NanoWorld Journal

https://doi.org/10.17756/nwj.2023-s2-050

Research Article

Open Access

Thermal Performance Optimization of Hollow Clay Bricks Subjected to Unsteady Conditions

Yassine Chihab[1,2*], Najma Laaroussi[1], Mohammed Garoum[1], Rachid Bouferra[2], Mohamed Benjelloun[2] and Abdeltif Bouchehma[3]

[1] *Mohammed V University in Rabat, Materials, Energy and Acoustics TEAM, EST Salé, Rabat, Morocco*

[2] *Georessources, Geoenvironement and Civil Engineering Laboratory (L3G). Cadi Ayyad University, Marrakech, Morocco*

[3] *Team of Applied Physics and New Technologies, Sultan Moulay Slimane University, Béni Mellal, Morocco*

[*]Correspondence to:
Yassine Chihab
Mohammed V University in Rabat,
Materials, Energy and Acoustics TEAM,
EST Salé, Rabat, Morocco.

Georessources, Geoenvironement and
Civil Engineering Laboratory (L3G).
Cadi Ayyad University, Marrakech, Morocco.
E-mail: yassinechihab@research.emi.ac.ma

Received: July 25, 2023
Accepted: September 26, 2023
Published: September 27, 2023

Citation: Chihab Y, Laaroussi N, Garoum M, Bouferra R, Benjelloun M, et al. 2023. Thermal Performance Optimization of Hollow Clay Bricks Subjected to Unsteady Conditions. *NanoWorld J* 9(S2): S295-S299.

Published by United Scientific Group

Abstract

The Moroccan construction industry accounts for almost 33% of overall energy consumption, showing that it is one of the most energy-intensive sectors. When it comes to the design of buildings in Morocco, the time lag and decrement factor of the walls are generally not taken into consideration, although they are among the aspects that impact energy consumption. For this purpose, this study analyzes the possible benefits of placing insulating materials into the holes of hollow clay bricks, frequently used in Moroccan construction, to increase their thermal inertia. The incompressible Navier-Stokes and energy equations were discretized by employing the finite element method. When all cavities are insulated, the temperature peak is prolonged by nearly 5.5 h, and the decrement factor is decreased by around 50% to a value smaller than 0.1. Moreover, according to the study, closing holes with insulating material reduces the overall thermal load by approximately 53.77%. All used materials are nanoscale materials.

Keywords

Expanded polystyrene filling ratio, Hollow clay bricks, Thermal inertia, Decrement factor, Time lag

Introduction

The presence of national policies in Morocco, which aim to enhance energy efficiency across all sectors, has led to a significant focus on reducing the energy demands of buildings by improving their envelope's thermal performance. One of the industries that use the most energy is the building and construction industry, which is responsible for roughly 33% of the overall energy consumption [1]. As a consequence of this, the major purpose of this numerical study is to ascertain whether or not it is possible to reduce energy consumption through the incorporation of passive methods into the alveolar structures of the building envelope.

The majority of structures in Morocco are constructed using either hollow clay bricks or concrete blocks as major structural components. In order to have a better knowledge of the thermal characteristics of these hollow blocks, a number of investigations [2-11] have been carried out. Hou et al. [2] made use of a computer model to simulate the conjugate heat transfer over hollow clay walls while taking into account time-dependent boundary constraints. This research was conducted with the intention of determining how the dynamic thermal behavior of hollow bricks is affected when EPS (Expanded polystyrene) is used to fill voids in those bricks. A higher percentage of EPS filled in cavities was shown to improve the heat resistance of hollow bricks. In order to determine whether or not different passive construction approaches may improve the total heat resistance of hollow-core concrete blocks, Sassine et al. [3] undertook a parametric analysis. Modifying the block's form, packing the voids with insulation, and employing a variety of solid concrete compositions were among the methods investigated. Coupling heat and moisture transmission in hollow brick walls was the subject of computer research by Fraine et al. [4], who used the finite element approach. According to the research results, the heat-storing capability of walls can be greatly improved by adding additional phase change material to their cavities. Through experimental and numerical investigations, Zukowski et al. [5] demonstrated that filling hollow bricks with perlite can lead to significant improvements in thermal resistance. As a result, these enhanced hollow bricks with perlite can be utilized for constructing walls without the requirement of an additional insulation layer, making them suitable for practical applications. Morales et al. [6] suggest that by modifying the geometrical distributions of hollow clay brick walls, their thermal efficiency can be improved. In their study, Li et al. [7] conducted a numerical investigation to examine the time lag and decrement factor of hollow clay walls. The main objective of their research was to evaluate the energy performance of insulating materials utilized in the filling of sintered hollow bricks, aiming to demonstrate their effectiveness.

In this light, the purpose of this research is to analyze the transient thermal performance of insulated hollow clay bricks. The exterior heat loads experienced by the examined hollow bricks are numerically simulated using climatic data from Marrakesh, Morocco.

Materials and Method

Physical model

In this work, we test the hypothesis that filling the cavities of hollow clay walls with EPS insulation at various ratios can increase their thermal inertia. Figure 1 depicts the physical model investigated in this study (See table 1).

The current study makes the following assumptions:

- The study assumes that the air present in the various cavities of the model is incompressible and Newtonian and possesses constant thermophysical properties, as presented in table 2.

Table 1: Geometrical parameters used for 2D-modeling.

Brick	12 holes (Type 1)	16 holes (Type 2)
Width of the brick L (mm)	149	194
Height of the brick H (mm)	200	200
Height of the cavity d (mm)	41	41
Width of the cavity b (mm)	39	39

Table 2: Thermophysical properties of the utilized materials.

Material name	Air	Clay	EPS
Density ρ(kg/m³)	1.161	1810	22
Heat capacity c_p(J/kg.K)	1007	775	1280
Thermal conductivity λ (W/m.K)	0.0263	0.54	0.041
Kinematic viscosity μ_f (kg/m.s)	1.846×10^{-5}	-	-
Volumetric expansion β_T (K^{-1})	0.00353	-	-

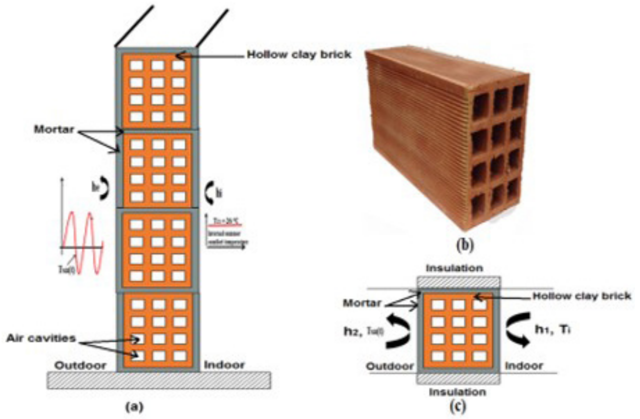

Figure 1: The physical model of the studied bricks.

- In this study, the Boussinesq formulation [12] is utilized to model the air density in the buoyancy term. This approximation is helpful in accounting for the variation of air density due to temperature changes.
- This study neglects viscous heat dissipation in the energy equation and only accounts for two-dimensional coupled heat transfer.

The equations below represent a 2D laminar flow model based on the aforementioned assumptions:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+\grave{u}.\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial P}{\partial x}+\quad {}_f\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$\frac{\partial v}{\partial t}+u.\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial P}{\partial y}+\mu_f\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\rho_f G\beta_T\left(T-T_0\right) \tag{3}$$

$$\frac{\partial T}{\partial t}+u.\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\lambda_f}{\rho_f c_f}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

The radiosity modeling used in this investigation finds the net radiative flux density inside the brick cavities. The formula used to derive this amount is as follows:

$$q_{r,i}\left(r_i\right)=B_i\left(r_i\right)-\sum_{\underbrace{j=1}_{j\neq i}}^{4}\int_{S_j}B_j\left(r_j\right)K(r_i,r_j)dS_j \quad ,i=1....4 \tag{5}$$

with

$$B_i\left(r_i\right)=\varepsilon_i\sigma T_i^4+\left(1-B\right)\sum_{\underbrace{j=1}_{j\neq i}}^{4}\int_{S_j}K(r_i,r_j)\,r_j\left(r_j\right)dS_j \tag{6}$$

$$K\left(r_i,r_j\right)=\frac{dF_{dSi-dSj}}{dSj} \tag{7}$$

In this research, the external thermal loads are characterized using the sol-air temperature technique Ts-a(t). An equation [9] can be used to indicate this technique:

$$T_{s-a}(t)=\frac{|T_{max}-T_{min}|}{2}\mathrm{Sin}\left(\frac{2\pi t}{P}-\frac{\pi}{2}\right)+\frac{|T_{max}-T_{min}|}{2}+T_{min} \tag{8}$$

To determine the sol-air temperature, temperature data from the warmest day in the Marrakesh region in 2020 is utilized. Specifically, the sol-air temperature is calculated using temperature variation data from August 26th, 2020.

$$T_{s-a}(t)=9.5\times \mathrm{Sin}\left(\frac{2\pi t}{86400}-\frac{\pi}{2}\right)+36.5 \tag{9}$$

In order to solve the incompressible Navier-Stokes and energy equations in the transient regime, the following boundary conditions must be satisfied:

- At the inner surfaces of the brick cavities, the no-slip velocity condition is applied, which assumes that the velocity of the fluid at the walls is zero.
- For x=0. This refers to the location of the exterior vertical wall in question, which is in contact with the external environment.

$$-\lambda\left.\frac{\partial T}{\partial y}\right|_{x=0}=h_2\left(T_{s-a}(t)-T\right)\qquad \forall y \tag{10}$$

- For x = L. This refers to the location of the interior vertical wall in question, which is in contact with the ambient air.

$$-\lambda\left.\frac{\partial T}{\partial y}\right|_{x=L}=h_1\left(T-T_i\right)\qquad \forall y \tag{11}$$

- There is no heat exchange between the brick and its surroundings through the horizontal surfaces.

$$\begin{cases}-\lambda\left.\dfrac{\partial T}{\partial y}\right|_{y=0}=0 & \forall x\\ -\lambda\left.\dfrac{\partial T}{\partial y}\right|_{y=H}=0 & \forall x\end{cases} \tag{12}$$

As significant indications of thermal inertia, the time lag and decrement factor reveal the behavior of hollow clay walls under reel thermal loads. The time lag and decrement factor, and interior surface temperature of hollow clay bricks are analyzed to perform their thermal efficiency.

Numerical validation

In this work, a physical problem was examined to verify the reliability of the numerical method used to explore coupled heat transport via conduction, convection, and radiation. This issue included the study of laminar natural convection flows in a square hole subject to uniform heating at its boundaries. To do this, Basak et al. [13] conducted a quantitative analysis of the corresponding mathematical model of the physical issue using the penalized finite element method employing bi-quadratic rectangular elements. With the help of COMSOL software, a Galerkin finite element solution is found for the physical model. Findings from the literature [13] are compared to the results obtained.

Dimensionless temperature distribution in the hole was compared qualitatively in figure 2. Figure 2 depicts a significant resemblance between the data we got from the literature [13] and our numerical simulation results. As a result, the study's numerical method is considered to be of adequate accuracy.

Results and Discussion

In figure 3, the variation of time lags with different EPS filling percentages is illustrated. It can be observed that for hollow brick walls of types 1 and 2, as the EPS filling ratio increases from 0 to 100%, the time lag also increases by approximately 59.3% and 60.69%, respectively. This indicates that the introduction of insulating material into the cavities slows down the transfer of the outer thermal load wave to the interior environment. Consequently, the interior of the building can be kept at a comfortable temperature for a longer time.

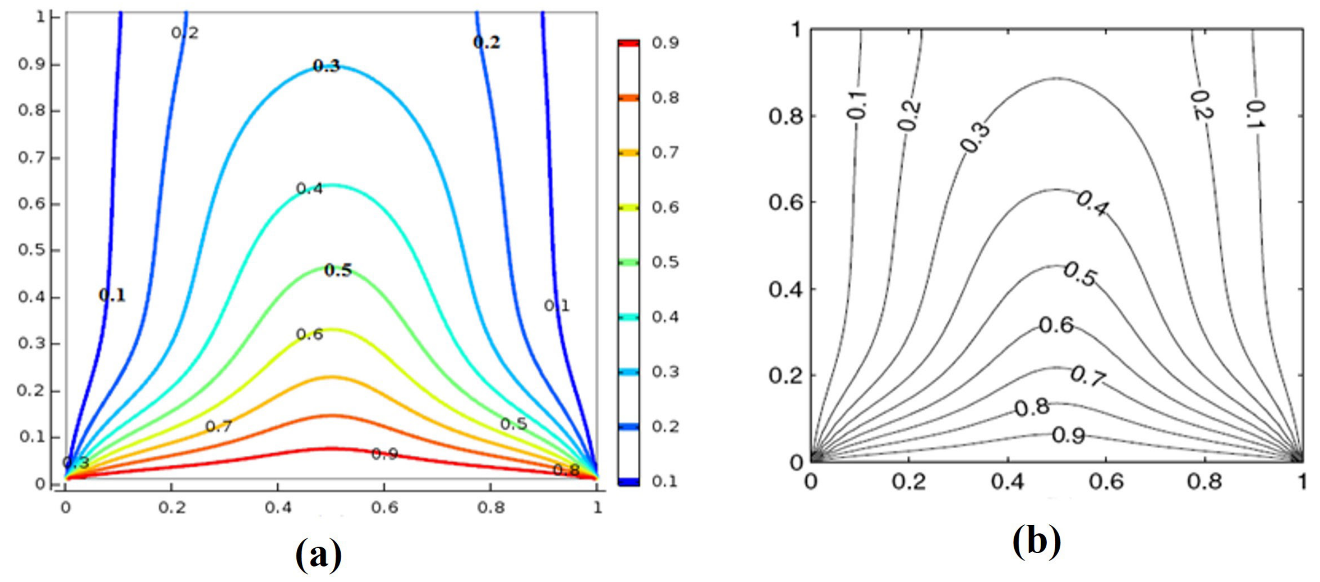

Figure 2: Dimensionless temperature distribution in the cavity: **(a)** present work and **(b)** the obtained results in [13].

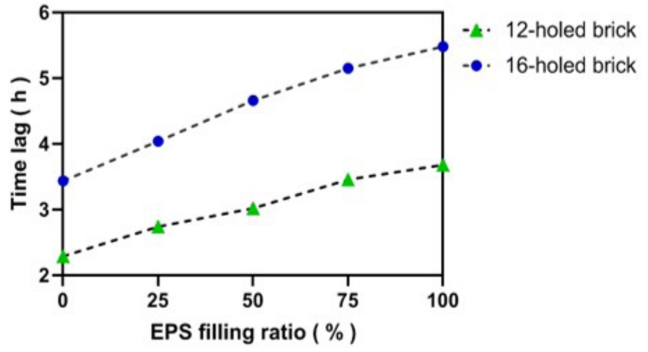

Figure 3: The time lag vs EPS filling ratio.

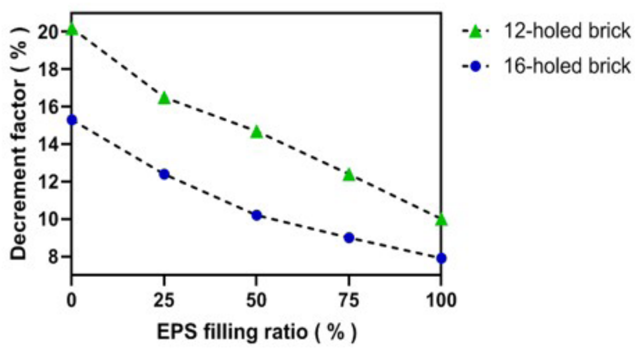

Figure 4: The decrement factor vs EPS filling ratio.

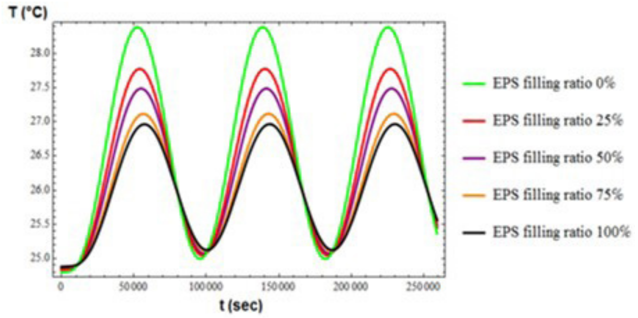

Figure 5: Internal temperature variations for various EPS filling ratios: Case of 12-holed brick.

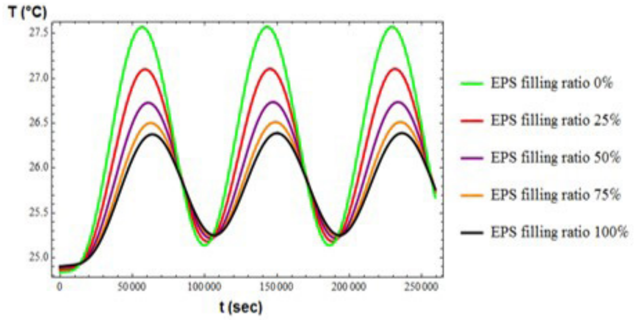

Figure 6: Internal temperature variations for various EPS filling ratios: Case of 16-holed brick.

The relationship between the inner surface temperature decrement factor and the EPS filling percentage is presented in figure 4. It can be observed that the decrement factor decreases as the EPS filling ratio increases, with a reduction of approximately 50% for both types of hollow clay bricks analyzed. By maintaining a low decrement factor, significant variations in ambient temperature can be minimized.

Figure 5 and figure 6 depict the effect of increasing the EPS filling ratio on the peak value of the inner surface temperature. It is evident that as the EPS filling ratio increases, the peak value of the inner surface temperature decreases significantly, with a 100% EPS filling ratio resulting in the removal of a significant proportion of the temperature swings. By filling the voids with insulating material, a protective layer is created against the outside thermal load wave, attenuating a significant degree of temperature variation.

As demonstrated by figure 3, figure 4, figure 5, and figure 6, increasing the number of horizontal row voids in hollow clay walls significantly increases their thermal inertia. This results in the internal thermal comfort level being sustained for a longer duration when switching from bricks with 12 cavities (Type 1) to bricks with 16 cavities (Type 2). Furthermore, adopting type 2 hollow clay bricks instead of type 1 hollow clay bricks leads to a 41.66% reduction in the decrement factor.

It is important to highlight that the results obtained in this study regarding the positive impact of filling cavities on the thermal performance of hollow bricks align closely with the findings reported in the literature [2, 5, 7]. This agreement reinforces the consistency and validity of the observed benefits derived from filling the cavities, as supported by previous research.

Conclusion and Perspectives

The major purpose of this numerical study is to ascertain whether or not it is possible to reduce energy consumption through the incorporation of passive methods into the alveolar structures of the building envelope. The results demonstrated that passive techniques included in typical hollow clay bricks improve their energy performance. The construction with a 100% EPS filling ratio had the lowest total heat flux Q at the inner surface, with a maximum improvement of 53.77% over the standard bricks (100% air-filling cavities). In addition, the findings showed that increasing the number of horizontal row voids improves hollow clay bricks' thermal inertia significantly. Changing the material type from brick with 12 cavities (Type 1) to brick with 16 cavities (Type 2) increases the time lag by about 61.2% and decreases the decrement factor by approximately 41.6%. (Type 2).

As part of our future work, we plan to undertake an experimental study to assess the impact of filling cavities with EPS insulation materials on the thermal conductivity of hollow clay bricks. Additionally, we aim to investigate the dynamic thermal behavior of hollow clay walls in Moroccan climates by studying the coupled heat and moisture transfers. In particular, we will examine the influence of humidity on the thermal performance of these walls.

Acknowledgements

None.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

1. Moroccan Agency for the Energy Efficiency. [http://www.amee.ma] [September 27, 2023]
2. Hou C, Meng X, Gao Y, Mao W, Long E. 2018. Effect of the insulation materials filling on the thermal performance of sintered hollow bricks under the air-conditioning intermittent operation. *Case Stud Constr Mater* 8: 217-225. https://doi.org/10.1016/j.cscm.2018.02.007
3. Sassine E, Cherif Y, Dgheim J, Antczak E. 2020. Experimental and numerical thermal assessment of lebanese traditional hollow blocks. *Int J Thermophys* 41: 1-21. https://doi.org/10.1007/s10765-020-02626-7
4. Fraine Y, Seladji C, Aït-Mokhtar A. 2019. Effect of microencapsulation phase change material and diatomite composite filling on hygrothermal performance of sintered hollow bricks. *Build Environ* 154: 145-154. https://doi.org/10.1016/j.buildenv.2019.02.036
5. Zukowski M, Haese G. 2010. Experimental and numerical investigation of a hollow brick filled with perlite insulation. *Energy Build* 42(9): 1402-1408. https://doi.org/10.1016/j.enbuild.2010.03.009
6. Morales MP, Juárez MC, Muñoz P, Gómez JA. 2011. Study of the geometry of a voided clay brick using non-rectangular perforations to optimise its thermal properties. *Energy Build* 43(9): 2494-2498. https://doi.org/10.1016/j.enbuild.2011.06.006
7. Li J, Meng X, Gao Y, Mao W, Luo T, et al. 2018. Effect of the insulation materials filling on the thermal performance of sintered hollow bricks. *Case Stud Therm Eng* 11: 62-70. https://doi.org/10.1016/j.csite.2017.12.007
8. Chihab Y, Essaleh L, Bouferra R, Bouchehma A. 2021. Numerical study for energy performance optimization of hollow concrete blocks for roofing in a hot climate of Morocco. *Energy Convers Manag X* 12: 100113. https://doi.org/10.1016/j.ecmx.2021.100113
9. Chihab Y, Bouferra R, Garoum M, Essaleh M, Laaroussi N. 2022. Thermal inertia and energy efficiency enhancements of hollow clay bricks integrated with phase change materials. *J Build Eng* 53: 104569. https://doi.org/10.1016/j.jobe.2022.104569
10. Bouchair A. 2008. Steady state theoretical model of fired clay hollow bricks for enhanced external wall thermal insulation. *Build Environ* 43(10): 1603-1618. https://doi.org/10.1016/j.buildenv.2007.10.005
11. del Coz Díaz JJ, Nieto PG, Sierra JS, Biempica CB. 2008. Nonlinear thermal optimization of external light concrete multi-holed brick walls by the finite element method. *Int J Heat Mass Transf* 51(7-8): 1530-1541. https://doi.org/10.1016/j.ijheatmasstransfer.2007.07.029
12. Boussinesq J. 1903. Théorie Analytique de la Chaleur. Gauthier Villars, Paris.
13. Basak T, Roy S, Balakrishnan AR. 2006. Effects of thermal boundary conditions on natural convection flows within a square cavity. *Int J Heat Mass Transf* 49(23-24): 4525-4535. https://doi.org/10.1016/j.ijheatmasstransfer.2006.05.015