Energy and Buildings 85 (2014) 410–415

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A new Chinese Kang with forced convection: System design and thermal performance measurements

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ARTICLE INFO

Article history:
Received 28 April 2014
Received in revised form 28 August 2014
Accepted 25 September 2014
Available online 13 October 2014

Keywords:
Rural energy
Space heating
Heating terminal device
Local thermal comfort

ABSTRACT

The Chinese Kang, a traditional heating device, is widely used in northern rural China. It recovers the heat from cooking smoke and provides local thermal comfort to people sitting or lying on it. However the heat supply ability of the traditional Kang is limited due to constraints of the surface temperatures and heat transfer coefficients. In this paper, a new Chinese Kang with forced convection (CKFC), which adopted hot water as the heat transfer medium and added a small fan to enhance convective heat transfer, was developed. A full-scale CKFC system was constructed for actual application in a rural house and its thermal performance was measured. Experimental data show that during the space heating period, the heating power of forced air convection ranged from 625 W to 1170 W, while that through the CKFC surfaces was only 200–500 W in the local heating or space heating mode to maintain local thermal comfort. Meanwhile, the CKFC retained the merits of a traditional Kang by providing local thermal comfort. The measured asymmetry of Kang plate surface temperatures was 6.7 °C. Overall, the CKFC has satisfactory performances as a new heating terminal device in rural houses.

1. Introduction

Presently, more than 170 million people live in northern rural China, which has an average outdoor temperature in January (the coldest month in a year) below 0 °C [1]. Thus room heating is critical to sustain indoor thermal comfort. The Chinese Kang is a traditional heating device that has been used for more than 2500 years [2]. With continuous evolution and improvement, it has become the most commonly used heating system in northern rural China. Presently, there are approximately 67 million Kangs in northern rural China [2].

The traditional Kang, with smoke flues laid inside, is made of bricks or other materials of high thermal mass. It is usually connected with a stove and a chimney. When fuel is burned in the stove, the Kang body absorbs and stores the surplus heat of high temperature smoke, and releases heat to the Kang surface gradually in the following hours. Thus, the Kang can create a comfortable local thermal environment. Similar devices are also used in other countries, such as the ondol in Korea and the hypocaust in ancient Rome [3–6]. They even play an important role as the symbols of their local cultures.

However, the Kang heating system also has limitations. Firstly, it is mainly constructed for people lying or sleeping. The Kang plate surface temperature has to be controlled within the range of 21 °C to 35 °C due to people's direct contact with the Kang plate [7]. Too high or low temperatures may cause burn or discomfort. Second, the heat transfer between the Kang surface and room is mainly by low temperature radiation and natural convection. In most of cases, the Kang is considered as a local heating device and only provides local thermal comfort. Its ability to elevate indoor air temperature is quite limited due to limited heat supply ability [8,9]. Moreover, the surface temperature distributions of traditional Kang systems are not uniform, which may cause discomfort. It is an important parameter in similar heating systems which involves direct contact with people [10]. Finally, the traditional Kang transfers heat through high temperature smoke from the stove combustion. The smoke may leak into the room and cause indoor air pollution or even carbon monoxide poisoning.

Zhuang et al. studied the thermal performance of the traditional Chinese Kang and developed a heat transfer and smoke flow model of the system [11,12]. They also gave some advices to improve the Kang's energy efficiency and heat supply ability. Yang et al. combined the traditional Kang with solar air collectors [13,14], which

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http://dx.doi.org/10.1016/j.enbuild.2014.09.073
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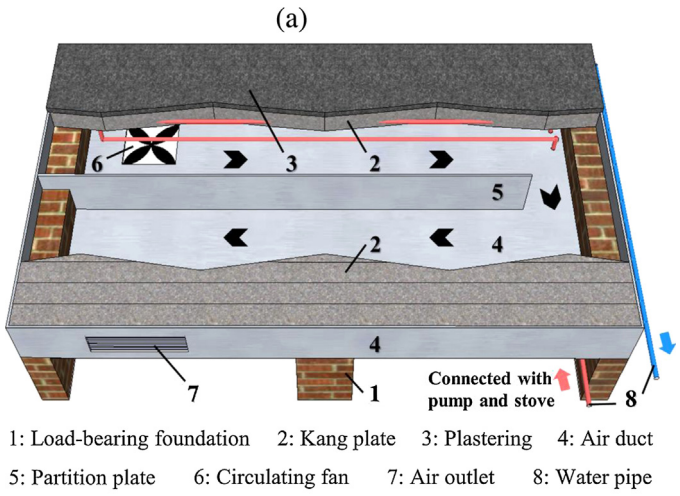

Fig. 1. Illustration of the Chinese Kang with forced convection (CKFC) and its components, (a) CKFC, and (b) reinforced concrete pillar.

used the hot air generated by solar energy to replace part of the heat from high temperature smoke. In terms of the system structure improvement, He et al. embedded hot water pipes into the Kang plate [15]. Hot water, instead of hot smoke, was used as the medium to heat the Kang. However, a common problem of the above Kangs is their limited ability to heat the room air, due to the limited temperatures and heat transfer coefficients of the Kang surface only by natural convection and low temperature radiation.

In this paper, a new Chinese Kang with forced convection (CKFC) was developed. It adopted hot water as the heat transfer medium, and the inclusion of forced air convection could enhance the heating capability of the system. A full-size CKFC was constructed for actual application in a rural house. Thermal performances of the CKFC were measured and analyzed. The new system intends to provide a realistic and low-cost solution to improve the indoor thermal comfort in rural houses by considering local and space heating simultaneously.

2. The Chinese Kang with forced convection

2.1. System components

The CKFC is a new designed heating terminal device, which adopting the hot water as the heat transfer medium. It consists of eight components, namely load-bearing foundation, Kang plate, plastering, air duct, partition plate, circulating fan, air outlet and water pipes. The schematic of the system is shown in Fig. 1(a).

The load-bearing foundation is made of bricks. An air duct is put on it, which is divided into a U-type duct by a partition plate placed in the middle. The circulating fan is installed at the bottom plate of the air duct, and the air outlet is on the side plate of the other side. The air duct, circulating fan and air outlet constitute the new forced air convection system, which can circulate and heat up the indoor air. The Kang plate is composed of several reinforced

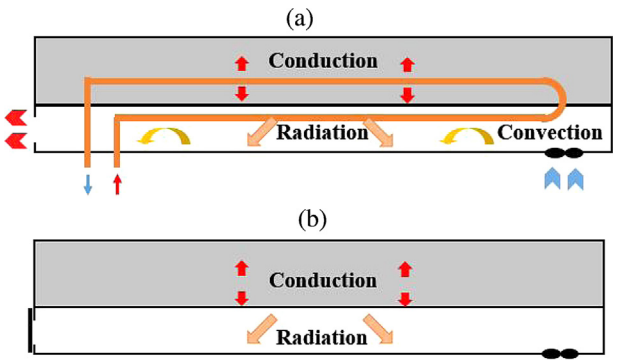

Fig. 2. Heat transfer processes of CKFC in different operating modes, (a) space heating mode, and (b) local heating mode.

concrete pillars, in which the U-type water pipes are all half buried, as shown in Fig. 1(b). The other half of water pipes are exposed in the air duct. These pipes are connected in parallel, and linked with a water pump and a stove. All of them constitute the hot water circulating system.

As a heating terminal device, the CKFC could be connected to any heat source as long as it is able to provide hot water. The circulating water from the heat source is pumped into U-type pipes of CKFC. It not only heats up the Kang plate by conduction through the buried pipes for local heating, but also transfers heat to the forced air flow by convection through the naked pipes in the air duct for space heating. Hence, the CKFC can convey warm air into room by the forced air convection system, meanwhile still maintains a comfortable surface temperature for people lying on the Kang plate.

2.2. Heat transfer processes

There are two operating modes for the CKFC system, namely the space heating mode and the local heating mode, with different heat transfer processes shown in Fig. 2(a) and (b). In the space heating mode, both the water pump and circulating fan are in operation. Hot water flows into the pipes and the Kang plate is heated up gradually by conduction. Meanwhile, indoor air is inhaled into the air duct by the circulating fan and exchanges heat with the naked water pipes and lower surface of the Kang plate by forced convection. The warm air is then blown into the room for space heating. The local heating mode is usually activated at night when people are sleeping, after the Kang plate is well-heated. In this mode, the heat transfer process is similar to a traditional Kang. The Kang plate surface temperature could be maintained within a comfortable range all night long due to the high thermal mass of the Kang body.

There are several key parameters that can affect the thermal performance of the CKFC, which should be carefully considered in system design. The first is the CFKC's construction material. The high heat capacity and density ensure a good thermal mass of Kang plate that could reduce the surface temperature fluctuations, and the thermal conductivity influences CFKC's surface temperatures. The thickness of Kang plate and the embedded depth of water pipes are another group of key parameters. For the same material, increasing the thickness helps to increase the thermal mass of the Kang plate, and the embedded depth of water pipes affects the heat transfer coefficient between the hot water and Kang plate surface. The circulating air flow rate is also a significant factor. It influences both the convective heat transfer coefficient and the supply air temperature.