

# Comparative study of thermal performance indicators of five hollow bricks configurations

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**Abstract.** In every country on the globe, there are still actions to perform in order to improve buildings' energy efficiency, particularly in regions with severe weather conditions. Since walls are heat-dissipating elements in the building, designing them effectively can help reduce the energy consumption of the HVAC (heating, ventilation, and air-conditioning) systems, which are notorious for using excessive amounts of energy. The use of self-insulating construction materials with relatively high thermal resistance and low transmittance is the most effective approach to achieve universal thermal insulation in all buildings. In order to enhance the thermal performance of red clay bricks, the present study evaluates several design approaches. Five configurations are assessed, namely the case of conventional bricks, the use of aluminum shields, low thermal emissivity coating, extruded polystyrene and air cavity partitioning. Finite element method based analysis in steady-state and transient conditions enabled the assessment of the effects of each technique and their classification according to thermal performance level.

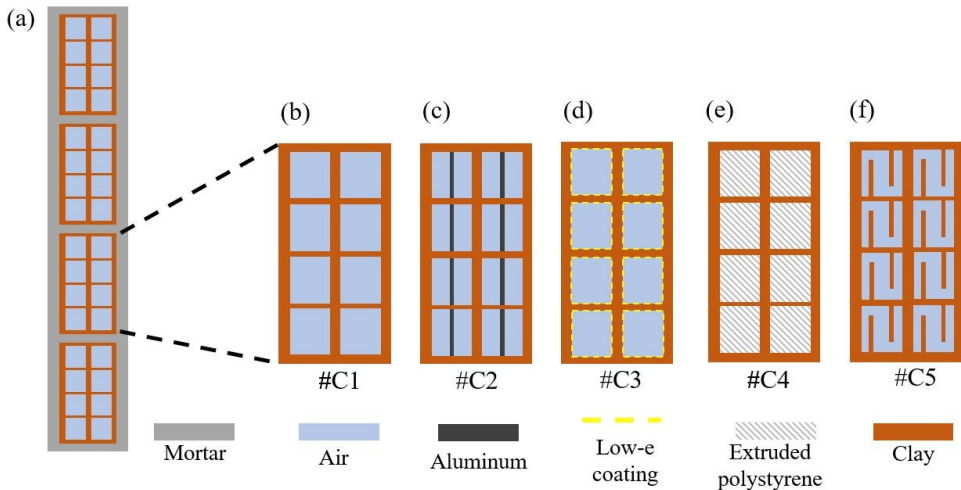
## 1 Introduction

Since hollow clay bricks are inexpensive, lightweight, and have a body made of material that provides superior thermal inertia, they are the most widely used units in construction sector. In order to convert bricks self-insulating materials and avoid the requirement for traditional thermal insulation of walls from the inside or outside, research interest has recently focused on upgrading hollow bricks' thermal performance which is problematic since they house the three modes of heat transfer: conduction, convection and radiation [1]. The raw material's mineral composition has a significant correlation with conduction in the solid sections of bricks [2]. Many research investigations have addressed increasing the thermal conductivity of building material bodies by enhancing clay's insulating capacity through waste recycling and incorporating these products into its microstructure [3]. Numerous studies have examined the convection of air in enclosures exposed to temperature differentials [4-6]. This mechanism accounts for 17.59% of the total flux conveyed by a clay brick wall with a thermal

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conductivity of 0.6 W/m.K when exposed to a 20°C temperature difference [7]. Creating obstacles to obstruct air flow has been an effective technique to attenuate or inhibit convection in confined spaces [8, 9]. As thermal radiation is a correlated heat transfer mode to convection in enclosures, it is the third transfer mechanism that occurs in bricks, notably at the inner surfaces of cavities [10, 11]. Reflective or low thermal emissivity materials are typically employed inside the cavities as coverings to attenuate the radiation. For instance, a clay block with a thermal conductivity of 0.9W/m.K would have its equivalent thermal conductivity reduced by 64% with an emissivity of 0.1 [12]. Thermal resistance is affected by the insulating materials filled into brick cavities, according to several studies in the literature that have examined coupled heat transfer in bricks [13, 14]. Thermal resistance can increase by 88.64% [15] and the heat exchange rate can be decreased by 36% [13] by inserting polystyrene bars into the cavities. According to earlier study, the design of self-insulating bricks is dependent on a range of factors, including the environmental conditions, the geographical location, etc. In the literature, comparative analyses of hollow brick insulating techniques are rare. A comparison of the effects of cavity filling with insulation, aluminum shielding, low-thermal-emissivity coating, and cavity airflow blockers is investigated in the present study.



**Fig. 1.** Schematic of the studied configurations. (a) Basic structure: Wall made of 4 bricks with mortar joints (b) Conventional brick (c) Brick with aluminum shield (d) Brick with low-e coating (e) Brick with cavity filled in extruded polystyrene (f) Brick with clay air-movement blockers.

## 2 Materials and method

### 2.1 Numerical model

Finite element analysis is used to evaluate thermal performance indicators for a wall composed of four bricks spaced apart by a 1 cm mortar joint. Five different brick configurations are investigated as shown in Figure 1. The brick measures 10 cm in width and 26 cm in height. It includes eight holes, two on the line and four on the column, each measuring 3.5 cm in width and 5 cm in height. A typical brick without any thermal insulation is used in the first configuration (C1). The second configuration (C2) is a brick that has a radiation barrier made of 2 mm aluminum placed in the middle of the cavities. The brick in the third configuration (C3) has an inner surface coating with 0.5 emissivity applied to its

cavities inner surfaces. Extruded polystyrene insulation is inserted into the air pores of the brick in the fourth configuration (C4). The brick with clay air displacement blockers separating the air cell into three smaller cells is the fifth configuration (C5). The materials' thermophysical properties are listed in Table 1.

**Table 1.** Thermophysical properties of materials.

Material	Thermal conductivity (W/m.K)	Heat capacity (J/kg.K)	Density (kg/m <sup>3</sup> )
Red clay	0.54	775	1810
Mortar	0.613	1701	1650
Aluminum	237	903	2702
Extruded polystyrene	0.027	1210	55

Building standards in Morocco set the comfort temperature for summer at 26°C because the typical summertime temperature fluctuates, in average, between 25°C and 45°C during a 24-hour period. Therefore, in the steady-state study the left and right ends of the wall are isothermally heated to temperatures  $T_h= 45^\circ\text{C}$  and  $T_c=26^\circ\text{C}$ , respectively. The thermal performance of the bricks is evaluated under a temperature differential of  $\Delta T=19^\circ\text{C}$ . The upper and lower limits of the wall are perfectly insulated. There is no slip,  $u=0$  and  $v=0$ , at the level of the solid walls confining the cavity's air that is considered as a laminar, Newtonian, incompressible, dilatant and transparent fluid so does not participate in the radiation. The interior surfaces of the cavity are diffuse, gray and of the same emissivity. The materials' thermophysical properties are constant, with the exception of the air's density, which varies with temperature and is determined by the Boussinesq approximation. The conservation of thermal energy equation does not take into account the energy contributions due to viscous dissipation and temperature change owing to reversible deformation. Two dimensional heat equation is used to determine the temperature in the solid domains and given as follows:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \tag{1}$$

The following equations represent mass, momentum, and energy conservation in fluid regions:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \nabla^2 u \tag{3}$$

$$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \nabla^2 v + g\beta(T-T_0) \tag{4}$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k_a}{\rho_a c_{p,a}} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \tag{5}$$

The radiative heat flux received by each surface  $i$  of the four inner cavity surfaces is given by the classical radiosity model and can be expressed as follows:

$$q_i = G_i - J_i \tag{6}$$

Where  $G_i$  is the incident radiative flux on the surface  $i$  and  $J_i = (1-\epsilon)G_i + \epsilon\sigma T_i^4$  is its radiosity.

The equivalent thermal resistance of the wall is calculated as follows:

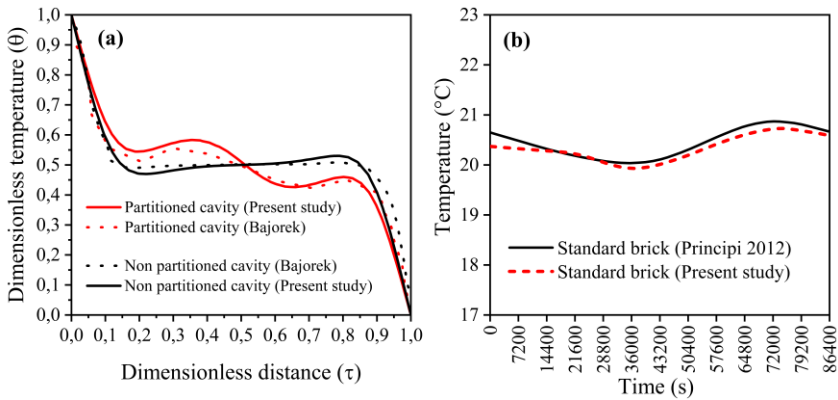
$$R = \frac{\Delta T}{Q} = \frac{T_h - T_c}{Q} \tag{7}$$

Where  $Q$  in the total heat flux received at the inner surface.

The relative change in the equivalent thermal resistance of the wall is computed as follows:

$$\Delta R (\%) = \frac{R - R_1}{R_1} \times 100 \tag{8}$$

Where  $R_1$  is the equivalent thermal resistance of the conventional brick wall (C1).



**Fig. 2.** Comparison with results obtained in literature.

### 2.2 Model validation

The experimental data of Bajorek and Lloyd [8] on natural convection in a partitioned and non-partitioned enclosures were compared to the computational model put out in this study to validate it. In the latter study, Mach-Zendher interferometer is used to extract the fluid's velocity inside a unity aspect ratio vertical cavity. Convective heat transfer is started by subjecting the two vertical edges of a vertical chamber to differing uniform temperatures. In adiabatic conditions, the two horizontal edges are involved. Monitoring the temperature of the transverse plane of cavity allows for a comparison of numerical results to experimental data. Figure 2 (a) depicts the changes in the dimensionless temperature as a function of the dimensionless coordinate for non-partitioned and partitioned cavity. The findings of the present study exhibited strong agreement with the outcomes of the experimental results of Bajorek and Lloyd. The results of Principi's study [12] were compared in order to evaluate the accuracy of the finite element approach for heat transfer in multi-hole bricks. The two outcomes, which are displayed in Figure 2 (b), accord fairly well.

### 3 Results and discussion

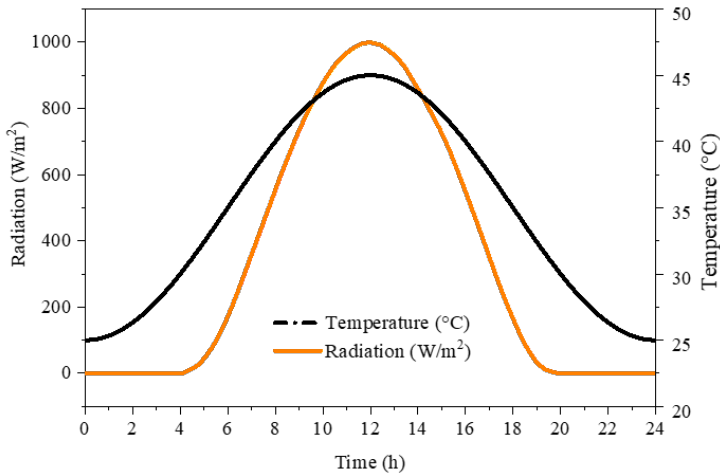
In this section, the effects of different techniques on improving the thermal performance of hollow bricks are analyzed and compared under steady-state conditions to calculate thermal resistance, and under transient conditions over a 24-hour period to study the temporal response of all configurations.

**Table 2.** Variation in equivalent thermal resistance of the brick wall with different configurations relative to conventional brick wall configuration (C1) .

Configuration	C1	C2	C3	C4	C5
Equivalent thermal resistance (K.m <sup>2</sup> /W)	0.509	0.631	0.597	0.764	0.771
Improvement with reference to C1 (%)	-	23.96	17.28	50.09	51.47

### 3.1 Steady state evaluation of thermal resistance enhancement umbering

For each of the five brick configurations, the equivalent thermal resistance is computed in this phase, assuming a 19°C temperature differential between the opposing brick surfaces. The resistance values are displayed in Table 2 along with the percentage improvement in resistance when compared to the reference configuration C1, which is a conventional brick. For a wall consisting of 4 bricks joined by a mortar joint, the thermal resistance is 0.509 K.m<sup>2</sup>/W. For the remaining four configurations (C2 to C5), an improvement in equivalent resistance is observed. By applying a 2mm-thick aluminum shield to the center of the cavities, thermal resistance improves by 23.96% to a value of 0.631 K.m<sup>2</sup>/W due to the mirror-like role radiant shield plays inside the brick, such that it reflects heat coming from the outside and reduces the rate of thermal energy that can reach the inner surface of the brick.



**Fig. 3.** Hourly variations of solar radiation and external ambient temperature.

The low-thermal-emissivity 0.5 coating applied in the C3 configuration improves thermal performance by 17.28%, such that thermal resistance reaches 0.597 K.m<sup>2</sup>/W thanks to the reduction in the rate of radiant energy through radiative heat transfer within the brick. In Principi's research [12], for cavities with dimensions analogous to those examined in the current study, a 0.5 emissivity coating applied to the inner surfaces of the cavities resulted in a 19.35% reduction in thermal transmission. Filling cavities with insulating materials remains a widespread technique, as long as the density of the brick increases and air movement

correlated with convective heat transfer is inhibited. The C4 configuration representing this option improves the equivalent resistance of the wall by 50.09%, with a value of 0.764 K.m<sup>2</sup>/W. In the C5 configuration, using air movement blockers in the same material as the brick body, the wall achieves optimum performance, with an improvement of 51.47% at a resistance of 0.771 K.m<sup>2</sup>/W. As reported in Alhazmy's study [16] on convection blockers in a square-cavity brick exposed to a temperature differential of 30K, baffles can increase thermal resistance by 53%. By blocking air movement in the cavities, the fluid transfers heat by conduction, replacing the convective mode. As a result, the insulating properties of the brick improve, since stagnant air is a very good insulator of heat.

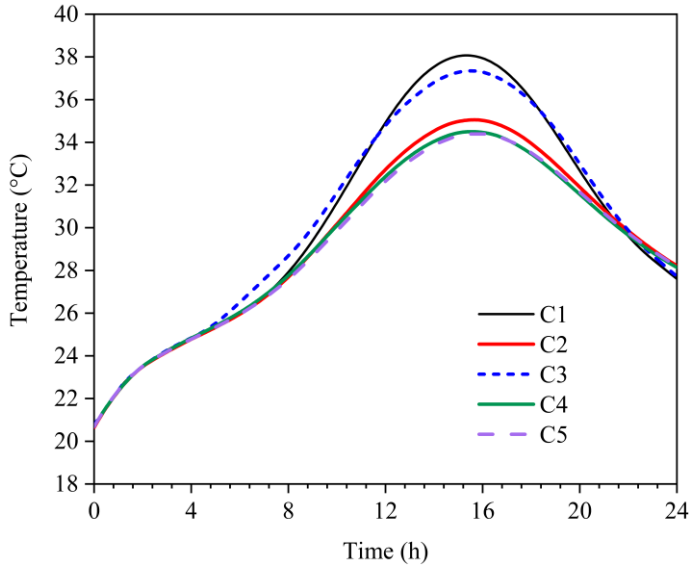


Fig. 4. Hourly variations of inner surface temperature.

### 3.2 Case study: one day simulation of thermal response

A transient study was carried out to analyze the thermal performance of the five brick configurations. The brick walls studied were exposed on the external surface to convective flow with a sinusoidal temperature ranging from 25°C to 45°C, a heat exchange coefficient of 20W/m<sup>2</sup>.K and solar irradiation from 0 to 1000W/m<sup>2</sup> over a 24-hour period. The inside surface of the wall is exposed to internal convection with a coefficient of 8W/m<sup>2</sup>.K and a comfort temperature of around 26°C. The ambient conditions to which the outer surface is subjected are shown in Figure 3. The temperature variation of the unexposed interior surface under external conditions of temperature and irradiation, as well as the heat flux received instantaneously, are predicted analytically and are shown in Figures 4 and 5 for the five configurations. The inner surface of the conventional brick wall reaches a maximum temperature of 38.07°C and heat flux of 96.57 W/m<sup>2</sup> at 15.33h. By inserting an aluminum shield in the center of the cavities in configuration (C2), the maximum temperature reached is 35.05°C and the heat flux 72.43W/m<sup>2</sup> at 15.66h. The third configuration (C3), with a low-emissivity coating, achieves a maximum temperature of 37.43°C and a heat flux of 90.78W/m<sup>2</sup> at 15.55h. For the fourth configuration (C4) with polystyrene blocks inserted inside the cavities, the maximum temperature reached is 34.49°C and the maximum flux received at the inner surface is 67.74W/m<sup>2</sup> at 15.61h. For the fifth configuration (C5) with

clay obstacles in the cavity, the maximum temperature and flux are 34.40°C and 67W/m<sup>2</sup>, respectively reached at 15.83h.

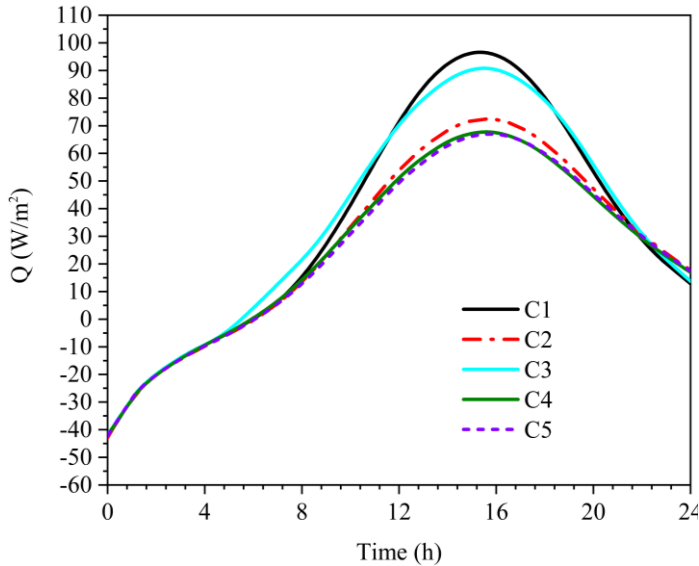


Fig. 5. Hourly variations of inner surface heat flux.

## 4 Conclusion

In order to categorize the performance levels of multiple techniques for enhancing the thermal performance of red clay hollow bricks, a two-dimensional investigation in both stationary and transient regimes is performed. For a temperature difference of 19°C between the outer and inner surfaces of walls based on five different brick configurations, the impact of partitions for air convection inhibition is remarkable and ranked first, giving a 51.47% improvement in thermal resistance. The substitution of air in cavities by extruded polystyrene comes second with an increase of 50.09% of thermal resistance. Positioning an aluminum shield to reflect radiation improves thermal resistance by 23.96%. Finally, the coating of cavity interior surfaces contributes to a 17.28% improvement in thermal resistance. When the structures are subjected to intense solar radiation and a sinusoidal input temperature, the configurations maintain the same ranking. When barriers are utilized to prevent air movement in the cavities, the heat flux and temperature received at the unexposed surface to external conditions are lowered by 30W/m<sup>2</sup> and 4°C during peak time, respectively.

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