Int. J. Architect. Eng. Urban Plan, 27(2): 83-94, December 2017
DOI: 10.22068/ijaup.27.2.83

Research Paper

Evaluation of the Thermal Performance of the External Walls of Buildings with Hollow Clay Blocks in Temperate and Humid Climate

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Received: 26 January 2017, Revised: 10 August 2017, Accepted: 15 August 2017, Available online: 30 December 2017

Abstract

The external walls are regarded as an important source for the thermal exchange between the outside and inside of a building. Despite the significance of building walls for energy savings, a large body of research has focused mainly on thermal comfort, environmental impacts, and economic costs of residential buildings. However, few researchers have addressed the thermal performance of common building materials. The clay block has attracted a lot of attention as the important building material in temperate and humid climate. The present study aimed to study the thermal performance of three clay block external walls systems in temperate and humid climate by increasing trapped air thickness between internal and external walls of buildings. FLUENT software was employed to simulate and calculate the thermal characteristics, which were extracted and compared to the calculated data according to chapter 19 of "Iranian National Building Regulations". The results indicated that the air trapped between the internal and external the leaves of cavity walls considerably influenced thermal resistance. In addition, the new combined wall system could considerably save the energy, compared to the existing wall systems. In conclusion, the energy goals can be fulfilled by improving the layout of the walls.

Keywords: *Energy optimization, External walls, Heat transfer, Thermal resistance, Clay blocks.*

1. INTRODUCTION

Global energy crisis has caused to pursue energy conservation in buildings. Therefore, some guidelines focusing on building models, wall materials and structure should be taken into consideration .Particularly, studying the thermal performance of walls based on heat transfer seems essential. Cavity walls are used to prevent energy loss among the buildings, which has attracted more attention due to an increase in energy price. Therefore, the heat transfer rate through the external wall was evaluated via modeling by assuming that cavity wall thermal resistance increases during an increase in the thickness of the air trapped between the internal and external walls.

Todays, the world has faced a continuous reduction of fossil energy sources. Some researchers believe that about 35% of the world total energy is consumed in the household sector for heating and cooling purposes, which is regarded as the main reason for a large amount of greenhouse gases emissions and accordingly contributes to the global warming and climate change [1]. As the environment and climate may influence the types of construction, most of the architectures of the buildings in different climates are made with the same kind of construction and building materials. Further, in addition to environment, the thermal mass of materials is another source of energy conservation and dissipation in buildings [2]. In this regard, a better performance of energy conservation is observed in compound wall construction [3-5]. External walls are an important source of energy loss or conservation in a building Fig. 1. Thus, walls can be insulated in order to stop energy waste or energy conservation in buildings. In addition, the wall thickness can play a significant role in the energy consumption, especially in specific climates. Further, it can have a greater influence on energy consumption when it is accompanied by insulating external walls [6]. Recently, the insulation of external walls has been considered as the best alternative to prevent energy dissipation where the amount of energy loss from different building materials is ambiguous and a solution is required for all types of walls with different building materials.

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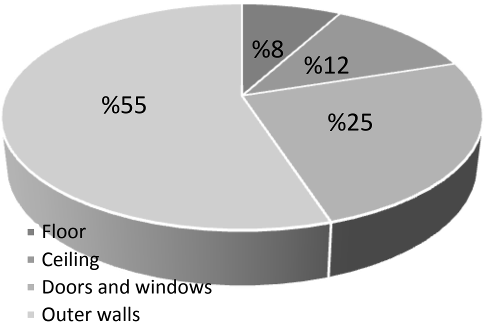


Fig.1 The loss of Energy through external walls

The present study aimed to evaluate different clay brick wall constructions to optimize the materials of the external walls, which were presented in chapter 19 of "Iranian National Building Code" as the most important part of a building with respect to both inside and outside of buildings. To this aim, a constant temperature was established to meet the residents' comfort by controlling and conducting the flow of heat and thermal resistance of walls. Therefore, the following research questions were raised in this regard:

1. Is the amount of intrusive heat flux reduced by prolonging the heating path from the hot surface to the cool surface of the wall?
2. Does an increase in the air between the two walls and a decrease in the heat transfer lead to an increase in the heat resistance?
3. Is the thermal bridge eliminated by removing the cross-link between the two internal and external walls and decreasing the thermal flux?

In most of the conducted studies, the impact of block geometry and its role on the amount of thermal flux were emphasized. However, significant results may be obtained by using conventional clay blocks and changing the layout such as the use of two blocks of veneer laminate with a distance of 5 cm to 7 cm, instead of using 20 cm blocks, depending on the area where most energy is dissipated. Further, a reduction can take place in the cost, along with saving the amount of energy consumed in the type of the used materials.

2. REVIEW OF THE RELATED LITERATURE

Nowadays, the reduction of fossil energy sources as the most consumed energy in the housing sector is regarded as one of the main challenges the world is facing with. Heat energy is transferred from homes by conducting through the walls. Some investigated the houses built in different climates and environments and found that the possibility of estimating the compatibility of aggregate-based construction materials or proximity of building materials against chemical and physical reactions can pave the way for selecting and using a variety of appropriate building materials which can influence energy loss [1]. Building materials and the thermal mass are one of the elements affecting the amount of energy consumption in buildings. In addition, concrete can store heat and then release heat when it is exposed to heating sources by considering its energy storage capacity. Further, concrete may reduce the maximum temperature in a building by 3-4 °*C* [2].

Furthermore, the building materials with specific thermal masses and the recycled materials from ceramic are considered as the best alternatives for common materials including a high elasticity in terms of the thermal and mechanical properties such as cost and energy [7]. Finally, based on the results, the external walls have the highest level of contact with the outside air and heat exchange between the interior and exterior of a building is highly conducted through external walls. Some researchers found that cavity walls hold greater potential for saving in energy consumption by examining the increase and decrease of the thermal inertia of buildings with a normal wall system and with compound wall construction (cavity walls) [3,5].

Walls are built with different thicknesses. The evaluation of the thickness of external wall insulation and their energy saving potentials indicated that energy saving varies through increasing the insulation thickness of the external walls in different climates in China, Guangzhou, Shanghai and Beijing. In addition, an increase in the external wall insulation thickness in external zones in all orientations led to a considerable amount of energy saving in Beijing [6].

In another study, evaluated thermal transfer in the vertically perforated bricks and found that walls can be constructed only from clay and plastering mortars [8]. In addition, the heat transfer was not completely recognized in these assemblies. Further, regarding brick construction, convection heat transfer was insignificant in the perforations resulting in increasing the thermal resistance of the brick.

In general, most of the studies in the field of cavity walls focused more on some variables such as building orientation (the effect of insulation application in different geographical directions), the difference between cavity walls in different climates, the effect of height, wall thickness on thermal resistance, and the like. However, few researchers have addressed to measure the geometry of the blocks and their arrangement by controlling the various factors.

3. MATERIALS AND METHOD

3.1. Variables of the study

This paper seeks to evaluate the effect of increasing the trapped air thickness between internal and external walls of buildings on heat transfer. It was hypothesized that heat transfer rate and consequently energy consumption would reduce if the thermal resistance increased as an effective factor, Fig. 2. Since it is impossible to study the effect of all variables simultaneously, the effects of some factors such as humidity, temperature and plastering mortar were considered as the control and constant variables. In addition, a metal belt connecting the internal and external walls and affecting the rate of heat transfer was regarded as an intervening variable.

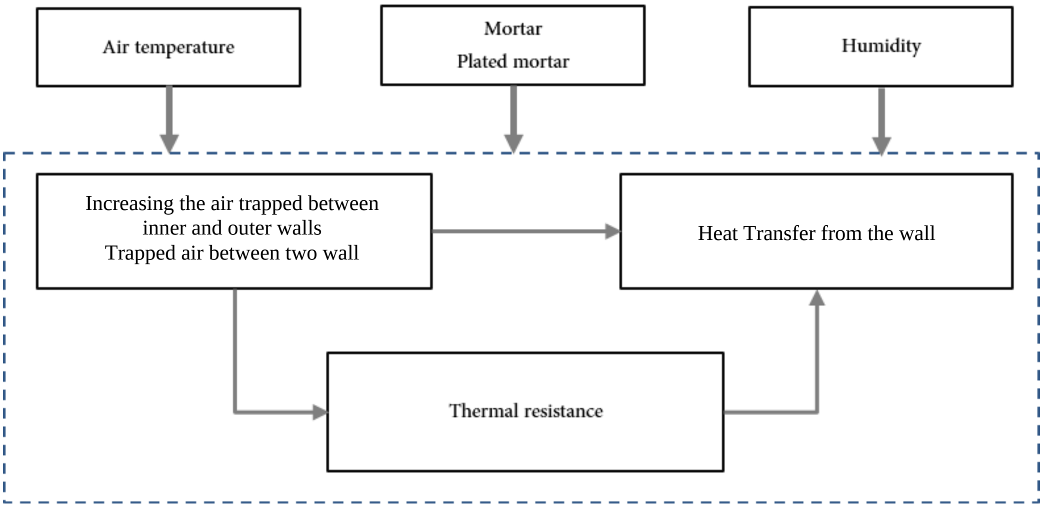
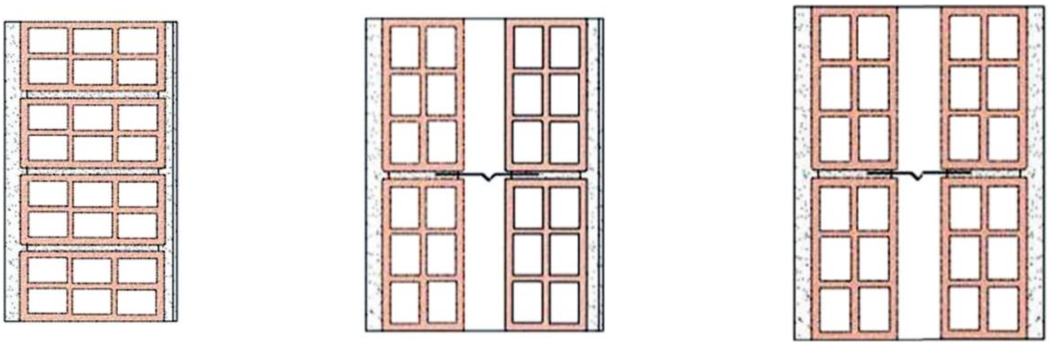


Fig. 2 The conceptual framework of the research variable

3.2. Data analysis method

In this study, observation and simulation method of calculation were used for data collection by using FLUENT software. The FLUENT software is a computer-assisted engineering software designed in the field of computational fluid dynamics for modeling fluid flow and heat transfer with complex geometry. The software can model two and three-dimensional flows .In order to use this software, GAMBIT is first used to determine the geometry of flow for performing mesh operations. The result from GAMBIT software is used by FLUENT software. Compared to other similar software, FLUENT software can evaluate the fluids with higher resolution. FLUENT software was employed in the present study to evaluate the air trapped between internal and external walls as well as investigating its function in heat transfer.

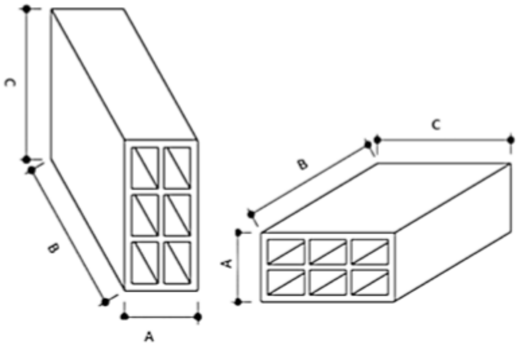
Table 1 Three models



20 cm thick clay block wall | Double layer wall with a 5 cm air layer | Double layer wall with a 7 cm air layer

3.3. Sample models

The present study was conducted by making three models of normal and cavity walls made of 10 cm clay blocks and the most common type of materials, along with plaster mortar in temperate and humid climate Fig. 3. In all these three models, four clay blocks with similar mortars were used. Table 2 displays the characteristics of plaster mortar.



Side	Size
A	10
B	25
C	20

Fig. 3 The dimension of 10 cm clay blocks

Table 2 Physical properties of mortar

	Mortar type	Thickness (cm)
Connecting blocks	Sand cement	2
Interior Plastering	Plaster	1.5
	Final plaster	0.5
Exterior plastering	Cement	2

As shown, Model 1 is related to a clay block with 20 cm thickness while the Models 2 and 3 are regarded as the cavity walls, which were made of 10 cm clay blocks at each side and a middle layer including a ventilated 5-7 cm air cavity. The total wall thickness should be at least 25cm. The walls should be tied by the galvanized straps at interval space not more than 50 cm apart vertically and 60cm horizontally. In addition, four straps should be placed at each 1 meter. The only difference is that Model 2 has a 5 cm air layer while Model 3 includes 7cm air layer.

3.4. Temperature conditions and properties

In all the three models based on temperate and humid climate, the inner air temperature and the convection heat transfer coefficient were 24°C and 9 w/m2, respectively. The outside air temperature and the outside convection heat transfer coefficient at 80% relative humidity were 5 ° C and 16 w/m2, respectively [9]. Table 3 indicates the thermal properties of air, brick, mortar and straps were based on Chapter 19 of "Iranian National Building Code". It is worth noting that the thermal conductivity of bricks and mortar were considered constant in the evaluations.

4. RESULTS

The simulation was performed by using Fluent 6.3 software. The heat radiation effect was ignored due to low temperature.

Table 3 Thermal conductivity coefficient of materials

	Thermal conductivity (w/mk)
Clay	1.00
Mortar	1.00
Air	0.0242
Strap	16.27

4.1. Thermal behavior of model 1

Table 4 displays the simulation results for the wall made of 20 cm clay blocks. As illustrated in Fig. 5, the heat flux profile of the wall, the horizontal walls of clay block and horizontal mortar joints of two blocks could directly connect the warm surface of the block to its cold surface. Further, the heat fluxes were approximately doubled since the wall was relatively short in length, compared to other two walls.

Table 4 Obtained numerical results for Model 1

Thermal resistance (m^2K/W)	1.05
Inner surface temperature (° C)	22
Outer surface temperature (° C)	6.80
maximum heat flux (W/m^2)	0.95
Minimum heat flux (W/m^2)	0.75
Thickness (cm)	24
Maximum air speed (m/s)	7.50

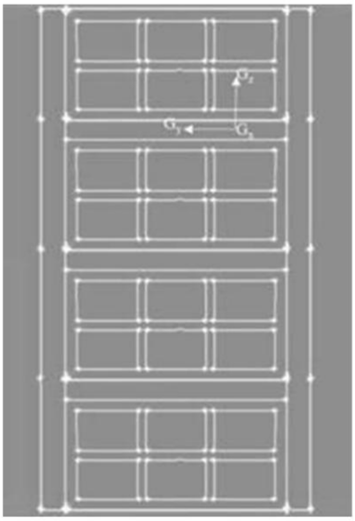


Figure 4. Simulation of Model 1

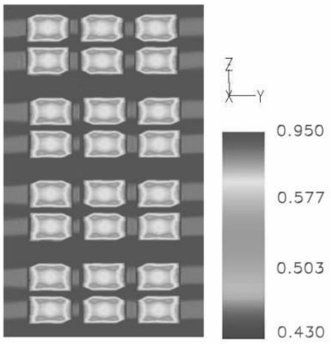


Fig. 5 Heat flux profile of Model 1

In addition, according to isothermal profiles Fig. 6, the inner air, and surface temperature of the wall was 24°C and 22°C, respectively. However, it failed to impose high thermal loads on the structure. The outside air, and surface temperature of the wall was 5°C and 6.80°C, respectively. In fact, the outside surface temperature was higher than the outside air temperature. Therefore, a slight heat loss happens in the building. In addition, the convective heat transfer depends on this temperature difference. As illustrated in Fig. 7, regarding the insignificant difference between the air-to-surface temperatures (air circulates at

15 meters per second inside the block hollow), it is concluded that convective heat transfers could slightly contribute to conducting heat transfer.

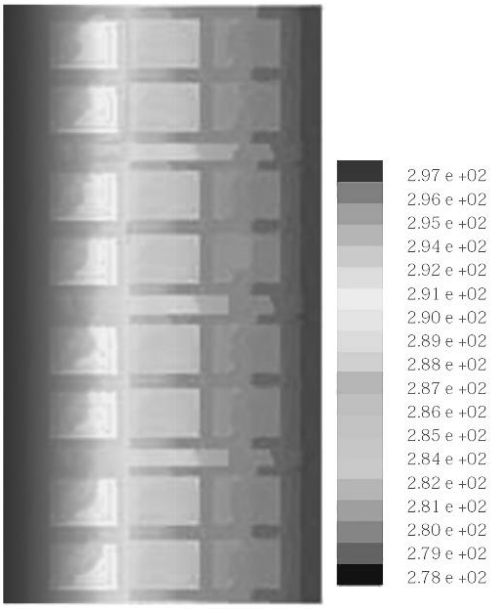


Fig. 6 Isothermal profile of Model 1

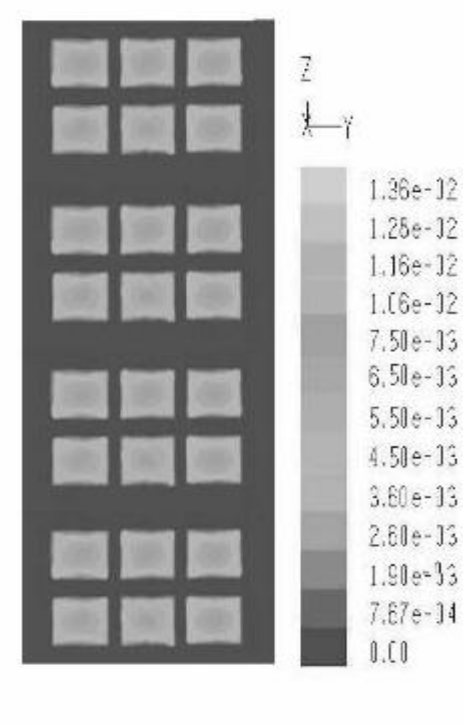


Fig. 7 Air velocity profile of Model 1

4.2. Thermal behavior of Model 2

Based on the stimulation Model 2 Fig. 8, by regarding the air layer with 5 cm thickness between the inner and outer walls, an increase in the wall length, and the disconnection of warm surface from cold surface through convection, conduction is considered as the only way for transferring heat. Table 5 presents the obtained results.

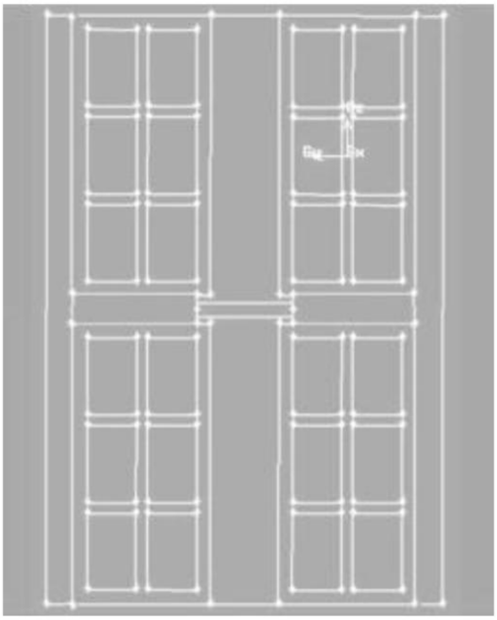


Fig. 8 Simulation of Model 2

Table 5 Obtained numerical results for Model 2

Thermal resistance (m^2K/W)	2.90
Inner surface temperature (° C)	23.85
Outer surface temperature (° C)	4.85
Maximum heat flux (W/m^2)	0.65
Minimum heat flux (W/m^2)	0.43
Thickness (cm)	29
Maximum air speed (m/s)	9.70

Fig. 9 illustrates the heat flux profile of the wall. As shown, no connection was observed between the two walls although the horizontal walls of clay blocks, horizontal mortars between the blocks and the straps connecting two walls could act as a thermal bridge and connect the warm surface of the block to its cold surface. In addition, due to the relatively large length of the wall, the thermal flux was reduced by about 30%, compared to the previous model. According to Figs. 10 and 11, the difference between the inner air temperature and the inner surface of the wall, as well as the difference between the outside air temperature and the outer surface of the wall could reduce to 0.25 °C, which offers some benefits in terms of energy-saving. As it was already mentioned, by considering the relationship between convective heat transfer and the temperature difference between air and surface temperatures, along with a decrease in the maximum speed of trapped air Fig. 12, convective heat transfers could slightly contribute to heat transfer, compared to the previous model. Finally, the maximum heat transfers from the wall occurred through conduction.

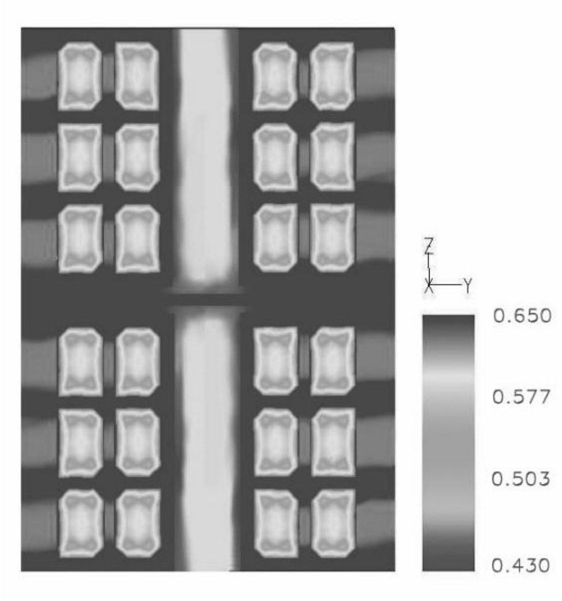


Fig. 9 Heat flux profile of Model 2

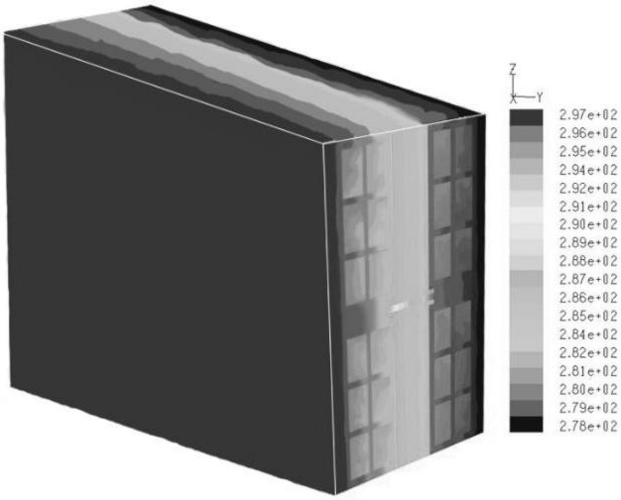


Fig. 10 Isometric profile of Model 2

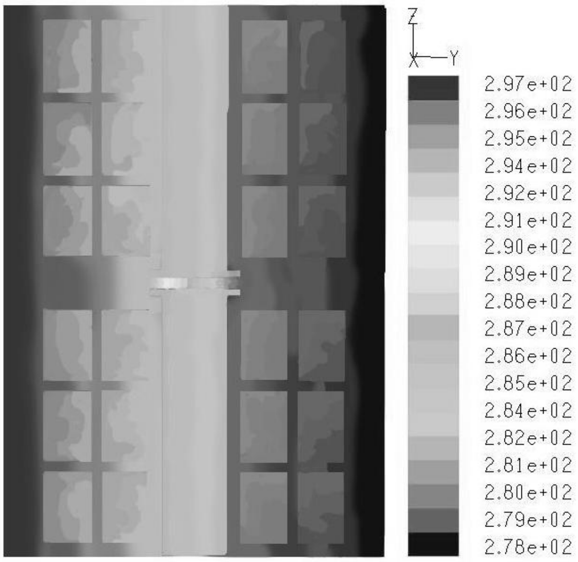


Fig. 11 Isothermal profile of Model 2

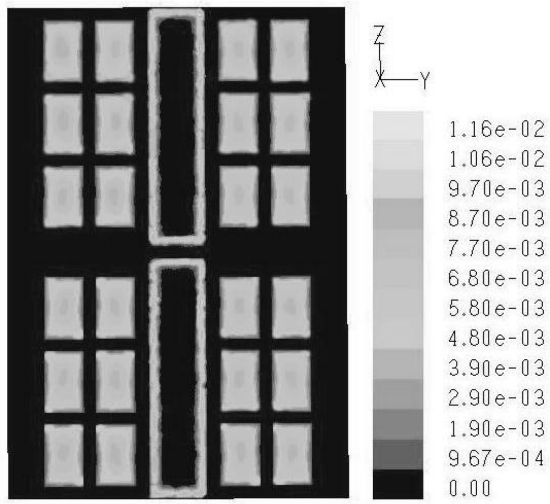


Fig. 12 Air velocity profile of Model 2

4.3. Thermal Behavior of Model 3

Based on the stimulation model 3 Fig. 13, the wall length increased from the cold surface to the warm surface by considering the air layer with 7 cm thickness between the internal and external walls. The results are indicated in Table 6.

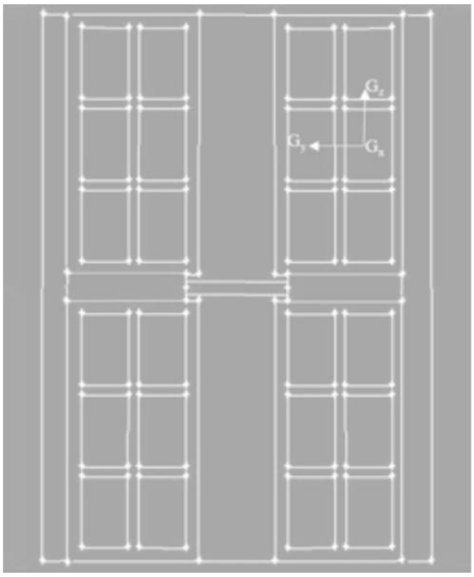


Fig. 13 Simulation of Model 3

Table 6 Obtained numerical results for Model 3

Thermal resistance (m^2K/W)	3.70
Inner surface temperature (° C)	23.85
Outer surface temperature (° C)	4.85
Maximum heat flux (W/m^2)	0.51
Minimum heat flux (W/m^2)	0.39
Thickness (cm)	31
Maximum air speed (m/s)	9.90

According to this model, it was observed that the air layer between the internal and external walls, the connection between warm and cold surfaces of clay blocks through convection was completely stopped. Fig. 14 represents the reduction in thermal flux by 50% and 20%, respectively, in comparison to model 1 and model 2. Further, the significant impact of air trapped between the layers was emphasized. No difference in temperature was observed between the inside air and wall surfaces, compared to the previous models Figs. 15, 16. However, the maximum air speed increased by 9.90 meters per second Fig. 17. In conclusion, thermal conductivity was more substantial based on the model 3.

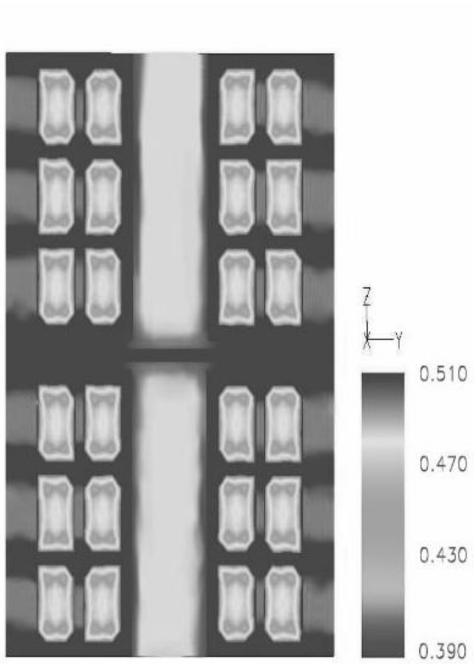


Fig. 14 Heat flux profile of Model 3

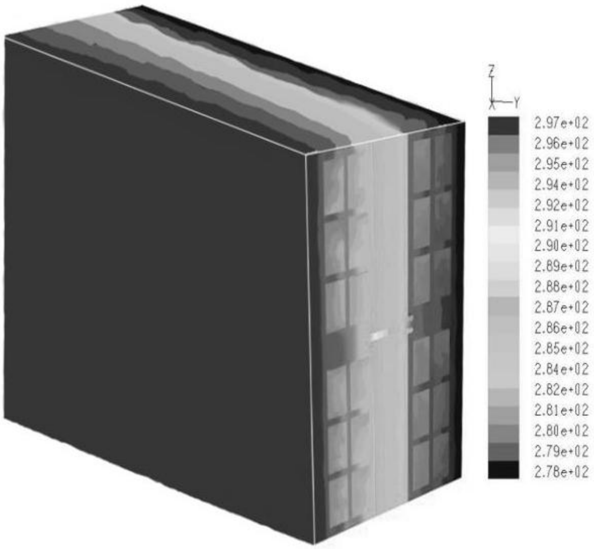


Fig. 15 Isometric profile of Model 3

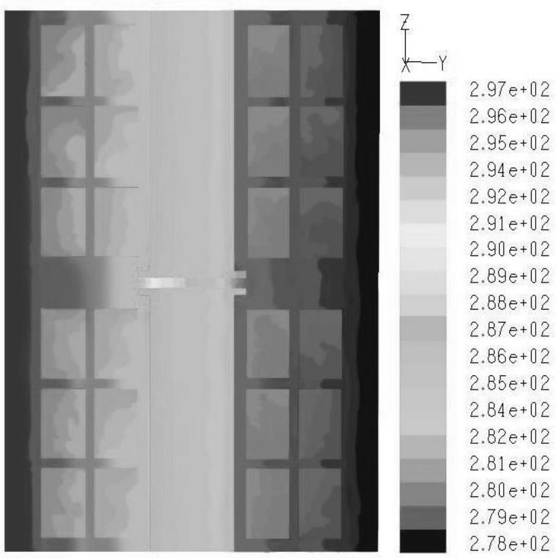


Fig. 16 Isothermal profile of Model 3

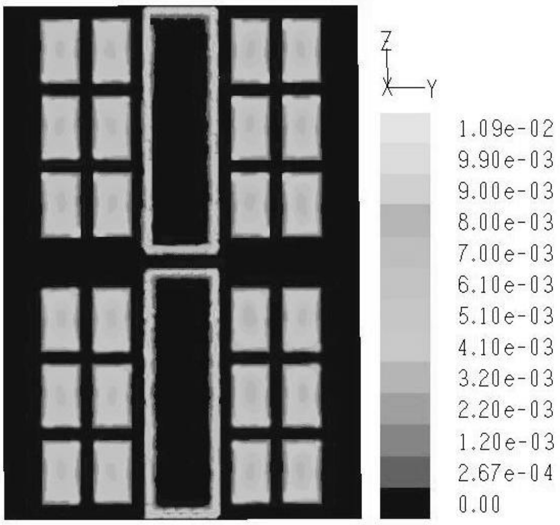


Fig. 17 Air velocity profile of Model 3

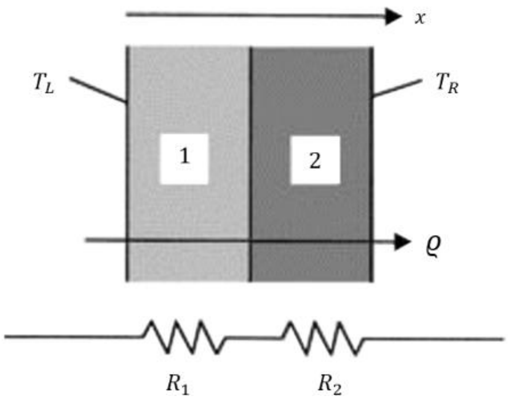


Fig. 18 The heat transfer across the wall (series thermal resistance)

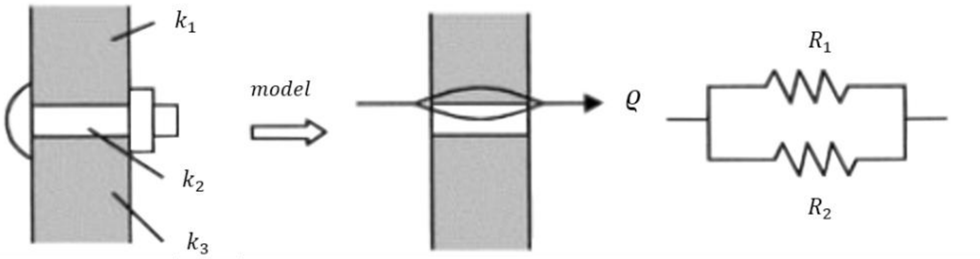


Fig. 19 The heat transfer of the wall (parallel thermal resistance)

4.4. Computational methods

In order calculate the thermal resistance of the walls, a thermistor circuit approach was used as follows:

$$Q = \frac{T_1 - T_2}{R} \tag{1}$$

$$R_1 + R_2 \tag{2}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

Where, R represents the thermal resistance, Q indicated the heat transferred rate, T is used for surface temperature, L is regarded as the thickness of the Surface, K means the thermal conductivity, and A displays the surface Area (m^2).

The surface area of Model 1, 2 and 3 were 0.115 m^2, 0.105 m^2 and 0.105 m^2, respectively. It was assumed that the resistance of the air holes in the clay blocks was based on the conductive form rather than convective one. Therefore, the thermal resistance of the wall is calculated through the following equation:

$$R = \frac{L}{KA} \tag{4}$$

4.4.1. Calculation of Model 1

Fig. 20 illustrates seven vertical sections through a diaphragm wall. 20cm thick clay block walls are calculated below. The horizontal walls of the model including the holes (R_2, R_4 and R_6) have the highest thermal resistance. Further, the ultimate resistance of the Model is R= 6.373 k / w. The major part of the ultimate resistance (about 70%) is related to the air trapped inside the clay blocks cavity.

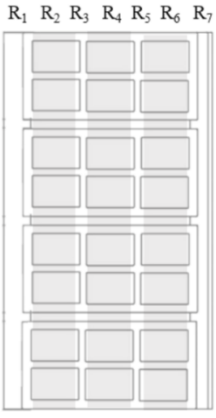


Fig. 20 Segmentation of thermal resistance in Model 1

$$R_1 = \frac{0.03}{1 * 0.115} \tag{5}$$

$$R_3 = \frac{0.008}{1 * 0.115} \tag{6}$$

$$R_5 = \frac{0.08}{1 * 0.115} \tag{7}$$

$$R_7 = \frac{0.03}{1 * 0.115} \tag{8}$$

$$\frac{1}{R_2} = 12 * \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.01}}\right) + 8 * \left(\frac{1}{\frac{0.055}{0.0422 * 0.25 * 0.036}}\right) + \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.02}}\right) \tag{9}$$

$$\frac{1}{R_4} = 12 * \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.01}}\right) + 8 * \left(\frac{1}{\frac{0.055}{0.0422 * 0.25 * 0.036}}\right) + \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.02}}\right) \tag{10}$$

$$\frac{1}{R_6} = 12 * \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.01}}\right) + 8 * \left(\frac{1}{\frac{0.055}{0.0422 * 0.25 * 0.036}}\right) + \left(\frac{1}{\frac{0.055}{1 * 0.25 * 0.02}}\right) \tag{11}$$

The ultimate resistance of Model 1: $R = \sum_{i=1}^{7} R_7 = 6.373$ (12)

4.4.2. Calculation of Model 2

This model represents the calculations of the cavity wall with a 5 cm air layer Fig. 21. The horizontal wall including the holes (R2, R4, R8 and R10) and an air layer between the two walls (R6) indicate the highest thermal resistance of the wall. The ultimate resistance of the model is R= 24.4609 k/w, among which 70% is related to the air trapped between the layers and about 20% is related to the air trapped inside the clay holes.

$$R_1 = \frac{0.03}{1 * 0.105} \tag{13}$$

$$R_3 = \frac{0.08}{1 * 0.105} \tag{14}$$

$$R_5 = \frac{0.01}{1 * 0.105} \tag{15}$$

$$R_7 = \frac{0.01}{1 * 0.105} \tag{16}$$

$$R_9 = \frac{0.08}{1 * 0.105} \tag{17}$$

$$R_{11} = \frac{0.03}{1 * 0.105} \tag{18}$$

$$\frac{1}{R_6} = \left(\frac{1}{\frac{0.07}{0.0242 * 0.105}}\right) + \left(\frac{1}{\frac{0.07}{16.27 * \frac{3.14 * 0.004^2}{4}}}\right) \tag{19}$$

$$\frac{1}{R_2} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{20}$$

$$\frac{1}{R_4} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{21}$$

$$\frac{1}{R_8} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{22}$$

$$\frac{1}{R_{10}} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{23}$$

The ultimate resistance of Model 2 is $R = \sum_{i=1}^{11} R_{11} = 24.4609$ (24)

4.4.3. Calculation of Model 3

Fig. 22 displays seven vertical sections through a diaphragm wall. The cavity wall was calculated with a 7 cm air layer. The calculation of Model 2 indicated that horizontal walls such as R_2, R_4, R_8 and R_{10}, along with an air layer between two layers (R_6) had the maximum thermal resistance of the wall. The ultimate resistance of this Model is R = 31.7460 k/w. In addition, a 2 cm increase in air layer led to a 10% increase in the thermal resistance reaching 80%, compared to the previous Model and. Further, the resistance of the air inside the clay block holes reached 17%indicatingthat the amount of air layer played a significant role in the thermal resistance of the wall.

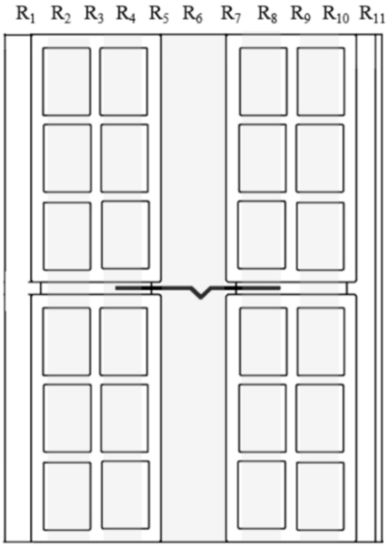


Fig. 21 Segmentation of thermal resistance in Model 2

$$R_1 = \frac{0.03}{1 * 0.105} \tag{25}$$

$$R_3 = \frac{0.08}{1 * 0.105} \tag{26}$$

$$R_5 = \frac{0.01}{1 * 0.105} \tag{27}$$

$$R_7 = \frac{0.01}{1 * 0.105} \tag{28}$$

$$R_9 = \frac{0.08}{1 * 0.105} \tag{29}$$

$$R_{11} = \frac{0.03}{1 * 0.105} \tag{30}$$

$$\frac{1}{R_6} = \left(\frac{1}{\frac{0.07}{0.0242 * 0.105}}\right) + \left(\frac{1}{\frac{0.07}{16.27 * \frac{3.14 * 0.004^2}{4}}}\right) \tag{31}$$

$$\frac{1}{R_2} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{32}$$

$$\frac{1}{R_4} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \tag{33}$$

$$\frac{1}{R_8} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \qquad (34)$$

$$\frac{1}{R_{10}} = 8 * \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.01}}\right) + 6 * \left(\frac{1}{\frac{0.036}{0.0422 * 0.25 * 0.055}}\right) + \left(\frac{1}{\frac{0.036}{1 * 0.25 * 0.02}}\right) \qquad (35)$$

The ultimate resistance of model 3 is $R = \sum_{i=1}^{11} R_{11} = 31.7460$ (36)

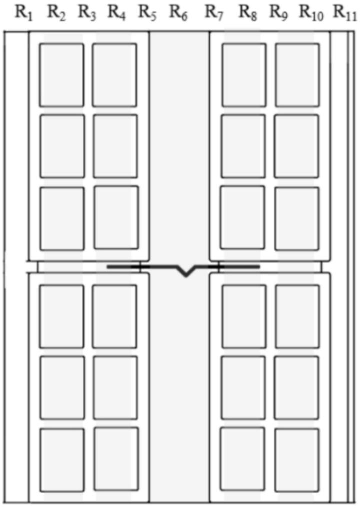


Fig. 22 Segmentation of thermal resistance in Model 3

5. DISCUSSION

The thermal resistance (RC) of the air-filled wall cavity is different based on the air layer thickness. The results indicated that the thermal resistance for the wall made of 20 cm clay blocks, the wall cavity with 5 cm wide air layer and the wall cavity with 7 cm wide air layer were R =6.373 k/w, R =24.4609 k/w, and R=31.7460 k/w, respectively. In addition, regarding stimulation results, the thermal resistance for the wall made of 20 cm clay blocks, the wall cavities with 5 cm wide air gap and the wall cavities with 7 cm wide air gap were R = 0.733 m^2 k/w, R = 2.5684 m^2 k/w, and R = 3.333m^2 k/w respectively. The numerical results of the thermal resistance of three modeling walls were almost consistent with the stimulation results. Therefore, the large amount of resistance is related to the thermal resistance of the air layer between the walls. An increase in the air layer thickness leads to a decrease in the effect of the air resistance in hollow block. In addition, the effect of the thermal resistance of air layer was more considerable. As shown in Fig. 23, the amount of resistance in Model 3 was 5 times and 1.5 times more than that of the Model 1 and model 2, respectively. Further, the heat transfer of the walls was calculated based on the equation (37).

$$q = \frac{A\,\Delta T}{R} \qquad (37)$$

The amount of heat transfers through the 20 cm wall, the wall cavity with 5 cm wide air layer, and the wall cavity with 7 cm wide air layer were q =0.7767 w, and q = 0.5985 w, respectively, which demonstrated a minor error in calculating the heat transfer results obtained via simulation method Fig. 24. Based on the results, Model 2 and 3 were regarded as one of the best examples of walls for optimizing energy consumption and reducing the cost stemming from heat loss through walls of buildings by reducing heat transfer by 75% and 85%, respectively.

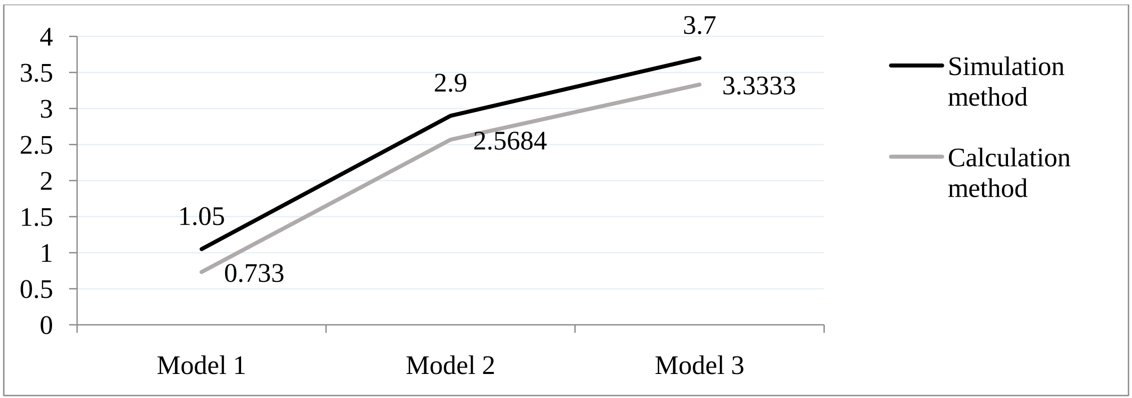


Fig. 23 The thermal resistance of the models (m^2k/w) regarding increasing air layer thickness

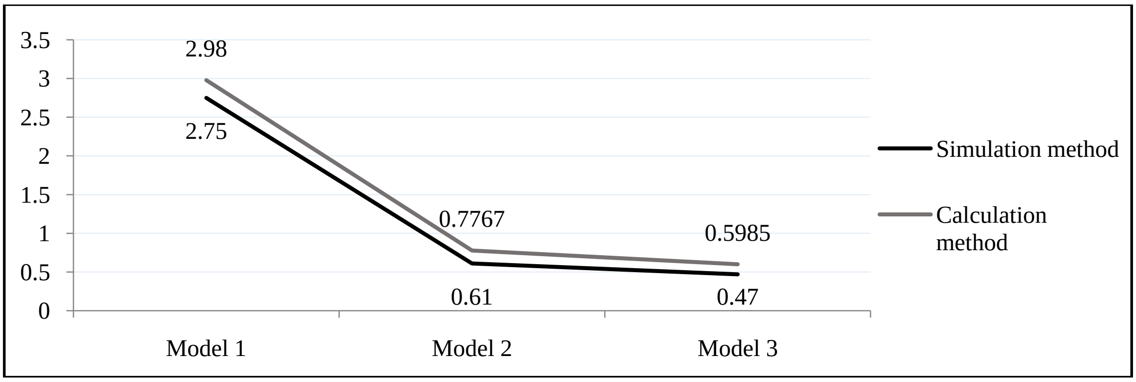


Fig. 24 Heat transfer of models (m2k/w) regarding an increase in entrapped air

The findings indicated that the rate of heat transfer and heat resistance was closely related to an increase in the air layer thickness. In addition, an improvement in wall layout can fulfill the energy-savings objectives determined in Chapter 19 of “Iranian National Building Code”. The findings are in line with another study conducted by [8], which examined the effect of block geometry on reducing the amount of penetrating heat flux. Further, [10] found that the change in the block hollow circumference to allow far more air circulation can significantly increase the thermal resistance of clay block. Furthermore, expanding the distance traveled by the heat from the warm to the cold surface of bricks through the body of clay blocks is regarded as one of the most effective ways to optimize the design of walls [11].

6. CONCLUSION

The walls are made from high heat capacity materials such as concrete or water in temperate and humid climates due to relatively warm and cold air and the sultry phenomena. However, the walls are insulated if they are made of high heat capacity. Some researches emphasized that using cavity walls and the air brick to ventilate the cavity wall can increase the potentials for energy-saving in this climate [5].

Practically, it is worth noting that an increase in thermal resistance is associated with an increase in wall thickness and accordingly heavier wall, despite the limitations on the thickness of the wall and the clay block. Therefore, based on the results, the amount of thermal flux decreases and the thermal resistance increases by changing the layout of the clay block, prolonging the heat transfer from the hot surface to the cold surface of the wall, and increasing the air of the intermediate wall of the two wall layers, as well as the clay block holes. In addition, the thermal resistance increases and the thermal bridge is removed by decreasing the number and thickness of transverse walls between the surfaces of the clay block and changing its layout from horizontal to vertical in a wall with 20 cm thickness to a cavity wall with two 10 cm blocks, and removing the cross-link between internal and external walls.

Finally, it is worth noting that increasing the thermal resistance of the wall by increasing the thickness of air layer in cavity walls results in decreasing the heat transfer significantly. Economically speaking, heat transfer resistance should be implemented in terms of the square meters of the wall. The use of 7cm cavity wall with the layers of heat-resistant impressive R =3.333 m^2k/w per square meter of wall surface and less expensive layers can increase the thermal insulation and accordingly the cost of high fuel consumption will save for the future.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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HOW TO CITE THIS ARTICLE

A. Emami., E. Barzamini., S. Aloustani., (2017). Evaluation of the Thermal Performance of the External Walls of Buildings with Hollow Clay Blocks in Temperate and Humid Climate. Int. J. Architect. Eng. Urban Plan, 27(2): 83-94, December 2017.

URL: http://ijaup.iust.ac.ir/article-1-207-en.html