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Burning Cave-Pipe Coil-Kang Coupled Heating System Research

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Abstract: Nowadays, people still rely on traditional heating methods in rural areas of northern China, such as Kang (bed-stoves) and burning caves in cold winter. Field measurements of indoor environment were carried out in several rural houses with burning-cave-coil-Kang coupling heating system in northern China. The results show that this system is able to realize the graded use of internal energy of burning cave. The temperature of supply pipe water ranged from 30 ℃ to 50 ℃ which met the demands in 74.7% of time. The surface temperature of Kang maintained at above 25 ℃. Compared with traditional burning cave, using burning-cave-coil-Kang coupled with heating system has a higher thermal efficiency of 48.9%, which is 8.32% higher than the traditional one.

Keywords: burning cave; pipe coil; Kang; coupled heating system; thermal performance

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1 Introduction

In rural areas of north China, over 50% farmers use Kang heating. Kang has the function of health care, especially to the elderly with backache and arthrists. For hundreds of years, northern farmers have been accustomed to Kang lifestyle. However, scholars found that traditional oven-Kang system had the problems of local overheating, uneven temperature distribution on surfaces of Kangs, and unstable indoor temperature between day and night etc. Therefore, burning cave heating came out. It can not only provide continuous heat but also make optimal use of biomass energy. The Refs. [1 - 6] illustrated that thermal efficiency of traditional burning cave was low. Relative scholars led a series of methods to improve through the issues in the study[7-15]. However, the above research for improvement ignored the Kang lifestyle of northern farmers. It is necessary to introduce an effective heating mode which can ensure the heating-comfort performance of Kang surface and reduce the energy waste at the same time.

The paper proposed an improved burning-cave-pipe coil-Kang coupled heating system, as shown in Fig.1. It makes optimal use of the energy of internal fuel smoldering combustion: the first part is based on the temperature of burning cave cover plate to heat the indoor air by radiation and convection heat transfer. The other part is based on the radiation heat transfer of the burning cave coil to heat the supply pipe. With the aid of a circulating pump, the hot water heat is introduced into the Kang coil, increasing the temperature of Kang surface. Field measurements and theoretical analysis were also conducted to verify the performance.

2 Experiment and Methods

2.1 Experiment Table

To discuss the thermal performance of the coupled heating system, a house integrated with an optimized burning cave and Kang has been built in Fuxin of northern China as shown in Fig.2. The system is composed of a burning cave, burning cave coils, a Kang, Kang coil and a pipe system. The diameter of burning cave coil is 32 mm, linked at right angles in a diminishing concentric spiral, as shown in Fig.3. The burning cave coils are designed 150 mm below the burning cover plate, as shown in Fig.4. The water in the coils is filtered. Water hardness < 450 mg/L and 6.5<pH<9.

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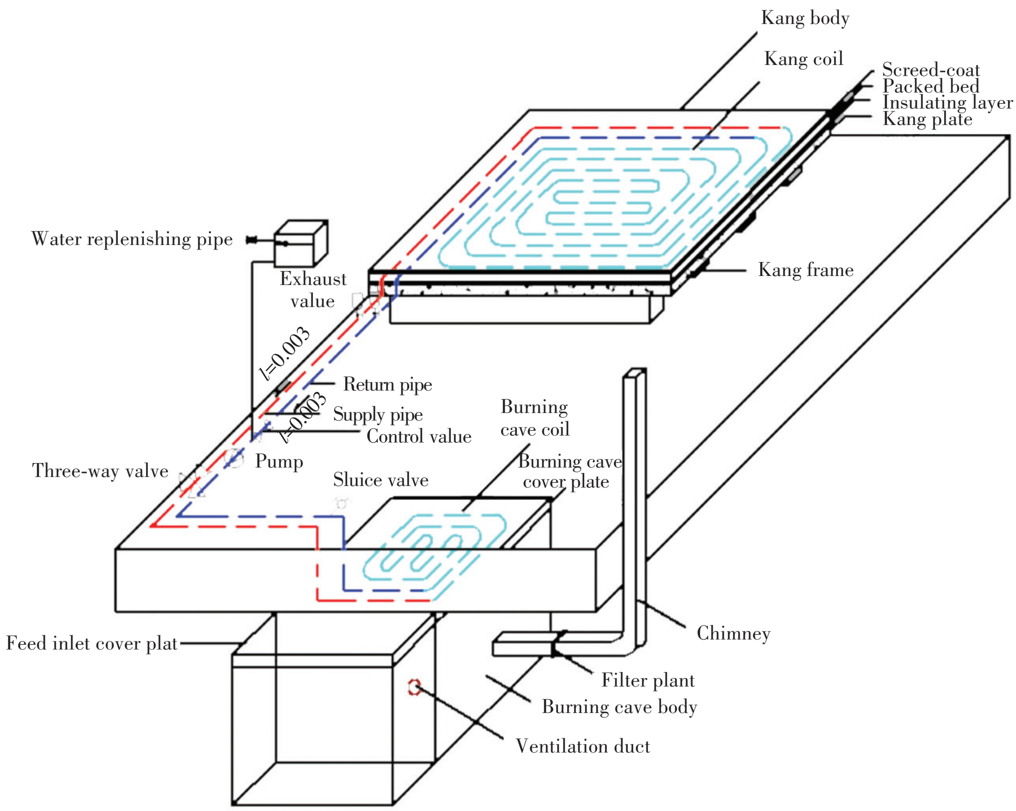


Fig.1 The structure diagram of burning cave-coil- kang coupled heating system

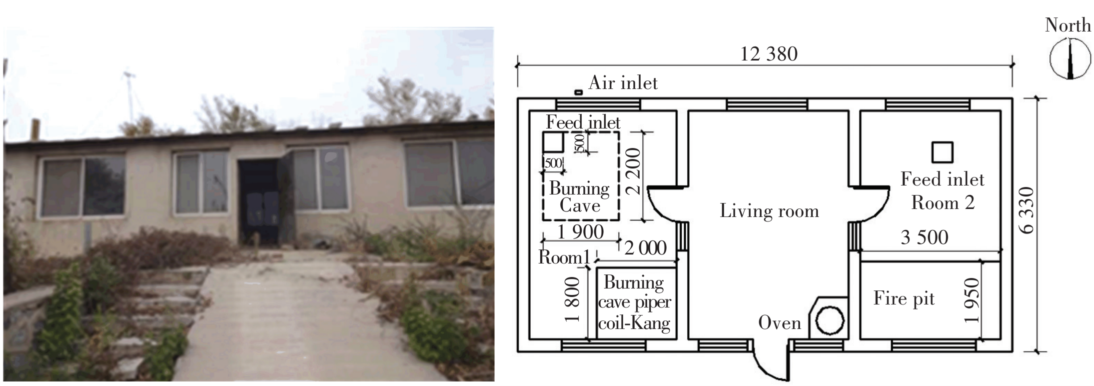


Fig.2 Test room and architectural plan

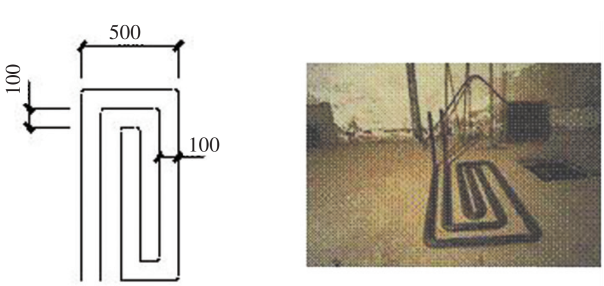


Fig.3 The layout form of burning cave coil

Fig.4 The layout of burning cave coil

The diameter of Kang coil is 15 mm and made of cross linked polyethylene. The Kang coil takes form and shape as shown in Fig.5. The structure of Kang body is shown in Fig.6 and the materials of each layer are shown in Table 1.

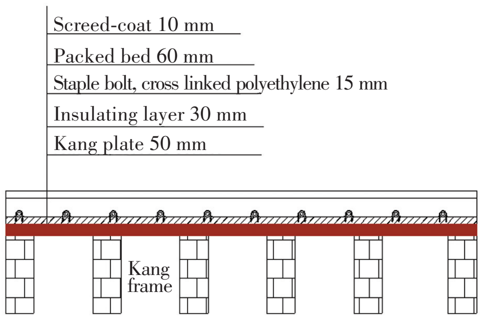


Fig.5 The structure schematic diagram of Kang body

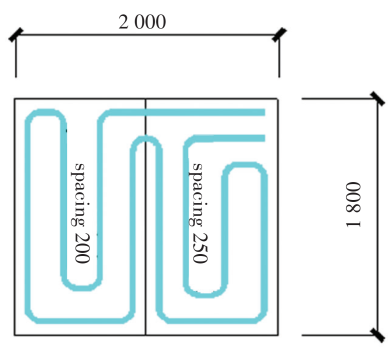


Fig.6 The layout of Kang coil

Table 1 Kang body structural materials and their physical property parameter values

Structural material	Thickness (mm)	Density (kg/m^3)	Thermal conductivity (W/m · K)	Specific heat (kJ/kg · K)
Kang plate	50	1 560	0.490	0.754
EPS	30	20	0.047	1 470
Clay sand inclusion	60	1 460	1.303	1.968
Cement mortar	10	1 800	0.930	1.050

The model of pump is LRS25-6. The volume of expansion tank is 10 L. The diameter of pipe is 32 mm, as shown in Fig.7. According to the calculation, the speed of system water is 32 kg/h, and the quantity is 7.65 L. Based on the above parameters, the selected pump model is LRS25-6, the maximum lift of water pump is 6 m, and the maximum flow is 50 L/min, as shown in Fig.6. The volume of the expansion tank is 10 L, as shown in Fig.8.

Fig.7 The appearance and install location of pump

Fig.8 The install location of expansion tank

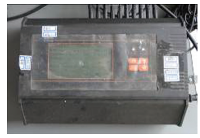
2.2 Experiment Condition

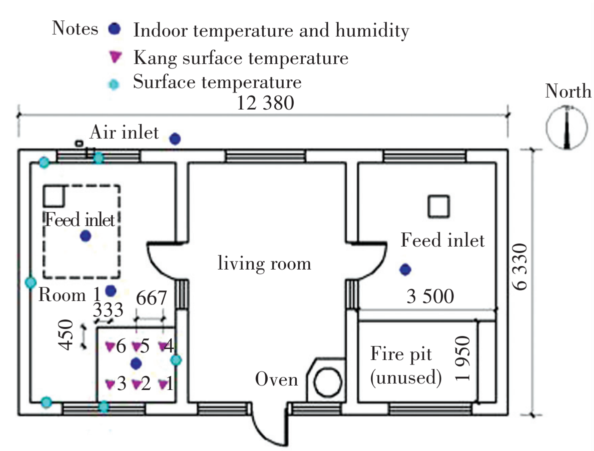
The experimental table is 2 200 mm×1 900 mm×1 200 mm(length×width×height). The fuel filled in the burning cave is cob. After filling the fuel, we put dry twigs on the surface of the fuel to ignite. The height and weight of the fuel are 550 mm and 220 kg respectively. The low calorific value of the fuel is 13 129.82 kJ/kg. The running time is from October 29, 2014 to November 6, 2014, exactly in heating period.

The main test parameters of the experiment include indoor and outdoor temperature and humidity, Kang surface temperature, the temperature of supply and return pipe, the temperature of enclosure structure, burning cave temperature, flue gas temperature, burning cave floor surface temperature, above Kang air temperature, above burning cave floor air temperature, indoor air temperature and indoor air quality, as shown in Table 2.

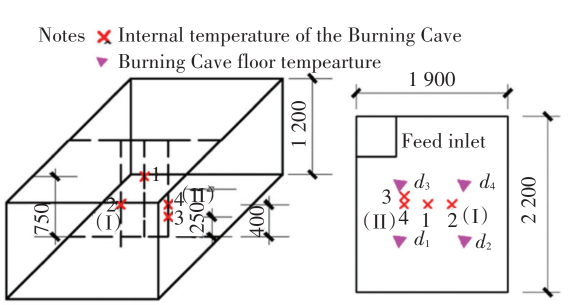
The measuring points of indoor temperature and relative humidity were arranged in the indoor center 1.5 m above the ground and the test interval is 10 min. The measuring points of burning cave floor air temperature are arranged at a distance of 0.8 m from the burning cave floor. Specific measuring point arrangement is shown in Fig.9.

Table 2 Information of the test instrument

Test parameters	Test instrument	Instrument accuracy	Appearance of test instrument
The temperature of Kang surface, burning cave floor, supply and return pipe and enclosure structure	JTNT-A	±0.5 ℃	
Burning cave and flue gas temperature	K type thermocouple+ Changhui SWP-ASR color paperless recorder	0.5%FS	
Indoor and outdoor temperature and humidity	Testo DE	±0.5℃; ±3%RH	
Indoor CO_2 concentration	CO_2 automatic recorder	$\pm 50\times 10^{-6}$	



(a) Kang surface, enclosure structure and indoor temperature and humidity measuring point



(b) Internal and burning cave floor temperature measuring point

(c) Arrangement of measuring points

Fig.9 Layout photos

3 Results and Analysis

3.1 Thermal Performance Analysis of Burning Cave

As shown in Fig. 10, during the smoldering process, the temperature of burning cave floor fluctuated dramatically. At the initial stage, it climbed to the peak value 61.5 ℃ which exceeded the temperature of human body. When the water pump started to work on October 30, 2014, 4 PM the temperature was in a downtrend. Generally speaking, the pump started to work, so as to take part of the heat of the burning cave into the Kang body, so that the heat of the burning cave floor was reduced, and the excess heat can be used in steps.

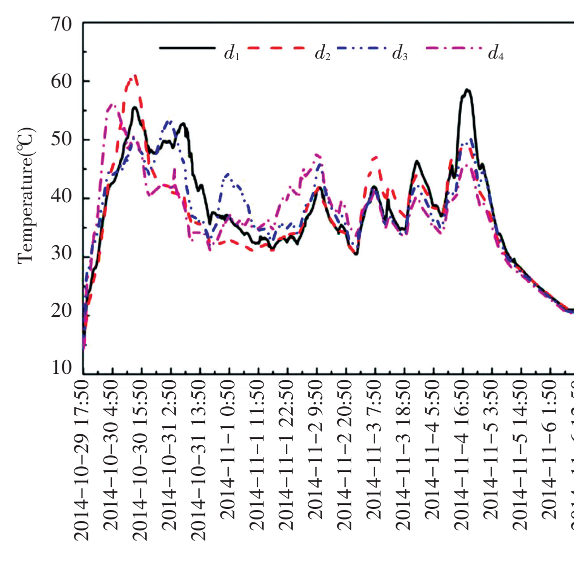


Fig.10 The temperature of the burning cave floor

Known from the analysis, when internal burning cave temperature declined, the temperature of burning cave floor dropped rapidly after slight respond time. In addition, the burning cave floor temperature was not only related to burning cave internal heat source temperature, but also related to the structure of the burning cave cover plate. The structural layer of burning cave cover plate was shown in Table 3.

Table 3 Construction materials of burning cave floor and their physical property parameter values

Structural material	Thickness (mm)	Density (kg/m^3)	Thermal conductivity (W/m·K)	Specific heat (kJ/kg·K)
Concrete slab	30	1 930	0.790	0.837
Filling(Clay sand inclusion)	60	1 460	1.303	1.968
Cement mortar	10	1 800	0.930	1.050

Using the heat capacity calculation method[16], experimental burning cave floor heat capacity was 239.76 kJ/(m^2·K), which is less than the floor construction capacity 462.6 kJ/ (m^2·K). Therefore this burning cave floor was easy to be affected by heat source, which should be built based on reasonable structure design to meet the needs of personnel activities.

3.2 Analysis of Heat Transfer Characteristics of Pipe

The heated water was transported under the action of the water pump, and the temperature of Kang supply pipe ranged from 21 ℃ to 46.3 ℃ as shown in Fig.11. The maximum difference between temperature of supply and return pipe was 8.6 ℃. As shown in Fig.12, the Kang coil temperature ranged from 30 ℃ to 50 ℃ accounted for 74.7% in line with the relevant norms. Thus the excess heat of the burning cave was able to meet the temperature of the Kang coils. What's more it ensured comfort Kang surface in terms of temperature.

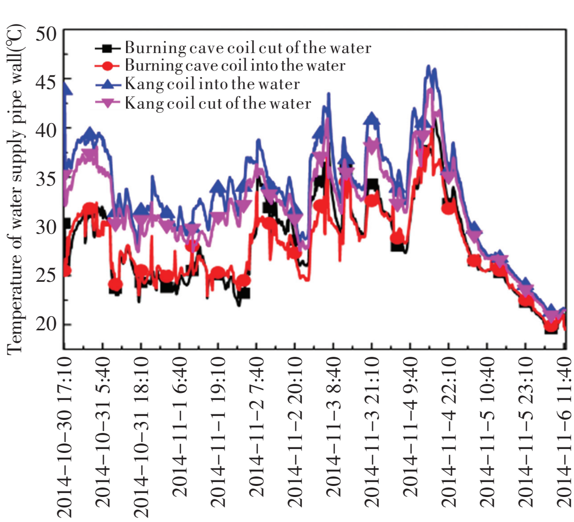


Fig.11 The surface temperature of supply and return pipe

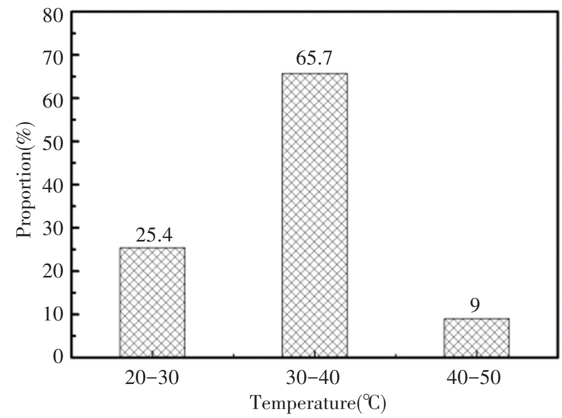


Fig.12 The proportion of surface temperature

3.3 Thermal Characteristics of Kang Body

In order to study whether the system can meet the requirements of thermal comfort, the experiment used a quilt with a thickness of 30 mm to simulate the working condition at night as shown in Fig. 13. In the early stage, the temperature of spot 4 and spot 5 were higher than other spots. The reason is these two spots simulated the conditions of night and the quilt is used for heat preservation of the part of the Kang surface to keep 25 ℃. What's more, the highest temperature was 34 ℃ which satisfied the human body thermal comfort requirements. It solves the problem that the traditional Kang system overheats more than 40 ℃.

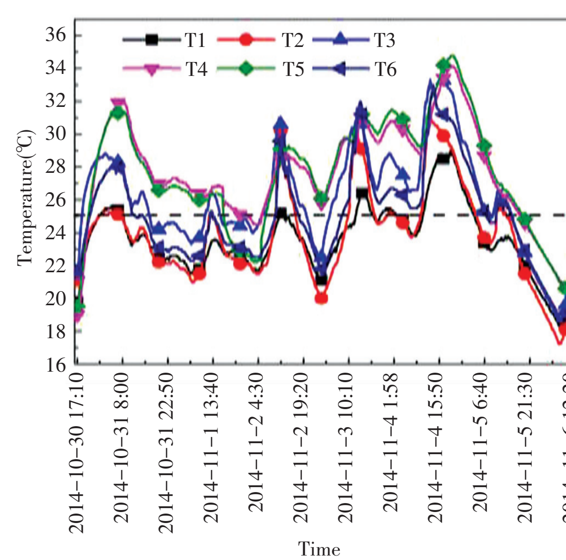


Fig.13 The temperature variation of Kang surface

A measuring point without a quilt such as spot 3 and spot 6 was higher than the one of spot 1 and spot 2. Combined with Fig.4 and Fig.9(a), the reason is that the human foot coil spacing was set to 200 mm and the human head coil spacing was set to 250 mm which met the law 'warm feet and cool roof '. This system avoids the farmers repeat packing multifarious every day, but also guarantees the Kang surface temperature to satisfy the human body thermal comfort of sleep at night, to improve the indoor thermal instability caused by intermittent heating.

3.4 The Analysis of Heating Effect

3.4.1 Temperature variation of enclosure structure

The Fig.14 gives the information about enclosure structure temperature changing rule. Excluding outside window it basically keeps enclosure structure temperature more than 15 ℃. As is known to all, sensible temperature was closely related to the temperature of enclosure structure. From Fig.14 we can see that the burning-cave-pipe coil-Kang coupled heating system can effectively guarantee the enclosure structure radiation temperature averaged 23. 1 ℃, which effectively improve the average body temperature and indoor thermal comfort.

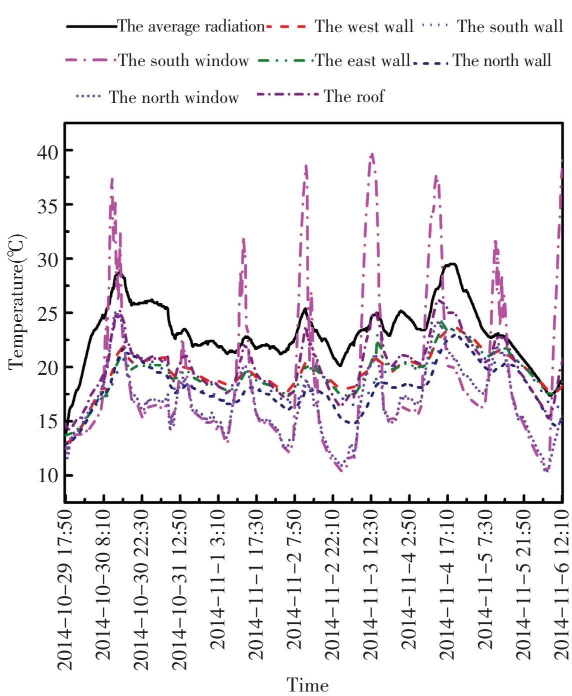


Fig.14 Building enclosure structure wall temperature

The Fig. 15 shows the temperature of the room equipped with burning-cave-pipe coil-Kang coupled heating system is 6.5 ℃, higher than rooms without heating and 3.5 ℃ higher than the only Kang heating room. From November 2, 2014, 19:50 to November 3, 2014, 6:30, outdoor air temperature ranged −2.4 ℃ to 0.6 ℃ meanwhile indoor air temperature ranged 18.4 ℃ to 20.4 ℃. Therefore, in cold winter, this system ensures the indoor temperature.

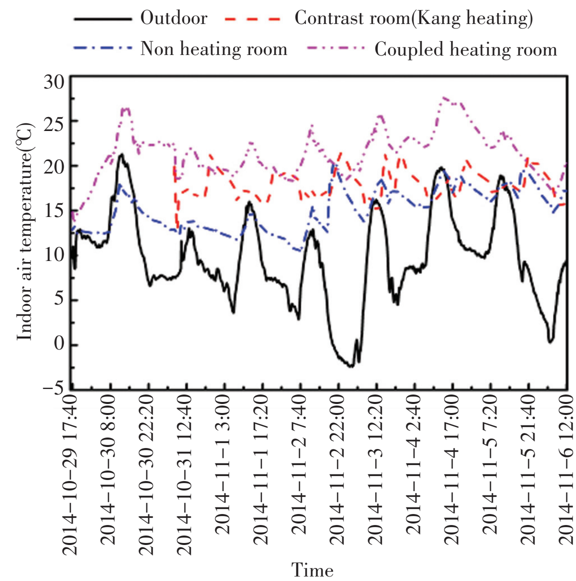


Fig.15 The indoor air temperature in different rooms

3.4.2 Burning cave floor heat output

The corresponding convection and radiation heat transfer calculation methods were used to analyze the change of burning cave floor heat output. The Fig.16 illustrates that the floor radiation heat transfer is greater than the convection heat transfer. The total heat of burning cave floor output ranged from 16.87 W/m^2 to 360.5 W/m^2, the average heat flux was 178.44 W/m^2 and the total heat output was relatively large. According to the burning cave floor temperature analysis, the floor heat capacity was small, this leads to excess heat directly into the room and cannot be stored in the floor, resulting in a larger indoor thermal environment fluctuations.

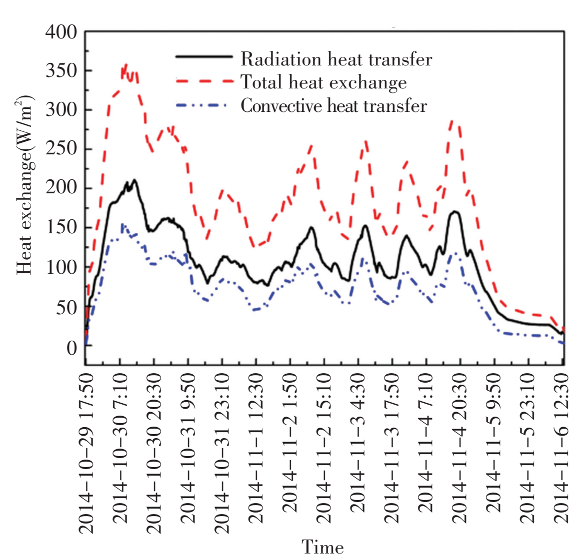


Fig.16 The heat output of burning cave floor

3.4.3 Kang surface heat output

Fig.17 shows the surface of the Kang at different times to provide heat for the room, in the initial stage of the system, Kang surface heat loss was negative value, indicating that the Kang surface temperature was less than air temperature, cannot provide heat for the room. With fuel smoldering and releasing heat, the temperature of the water putting into the Kang body gradually raised, which manifested as heat dissipation.

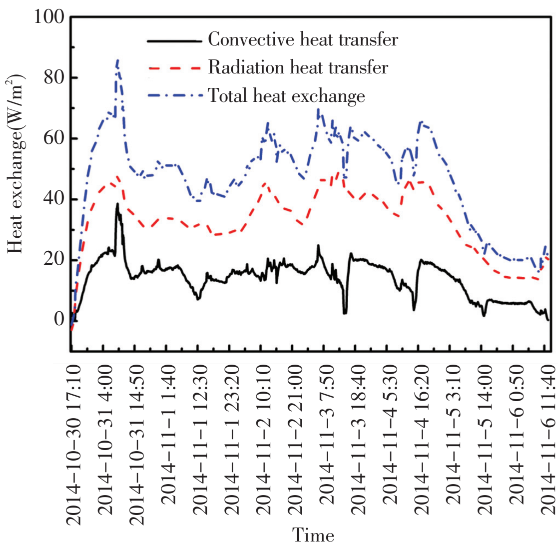


Fig.17 Kang surface heat release curve

According to Fig. 17, the average total heat transfer of Kang surface was 47.36 W/m^2 and the maximum heat transfer was 86.27 W/m^2. In rural areas of northern China, the building enclosure structure usually adopts 240 mm or 370 mm brick wall and the building thermal load is large. Obviously, the only Kang heating cannot fully meet the needs of rural traditional architecture, thus, burning-cave-pipe coil-Kang coupled heating system is necessary.

On the basis of building indoor thermal load calculation method, using the analysis of the burning cave floor and the Kang heat output and the outdoor heating calculation temperature, the indoor air temperature in Liaoyang can be achieved. The average heat output of burning cave floor and Kang surface was 225.8 W/m^2. It was calculated that this system under the condition of the outdoor heating calculation temperature can provide 14. 5 ℃ for indoor air temperature which meets the northern winter indoor thermal comfort temperature 12-16 ℃.

3.4.4 Pipe heat distribution

According to the use of hot water heat, we can get the information about the heat carried out by hot water pipes, including Kang surface heat and part of heat loss of return pipe. The heat loss includes the convection heat transfer between pipe and indoor air and radiation heat transfer between the pipe and building enclosure structure. The experimental correlations of convection heat transfer between pipe and air are as follows[17-20]:

$$Q = \pi d L \varepsilon \sigma (T_s^4 - T_w^4)$$

where d represents pipe outside diameter (m); L is pipeline length (m); T_s represents pipe surface temperature (℃); T_w is retaining structure wall temperature (℃)

According to the above method and Fig.18, the pipe average heat loss is 31.72 W, which accounts for 15.7% of the total heat of return pipe. The heat loss proportion is not obvious. However, if set the pipes in other non-heating room, it will lead to large heat loss, Kang surface temperature cannot meet the requirements in the winter.

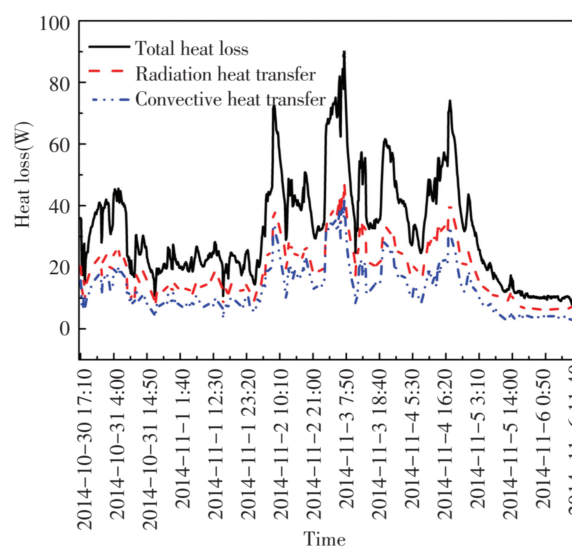


Fig.18 The heat loss variation of pipe

3.4.5 System heat distribution

Fig.19 shows the distribution of heat supplied by burning cave. It illustrates that burning cave floor heat in the process of fuel burning is a large proportion, the floor heat release have fallen sharply at the end of the combustion, but is larger than Kang surface heat release.

Fig.20 gives the information about the proportions of outward heat distribution inside the burning cave. The maximum proportion of the effective heat provided by burning cave is the floor heat release from indoor environment which is 78.14%. Meanwhile, the water heated by the burning cave represented 18. 36%.

Therefore, radiant floor heating has a high heat utilization rate. On the contrast, the heat utilization of pipe system is low which provides less heat for indoor environment.

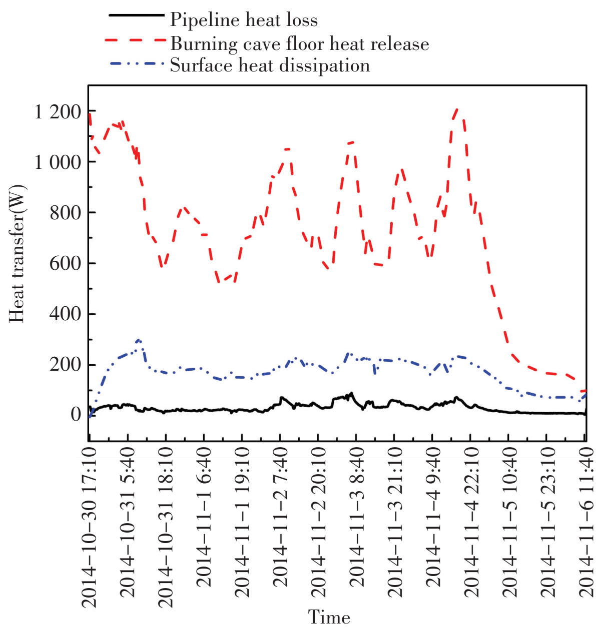


Fig.19 The variation of system heat distribution

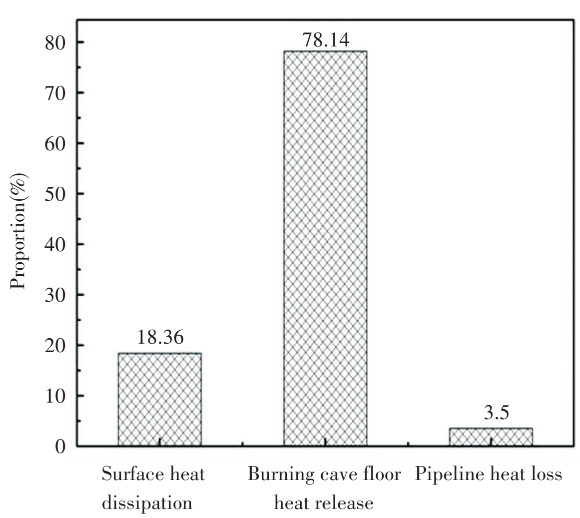


Fig.20 The proportion of heat distribution

3.4.6 Integrated thermal efficiency

According to the calculation method of the thermal efficiency of the above mentioned, it is applied to the comprehensive thermal efficiency of the burning-cave-pipe coil-Kang coupled heating system, the calculation formula is:

$$\eta = \frac{Q_{\text{eff}}}{Q_z} = \frac{Q_{\text{bur}} + Q_{\text{kang}}}{Q_z} = \frac{Q_{\text{bur}} + Q_{\text{kang}}}{v \cdot Q_J}$$

where η is Burning-cave-coil-Kang coupled heating system comprehensive thermal efficiency (%); Q_{eff}: Effective use of heat (W); Q_{bur}: Burning cave floor effective heat (W); Q_{kang}: Kang surface effective heat release (W); v: Smoldering combustion rate (kg/s); Q_J: low calorific value of corn cob fuel (kJ/kg).

Based on burning cave floor heat output and Kang surface heat release, the highest comprehensive thermal efficiency of burning-cave-coil-Kang coupled heating system is 48.9%, comparing with the traditional burning cave increased by 8.32%. Therefore, it can be used to make full use of the heat in the burning cave to heat the Kang surface so as to provide heat for the room.

4 Conclusions

The paper is based on the completedburning-cave-coil-Kang coupled heating system, using the performance data to analyze the heat distribution and performance. The main conclusions are as follows:

1) Smoldering combustion duration is about 216 h. The average speed of smoldering combustion is 0.25 mm/h. Combustion flue gas temperature is stable inside burning cave: because of thin burning cave floor layer, the heat storage capacity of the floor is weak and the burning cave floor even over 40 ℃ in parts.

2) The temperature of supply pipe which enters the Kang coil ranges from 21 ℃ to 46.3 ℃, the largest temperature difference of supply and return pipe is 8.6 ℃. 74.7% of Kang coil supply temperature meets standard requirements.

3) The night working conditions test spots with aquilt stay above 25 ℃ and the highest temperature is 34 ℃ which satisfys the human body thermal comfort range. It avoids overheating more than 40 ℃ in the traditional Kang system .

4) Indoor floor heat release accounts for 78.14% of the effective heat of burning cave. The water heated by the burning cave represented 18. 37%. The comprehensive thermal efficiency of burning-cave-coil-Kang coupled heating system is as high as 48. 9%, comparing with the traditional burning cave increased by 8.32%.

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