the same time, the objective environment parameters were measured con-

secutively, and subjective thermal sensations were also recorded. Secondly, the influence of residents behavior pattern on their thermal sensation was analyzed based on the large number of field investigations. Thirdly, the membership function of multiply factors being subordinate to thermal sensation in different functional rooms was established. Lastly, the rural residence heating temperature of different functional rooms was determined by combining the residents behavior patterns in real life and the established membership function. This paper will provide new ideas for the heating temperature study in rural China, and it can be used as a theoretical guidance for the local New Rural Construction.

2. Research methods

The rural residents behavior pattern refers to the regular habits and its essential characteristic, which is driven by the needs and productive demands over a long period of time. It has a close connection with the rural residents' daily life pattern, historic culture, the courtyard layout, the interior layout and so on. In this paper, south of Liaoning province, located in Northeast China was selected as the survey region. This area has the obvious climate characteristic of the Cold Region, where winters are long and cold. The average temperature and minimum temperature is about $-6.6\sim-2.2$ °C and -22.7 °C, respectively. The heating lasts almost 6 months (from November to April).

The study was conducted from 2013 to 2016. 102 rural residences, located in six different villages, were involved in this study.

In the first survey of 2013, basic information, such as the room function and plan layout, energy consumption, residents' satisfaction with indoor thermal environment (see Table 2 in detail) were obtained through a comprehensive questionnaire. According to the extensive visits, we found that rural residential layout, room function, residents' behavior and their demand on thermal environments were basically similar. So in the further study of rural residential heating temperature, we chose some typical residences as the survey targets. The typical residences represented most rural residences in south of Liaoning Province to a certain extent in terms of population structure, economy condition, layout, indoor environment, residential activity and clothing, and so on.

Instead of the common door-to-door field investigation (in 2013), in this detailed survey about rural residents' behavior and thermal sensation in 2014 to 2016, the method of continuous tracking was adopted. The investigators stayed with rural residents in order to record their daily lives and behavior pattern. In addition, environmental parameters and the residents' subjective thermal sensation were measured.

The detailed survey information can be seen in Table 2.

2.1. Monitoring of residents behavior

The residents' yard activity was continuously recorded by the behavior-monitoring device (Fig. 1), including the residents' clothing, activity time and trace, activity intensity, and so on. The monitoring scope should cover the whole yard.

To respect individual privacy, the residents' indoor activity was recorded by the investigators (instead of by the behavior-monitoring device). This includes the residents' activity duration in each room, intensity of each activity and clothing.

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