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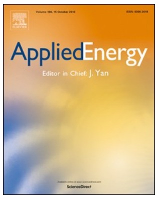

Effects of key factors on the heat insulation performance of a hollow block ventilated wall

Junchao Huang[a,b], Jinghua Yu[a,*], Hongxing Yang[b]

[a] School of Environmental Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

HIGHLIGHTS

- Heat transfer model of hollow block ventilated wall is built.
- Temperatures obtained from the heat transfer model are verified by experiments.
- Effects of airflow rate, inlet airflow temperature and cavity size are investigated.
- Decrement factor, time lag and heat flux of this ventilated wall are analyzed.
- Cavity size has the most influence on heat transfer characteristics.

ARTICLE INFO

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ABSTRACT

A hollow block ventilated wall can be cooled down in the summer and warmed in the winter by utilizing the air that flows through cavities. The heat transferred between the outdoor and indoor environments can also be removed. However, neither simulations nor experimental studies on the hollow block ventilated wall have been complete, and factors that affect the thermal insulation performance of hollow block ventilated walls need to be identified. In this paper, the frequency-domain finite-difference method and the Number of Transfer Units method are adopted to build the coupled three-dimensional heat transfer model for investigating the temperature distribution on wall surfaces and the exhaust airflow. Experiments are carried out to validate the three-dimensional model, and comparisons prove that the model has considerable accuracy. In addition, both the numerical and experimental studies show that the hollow block ventilated wall can significantly reduce the heat transferred from outdoor environments to indoor rooms through ventilation in the summer. The effects of influential factors, including the airflow velocity, the inlet temperature of the airflow and the cavity size, on the thermal insulation performance of the hollow block ventilated wall are investigated based on the heat transfer model. Results show that the temperature of the inner surface of the hollow block ventilated wall at four orientations is reduced and ranges from 24.8 to 27.0 °C during a typical summer day. The heat flux through the inner surface is reduced by 55.08%, 55.07%, 56.03% and 55.19% respectively for the east, west, south, and north hollow block ventilated walls, indicating the energy saving potential of hollow block ventilated walls. The most critical factor is the cavity size. When the cavity dimension is constant, the influence of the airflow velocity on thermal insulation is much larger compared to the airflow temperature, and the suggested airflow rate is 1.3 m/s. Results show that a higher airflow rate, higher inlet airflow temperature, and larger cavity size, enable the hollow block ventilated wall to achieve better thermal insulation performance.

1. Introduction

Residential and commercial energy use made up around 20% and 18% of the total energy consumption of China in 2017, respectively [1], indicating that buildings are largely responsible for energy shortages. Furthermore, it has been stated that 20–50% of the cooling and heating load is caused by building envelopes [2]. Improving thermal insulation is important in reducing the energy consumption of buildings. Many researchers have carried out comprehensive work on walls [3–5] and windows [6–8], aiming to propose effective methods of reducing cooling and heating loads that result from the building envelope. Leccese et al. [3] explored the dynamic thermal performance of different

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* Corresponding Author.

E-mail addresses: junchaohuang@hust.edu.cn (J. Huang), yujinghua@hust.edu.cn (J. Yu), hong-xing.yang@polyu.edu.hk (H. Yang).

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Nomenclature

c	specific heat (J/(kg·K))
dx	length of the heat transfer cell (m)
dy	width of the heat transfer cell (m)
h	the order of the Fourier series expansion
h_{in}	convective heat transfer coefficient of the inner wall surface
h_{out}	convective heat transfer coefficient of the outer wall surface
h_{zj}	integrated heat transfer coefficient considering radiation and convection on each surface of the cavity
i	imaginary unit
k	sequence number of the heat transfer cell
K	heat transfer coefficient of convection between the airflow and the wall mass (W/(m^2·K))
M	the mass flow rate of the fluid (kg/s)
q_{is}	average inner surface heat flux
R_4,R_5&R_6	the equivalent resistances calculated by the convective resistance and radiation resistance
R_{c1}&R_{c2}	the convective thermal resistances happening between airflow and cavity surface 1 and 2
R_r	the radiation heat transfer thermal resistance
s	heat transfer factor (W/(m^2·K))
t	time of heat transfer (h)
T	temperature (°C)
$T_{(b,0)}$	the initial value of inlet airflow temperature
$T_{(b,n)}$	the outlet airflow-temperature of number n heat transfer unit
$T_{(b,n-1)}$	the outlet airflow temperature of number ($n-1$) heat transfer unit, also the inlet temperature of number n heat transfer unit
$T_{(in,l)}$	hourly indoor air temperature at moment l
$T_{(is,l)}$	hourly inner wall surface temperature at moment l
$T_{(m,n)}$	the wall average temperature of number n heat transfer unit
T_0	phase constant
T_a	airflow temperature inside the cavity
$T_a{}'$	the hypothetical temperature of airflow
T_{b1}	temperatures of the cavity surface 1
T_{b2}	temperatures of the cavity surface 2
T_{in}	indoor air temperature
T_{is}	inner surface temperature of the wall
	the maximum inner surface temperatures of the wall
T_{is}^{min}	the minimum inner surface temperatures of the wall
T_{os}^{max}	the maximum outer surface temperatures of the wall
T_{os}^{min}	the minimum outer surface temperatures of the wall
u	real part
v	imaginary part
θ	plural temperature (°C)
λ	thermal conductivity
ρ	density of the hollow block (kg/m^3)
τ_{is}^{max}	the moments when the maximum inner surface temperature appear
τ_{os}^{max}	the moments when the maximum outer surface temperature appear
φ	phase angle
ω	angular velocity
2D/3D	two-dimensional/ three-dimensional
Cbrick	coat brick
DF	decrement factor
DSF	double skin facade
EPfoam	extrude polystyrene foam
FDFD	frequency-domain finite-difference
FDM	finite difference method
GB	Guo Biao (Chinese, which means national standard)
HBVW	hollow block ventilated wall
HCbrick	horizontal cavernous brick
HVAC	Heating, Ventilation and Air Conditioning
mPCM	micro-encapsulated phase change materials
NTU	number of transfer units
PIM	point iteration method
TCHCM	temperature-change hot chamber method
TL	time lag
VCbrick	vertical cavernous brick

multi-layered walls, where the impact of thermal insulation on the enhancement of the thermal performance was investigated. Cui et al. [4] probed into the thermophysical characteristics, incorporation methods, and detailed application means of phase change walls. Using the Finite Volume Method, Huo et al. [5] reviewed the widely used efficient energy-saving methods in four climate areas under unsteady-state. They suggested that the roof and the outer walls are pivotal building envelopes, which need to adopt energy saving technologies. As for energy-saving windows, Cuce et al. [6] indicated that vacuum glazing achieved minimum heat loss, high visible transmittance and uncomplicated manufacturing process in one product. Wang et al. [7] listed seven advantageous aspects of photothermal thin films in order to argue that the use of nanostructures in window design could actualize the promising decrease in building energy consumption. Casini [8] compared different types of active dynamic glazing technologies in terms of their operation, characteristics, and application potential, and pointed out that these technologies could obtain better thermal comfort and energy saving improvement. One alternative for decreasing building energy consumption is adopting air layers within building envelopes [9], which may include Trombe walls, internal hollow composite walls, double-skin façades, PV façades, multi-layer windows, and airflow windows. Ana Briga-Sá et al. [10] researched the Trombe wall from both analytical and experimental perspectives, and found that there would be a decrease of over 30 °C in the temperature of the external surfaces when the walls are equipped with an occlusion device, and that switching off the ventilation openings leads to a significant heat delay. Wang et al. [11] developed a novel exhaust air insulation wall, which was characterized by an air permeable porous layer. The thermal performance was investigated, and the results showed that the exfiltration process of the exhaust air across the porous layer could significantly reduce the inward conductive heat flux through the wall. Souza et al. [12] established a test cell to collect temperature data of a double skin façade and their results showed that double skin façade (DSF) could reduce the indoor temperature. Han et al. [13] investigated the natural convection in the air cavity of a double-pane window and indicated that adopting low-e coating helps to reduce the mass of heat transfer by radiation within the cavity. Peng et al. [14] carried out experiments to study the influence of diverse ventilation modes on thermal and power performances of a ventilated photovoltaic DSF. Their results demonstrated that the ventilation design brings about more reduction of heat gain and improvements in energy generation. They also presented a simulation study [15] for investigating the overall energy performance of this building structure, which proved that it can effectively reduce solar radiation. Wang et al. [16] compared this structure with a photovoltaic insulating glass unit and found that the former was better at decreasing solar heat gains and worseat thermal insulation.

Studies related to energy saving in building envelopes can be divided into two categories in terms of ventilation in the air layer. When there is no ventilation in the air layer, which can be regarded as steady,