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## Thermal Effect of Metal Fin inside Elevated Radiant Floor Based on the Thermal Utilization of a Burning Cave

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### ABSTRACT

A rural house integrated with an elevated floor heating system based on the thermal utilization of a burning cave has been established to provide a more comfortable and clear indoor environment. Inside the elevated floor heating system, air is taken as the heat transfer medium and tin layer is designed as metal fin in the middle layer of the elevated floor to enhance heat transfer. In this study, heat transfer process and thermal performance of the inner metal fin were analyzed by theoretical calculations and field measurements. The results show that while the heat flux of the burning cave is decreased from  $460 \text{ W/m}^2$  to  $200 \text{ W/m}^2$ , the convection heat intensity of the hot air inside the elevated floor under each room is from  $2 \text{ W/m}^2$  to  $9 \text{ W/m}^2$ . Finally, it confirms that the effective length of the metal layer should be less than  $0.4 \text{ m}$ . All the above results show that appropriate design parameters can lead to an optimum heat transfer process.

### KEYWORDS

Elevated floor heating, Effective length, Heat transfer performance

### INTRODUCTION

In order to solve existing problems, such as larger indoor temperature fluctuation, poorer indoor air quality, lower thermal efficiency in a rural house (shown in Figure 1(a)), the model house integrated with an elevated radiant floor heating system based on the thermal utilization of a burning cave was presented (shown in Figure 1(b)). The heat is released from the burning cave to each heating room through the raised floor. The thermal efficiency was increased from 30% to 56.7% (Zhang, 2014).

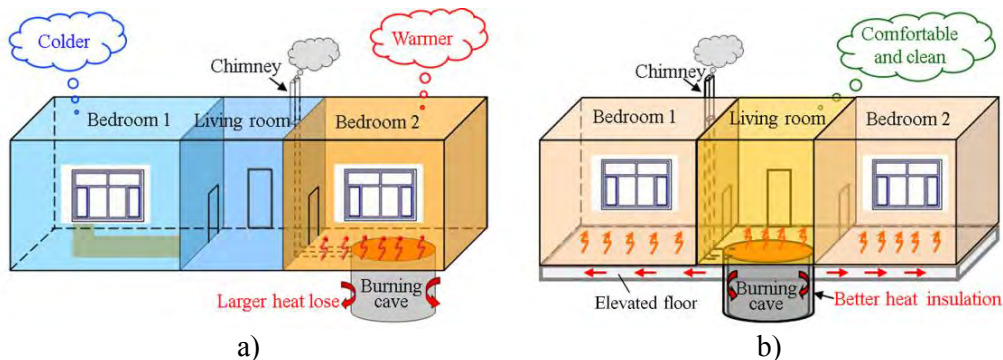


Figure 1. Optimization of a burning cave for residential heating. a) Burning cave is used to heat a room, b) Burning cave is used to heat the whole house.

As a result of lower heat storage coefficient and lower specific heat of the air, an enhanced heat transfer mode was taken into account for improving heat distribution inside the raised

floor. Natural convection in a differentially heated inclined square enclosure with a fin attached to the solar collector for reducing heat losses has been studied numerically (Frederick, 1989). The fin position inside a differentially heated cavity is a major role in heat transfer inside the cavity, the effect of fin position on the heat transfer rate is strongly affected by Rayleigh number and the fin length (Bilgen 2005). The steady laminar natural convection within a differentially heated by square cavity with a thin fin was found that for high Rayleigh numbers, heat transfer can be enhanced regardless of the position or the length of the fin (Shi and Khodadadi, 2003.). Natural convection inside an enclosure with three thick cold walls and a hot thin vertical left wall was studied numerically (Abdullatif and Chamkha, 2007). For the case of highly conductive fin, it was found that the Nusselt number on the cold wall increased compared to the case with no fin (Nag, Sarkar, et al, 1993). Laminar flow regime was found while turbulent flow regime starts to be formed for higher values of Rayleigh number (Bilgen, 2002). Natural convection inside cavities was examined extensively for different boundary conditions, aspect ratios and Rayleigh numbers (Du and Bilgen, 1992.). In this paper, the fin efficiency of the thin metal plate in the middle layer inside the elevated floor can be discussed, and the optimum length of the metal layer can be determined.

## METHODS

In the whole heating house, some parameters are including: air temperature, surface temperature, heat flux. The detailed structure information inside the elevated floor is shown in Figure 2. The measured parameters and test error of test instruments are shown in Table 1 respectively. The record interval of all the analyzers was 10 mins.

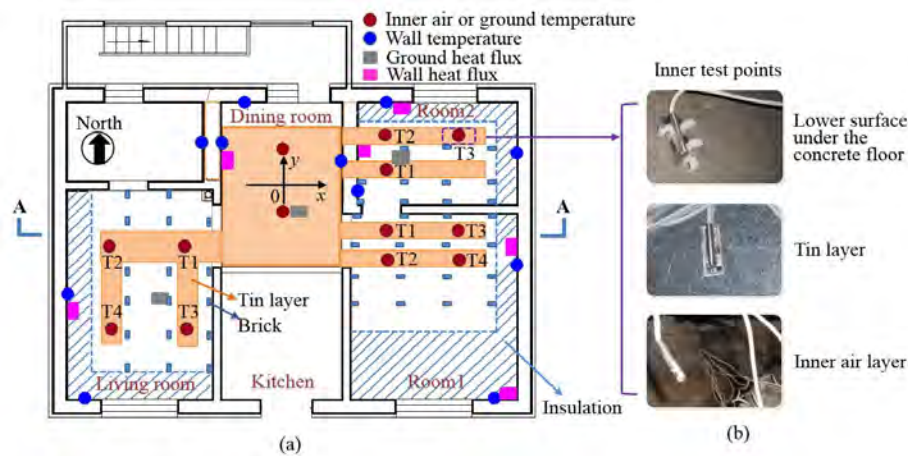


Figure 2. Test points and construction. a) Test points in the whole house, b) Test points in each layer inside the elevated floor.

Table 1. The measured parameters and test instruments

Measuring parameters	Name of instruments	Measuring accuracy
The quality of fuels	Desk type electronic scale	$\pm 0.1g$
Thermal parameter of the building envelops and heating surfaces	Multi-channel heat flow tester JTNT-A/C (SWP-L816)	$\pm 0.1^{\circ}C$ $\pm 1\sim 2 W/m^2$
Indoor/outdoor air temperatures and relative humidity	Digital thermo recorder TR-72U	$\pm 0.1^{\circ}C$
Inner temperature inside the burning cave	High temperature thermocouple	$\pm 1^{\circ}C$
Recording system	Automatic communication and recording system	$\pm 0.1\%$

According to the fin efficiency calculation method of heat transfer in reference (Rohsenow, Hartnett, et al, 1998), the heat distribution transferred by metal layer is equal to the heat gained from the basis of metal layer. The equation that applies to this case is:

$$\frac{d\theta}{dx^2} = m_t^2 \theta \tag{1}$$

Where,  $\theta = T - T_\infty$  is the temperature excess,  $x$  is the axial coordinate.

$$L_e = \lambda_t A_L m_t \theta_t \left[ m_t \left( l_t + \frac{\delta_t}{2} \right) \right] + \frac{2\pi}{\sqrt{5}} \varepsilon \delta_t \theta_t m_t, \quad m_t = \sqrt{\frac{l_t U_t}{(\lambda_t + \varepsilon \sigma) A_L}} \tag{2}$$

Where,  $L_e$  is heat changed from metal surface to the air layer at steady state,  $W$ .  $l_t$  is the effective length of metal layer,  $m$ .  $A_L$  is the effective area of metal layer,  $m^2$ .  $\lambda_t$  is thermal conductivity coefficient,  $W/(m \cdot K)$ .  $U_t$  is the total length of metal layer,  $m$ .  $\delta_t$  is the thickness of metal layer,  $m$ .  $\theta_t$  is temperature excess,  $^\circ C$ .  $m_t$  is the metal layer performance factor.

$$\eta = \frac{Q_a}{Q_{a,max}} \tag{3}$$

Where,  $\eta$  is the fin efficiency of metal layer;  $Q_a$  is the actual heat transfer, including radiation and convection heat transfer inside the elevated floor,  $W$ ;  $Q_{a,max}$  is the theoretically maximum heat transfer that can be diffused by the metal layer, under the assuming condition is that the entire area of the metal layer is at the maximum temperature.

**RESULTS**

**Temperatures inside the burning cave**

During the heating period, temperature field inside the burning cave is shown in Figure 3. After igniting the fuels for 12h, the temperature of test point BN1 (at the height of 1.1m) in Part I is reached to 300 $^\circ C$ , but the temperature of test point BS1 (at 1.1m height in Part II) is 100 $^\circ C$  lower than BN1. In part II, the burning time for reaching to the highest temperature is 6h longer than which in part I. Because the air inlet was on the wall of Part I. Through calculation, average burning velocity is about 1.31 mm/h, 1.34mm/h respectively in part I and Part II, which is larger than the results in reference (Beijing civil construction society, 2008.), because the moisture of mixed biomass fuels is 3.36% lower than which in reference.

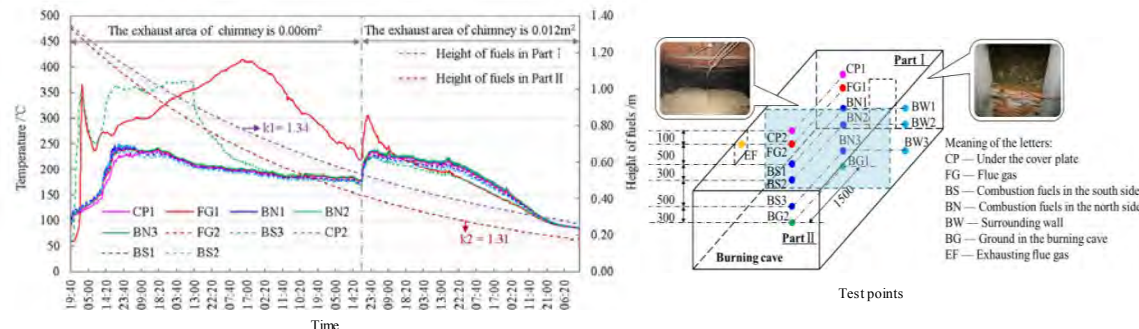


Figure 3. Temperature variations inside the burning cave

**Indoor Air Temperatures in the whole house**

Temperature variations of the elevated radiant floor heating system and indoor air temperatures during the heating period are shown in Figure 4. While the outdoor air

temperature is between  $-15^{\circ}\text{C}$  and  $2^{\circ}\text{C}$ , the average indoor air temperature is about  $3^{\circ}\text{C}$  higher than a room heated by traditional Kang. The temperature difference between adjacent rooms is only about  $2.0^{\circ}\text{C}$ . The results show that using the elevated floor heating system is effect for reducing temperature difference between different rooms in the whole house.

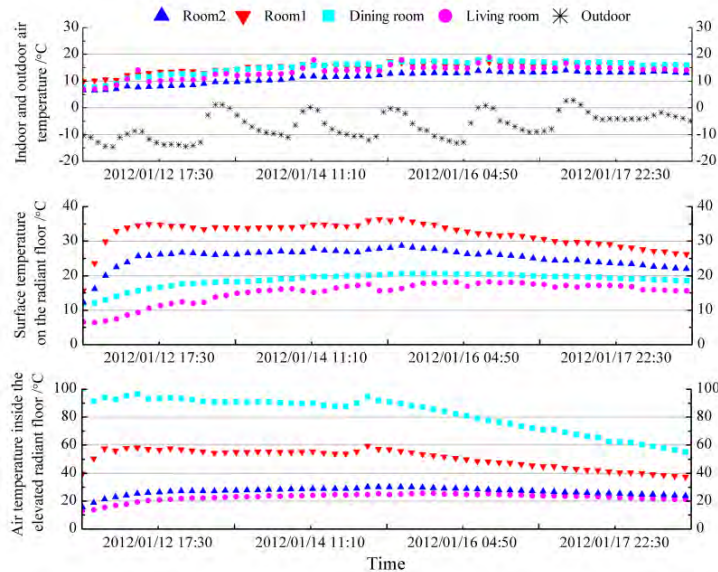


Figure 4. Temperature variation inside the elevated floor and in the house

### DISCUSSIONS

As shown in Figure 5(a), the radiation heat is about two to six times more than convection heat. The value of radiation heat on test point 3 in each room is nearly close to zero, and the value of radiation heat on test point 4 in each room is negative. It shows that the effect of the metal plate is heat absorption, and convection is the main heat transfer method. It illustrates that inner heat transferred from heat source to room1 facing south is the best. So that the effective length of the metal layer should be determined to reach the optimum state.

Through comparison in Figure 5(b), the fin efficiency of the metal plate is decreasing as its length was increasing. In order to take the fin efficiency of metal plate maintain at 50%, the effective length of metal plate is determined to be no more than 0.4m by calculation.

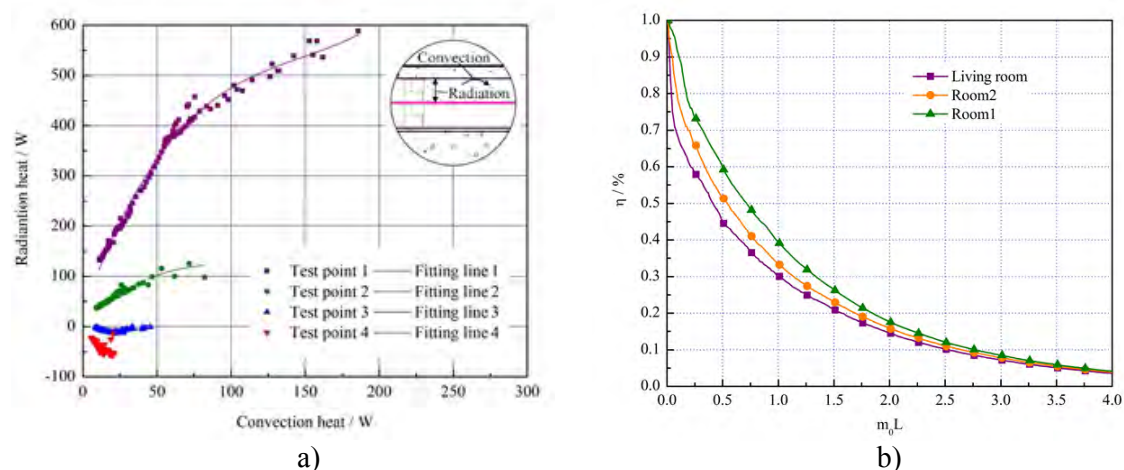


Figure 5. Heat transfer comparison inside the elevated floor. a) Heat transfer analysis, b) The length of metal layer impact on the fin efficiency

## CONCLUSIONS

Some significant conclusions are described as follows: (1) In this elevated radiant floor heating house, the temperature difference between adjacent rooms is only about 2.0°C. It illustrates that the heating environment can be more comfortable than using traditional Kang, and the heating time can be maintained for twenty days with once filling by biomass fuels. (2) The temperature drop rates of inner hot air inside the elevated floor under different function rooms were between 0.3°C/m and 0.9°C/m. (3) To maintain the higher fin efficiency, though thermodynamic criterion analysis on the heat transfer performance of the elevated floor, the effective length of inner metal plate was confirmed and should be no more than 0.4m. The optimized method is enhancing convection heat transfer inside the elevated floor heating system to get a more comfort indoor heating environment.

## ACKNOWLEDGEMENT

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## REFERENCES

- Zhang X.Y. 2014. Study on Heat Source Characteristics and Heat Transfer Process of Burning Cave Heating System, Doctorate dissertation from Dalian University of technology, 25-40. (in Chinese)
- Frederick R. L. 1989. Natural convection in an inclined square enclosure with a partition attached to its cold wall, *International Journal of Heat and Mass Transfer* 32(1), 87-94.
- Bilgen E. 2005. Natural convection in cavities with a thin fin on the hot wall, *International Journal of Heat and Mass Transfer* 48(17), 3493-3505.
- Shi X.D., Khodadadi J.M. 2003. Laminar natural convection heat transfer in a differentially heated square cavity due to a thin fin on the hot wall, *Journal of heat transfer* 125(4), 624-634.
- Abdullatif B.N., Chamkha A. J. 2007. Conjugate natural convection in a square enclosure with inclined thin fin of arbitrary length, *International Journal of Thermal Sciences* 46(5), 467-478.
- Nag A., Sarkar A., Sastri V.M.K. 1993. Natural convection in a differentially heated square cavity with horizontal partition plate on the hot wall, *Computer Methods in Applied Mechanics and Engineering* 110(1-2), 143-156.
- Bilgen E. 2002. Natural convection in enclosures with partial partitions, *Renewable Energy* 26(2), 257-270.
- Du Z.G., Bilgen E. 1992. Coupling of wall conduction with natural convection in a rectangular enclosure, *International Journal of Heat and Mass Transfer* 35(8), 1969-1975.
- Rohsenow W.M., Hartnett J.P., Cho Y.I., et al. 1998. *Hand Book of Heat Transfer*, Third ed., McGraw-Hill Professional publishing, New York, United States of America, 198 pages.
- Beijing civil construction society. 2008. *Building a new socialist countryside based on biomass energy utilization*, China electric power press, First ed., Beijing, China, 56 pages. (in Chinese)