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Three-dimensional simulation on the thermal performance of a novel Trombe wall with venetian blind structure

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ABSTRACT

A complete three-dimensional CFD model was developed to investigate the flow and thermal transport in a novel Trombe wall equipped with a venetian blind. The model was involved in flow and heat transfer in the Trombe wall, which was conjugated with heat conduction in the venetian blind. An experimental rig was constructed and utilized to validate the CFD prediction. It was found that the established model is able to predict the operational performance of the system at a reasonable accuracy. Effect of structural parameters of the Trombe wall was investigated in details under the specific operational condition. The present study indicates that the position of the venetian blind, the width of the air duct and the area of the inlet and outlet vents influence the thermal performance of the system. The results predicted that the optimum of the distance between the glass and the venetian blind is 0.09 m for an air duct of 0.14 m width, the width of the air duct is 0.14 m and the area of each vent is 0.60 m width × 0.10 m height. The research results would assist in developing a high efficient solar air heating system and thus help reduce fossil fuel consumption in the building sector.

1. Introduction

A conventional Trombe wall is a south-facing concrete or masonry wall in which glass and a ventilated air space separate the wall from the outdoor environment [1–3]. It is used by a building to capture solar energy and use it for space heating and provide thermal comfort. As a passive solar technique, Trombe wall can store the energy at times of peak solar radiation and supply energy when a building's occupants require it, thus leading to reduction in a building's energy consumption up to 30% [4]. Moreover, Trombe wall has some unique features, such as low cost, simple geometry and reliable operation.

Much numerical and experimental research has been used for studying the heat transfer and performance analysis of different types of Trombe wall. Different configurations of Trombe wall have been used depending on the purposes and weather conditions [5].

Stazi et al. carried out the dynamic simulations with software EnergyPlus and calibration of the model with experimental data to investigate the conventional Trombe wall's thermal behavior [6]. They demonstrated that Trombe wall provides heating energy savings and thermal comfort in winter and intermediate seasons. Rabani et al. developed a 2D simulation of the Trombe wall and indoor air environment under unsteady state condition in order to investigate the time duration of room heating during the non-sunny periods [7].

In order to decrease a building's dead load, a Trombe wall with phase-change material is proposed [8]. Zalewski et al. presented an experimental study of a small-scale Trombe wall containing the phase material [9]. Khalifa and Abbas conducted a computerized dynamic simulation on a zone heated by a thermal storage wall. They examined three different storage material and concluded that an 8 cm thick hydrated salt storage wall is capable of maintains temperature [10].

Another invention called PV-Trombe wall with PV cells on the glazing, which can produce electricity and heat simultaneously, has been theoretically and experimentally investigated in the previous works of our group [11–13]. The esthetic value that the dark blue solar cells bring can increase the building's appeal, and thus help the spread and application of Trombe wall.

To further improve the outward and thermal efficiency of Trombe wall, a novel Trombe wall with venetian blind structure is thereby proposed. This combined system, as shown in Fig. 1, is composed of a glazing cover, a venetian blind acting as a thermal absorber, an internal wall and an air duct in between. It should be mentioned that one side of the blind slats of the venetian blind is covered with high absorptivity coating and the other side is covered with high reflectivity coating. On one hand, the side covered with high reflectivity coating is overturned outward to prevent

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Nomenclature

A	effective absorbing area (m^2)
C_p	specific heat capacity (J/kg K)
G	solar radiation intensity (W/m^2)
h	heat transfer coefficient (W/m K)
m	mass flow rate (kg/s)
Q	energy rate (W)
T	temperature (K)
RE	relative error
V	wind speed (m/s)
X	value

Subscripts

exp	experimental
th	thermal
in	inlet
out	outlet
sim	simulated

overheating problem in summer. On the other hand, turning the other side covered with high absorptivity coating outward results in the solar radiation striking on the slats partly absorbed, causing the air in the air duct to warm up. The absorbed solar irradiance can be controlled by controlling the slat angle of the venetian blind installed between the glazing and the wall. When the room air temperature is relatively low in the morning, the slats can be inclined at the angle ensuring the total solar radiation striking on them, and thus leading to the air temperature rising fast. However, the solar radiation and the air temperature are both relatively higher about noon. And the slats can be turned to another angle in order to absorb less solar radiation and permit some part of the radiation striking on the wall. In this way, the room temperature can remain a relatively stable and comfortable temperature. To enable this effect, a venetian blind is worthy of implementation. The integration will expect to improve the energy efficiency of heat collecting and prevent overheating in summer.

In this work, a complete three-dimensional model is developed to analyze the thermal/flow characteristics in the Trombe wall. Temperature and pressure in the air inlet vent and outlet vent are determined by coupling the heat transfer and flow in the whole loop. The influence of the location of the venetian blind and the structural parameters of the Trombe wall is analyzed. This will help improving the efficiency of such an innovative technology, and thus contribute to reducing fossil fuel consumption in the building sector.

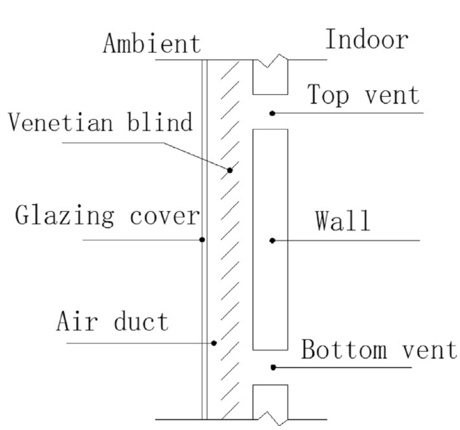

Fig. 1. Schematic of the Trombe wall with venetian blind structure.

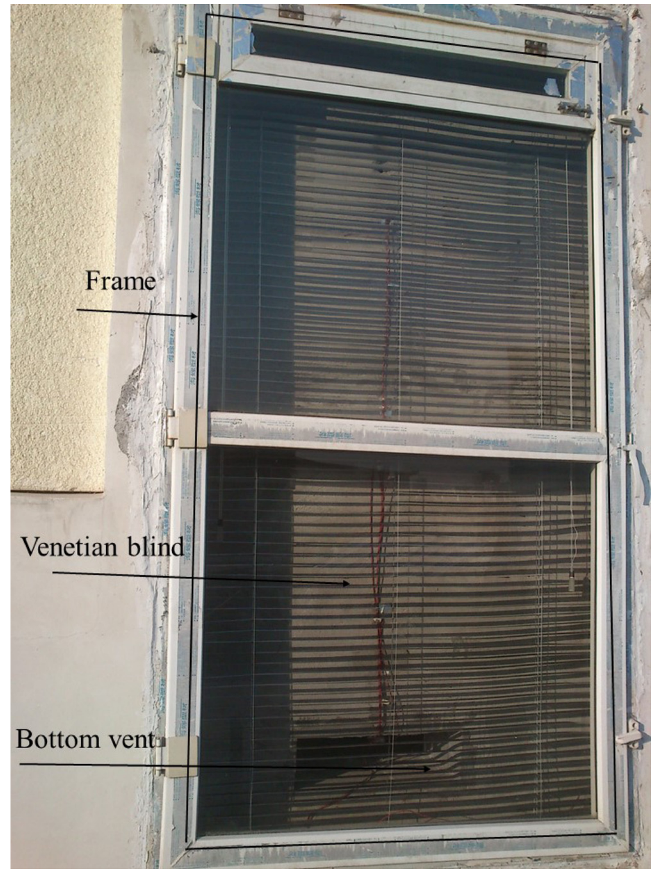

Fig. 2. Photograph of the prototype.

2. Experimental setup

A prototype system was constructed in Hefei, China. The photograph of the prototype is shown in Fig. 2. The area of the Trombe wall was 2.00 m high and 1.00 m width. Behind the glazing cover, an air duct of 0.14 m width was left, and the venetian blind was installed in the air duct between the glass and the internal wall. The slats were inclined at 0° from the horizontal. There were also two air vents (0.40 m width × 0.10 m height) on the internal wall for winter heating. They were located at 0.10 m away from the top of the Trombe wall and 0.1 m away from the bottom. The cold air entered into the cavity from the bottom air vent while the hot air leaves the cavity from the top air vent driven by the thermosyphonic effect.

Three important thermocouples were placed to measure the outdoor, Trombe wall bottom vent and top vent air temperature. A Pyranometer was kept to the same south-facing vertical surface position as the Trombe wall to measure the vertical solar radiation. A kanomax A533-type anemometer was used to measure and record air mass flow rate, the measurement accuracy is 0.01 m/s. The measured solar radiation, inlet and outlet temperatures measured on December 24, 2013 are shown in Fig. 3. The steady-state simulation conducted in this model used the average value of measured data from 12:15 to 12:30. The average outdoor temperature of 5.6 °C and the average indoor temperature of 11.7 °C were used as boundary condition. The corresponding average inlet temperature and solar radiation value were 11.7 °C and 454 W/m^2 respectively.

A parametric study was conducted to identify the influence of the structural parameters of the Trombe wall and the position of the blind in the air cavity. Table 1 gives the location of the venetian blind (distance between the glass and the blind), width of the air cavity between the glass and internal wall and the area of the inlet and outlet (bottom and top) air vents.