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Case study

Effect of the insulation materials filling on the thermal performance of sintered hollow bricks under the air-conditioning intermittent operation

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ABSTRACT

Wall insulation performance is an important factor affecting building energy consumption and indoor comfortable level. This study proposes that the insulation materials are filled into the cavities of the sintered hollow brick to replace the single insulation layer. The physical models of typical walls were built by the hollow bricks filled with expanding polystyrene board (EPS) in cavities and wall thermal performance is numerically analyzed by the Finite Volume Method under air-conditioning intermittent operation, which conforms to the actual operation rules of air-conditioning. Results show that filling EPS in cavities is beneficial to improve the thermal performance of the bricks, and the larger the EPS filling ratio, the higher the thermal performance improvement. The EPS filling ratio increase has the higher sensitivity on inner surface heat flow under the low EPS filling ratio, and filling EPS in the external cavities is optimum with the decrement rate 5.92% higher than filling EPS in internal cavities for the EPS filling ratio of 20%, while filling EPS in internal and external cavities simultaneously is optimum with decrement rate 2.45%–6.87% higher than that with filling EPS in the internal cavities for the EPS filling ratio of 40%–80%.

1. Introduction

Energy and environment are two major challenges faced by the mankind. Building energy consumption accounts for more than 30% of the social energy consumption [1] and becomes the largest terminal part, so building energy conservation has a great significance on the energy crisis alleviation and the environment protection [2]. Due to the fact that the heat transfer loss in building envelopes account 60–80% of the building total heat transfer loss [3], it is of vital importance to create the high comfort level and decrease energy consumption by bettering the thermal performance of the building external envelopes [4,5]. However, for the common insulation wall with the angle insulation layer, the twice construction of the foundation wall and the insulation layer installation not only increases the construction cost but also delays the construction time [6,7]. To overcome this twice construction disadvantages, this study proposes insulation materials are filled into the air cavities of the sintered hollow brick to replace the single insulation layer.

The sintered hollow brick is always the core wall material in the construction material market of China and the core research of its thermal performance is concentrated on the layout and heat transfer of air cavities [8–12]. Antar and Baig [8,9] carried out the conjugate heat transfer analysis to calculate the heat transfer rate. And their results show that increasing the amount of cavities while

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keeping the block width constant decreases the heat loss significantly and that thermal radiation plays a considerable role in the heat transfer process of this application. Arendt et al. [13] proposed an optimized hole pattern and studied the effect of hollow ratio on the thermal parameters of hollow brick. And their consequences presented the optimum hole rate under this hole pattern was 45–65%. The indexes used in the evaluation were the time lag, the decrement factor, the equivalent thermal diffusivity and the equivalent thermal conductivity.

Meanwhile, many studies have also attempted to integrate the insulation materials with the cavities of the hollow bricks [14–18]. Hou et al. [15] researched the coupled heat and moisture transfer in hollow concrete block wall filled with compressed straw bricks experimentally and their research illustrated that filling the compressed straw bricks into hollow concrete block can hinder heat transfer and improve moisture buffering performance of multilayer wall. And Zukowski and Haese [16] researched the thermal properties of hollow brick unit filled with perlite insulation and their results showed that heat conductivity of this brick can be equal to 0.09 W/(m K), which revealed the high insulation property. The similar reseach of Topçua and Işkdaġ [17] showed the compressive strength decreases and heat conductivity resistance and shrinkage of perlite bricks increase as the replacement ratio of perlite increases. Al-Hadhrami and Ahmad [18] assessed thermal performance of nine types of clay brick and two types of concrete brick in use in Saudi Arabia and their results of the measured data showed the addition of insulation material increases the thermal resistance significantly either within the masonry brick mix to make the brick more lightweight or through filling insulation material into the holes of masonry bricks.

For the air-conditioning intermittent operation, Xu et al. [19] analyzed the effect of air-conditioning intermittent operation behaviors on building energy consumption in Hong Kong and their research shows that most respondents were willing to switch off lighting and small power equipment because they knew the energy saving in doing so, and that up to 11% of annual energy consumption of air-conditioning could be saved for the office. And Budaiwi and Abdou [20] research the HVAC system operational strategies for the reduced energy consumption in buildings with the intermittent occupancy in mosques and their results show that annual cooling energy can be reduced by up to 23% through employing the suitable HVAC operation strategy and 30% through the appropriate operational zoning. Cho and Zaheer-uddin [21] explored a predictive control strategy as a means of improving the energy efficiency of the intermittently heated radiant floor heating systems. However, research of Kim et al. [22] shows that the simple “on-off” intermittent control can obtain the higher energy-saving rate. Meanwhile, Fraisse et al. [23–25] analyzed the relationships among the required the pre-heating time, the thermal comfort level and the energy consumption under the intermittent heating system, and Hazyuk et al. [26,27] proposed the optimal temperature control of intermittently heated buildings using the model predictive control.

According to the above problems, the physical models of typical walls were built by the sintered bricks with the different insulation filling ratios and locations. The influence of the insulation filling is numerically researched on temperature and heat flow in the inner surface of walls with air-conditioning intermittent operation under the Chengdu climate conditions by the Finite Volume Method.

2. Physical model and governing equations

2.1. Dsecription of physical model

In order to obtain the best filling result of insulation materials in the sintered hollow bricks, the different ratios and locations of the insulation filling are considered. Fig. 1(*a*)–(*f*) shows the schematic diagram of the sintered bricks with the different insulation filling ratios and locations in this study and the insulation material is considered as expanding polystyrene board (EPS). As showed in Fig. 1(*a*)–(*f*), the EPS filling ratio increases from 0 to 100%, while the insulation filling location moves from internal cavities to external ones. Meanwhile, to reflect the wall thermal performance improvement due to the filling of EPS in the cavities of bricks, the typical wall is built by the sintered hollow bricks shown in Fig. 1(*a*)–(*f*). Fig. 1(*g*) shows the wall section built by the sintered hollow brick. Table 1 shows the thermophysical properties of wall materials referred in this study.

2.2. Thermal boundary conditions

To research the influence of EPS filled in the sintered hollow bricks on the thermal performance of walls under air-conditioning intermittent operation, air-conditioning runs at 8:00–12:00 and 14:00–18:00 according to the working rules in offices. Fig. 2(a) and (b) shows the indoor picture and the size of the experimental room. The typical outdoor thermal environment in Chengdu is measured as shown in Fig. 2(c), while indoor air temperature is measured in the same day under the air-conditioning intermittent operation in Fig. 2(d). In addition, outside and inside convective heat transfer coefficients are 19W/(m^2 K) and 8.7W/(m^2 K) respectively, and the solar radiation absorptivity is 0.457 for outer surface.

2.3. Description of the governing equations

Based on the walls shown in Fig. 1(*g*), the wall dynamic heat transfer model is considered. Due to the fact that wall heat transfer can be ignored along the height direction, the building wall is assumed as two-dimensional for the simplicity. Meanwhile, the assumption has been done in the numerical simulation as following: (1) Air filled in the cavity is Newtonian and incompressible; (2) The flow is laminar in the cavity; (3) Thermophysical properties are constant except for the density in the buoyancy force;

With the foregoing assumptions, the continuity, momentum, and energy equations for laminar and transient natural convection in