Building and Environment 98 (2016) 158–179

Contents lists available at ScienceDirect

Building and Environment

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

A glazed transpired solar wall system for improving indoor environment of rural buildings in northeast China

Tiantian Zhang*, Yufei Tan, Xuedan Zhang, Zhigao Li

School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, China

ARTICLE INFO

Article history:
Received 19 October 2015
Received in revised form
12 January 2016
Accepted 13 January 2016
Available online 14 January 2016

Keywords:
Transpired solar collector
Operating modes
Indoor air temperature
Indoor pollutants
Operating strategy
Rural dwellings

ABSTRACT

In rural areas of northeast China, residents often use a traditional Chinese kang for domestic heating. However, this heating method is associated with an uncomfortable thermal environment and poor indoor air quality. Therefore, this paper proposes a glazed transpired collector (GTC) based solar wall system, as a solution. Similar to air conditioning systems, the GTC is able to generate various airflow settings, which is one creative concept of the proposed system. Experimental and numerical studies were conducted to investigate the space heating and indoor air-quality improving performance of the system. The experimental results show that the average indoor temperatures can be increased from 12.12 °C to 16.17–18.19 °C, relevant to the various operating modes. The return-air mode reduces the concentrations of CO, CO_2, $PM_{2.5}$, and PM_{10} by 34.8%, 20.3%, 14.4%, and 11.6%, respectively. The reductions relevant to the mixture mode are 69.6%, 28.0%, 45.0%, and 41.6%, respectively, and those to the fresh-air mode are 73.9%, 42.7%, 56.2%, and 58.1%, respectively. By numerically simulating the distributions of indoor air temperature and the concentrations of CO, CO_2, $PM_{2.5}$, and PM_{10}, the GTC-based solar wall system is able to enhance the uniformity of temperature distribution and dilute indoor pollutant concentrations. To conclude, a summary of the simple and easy operating manual of the solar wall system is presented in this paper. The solar wall system can solve the problem of unacceptable indoor thermal comfort and indoor environmental pollution in rural dwellings in cold climates.

1. Introduction

In the cold regions of rural China, people often use a traditional stove-kang (Chinese kang) system to heat their dwellings. The stove-kang is an effective system that uses local biomass for heating, ameliorating the energy and environmental problems associated with rural residential buildings [1]. The system probably dates back 2500 years, and is still widely used today [2]. A large-scale field survey in 2006 indicated that this ancient system was still used for domestic heating in nearly 85% of rural homes, by 175 million people [3]. A typical Chinese kang comprises a stove, the kang body, and a chimney, and is often constructed from masonry, adobe, and cement [4], as shown in Fig. 1. Various functions, such as cooking, a place for sleeping, domestic heating, and ventilation are integrated in this one system. In most of the kang applications, the stove is placed in the kitchen, additionally serving as cooking place. An inner chamber functions as a flue for the high-temperature smoke produced by the stove, which burns biomass such as straw, corncobs, wood, and the like. Heat is transferred from the smoke to the massive structure as the smoke flows through the chamber to the chimney and subsequently outside. The massive structure stores the heat and gradually releases it to the indoor space to keep the room warm for several hours after the combustion process.

The kang system can maintain the average indoor air temperature at 13–16 °C during the day [5]. Using straw, corncobs, and wood as fuel helps to reduce fossil fuel consumption for cooking and domestic heating. To some extent, the system solves the energy and environmental problems related to rural residential buildings. However, applying the system causes significant other problems. As the main structures of the detached houses in the rural areas are usually poorly insulated, the general indoor thermal condition remains relatively unsatisfactory if the kang is the only heating source. The kang system alone does not provide enough heat to increase and maintain the indoor temperature to a comfortable level on the coldest winter days. The average indoor temperature often drops below 13 °C [6], the acceptable minimum indoor

* Corresponding author.
E-mail address: x418298537@163.com (T. Zhang).

http://dx.doi.org/10.1016/j.buildenv.2016.01.011
0360-1323/

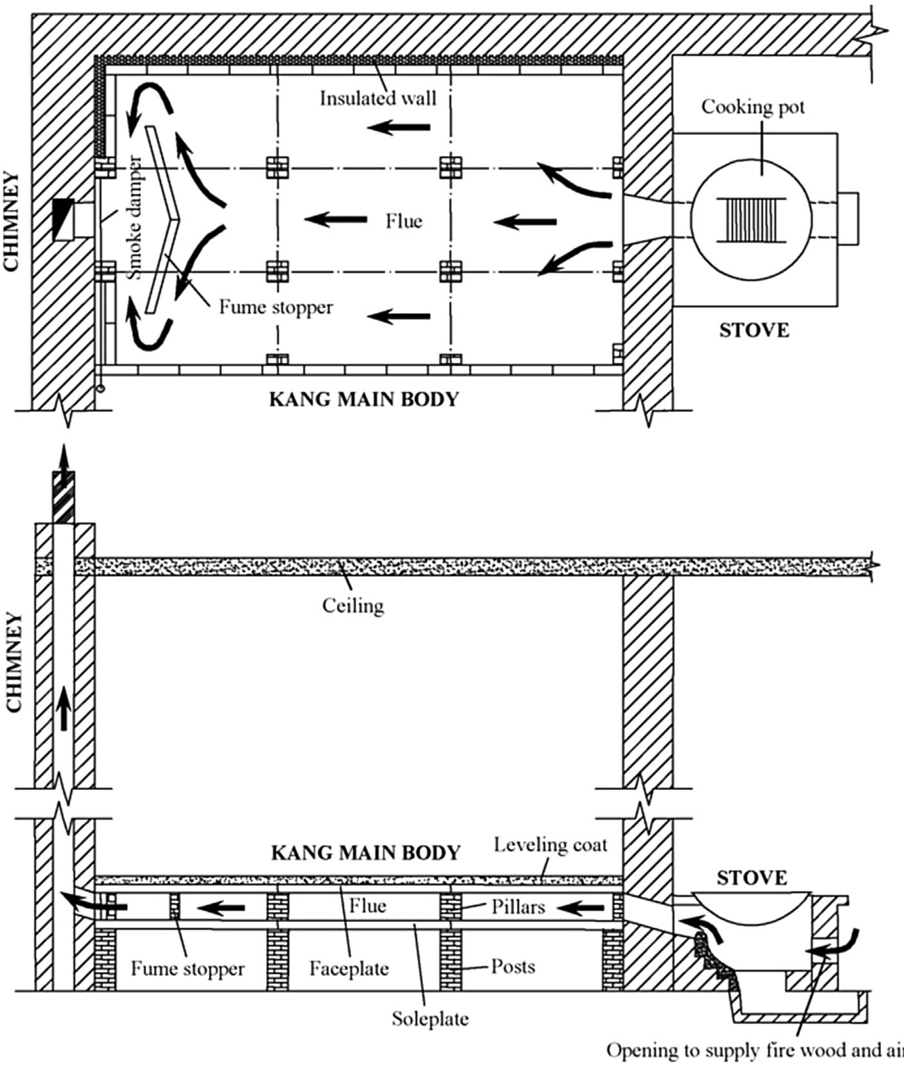

Fig. 1. An illustration of the elevated kang system.

temperature according to the standard for rural residential buildings [7]. Furthermore, in winter, the stove is used twice daily, namely, in the morning for cooking breakfast and late in the evening for cooking dinner. Sometimes, the kang is used again at midday to cook lunch. Consequently, the indoor air temperature can fluctuate wildly [8]. During the combustion period and for several hours afterwards, the body of the kang remains warm and transfers heat to the indoor air, raising the temperature to even more than 20 °C. However, eventually the air temperature drops, sometimes to below 10 °C, especially during the night [9]. The low temperature during non-combustion periods and the temperature fluctuations adversely affect the indoor thermal comfort. A survey on the indoor thermal comfort in ten rural houses in two villages near Harbin has indicated that the average indoor temperature was 12.3 °C and the magnitude of temperature variation was 7.8 °C. Forty percent of the occupants indicated that they experienced cold or intense cold on winter days and 60% were cold during winter nights. In the daytime, the occupants usually wear thick clothes, with an average clothing insulation of 1.47clo, to keep warm [10].

The poor indoor air quality of rural buildings, caused by fuel combustion, is of serious concern [11]. The design and construction of the traditional kang is mostly directed by intuition and the practical knowledge of the craftsmen, but there is no scientific theory or basis to ensure effective functioning. Consequently, the heating efficiency of the traditional kang system is less than 20% [12], and that of the improved elevated system is 45–60% [13]. The low energy efficiency results in a significant waste of energy and the system requires large amounts of fuel to maintain the indoor thermal environment. The occupants often supplement the kang system with coal-fired boilers or radiators to improve the indoor temperature during the non-combustion periods [14]. The fuel combustion process releases various types of pollutants to the indoor space, including CO, particulate matters ($PM_{2.5}$ and PM_{10}), and others. According to Zhang [15], a field test on the indoor environment of 12 rural residential houses heated by the Chinese kang has indicated that the average indoor temperature was 10–13 °C, i.e., far below the comfort level. Moreover, the main pollutants found were CO_2, particulate matters, NO_x, and SO_2, and their concentrations exceeded the acceptable standards. The average concentrations of CO_2, $PM_{2.5}$, NO_x, and SO_2 reached 1514 ppm, 0.425 mg/m^3, 0.24 ppm, and 0.63 ppm, respectively. Wang et al. [16] investigated the indoor air quality of rural dwellings in the severe cold regions of China and concluded that the over-standard ratios of $PM_{2.5}$, PM_{10}, SO_2, NO_x, and CO_2 were 97%, 79%, 99%, 63%, and 71%, respectively. According to another survey, more than 40% of the farmers reported heavy indoor smoke during the cooking