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Experimental study of a combined system of solar Kang and solar air collector

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ABSTRACT

Chinese Kang is widely used as heated bed and for heat recovery of cooking stove in Northern China. However there are main drawbacks of indoor and outdoor air pollutant generation and heavy demands on solid fuel handling. A novel combined Kang system, which integrates solar Kang and solar air collector, is here proposed. Experiments were conducted to examine the alternative operating modes: (i) only solar air collector in service, (ii) only solar Kang in service, and (iii) both solar Kang and solar air collector in service. The results show that these three modes behave differently and have distinct effects on room thermal environment in winter. When this pollution-free system operates under the third combined mode, the room temperature increases significantly and the vertical temperature gradient reduces. The Kang surface temperature increases and its uniformity is improved. It is also found that the room air temperature is closely related to the Kang surface temperature. Furthermore, most of the time the thermal environment meets the occupant need. This paper reports the experimental work and investigates into the effects on indoor thermal environment as in rural residences in Northern China.

1. Introduction

Northern China is cold and dry in winter and thus domestic heating is in required. In the recent past, solar thermal application has drawn increasing attention as a clean energy source. Passive solar heating and thermal storage are the two key concerns in its applications [1,2]. During the past decades, many studies on passive solar heating in building were reported, such as the Trombe wall system and the composite Trombe wall [3–5]. A PV-Trombe wall was presented and the temperature distribution and electrical performance of the system was evaluated [6]. A dual-function solar collector integrated with buildings was proposed, and it could work as a passive space heating collector in cold sunny days [7]. In 1990s, Yakubu presented an user-experience survey about living in passive solar homes [8]; Maurer et al. introduced transparent facade collectors that are able to provide solar heating and cooling, and incur more primary energy saving than opaque wall as well [9]. Although these systems have promoted the development of the application of solar space heating, solar air collectors that serve as passive heating equipment in the rural areas with ample sunshine may become inefficient or even infeasible under poor weather condition if thermal storage is not available.

A traditional Chinese Kang is composed of a Kang body, a stove and a chimney. During the stove's firing time, the thermal energy from hot fume is first stored in the Kang body and then gradually released into the room space via thermal convection and radiation. People use fire Kang as bench in daytime and as bed at night. So the fire Kang is usually located in the bedroom. Nowadays, Chinese Kang being widely used as the rural home heating system in cold Northern China has arisen much research interest. Zhuang et al. [10] gave a thorough review of the traditional grounded Kang and elevated Kang, including their thermal performance. Ren put forward an up-to-date Kang design [11], with details about the proposed structure, material, construction, performance as well as energy-saving potential. Several scholars developed numerical models for Kang. For example, a thermal and airflow model for elevated Kang was developed by Zhuang et al. [12]; Cao et al. established a set of models to simulate the energy performance of a Kang heating system in Chinese detached house, and accomplished this with experimental field study [13]. This traditional Chinese Kang is heated by smoke coming from stove by burning solid fuels such as stalks, firewood and agricultural residues. High levels of pollutants are emitted and are hazardous to occupant health.

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Because of the firing interruption, the temperatures of the Kang surface and room air were found to be not uniform. All above mentioned problems have brought restrictions to the development of traditional Chinese Kang. In order to overcome the drawbacks, an opportunity then comes to integrate solar energy system with the traditional Chinese Kang system. Although the concept of solar Kang has been proposed since several years, very few studies were actually carried out in this field. Ren put forward the heated Kang facilities, which integrated solar energy with the fossil fuel methane [14]. He et al. presented a mathematical model of solar Chinese Kang, and studied its thermal performance as well as energy consumption based on the evaluation of sleeping thermal comfort with predicted mean vote (PMV) [15]. Yang et al. developed a Kang system that integrates solar air collector into the conventional Chinese Kang [16,17]. The impacts of thermal capacity, thermal conductivity and convective heat transfer resistance of Kang plate on the Kang's heat transfer process were investigated. Chen et al. conducted two field surveys based on three residences to investigate the thermal environments of rural residences with a coupled Chinese elevated Kang and passive solar collecting wall heating system [18]. These solar Kang are able to improve the indoor thermal environment. However, owing to its high thermal capacity, a flaw thus lies in the difficulty to increase the Kang surface temperature at the start of the heating period. As the degree of radiation heat transfer is very small, the room air temperature remains low during this start-up period. In order to resolve the problem, this study proposes a combined system that includes the solar Kang and the solar air collectors. The solar air collectors are used to make space heating possible during the beginning period and to elevate the room air temperature in a relatively short time. After several hours the heated Kang body can operate well via radiative heat transfer, and is able to keep the Kang surface as well as the room air at elevated temperature during night time. The above mentioned system is able to make full use of the storage capable of the Kang body.

The aim of our work is to offer a clean heating facility in north China. In this paper, a new combined system consists of solar Kang and solar air collector is proposed. Experiments have been conducted to investigate the effect on indoor thermal environment of the combined system. A comparison between the thermal environments of the test room and the reference room is discussed. Moreover, the thermal performances of the test room are analyzed under three different operation modes respectively. It was found that the combined system should adopt the combined mode (SACSK) to work in order to keep the thermal environment at an acceptable level. This study results pave the way for future optimization of the combined system designs. The below part explains the experimental tests on this combined system with comparisons among its three operating modes: (i) only the solar air collectors are working, (ii) only the solar Kang is working, and (iii) the combined system is working. Experiments were conducted to investigate the distinct thermal performances of these three operating modes.

2. System description and experimental set-up

In principle, the combined system has two sub-systems: the solar air collector sub-system (SAC) and the solar Kang sub-system (SK). The SAC carries two separated solar air collectors, and the SK carries a Kang body, solar water collectors, a water storage tank, and the interconnecting water pipework.

The test site was at the campus of the University of Science and Technology of China in Hefei (at 31.89°N and 117.3°E). A hot box was constructed on the roof-top of an office building, as shown in Fig. 1. This is basically a chamber that houses three separate rooms having the same structure and dimensions. Referring to the layout plan in Fig. 1(a), the room at the left is the test room and the one at the right is the reference room for performance comparison purpose. The middle room did not take part in this experimental test. Fig. 1(b) shows the outside view of the hot box. Two identical solar air collectors of the SAC sub-system were mounted on the south wall. The design of the collector is based on the traditional flat-plate collector and with two openings at insulated backboard. Fig. 2 shows the detailed arrangements. Each solar air collector is of size 2 m (H) by 1 m (W). The air duct inside the air collector is 50 mm (D). The four side edges and the backboard of the solar air collector are well insulated from the outside. Cross-section view is shown in Fig. 2(a), the upper and lower vents connect the air gap (or air duct) to the test room space for air circulation air collectors on the south wall of the test room.

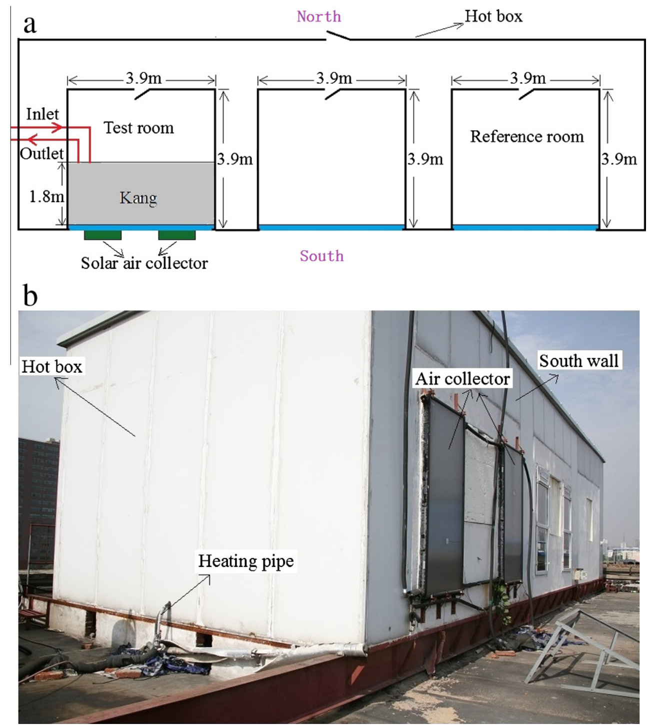

Fig. 1. Views of the hot box: (a) floor plan; and (b) outside view showing the two solar air collectors.

The Kang was built next to south wall. Same as the traditional elevated Kang, the body was supported well above the floor level, as shown in Fig. 3, with the side edges well insulated from the enclosing walls. Typically the heating water pipe at the Kang is for connection to solar water collector, water storage tank and circulating pump outside. The circuit diagram is shown in Fig. 4(a). The test/reference room dimensions are 3.9 m (W) by 3.9 m (D) by 2.6 m (H). The south wall is made of brick. All the other outside walls and partitions of the hot box are made from insulation material sandwiched in steel plates. The walls thicknesses are listed in Table 1. The Kang body is of dimensions 3.9 m (W) by 1.8 m (D) by 0.24 m (H), with the following five layers from top to bottom: cement layer (30 mm), brick layer (50 mm), sands layer (30 mm), thermal insulation layer (30 mm), and concrete layer (100 mm), as displayed in Fig. 3(b). Their material properties are listed in Table 2. A heating pipe of total length 50 m and the diameter of 15 mm is buried in the sands layer as shown in Fig. 3(c). It shows the pattern of the horizontal pipe arrangement, with the “inlet” and “outlet” ends connected to the other SK components outside the test room. The water holding capacity of the tank is 300 l.