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Utilization of Recycled Construction and Demolition Waste in the Manufacture of Prefabricated Wall Claddings to Achieve Sustainability

Omar Yousef Serag Eldein [1], Eman Mohammed Eid Attiya [2], Hesham Hassan Awad Muhammed [3,4]

[1] Teaching Assistant, Department of Architecture,Faculty of Engineering, Menoufia University – email: omaryousef995@gmail.com
[2] Prof. of Architecture & Architectural History and Theories,Department of Architecture, Faculty of Engineering, Menoufia University – email: emaneid@outlook.com
[3] Assistant Professor in, department of Architecture,Faculty of Engineering, Menoufia University
[4] Assistant professor, department of Architecture,Nile Higher Institute for Engineering and Technology, Mansoura– email: hesham.hassan@sh-eng.menofia.edu.eg

***Abstract*- The climate of Egypt is characterized by high temperatures. Clay bricks, the most common type of building bricks in Egypt, are one of the main reasons for increasing the heat gain of buildings. The absence of suitable environmental alternatives for clay bricks calls for an attempt to find and evaluate effective alternatives.**

This research aims to manufacture wall claddings that meet the environmental requirements and thermal comfort needs of buildings in Egypt through recycling construction and demolition waste (CDW). Multiple proposals featuring different mixtures of cement, sand, water and CDW (crushed concrete and crushed bricks) were tested to determine the most suitable mixture in terms of thermal insulation. After comparing the results of each proposal, the best performing samples were further tested and applied to clay bricks to assess their performance and effectiveness in achieving thermal comfort. These tests yielded promising results, as the best performing wall claddings succeeded in reducing heat gain by up to 86%. Results revealed that the application of the proposed wall claddings could significantly reduce the energy consumed for cooling and air conditioning. Furthermore, wall claddings made from CDW have a relative environmental advantage over clay bricks commonly used in residential buildings in Egypt as they represent a safe way to dispose of construction and demolition waste that is normally disposed of in improper and harmful ways with a negative impact on the environment. The researchers recommend examining other materials and different alternatives that can be manufactured from construction and demolition waste, as the available capabilities remain large, numerous and not sufficiently researched.

***Keywords*- Recycled, CDW, Wall Cladding, Sustainability, Prefabricated.**

I. Introduction

Construction and Demolition waste (CDW) is considered a wasted potential in Egypt, especially in the absence of a comprehensive and integrated framework to benefit from these wastes .The quantities of CDW increase every year, and the latest report issued by the Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS) estimates the total annual solid waste generated annually at about 95 million tons, half of which is construction and demolition waste (41 million tons) as shown in table 1, with an annual increase rate of 3.2% [1]. Sustainable management of solid waste is an integrated system for waste management in an environmentally and economically safe manner. In order to achieve sustainable development in waste management, four strategies can be applied, namely: waste reduction, reuse, recycling, and disposal; Where the least preferred and undesirable option is waste disposal [2].

On the other hand, the arid region that covers most of the area of Egypt is characterized by harsh conditions in which the temperature varies significantly through seasons, rising sometimes up to 45 °C or more [3]. Clay bricks, the most common type of building bricks in Egypt, has a thermal conductivity of 0.82 W/mK, and therefore is one of the main reasons for the increased heat gain for buildings in Egypt [3].

As a result, the need arose to think about the use of insulating materials within buildings in order to reduce the buildings' gain of external heat. Insulating materials are characterized by low thermal conductivity, which can reduce the amount of heat leaking through the walls, ceilings and openings of buildings and thus reducing the costs of energy consumption and appliances used for heating and cooling [4].

Table 1. Quantities generated from solid waste in Egypt [1]

Waste type	Tons generated
Solid	13,806,269
Construction and Demolition (CDW)	41,748,603
Agricultural	30,000,000
Industrial	2,906,895
Medical	3,416,254
Wastewater Purification	3,058,509
Total	94,936,530

Introducing the concept of sustainability encouraged researchers to develop heat insulation claddings using natural or recycled materials. Cladding is the application of one material over another to provide an additional layer to obtain thermal insulation and weather resistance, and to improve the appearance of buildings [4]. Sustainable wall claddings can be made from natural plant waste or recycled materials. The thermal insulation properties of these wall claddings have been studied by many researchers in order to evaluate the opportunity for their reuse in the construction

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sector. The use of these products is not widespread, and in some cases, is limited to experimental and laboratory use [4].

There have been multiple examples of Sustainable wall claddings made from natural plant waste. According to official figures, rice is the third-highest produced commodity in the world, resulting in a considerable quantity of trash, causing disposal concerns, while they can be successfully used to produce sustainable materials [5]. The thermal efficiency of wall claddings made from rice hulls, a valuable by-product of rice farming, was investigated. The sample with the density of 154 kg/m3 had the lowest recorded thermal conductivity 0.0464 W/mK displayed in (Fig. 1) [6]. The same research refers to the results of thermal insulation tests conducted on claddings made of pecan shells, but the results showed that this material is not suitable for insulation (0.0884 W/m K) [6].

Straw is a byproduct of grain farming that is widely available and cheap in a variety of countries. The straw obtained from wheat is commonly utilized in building applications. Several studies have been conducted to examine the use of straw as insulation claddings; the thermal conductivity was determined to be 0.067 W/mK, which is high compared to typical insulation materials [7]. It was also reported that samples made of straw stalks perpendicular to heat flow had better thermal insulation properties [7].

Figure 1. Wall claddings made of rice waste (left) and straw bale (right) [6], [7].

On the other hand, recycling synthetic materials or utilizing industrial by-products may also be a sustainable approach for reducing raw material consumption and waste disposed of in landfills. As a result, numerous studies have been conducted to develop creative and sustainable applications for these materials. Several companies develop heat insulation claddings from recycled cotton and denim fibers shown in (Fig. 2). These products typically have a thermal conductivity of 0.039 to 0.044 W/m K (good values when compared to conventional insulating materials), but a low density ranging from 25 to 45 kg/m3 [8].

Figure 2. Wall claddings made of recycled denim (left) and cotton (right) [8].

The accessibility of these claddings' components is a key factor impacting their sustainability since using local resources has a positive influence on both the economy and the environment. Producing claddings from natural materials shouldn't interfere with growing and harvesting food crops; instead, it should concentrate on making use of the leftovers and waste products from the agricultural industry. Utilizing these materials can lower the reliance on non-renewable energy sources. Furthermore, agricultural waste products are typically generated in regions with a high need for cooling during the summer [2] [3]. It was found through the study and review of different types of thermal insulation wall claddings that when the density of the material increases, the interaction of the material particles becomes stronger. Thus, they will transfer the temperature faster. This means that as the density of the material increases, the coefficient of thermal conductivity increases [10]. It was also established that the claddings made from recycled materials showed better results than the claddings made from natural plant waste, which contributed to directing this research towards producing wall claddings from CDW as a recycled material.

II. Research Problem

The thermal properties of building bricks in Egypt do not meet the general requirements for internal thermal comfort [2]. In addition, the quantities of solid waste generated in Egypt rise every year, especially construction and demolition waste [1]. Hence the research is trying to solve two architectural environmental problems using the second as a direct solution to the first. The absence of suitable and efficient environmental alternatives for red bricks, calls for an attempt to find effective alternatives from different sources including construction and demolition waste (CDW).

III. Research Objectives

The main objective of the research is to manufacture wall claddings that meet the environmental requirements of residential buildings in Egypt through recycling construction and demolition waste. The main objective can be achieved through the following sub-objectives:

- Identifying the nature of CDW and ways of managing it into reduction.
- Carrying out experiments to produce wall claddings from CDW and choosing the most suitable mixture.
- Comparing test results for clay bricks before and after the application of manufactured wall claddings.

IV. Research Methodology

In order to achieve the previous objectives This quantitative research follows the experimental approach, by conducting a set of laboratory experiments aimed at reaching a model for the proposed wall claddings. Bricks with applied claddings represent the "experimental group" They are exposed to a set of independent variables represented by different wall claddings, while normal building bricks without applied claddings represent the control group. The differences between the experimental group and control group are due to the experimental variables that the experimental group was exposed to i.e., the wall claddings.

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Consequently, this will determine the performance and effectiveness of the proposed wall cladding system in achieving thermal comfort (Detailed information pertaining to the experiment will be presented in section VI).

V. Wall Claddings Manufacture

Construction and demolition waste, as well as many complementary materials, were used in the manufacture of wall claddings in the laboratory for insulation purposes. Samples of building units were manufactured according to a set of steps, with their physical properties measured.

A. Materials

Construction and demolition waste represented by waste crushed concrete and waste crushed brick were used as coarse aggregate [11]. The cement used was Portland cement CEMI-32.5N. Fly ash was used as Supplementary Cementitious Material (SCM) responding to ASTM C618-19 [12]. Fine aggregate was natural siliceous sand with a specific gravity of 2.65.

Marble dust powder, which is an unexploited byproduct of marble industry, was also utilized in the mixes especially as its quantities increased and became a strong threat to the environment. Some additives such as Sika ViscoCrete-3425 and Addipor55 were used to give the mixtures some desirable properties or characteristics (such as increased workability and lighter weights), whether during preparation or after completion [13] [14]. Compressed High Density Foam Boards as well as Mineral wool boards were also used to achieve better insulation performance. In addition to the above, potable water was used for all mixtures.

These materials are grinded, with different proportions from one sample to another, to obtain different results that allow comparison. Then water is added to the mixture. Next the wall claddings are cast in a form with a specific size. The mixtures stay inside the form for 3 days, until the setting of mixtures is reached. Multiple tests are then conducted on mixtures to determine their properties.

Figure 3. Brick waste (left) marble dust (right) [11].

B. Casting Forms

More than one form of wall cladding has been suggested in order to reduce the cladding's weight and hence its density. The researcher manufactured a steel form with a thickness of 5 mm and internal dimensions of 50×50×9cm in order to reach a standard dimension. The form has two sides that can be separated from the rest of the form body for easy removal of the cladding after the setting time is over, and they are fixed with screws during the pouring of the mixture. It also has a cover from the top made of steel, which is pressed on the mixture manually or by an automatic press to achieve a smooth surface. In some mixtures, wire mesh was used when needed to increase cohesion between different layers.

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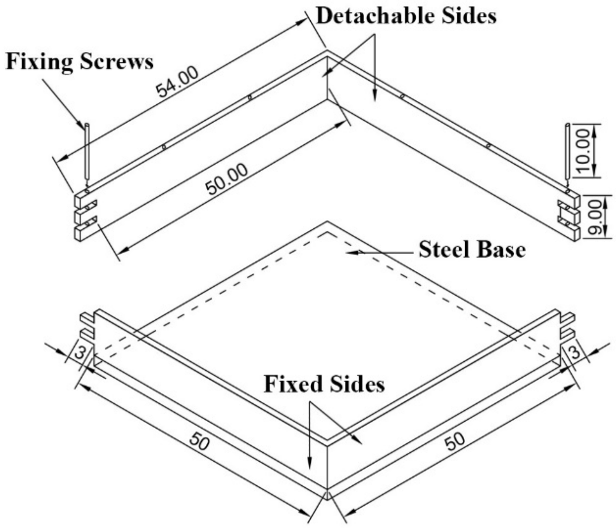


Figure 4. Design of the steel form [Authors].

A smaller wooden form with internal dimensions of 30×30×5cm was also manufactured so that it is easier to carry and transport, which facilitates the production process of these claddings on a large scale without the need for more expensive and complex manufacturing techniques. It also costs less to manufacture and is suitable for mixtures with light weights that won't have relatively large thicknesses.

Figure 5. Steel form (left) wooden form (right) [Authors].

It should be noted that all tests and experiments were conducted using devices and machines belonging to the certified Materials Properties Laboratory of the Department of Civil Engineering, Faculty of Engineering, Menoufia University.

C. *Determination of Physical Properties*

The measurements that determine the physical properties of the wall claddings are as follows:

- Dimensions measurement: the length, width and height of each cladding are measured using a measuring tape. The dimensions of each cladding are measured to the nearest millimeter and the volume of each of the tested claddings is calculated.
- Mass measurement: the mass of each cladding is measured using a digital scale. The report states the mass of each of the tested claddings in grams.
- Density measurement: through the previous two tests, the volume and mass of the sample are calculated, and then the density is calculated according to the equation: Density = mass/volume (g/cm3)

D. *Mixtures*

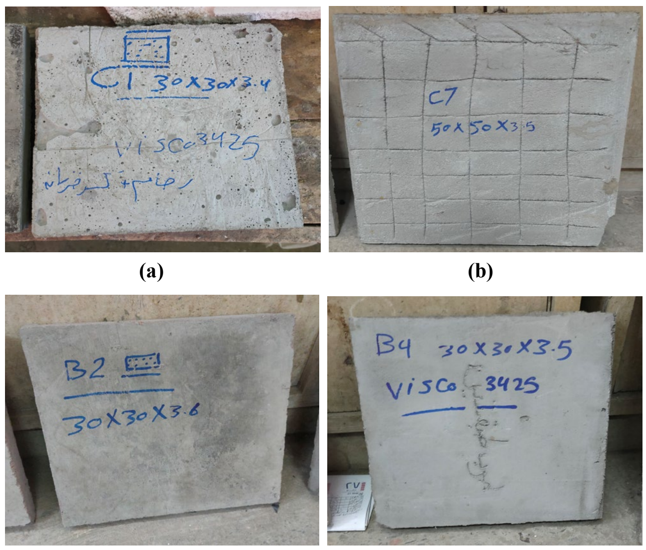
More than one mixture of cement, sand, water and crushed concrete and crushed bricks as aggregate were tested to determine the appropriate, most suitable mixture and the best in terms of thermal insulation, the following proportions were used on all samples in the first group.

Table 2. Volumetric proportions of the mixtures of the first group of wall claddings [Authors]

Components	Volumetric Proportions	Percentages
Water	1	10%
Cement + Fly Ash	1.5	15%
Sand	3.0	30%
Crushed Concrete or Crushed Bricks	3.0	30%
Additives	1.5	15%
Total	10	100%

Four different mixtures were achieved using these proportions (reported in table 4) as follows:

- 1st mixture, crushed concrete with marble dust and compressed foam: 3 samples were designed using this proposal, namely C1, C2 and C3.
- 2nd mixture, crushed concrete and compressed foam (with no marble dust): 4 samples were designed using this proposal: C4, C5, C6 and C7.
- 3rd mixture, crushed bricks with marble dust and compressed foam: 3 samples were designed using this proposal, namely B1, B2 and B3.
- 4th mixture, crushed bricks and compressed foam (with no marble dust): 3 samples were designed using this proposal: B4, B5 and B6.



(a) (b)

(c) (d)

Figure 6. Multiple samples from the mixtures of the first group C1 (a) C7 (b) B2 (c) B4 (d) [Authors].

After taking measurements of the samples of the first group, some adjustments were made to the proportions and components of the samples in order to achieve claddings that are lighter in weight and less dense, which makes them easier to handle, transfer and apply to walls.

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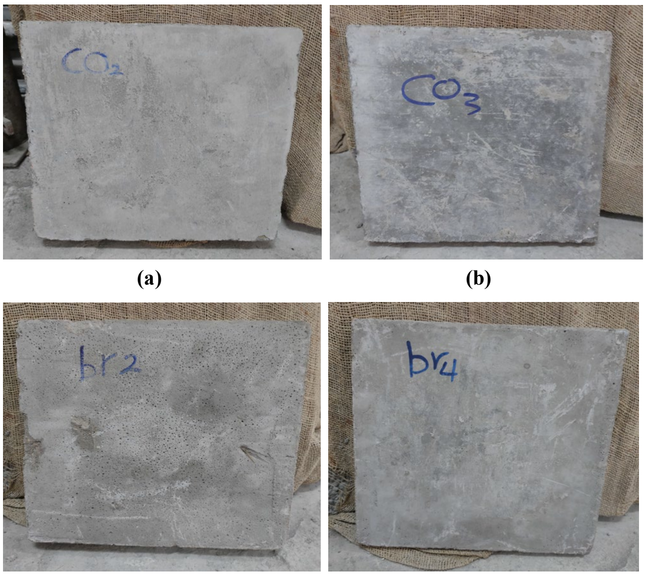
Table 3. Volumetric proportions of the mixtures of the second group of wall claddings [Authors]

Components	Volumetric Proportions	Percentages
Water	1	10%
Cement + Fly Ash	2.5	25%
Sand	3.0	30%
Crushed Concrete or Crushed Bricks	2.0	20%
Additives	1.5	15%
Total	10	100%

Four different mixtures were Achieved using these proportions (also reported in table 4) as follows:

- 5th mixture, crushed concrete with marble dust and mineral wool: 2 samples were designed using this proposal, namely CO1 and CO2.
- 6th mixture, crushed concrete with marble dust and compressed foam: one sample was designed using this proposal: CO3.
- 7th mixture, crushed bricks with marble dust and mineral wool: 2 samples were designed using this proposal, namely BR1 and BR2.
- 8th mixture, crushed bricks and compressed foam: 3 samples were designed using this proposal: BR3, BR4 (both with marble dust) and BR5 (with no marble dust).



(a) (b) (c) (d)

Figure 7. Multiple samples from the mixtures of the second group CO2 (a) CO3 (b) BR2 (c) BR4 (d) [Authors].

The above is considered the initial steps in the production of wall claddings, but the environmental and thermal performance remains the decisive factor for the possibility of using these claddings widely in the construction sector.

Next, the environmental performance and thermal insulation properties of the wall claddings proposed to be manufactured from construction and demolition waste will be evaluated and compared to the thermal properties of clay bricks as it is the most widespread building material in Egypt.

Table 4. Mass, volume, density and description for samples of wall claddings [Authors]

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Group No.	Mixture	Sample	Mass (g)	Sample Dimensions			Volume (cm^3)	Density (g/cm^3)	Description
				Length (cm)	Width (cm)	Thickness (cm)			
First Group	1st	C1	3426	30	30	3.40	3060	1.119	two layers of mixture, with a layer of compressed foam in between.
		C2	3190	30	30	3.50	3150	1.012	one layer of mixture, with a layer of compressed foam.
		C3	5310	30	30	3.00	2700	1.966	addipor with the mixture.
	2nd	C4	4260	50	50	2.40	6000	0.71	one layer of mixture, with a layer of compressed foam.
		C5	9090	50	50	3.30	8250	1.101	two layers of mixture, with a layer of compressed foam in between.
		C6	6610	50	50	2.40	6000	1.101	two layers of mixture, with a layer of compressed foam in between.
		C7	9500	50	50	3.50	8750	1.086	one layer of mixture, with a layer of compressed white foam.
	3rd	B1	3296	30	30	3.40	3060	1.077	two layers of mixture, with a layer of compressed foam in between.
		B2	3190	30	30	3.60	3240	0.984	one layer of mixture, with a layer of compressed foam.
		B3	5254	30	30	3.40	3060	1.716	addipor with the mixture.
	4th	B4	3472	30	30	3.50	3150	1.102	two layers of mixture, with a layer of compressed foam in between.
		B5	11366	50	50	3.30	8250	1.377	addipor with the mixture.
		B6	4662	50	50	3.50	8750	0.532	one layer of mixture, with a layer of compressed white foam.
second Group	5th	CO1	3664	30	30	6.50	5850	0.62	one layer of mixture, with a layer of mineral wool.
		CO2	6292	30	30	8.50	7650	0.82	two layers of mixture, with a layer of mineral wool in between.
	6th	CO3	3746	30	30	3.50	3150	1.18	two layers of mixture, with a layer of compressed foam in between.
	7th	BR1	5520	30	30	7.00	6300	0.87	one layer of mixture, with a layer of mineral wool.
		BR2	6760	30	30	7.00	6300	1.07	two layers of mixture, with a layer of mineral wool in between.
	8th	BR3	2903	30	30	3.50	3150	0.92	two layers of mixture, with a layer of compressed foam in between.
		BR4	2654	30	30	3.50	3150	0.84	one layer of mixture, with a layer of mineral wool.
		BR5	2895	30	30	3.50	3150	0.92	two layers of mixture, with a layer of compressed foam in between.

VI. Experimental Program

The Authors conducted an experiment aimed at measuring the thermal properties of wall claddings made from construction and demolition waste, then Those claddings were compared to the most common building material in Egypt (clay bricks).

A. Determination of Physical Properties

Time Lag and Decrement Factor are among the most important thermal performance properties that determine the heat capacity of any material. The exterior surfaces of buildings exposed to sunlight increase their temperature during the day until they reach their highest value, and then begin to decrease and reach their lowest values after midnight. This change in the temperature of the external surfaces affects the internal surfaces of the building that are not exposed to the sun and after a time difference that may range from a short period to several hours and depends on the type of building material used and its chemical composition. This time is what is called the Time Lag (TL) and is symbolized by the symbol (**Φ**) and its unit of measure is the hour [15]. Thus, Time Lag can be defined as the time it takes for a heat wave to move from the outer surface of a body to its inner surface [16]. It is given by the equation:

$$\mathbf{TL\ (\Phi) = t_{T\ (max\ inside)} - t_{T\ (max\ outside)}} \quad (1)$$

Where:

- TL (Φ) is Time Lag.
- $t_{T\ (max\ inside)}$ is the time it takes to reach the maximum temperature inside.
- $t_{T\ (max\ outside)}$ is the time it takes to reach the maximum temperature outside.

As for the Decrement Factor, it can be defined as the ratio between the maximum change in temperature of the inner surface and the maximum change in temperature of the outer

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surface over a period of 24 hours and is symbolized by the symbol (**μ**) [16]. It is given by the equation:

$$\mu = T_{in(max)} - T_{in(min)} / T_{out(max)} - T_{out(min)} \quad (2)$$

Where:

- μ is the Decrement Factor.
- $T_{in(max)} - T_{in(min)}$ is the maximum change in the temperature of the inner surface.
- $T_{out(max)} - T_{out(min)}$ is the maximum change in the temperature of the external surface.

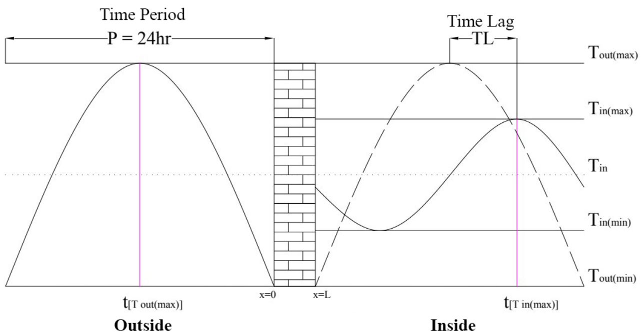

Figure 8. Diagram illustrating time lag and decrement factor [16].

The thermal performance of the claddings can be measured in the same way, by exposing one of its faces to a specific amount of heat in a known period through a heater that raises the temperature of the surface in contact with it, and then measuring the change in temperature on the opposite face every 10 minutes for an hour using a thermal monitor. Thus, the heat source simulates the sun's rays falling on buildings, the face of the cladding exposed to this heat simulates the outer surface of the building, and the opposite face simulates the internal surfaces of the building.

B. Experiment Apparatus

A set of devices and tools were used to conduct the experiment, as follows:

- An electric heater equipped with a thermostat that controls and stabilizes the temperature.
- A plate connected to the heater and used to distribute heat evenly on the face of the tested cladding.

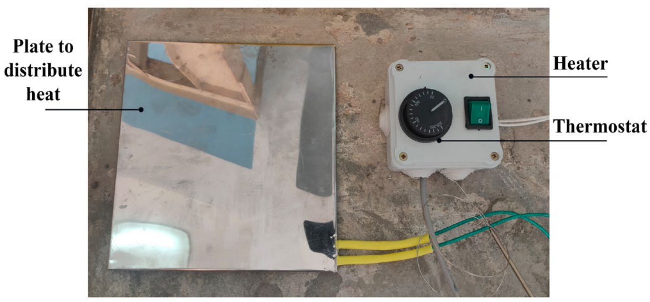

Figure 9. Apparatus used to conduct the experiment [Authors].

- FLUKE digital infrared laser thermometer that measures temperatures from -30°C to 650°C with an accuracy of 99% with a margin of error of only 1% for readings from 0 to 650°C and is certified with an IP54 rating for water and dust resistance.
- Samples of wall claddings manufactured from CDW.
- digital watch.

Figure 10. Digital infrared laser thermometer [Authors].

C. Experiment procedure

- The heater is used to generate a temperature of 70°C through the thermostat while testing two fixed samples at the same time on both sides of the plate so that there is no heat loss to the sides. The samples act as barriers that prevent the escape of heat through convective currents, and the flat face of the plate Distributes the heat uniformly over the surface of the samples.
- Using a Fluke 62 Max Infrared Digital Laser Thermometer, the change in temperature that occurs on the opposite side is monitored and determined.
- Measurements are recorded every 10 minutes for an hour, the time is kept using a digital watch.
- Measurements are taken at five different points (one in the middle and one at each corner of the sample).
- The average of those five measurements is then recorded in the results table. Samples should also be tested at the same time and place.
- After that, an additional test is then carried out for the best-performing samples of each mixture. Clay bricks are placed directly on the plate (representing a wall without applying the cladding), and on the other side of the plate, the cladding is installed with clay bricks behind (representing the wall after applying the cladding).

Figure 11. Testing samples of wall claddings (right) with bricks (left) [Authors].

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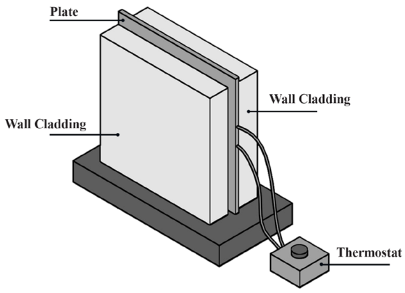

Figure 12. Diagram illustrating Testing wall claddings with each other [Authors].

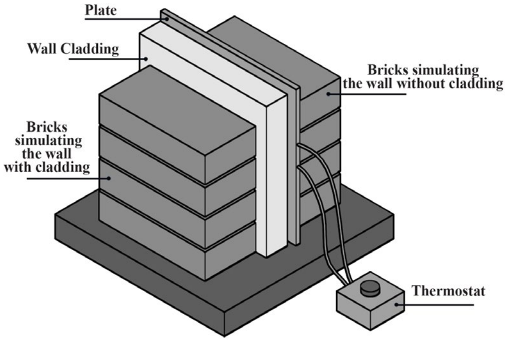

Figure 13. Diagram illustrating Testing wall claddings with bricks [Authors].

By comparing the difference in the time lag between the two sides, it is possible to determine the actual performance of these claddings and judge their insulation as well as their ability to delay the time of heat gain.

VII. Experiment Results and Discussion

A. First Mixture, Crushed Concrete with Marble Dust and Compressed Foam

The temperature on the faces of the samples of this proposal initially indicated approximately 24°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 5. Time lag of the samples of the first mixture [Authors]

time (min)	C1	C2	C3
0	24	24	24.1
10	24	24.2	24.8
20	24.8	25.1	26.6
30	26.2	26.8	31.4
40	27.5	28.3	33.7
50	28.8	29.6	34.3
60	29.3	30.2	35

The temperature of sample C1 increased at a rate of 0.88°C every 10 minutes, while the rate of increase for sample C2 was 1.03°C every 10 minutes, finally sample C3 increased at a rate of 1.81°C every 10 minutes. Thus, sample C1 is the best performing sample of this proposal, and it is chosen for further testing with clay bricks to determine its actual performance in terms of thermal insulation.

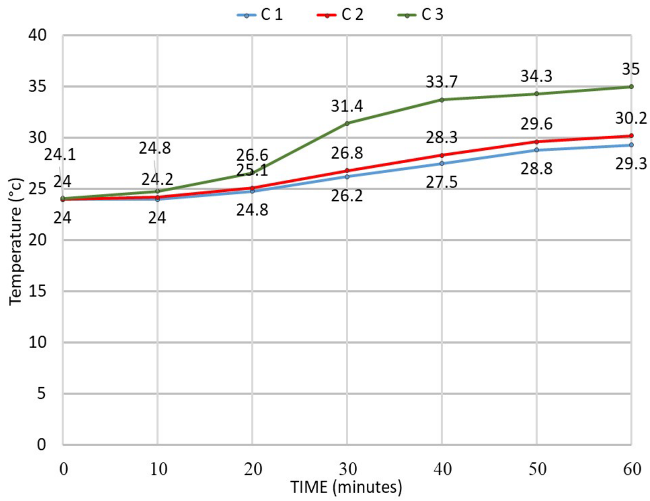

Figure 14. Time Lag of the samples of the first mixture [Authors].

The temperature on the faces of the brick samples initially were about 19°C, then the average readings on the faces of the brick samples with and without cladding C1 were as follows:

Table 6. Time lag of bricks with and without cladding C1 [Authors]

time (min)	Bricks without cladding	Bricks with cladding C1
0	19.6	19.6
10	20.8	19.8
20	22	20
30	23.4	20.3
40	24.2	20.7
50	25.9	21.2
60	27.1	21.7

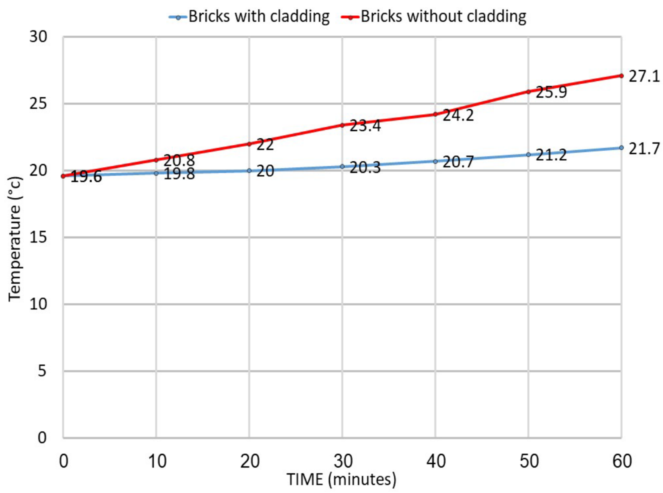

Figure 15. Time lag of bricks with and without cladding C1 [Authors].

The temperature of the brick samples with no cladding applied increased at a rate of 1.25°C every 10 minutes, after applying the cladding the rate of increase dropped to 0.35°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.28 (28%) of the rate of heat transfer through the bricks without the use of cladding.

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B. Second Mixture, Crushed Concrete and Compressed Foam (With No Marble Dust)

The temperature on the faces of the samples of this proposal initially indicated approximately 24°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 7. Time lag of the samples of the second mixture [Authors]

time (min)	C4	C5, C6	C7
0	24	24	24
10	25.5	24.6	24.4
20	29.2	28.9	27.6
30	33.2	33.1	30.7
40	36.4	34	32.1
50	38.1	36.2	33.3
60	40.8	38.2	35.8

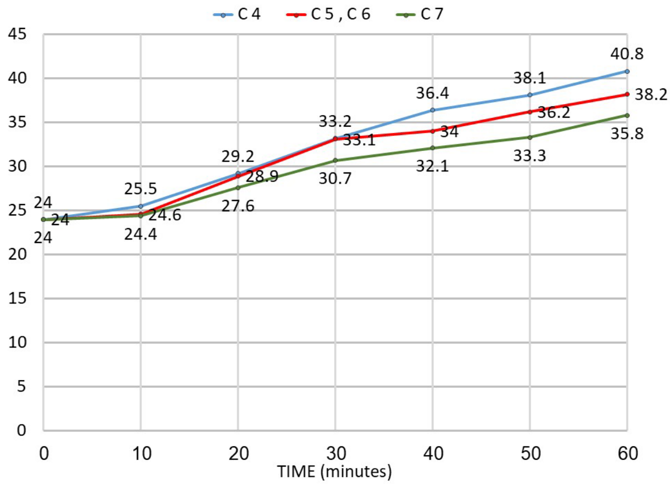

Figure 16. Time Lag of the samples of the second mixture [Authors].

The temperature of sample C4 increased at a rate of 2.63°C every 10 minutes, while the rate of increase for sample C5 and C6 was 2.36°C every 10 minutes, finally sample C7 increased at a rate of 1.96°C every 10 minutes. Thus, sample C7 is the best performing sample, and it is chosen for further testing with clay bricks to determine its actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 22°C, then the average readings on the faces of the brick samples with and without cladding C7 were as follows:

Table 8. Time lag of bricks with and without cladding C7 [Authors]

time (min)	Bricks without cladding	Bricks with cladding C7
0	21.8	21.8
10	22.4	22
20	23.9	22.6
30	25.5	23.2
40	28.9	24.9
50	30.2	26.6
60	32.1	28.7

The temperature of the brick samples with no cladding applied increased at a rate of 1.72°C every 10 minutes, after applying the cladding the rate of increase dropped to 1.15°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.67 (67%) of the rate of heat transfer through the bricks without the use of cladding.

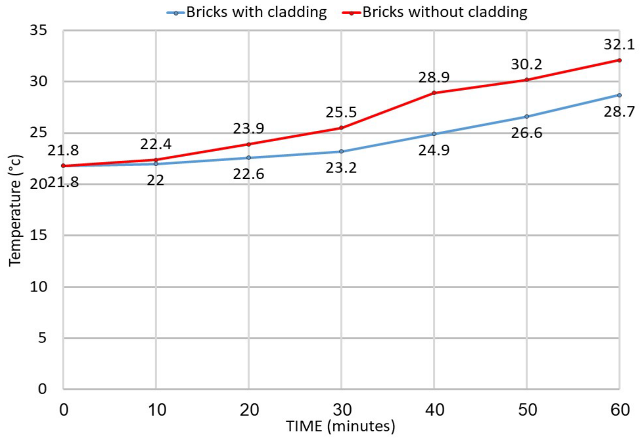

Figure 17. Time lag of bricks with and without cladding C7 [Authors].

C. Third Mixture, Crushed Bricks with Marble Dust and Compressed Foam

The temperature on the faces of the samples of this proposal initially indicated approximately 24°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 9. Time lag of the samples of the third mixture [Authors]

time (min)	B1	B2	B3
0	24	24	24
10	24.8	24.8	24.3
20	26.3	27.3	26.8
30	27.7	29.8	29.8
40	29.8	30.3	34.4
50	33.2	31.9	38.5
60	33.8	33.4	41.6

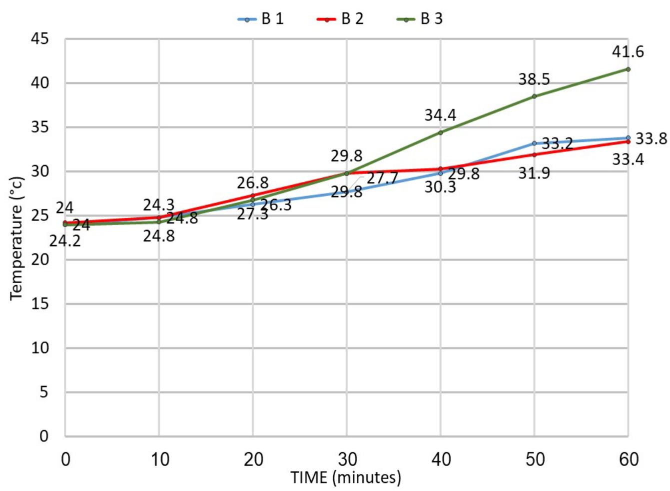

Figure 18. Time Lag of the samples of the third mixture [Authors].

The temperature of sample B1 increased at a rate of 1.63°C every 10 minutes, while the rate of increase for sample B2 was 1.53°C every 10 minutes, finally sample B3

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increased at a rate of 2.93°C every 10 minutes. Thus, sample B2 is the best performing sample of this proposal, and it is chosen for further testing with clay bricks to determine its actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 21°C, then the average readings on the faces of the brick samples with and without cladding B2 were as follows:

Table 10. Time lag of bricks with and without cladding B2 [Authors]

time (min)	Bricks without cladding	Bricks with cladding B2
0	20.9	20.9
10	21.7	21.2
20	22.9	21.4
30	24	21.9
40	25.7	22.4
50	27.3	23
60	29.2	23.6

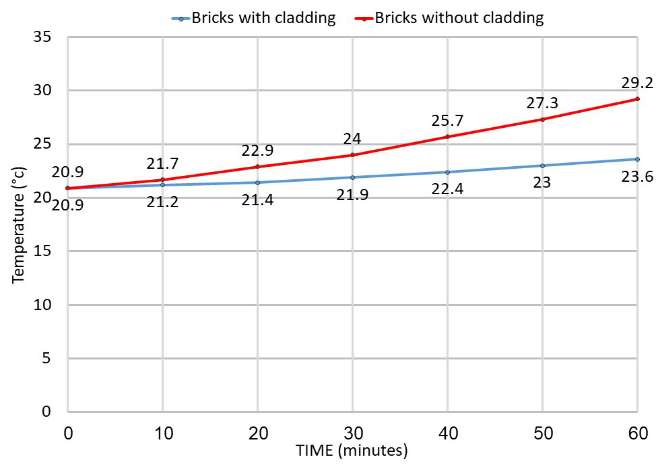

Figure 19. Time Lag of bricks with and without cladding B2 [Authors].

The temperature of the brick samples with no cladding applied increased at a rate of 1.38°C every 10 minutes, after applying the cladding the rate of increase dropped to 0.45°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.33 (33%) of the rate of heat transfer through the bricks without the use of cladding.

D. *Fourth Mixture, Crushed Bricks and Compressed Foam (With No Marble Dust)*

The temperature on the faces of the samples of this proposal initially indicated approximately 24°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 11. Time lag of the samples of the fourth mixture [Authors]

time (min)	B4	B5	B6
0	24.5	24.5	24.5
10	24.7	27.4	24.9
20	25	30.2	25.2
30	27.3	32.3	26.4
40	29.8	35.5	29.6
50	32.1	38.4	32.4
60	33.3	41.2	34

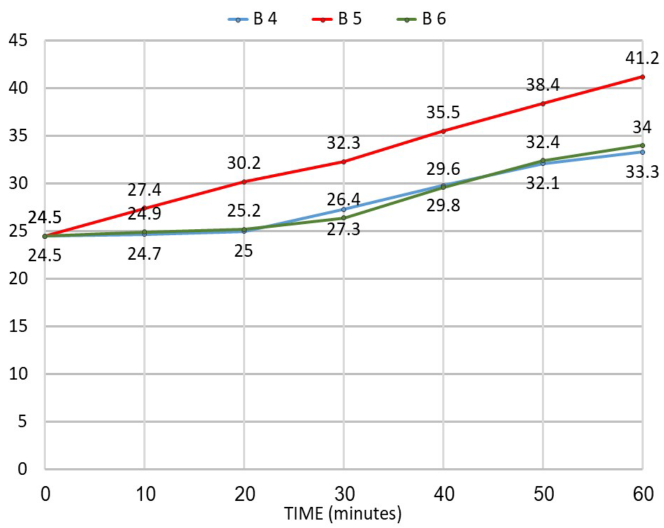

Figure 20. Time Lag of the samples of the fourth mixture [Authors].

The temperature of sample B4 increased at a rate of 1.46°C every 10 minutes, while the rate of increase for sample B5 was 2.78°C every 10 minutes, finally sample B6 increased at a rate of 1.58°C every 10 minutes. Thus, sample B4 is the best performing sample of this proposal, and it is chosen for further testing with clay bricks to determine its actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 21°C, then the average readings on the faces of the brick samples with and without cladding B4 were as follows:

Table 12. Time lag of bricks with and without cladding B4 [Authors]

time (min)	Bricks without cladding	Bricks with cladding B4
0	21	21
10	21.8	21.3
20	22.6	21.5
30	23.9	22
40	25.7	22.4
50	27.2	22.9
60	28.9	23.5

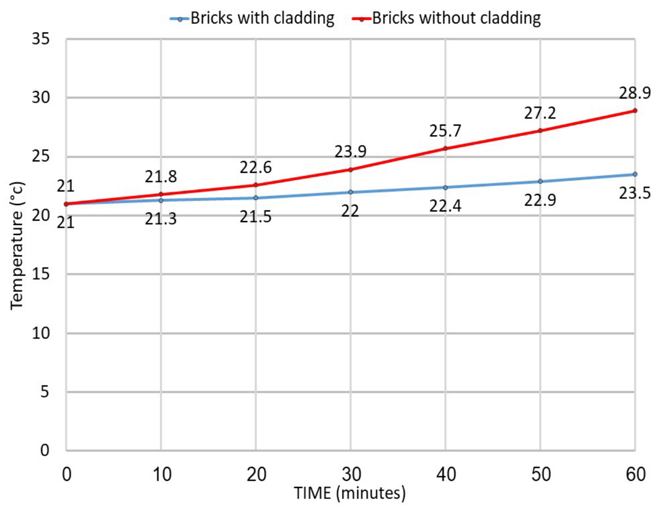

Figure 21. Time Lag of bricks with and without cladding B4 [Authors].

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The temperature of the brick samples with no cladding applied increased at a rate of 1.32°C every 10 minutes, after applying the cladding the rate of increase dropped to 0.42°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.32 (32%) of the rate of heat transfer through the bricks without the use of cladding.

E. Fifth Mixture, Crushed Concrete with Marble Dust and Mineral Wool

The temperature on the faces of the samples of this proposal initially indicated approximately 21°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 13. Time lag of the samples of the fifth mixture [Authors]

time (min)	CO1	CO2
0	20.8	20.8
10	21.2	21.1
20	21.5	21.3
30	21.6	21.4
40	22.2	21.6
50	23.9	22.8
60	24.6	23.8

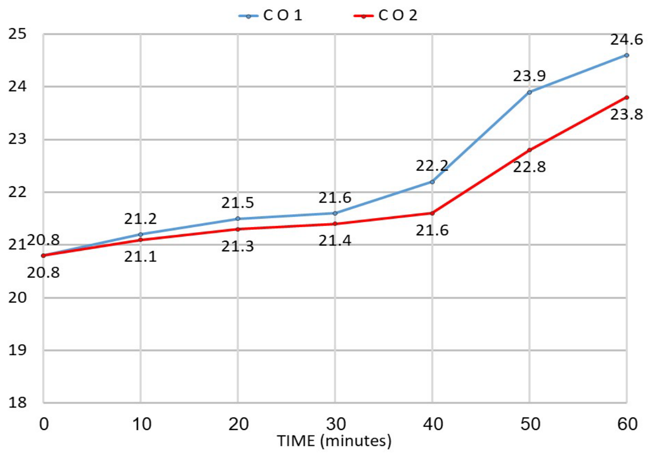

Figure 22. Time Lag of the samples of the fifth mixture [Authors].

The temperature of sample CO1 increased at a rate of 0.63°C every 10 minutes, while the rate of increase for sample CO2 was 0.5°C every 10 minutes. Both samples performed relatively well, hence both were chosen for further testing with clay bricks to determine their actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 21°C, then the average readings on the faces of the brick with and without cladding CO1 and CO2 were as follows:

Table 14. Time lag of bricks with and without cladding CO1 [Authors]

time (min)	Bricks without cladding	Bricks with cladding CO1
0	21.2	21.2
10	21.7	21.3
20	22.5	21.4
30	23.9	21.6
40	24.7	21.7
50	25.9	22
60	27.3	22.3

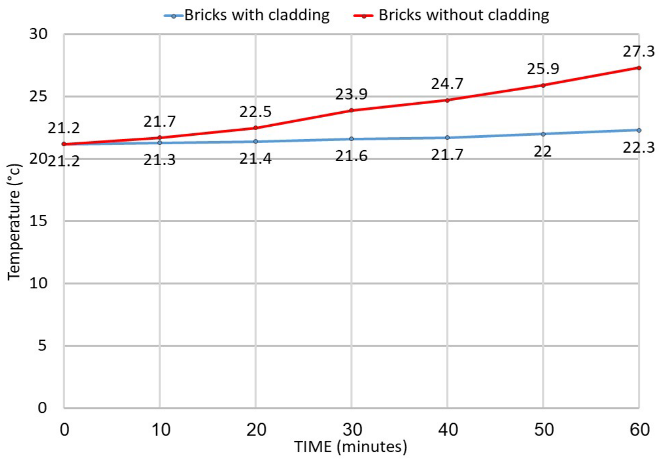

Figure 23. Time lag of bricks with and without cladding CO1 [Authors].

Table 15. Time lag of bricks with and without cladding CO2 [Authors]

time (min)	Bricks without cladding	Bricks with cladding CO2
0	20.9	20.9
10	21.4	21
20	22.6	21.2
30	23.2	21.3
40	24.7	21.3
50	25.8	21.5
60	26.6	21.7

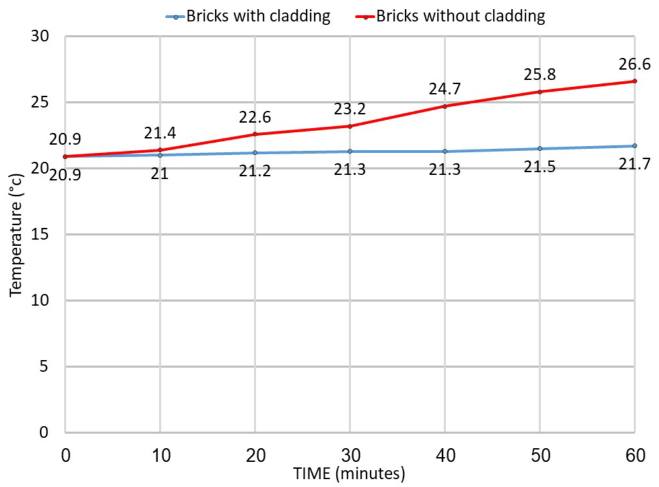

Figure 24. Time lag of bricks with and without cladding CO2 [Authors].

The temperature of the brick samples with no cladding applied increased at a rate of 1.02°C every 10 minutes, after applying cladding CO1 the rate of increase dropped to 0.18°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.18 (18%) of the rate of heat transfer through the bricks without the use of cladding.

Whereas for CO2, the temperature of the brick samples with no cladding applied increased at a rate of 0.95°C every 10 minutes, after applying the cladding CO2 the rate of increase dropped to 0.13°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.14 (14%) of the rate of heat transfer through the bricks without the use of cladding.

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F. Sixth Mixture, Crushed Concrete with Marble Dust and Compressed Foam

The temperature on the faces of the sample of this proposal initially indicated approximately 21°C, then the average readings at 5 different points on the face of the sample every 10 minutes were as follows:

Table 16. Time lag of the sample of the sixth mixture [Authors]

time (min)	CO3
0	20.9
10	21.3
20	22.6
30	24.8
40	26.4
50	28.2
60	31

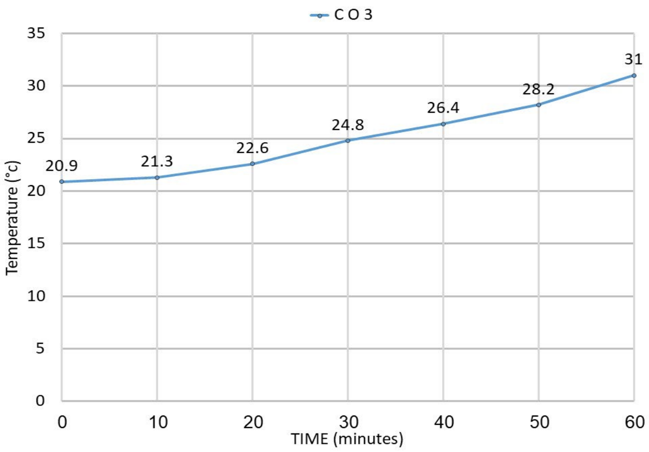

Figure 25. Time Lag of the sample of the sixth mixture [Authors].

The temperature of sample CO3 increased at a rate of 1.68°C every 10 minutes. The sample will be further tested with clay bricks to determine its actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 21°C, then the average readings on the faces of the brick samples with and without cladding CO3 were as follows:

Table 17. Time lag of bricks with and without cladding CO3 [Authors]

time (min)	Bricks without cladding	Bricks with cladding CO3
0	21.1	21.1
10	21.7	21.3
20	22.5	21.6
30	24	22
40	25.2	22.2
50	27.1	22.5
60	28.3	23

The temperature of the brick samples with no cladding applied increased at a rate of 1.2°C every 10 minutes, after applying the cladding the rate of increase dropped to 0.32°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.26 (26%) of the rate of heat transfer through the bricks without the use of cladding.

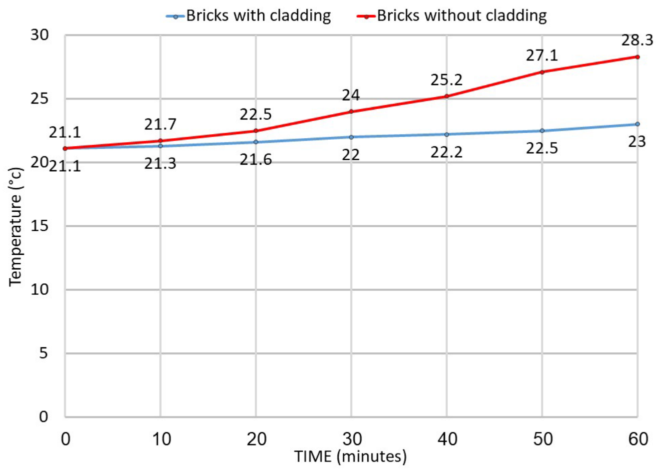

Figure 26. Time lag of bricks with and without cladding CO3 [Authors].

G. Seventh Mixture, Crushed Bricks with Marble Dust and Mineral Wool

The temperature on the faces of the samples of this proposal initially indicated approximately 22°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 18. Time lag of the samples of the seventh mixture [Authors]

time (min)	BR1	BR2
0	21.8	21.8
10	21.8	21.8
20	22.2	22
30	22.4	22.3
40	22.7	22.5
50	23.1	22.9
60	23.7	23.3

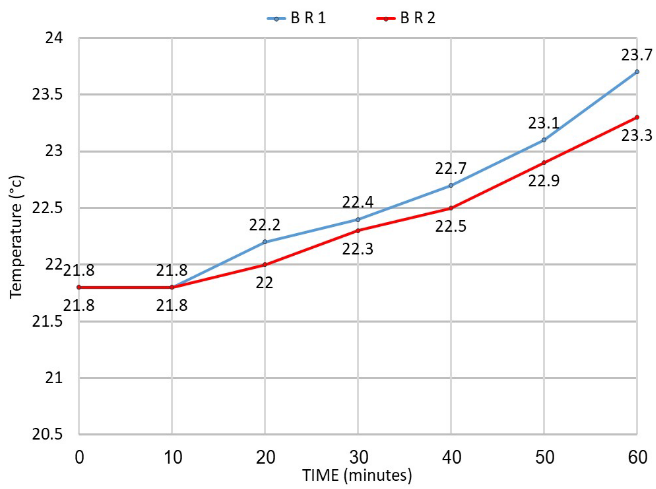

Figure 27. Time Lag of the samples of the seventh mixture [Authors].

The temperature of sample BR1 increased at a rate of 0.32°C every 10 minutes, while the rate of increase for sample BR2 was 0.25°C every 10 minutes. Both samples performed relatively well, hence both were chosen for further testing with clay bricks to determine their actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 20°C, then the average readings on the

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faces of the brick with and without cladding BR1 and BR2 Respectively were as follows:

Table 19. Time lag of bricks with and without cladding BR1 [Authors]

time (min)	Bricks without cladding	Bricks with cladding BR1
0	20.7	20.7
10	21.5	20.8
20	22.8	21
30	24.2	21.3
40	25.3	21.6
50	26.6	21.8
60	27.5	22.1

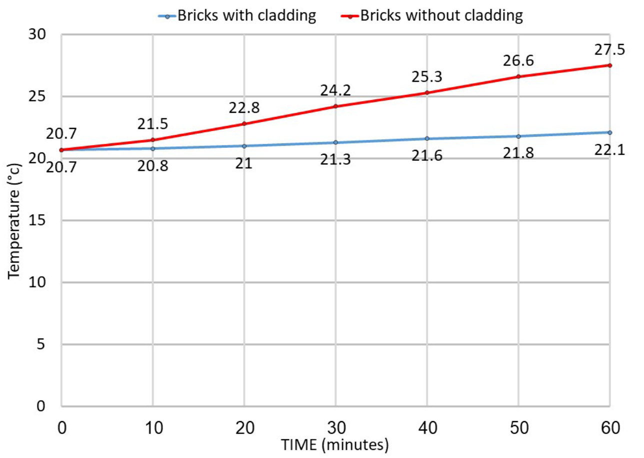

Figure 28. Time Lag of bricks with and without cladding BR1 [Authors].

Table 20. Time lag of bricks with and without cladding BR2 [Authors]

time (min)	Bricks without cladding	Bricks with cladding BR2
0	20.3	20.3
10	20.9	20.5
20	21.7	20.7
30	22.9	20.8
40	24.1	21.1
50	25.5	21.2
60	27.1	21.4

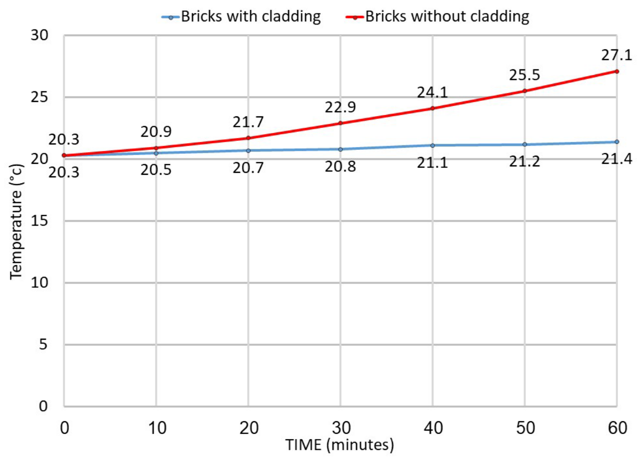

Figure 29. Time Lag of bricks with and without cladding BR2 [Authors].

The temperature of the brick samples with no cladding applied increased at a rate of 1.13°C every 10 minutes, after applying cladding BR1 the rate of increase dropped to 0.23°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.205 (20%) of the rate of heat transfer through the bricks without the use of cladding.

Whereas for cladding CO2, the temperature of the brick samples with no cladding applied increased at a rate of 1.13°C every 10 minutes, after applying cladding CO2 the rate of increase dropped to 0.18°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.16 (16%) of the rate of heat transfer through the bricks without the use of cladding.

H. Eighth Mixture, Crushed Bricks and Compressed Foam

The temperature on the faces of the samples of this proposal initially indicated approximately 21°C, then the average readings at 5 different points on the face of each sample every 10 minutes were as follows:

Table 21. Time lag of the samples of the eighth mixture [Authors]

time (min)	BR3	BR4	BR5
0	20.6	20.6	20.6
10	21.1	21	21.6
20	23.1	22.1	23.9
30	24.6	23.8	25
40	25.4	24.6	28.2
50	26.3	25	29.9
60	28.5	25.4	32.3

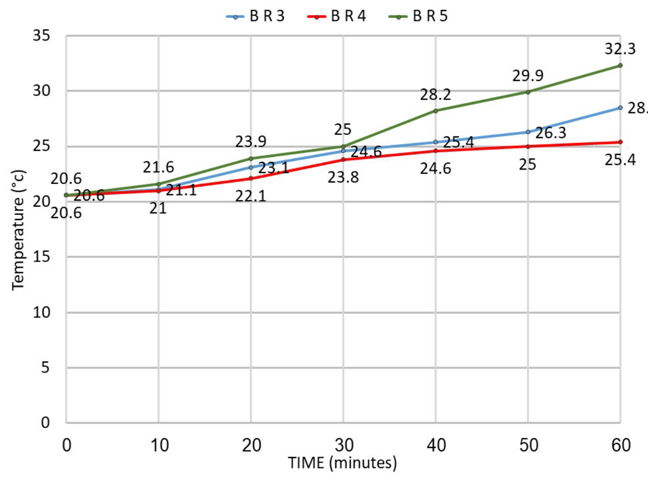

Figure 30. Time Lag of the samples of the eighth mixture [Authors].

The temperature of sample BR3 increased at a rate of 1.32°C every 10 minutes, while the rate of increase for sample BR4 was 0.8°C every 10 minutes, finally sample BR5 increased at a rate of 1.95°C every 10 minutes. Thus, sample BR4 is the best performing sample, and it is chosen for further testing with clay bricks to determine its actual performance in terms of thermal insulation.

The temperature on the faces of the brick samples initially were about 20°C, then the average readings on the faces of the brick samples with and without cladding BR4 were as follows:

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Table 22. Time lag of bricks with and without cladding BR4 [Authors]

time (min)	Bricks without cladding	Bricks with cladding BR4
0	20.3	20.3
10	21.2	20.7
20	22.8	21.1
30	23.7	21.6
40	25.9	22.2
50	27.4	23.1
60	29	23.8

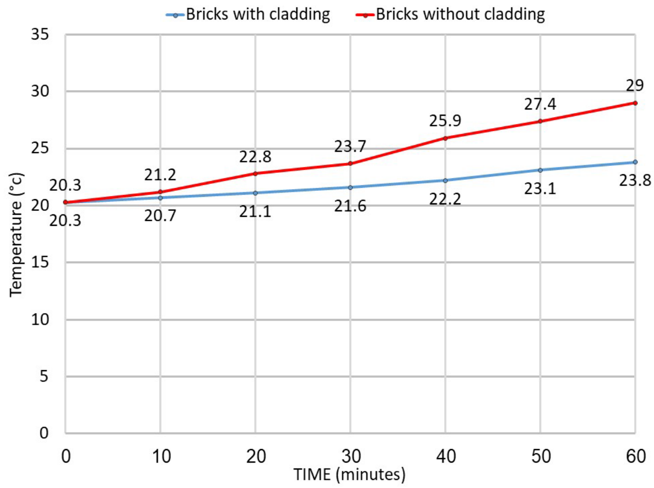

Figure 31. Time Lag of bricks with and without cladding BR4 [Authors].

The temperature of the brick samples with no cladding applied increased at a rate of 1.45°C every 10 minutes, after applying the cladding the rate of increase dropped to 0.58°C every 10 minutes. This means that the rate of heat transfer through the body of the brick after using the cladding is approximately 0.4 (40%) of the rate of heat transfer through the bricks without the use of cladding.

VIII. Conclusion

The Construction and Demolition Waste (CDW) constitute a significant percentage of the total solid waste generated in Egypt. The Egyptian laws related to this matter are not sufficiently enforced, and the necessary institutional arrangements do not exist to ensure their implementation. Also, although they include provisions directing the disposal of construction and demolition waste, they do not include any provisions indicating limiting their generation.

CDW cand be exploited in the manufacture of recycled, sustainable wall claddings, the actual sustainability of the materials used in wall cladding is related to their local availability and spread. It is preferable to use local materials i.e., in places where those materials are harvested, produced, or manufactured.

The researchers tested different mixtures of construction and demolition waste for the manufacture of wall claddings, then the researcher tested the best performing wall claddings by applying them to clay bricks. These tests yielded promising results, as the best performing claddings succeeded in reducing heat gain by up to 86%.

The climate of Egypt is characterized by high temperatures. Clay brick, which is the most common type of building brick in Egypt, is one of the main reasons for increasing the heat gain of buildings. Therefore, large amounts of energy are wasted in air conditioning to control the internal temperature and reach thermal comfort conditions, and through the employment of the proposed wall claddings, it is possible to significantly reduce the energy consumed for cooling and air conditioning, as the amount of heat transferred from the outside to the inside is reduced. Furthermore, wall claddings made from construction and demolition waste have a relative environmental advantage over clay bricks commonly used in residential buildings in Egypt.

IX. Recommendations

Based on these conclusions, the researchers recommend developing the Egyptian building code and including more clear information regarding the reuse and recycling of demolition and construction waste, with clarification of the specifications of reused materials or materials resulting from recycling.

Future research could further examine other materials and different alternatives that can be manufactured from construction and demolition waste, as the available capabilities remain large and numerous and have not been sufficiently researched, especially through the experimental approach.

The researchers recommend focusing on the use of the remnants of the agricultural sector and its waste in Egypt, with the aim of accessing other materials (such as building units or internal and external wall claddings), as the use of local materials would reduce the economic and environmental impacts and achieve sustainability.

Further research is necessary to find an alternative to cement as a binder in recycled cladding mixtures, in order to achieve the highest possible environmental and economic benefit.

Additional research could address conducting an in-depth economic study of materials manufactured from recycled waste to determine the extent of their feasibility and the possibility of their commercial use.

The researchers recommend continuing to develop the proposed mixtures by conducting a complete or partial replacement of its components and conducting further experiments, as this can lead to improving the thermal properties of the mixture or reducing the costs of reaching the final product.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

References

[1] Central Agency for Public Mobilization and Statistics, "Annual report of solid waste management in Egypt", 2018, pp. 55.

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Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

[2] S. Azab, "Environmental and Economic Impact Assessment of Construction Waste using System Dynamics" M.Sc., Faculty of Engineering, Cairo University, 2013, pp. 8.
[3] S. Dash, et al, "Comparative feasibility analysis of fly ash bricks, clay bricks and fly ash incorporated clay bricks" Magazine of Civil Engineering, 2022, Vol. 115(7), No. 11502, pp. 1-7.
[4] Neha Kolan, Er. Ekta Purandare, "Study of Evolution and Changes of Interior Wall Cladding with Time", International Research Journal of Engineering and Technology (IRJET), Volume: 06 Issue: 11, 2019, 986-988.
[5] The Food and Agriculture Organization (FAO) Official data available at website: http://faostats.fao.org/.
[6] D.W. Yarbrough, K.E. Wikes, P.A. Olivier, R.S. Graves, A. Vohra, "Apparent thermal conductivity data and related information for rice hulls and crushed pecan shells", Therm. Cond. 27, 2005, pp. 222–230.
[7] S. Dance, P. Hervin, "Straw bale sound insulation: blowing away the chaff", Proceedings of ICA 2013, Montreal, Canada, 2013.
[8] http://www.inno-therm.com /buy/specifications/
[9] A. Patnaik, M. Mvubu, S. Muniyasamy, A. Botha, R.D. Anandjiwala, "Thermal and sound insulation materials from waste wool and recycled polyester fibers and their biodegradation studies", Energy Build, 2015, pp. 161-169.
[10] X. Zhou, F. Zheng, H. Li, C. Lu, "An environment-friendly thermal insulation material from cotton stalk fibers", Energy Build. 42 (2020) 1070–1074.
[11] G. D'Angelo, M. Fumo, M.d.R. Merino, I. Capasso, A. Campanile, F. Iucolano, D. Caputo, B. Liguori, "Crushed Bricks: Demolition Waste as a Sustainable Raw Material for Geopolymers". Sustainability 2021, 13, 7572, https://doi.org/10.3390/su13147572.
[12] ASTM C618-19, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, American Society of Testing and Materials, West Conshohocken, PA, 2019.
[13] Sika, "Sika ViscoCrete ® - 3425," datasheet, 2017.
[14] CMB – Chemicals for Modern Building, "Addipor 55" datasheet, Jan. 2018.
[15] D.Mazzeo, G. Oliveti, N. Arcuri, "Influence of internal and external boundary conditions on the decrement factor and time lag heat flux of building walls in steady periodic regime", 2016, P 509-531. 10.1016/j.apenergy.2015.11.076.
[16] N. Balaji, M. Mani, B. Reddy, "Thermal Performance of the Building Walls", 2013, P 152.

Doi: 10.21608/ERJENG.2023.230391.1212