J Ther Eng, Vol. 10, No. 4, pp. 1011–1020, July, 2024

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000845

Research Article

Thermal performance analysis of local building materials for energy efficiency in Iraq

Riyadh Husni ALJAWAD[1], Atif Ali HASAN[2], Mahmood Hussain KHALEEL[3], Omer Adil ZAINAL[4]

[1]*Department of Engineering Construction and Projects, Middle Technical University, Baghdad, 8998+QHJ, Iraq*
[2]*Department of Power Machines, Institute of Technology, Middle Technical University, Baghdad, 8998+QHJ, Iraq*
[3]*Department of Power Machines, Kirkuk Institute Northern Technical University, Mosul, 41000, Iraq*
[4]*Department of Mechanical Engineering, College of Engineering, University of Kirkuk, Kirkuk, 36013, Iraq*

ARTICLE INFO

Article history
Received: 27 July 2023
Revised: 08 December 2023
Accepted: 09 December 2023

Keywords:
Aso Brick Factory Production; Building Thermal Properties; Thermal Behavior; Traditional Materials

ABSTRACT

Due to the harsh climate in summer of the Iraq, the outer shell of buildings is exposed to heat flow from the outside ambient to the inside building space, and causes increase of heat gain in the space, so it requires the using of air conditioning units, which is led to consume electrical energy to remove that heat gain. The objective of this paper to reduce levels of electrical consumption by choosing best building materials. The best building materials which are those have good resistance against heat flow, that's why the cost of building material difference each of other in the local market. While Aso Company for Bricks is considered one of the largest modern companies producing building materials and the most present in the entire area of Iraq. The aim of this study to focus was on its products, and five types models were selected and compared with the traditional model that is still used now. Therefore, heat gain test was experimentally conducted in a test room located in Baghdad city (zip code 10016, latitude of 33.2°N and longitude of 44°E) for one day from 6 a.m. to 7 p.m. and for the 21st day of each of the summer months (May to September) in 2021. The electrical energy consumed by the air-conditioning unit in the test room was measured, and the researchers concluded that the percentage of energy savings achieved within the limits (13.88–1.2%) depending on the type and thickness of the building material. Results shown the best building material is (Type IV), these blocks can be used to create walls with a thickness of 200 mm or 100 mm. Building blocks (the fourth kind), on the other hand, have a delay time of 6:30 hours and a thermal shrinkage coefficient of 0.63. They also have a density of 919 kg/m^3. Therefore, the electrical consumption by A.C. units if used the blocks (Type IV) less than others.

Cite this article as: Aljawad RH, Hasan AA, Khaleel MH, Zainal OA. Thermal performance analysis of local building materials for energy efficiency in Iraq. J Ther Eng 2024;10(4):1011–1020.

***Corresponding author.**
*E-mail address: mahmood.aboretag.husain@gmail.com

This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University Press, İstanbul, Turkey

INTRODUCTION

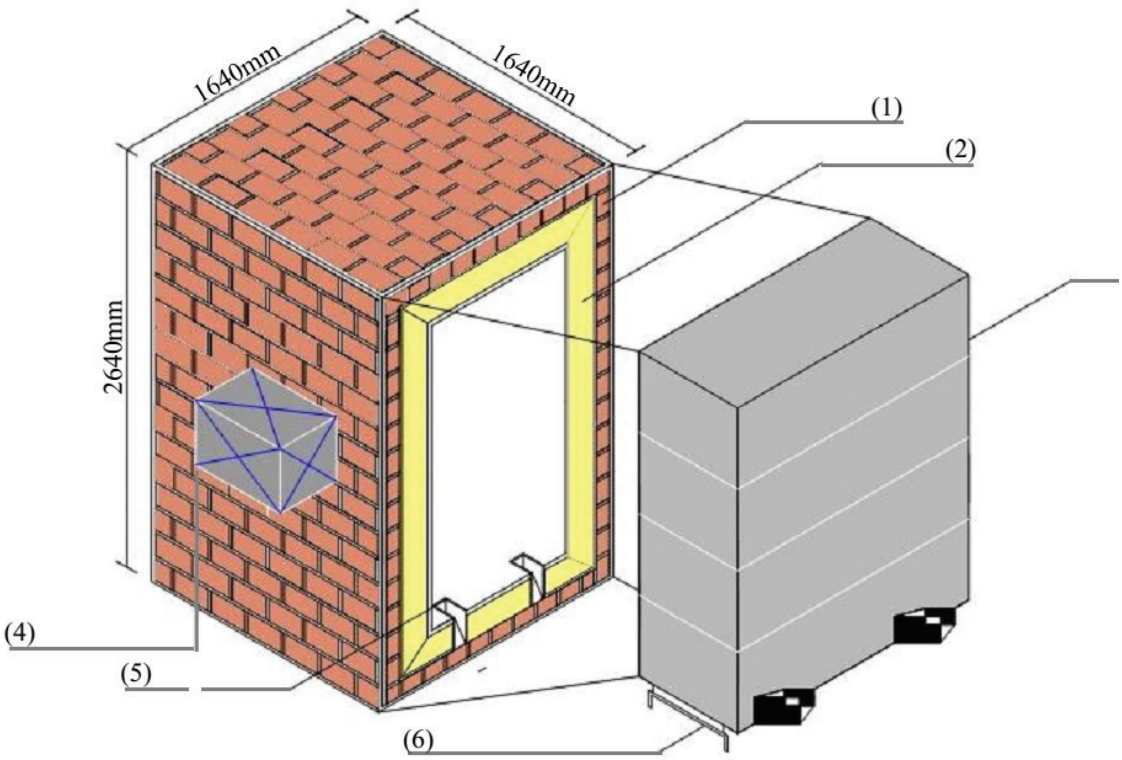
Brick has been the main building material used for the construction of buildings of all kinds in most regions since the beginning of the last century and is still used to this present time [1]. The traditional wall is composed of 240 mm, with two external finishing layers of cement mortar of 20 mm thickness and an inner layer of stucco 25 mm thick. It provides a total heat transfer coefficient of (1.514) W/m2.oK, while the amount of thermal reduction is (0.406), and the thermal delay time is (3:30) hours. The amount of heat transferred from the environment in the summer through a wall's surface area to the building space is 37 kilowatts/m^2 [2]. The heat caused by the environment through the area of the wall facing the environment will change the values of the design conditions of thermal comfort within the building space, which uses air conditioning units for the purpose of treating that space to maintain comfortable zone conditions. These devices will work for longer periods and consume more electrical energy. It is estimated that the percentage of electrical energy spent annually to operate air conditioning units in buildings constructed by this system amounts to approximately 70% of the total energy consumed by the Iraqi family [3]. Therefore, any reduction in the level of what is consumed for the purposes of annual air conditioning will inevitably lead to a reduction in the demand for energy produced, as well as reducing the percentages of carbon liberated from burning fuel in power plants. From the above, we can distinguish the efforts made to reduce the effect of environmental factors through the building shell into several axes, the first of which is to increase the amount of the thermal resistance value of the wall section, which is achieved by using thermal insulation (expanded polystyrene) with a thickness of 65 mm [4]. Calculating thermal loads inside buildings and optimizing the use of buildings and insulating materials because availability of such data is important for the climatic design of buildings, thermal load calculations for air conditioning, and choosing the insulating materials for the enhancement of building thermal performance [5]. Adding the thermal insulation to the traditional building block will reduce the value of the overall heat transfer coefficient (U) from (2.39) to (0.431) W/m2.K [6]. As well as providing an unventilated air gap within the structural section of the building's exterior [7], The values for the cooling load temperature differential and heat gain are significantly influenced by solar radiation flux, ambient air temperature, surface absorptivity, and the thermal and physical characteristics of the building walls and roofs [8]. The square geometry of buildings with an aspect ratio of 1:1 achieves an energy savings of about 10% of the annual air conditioning load compared with the rectangular shapes with aspect ratios of 1:2, as well as the highest savings due to the best direction of buildings at about 1.43% of the annual air conditioning load, while the orientation effect of covering the building's external roof reduced the amount of heat gain for the building by about 54% [9,10] or using natural ventilation, an open gap through which the air of the environment moves will have a good effect on reducing the energy consumed for air conditioning [11]. Likewise, more than 90% of space users feel thermal comfort while reducing the required load [12]. While the use of the open sky court in most high buildings as a source of air movement inside the building will lead to the same result in reducing the required energy [13], using the negative effect of sunlight for the purpose of providing good ventilation for the building [14]. Humidifying the environment's air before it passes into the open gap will absorb the accumulated heat in a sensible latent manner, thus reducing heat transfer from it into the building by 50% [15]. The use of multi-layered building materials instead of a single layer that has higher insulation will lead to an increase in the thermal resistance of the structural section [16,17], or the use of an air gap with reflective surfaces [18]. The use of thermal insulating boards made of remaining chicken feathers to form the finishing material [19], and the second of those axes is usually the use of expired materials and their reuse with the soil paste before reaching the heating stage (paper waste) [20] , cigarette butts [21], chicken feathers [22], any natural or agricultural residues such as straw or crushed eucalyptus bark [23], sunflower seed peels [24]. Upon heating, the degree of these additives will rise and burn, which leads to the production of porous building blocks, and this is reflected in a reduction in their density within the range of 33%, while the decrease in the conduction heat transfer coefficient (k) is in the range of 43% with an increase in the compressive strength by 24%. [25,26]. Sometimes construction waste is crushed from broken bricks and re-added to the soil paste [27], or glass powder [28], or alabaster dust [29]. For the production of building blocks characterized by high resistance to compression, and since the production of bricks requires raw materials free of salt and the continuation of production reduces the area of agricultural lands near the factory, the desert sand and soil were mixed in special proportions to produce bricks with acceptable properties and at the same time reduce the reduction of agricultural lands [30]. While the third axis to reduce the environmental impact on the building space is through the use of two-phase materials (PCM) inside the building block or within the finishing materials to increase the amount of heat stored and reduce the heat transfer from our homes into the building space [31]. Because of the energy crisis in the world, electricity is one of the types of this energy, and Iraq is also one of the countries in which there is an electrical energy crisis, and that air conditioning systems are the ones that consume a large amount of electricity. This study came for the purpose of reducing electrical energy consumption by choosing the best building materials for the walls and roofs of buildings. There are many brick building materials in the commercial markets in Iraq; for the purpose of rationalizing the electrical energy required to operate the air-conditioning units, it first requires a study of the thermal performance of the building materials which used to build the walls and roofs. to determine the best of them, and then requires the development of their use. From this point of view, the focus was on the factories with the highest productivity, as were the factories of Aso Company for the production of bricks and other building blocks, which were built in the city of Sulaymaniyah - Iraq, which covers the productivity of the entire area of Iraq through its agents, who are distributors in most of the governorates of Iraq, so samples were taken of what is used from its products to study their thermal behavior.

MATERIALS AND METHODS

For the purpose of conducting thermal tests and studying the thermal behavior of the walls under study, a room with three walls (known as the test room, as shown in Figure 1 was constructed on the third floor of a building in the city of Baghdad (zip code 10016, Latitude 33.2°N, longitude 44°E), The walls materials built from traditional fire bricks with 240 mm thick, and thermstone with 200 mm thick, and the floor covered with thermal insulating panels made of polystyrene with 200 mm thickness, which its specifications identified in Table 1, while the roof was roofed using the brick plastering method, with the addition of thermstone and thermal insulation to it. So internal dimensions of test room is (2x1x1) m were provided, and the fourth wall of the room (known as the test wall) was built on a moving cart of the building material to be tested and then pushed towards the room. The wall and the test room were sealed. The room is equipped with an air conditioning unit with a cooling capacity of 3.5kW (1 Ton of Refrigeration), to provide a standard comfortable thermal conditions inside the test room (26.5°C, 65% RH) [32]. It is directly connected to a cumulative electrical energy meter linked to the electrical grid supplying energy, to measure the total amount of electrical energy consumed throughout the test period.

A smart auto-digital thermometer was used to measure the temperature of the outside wall that faced the ambient air (To) and the ambient temperature in the shadow (Tsh). Employing digital thermometers, data logger with calibrated thermocouples, the temperatures of the inner wall-facing space (Ti) and the room air temperature (Tr) have been recorded. The readings were taken in 2021 on the 21st of the summer's months (from the 5th of May to the 9th of September), from 6 a.m. until 7 p.m. As a peak time and the which the Air-conditioner unit consume a big amount of electrical energy.

While the electrical energy meter has a direct connected to the electrical circuit that supplies the air conditioner, it



(1)The room's net specifications were 1 * 1 * 2 meters, where the wall was studied, (2) 200 mm insulation layer (3) wall under study ,(4) Air-conditioner, (5) slot for the wall mounted and (6) rectangle-shape support,

Figure 1. Experimental room for studied wall models details.

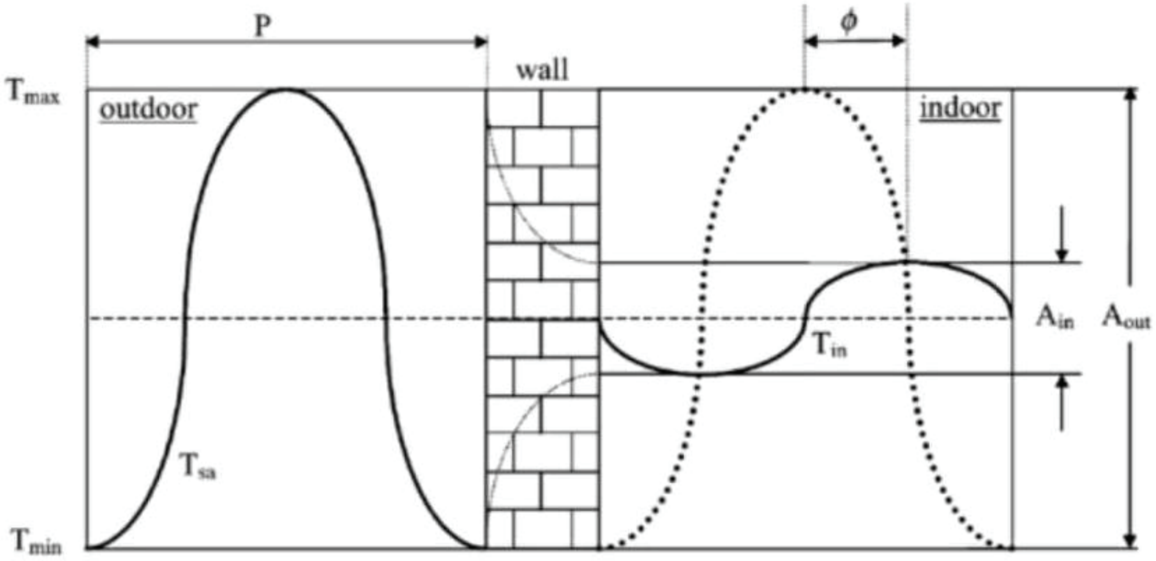


Figure 2. Time lag and decrement factor calculation.

also records the total electrical energy consumed by the air conditioner during its operating throughout the recording period of the measurements to collecting data, and the energy consumption of the all models of materials will be compared each other and with the traditional model, which this meter records the cumulative value of energy consumption since the start of operation until the temperature drops to the comfort value, converting this consumption to the annual amount mathematically and for each model of building consumed. The experimental reading was recorded through the summer months (May to September in 2020), from 6 a.m. to 7 p.m., and for the 21st day of each of the summer months (May to September) in 2021. The free convection heat transfer coefficient (h) between the interior surface of the test wall and the room environment can be calculated as [33].

$$h_{air} = 1.3(\Delta T_{i-r})^{1/3} \quad (1)$$

Then, the cooling load for the test wall (Q) will be equal to [33]:

$$Q_{cooling} = h_{air} \times A_s(\Delta T_{i-r}) \quad (2)$$

Where: (A_s) is the wall surface area**,** the thermal properties of that drilled cement mortar finishing material (density, (ϕ) Time lag, and decrement factor (DF)) were obtained as follows:

Density was measured in building materials laboratories at the Institute of Technology in Baghdad, while Time lag and decrement factor were calculated as illustrated in Figure 2, as in [32]:

$$\emptyset = t_{T_{in\ [max]}} - t_{T_{out\ [min]}} \quad (3)$$

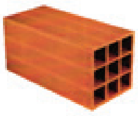
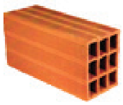
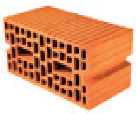
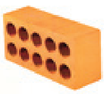
$$Df = \frac{t_{T_{in\ [max]}} - t_{T_{in\ [min]}}}{t_{T_{out\ [max]}} - t_{T_{out\ [min]}}} \quad (4)$$

Where: $t_{T_{in\ [max]}} - t_{T_{in\ [min]}}$ are maximum and minimum inside surface temperatures, respectively, while $t_{T_{out\ [max]}} - t_{T_{out\ [min]}}$ are the maximum and minimum outside surface temperatures, respectively.

Investigative Material's Model Description

The **first model is** a 400x200x200 mm non-load-bearing construction block with three rows of holes, each row containing three long holes listed in Table 1. The 400x46.7x53.4 mm size is represented by the manufacturer's manual as E. Due to the process of employing these blocks to form walls, it has been suggested that these holes only continue to be totally filled with air, that they are each 897760 mm^3 in size, and that they account for 56.1% of the block's overall volume. The **second type is** a non-load-bearing construction block with dimensions of (400x200x150) mm and three rows of holes, each row consisting of three longitudinal holes with dimensions of (400x33.4x53.4) mm. This building block is denoted by the manufacturer's manual symbol D. It is assumed that these holes are within one building block (6420816 mm3), and the percentage of them to the total volume of the mass is 53.5% due to the nature of using this block (with a thickness of 200 mm or 150 mm) (Type I., II.) in the construction of walls. **The third model's** construction block is denoted by C in the (non-load-bearing) manual and has dimensions of 400x200x100 mm. It also has three rows of holes, each row consisting of two

Table 1. Dimensions and thermal properties of studied wall models

Case study		Portrayal	Dimensions mm	Thickness mm	Density kg/m³	No. of bricks / m² of wall area	Time lag (Hr)	Decrement factor
First model			W=200 H=200 L=400	200	594	12.5	5:30	0.567
Second model	I II		W=150 H=200 L=400	200 150	625	12.5 16.7	5:00 3:30	0.52 0.45
Third model	III IV		W=100 H=200 L=400	200 100	713	12.5 25	4:30 2:30	0.47 0.39
Forth model			W=200 H=200 L=400	200	919	12.5	6:30	0.63
Fifth model			W=75 H=120 L=240	240	1265	55.5	5:00	0.53

longitudinal holes with dimensions of 400x33.4x53.4 mm. Due to the nature of using this block (200 mm thick or 100 mm thick) (Type III or IV) to build walls, it is assumed that these holes always remain completely filled with air, that they are each 4280544 mm3 in size, and that their ratio to the mass's volume is 53.5%. **The fourth type**, the construction block represented by F in the load-bearing suggestions, has dimensions of (400x200x200) mm, and its surface has many small holes of different sizes. Due to the nature of the way this block is used to construct walls, the bonding substance will only partially fill these gaps. **Fifth model:** The 240x120x75 mm construction block, denoted A in the product information, has two rows of holes, each containing five holes that are each 30 mm in diameter and 75 mm deep, due to the fact that this block is commonly used to build walls. The binder that is applied will partially fill these gaps. **The conventional** construction block has dimensions of (240x120x75) mm and two rows of holes, each with five holes, each measuring 25 mm in diameter and 75 mm in depth. The basic idea is to completely fill the holes in the bricks or blocks with air so that they remain at rest, meaning the air velocity is zero. While air gap at air velocity is zero become best insulation which resistance to heat flow.

RESULTS AND DISCUSSION

To achieve the research objective, one day every month was dedicated to investigating the building material's hourly thermal performance. Additionally, as a model and for all the construction materials that were investigated for follow-up thermal behavior during the seventh month.

Thermophysical Properties

Figure 3 shows the hourly thermal behavior using the seventh month as a model. This was used to determine the decrement Factor and the time lag for the passage of the impacted heat from the environment into the room. A heat wave that affects the environment in the summer will pass through seven resistors, four of which are conduction and three of which are convection (according to the nature of the mass composition), as shown in Table 1, where the mass density of the building block (the first model) is 594 kg/m³. This resulted in a 5:30-hour thermal delay and a 0.567 thermal shrinkage coefficient. The second model's building pieces, however, have a mass density of 625 kg/m³. It can be used to create walls that are either 150 mm or 200 mm thick. The thermal shrinkage coefficient for the wall (Type I) was (0.52), while the values for the wall (Type II) were (3:30) hours (0.45). The thermal delay time was measured at (5) hours. The third model's construction components have a mass density of 713 kg/m3. The delay period is (4:30) hours and the delay factor is (0.47) for the wall (Type III), while it is (2:30) hours and (0.39) for the wall (Type IV). These blocks can be used to create walls with a thickness of 200 mm or 100 mm. Building blocks (the fourth kind), on the other hand, have a delay time of 6:30 hours and a thermal shrinkage coefficient of 0.63. They also have a density of 919 kg/m³. Bricks, the fifth type, had a density of

1246 kg/m^3 and were found to have a thermal delay time of (5) hours as well as a reduction coefficient of 0.53. The sixth model, a conventional construction block, has the same dimensions as the fifth model but weighs 1460 kg / m^3. It is produced at a location in Baghdad. A decrease factor of 0.406 and a delay time of 3:30 hours were noted. From the foregoing, it can be seen that the thermal characteristics of a wall built from one of the first, second, or third building blocks and having a thickness of 200 mm will not be stable. This is due to the fact that, when using the first model, 25 pieces are required to construct the wall over an area of 2 m^2. Dimensions (200x200x400) mm: when using the model, it takes about 34 pieces. When using the third model, which has dimensions (200x100x400) mm, and stacking these pieces together to form the wall (12 m), spaces will be left between one block and another, and the use of materials for external and internal termination will lead to the closure of these spaces. However, because the thermal expansion coefficients of the building blocks and finishing materials are different, there will be gaps between one block and another. Instead, it will be partially open to the outside environment, and the more components that make up the wall's unit area, the more capillary gaps there are for the air to pass through [34]. The results showed that the drilled face of the finishing material gave a good result, and the more efficient wall that was drilled hole with 6 mm [35].

Surface Temperature of the Building Material Ti Facing the Room

The temperature of the inner surface of the wall facing the building space indicates the thermal resistance of the construction materials, which dampen the heat that impacts the environment. Ti, it is evident from Figures 2 and 3 that the Ti wall's surface temperature for the first model (200x200 mm) was measured at 38 °C. In comparison, when the second model's construction blocks (200 × 150 mm) were constructed with a thickness of 200 mm (Type I) and 150 mm (Type II), respectively, the inner surface Ti temperature was caused to be 38.3 °C and 39.8 °C. When building a wall with a thickness of 100 mm (Type III) and a thickness of 200 mm (Type IV), respectively, the temperature of the inner surface Ti was caused by the use of the third model building blocks (200×100) mm to be 38.9 °C and 41.9 °C, respectively. Ti achieved a temperature of 37.7°C when employing the bearing blocks (200×200) mm, the fourth model. While the fifth model's employing of perforated bricks caused Ti to be 38.4 °C, the typical wall recorded Ti at 39.2 °C.

The Temperature Difference Between Inner and Outer Surface of the Wall ΔTio

Despite the dampening of its high frequency, the thermal resistance of the building blocks against the environment's heat flow will result in an increase in the temperature of the interior surface of the building blocks facing the room. An essential factor to know about any construction material is the temperature differential measured between the two sides of the building block facing the environment (To) and the facing of the room space (Ti). Fortunately, notice that the first model building block with dimensions (200x200 mm) has generated a difference between the two surface temperatures (ΔTi-o) of 8.3 °C through the thermal behavior of the building blocks shown in Figures 2 and

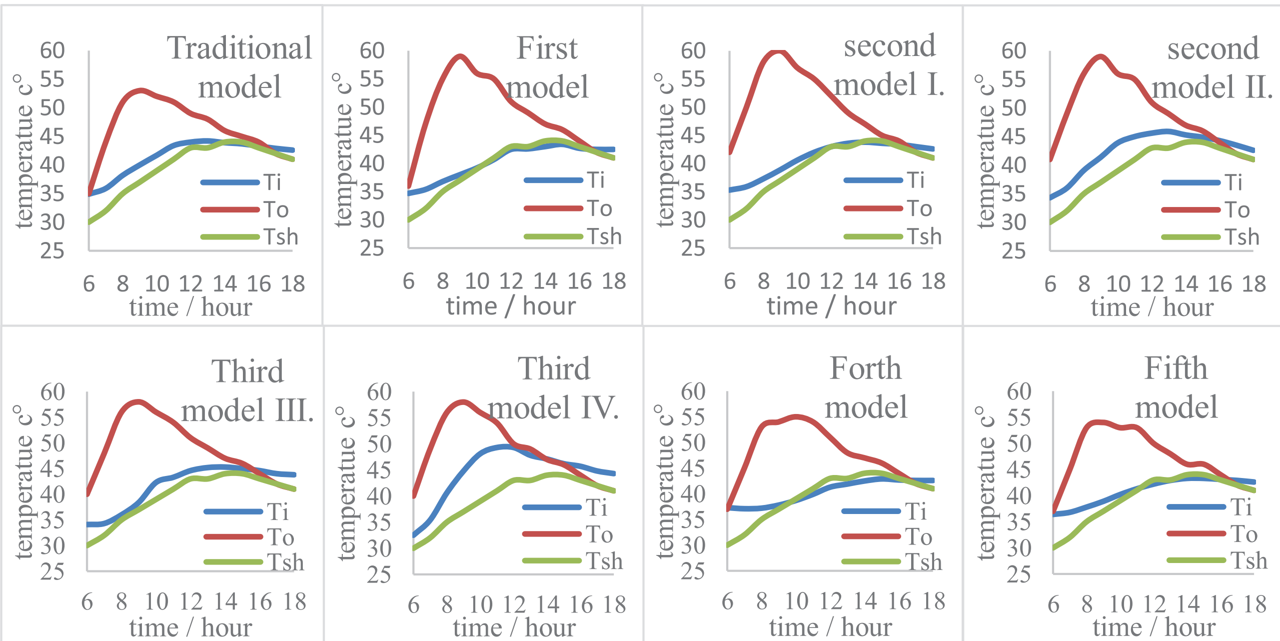


Figure 3. Thermal behavior of studied models.

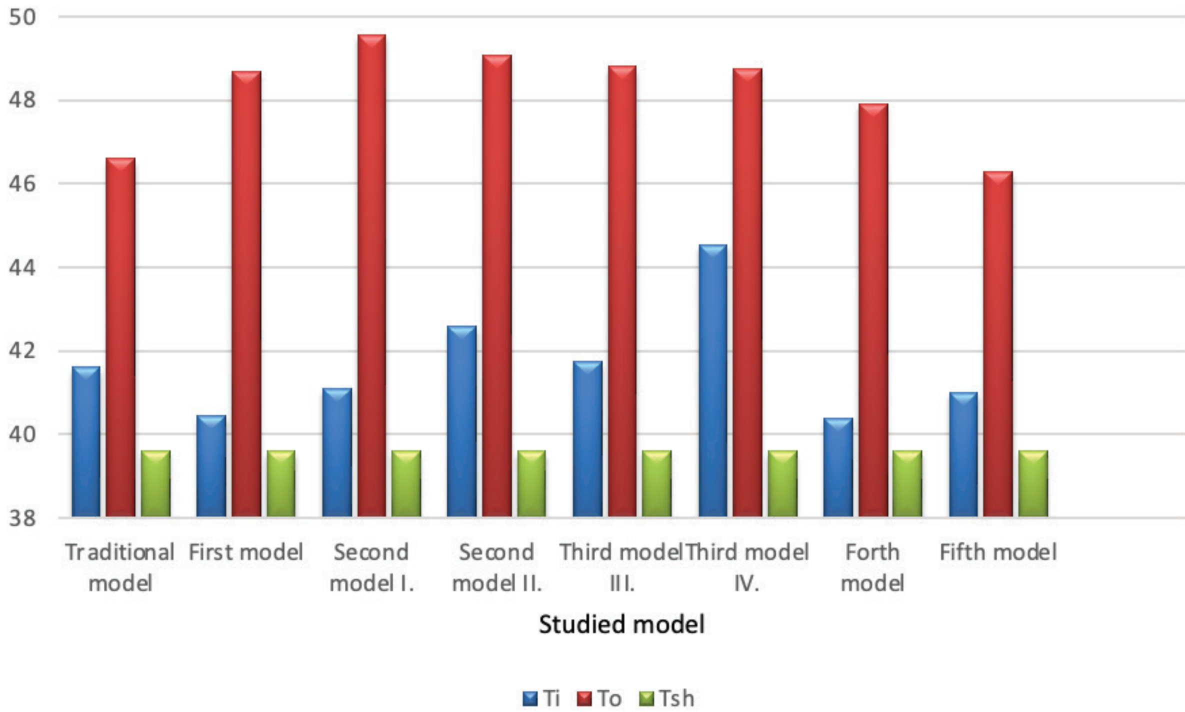


Figure 4. Temperature values of wall surfaces for all studied cases at June month.

3. The second model's construction block had dimensions (200x150 mm, but for thicknesses of 200 mm (Type I) and 150 mm (Type II), respectively, the surface temperature differential (ΔTi-o) was equivalent to 8.3 °C and 6.8 °C. The values of ΔTi-o for the third model's construction block, which has dimensions of 200x100 mm, were 7.6 °C and 4.7 °C for thicknesses of 200 mm (Type III) and 100 mm (Type IV), respectively. The fourth model's load-bearing blocks had dimensions of 200x200 mm, so the difference was 8.5 °C. The fifth model's utilization of bricks, which have a thickness of 240 mm, was 6.3 °C, compared to 5.1 °C for conventional, common bricks.

The Temperature Difference Between the Inner Wall Surface and the Room Air ΔTir

As shown in Figure 4, the building blocks of the first model with dimensions (200x200) mm give ΔTir =11.5 °C. The difference within the surface temperature of the building block and the design room air temperature is very important because it is a function of the heat gain, which requires the air conditioning unit to work on removing it. While the second model's 150x200 mm construction block produced 11.6 °C and 13.3 °C for thicknesses of 200 mm (Type I) and 150 mm (Type II), respectively. While the third model's construction block, which has dimensions of (100x200) mm, increased the temperature by 12.4 °C and 15.4 °C, respectively, for thicknesses of 200 mm (Type III) and 100 mm (Type IV). The fourth model building block's measurements (200x200 mm) were recorded at 11.4 °C, while the fifth model's 240 mm brick wall thickness was recorded at 11.9 °C and the conventional wall's 240 mm thickness was recorded at 12.7 °C.

Electricity Consumed and Percentage of Savings

Figure 5 shows the wall which constructed with the first model's building block. The total electrical energy employed by the air conditioning unit to maintain the test room's conditions to the comfortable standard conditions for a unit area (1x1) m^2 was 36.86 kilowatt-hours, saving 12.4% compared with the traditional wall which constructed from yellow bricks with a thickness of 240 mm . Total energy used for construction utilizing the second model's building blocks was 37.2 kWh and 44.6 kWh, respectively, saving 11.44% and 1.2 percent for walls with a thickness of 200 mm (Type I) and 150 mm (Type II). For the third model's construction using building blocks, the consumption was 40.6 kWh and 54.2 kWh, respectively, with reductions in consumption of 7.34% and -9.1% for thicknesses of 200 mm (Type III) and 100 mm (Type IV). The new conventional wall is 240 mm thick; therefore, building blocks with a thickness of 100 mm will need more energy to construct, but when compared to blocks with a thickness of 120 mm, the identical blocks have a yield of 6.4%. The wall, which was constructed using the fourth model's load-bearing blocks, had a 36.3 kilowatt-hour energy consumption and a 13.8% seasonal savings. The fifth model, which used red bricks, used 38.5 kilowatt-hours of energy and had an 8.34 percent savings ratio.

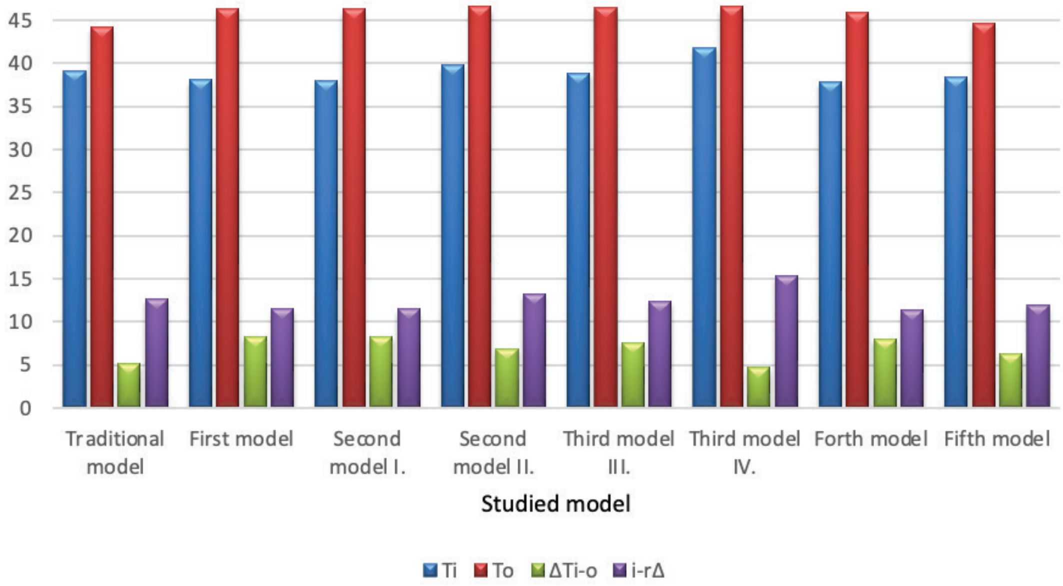


Figure 5. Seasonally average temperature values of wall surface.

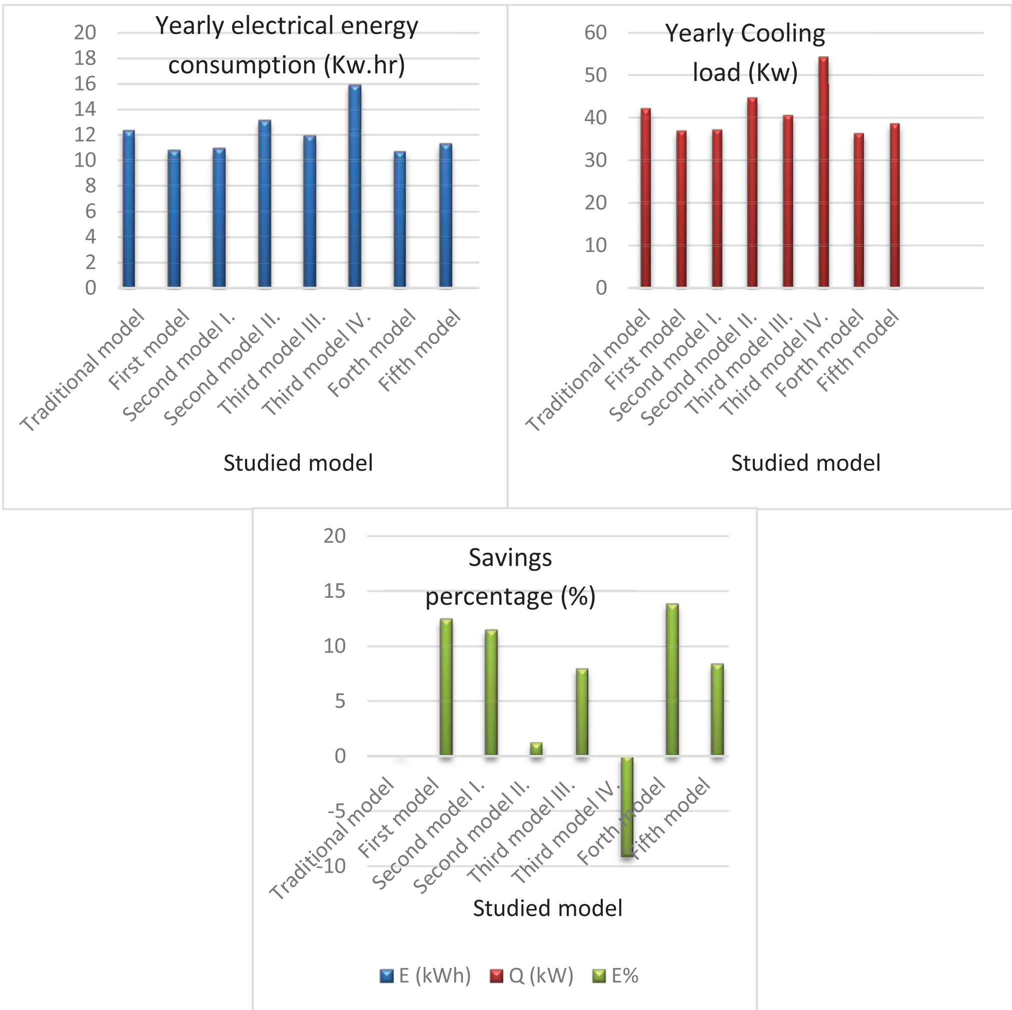


Figure 6. Yearly electrical energy consumption (kW) and percentage saving (%).

CONCLUSION

The following conclusions may be drawn from the findings and discussion:

1. The Aso Building Materials Company's building blocks are differentiated by their high thermal resistance, which reduces the amount of heat generated by the environment within the building's walls. Therefore led to reduce the electrical consumption by Air conditioning units.
2. A load-bearing construction block with dimensions of 400x200x200 mm reduced electrical energy used for air conditioning by the highest percentage, 13.8%; the savings equaled 1.4 cooling tons per square meter of outside surface area. This is due to the reduction in the amount of heat gain resulting from the use of these types of building materials.
3. During construction with a thickness of 200 mm, the non-bearing building blocks with dimensions (400x200x200), (400x200x150), and (400x200x100) mm achieved a percentage reduction of electrical energy in the range (12.44–79.4%); the reduction will be within the range (1.53–1.19) of refrigeration tons per square meter of the facade wall area, and the percentage decreases when building with a lower thickness. Which wall thickness proportional directly with heat resistance and inversely with heat flow.
4. When compared to common construction, using bricks with a thickness of 240 mm would result in a reduction of 8.34%, about 1 refrigeration ton per square meter of the facade wall area.
5. In the range (60–51%), the values of the mass density of non-carrying products were lower than those of common materials. The reduction of loads carried by the structure was impacted by the fact that the density reduced within 14% of the blocks and the load-bearing blocks fell to 37%.

From the above and looking at the results obtained, we note that choosing the type and thickness of building materials is an important matter that leads to reducing electrical energy consumption, which is reflected in the country's economy and thus politically affects the state's administration.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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