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Effect of the insulation materials filling on the thermal performance of sintered hollow bricks

Jing Li[a], Xi Meng[a], Yanna Gao[a,*], Wei Mao[b], Tao Luo[b,c], Lili Zhang[a]

[a] College of Architecture and Urban-Rural Planning, Sichuan Agricultural University, No. 288, Jianshe Road, Dujiangyan, Chengdu, Sichuan Province 610065, PR China

[b] Biogas Institute of Ministry of Agriculture, Chengdu 610041, PR China

[c] College of Architecture and Environment, Sichuan University, Chengdu 610065, PR China

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ABSTRACT

Wall insulation performance is an important factor affecting building energy consumption and indoor comfortable level. The common method to improve the wall insulation performance is to integrate the insulation layer into the built foundation wall, but it increases the construction cost and also delays the construction time due to the twice construction of both the foundation wall and the insulation layer. This study proposes the insulation materials are filled into the cavities of the sintered hollow brick to replace the single insulation layer. To obtain the best filling effect of insulation materials, the typical walls constructed by the hollow brick filled with EPS in cavities are built and wall thermal performance is numerically analyzed. Results show inner surface heat flow is lowest with EPS materials filled into the external cavities of bricks, while inner surface temperature has the longest time lag and the lowest decrement factor with EPS filled into the internal and external cavities simultaneously. And with the increase of the EPS insulation filling ratio, the time lag is increased and the decrement factor is decreased for the inner surface temperature, while the inner surface heat flow is reduced obviously.

1. Introduction

Energy and environment are two major challenges faced by the mankind and building energy consumption accounts for more than 40% 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 accounts for 60–80% of the total loss [3], it is of the vital importance to create the high comfort level and decrease building energy consumption by bettering the thermal performance of the building external envelopes, especially the wall body [4,5]. Now the common method of the wall insulation performance improvement is to integrate the insulation layer into the built foundation wall at the external, the middle or the internal, and the wall energy conservation optimization with the angle insulation layer has been matured under the different climatic conditions and the detailed studies were reported by Kaynakli [6], Sadineni et al.[7] and Shekarchian et al. [8].

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 [9,10]. To overcome this twice construction disadvantages, this study attempts to propose that insulation materials are filled into the air cavities of the sintered hollow brick to replace the single insulation layer.

* Corresponding author.
E-mail address: gynhvac@163.com (Y. Gao).

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The sintered hollow brick is always the core wall materials 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 [11–19]. Antar and Baig [11,12] carried out the conjugate heat transfer analysis numerically to calculate the heat transfer rate under the consideration of conduction heat transfer in the brick material and both natural convection and radiation in the cavity. And their results show that increasing the amount of cavities while 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. And the numerical research of Sun and Fang [13] showed that increasing the enclosure numbers in the parallel direction becomes more favorable to decrease the equivalent thermal conductivity than that in the vertical direction of heat transfer.

In addition, research of Bouchair [14] proposes a theoretical model to study the steady state thermal behavior of fired clay hollow bricks for enhanced external wall thermal insulation. Li et al. [15] examined the 50 kinds of combination of holes and arrangements in the a multi-holed clay brick with the size of 240 mm × 115 mm × 90 mm and the configuration of L5W4H1 (5 holes in length, 4 holes in width and 1 hole in height) can be regarded as the optimum, which not only has the lowest equivalent thermal conductivity at the standard temperature difference, but also keeps its best isolation character insensitive to the temperature difference.

Moreover, Arendt et al.[16] proposed an optimized hole pattern and studied the effect of hollow ratio on the thermal parameters of hollow brick using two-dimensional energy equation. 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, reseach on the hollow block ventilated wall has also been paid the much attention to [17–19].

Meanwhile, many studies have also attempted to integrate the insulation materials with the cavities of the hollow bricks [20–25]. Zhang et al. [20] analyzed the influence of thermal conductivity and thermal capacity of block material, the equivalent thermal conductivity of the material inside holes and the configuration of hollow block on the thermal performance of hollow block wall with the consideration of the thermal resistance, the decrement factor, and the time lag as the evaluation indexes. Al-Hazmy [21] considered the heat transfer through a common hollow building brick. The insulation assessment of the building blocks was examined based upon the heat transfer rate. Three different configurations for building bricks were studied including a gas-filled and insulation-filled cavity. Results showed that cellular air motion inside bricks cavities contributes considerably to the heat loads. Insertion of polystyrene bars reduced the heat transfer rate by a maximum of 36%. If the varying temperature is considered, then the use of polystyrene may reduce the heat transfer rate by 25%.

Hou et al. [22] researched the coupled heat and moisture transfer in hollow concrete block wall filled with compressed straw bricks experimentally and their research illustrated that filling compressed straw bricks into hollow concrete block can hinder heat transfer and improve moisture buffering performance of multilayer wall. And Zukowski and Haese [23] 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 Işkdaģ [24] 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 [25] 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 that the addition of insulation material either within the masonry brick mix to make the brick more lightweight or through filling insulation material into the holes of masonry bricks increases the thermal resistance significantly.

Based on above review, although there is the contain research on the hollow bricks filled with insulation materials, it is still at an exploratory stage and most of them considered that all air cavities in the hollow bricks have been filled the insulation materials. In fact, the partial filling of insulation materials in the hollow bricks is more suitable in the engineering practice due to the difference of the wall insulation demand, the energy conservation demand, the brick cost and so on. Therefore, it is necessary to analyze the influence of the ratios and location of the insulation materials filled in the hollow bricks on thermal performance of the sintered hollow bricks.

2. Physical model and governing equations

2.1. Dscription of physical model

In order to optimize the filling effect of insulation materials in the sintered hollow bricks, the different ratios and locations of the insulation filling are considered. Fig. 1 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 EPS (Expanding Polystyrene Board). As showed in Fig. 1, the insulation 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 integration of EPS in the cavities of bricks, the typical wall is built by the sintered hollow bricks shown in Fig. 1. Fig. 2 shown the wall section built by the sintered hollow brick. Table 1 shows the thermal physical properties of wall materials referred in this study.

2.2. Dscription of the governing equations

Based on the walls shown in the Fig. 2, the wall dynamic heat transfer model is considered. And building walls are always three-dimensional, but their heat transfer can be ignored along the height direction, so the building wall is assumed as two-dimensional for