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Modeling the Thermal Behavior of Egyptian Perforated Masonry Red Brick Filled with Material of Low Thermal Conductivity

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ABSTRACT

Frequently, there is an international call for energy savings in all aspects of life due to the annoying continuous increase in energy consumption. One of the highly energy consumption sectors in a community is the residential sector. In summer, a significant amount of heat is usually gained through building's envelope due to the used type of construction materials. In Egypt, a perforated red brick with different configurations is commonly used in building constructions. In the present study, the thermal analysis of an Egyptian perforated masonry red brick filled with material of low thermal conductivity is carried out numerically. A finite volume model was developed and a FORTRAN computer program that uses the line-by-line over relaxation method was built to predict the temperature distribution and heat transmission through a wall mounted of this type of brick. A grid-independent solution was proved. The results quantitatively showed that increasing brick thermal resistance results in a lower wall inner surface temperature, and accordingly this reduces the amount of heat convected to the indoor space. Filling the holes with polyurethane foam or cork showed a reduction in the heat transmitted through the brick due to a decrease in the equivalent thermal conductivity by almost 45%, and accordingly an increase in the thermal resistance.

1. Introduction

Increasing the energy consumption in any country is a crisis that importantly requires the integration of efforts in over all sectors to save energy. The electrical energy consumption in buildings' lighting, ventilating, and air conditioning is a major problem. According to Fig. 1, the residential sector almost consumes 50% of electrical energy [1]. The way the residential buildings are constructed and oriented plays a major role in increasing or decreasing this energy consumption. The properties of the construction are of great importance since they enclose the buildings and form its envelope. The masonry brick is usually used in the building construction in Egypt. Brick properties contribute to the transmitted load and accordingly determine the building interior thermal comfort. Therefore; it is necessary to have an appropriate understanding of the thermal performance of brick behavior to propose modifications to minimize the transmitted thermal load.

ASHRAE [2] reported that thermal insulation in building envelopes conserves energy by reducing heat loss or gain of the building in addition of reducing temperature fluctuation s in unconditioned or partly conditioned spaces. Diaz et al. [3] carried out a non-linear complex heat transfer analysis of light concrete hollow brick walls. The non-linearity is due to the radiation boundary condition inside the inner holes of the bricks. The authors took into consideration conduction and convection phenomena for three different values of the conductivity mortar and two values for the brick. Finally, the numerical and experimental results were compared and a good agreement was shown.

Al-Hazmy [4] studied the coupled convective and conduction heat transport mode in a common hollow building brick to assess suitable brick insulation configuration. Three different configurations for building bricks were considered: a typical brick of three identical hollow cells (air cavities), cells were filled with ordinary polystyrene bars and finally hollow polystyrene bars were used. A computational model, using fluent software, showed that the cellular air motion inside blocks' cavities contributes significantly to the heat loads. Insertion of polystyrene bars reduced the heat rate by a maximum of 36%. Using a hollow polystyrene bars reduces the heat rate by 6% only due to the air motion inside cells.

Conjugate heat transfer across a hollow block was numerically investigated by Antar and Baig [5]. The authors reported that increasing the number of cavities while keeping the block width constant decreases the heat loss significantly. Further, a maximum number of six cavities are recommended and hence; no insulation would be needed to fill the cavities as a result of the reduced effect of natural convection.

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Nomenclature

A, a	Area, m^2, coefficients in Eq.[4]
h	convective heat transfer coefficient, W/(m^2 K)
k	Thermal conductivity, W/m K
L, ℓ	brick length, domain of interest length, m
q”	heat flux, W/m^2
S	source term with constant part, S_c, and slope, S_P
T	temperature, °C
W	brick width, m
x, y, z	local coordinate axes

Greek letters

δ	diffusion length, m
Δ	geometric length, m

Subscripts

e, E	east interface, east node
o	outside
nb	neighbors
n, N	north interface, north node
P	pole or central
r	room
s, S	south interface, south node
w, W	west interface, west node

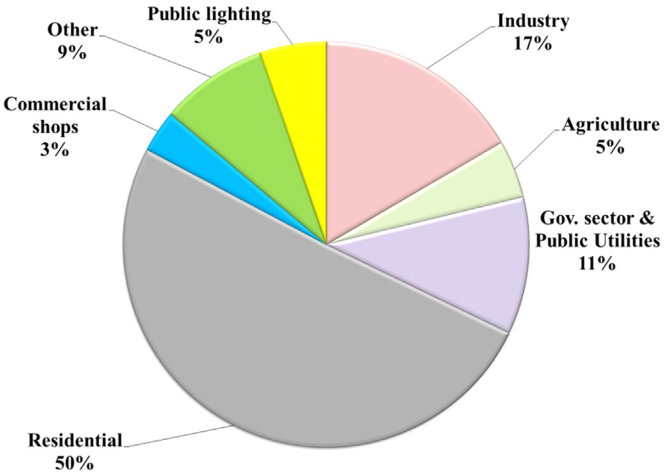

Fig. 1. Electrical energy distributed over purposes [1].

The thermal performance of nine types of clay bricks and two types of concrete blocks in Saudi Arabia was experimentally studied by Al-Hadhrami and Ahmad [6]. They reported that in general the addition of insulation increases the thermal resistance significantly. Moreover, the authors reported that from an economic point of view, the insulated clay brick showed the most effective as it has the lowest net present value.

Finding the optimum number and configuration of holes in hollow clay bricks (290 mm × 140 mm × 90 mm) was carried out by Li et al. [7] using the finite volume method. They mentioned that the optimum configuration has eight holes in length, four holes in width and one hole in height, whose equivalent thermal conductivity is the lowest (0.4 W/(m K)). They added that a temperature difference ranges from 50 °C to 20 °C between outdoor and indoor does not significantly affect the equivalent thermal conductivity for this configuration. In another study on multi-holed clay bricks, Li et al. [8] shows similar results as in [7]. They further concluded that depending on the relative importance of natural convection, surface radiation and heat conduction through the clay solid, the obtained equivalent thermal conductivity (0.419 W/(m K)) may decrease or increase with the hole number.

Svoboda and Kubrs [9] studied computationally the heat transfer in vertical cavities with small cross-sectional areas in hollow bricks heated from below to predict a ratio between the equivalent thermal conductivities in vertical and horizontal directions. The results showed that this ratio is smaller than 1.0 for downward heat flow and is between 1.0 and 1.5 for upward heat flow in bricks with a small number of large cavities. By contrast, bricks with a large number of small cavities showed almost the same ratio for both vertical directions of heat flow (from 2.2 to 2.7) depending on the holes structure.

A numerical analysis of vertically perforated bricks was carried out by Lacarriére et al. [10]. They reported that the vertically perforated bricks offered better mechanical properties than the horizontally perforated ones. In addition, walls can be constructed without any other materials than clay and mortar. They studied convection in ruptures and reported that it is a local phenomenon preferable to the thermal bridges caused by continuous mortar joints.

Lorente et al. [11] studied and developed an analytical model for heat transfer through a type of bricks full of large vertical cavities. They proved that heat exchange is two-dimensional. Finally, the authors extend their model to a whole hollow brick with lined-up cavities to calculate heat flux and thermal resistance. In another study, Lorente et al. [12] determined the thermal resistance of a wall built with vertical hollow bricks with different shapes under different boundary conditions. The authors tried to determine the most performing outline from a thermal point of view.

Zukowski and Haese [13] focused on the investigation of the effective thermal properties of a modern vertically perforated masonry unit filled with perlite insulation. The authors concluded that modern hollow bricks filled with perlite characterizes high thermal resistance and can be applied without any additional insulation layer.

The influence of cavity concentration in hollow bricks on static and dynamic thermal parameters was studied by Arendt et al. [14]. A semi-analytical method was proposed to enable calculations of thermal parameters of hollow bricks. They reported that hollow bricks made from materials with relatively high thermal conductivity required a cavity concentration of 45–65% which was impossible to obtain technologically.

Morales et al. [15] aimed to improve geometrical distributions of bricks in a wall to improve wall thermal conductivity. The authors concluded that with nonrectangular voids, the heat flux has to cross a higher number of voids, which improves its thermal properties. They also added that if the internal perforations are extended to the end of the tongue and groove, the direct thermal bridge in this type of brick is broken.

2. Problem formulation

In Egypt, masonry bricks with different configurations, Fig. 2a, are used in building construction. The red brick with circular holes aligned either in-line or staggered pattern along the brick length is commonly used. In summer, this type of brick transmits heat absorbed over a period of time to the occupied space. This increases