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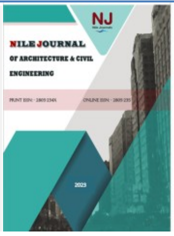

Experimental Study to Compare Thermal Properties of Bricks Made from Construction and Demolition Waste with Clay and Cement bricks

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Abstract:

The author conducted an experimental study for determining the thermal characteristics of bricks, which fabricated from the building construction and demolition waste. The brick units contain air spaces to increase the possibility of thermal insulation of walls. Such units are used as an alternative to red brick or cemented brick.

The results indicated that the manufactured units achieved highly successful of mechanical and physical properties. However, that indicator cannot be introduced as an only indication of the possibility of replacing red and concrete bricks by these manufactured units in the store. However, environmental and economic feasibility of these manufactured units must be studied. Therefore, this study investigates and identify the characteristics of the conductivity and thermal insulation of the manufactured units. In addition to the mechanical properties, the results of thermal properties are used for assessing the environmental performance of the manufactured units compared with thermal insulation properties of red and cemented bricks.

The significance of research linking a bunch of different sciences in architecture, science of material properties, heat transfer and environmental studies. In the framework of a systematic system works to achieve sustainability principles to reap the potential benefits of the application of one of the most important sustainability principles and techniques which is Recycling. This leads to the creation of a new concept of the architect's message beyond urban or architectural design that meets the needs of an individual or a body or institution to meet the requirements of the environment not only by shape and function, but also by a full curriculum that respects the environment and achieve sustainability principles.

Keywords: construction and demolition waste, building bricks, thermal properties, thermal insulation, a time Lag.

Introduction:

Egypt falls within the range of hot arid regions, where about 96% of Egypt's area falls within the scope of this region. The climate of dry desert areas is characterized by drought and very high temperatures that reach 40-50 º C. As a result, large amounts of heat leak into the building, which requires the consumption of a large amount of electrical energy for cooling. In order to reduce energy consumption, it is necessary to treat ceilings and walls thermally to reduce heat transfer and leakage into the building.

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Studies indicate that the percentage of heat leaking from walls and ceilings in the architecture of desert areas is estimated at about 60-70%, while the rest comes through window and door openings. Therefore, thermal insulation is of great importance because it reduces the heat leaking into the building and thus reduces the consumption of electrical energy used to cool it.

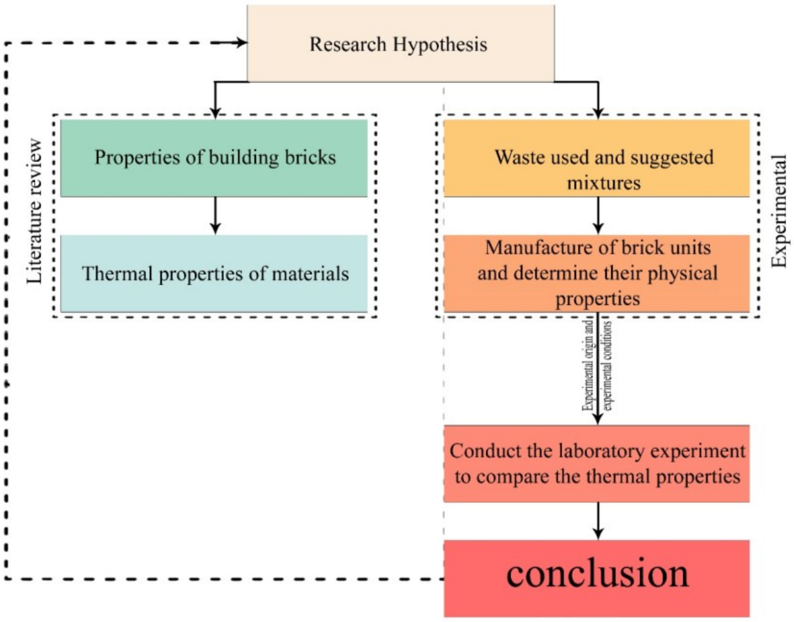
It has been proven that the thermal conductivity of a wall is inversely proportional to the thickness of the wall, and what affects the rate of heat flow between the external and internal air through a wall or ceiling material is the presence of a layer of static air adjacent to each of the two surfaces, as this layer gives the wall greater resistance because the air A poor conductor of heat, and the thickness of this layer decreases with the increase in air velocity and increases with the increase in surface roughness.[1]

The thermal absorption coefficient of red clay brick is 0.65 kW/m.C^0, while for cement bricks it is 0.85 kW/m.C^0, and they are the most common types of bricks in buildings in Egypt, so, the use of these types of bricks is one of the most important factors affecting positively the heat gain of buildings in Egypt and thus increasing the rate of energy use to operate air conditioning and refrigeration equipment in order to get rid of this heat gained, and from this point the need arose It is urgent to search for an alternative to clay or cement bricks that has a lower thermal absorption coefficient to rationalize the energy consumption used in cooling and air conditioning in an effort to reach thermal comfort within residential spaces.[2]

Research hypothesis:

The researcher seeks to prove a research hypothesis that the thermal properties of bricks made from construction and demolition waste are better than the thermal properties of clay and cement bricks.

Research Methodology:



1- Properties of building bricks:

It is divided into physical properties and mechanical properties.

1-1 Physical properties: These properties include shape, homogeneity, density, absorption, and flowering percentage.

1-2 Mechanical properties: Compressive strength is the basic mechanical property that must be assigned to different types of manufactured building units, followed by thermal properties such as insulation and heat absorption, but first we will talk briefly about these thermal properties.

2- Thermal properties:

It means the ability of the material to insulate thermally, and the thermal properties of a material can be identified in more than one way, such as the coefficient of thermal conductivity, which is a function of thermal transfer. And the properties of the surface of the material, reflective materials are considered effective in thermal insulation whenever they have a high ability to respond to radiation and heat waves, and the greater the gloss and refinement of the material, the greater its ability to insulate, and each of the thermal insulation materials has a specific thermal conductivity coefficient, and the greater the resistance of the material to leakage Heat increases its efficiency and gives better results in insulation [3], and we will learn about the means of measuring the thermal properties of a material as follows:

2-1 Thermal transfer: There are several ways of the natural transfer of heat, Fig (1):

a- Conduction: It is the direct flow of heat through the molecules of a substance from the part with the highest thermal energy to the part with the lowest thermal energy.

b- Convection: It means the flow of particles of the hot substance itself from one place to another using a surrounding medium, and this method often occurs with fluid materials such as liquids and gases, and depends on the density difference between the bodies, as the colder fluids are denser, while the hotter ones are the least dense.

c- Radiation: It is the transfer of heat directly by means of electromagnetic waves, and the method of heat transfer by radiation is distinguished by not requiring contact between two different bodies.[4]

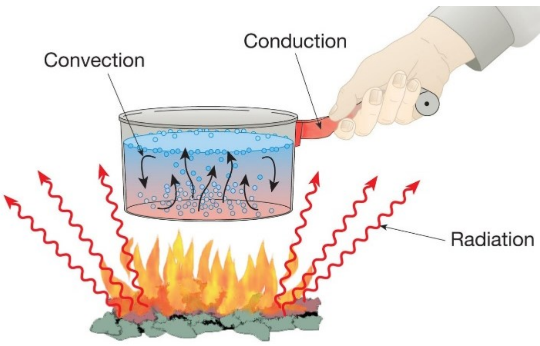


Figure 1: **Three forms of Heat transfer** [5]

2-2 Thermal Conductivity & Resistance [6]**:**

The rate of heat transfer from and to the building is affected by the natural thermal properties of building materials, which are thermal conductivity and thermal resistance. The coefficient of thermal conductivity of a material is the amount of heat flowing by conduction per unit time through a unit of thickness per unit area with a difference of a thermal measurement unit between the two surfaces of the material, this is assuming that the temperature is on both sides of the material And its distribution through it is homogeneous and constant over time, and the thermal conductivity coefficient is measured in a unit of measurement that is joules / second.m^2.C^o

As for the resistance of the material to the heat flow (s), it is the opposite of the thermal conductivity, and it has been proven that the thermal conductivity of a wall is inversely proportional to the thickness of the wall.

2-3 Heat Capacity [7]**:**

It is a value that indicates the ability of an object to store thermal energy. The heat capacity of a wall or ceiling is the amount of heat required to raise the temperature of a volume unit of 1 °C. It is known as the volumetric heat capacity of the material and its unit is joules/cm^3. °C. The heat capacity of the material depends on the specific heat. Density, which is the decisive factor in determining the thermal capacity of building materials, and then the conductive capacity of these materials, because the difference in specific heat between building materials is very small.

2-4 Time lag [8]**:**

The energy absorbed by the outer shell of the building raises its temperature, then returns to radiate it again after sunset, and the amount of heat received by any outer surface is not constant during the day due to the change in the angles and intensity of the sun's rays, and the heat moves from the outside to the inside through the thickness of the wall to reach the inner surface after A certain period of time, meaning that the temperature of the inner surface reaches its maximum after the outer surface in a period where the latter begins to lose its heat. It shows the heat capacity, thermal conductivity and lag time for some building materials.

The researcher chose the time lag of the material as an indicator for judging the extent of thermal insulation of the manufactured brick units and comparing them with similar clay and cement bricks, and then determining the thermal properties of each type of manufactured building units and knowing whether their thermal properties are higher or lower than clay bricks and cement bricks. This is because it is easy to test and gives results that have direct evidence of the thermal properties of the material without going into details and mathematical equations for heat transfer and thermal conductivity, which may take us to the field of heat transfer mechanics, a little away from the architectural specialization.

3- Waste used and suggested mixtures:

- Construction waste (represented by broken concrete)
- Marble ash

- Broken glass.
- Rubber residue.
- Iron slag.

3-1 Samples of building units are manufactured according to the following stages:

• Grinding the mixture materials, taking into account the varying proportions of these materials from one sample to another, to obtain different results that allow comparison to choose the best.

• Kneading mixtures with water.

• Casting brick molds in a form with specified sizes.

• Leave the mixtures inside the form and stack them on flat pallets for 3 days until solidify.

• Conducting tests on it to determine its properties.

This is done on the following mixtures:

1. Breaking concrete and marble ash with cement and water.
2. Breaking concrete, in addition to breaking glass with cement and water.
3. Breaking the concrete with the addition of rubber with cement and water.
4. Concrete fracture with iron slag added to it.

3-2 Compression resistance test:

At least three samples of each of the types to be tested were prepared with the following volumetric mixing ratios as shown in table 1:

Table 1

Components	Water	Cement	Sand	Broken concrete	Suggested addition
Parts	1	2	3	3	1.5
Ratio	10%	20%	28%	28%	14%

3-2-1 Devices:

A suitable mechanical or hydraulic pressure testing machine equipped with two loading plates so that the upper plate rests on a spherical base whose axis is identical to the center of the surface of the plate in contact with the sample, while the lower plate is fixed, Figure (2).

When the faces of the pallet are not sufficient to completely cover the sample surface, a smooth surfaced steel plate of a size sufficient to cover the sample shall be placed.

3-2-2 Test method:

The loading surfaces shall be covered to ensure that the load is distributed evenly with a gypsum or sulfur cover or the like, so that the two sides of the load after covering are balanced and perpendicular to the vertical axis of the unit, and that the thickness of the cover does not exceed 5 mm.

The unit that has been prepared for testing shall be placed between the two pallets of the testing machine with the load in the direction in which the unit will be used.

The load shall be applied taking into consideration not to ram the sample at an appropriate rate up to 30 Newton/mm2 per minute. When the load reaches half of the expected maximum load, the rate of increment shall be adjusted to become 15 Newton/mm2 until the fracture and the value of the maximum load shall be recorded [9].

3-2-2 Calculation method:

The compressive strength per unit is calculated as follows:

Compressive strength (m) = h/h (n/mm2)

Where:

m = compressive strength n/mm2.

h = the maximum load that the brick can bear in Newton.

Q = average total area of the two faces of the brick subjected to loading in mm.

Then the arithmetic mean of the compressive strength of the tested units is calculated [10]

Figure 2: **Different types of compression testing machines and a sample of testing bricks in its iron form** [11]

3-3-3 Pressure resistance test results:

The researcher tested different mixtures previously used to manufacture building bricks. These tests yielded the following results:

- By using crushed concrete in addition to marble ash with cement and water, it was possible to manufacture building units of heavy load-bearing bricks with very high compressive strength that achieved an average of 13.1 Newton / mm ^{2}, and an average absorption rate of 5.4%, which is almost a quarter of the percentage allowed in the Egyptian code. Not more than 16% for bearing bricks and not more than 20% for non-bearing bricks.
- By using broken concrete in addition to breaking glass with cement and water, it was possible to manufacture building units of heavy load-bearing bricks with high compressive strength that achieved an average of 9.9 Newton / mm ^{2}, and an average absorption rate of 6.13%, which is approximately one-third of the percentage allowed in the Egyptian code.

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- By using crushed concrete plus iron furnace slag with cement and water, it was possible to manufacture building units of heavy load-bearing bricks with high compressive strength that achieved an average of 11 Newton / mm ^{2}, and an average absorption rate of 5.6%, which is almost a quarter of the percentage allowed in code.
- By using crushed concrete in addition to chopped rubber with cement and water, it was possible to manufacture building units of non-heavy load-bearing bricks that have low compressive strength, achieving an average of 3.03 Newton / mm^2, which is an average that is in line with the minimum limits of the Egyptian code, and achieved an average absorption rate of 6.21%, which is Almost a third of the percentage allowed in the Egyptian code.

After the manufactured brick units achieved success at the level of pressure tolerance and absorption, the researcher proceeded to measure the extent of their success at the level of thermal properties.

4- Comparison test of manufactured bricks, clay and cement bricks thermal properties:

The researcher conducted an experiment to compare the thermal properties of brick units manufactured from construction and demolition waste with those of clay and cement bricks.

4-1 Experimental origin:

The temperature of the external surfaces of the building elements exposed to sunlight and hot air during the day rises to reach its peak around midday, then begins to decrease until it reaches its lowest value during the hours after midnight, and the temperature change reaches the internal surfaces after a time difference ranging from Relatively short to several hours, depending on the composition of the element concerned. The time difference that a heat wave takes to move from the outer surface of an element to its inner surface is called the time lag - as previously explained- and is symbolized by (Θ) and measured in hours, Figure(3).

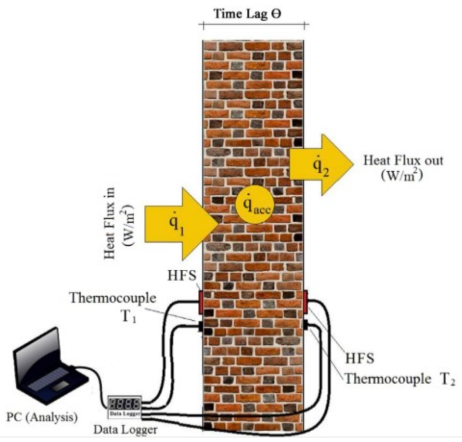

Figure 3: **Experimental origin and time lag** [12]

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As for the ratio between the maximum change in the internal surface temperatures of an element and the maximum change in the external surface temperatures during a period of (24) hours, it is called the factor decrement, and it is symbolized by (μ) and is given by the relationship:

Decreasing coefficient (μ) = maximum change in inner surface temperature / maximum outer surface temperature change [13]

Accordingly, it is possible to judge the thermal behavior of the bricks by exposing one of its faces to a known amount of heat and measuring the thermal change in the face opposite the face exposed to heat in a certain period of time, provided that the brick is placed in a position simulating its position in the built wall, and in this case it represents the source of heat The solar radiation falling on the exterior wall of the building, and one of the faces of the brick is the face exposed to solar radiation and represents the outer surface of the wall, and the other face to be measured by the temperature change is the face that represents the inner surface of the wall, as in the figure (4).

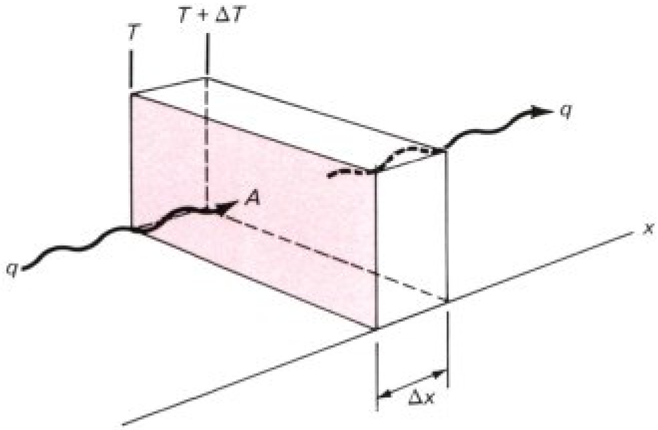

Figure 4: **Experimental origin and time lag** [14]

4-2 Experimental tools and devices:

- An ordinary air heater, powered by electricity, with a known wattage, equipped with a thermostat to control its temperature, and a temperature sensor.
- Two fork digital thermometers.
- Digital clock.
- Complete samples of manufactured bricks, perforated and cement clay bricks.

4-3 The idea of the experiment:

It's based on exposing one of the brick faces to a known amount of heat through an air heater and measuring the thermal changes that occur on the opposite face every 10 minutes for an hour with a digital thermometer, and conducting this process on brick units made from construction waste, the subject of the study, clay bricks and cement, but for doing this, several factors must be taken into account:

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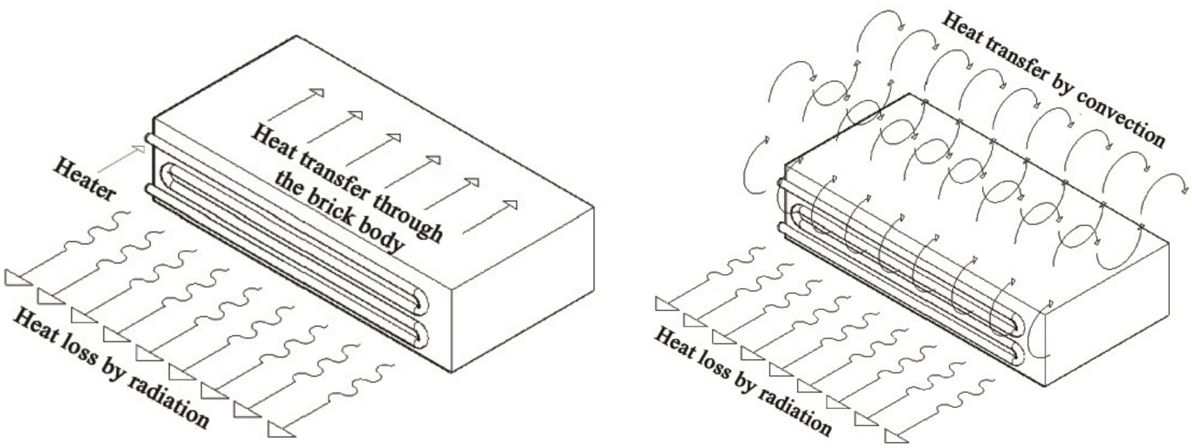
- Standardization of measurement time for all samples, whether of manufactured bricks or clay and cement, to avoid differences in air temperature.
- Standardize the place of measurement for all samples also to avoid the difference in air temperature.
- When one of the sides of the heater touches one of the faces of the brick, the other side of the heater - which is in contact with the air - loses an amount of heat in the direction of the air by radiation that cannot be measured, as in Figure (5a), and this affects the accuracy of the experiment.
- After a period of heating, the air surrounding the brick is heated by radiation and part of the heat is transferred by convection currents to the other side of the brick, as in Figure (5b), and this also affects the accuracy of the experiment.



(a) (b)

Figure (5): shows the heat loss of the heater by radiation and heat transfer by convection [11]

4-4 Experiment procedure:

a- In the light of the previous considerations, the researcher conducted the experiment on brick units manufactured once with clay bricks at the same time, and once with cement bricks at another time, so that the researcher placed a sample of manufactured bricks next to a sample of clay bricks and between them the heater once, Figure (6a), and a sample of manufactured bricks is next to a sample of cement bricks, and between them is the heater again, Figure (6b).

b- Then the researcher used the heater - with a capacity of 700 watts - to generate a temperature of 150 ^{o} C using the thermostat, fixing this temperature using the sensor, and thus the researcher ensured that the heater is in contact with the face of the brick on his right and the face of the brick on his left at the same time, so that no Thermal loss occurs in any direction, then he placed a barrier over the right brick and another barrier over the left brick to ensure the retention of convection currents between the two barriers, thus the following is done:

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• Samples are tested at the same time.

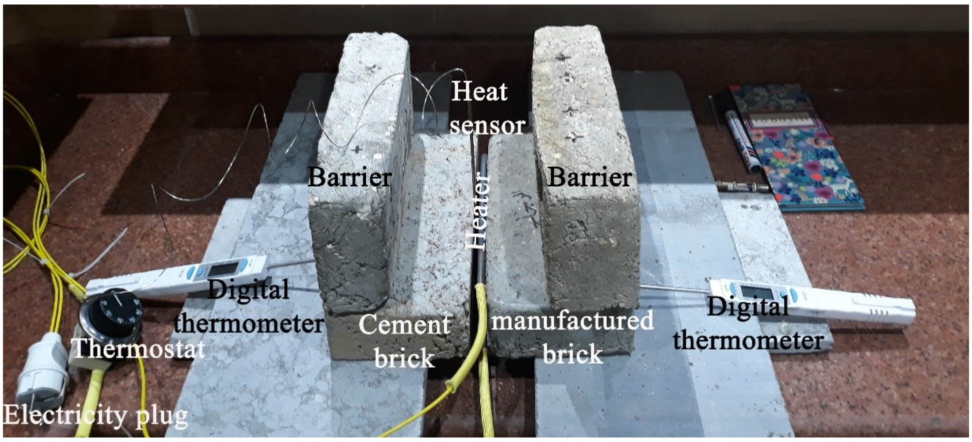
• Samples are tested in the same place.

• The heater does not lose any heat in the right or left direction because both surfaces of the heater are in contact with a test sample.

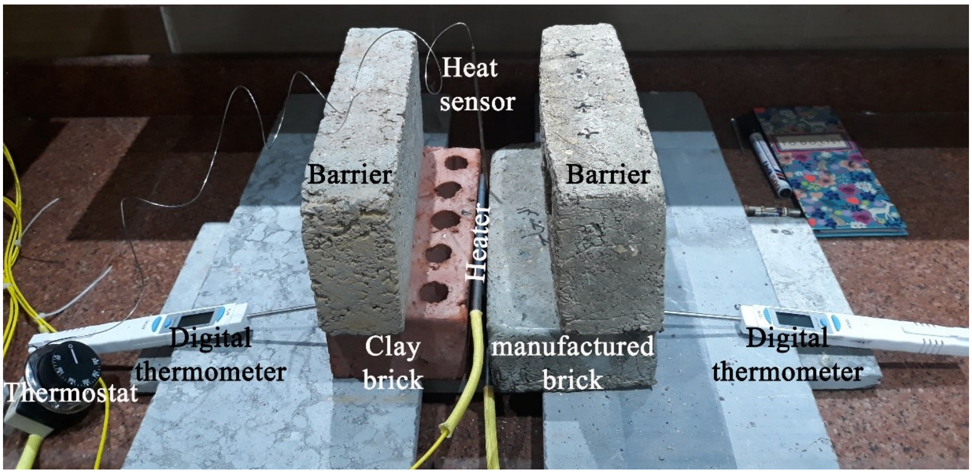
• A small part of the heater's heat is lost in the upward direction to heat the air above the two bricks by a small amount. This hot air is held between the two barriers placed so that its temperature does not transfer to the faces of the bricks under measurement, especially since the test period does not exceed an hour.

c- Using digital thermometers with a metal fork, the researcher monitored the temperature changes that occur on the other two sides of the two bricks under test, every 10 minutes calculated by the digital clock for an hour, and recording the results.

d- Readings are taken at four different points on each face, and the average temperature of the four readings is recorded.



(a)



(b)

Figure (6): Testing thermal properties of manufactured, clay and cement bricks [11]

The researcher conducted the experiment on the following pairs:

- Bricks made from construction and rubber waste, with clay bricks
- Bricks made from construction waste and glass, with clay bricks.
- Bricks made from construction waste and marble ashes, with clay bricks.
- Bricks made from construction waste and iron slag, with clay bricks.

Then he tested the following pairs:

- Bricks made from construction waste and rubber, with cement bricks.
- Bricks made from construction waste and glass, with cement bricks.
- Bricks made from construction waste and marble ashes, with cement bricks.
- Bricks made from construction waste and iron slag, with cement bricks.

5- Experimental results and discussion

After conducting experiments on the previously described pairs, the results of the experiments were as shown in the following tables and figures:

For example, when conducting the experiment on the first pair of bricks under test, the temperature reading on the face of the clay brick and the rubber brick at the beginning of the experiment indicated 30.3 ^{o}C, then the average readings were every 10 minutes at 4 different points on the face of each brick as shown in the table number (2)

In the beginning, the temperature was 30.3 5C on both sides under test, and after operating the heater at a temperature of 150 5C and the temperature was constant, the readings every 10 minutes at the face of the clay brick were 31.2, 31.9, 32.6, 33.6, 35, 36.3 5C, i.e. at an average rate of increase. of about 1.2 5 m every 10 minutes, while the readings every 10 minutes at the face of the bricks made of construction and rubber waste were 30.9, 31.2, 31.6, 32.1, 32.6, 33.3 5 m, i.e. Figure (7), an average increase rate of about 0.48 ^{o} C every 10 minutes, meaning that the average The heat transfer through the body of this brick is equal to 0.4 of the rate of heat transfer through the body of the clay brick, meaning that the thermal insulation of this brick is approximately two and a half times the thermal insulation of the clay brick. Good for heat.

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Table2: Time lag for clay bricks with Recycled rubber bricks [11]

Time (minutes)	Clay Bricks (ºC)	Rubber Bricks (ºC)
0	30.3	30.3
10	31.2	30.9
20	31.9	31.2
30	32.6	31.6
40	33.6	32.1
50	35	32.6
60	36.3	33.3
70	37.5	33.8

Table3: Time lag for clay bricks with Recycled glass bricks [11]

Time (minutes)	Clay Bricks (ºC)	Glass Bricks (ºC)
0	29	29
10	29.3	29.1
20	29.7	29.5
30	31.1	29.9
40	31.9	30.7
50	33.1	31.6
60	34.1	32.4
70	35	33.3

Table4: Time lag for clay bricks with Recycled marble ash bricks [11]

Time (minutes)	Clay Bricks (ºC)	Marble ash Bricks (ºC)
0	29	29
10	31.6	30.7
20	33.7	31.3
30	35.1	32.3
40	35.9	32.7
50	37.7	33.6
60	38.2	34.7
70	39.2	35

Table5: Time lag for clay bricks with Recycled iron slag bricks [11]

Time (minutes)	Clay Bricks (ºC)	Iron slag Bricks
0	29	29
10	31.5	30.7
20	33	31.5
30	34.9	32.4
40	36	32.9
50	37.9	33.5
60	38.1	35
70	39.1	35.9

Table6: Time lag for Cement bricks with Recycled rubber bricks [11]

Time (minutes)	Cement Bricks	Rubber Bricks (ºC)
0	25	25
10	26.2	25.5
20	28	26.7
30	31.3	28.1
40	35.4	30.2
50	38.1	32.1
60	41.4	34
70	44.1	34.6

Table7: Time lag for Cement bricks with Recycled glass bricks [11]

Time (minutes)	Cement Bricks	Glass Bricks (ºC)
0	28	28
10	29.8	29.1
20	31	29.8
30	32.2	30.6
40	33.9	31.1
50	35.4	31.6
60	36.7	32.7
70	37.2	33.3

Table8: Time lag for Cement bricks with Recycled marble ash bricks [11]

Time (minutes)	Cement Bricks	Marble ash Bricks (ºC)
0	27	27
10	28.5	27.9
20	30.8	28.8
30	33.3	29.8
40	36.2	33.3
50	39.3	35.3
60	44.2	37.6
70	45.3	39.6

Table9: Time lag for Cement bricks with Recycled iron slag bricks [11]

Time (minutes)	Cement Bricks	Iron slag Bricks
0	27	27
10	28.5	25
20	30.7	29
30	33.1	30.1
40	36.1	33.5
50	39.2	35.5
60	44.3	37.5
70	45.5	40

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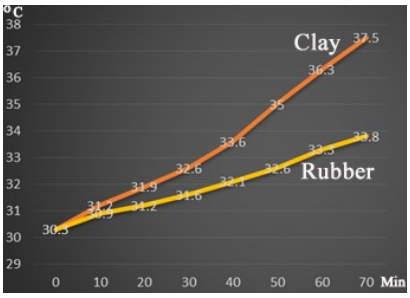

Figure (7): Time lag
for clay bricks with Recycled rubber bricks

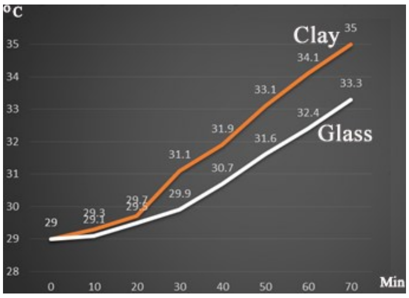

Figure (8): Time lag
for clay bricks with Recycled glass bricks

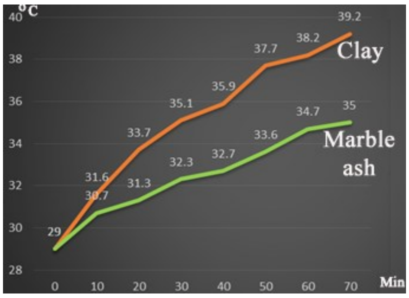

Figure (9): Time lag
for clay bricks with Recycled Marble ash bricks

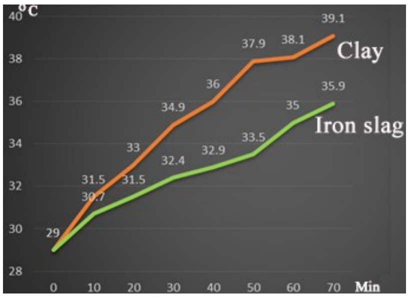

Figure (10): Time lag
for clay bricks with Recycled Iron slag bricks

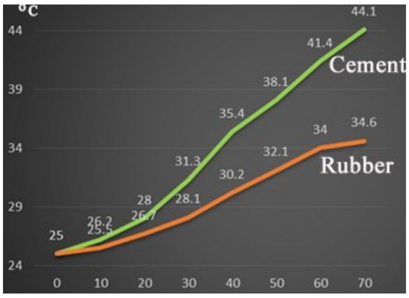

Figure (11): Time lag
for Cement bricks with Recycled rubber bricks

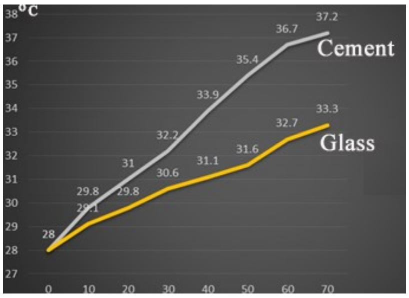

Figure (12): Time lag
for Cement bricks with Recycled glass bricks

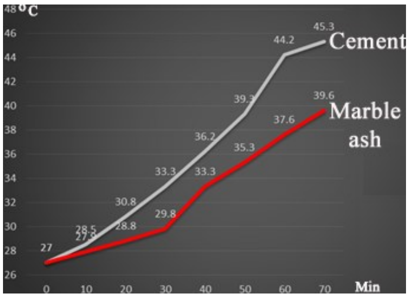

Figure (13): Time lag
for Cement bricks with Recycled Marble ash bricks

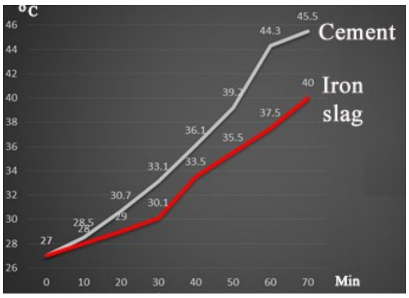

Figure (14): Time lag
for Cement bricks with Recycled Iron slag bricks

Results:

From the previous study, the following can be concluded:

- Bricks made of construction waste with rubber achieved the highest amount of thermal insulation, as their thermal insulation capacity was about two and a half times the ability of clay bricks to insulate, while its thermal insulation capacity was about three times that of solid cement bricks.
- The bricks made from construction waste and broken glass achieved a thermal insulation capacity of about one and two-thirds of the clay bricks' ability to thermally insulate, while its capacity was about two times of the thermal insulation capacity of cement bricks.
- The bricks made of construction waste and marble slurry achieved a thermal insulation capacity of about one and a half times the thermal insulation capacity of clay bricks, while its capacity reached about one and three quarters of the thermal insulation capacity of cement bricks.
- The bricks manufactured from construction waste and iron furnace slag achieved a thermal insulation capacity of about one and a third times the thermal insulation capacity of clay bricks, while its capacity reached about one and a half times the thermal insulation capacity of cement bricks.

Thus, it can be said that the manufactured building units have achieved remarkable success at the environmental level, as they have shown a significant ability in thermal insulation and exceed the ability of both clay and cement bricks in thermal insulation, and these units also outperformed clay and cement bricks in terms of mechanical properties as compression and absorption.

Recommendations:

- The Egyptian government should assign both the Ministries of Environment and Local Development to support investment in the field of recycling construction waste because it is a wasted national wealth that can be exploited in the manufacture of building brick units that have better mechanical properties than the current clay and cement building bricks.
- The state should encourage scientific research in the field of solid waste recycling in general and construction and demolition waste in particular, due to its fruitful results on the environmental level.
- Training of technical personnel who have the ability to work in the field of solid waste.
- The development of engineering education techniques by introducing the experimental aspect of the recycling field at the university level to train students and make them aware of the importance and benefit of this field.

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