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INDOOR CLIMATE OF DETACHED RURAL HOUSES WITH INTERMITTENT AND CONTINUOUS HEATING IN CHINESE SEVERE COLD REGION

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ABSTRACT

In the Chinese severe cold region, a large number of rural houses apply Chinese Kangs (heated beds as living and sleeping platforms) and coal boilers with water radiators for space heating. They mainly operate intermittently and are controlled manually by users. This paper aims to simulate the operating performance and indoor thermal conditions in the rural house, as well as differences between intermittent and continuous heating modes. A single-family rural house in Harbin was applied as a case building, representing the typical condition of similar houses in this climate. The obtained results demonstrate that continuous heating has 3.2°C lower daily temperature variations than intermittent heating, while a 31% increase in heating energy consumption is also observed.

INTRODUCTION

In the severe cold region of China, a large number of rural houses have high heating demand, poor envelope thermal insulation and inefficient heating systems, all of which raise annual heating energy consumption. The severe cold region is defined as having an average temperature of less than -10°C during the coldest month and more than 145 days with a daily average temperature of less than 5°C /1/. Rural houses are mainly constructed by local builders with few restrictions from building codes, which leads to high energy and consumption and emissions. Combined with the extremely low temperature in winter, these houses have a considerable level of heating demand.

Without access to district heating, the primary heating systems in these rural houses are Chinese Kangs (heated beds as living and sleeping platforms) and boilers with water radiators, representing 99% and 51% of heating systems, respectively /2/. The systems are manually operated intermittently due to economic reasons and traditional customs. Continuous heating systems are often used in cold climates to ensure that the indoor temperature meets high-level thermal requirements, like in northern Europe. However, there is little research exploring the differences when applying intermittent and continuous heating modes in Chinese rural houses. Besides, Chinese severe cold region has a long heating season and a large temperature range. It is also meaningful to study the effect of heating operation modes on indoor thermal comfort under different weather conditions.

The main objective of this study is to simulate the operating performance and indoor thermal conditions when two traditional heating systems, a Kang system and a coal boiler with water radiators, are combined in the same rural house. The study also compares the differences between the original intermittent heating mode and the assumed continuous heating mode. The different heating modes were compared separately in different weather conditions and evaluated from indoor thermal comfort and energy consumption perspectives.

METHODS

Description of case building

A single-story detached house located in Harbin was selected as a case building in this study because the local weather conditions and building construction could represent a major share of rural houses in this climate region in China.

As shown in Figure 1, the case building contains two bedrooms, a kitchen, and a storage room. Most of the load-bearing structures are brick, which is the dominant structure type in this region. Its envelope structures and other building parameters are presented in Table 1. Its material selections and construction details could represent the common construction approaches in this climate region. The building was constructed in the 1990s by local builders. There was no restriction of any energy-efficient building codes in rural areas during that time regarding airtightness or envelope materials.

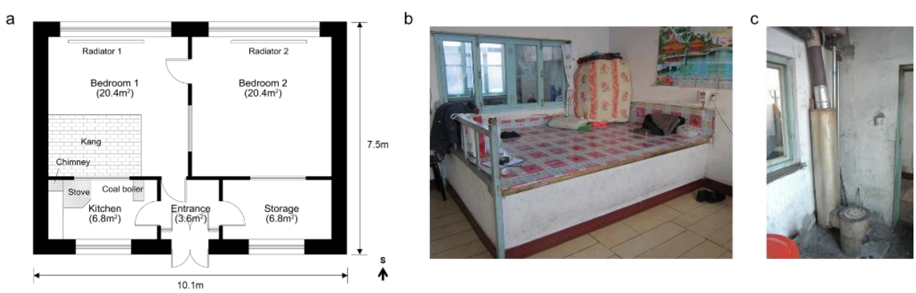

Figure 1. (a) Layout of case building, (b) Chinese Kang in bedroom 1, and (c) coal boiler in kitchen.

Table 1. Building parameters.

Parameters		Values
Envelope area [m^2]		199.9
U-values [W/m^2k]	External walls	0.92
	Roof	0.42
	Ground floor	3.88
	External windows	2.3
	Entrance door	2.5
Airtightness, n_{50} [ACH]		7
Internal gains [W/m^2]	Lighting	5
	Equipment	3.8

The occupants open the windows according to their comfort sense. For maintaining the indoor temperature and saving energy costs, ventilation in winter is only conducted by envelope infiltrations instead of opening windows. Because of the poor airtightness, the airflow rate is able to maintain acceptable CO_2 level. Other issue is cooking that we are not study here.

The heating season in Harbin lasts 183 days, from October 20 to April 20 of the following year in the studied case. The local average temperature is -7°C during the whole heating season. January is the coldest month, with the minimum temperature of -30.5°C /3/. Without the district heating network cover, the space heating of this rural house is operated through two sources: one Chinese Kang system and one coal boiler with two water radiators. Raw coal is used as heating fuel.

The traditional Chinese Kang system consists of a stove, a Kang body and a chimney. The stove in the kitchen serves as the heat source and cooking function. The Kang body in bedroom 1 is a cavity constructed of brick, and it leans on the wall between bedroom 1 and kitchen. The high-temperature smoke flows from the stove, through the hole on the shared wall, into the chamber of Kang, and finally exhausts through the chimney. In winter, people sit on the Kang during the daytime and sleep on it at night. Therefore, the Kang is regarded as a heated bed, serving as a living and sleeping platform. The input power of the stove and Kang are set as 3 kW and 11 kW. The coal boiler is another heat source in the rural house, which is in the kitchen. The water heated by the boiler goes through the pipes and is then transferred to the radiators in two bedrooms. The peak heating power of boiler is 7.5 kW, with total heating efficiency of 40%.

Figure 1 shows the Kang body in bedroom 1 and the coal boiler in kitchen. The systems are manually operated intermittently due to economic reasons and traditional customs to accept large variation in room air temperature. According to Cao et al.'s research /4/, the power output of them varies in different heating times and different weather conditions. As shown in Figure 2, the whole heating season could be divided into three weather groups based on the outdoor weekly average temperature, namely slight cold, cold, and severe cold groups. One week in each group is chosen as a typical week which represents the typical weather conditions of this group (see Table 2). The Kang and stove are heated three times a day. The Kang's output power reaches its peak in an hour and then decreases within the following four hours. Generally speaking, colder weather leads to higher power of heating systems.

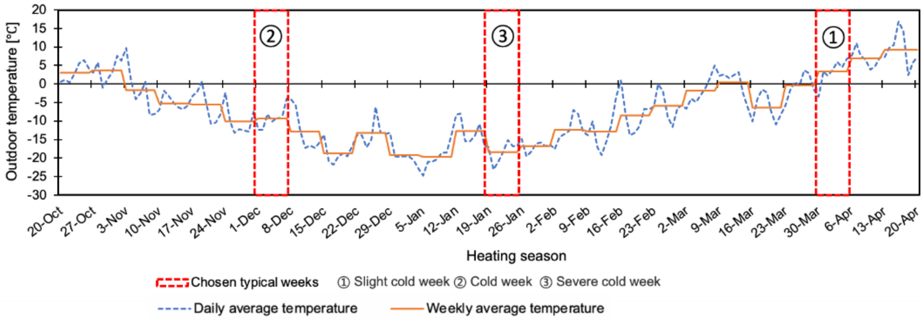

Figure 2. Average temperature variation and typical weather weeks during heating season.

Table 2. Weather condition classification and chosen typical weeks.

Weather condition	Temperature range	Chosen typical week	Weekly average temperature of the typical week
Slight cold	> -5°C	Mar 30 - Apr 5	3.3°C
Cold	-5°C ~ -15°C	Dec 1 - Dec 7	-9.4°C
Severe cold	< -15°C	Jan 19 - Jan 25	-18.3°C

Simulation cases

Six cases are defined to analyze the impact of intermittent and continuous heating modes in three weather conditions. Intermittent heating mode mimics the original operation of the case building, where the Kang system and coal boiler operate for 15 hours and 6 hours per day. While continuous heating mode sets the coal boiler system to run 24 hours per day with a heating setpoint of 14°C /5/ with Kang system maintaining the original intermittent schedule.

Case 1 and **Case 2** simulate in the typical slight cold week with coal boiler operating intermittently and continuously, respectively.

Case 3 and **Case 4** simulate in the typical cold week with coal boiler operating intermittently and continuously, respectively.

Case 5 and **Case 6** simulate in the typical severe cold week with coal boiler operating intermittently and continuously, respectively.

IDA Indoor Climate and Energy simulation software (IDA ICE) 5.0 was applied to create and simulate these cases.

RESULTS

Due to the fact that the residents spend their time mostly in two bedrooms, the indoor temperatures of these two rooms is analyzed. Table 3 illustrates the average room air temperature and daily average temperature variation of bedrooms in each case.

Results of cases with intermittent heating (Cases 1, 3, and 5) illustrate that significant temperature variation occurs in two bedrooms. Especially during severe cold week (Case 5), the average daily temperature differences are as large as 8.3°C and 12.9°C in two bedrooms, which worsens the thermal comfort and increases the possible health risk of elderly occupants.

In addition, bedroom 2 relies on the water radiator for space heating only, and its average temperatures in Cases 1, 3 and 5 are all lower than 14°C. While in bedroom 1, both Kang and water radiator provide heat. During the slight cold week in Case 1, the average room air temperature in bedroom 1 reaches 16°C. However, during cold week and severe cold week (Case 3 and 5), the temperatures are also lower than 14°C. Besides, the indoor temperature of bedroom 1 is more stable than bedroom 2 in all weather conditions.

Results of cases with continuous heating (Cases 2, 4 and 6) demonstrate that average temperature in two bedrooms maintain 14°C with fewer daily temperature differences.

Table 3. Temperature conditions in bedrooms during chosen weeks with different heating modes and weather conditions.

		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
		intermittent, slight cold	continuous, slight cold	intermittent, cold	continuous, cold	intermittent, severe cold	continuous, severe cold
Average temperature during chosen week [°C]	Bedroom 1	16.0	16.8	12.9	14.8	11.0	14.3
	Bedroom 2	13.1	14.7	9.8	14.0	7.2	14.0
Average difference of daily maximum and minimum temperatures during chosen week [°C]	Bedroom 1	4.6	4.0	5.7	2.3	8.3	1.7
	Bedroom 2	5.7	2.4	8.9	0.1	12.9	0.0

Table 4 lists the comparison results of intermittent and continuous heating modes during the whole heating season based on indoor temperatures and energy consumption.

It can be seen that during the heating season, when applying intermittent heating mode, the two bedrooms have a large average daily temperature variation of 6.1°C and 8.8°C, respectively. Continuous heating mode increases the average temperature in two bedrooms by 2°C and 3.8°C, as well as reducing the daily temperature difference by 3.2°C and 7.3°C, respectively. However, this improvement is achieved based on the increased heating energy consumption by 31%.

The delivered heating energy consumption of the Chinese rural house is 281 kWh/m^2-a by continuous heating mode. Hirvonen et al.'s research /6/ reported that the delivered energy consumption of old Finnish detached houses, which were constructed before 1975 and heated by wood boilers continuously, is 234 kWh/m^2-a. Thus, Chinese rural houses in severe cold region consume 20% more energy consumption than old Finnish detached houses in similar climate. Besides, the setpoint for heating is 22°C in Finnish houses, while that in Chinese rural houses is only 14°C.

According to the current building performance of Chinese rural houses, increasing heating setpoint and operating continuously would lead to more energy consumption. However, to save energy costs, occupants tend to choose the intermittent heating mode and tolerate lower indoor temperatures and larger temperature variation.

Chinese solution in this severe cold region is that people sleep and live on the Kang with thick jackets and blankets. According to calculation in Jia et al.'s research /7/, the clothing resistance of rural occupants in winter is 1.42 clo. Although the simulation results show low temperature in bedroom 1, occupants could achieve a more comfortable level by gaining heat through contact with Kang surface.

Table 4. Indoor thermal comfort and energy consumption during heating season.

		Intermittent	Continuous
Average temperature during heating season [°C]	Bedroom 1	14.1	16.1
	Bedroom 2	10.8	14.6
Average difference of daily maximum and minimum temperatures during heating season [°C]	Bedroom 1	6.1	2.9
	Bedroom 2	8.8	1.5
Delivered energy consumption for space heating [kWh/m^2-a]		213.7	281.0

CONCLUSIONS

This study simulated the operating performance and indoor thermal conditions when two traditional heating systems, Kang system and coal boiler with water-based radiators, are combined in the same rural house in Chinese severe cold region.

It is found that significant temperature variations occur in two bedrooms during all three typical weeks when applying intermittent heating mode. During cold week and severe cold week, the temperature in two bedrooms is lower than the setpoint of 14°C. During the heating season, continuous heating has a 2°C higher average temperature and 3.2°C lower daily temperature variations than the one with intermittent heating. However, a 31% increase in annual heating energy consumption is also notable.

Considering the current indoor climate conditions of rural houses, renovations of envelope, ventilation and energy system would be considered and designed in the next phase. The results of this study could be used as fundamental data and comparison objects in future research.

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