Energy and Buildings 84 (2014) 46–54

Contents lists available at ScienceDirect

Energy and Buildings

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

Thermal performance of a traditional Chinese heated wall with the in-series flow pass: Experiment and modeling

Pengsu Wang[a], Ming Yang[b], Xudong Yang[a,*], Ming Shan[a]

[a] Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, PR China
[b] Key Laboratory of Solar Thermal Energy and Photovoltaic System, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, PR China

ARTICLE INFO

Article history:
Received 16 September 2013
Received in revised form 25 July 2014
Accepted 29 July 2014
Available online 7 August 2014

Keywords:
Chinese heated wall
Space heating
Rural energy
Heat transfer

ABSTRACT

Chinese heated wall is a traditional space heating device commonly used in the northeast rural China. It absorbs and stores the surplus heat of high temperature smoke from solid fuel combustion in the stove, and releases the heat to room gradually in the following hours. In this article, a full-scale heated wall was constructed for measuring its thermal performances. The experimental results show that the heated wall could recover approximately 70% of the surplus heat from the stove under the measurement conditions. A dynamic heat transfer model considering heat transfer between the hot smoke and the wall body and the room was also developed. The simulated temperatures agreed well with the experimental data. Therefore, the model could be applied to analyze the thermal performance and optimize the design of the heated wall in future.

1. Introduction

The Chinese heated wall is an ancient space heating system commonly used in the northeast of rural China. It absorbs and stores the heat of high temperature smoke from solid fuel combustion, and then releases the heat to the room gradually by convection and radiation.

The heated wall normally consists of three parts, namely stove, wall body and chimney, as shown in Fig. 1. The stove serves as the heating source and linked to the wall body through an opening. Usually, it is located in the kitchen and can be used for cooking as well. The wall body is the main component of the whole system which is located in the space where heating is needed. In order to have a high thermal mass, the wall body is made of heavy materials such as brick. The common dimensions of the wall body are approximately 1.5–2.5 m long, 1.0–1.8 m high and around 0.3 m wide, depending on the heating load and layout of the room. There is a chimney at the end of wall body, usually made of metal or brick.

When fuel burns in the stove, high temperature smoke is generated. With the force of buoyancy, the smoke transfers heat to the interior surfaces of the heated wall body and chimney by convection, and is cooled down along the moving path. The heated wall body then transfers heat to the exterior surfaces by conduction. Meanwhile, the room is heated by convection and long-wave radiation. On the basis of the thermal process, the heated wall could be regarded as the heat recovery device of the cooking stove, which helps to increase the overall thermal efficiency of the system.

The Chinese heated wall is similar to the Chinese Kang, because they are both traditional heating devices widely used in rural China [1,2]. But the differences between heated wall and Kang exist. Kang is a heated bed that provides local thermal comfort to people sitting or laying on it, while the heated wall is mainly for space heating. So the thermal performance and surface temperature distributions are quite different. There are some other traditional heating systems used around the world. Ondol is an under-floor heating system used in bedrooms in Korea [3]. Its operating principle is more like a Kang than a heated wall. Similar heating systems, named hypocaust, also existed in ancient Roman time [4,5]. Compared with these heating systems, the research on the heated wall is so scarce that the construction is entirely based on worker's personal experience.

In this article, a Chinese heated wall was constructed and key variables related to its thermal performance were measured. A dynamic heat transfer model of the heated wall was also established.

* Corresponding author. Tel.: +86 10 6278 8845; fax: +86 10 6277 3461.
E-mail address: xyang@tsinghua.edu.cn (X. Yang).

http://dx.doi.org/10.1016/j.enbuild.2014.07.075
0378-7788/

Nomenclature

$A_{o,1}$	inlet sectional area of stove (m^2)
Cp	specific heat of smoke (J/(kg K))
Cp_w	specific heat of heated wall body (J/(kg K))
D_w	qualitative dimension of heat convection (m)
E	heat source intensity (W)
f	turbulence friction coefficient
F_c	interior surface area of chimney (m^2)
$F_{i,j}$	area of interior surface j of wall body in zone i (m^2)
F_r	interior surface area of room or exterior surface area of heated wall (m^2)
G_r	Grashof number
$h_{cc,in}$	convective heat transfer coefficient between the smoke and chimney (W/(m^2 K))
$h_{cc,out}$	convective heat transfer coefficient between chimney and indoor air (W/(m^2 K))
h_{forced}	heat transfer coefficient of forced convection (W/(m^2 K))
$h_{wc,in,i,j}$	convective heat transfer coefficient between the smoke and interior surface j of wall body in zone i (W/(m^2 K))
$h_{wc,out,i,j}$	convective heat transfer coefficient between the indoor air and exterior surface j of wall body in zone i (W/(m^2 K))
h_{cr}	radiation heat transfer coefficient between the interior surface of room and exterior surface of chimney (W/(m^2 K))
$h_{wr,i}$	radiation heat transfer coefficient between the interior surface of room and exterior surface of wall body in zone i (W/(m^2 K))
H_i	height of zone i (m)
k_s	absolute roughness of martial of wall body (mm)
K_b	coefficient of pitot tube
l	length of smoke flue (m)
Nu	total Nusselt number of mixed convection
Nu_{forced}	Nusselt number of forced convection
$Nu_{natural}$	Nusselt number of natural convection
P_d	dynamic pressure (Pa)
P_o	atmosphere pressure (Pa)
P_r	Prandtl number
Q_e	energy exhausted outside the room (J)
Q_s	energy obtained from stove (J)
Q_{s-c}	energy transferred from smoke to chimney (J)
Q_{s-w}	energy transferred from smoke to wall body (J)
R	equivalent radius of the rectangular flow cross section (m)
Ra	Rayleigh number
Re	Reynolds number
T_a	indoor air temperature (K)
T_i	smoke temperature in zone i (K)
T_r	interior surface temperature of room or exterior surface temperature of heated wall (K)
T_o	stove inlet air temperature (K)
$T_{w,in,i,j}$	temperature of interior surface j of wall body in zone i (K)
$T_{w,out,i,j}$	temperature of exterior surface j of wall body in zone i (K)
T_z	interior surface temperature of room (K)
v	smoke velocity (m/s)
$X_{i,j}$	radiation angle factor

Greek letters

ε	emissivity
λ_w	thermal conductivity of heated wall body (W/(m K))
ρ_i	smoke density in zone i (kg/m^3)
ρ_o	stove inlet air density (kg/m^3)
ρ_w	density of heated wall body (kg/m^3)
ΔP	total flow resistance of heated wall or pressure drop (Pa)
ΔP_i	total flow resistance of zone i (Pa)
σ_b	Stephen Boltzmann constant (W/m^2 K^4)
ξ_i	comprehensive drag coefficient of zone i

2. Experiment

2.1. Experimental setup

In order to study the dynamic thermal performance of the heated wall, especially the heated wall body, a test room with a heated wall was constructed in Beijing, China. The test room walls were made of brick without additional thermal insulation, representing the typical housing situation in rural China. The heated wall body was located in the middle of the room, with a traditional cook stove located outside of the room. The layout of test room and the dimensions of heated wall are shown in Fig. 2, and the detailed physical properties of each component are given in Table 1.

Key parameters related to the thermal performance of the heated wall were measured in the experiment, including the smoke temperatures, interior and exterior surface temperatures, and the heat fluxes of the exterior surfaces. With consideration of the non-uniform temperature and heat flux distributions on the surfaces, several testing points were measured along the smoke flow path.

There were totally eleven temperature measuring points along the smoke flow direction of the heated wall, as shown in Fig. 3(a). Six of them were on the main walls. At each test point, five thermocouples were used. One was in the flue to measure the smoke temperature, and the other four were on the interior and exterior surfaces of two main walls to measure the surface temperatures. Besides that, there were three test points located on the bottom wall, side wall, and upper wall respectively. Two thermocouples were set on the interior and exterior surfaces at each testing point accordingly. Another two test points were placed at the inlet and outlet of the chimney to measure the smoke temperatures.

It was expected that the heated wall would release heat into the room mainly by the main wall surfaces due to the larger heat transfer area compared with the other wall surfaces. Therefore, the

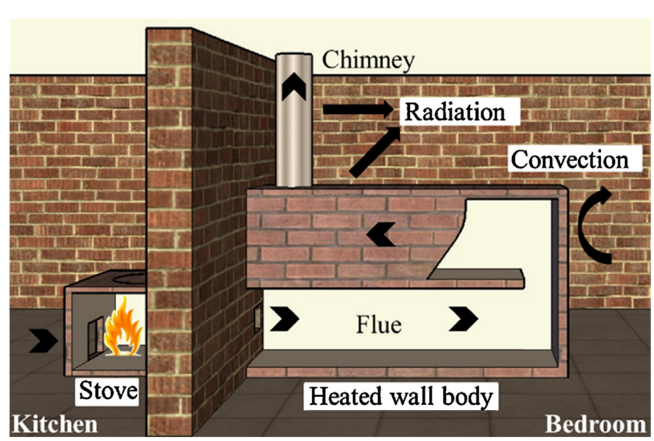

Fig. 1. Illustration of a typical Chinese heated wall.