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Improving the thermal performance of red clay holed bricks

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ABSTRACT

A numerical study is conducted to improve the thermal performance of red clay holed bricks, considering protuberances to inhibit natural convection and radiation heat transfer inside the brick holes. Protuberances are made of the same red clay and have the same thickness as the remaining elements of the bricks, the best solution leading to the lowest overall heat transfer rate with shorter protuberances. Protuberances increase conduction heat transfer but decrease natural convection and radiation heat transfer, and a minimum overall heat transfer exists. Protuberances allow an overall heat transfer reduction which increases as increases the Rayleigh number. For fixed solid material (red clay) and fluid (air), the Rayleigh number depends mainly on the temperature difference between the opposite faces of the brick. For increasing temperature differences, when the thermal performance of the buildings' walls is more important, protuberances increasingly improve the thermal performance of the bricks, giving to the bricks a smart character. Relevant information is obtained, helping holed bricks makers to obtain better bricks for energy savings and energy consumption reductions in buildings, the obtained results leading to overall heat transfer reductions up to 23%. Some comparisons are made with experimental results for common and commercially available red clay holed bricks without protuberances.

1. Introduction

Red clay holed bricks are common elements in constructions, domestic or other, being mainly used to construct the buildings' walls. Walls with high heat transfer surface areas exist, through which considerable heat gains or losses occur, even for low overall temperature differences between their vertical opposite faces. Between the many types of red clay holed bricks, the 11 cm width bricks (Fig. 1a) and the 15 cm width bricks (Fig. 1b) are the most largely used in Portugal. Heat transfer through the holed bricks occurs mainly by conduction in the solid clay material, by natural convection in the air filling the brick holes, and by radiation between the internal surfaces of the holes. Relevance of radiation heat transfer increases as decreases the relevance of the natural convection heat transfer, that is, as decreases the overall temperature difference between the vertical opposite faces of the bricks.

Some complex internal structures of the bricks can be made, leading for example to the *thermal* brick in Fig. 1c, which includes much more solid material than the usual holed bricks, thus promoting heat conduction, retaining that the thermal conductivity of dry red clay is considerably higher than the thermal conductivity of the dry air. This increased heat conducting effect can be attenuated geometrically, through discontinuities of the solid elements in the main (horizontal) direction of heat transfer. Additionally, due to the complex and dense internal forms of such bricks, they are considerably heavy, expensive, and the involved processes to obtain them are relatively more complicated and expensive. So, some few and small protuberances attached to the horizontal internal walls of the holes, can be considered in the red clay holed bricks with holes disposed in the horizontal direction, decreasing natural convection and acting as radiation shields without considerably increasing conduction heat transfer. Such protuberances lead to a better overall thermal performance of the holed bricks, without considerably increasing their weight, cost and fabrication complexity. Considered protuberances are part of the holed bricks made of red clay, the bricks being obtained through the same processes as for the usual holed bricks.

Some recent studies can be found concerning the study of heat transfer through holed bricks. Work by Li et al. [1] is devoted to the numerical study and optimization of the heat transfer process in holed bricks, which are assembled in a wall such that the holes develop along the vertical direction. Li et al. [2] considered a similar situation as in [1], now using 3D simulations and a particular overall dimension for the bricks arrangement in the wall. In the work by Svoboda and Kubrs [3] are numerically studied bricks with very dense and complex internal structures, similar or even more complex and dense than that of the brick in Fig. 1c, the holes developing also along the vertical direction. In practice, use of bricks with holes in the vertical direction requires special care to avoid filling of the holes with mortar during the walls' construction process. Filling

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Nomenclature

e	thickness
F	view factor
g	gravitational acceleration
H	height (and width) of the enclosure
H	length of the protuberances
J	radiosity
k	thermal conductivity
L	distance (placement of the protuberances)
n	normal coordinate (at solid–fluid interface)
n	number of holes in a given direction
N	number of radiation surfaces of each hole
Nu	overall Nusselt number
p	pressure
Pr	Prandtl number
Ra	Rayleigh number
R_t	thermal resistance
$\dot{Q}''$	heat flux
R_k	solid to fluid thermal conductivity ratio
T	temperature
u,v	Cartesian velocity components
$x,y,$	Cartesian coordinates

Greek symbols

α	thermal diffusivity
β	volumetric expansion coefficient
Δ	difference (of temperature)
ε	emissivity
ν	kinematic viscosity
ρ	density
σ	Stefan–Boltzmann constant
ψ	streamfunction

Subscripts

a	air
c	cold (lower temperature value)
f	fluid
h	hot (higher temperature value)
i,j	surfaces i and j, for radiation heat transfer
min	minimum
rad	radiation
s	solid
t	total
1	protuberances' location and length
1	referring the basic module with one hole
*	dimensionless

of the holes with mortar results on an unwanted decrease of the overall thermal resistance of the bricks, and thus also of the walls. All the previously referred works by Li et al. [1,2], and Svoboda and Kubrs [3] consider radiation heat transfer between the internal surfaces of the bricks' holes. Al-Hadhrami and Ahmad [4] conducted a study concerning the thermal performance of some types of holed bricks and blocks used in Saudi Arabia. In [5], Alhazmy numerically studied the use of inclined partitions inside the holes of the bricks to partially inhibit natural convection, the holes developing along the horizontal direction similarly to the here considered bricks. Alhazmy [6] also numerically studied the influence of two fins in a special holed brick, with three holes along the vertical direction and only one hole in the horizontal direction. One fin is attached to the lower surface of the hole and the other fin is attached to the upper surface of the hole, like in Fig. 2c, the fins' thickness being considerably smaller than those of the remaining solid elements of the brick. Conduction, convection and radiation heat transfer are considered in this study, even if the main part of the paper deals with only the conduction and convection heat transfer effects. However, to the author's best knowledge no relevant studies were found concerning the evaluation of the thermal behavior of the here considered holed bricks, and especially their thermal performance improvement considering internal protuberances attached to the upper or lower walls of the holes.

Problem under analysis is a conjugate heat transfer problem, conduction heat transfer occurring over the solid parts of the bricks, natural convection heat transfer occurring in the air filling the holes, and radiation heat transfer occurring between the internal surfaces of the holes, heat transfer occurring also at the interfaces between the solid and fluid domains.

In what concerns natural convection heat transfer in enclosures, many studies can be found in the literature, as for example in Bejan [7] and in the references therein, and even in parallelogrammic enclosures [8]. Some studies can also be found concerning conjugate heat transfer problems, including conduction heat transfer in a solid part of the domain and convection heat transfer in the adjacent fluid part of the domain, as for example in [9–16], where sometimes the solid part is a partition inside the enclosure for natural convection heat transfer inhibition and control [16]. Recent related examples of numerical works considering radiation heat transfer in enclosures are the works by Li et al. [1,2], and Svoboda and Kubrs [3], and Sun et al. [17].

2. Physical modeling

2.1. Model assumptions and equations

The overall behavior of a wall is the behavior of an assembly of holed bricks, the thermal behavior of each brick being mainly conditioned by the thermal behavior of each individual module that can be identified in it, given the special periodicity existing in each brick. Thus, the present study is conducted considering firstly a hole of the brick, including its solid walls and the here proposed protuberance. This is the basic module from which relevant conclusions can be extrapolated for the overall and complete brick, and then for the walls made of holed bricks.

The basic module considered is presented in Fig. 2a, a square domain of overall side length $H = 0.056$ m, which includes the walls of the hole with thickness $e = 0.008$ m, and the air filling the hole, the basic hole being an air filled $0.04 \times 0.04\,m^2$ square enclosure. Different arrangements of the protuberances can be considered, always with the same thickness as the internal and external walls of the brick, $e = 0.008$ m, as presented in Fig. 2. However, preliminary studies indicate that significant improvements can be obtained considering only one protuberance, as in Figs. 2a and b, and that no significant differences exist considering the protuberance attached to the lower or to the upper wall of the enclosure. This is one advantage, as no care is needed when positioning the brick in a wall during its construction.

When a single protuberance is considered, different thermal performances can be expected depending if the protuberance is attached to the lower wall or to the upper wall of the hole, as presented in Figs. 1a and b, respectively. However, no significant differences were observed from the preliminary studies. When two protuberances are considered, different thermal performances are expected depending on the protuberances arrangement relative to the thermal boundary conditions prescribed at the vertical end walls [16], thus justifying the consideration of the situations presented in Fig. 1c and d. However, no significant improvements were observed when comparing with the improvements obtained with a single protuberance, the enclosure with a single protuberance