Turkish Journal of Electromechanics and Energy
ISSN: 2547-975X
Vol:6, No:2, Page 58-63 (2021)
https://www.scienceliterature.com

Turkish Journal of Electromechanics & Energy
an international open access journal
www.scienceliterature.com

An experimental study on the overall heat transfer coefficient of various wall brick models

A. Rahmanparast[1, *], B. Çuhadaroğlu[1], F. E. Kan[1]

[1]*Department of Mechanical Engineering, Karadeniz Technical University, 61080, Trabzon, Turkey*

ARTICLE INFO

Article Type:
Invited Article [©]

Article History:
Received: 23 April 2021
Revised: 10 July 2021
Accepted: 4 August 2021
Published: 25 September 2021

Editor of the Article:
Ö. N. Cora

Keywords:
Hollow-wall brick
Inclined cavity
Thermal insulation
Heat transfer direction
Energy saving

ABSTRACT

It is well known that most of the heat losses of buildings occur at outer walls, which are made of a few layers such as plaster, wall bricks, insulation material, etc. It is required that the wall bricks having a low overall heat transfer coefficient to reduce heat losses through buildings to increase the heating performance of buildings. In order to address the requirement, the wall bricks are produced of low thermal conductivity materials and with cavities (hole), weakening the thermal transport mechanism. This study, is aimed to decrease the overall heat transfer coefficient of wall brick models with various cavities, which affect the natural convection mechanism. For this purpose, some changes are made to the cavity geometry of a single cell of the hollow wall brick model. The proposed geometries' heat transfer experiments were repeated under three different (7, 9, 12 W) thermal power conditions. The building is simulated as an insulated chamber made of extruded polystyrene (XPS) with 300 mm x 300 mm x 300 mm. The wall brick models are produced from polyvinyl chloride (PVC) material in 160 mm x 160 mm x 50 mm and mounted to a wall of the insulated chamber. The experiments are carried out on the brick models with the cavity geometries of regular symmetrical *I* and asymmetrical *Z* profiles. The temperatures are measured at 3 points on both sides of the brick models. It has been measured that the overall heat transfer coefficient of the *Z* model is lower than that of the regular *I* profile at 7.1%, depending on the heat transfer direction.

Cite this article: A. Rahmanparast, B. Çuhadaroğlu, F. E. Kan, "An experimental study on overall heat transfer coefficient of various wall brick models," *Turkish Journal of Electromechanics & Energy*, 6(2), pp.58-63, 2021.

1. INTRODUCTION

The bricks are building elements that frequently used in building constructions. In addition to creating independent sections in buildings, the bricks also have an important role in thermal performance of buildings. Heat losses through buildings should be calculated for energy performance analysis of buildings. Heat losses occur through the floor, ceiling, window, etc., as well as walls. Building walls should have a low overall heat transfer coefficient to save energy. Therefore, the lower overall heat transfer coefficient of bricks forming walls in buildings the higher energy performance for buildings. When the heat transfer mechanism in building bricks is examined, it is seen that it has a periodic structure such as conduction in solid walls and convection in air space following it. It is well known that to reduce the overall heat transfer in this kind of structure, materials having a low heat conduction coefficient should be used, or some specific cavity geometry should be designed to reduce heat conduction. A combination of these concepts may lead to the best thermal performance of bricks. Fourier's law defines the heat transfer through multi-layered and spaced materials as [1]:

$$\dot{Q} = UA\Delta T \tag{1}$$

Here $\dot{Q}$ $W\,/\,m^2$(W) represents transferred heat, ΔT (˚C) refers to the temperature difference in the direction of heat transfer, and U (W/m^{2}K) refers to the overall heat transfer coefficient. The overall thermal resistance R$_{equ}$ (m^{2}K/W) is defined as follows:

$$U = \frac{1}{R_{equ}} \tag{2}$$

$$R_{equ} = [\frac{L_1}{k} + \frac{1}{h_1} + \frac{L_2}{k} + \frac{1}{h_2} + \cdots + \frac{1}{h_n} + \frac{L_n}{k}] \tag{3}$$

Here the L_n (1, 2,.., n) is the inner part thicknesses of the brick separating the spaces, and the k is the heat conduction coefficient of the brick material. The h_n (1, 2,…, n) refers to

---

[©] *Initial version of this article was presented in the 5th International Anatolian Energy Symposium (5th AES) proceedings held on March 24-26, 2021, in Trabzon, TURKEY. It was subjected to a peer-review process before its publications.*

**Corresponding author e-mail: rahmanparast@ktu.edu.tr*

heat conduction coefficients on solid surfaces of the space cells, which varies depending on the natural convection in the spaces. The majority of the studies on the subject were performed as numerical modelling and experimental in the literature. In the numerical analysis by Al-Hazmy, the heat transfer was studied on three different bricks' configurations under the summer climatic conditions of the city of Jeddah, Saudi Arabia [2]. He revealed that the heat transfer rate through hollow building blocks could be reduced by 36% when polystyrene bras is filled into the cavities. Ait-Taleb et al. studied heat transfer in brick with two vertical and three horizontal holes under the condition of constant heat flux from the lower or upper surface [3]. They used different distributions of spaces as parameters and obtained that the hollow block with two air cells deep in a vertical direction reduces heat transfer from inside to outside of the building roofs. Arıcı et al. performed a thermal analysis on building bricks with unequally ordered holes, both experimentally and numerically [4]. They obtained that the most suitable configuration to increase thermal resistance is to configure the gaps along the heat transfer direction. The worst one is to configure an arrangement just opposite of it. Gossard and Lartigue developed a three-dimensional numerical model for coupled heat transfer in building components with air-filled vertical cavities and verified the model's validity with the experiments [5].

A rule of thumb, the numerical studies should be verified and validated by the experimental studies, which is quite essential. Vivancos et al. studied heat transfer on different clay and concrete bricks using a standard measurement method and developed a model based on experimental data [6]. Jaipeng Sun et al. performed a numerical optimization by combining artificial neural network (ANN), hybrid genetic algorithm (HGA) and popularization (dissemination) methods [7]. The goal was to minimize the heat transfer by subjecting the gaps to different geometric shapes (provided that they are rectangular) in the brick element produced from concrete containing four voids. As a result, they concluded that the combination of ANN and HGA reveal a more robust optimization than the other combinations. Arendt et al. numerically investigated the effects of cavity concentration in the cavity [8]. The variation of hole concentration from solid brick to placement of cells to fit the maximum hole was considered as a parameter. The results of the study were examined thermally. They explained that the concentration ratio in bricks made of materials with high thermal conductivity is between 45-65% for the best thermal conductivity. In their numerical studies, Arıcı and Kan [9] compared the thermal resistances in arranging the brick cavities with a 45° inclination. Their study argued that the 45° inclination increases the total thermal resistance of the brick, taking the radiation effects in spaces into account. Thus lower insulation costs will be realized in building applications. In their numerical studies, Jamal et al. examined the thermal behavior of three different types of hollow bricks, which are primarily used in unstable conditions [10]. They also took into the effect of surface radiation account in their studies. The vertical surface of the outside is subjected to a sinusoidal thermal excitation, while the inside vertical surface has a constant temperature. The study revealed that the emission in the internal cavities significantly affects the heat transfer in bricks. Jia et al. performed experiments on wall applications in different variations by filling the inner cavities of the brick with thermal insulation material and phase change material [11]. They found that when the thermal insulation material fills all the gaps, and the average heat transfer decreases by 29.7%. They argued that thermal resistance and thermal inertia would be improved comprehensively when the applications were used together. The study conducted by Morales et al. gives information on geometrical arrangements of the partitions of bricks [12]. According to the results of this study, thermal bridges must be avoided in the brick. A small gap in the brick assembly also notably improves the brick's conductivity; the more rows, the more improvement.

The present study is aimed to increase the thermal resistance by reducing the heat transfer in the cavities of the bricks. The study was carried out experimentally, considering a single hole of the brick. The brick cavity was examined with two models divided by a diagonal plate, and the other is a standard model which was considered for comparison.

2. EXPERIMENTAL

Two types of brick models with different internal geometries were designed by SolidWorks software. One of them is a regular model with symmetrical cavity geometry referred to as Type *I* and used for comparison. The brick model has asymmetrical cavity geometry referred to as Type *Z*, divided diagonally, as seen in Figure 1. Both types of bricks used in the experiments are produced by PVC foam material using laser cutting and bonding techniques on ready-made plates. Firstly, the bricks models' mainframe is constructed, then the inner cavity has been divided with a plate. Type *I* model has two equal rectangular partitions, while Type *Z* has two equal triangle partitions. The images of the models produced in the study are seen in Figure 2.

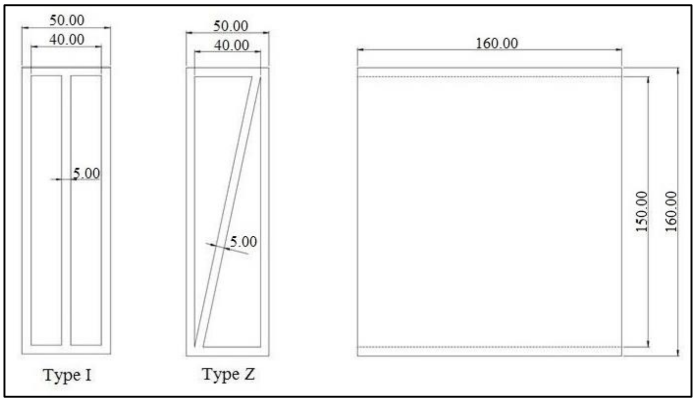
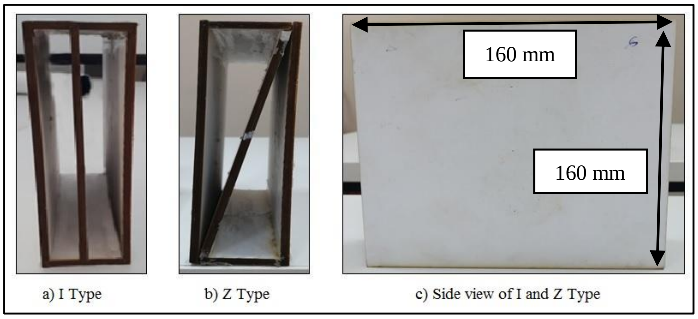


Fig. 1. SolidWorks design of the models.



a) I Type b) Z Type c) Side view of I and Z Type

Fig. 2. The brick models.

The experimental chamber with dimensions of 400x400x400 mm has been designed to simulate the building and keep the thermal power passing through the brick constant. The chamber is made of thermal insulation material to maintain the heat produced in the heater to pass through the brick model in the wall. Figure 3 shows images of the produced chamber. It is aimed to provide absolute insulation on other surfaces by covering with plaster material except for the part of the room where the brick is placed. Thus, it is assumed that all heat coming from the heater placed in the volume centre of the chamber passes over the brick by neglecting the cable losses.

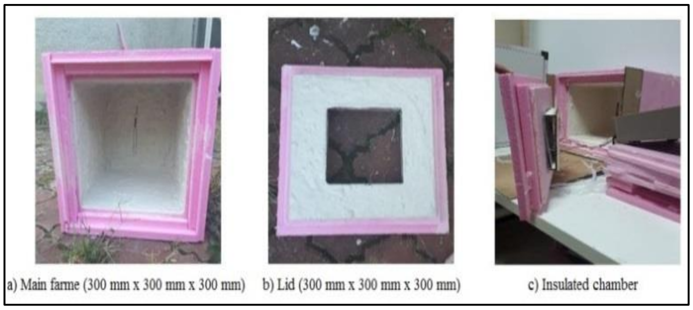

a) Main farme (300 mm x 300 mm x 300 mm) b) Lid (300 mm x 300 mm) c) Insulated chamber

Fig. 3. Insulated chamber and the wall which brick model is mounted.

The heater cartridge to provide constant heat input to the system is connected to a power source adjusted for voltage. The heater cartridge is placed in the volume centre of chamber through the circular section that opened in dimensions suitable for insulation on the upper surface of the chamber. The brick models with different cavity geometries were placed in the room where the thermal power was kept constant, in a square section space prepared in 160x160x50 mm dimensions on a wall. A guarded plate is mounted on the surface to prevent incorrect temperature measurements due to external air circulation on the outer surface of the brick model. The image of the experimental setup is shown in Figure 4.

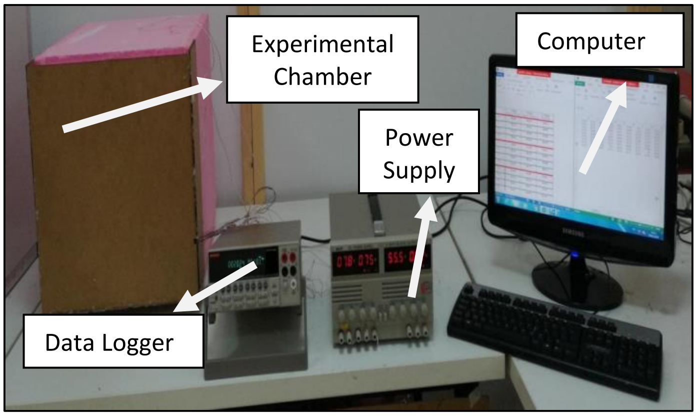


Fig. 4. A view of the experimental setup.

Temperature measurements were obtained from the brick surfaces to determine the overall heat transfer coefficient in Equation 1. In the temperature measurement process in which k-type thermocouples are used, the data were recorded in the computer environment at certain periods. Thermocouples are positioned at the midpoints of the surfaces, 40 mm away from the center horizontally and vertically. The average surface temperatures were determined from the three surface temperatures. The locations of the temperature measurements are given in Figure 5.

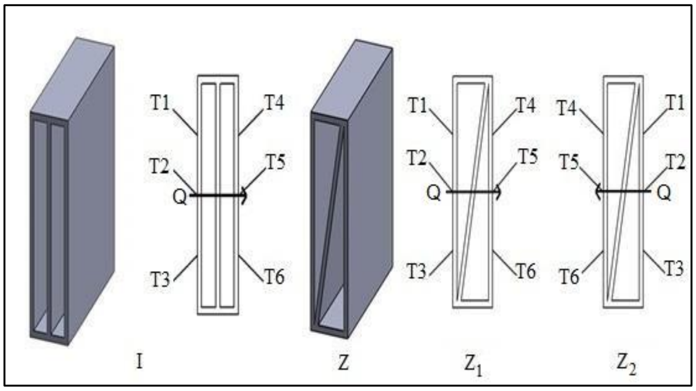


Fig. 5. Thermocouple locations.

The physical properties of the materials used in the experimental setup are given in Table 1.

Table 1. Physical properties of the material

Material	*Physical Properties*		
	Density (kg/m^3)	*Specific heat(J/kg.K)*	*Thermal conductivity (W/mK)*
PVC	1560	1130	0.03-0.05
XPS (Extruded Polystyrene)	30	837	0.039

2.1. Uncertainty Analysis

The uncertainty analysis method was used in the experimental study to obtain the measured power and temperature errors. In practice, different approaches have been developed to get the error rates of the experiment, which mostly used Kline and McClintock methods for error analysis of experimental findings [13]. According to this method,

$$w_R = \left[\left(\frac{\delta r}{\delta x_1} w_1\right)^2 + \left(\frac{\delta r}{\delta x_2} w_2\right)^2 + \cdots + \left(\frac{\delta r}{\delta x_n} w_n\right)^2\right]^{\frac{1}{2}} \tag{4}$$

the magnitude that should be measured in the system is R, and the n independent values that affect these quantities are $x_1, x_2, x_3, \dots, x_n$. In this case;

$$R = R(x_1, x_2, x_3, \dots, x_n) \tag{5}$$

is in the form. Error rates of each variable; w_1, w_2, w_3, …, w_n . U error rate is w_U given in the form considering Equation (1);

$$U = \frac{\dot{Q}}{A\Delta T} = \frac{I\,V}{A\Delta T} \tag{6}$$

$$w_U = \left[\left(\frac{\delta U}{\delta I} w_I\right)^2 + \left(\frac{\delta U}{\delta V} w_V\right)^2 + \left(\frac{\delta U}{\delta A} w_A\right)^2 + \left(\frac{\delta U}{\delta T} w_T\right)^2\right]^{\frac{1}{2}} \tag{7}$$

Where w_U, w_I, w_A and w_T are respectively means: the uncertainty of the overall heat transfer coefficient, power supply ampere, voltage, surface area measurement of the model and thermo-element error rates. The information and error rates of the devices and tools used in the measurement processes are presented in Table 2.

Table 2. Properties of device and tools

Device	*Manufacturer*	*Place of use*	*Error rate*
Power Supply	GW Instek-4303, New Taipei, Taiwan	Current, Voltage	±0.1 A, V
Data Loger	Tektronix Keithley 2701, Beaverton, USA	Temperature	±0.1 ℃
Caliper	Aydal Makine A 0082, İstanbul, Turkey	Area	±0.01mm

If we simplify and solve Equation (7) in the Type I model and according to the maximum overall heat transfer coefficient, the uncertainty of the overall heat transfer coefficient is obtained as 3.35 W/m^{2}K.

3. RESULTS

The brick models surface temperatures were measured at three heat power levels of 7, 9 and 12 W, generated by a heater in the insulated chamber. The overall heat transfer coefficient was calculated with the difference in the average temperatures of the surfaces. It can be obtained from Equation (1) as $U = \dot{Q}/(A\Delta T)$ depending on the surface area A of the brick model and heat power $\dot{Q}$ and temperature difference ΔT.$U = Q/(A\Delta T)$ The surface area of the brick models is 0.0256 m^2 (0.16 m x 0.16 m).

The overall heat transfer coefficients of the models were determined for three different configurations and three different heat power conditions. It is well known that the U value is used as an essential parameter for analyzing the thermal performance of a building. The coefficient of thermal conductivity directly results in positive effects on heat energy savings and environmental problems. In this context, the variation of the total heat transfer coefficients of the symmetrical and asymmetrical models is shown in Figure 5. The present study hypothesized that the U depends on heat transfer direction for asymmetrical brick configurations like the Type Z model. To confirm this hypothesis, the brick model of Type Z was tested for heat powers in two different directions: the right to left and left to right. The U variations, seen in Figure 6. revealed that overall heat transfer coefficients of the Z model are lower than that for the regular I profile for all heat powers. In addition, it was observed that the lowest U values are obtained for the heat power right to left (Z_2) configuration. This result confirmed the hypothesis that the U depends on heat transfer direction in asymmetrical hollow bricks.

Figure 7 shows that there is about a 7 % decrease of the U value for the Z_2 configuration compared to the regular I profile, which means heat saving in buildings and economy at heating systems directly affected. Brick models sorted according to the total thermal conductivity coefficient and temperature are presented in Figure 8. Comparing the U variations of the brick models with different internal structure geometries considered in this study, it was noted that the overall heat transfer coefficient U decreases with changing the internal structure geometry from symmetrical (regular) to asymmetrical (diagonal).

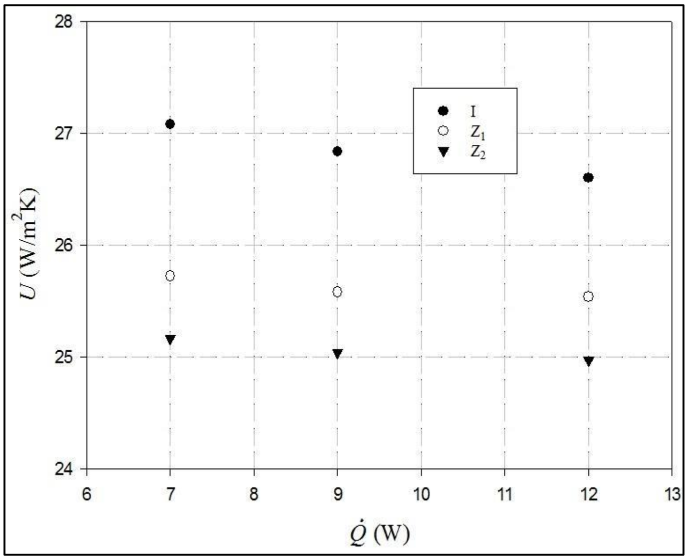


Fig. 6. The normalized U variations versus the rate of heat transfer.

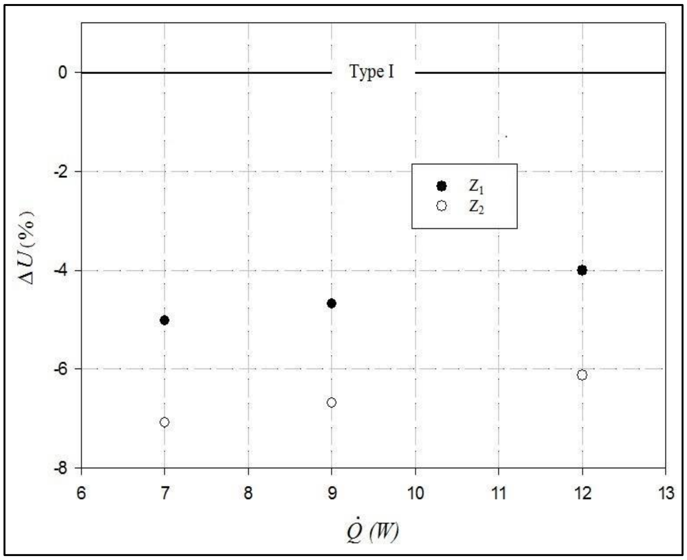


Fig. 7. The normalized U variations versus the rate of heat transfer.

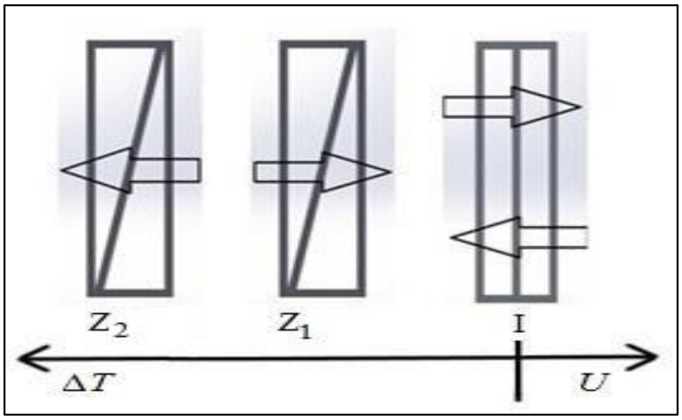


Fig. 8. Sorted view of the brick models.

4. CONCLUSION

The findings obtained from this study can be summarized as follows:

Within the limitations of the study, the overall heat transfer coefficients of the bricks models decrease with increasing heat power. The overall heat transfer coefficient of the asymmetrical brick model is lower than that for the regular symmetrical brick model. The overall heat transfer coefficient of the asymmetrical brick model depends on the heat transfer direction. The bricks having asymmetrical internal structure may provide heat saving in buildings.

References

[1] F. P. Incropera, D. P. Dewitt, T. L. Bergman, A. S. Lavine, Principles of Heat and Mass Transfer, Seventh Edition, *Wiley*, 2013.

[2] M. M. Al-Hamza, "Analysis of coupled natural convection-conduction effects on the heat transport through hollow building blocks," *Energy and Buildings*, vol. 38, pp. 515-521, 2006.

[3] T. Ait-Taleb, A. Abdelbaki, & Z. Zrikem, "Simulation of coupled heat transfers in a hollow tile with two vertical and three horizontal uniform rectangular cavities heated from below or above," *Energy and Buildings*, vol. 84, pp. 628-632, 2014.

[4] M. E. Arıcı, F. E. Kan, A. E. Candemir, & E. Özkan, "Eşit boyutlu olmayan ardışık boşluklara sahip bir tuğlada ısı transferi, *22th Congress on Thermal Science and Technology*, Kocaeli-Turkey, vol. 1, pp. 309-319, 2019.

[5] D. Gossard, & B. Lartigue, "Three-dimensional conjugate heat transfer in partitioned enclosures: determination of geometrical and thermal properties by inverse method," *Applied Thermal Engineering*, vol. 54, pp. 549-558, 2013.

[6] J. Vivancos, J. Soto, I. Perez, J. V. Ros-Lis, & R. Martinez-Manez, "A new model based on experimental results for the thermal characterization of bricks," *Building and Environment*, vol. 44, pp. 1047-1052, 2009.

[7] J. Sun, L. Fang, J. Han, "Optimization of concrete hollow brick using hybrid genetic algorithm combining with artificial neural networks," *International Journal of Heat and Mass Transfer*, vol. 53, pp. 5509-5518, 2010.

[8] K. Arendt, M. Krzaczek, & J. Florczuk, "Numerical analysis by FEM and analytical study of the dynamic thermal behaviour of hollow bricks with different cavity concentration," *International Journal of Thermal Sciences*, vol. 50, pp. 1543-1553, 2011.

[9] M. E. Arıcı, & F. E. Kan, "A numerical investigation of tilted holes effects on overall thermal resistance for a masonry brick," *13th HVAC+R Technologies Symposium*, İstanbul, 19-25, 2018.

[10] B. Jamal, M. Boukendil, L. El Moutaouakil, A. Abdelbaki, Z. Zrikem, "Thermal analysis of hollow clay bricks submitted to a sinusoidal heating," *Materials Today: Proceedings*, vol. 45, pp. 7399-7403, 2021.

[11] G. Jia, X. Geng, F. Liu, Y. Gao, "Thermal behavior improvement of hollow sintered bricks integrated with both Thermal Insulation Material (TIM) and Phase-Change Material (PCM), *Case Studies in Thermal Engineering*, vol. 25, 100938, 2021.

[12] M. P. Morales, M. C., Juarez, L. M. Lopez-Ochoa, & J. Domenech, "Study of the geometry of a voided clay brick using rectangular perforations to optimize its thermal properties," *Applied Thermal Engineering*, vol. 31, pp. 2063-2065, 2011.

[13] S. J. Kline, & F. A. McClintock, "Describing Uncertainties Sample Experiments," *Mechanical Engineering*, 1953.

Biographies

Amir Rahmanparast was born on March 24, 1988, in Tabriz, Iran. He graduated from Karadeniz Technical University Engineering Faculty Mechanical Engineering Department in 2016. He completed his master's degree at Karadeniz Technical University in 2021. He continues his doctorate at Karadeniz Technical University. He is working on heat transfer and thermodynamics.

E-mail: rahmanparast@ktu.edu.tr

Burhan Çuhadaroğlu completed his undergraduate education at ITU Mechanical Engineering Department in 1983 and his master's and doctorate education at Karadeniz Technical University Mechanical Engineering Department in 1986 and 1991, respectively. He became an assistant professor in 1992, an associate professor in 1998, and a professor in 2004 at the Department of Mechanical Engineering at Karadeniz Technical University, where he started to work as a research assistant in 1984. He still continues his professional life in the same institution. He has been serving as the head of the department since 2018. He is working on fluid dynamics, heat transfer and thermodynamics.

E-mail: burhan@ktu.edu.tr

Furkan Erman Kan was born in Bakırköy/Istanbul in 1988. He graduated from Atatürk University Engineering Faculty Mechanical Engineering Department in 2011. He worked as a mechanical engineer in a private company during the period of 2011-2015. He completed his master's degree at Karadeniz Technical University (KTU) in 2016. He continues his Ph.D. studies at KTU and works as a research assistant. He is working on heat transfer and thermodynamics, specializes in heat transfer with nanofluids in his doctoral study. In addition to his academic studies, he is a member of the Board of Directors of the Chamber of Mechanical Engineers Trabzon Branch.

E-mail: fekan@ktu.edu.tr