Research on Rural Heating Design Temperature Based on Residential Behavior Pattern

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Abstract

Purpose / Context - Rural heating design temperature is closely related to building thermal performance design, indoor plain layout and energy consumption.

Methodology / Approach - Focus on residential behavior pattern, this paper studied the rural heating design temperature based on the site research.

Results – Firstly, a site research is carried out taken rural region in south Liaoning province as an example, which in terms of the plain layout of yard and interior, residential behavior, residential clothing and activity, indoor thermal environment, residential thermal sense and so on. Secondly, based on site research, the influence of current residential behavior pattern on their clothing and activity intensity is analyzed. Thirdly, the subordination relation curves between indoor temperature and thermal sense subsets are established by means of fuzzy theory.

Key Findings / Implications – Based on maximum membership principle, rural residential heating design temperature is determined. And it is from 12 to 16 centigrade for master room.

Originality - This paper will offer theoretical foundation to the design of heating system in rural new rural construction.

Keywords - behavior pattern, heating design temperature, fuzzy statistics, thermal comfort, thermal sense
1. Introduction

With the advancement of society and improvement of living standard, people have higher requirements on indoor thermal environment (Guo and Wang, 2008; Li, Liu and Yao, 2007; Wan and Song, 2007; Wang, Y. Liu, J. Liu and Wang, 2010). Indoor thermal environment has a close relationship not only to human comfort and health, but also to building energy consumption and pollutant emission, even the sustainable development of resources. However, there still exist many rural residences with low indoor temperature in winter in China, which caused by the below reasons. One is the serious cold air infiltration and cold radiation caused by the worse thermal performance of building envelope and the unreasonable plain layout. The other is the low energy efficiency. Furthermore, the energy supplied to room is low for the restriction of residential economy (Ma, Shao, Zhang, Zhou, Liu and Tang, 2015). To improve indoor thermal environment, it is necessary to optimize thermal performance of building envelope, indoor plain layout and heating system. And the optimization degree is decided by the heating design temperature.

Urban residential heating design temperature ranges from 16 to 24 centigrade, which is required by standards (Ministry of Construction, PRC, 2003). However for the difference in life mode and behavior pattern between rural and urban, urban heating design temperature cannot be applied to the rural residence. How to determine rural residential heating design temperature? Against this problem, many researches were made in China. Jin Hong (Jin, Zhao and Wang, 2006) researched current situation of rural residence in severe cold area and the difference in thermal comfort between rural residents and urban residents. She integrated investigation data analysis, theoretical calculation and the rural development tendency, suggesting that the heating temperature should be from 15 to 18 centigrade. Taking Yinchuan as an example, Zhu Yiyun and Liu Jiaping (Zhu and Liu, 2010) analyzed factors that influence indoor thermal environment on the basis of the local residential characteristic, peasants’ life habit and clothing and heating system. They proposed the indoor thermal environment indicator that is suit to rural residence in northwest. Focus on serve cold area, Zhang Wei (Zhang, 2012) proposed indoor heating design temperature based on the use time and interior plain layout through combing the development tendency of yard and the calculation on subjective temperature. Zhang Yufeng (Zhang, 2015) investigated rural residential life habit and thermal behavior. He proposed the acceptable temperature respectively suitable to different ventilation measures, which provides theoretical basis to the design of passive and active building in hot summer and warm winter area.

Furthermore, a series of rules were published by Ministry of Housing and Urban-Rural Development. Energy saving technical guidance to rural housing in severe and cold area published in 2009 presents that heating temperature in master room is from 14 to 18 centigrade. Design standard for energy efficiency of rural residential buildings published in 2013 presents heating design temperature in master functional room is 14 centigrade (MOHURD, 2013). This standard provides basis to the energy-saving design of rural construction.

Rural heating design temperature aims to provide people with comfort indoor thermal environment. Its value is determined by residential thermal sense. Except environment temperature, residential clothing, activity and expectation also have influence on residential thermal sense. Those factors have a close relationship with residential life mode, behavior and daily routines. In other word, residential life mode, behavior and daily routines decide their clothing and activity, further affect the determination of heating design temperature. However in existing researches, most are in terms of thermal sense, clothing, activity intensity, indoor temperature. They hardly refer to residential behavior pattern that decides people’s clothing, activity intensity and thermal sense, which cause them fail to reveal the basis of determining rural heating design temperature.

Therefore, it is necessary to make research on rural heating design temperature from the prospect of residential behavior pattern. On the basis of rural site research in south Liaoning province, this paper discusses the method of heating design temperature based on residential behavior pattern.
2. Study on residential behavior pattern

A site research on 5 rural residences in south Liaoning province was carried out during 23 January to 27 January. To have a general grasp of residential life mode, activity and clothing, comfort demand on indoor thermal environment and so on, researchers live with residents in their houses during the investigation. Through measurement and communication with residents, rural residential basic information, production mode, and local cultural tradition were gained. Residential activity routines were learned through continuous record on their activity and clothing in yard by monitor system. In addition, to acquire the thermal environment condition, a continuous temperature test on different function room was made. At the same time, questionnaire investigation was carried out, including residential age, sex, activity room and intensity, clothing and thermal sense on surrounding environment.

2.1 Rural residential plain layout

2.1.1 Rural residential plain layout of interior

In research district, rural residences are unified constructed by the government, with the same areas and plain layout. Figure 1 gives rural residential indoor plain layout. In addition to the common rooms that can meet residential basic living requirement, such as bedroom and kitchen, there are also other functional rooms, such as washing room, living room, dining room and so on. In general, the function of rooms is relatively perfect.

![Figure 1 Rural residential indoor plain layout](image)

2.1.2 Rural residential plain layout of yard

An obvious characteristic of yard in rural residence in south Liaoning province is spacious, with the length of 15 meter and the width of 12 meters. Figure 2 portrays typical yard scene in local rural residence. A path of red brick lies between the outside door and the entrance to house as the main passageway to residence. Two open spaces are respectively beside the path used for growing vegetables, feeding poultries, storing firewood and so on. The plain layout of different residences varies with residential habit, but it is essential consistent for the existence of vegetable garden, poultry ring, straw heap and so on, which is decided by residential life style and habit.
2.2 Residential behavior pattern

2.2.1 Residential activity routines and clothing in yard

Based on residential activity in yard and inside the house, their behavior can be divided into three types, Busy type, Going-out type and House-oriented type.

For residents of Busy type, the notable characteristic is that they go out of the house frequently during the whole daytime and they spend more time out of the residence than inside the residence. For the long time of staying outdoors, to keep warm they have to wear thick and the clothing hardly changes in a day. Figure 3 shows the typical residential activity time and clothing in yard in a day. The horizontal axis is time and the vertical axis is the duration time in yard.

For residents of Going-out type, the notable characteristic is that they are not inside the residence or in the yard in most time during the day. They usually go home at meal and go out after dinner. Their activity and clothing status are given in Figure 4.
For residents of House-oriented type, they spend most time doing housework and recreation inside the house during the whole daytime but they go to the yard frequently in three time bucket, respectively in morning, at noon and at dusk. This is decided by the mode of cooking, heating and production. In rural district of south Liaoning, cooking and heating have a close relationship. The high-temperature flue gas generated by cooking flows into Kang to supply heat to room and the heat source is biomass energy, such as straw and firewood. Heating radiator as the other heating system is equipped in some residences and its heat source is coal. During the cooking in three time bucket, people need to go to the yard to take wood. And they usually take coal at the same time for convenience. In addition, they need to feed poultry before or after the meal. All of these decide that residents need shuttle indoor and outdoor frequently.

Figure 5 gives the typical House-oriented residential activity and clothing status in yard. According to the statistics, people stay in yard within a few minutes every time. However they still wear thick for the low outside temperature. Owing to the fact that they shuttle between indoor and outdoor frequently, so it is not convenient for them to frequently put on or off coats. Based on this reason, there is a little change on residential clothing no matter they are indoor or in the yard in a day. And they still wear thick even indoors, only at noon when indoor temperature reaches the highest, they may take off coat.

2.2.2 Residential activity routines in interior

Kang, which is used for rest, entertainment, having dinner and so on, is the master activity space in countryside of the northeast China. And master bedroom with Kang is the room where people stay at most times. Based on the investigation data, residents stay in master bedroom almost 17 hours, even to 20 hours. Figure 6 gives the percent of residential activity duration in different functional rooms.
3. Determination of rural heating design temperature

In rural residence, the duration time that people stay in master bedroom is longer than they stay in other rooms, and the activity intensity is lower. Therefore, people have higher demand on heating temperature in master bedroom. Taking master bedroom as an example, this paper studied the method of determining rural residential heating design temperature.

Heating design temperature is decided by residential thermal sense which is a fuzzy concept with large fuzziness. The first step to evaluate fuzzy concept is to divide the fuzzy grade. In present researches, ASHARE 7 point scales are widely adopted. And -3, -2, -1, 0, 1, 2, 3 represent for the grade of thermal sense, respectively represents cold, cool, slightly cool, moderate, slightly warm, warm, hot. Owing to the difference in linguistic expression and comprehension between English and Chinese, it is hardly to distinguish the limits between the contiguous thermal sense grades for Chinese. Therefore, the description of thermal sense should be easy to understood and chosen by residents. And thermal sense of groups who are served by the environment for a long time should be used to describe and evaluate environmental thermal comfort rather than thermal sense tested by researches. In this investigation, 5-grade thermal sense is adopted, referring to freezing cold, stretching out hands, moderate, feeling hot without sweat, feeling hot with a little sweat.

Choosing 2 centigrade as an interval, then the operating temperature is divided into several ranges. In every temperature range, thermal senses are statistic though fuzzy statistical method. And the central temperature in a temperature range is taken as independent variable. Though above method, the subordination curve of temperature to residential thermal sense in master room is gained, given in Figure 7.

[Figure 7 Thermal sense in master bedroom]

The subordination curve gained is not normal. However, in theory it should be normal, meaning that the maximum membership degree is 1 in every fuzzy subset. Fig. 7 shows that the temperature span of fuzzy subset is large, from 8 to 14 centigrade, and the membership degree of cross point between contiguous thermal sense degrees is small, about 0.4. In general, the fuzzy subset is similar to triangular distribution or normal distribution. But triangular distribution can’t meet the requirements of large temperature span and low crossing at the same time. Normal distribution is adopted here. The subordination curve is given in Figure 8.

[Figure 8 Theoretical normal subordination curve]

According to maximum membership principle, when the membership of a certain temperature to a fuzzy subset is bigger than it to other fuzzy subsets, then this temperature relatively belongs to this fuzzy subset. Based on this principle, rural heating design temperature in master room is determined. Freezing cold temperature is lower than 8 centigrade. Stretching out hand temperature is from 8 to 12 centigrade. Moderate temperature ranges from 12 to 16 centigrade. Feeling hot without sweat temperature is from 16 to 20 centigrade and feeling hot with a little sweat temperature is higher than 20 centigrade.
4. Discussion

4.1 Applicability of heating design temperature

In three kinds of behavior patterns proposed in this paper, Busy type and Going-out type are widely common in men, while House-oriented type is widely common in women. It is in accordance with the ancient pattern that is men plowed the fields and women wove cloth. From this point, behavior pattern is the inheritance of history, reflecting Chinese traditional culture to some degree. Therefore, it will not change in a short time.

Rural heating design temperature discussed in this paper is proposed under residential current behavior pattern. Residential behavior pattern is comprehensive role of traditional culture, social development, economy and production mode, and it has certain persistence, however it will still change with the advancement of society and improvement of economy. At the same time, heating design temperature should make corresponding change.

4.2 Accuracy of heating design temperature

Owing to Busy type and Going-out type stay outside for a long time which is longer than they stay in interiors during the daytime, so the data of thermal sense largely come from the House-oriented type, who stay most time in interiors. Furthermore, most of House-oriented are women, therefore heating design temperature proposed in this paper gives more priority to women.

In addition, restricted by time and manpower, this investigation was carried out focus on one village. And the number of household investigated was less. To increase sample capacity, investigation lasted 5 day. However, the number of data was still finite. Therefore, the accuracy of heating design temperature remains further study.

4.3 Indicator of heating design temperature

Operating temperature, the synthetic action of radiation temperature and air temperature, is as indicator of heating design temperature in current paper, which is decided by the heat dissipation characteristic of local heat source. If thermal convection is stronger than thermal radiation for heat source, then air temperature can be as indicator of heating design temperature.

5. Conclusion

Taking rural area in south Liaoning province as an example, a site survey was carried out, referring to the plain layout of yard and interior, indoor thermal environment, residential behavior pattern and thermal sense. The conclusions are as follows.

Firstly, residential behavior pattern is divided into three type based on residential activity routines in yard and inside the house, respectively is Busy type, Going-out type and House-oriented type. This pattern is the inheritance of traditional culture that men plowed the fields and women wove cloth.

Secondly, for House-oriented type, their behavior pattern is shuttling between indoor and outdoor frequently in three time bucket, respectively in morning, at noon and at dusk, which is decided by the mode of cooking, heating and production. Furthermore, the behavior pattern decides residential thick clothing.
Thirdly, the subordinate curve of temperature to thermal sense grade is gained though fuzzy statistical method, and the moderate temperature is from 12 to 16 centigrade under residential current behavior pattern.

6. References