OPTIMIZATION AND INTEGRATED APPROACHES OF TRADITIONAL HEATING METHODS OF COLD RURAL AREAS IN CHINA

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1. Introduction

In rural areas of Northern China, some traditional heating methods, such as Chinese Kang, smoke heated wall, burning cave, biomass-burning radiator, are still used in winter. The central heating methods are not available in the area due to the scattered locations of the houses. Some of the houses are constructed based solely on craftsman's experience. As a result, the indoor heat distribution is uneven in cold winter, and there exists comparatively large temperature differences between rooms in one house. Some other problems include the falling leather of the damp walls and icing of the window pane, as shown in Fig.1 (a) and Fig.1 (b). Poor families that make stove with Kang in one room face safety concerns as well as serious indoor quality problems, shown in Fig.1(c). Although the thermal environment has noticeable improvements after practical advancement of the heating technologies, from the stand point of total energy consumption of one building, the integrative energy utilization of the new technology is inefficient. Therefore, the optimization and integrated approaches of traditional heating methods are important part of this study.

(a) Uneven heat distribution (b) Freezing window pane (c) oven-Kang in the bedroom

Fig.1: The current situation of heating residence in cold rural areas in north China

In recent years, both domestic and foreign scholars have studied the heating methods in rural areas of China. Research lab of Building Environment and New Energy Resources in Dalian University of Technology has studied the internal smoke flow and heat transfer performance of Kang The lab improved the structures of inner flue and materials used in Kang [Zhuang,2009]. The combination effect of the coupled heating pattern of passive solar-collected wall and oven-Kang has been calculated to save about 50% coal for heating [Chen, 2007]. There exist great research value and room for technology improvements in the study of Kang. In addition, both at home and abroad, scholars are gradually starting to pay attention to the study of burning cave, which has evolved from the Chinese Kang. Sun[1994,2000] has performed in-depth theoretical study on the smoldering process, heat transfer performance and other influencial factors in the burning cave.

However, the research reference of integrating the burning cave into a practical residential heating methods and enhancing its technology is rare, and so far there is no research on the heat distribution in the whole building space. Based on the measurements and investigations in rural areas of Northern china, along with theoretical analysis and experimental studies, this paper proposes optimization and integrated methods to the traditional heating methods in balancing the heat distribution of the overall building space and improving indoor thermal environment in winter.

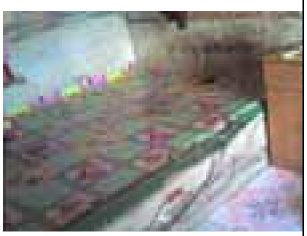
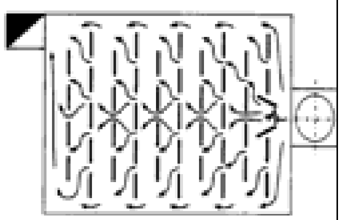
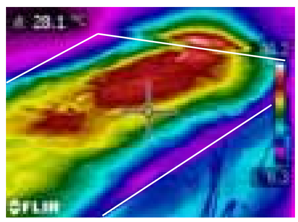
2. The analysis of operational effect of traditional heating methods

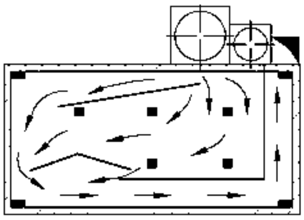
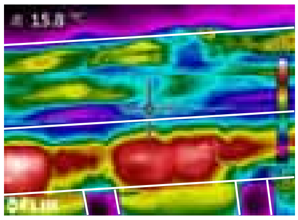
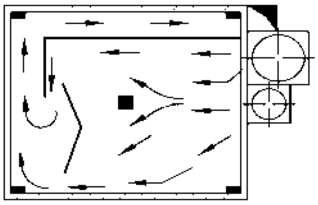
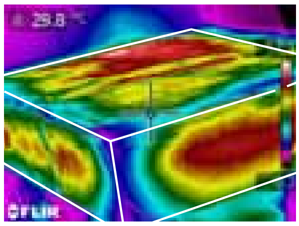
In order to study the operational effect and heat transfer performance of traditional heating methods, thermal performance of building envelope, indoor and outdoor temperature and relative humidity, indoor air quality, radiating temperature of different heating methods, energy consumption, and other parameters were measured during 2009 and 2010 winter. The advantages and disadvantages were summarized and analyzed in order to provide data supporting and theoretical basis for the study of optimization and integration of rural heating methods.

2.1 Heat transfer comparative analysis of different forms of Kang

The Kang is used in North, Northwest, and Northeast of China with utilization rate of 73.3%, 86.3%, and 96.2% respectively [Tsinghua university, Bei Jing,2006]. Due to regional and cultural differences, the layout of Kang has different structures, including the South Kang, North Kang, Wei Kang, L-shaped Kang, ring-shaped concave Kang, and etc. The internal flue of Kang also comes in many different forms, including parallel flue, perpendicular flue, grid-flue, turn-around flue, and others. Kang is the most effective way for intermittent heating and it changes periodically by people's daily activities. When wood is burning in the stove, a part of the heat generated by fuel is used for cooking, the other part of heat is used for indoor heating through the Kang body. The arrangement of Oven-Kang separation could help to improve the indoor air quality during the heating period. Heat transfer performance of Kang is mainly affected by the structure of internal flue, the position of stove and chimney, the materials of Kang body, and other factors.

Tab. 1: Contrastive structure and thermal performance of different Kangs

	Kang body	**The structure of internal flue**	**Temperature of Kang's surface**
Traditional grounded Kang			

Half-elevated Kang with Grid-flue			
New-style elevated Kang with turn ground flue like a bed			

Tab.1 mainly lists three representative Kangs and comparatively analyzes on their performances. With the changing of times, people start to pay more attention to the indoor environment and aesthetics. Therefore, the form of Kang has gradually been optimized. The ancient traditional grounded Kang is optimized to the Half-elevated Kang, further optimized to the New-style elevated Kang like a bed. At the same time, the structure of internal flue has also gone through great changes, from Ancient perpendicular flue to grid and turn around flue. The decrease in the number of internal brace greatly reduces the resistance of smoke flow. The fume stopper bricks in the Kang, which is used to divide smoke, are moved from the smoke inlet to the smoke outlet, improving uniformity of the heat transport. The temperature of Kang's surface shows when the Kang is heated, the Kang's surface temperature difference between the plate at smoke inlet and the plate at smoke outlet is more than 60℃ on traditional grounded Kang. The overheating of inlet prevents people from conducting normal activities or sleep on it, and people must take precautionary measures to avoid scald. But, the surface temperature distribution of turn-around flue Kang is more uniform, and the ambient walls' temperature of the Kang body is 10℃, higher than the temperature of the former, which means the heat transfer effect of Kang body has been significantly improved.

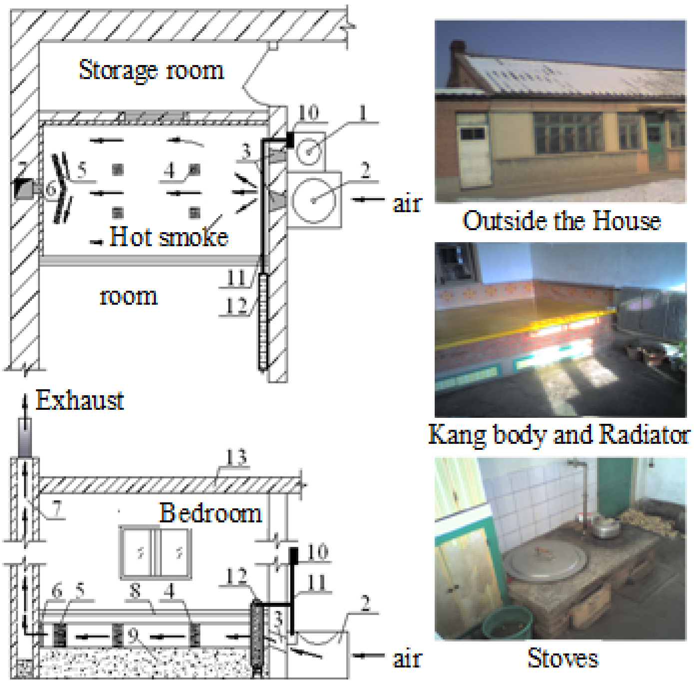
The comparative analysis of test data of different Kang in Tab.2 shows that under the same external conditions, elevated Kang with grid-flue has better heating effects: the indoor temperature is suitable during the heating period, and the indoor temperature difference is lower. The temperature difference of the bedroom heated by Turn-ground flue Kang like a bed is the biggest as a result of its weak heat storage and fast rate of heating and cooling. The temperature of the plate at smoke outlet is changed greatly by the temperature variation of the plate at smoke inlet. Under the condition of larger temperature difference between day and night in winter and envelope without insulation, a comfortable indoor thermal environment cannot be achieved by a Chinese Kang alone. Solely using Kang for heating could result in high energy consumption and affects peoples' daily activities on the Kang plate.

Tab. 2: The test data of different modal Kang

The structure of Kang	Parallel flue Kang	Perpendi-cular flue Kang	Elevated Kang with Grid-flue	Turn-ground flue Kang like a bed	Half-elevated Kang with turn-ground flue
Energy consumption (convert into standard coal (kg once time))	1.8	1.8	1.6	1.5	1.7
TEMP of the surface of Kang plate at smoke inlet(℃)	98	98	98	98	98
TEMP of the surface of Kang plate at smoke outlet(℃)	30	35	60	58	53
TEMP of the ambient surface of Kang(℃)	20	25	42	40	38
The indoor TEMP during heating period(℃)	14	13	15	16	15
The indoor TEMP after the Kang body was cooling (℃)	10	9	8	7	10
The indoor TEMP in the coldest day(℃)	6	7	7	5	7
The indoor TEMP difference (℃)	8	6	8	11	8
The heat storage coefficient J/(m^2sK)	18.7	19.7	15.3	14.9	18.7

2.2 The current heating situation of the coupled heating pattern of heated radiator and oven-Kang.

According to the investigations in the rural areas of Shengyang and Dalian, more than 70% use the biomass-burning radiator as an auxiliary heating equipment. The structure of the coupled heating pattern of heated radiator and oven-Kang is shown in Fig.2. The biomass-burning radiator system consists of a stove, a expansion tank, radiators, water pipes, and air release valve components. The heating source of Kang comes from the combustion heat of fuels inside the stove. In order to improve the thermal efficiency of stoves, radiator system could be connected to the stove with water jacket, forming a natural gravity circulation. Radiator releases its heat to the room air by convection, which is through indirect heating. The location of radiator is arbitrary in the house. To avoid taking too much floor space, radiators can be installed at the interior side of walls, below the edge of Kang, the bottom of sill, and etc. When the stove is heated at one time, the average temperature of Kang's surface could be maintained around 35℃, the radiator around 65℃, and the thermal efficiency of the stove could reach to 76%. The temperature fluctuations of the room heated by this coupled heating pattern could be 2℃ -4℃ higher than that of heated only by Kang, and the average indoor temperature could reach 12 ℃. Since the radiator heating system is added to the stove, the fuel consumption increases 1.0-1.5kg at one time.



1-Small stove 2-Big stove 3-Smoke inlet 4-Brace for faceplate
5-Fume stopper 6-Smoke outlet 7- Chimney 8-Faceplate 9- Loess layer
10-Gravity water tank 11-Water supply pipe 12-Biomass-burning radiator 13-Roof

Fig. 2: Configuration of the coupled heating pattern of biomass-burning radiator and half-elevated Kang

The thermal efficiency of the coupled heating system is increased, but there still exist some deficiencies and shortcomings on the process of application as shown in the following:

(1)The water jacket must be added to the wall outside the stove in the coupled heating system. The preheating time of the furnace is longer because of large amount of cold water in the water jacket before heating. Therefore, a large part of the heat is used to increase the water temperature.

(2)The radiator releases its heat to the indoor air mainly by convection, causing the uneven temperature distribution. Generally speaking, the upper area of the room and the area that is closer to the radiator are warmer than the rest. As for people living in the room, the body is warm, but the feet are still very cold.

(3)As a result of extremely cold winter, the residual water in the radiator could be frozen. Suddenly being heated could cause explosion due to the abrupt increase in pressure of the furnace, Fig.3 and Fig.4 showing the freezing crack is below the radiator.

(4)The heating room with the application of biomass-burning radiator could lead to a larger concentration of particulate matter and poor air quality. It is crucial to take precautionary measures to prevent carbon monoxide poisoning.

Fig.3: Explosion of coal-burning radiator

Fig.4: Frozen crack on the radiator

2.3 The operation effect of burning cave heating system

Burning cave, evolved from wei Kang, is one type of heating methods is gradually accepted by rural residents. This method is equivalent to the floor radiator heating in city buildings. The fuel is biomass, which could sustain heating for one month for every filling. This heating method not only saves energy, but also conserves the environment. Fig.5(a) and Fig.5(b) gives the schematic of existing burning cave. The indoor temperature could be 13℃-21℃ in the house heated by burning cave. Even on the condition that the outdoor temperature is below -20℃, the indoor temperature can still maintain at 13℃, which is 3℃ higher than the Kang heating room under the same condition of temperature and humidity. The indoor temperature balance could be maintained effectively. The indoor temperature fluctuation is lower than Kang heating room by 1℃-3℃. Fig.5(c) shows that the temperature distribution of the radiator floor is up to 40.4℃ at the preliminary stage. The lowest temperature areas are the surrounding surface around the burning cave, which is 23.4℃. The temperature difference of the floor is 17 ℃. The heat loss is 53% since there is no thermal insulation layer surrounding the burning cave. Large heat loss and low efficiency, caused by the random control of the combustion speed during smoldering process, are still serious problems. Most burning caves are not built with standard, so the leak tightness of cave body is poor, resulting in harmful gas seeping into the room and significant heat loss. When one burning cave is used alone, the indoor temperature could reach to the ideal state. Due to the fact that rural residence is a single house, the total heat load of the house is much bigger than one heating room. Heat is also dissipated on the building envelope and roof. The design of integration and optimization must be scientific and reasonable. On top of that, the corresponding thermal performance evaluation method [Zhonghai Zheng, Lin Fu,2006][Shoukang Qin,2003] should be formed.

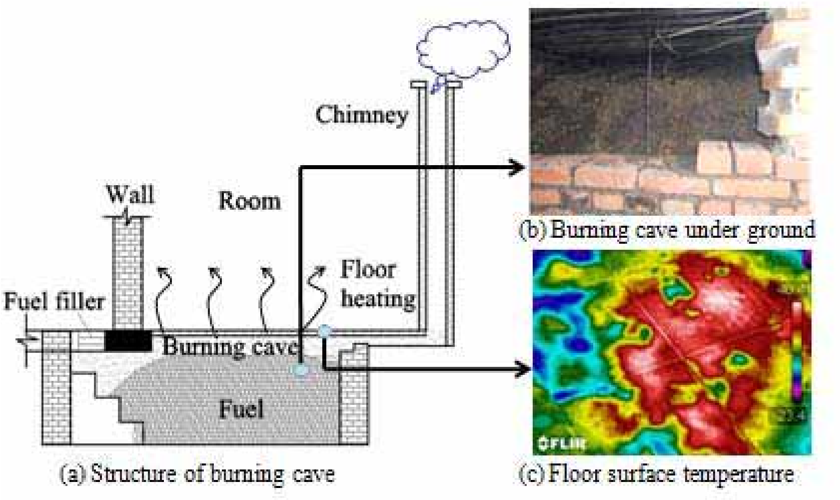


Fig.5: Schema of existing burning cave

3. Optimization and integrated approaches of the traditional methods

3.1 The technical measures of optimization and integrated design

During the past two winters in rural areas of Shenyang, Fuxin, and Dalian, the indoor thermal environment and air quality of different heating residences have been tested. The results show that heating effect in the house could be affected by several factors, such as types and forms of fuels, construction and thermal properties of heating equipment, thermal characteristics of building envelope, and etc.

According to the survey results, optimization design and technology improvements of traditional heating methods mainly include the following aspects:

(1) The half-elevated Kang should be used because its surface temperature distribution is uniform and heat storage of Kang plate is strong, as shown in Fig.6. The height of cavity below the soleplate is 350mm, improving the heat release and making it convenient for people's daily lives. The height difference between the stove and half-elevated Kang should be increased moderately to improve the pumping power of the chimney, and prevent smoke from flowing back. Some additional auxiliary heating equipment must be added in the room heated only by Kang, so the indoor temperature could reach the comfort standards.

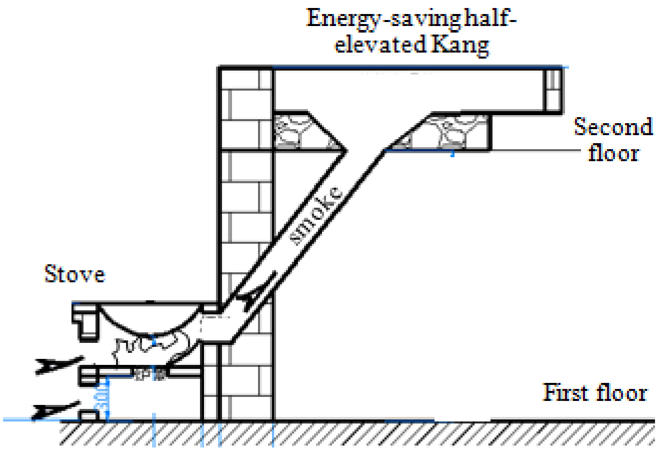


Fig.6: Overhead oven-Kang heating system

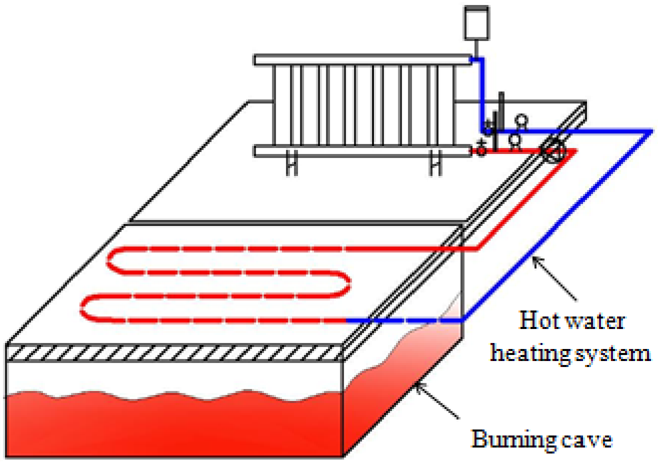


Fig.7: Burning cave and hot-water heating system

(2)The insulating layer must be added outside the ambient wall of the burning cave in order to reduce heat loss. As shown in Fig.7, the hot-water system could be designed with burning cave to improve its thermal efficiency. This coupled system using floor and radiator to release both radiative and convective heat to the bedroom could take the thermal efficiency up to 70%.

(3)The pressure gauge should be installed on the water supply pipe to prevent excessive pressure and explosion during the heating process. The pipe for supply and return must be installed in the room, so the heat could be diffused into the room, and heat loss could be reduced mostly.

3.2 Energy utilization status of heating house in winter

Through data analysis, the indoor temperature of heating room by burning cave is higher than any other heating methods by 5℃. As a result, the burning cave could be used as a basic heating method for the house. Taking into account of the comprehensive utilization of energy, the indoor thermal comfort could be improved and the fuel could be saved by 50% in each winter through using the coupled heating pattern with Kang, burning cave, passive solar-collected wall, shown in Fig.8.

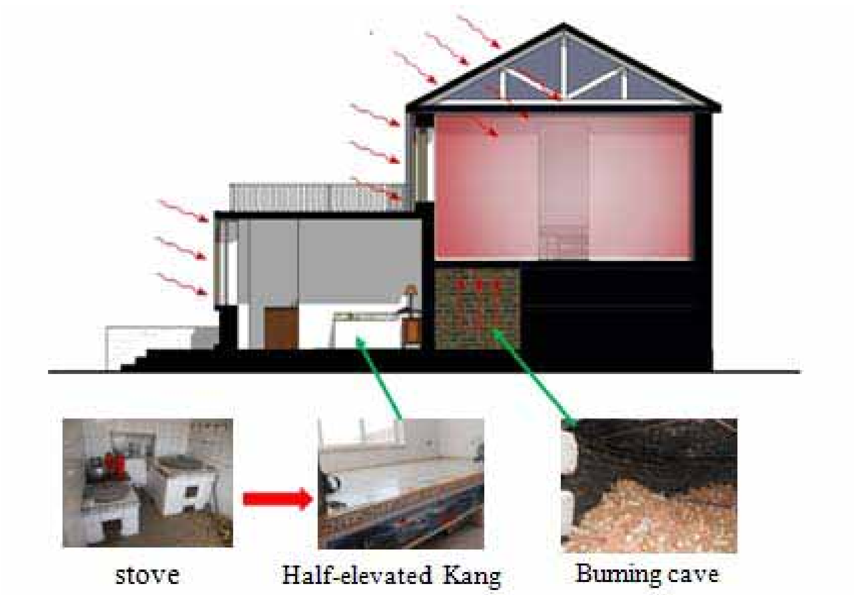


Fig.8: Optimization and integration of heating method in one house

The floor heat storage system based on the burning cave must be established to solve the problem of extremely uneven heat distribution of the whole building space. Fig.9 shows that there is a 100mm thick air layer for heat storage at the bottom of the whole building to solve the problem of overheated surface on the top of burning cave. The optimization changes the burning cave from heating only one room to the whole house. Therefore, the interior temperature of the whole house could be uniform.

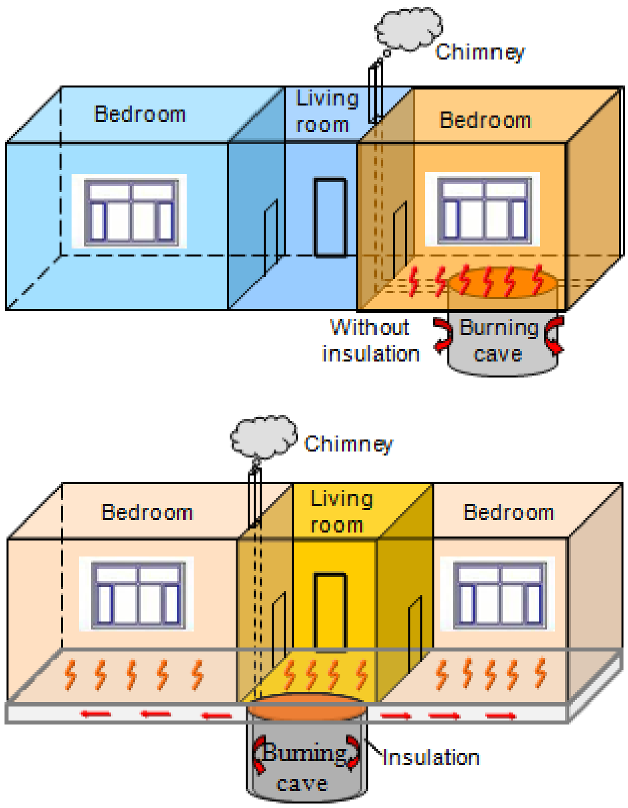


Fig.9: The contrastive temperature of the house from traditional burning cave to the optimized heating system

4. Conclusions

Based on the measured investigation and theoretical analysis on different houses with different heating methods, some conclusions could be summarized as follows.

(1)Chinese Kang is an indispensable heating method in rural areas. When heating room uses Kang alone, the indoor thermal environment could not achieve the ideal state, but it reflects Chinese people's living habits and national characteristic.

(2)The indoor temperature of the bedroom using the coupled heating method of radiator and Kang, could reach 3℃-5℃ higher than using Kang alone. But the concentration of inhalable particulate matter is twice as large as that of the room only heated by Kang. The air quality of the bedroom is worsened significantly, and there are other safety concerns.

(3)When the outside weather condition is execrable, the application of burning cave could maintain the indoor average temperature uniformly at 18℃ in the house. In order to prevent harmful gases from seeping into the room during smoldering process, the leak tightness of pool body must be ensured. In order to improve the temperature of radiation surface, insulation around the burning cave must be added.

(4) Through the energy analysis and comparisons, although the initial investment of the house will increase 15% using the optimized burning cave and Kang coupled with the passive solar collection, the entire building's thermal performance could be greatly improved. The indoor heat distribution could be uniform, temperature difference between two rooms could be reduced to 2 ℃, and overall greatly beneficial for people.

5. References

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