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Article

Optimization of Energy Efficiency in Reinforced Concrete Constructions by Using a Panel of Recycled Rubber as a Thermal Insulator

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ABSTRACT

The use of thermal insulation in the construction of homes and buildings is essential to create efficient and sustainable living spaces. These materials regulate heat flow, improving energy efficiency in construction. In Ecuador, buildings are mainly based on reinforced concrete, which offers strength and construction speed, but this system has a high thermal conductivity, thus increasing energy consumption due to the air conditioning system.

This study aims to explore in depth the benefits and challenges associated with the integration of recycled tire rubber as a key component in thermal insulation systems for reinforced concrete buildings. A thermal conductivity test was conducted comparing reinforced concrete with the proposed rubber insulation, where the proposal generated a 62.5% reduction in the thermal conductivity coefficient.

In the second part, temperatures were monitored in rooms built with reinforced concrete, one of which was insulated with 2 cm of rubber on the east and west walls. The insulation generated a 40.4% reduction in heat and a 13.32% saving in the energy consumption of the air conditioning system.

These results highlight the effectiveness of rubber as a thermal insulator to mitigate the thermal conductivity of reinforced concrete, contributing significantly to energy efficiency in construction. The implementation of this approach can promote more sustainable and economically viable constructions.

KEYWORDS: thermal insulation in buildings; energy efficiency; reduction of CO_2 emissions

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ABBREVIATIONS

INAMHI, Instituto Nacional de Meteorología e Hidrología; OECD, Organization for Economic Co-operation and Development; NEC, Ecuadorian Construction Standard; BTU, British Thermal Unit

INTRODUCTION

In a global context of growing environmental awareness and search for sustainable solutions, energy efficiency in buildings has become a central issue. The increasing energy demand for air conditioning, especially in reinforced concrete structures, poses significant challenges in terms of energy consumption [1–4] and its associated environmental impact, because the energy demand for air conditioning is expected to triple by 2050 [5,6]. In addition, due to global warming and its temperature increases [7–9], air conditioning units will need to operate at higher intensity and for longer periods of time.

In this regard, the reuse of tire rubber as thermal insulation emerges as a promising alternative that not only addresses the problem of waste tires that more than 4 billion tires accumulate in landfills [10–13] worldwide, but can also contribute substantially to the reduction of energy consumption in reinforced concrete-based buildings.

The use of recycled materials, in particular tire rubber, as thermal insulation represents an innovative approach with the potential to improve the thermal properties of structures, thereby reducing the need for intensive air conditioning by 17.56% [14–17].

Other studies demonstrate the importance of using different types of thermal insulators for reducing internal temperatures in buildings [18–21], but no study covers reinforced concrete building systems and how they would reduce their internal temperature.

This study aims to explore in depth the benefits and challenges associated with the integration of recycled tire rubber as a key component in thermal insulation systems for reinforced concrete buildings. By better understanding the heat transfer mechanisms and evaluating the long-term thermal performance, it seeks to provide a sound scientific basis to support the implementation of this strategy as an effective measure for the reduction of energy consumption in the construction sector. The results obtained will provide valuable insights for architects, engineers and policy makers seeking sustainable and energy efficient solutions for reinforced concrete buildings.

METHODOLOGY

The methodology of this research will consist of 3 stages:

Initially, 10 samples of conventional reinforced concrete and 10 samples of reinforced concrete incorporating a recycled rubber sheet with a thickness of 2 cm will be produced. Subsequently, in the next phase of the research, a thermal conductivity analysis will be carried out on both types of samples to facilitate a comprehensive comparison. Finally, an experiment will be carried out under real conditions, taking into account factors such as temperature, humidity and wind speed. This experiment will compare a room built with standard reinforced concrete and another room built using the same system, but integrating the 2 cm thick rubber sheet on the east and west facing walls. The objective will be to determine the reduction in heat transfer due to radiation, as well as to evaluate the electrical energy consumption for air conditioning.

Sample Fabrication

This section explains how the reinforced concrete specimens and the reinforced concrete specimens with the application of the rubber sheet were manufactured.

Composition of the reinforced concrete sample

Currently, construction companies in Guayaquil Ecuador are building houses with reinforced concrete with a thickness of 9 to 15 cm according to the Ecuadorian Construction Standard [22]. The construction of houses based on reinforced concrete consists of a system of electro welded mesh covered with concrete as shown in Figure 1. This method is used by most construction companies because it is much more efficient in project delivery time, which generates savings in the time of hiring personnel, more real estate projects can be advanced and there is a decrease in waste by leaving aside the conventional brick construction [22].

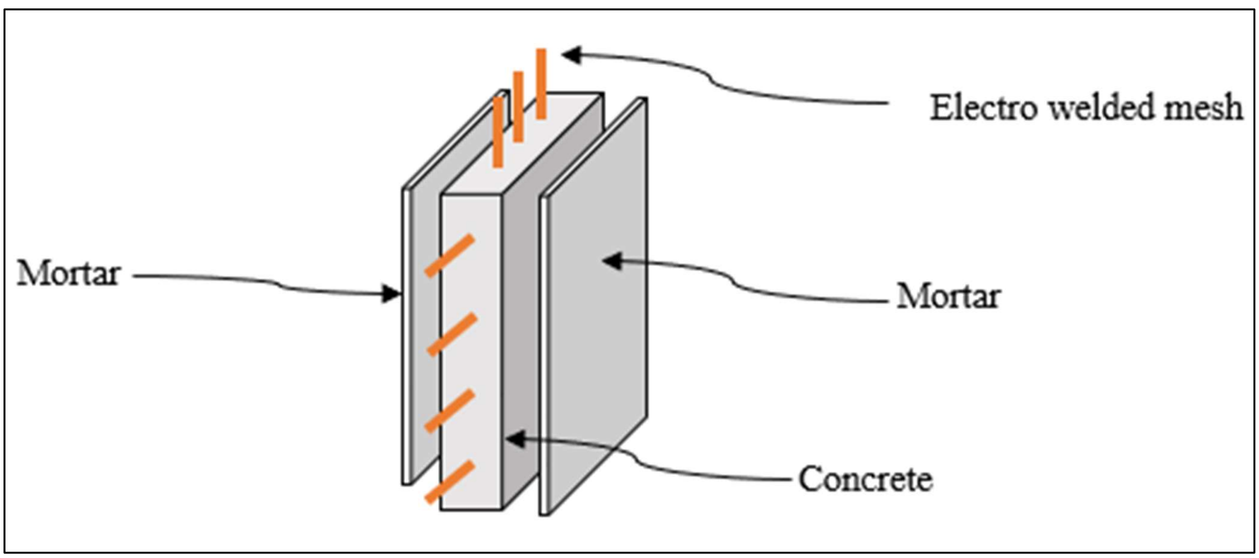

Figure 1. Reinforced concrete construction.

To obtain the concrete samples, a mixture of cement, sand and gravel was made with the proportion of 1 cement, 2 sand and 3 or 4 gravel [23] as shown in Table 1.

Table 1. Concrete batching.

Dosage or richness of cement per cubic meter of concrete (kg/m^3)	Proportions			Preferred uses of concrete
	Cement	Sand	Gravel	
300–350	1	2	3 o 4	Reinforced concrete; Footings; Special walls.

Manufacture of the rubber panel

In the manufacture of the rubber panel, car and truck tires were used, which were shredded into sizes between 300–400 mm long and 100 to 200 mm wide, followed by melting these particles at about 180 °C in order to make a 2 cm thick sheet.

Composition of the sample of the reinforced concrete with rubber insulation

The construction of the samples required a wooden formwork, electrowelded mesh, 2 cm thick recycled tire rubber thermal insulation, concrete and mortar as shown in Figure 2. The reinforced concrete samples without insulation that were constructed for the experiment were 10 cm thick to comply with the Ecuadorian Construction Standard and with an average density of 2400 kg/m^3. A reinforced concrete sample was also constructed with a 2 cm panel of recycled tire rubber insulation with a maximum rubber content of no more than 20% of the total volume of aggregate and an average density of 2150 kg/m^3 which would mean a reduction in density of approximately 10%.

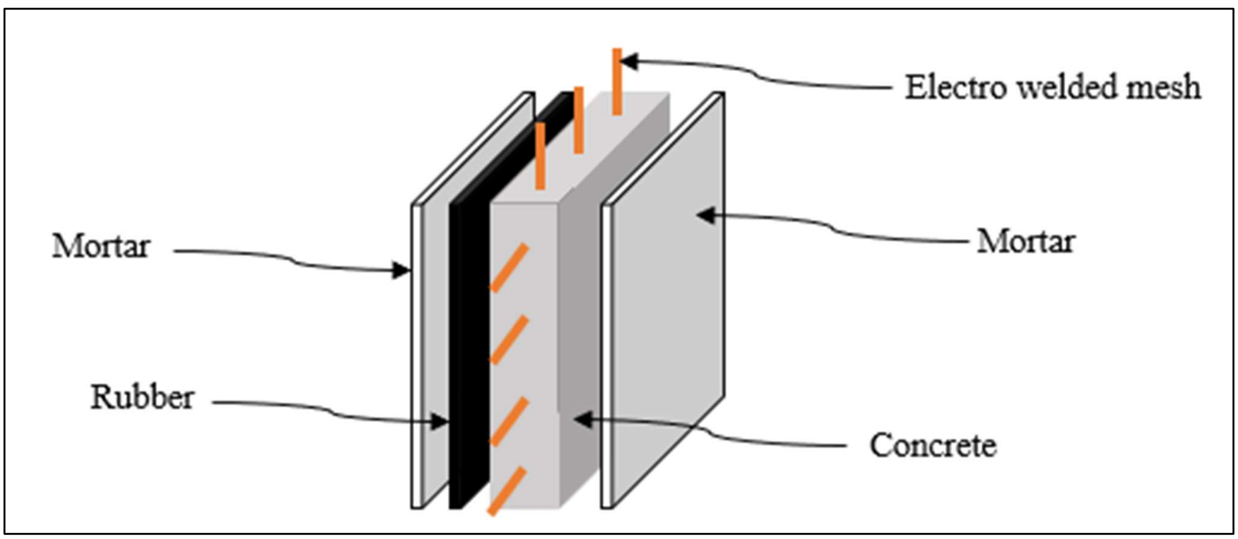

Figure 2. Composition of reinforced concrete with insulation.

According to Humberto Gutierrez Pulido and Román De La Vara Salazar [24], a total of 10 samples will be taken for thermal conductivity experiments and analysis. Also, 10 samples of the conventional reinforced concrete system (without insulation) will be carried out for comparison with the proposal.

Determination of Thermal Conductivity

The experiment consists of placing the sample of reinforced concrete with a rubber insulator between two plates Figure 3, a plate containing an electrical resistance that will supply heat to the sample, this plate called hot has a sensor that will determine the inlet temperature T_1. Through the block the heat will be transferred to the outlet plate, this plate called cold has a sensor PT1000 that will determine the outlet temperature T_2. By means of the temperature gradient ($\Delta T = T_2 - T_1$), the sample length L, the sample cross-sectional area A and the supplied heat Q (electrical power) the effective thermal conductivity k of the sample will be determined.

The time of heat supply will be 15 minutes, this time guaranteed the stability of the heat in the samples, during the experiment records of temperature T_1, T_2 and voltage V were taken. With the data obtained (T_1 and T_2) during the experiment and the dimensions of the sample, the thermal conductivity was obtained using equation (1). With the previously obtained dimensions of the samples, their mass was also measured using a digital balance to determine their density.

$$Q = \frac{k.A.\Delta T}{L} \quad (1)$$

The thermal transmission system used consisted of:

- Insulating chamber (a)
- Sample (b)
- Hot plate (h)
- Cold plate (c)
- PT 1000 sensors in T_1 and T_2 (S)
- Voltage submeter (V)
- Computer (p)

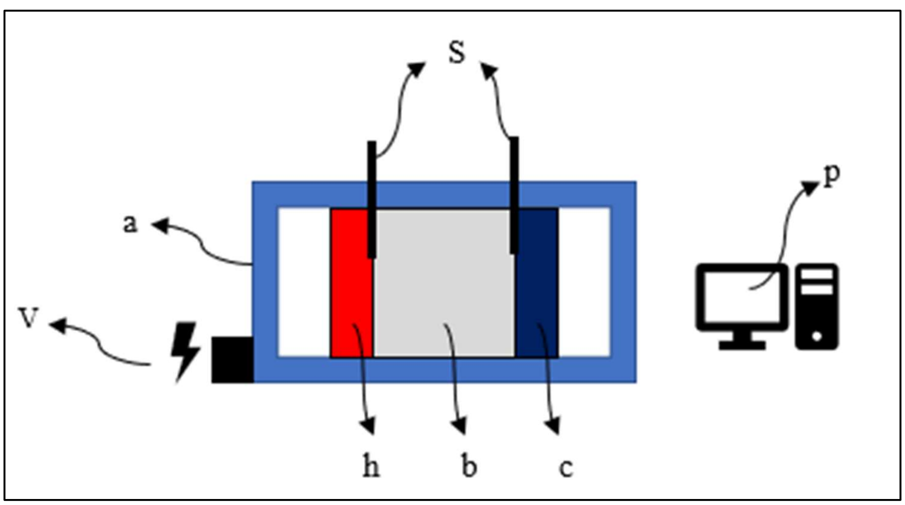

Figure 3. Thermal conductivity determination equipment.

The test conditions were as follows: power supplied 0.50 W, hot plate temperature 35.5 °C, ambient temperature 27.3 °C, humidity 76%, sample thickness 12 cm and sample area 300 cm².

Reduction of Energy Consumption for Air Conditioning

In order to determine the heat reduction and consequently the energy consumption for air conditioning, in a 3 m wide, 3 m long and 2.5 m high room built with the conventional reinforced concrete system, a 2 cm thick rubber panel was applied to the walls where there is direct solar radiation. Once the rubber insulation was placed on the walls, the external and internal temperatures of the room were taken during the hottest hours (6h00 to 20h00), as well as the amperage data of a 12,000 BTU air conditioning unit to see its behavior. The same experiment was carried out in a room with the same characteristics, with the same air conditioning equipment, but without the thermal insulation for comparison.

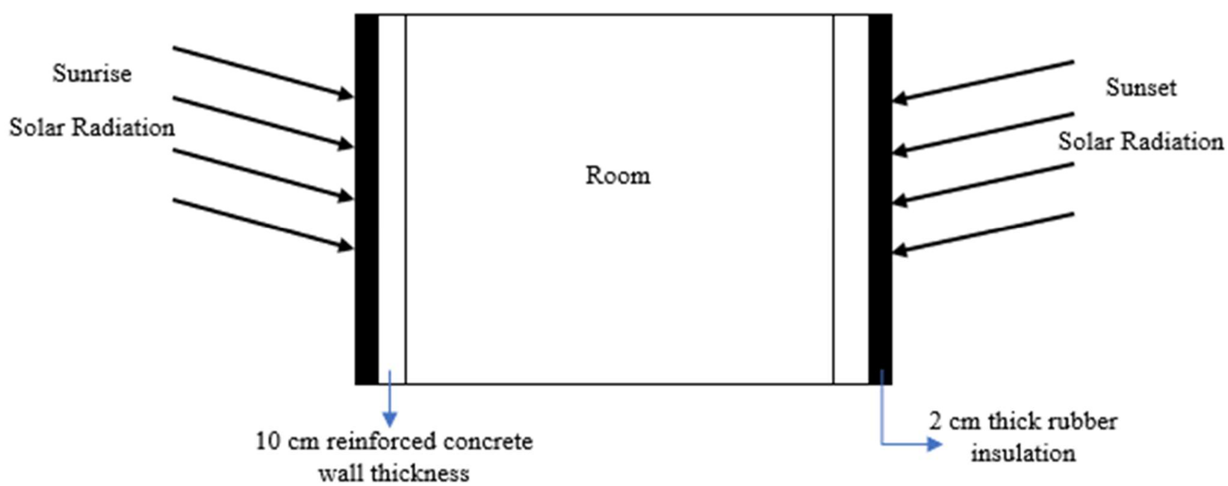

Figure 4. Rehearsal room.

RESULTS AND DISCUSSION

Determination of the Thermal Conductivity of Reinforced Concrete

The 10 reinforced concrete samples had densities ranging from 2390 kg/m^3 to 2410 kg/m^3 thus having an average density of 2400 kg/m^3. As can be seen in Figure 4 the thermal conductivity varied between 1.45 W/m K to 1.77 W/m K, giving an average thermal conductivity of 1.59 W/m K.

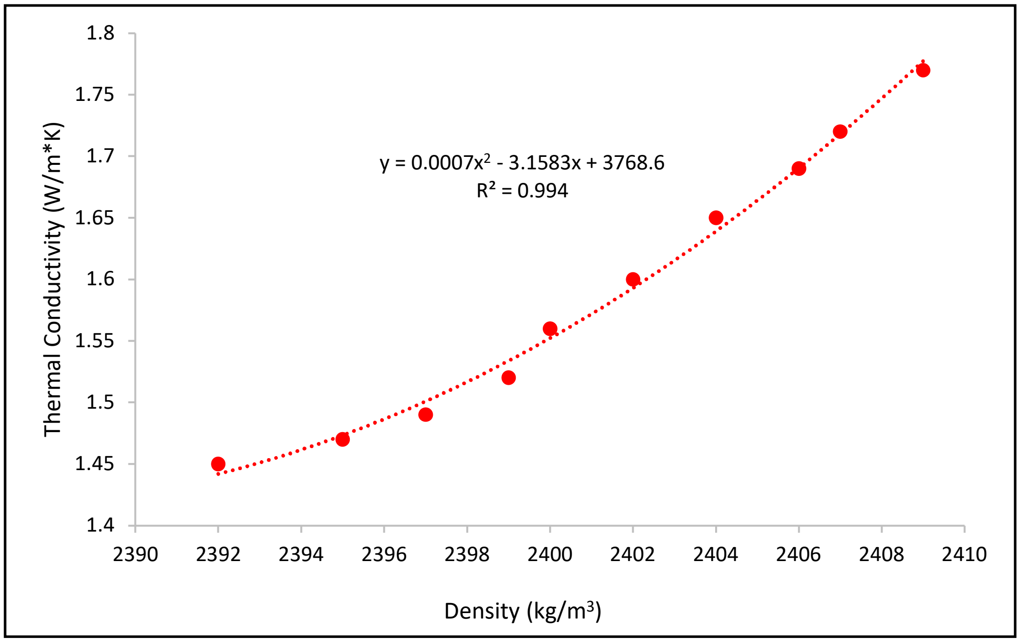

Figure 5. Thermal conductivity of reinforced concrete vs. density.

It should be noted that reinforced concrete has a higher thermal conductivity than other traditional construction methods as shown in Table 2 [19,20,25].

Table 2. Thermal conductivity of building materials.

Material	***k*** **(W/m K)**
Ordinary brick	0.80
Clay brick	0.57
Solid brick	1.50
Lightened concrete (Mortar)	0.90
Reinforced concrete	1.63

Determination of the Thermal Conductivity of Reinforced Concrete with Rubber Insulation

A 2 cm panel of recycled tire rubber was placed on the 10 reinforced concrete samples, which causes the average density to change with respect to the average density of the construction with conventional reinforced concrete. The densities varied from 2140 kg/m^3 to 2160 kg/m^3 with an average density of 2150 kg/m^3. As can be seen in Figure 5 the thermal conductivity varies between 0.53 W/m K to 0.77 W/m K, giving an average thermal conductivity of 0.61 W/m K which generates a reduction of 62.5%. It is worth mentioning that, if the thickness of the rubber is increased, the density decreases and the thermal conductivity decreases, on the other hand if the thickness of the rubber is decreased, the density increases and the thermal conductivity increases.

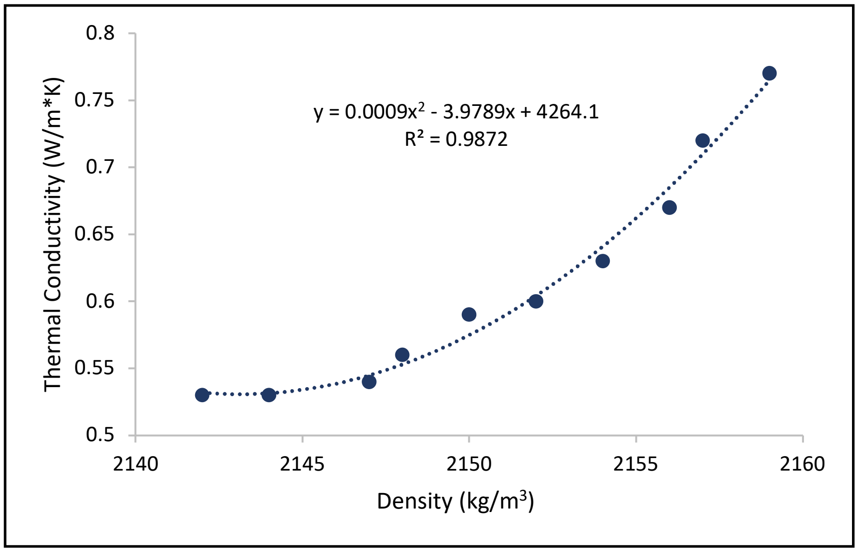

Figure 6. Thermal conductivity of reinforced concrete with rubber insulation vs. density.

This improvement in thermal conductivity by applying recycled rubber implied a 63.19% reduction in the thermal conductivity of reinforced concrete and thus it also has lower thermal conductivity than other traditional construction methods such as solid brick, lightweight concrete and reinforced concrete as shown in Table 3 [19,20,25].

Table 3. Thermal conductivity of building materials.

Material	***k*** **(W/m K)**
Ordinary brick	0.80
Clay brick	0.57
Solid brick	1.50
Lightened concrete (Mortar)	0.90
Reinforced concrete	1.63
Reinforced concrete with rubber insulation	0.60

According to the 204 report of the National Institute of Meteorology and Hydrology (INAMHI), Guayaquil will record an average temperature of 32 °C during the month of January 2024 [26]. This means that air conditioning equipment installed in homes or offices to maintain an internal thermal comfort of 21 to 22 °C will have a higher energy consumption.

Determination of Heat Reduction

During the period from 6h00 to 20h00 and using a digital thermohygrometer, the external and internal temperatures, humidity and wind speed were recorded in two rooms with the same reinforced concrete construction system, both with the same dimensions, located in the same position with respect to the sun and neither had an air conditioning system in operation as shown in Table 4. Internal room temperatures were recorded every 2 hours to ensure that the room recovered its internal heat, since there was a heat loss upon entering the room.

Table 4. Weather conditions.

Hours	Humidity (%)	Wind speed (km/h)	External temperatures (°C)	Indoor temperatures without insulation (°C)	Indoor temperatures with insulation (°C)
6h00	86	4	23.3	23.4	23.2
8h00	84	5	24.7	23.9	23.6
10h00	76	4	28.2	26.3	25.1
12h00	66	4	30.1	27.4	26.3
14h00	54	4	31.9	27.9	25.7
16h00	56	4	29.8	26.9	26.3
18h00	64	6	27.7	25.9	25.1
20h00	77	6	22.6	23.9	23.0

For the temperatures recorded above, an adjustment was made considering climatic conditions such as humidity, external wind speed and considering as insignificant the internal wind speed of the room as shown in Table 5.

Table 5. Temperature adjustment.

Hours	External temperature adjustment (°C)	Adjustment of internal temperatures without insulation (°C)	Adjustment of internal temperatures with insulation (°C)
6h00	26.8	26.5	26.1
8h00	28.6	28.3	27.8
10h00	33.3	31.1	29.3
12h00	34.8	31.5	29.9
14h00	35.7	30.7	27.6
16h00	32.9	29.5	28.7
18h00	30.6	29.1	27.9
20h00	26.7	26.3	26.3

In one of the rooms, a 2 cm thick rubber insulation panel was installed on the walls facing east and west, where they receive direct solar radiation as shown in Figure 6, obtaining an average heat reduction of 35.7% with respect to the reinforced concrete construction system, as shown in Table 6.

Table 6. Reduced heat transfer.

Hours	Heat transfer without insulation (W)	Heat transfer with insulation (W)	Reduced heat transfer
6h00	0.00	0.00	0.0%
8h00	109.50	37.16	66.1%
10h00	219.00	148.64	32.1%
12h00	438.00	222.96	49.1%
14h00	547.50	297.29	45.7%
16h00	328.50	185.80	43.4%
18h00	219.00	111.48	49.1%
20h00	109.50	37.16	0.0%

Reduction in Energy Consumption for Air Conditioning

During a period of 30 minutes, the amperage readings of the air conditioning equipment in both rooms were taken with the following characteristics Table 7.

Table 7. Air conditioning equipment features.

A/C conditions	Values
Capacity	12,000 BTU
Voltage	220 V
Air conditioning temperature	21 °C

For each minute a total of 6 amperages (intensity I) were recorded, these 6 records per minute were averaged and using equation 2 the kW of energy consumption was calculated. When graphing the energy consumption of both air conditioning units during that period of time, in the initial 3 minutes both air conditioning units have almost the same behavior due to the energy consumption of the compressor at start-up but, in the 4 to 16 minutes the air conditioning unit installed in the room with the thermal insulation achieves much faster the desired temperature of 21 °C and its energy consumption varies between 0.025 to 0.032 kW, while in the room without the insulation it takes 2 minutes longer to reach the desired temperature and in that time its energy consumption varies between 0.035 to 0.042 kW as shown in Figure 7. This difference between the amperage records represents a reduction in energy consumption and therefore in CO_2 emissions of 13.32%.

$$energy\ consumption\ (kW) = \frac{I * V}{1000} \quad (2)$$

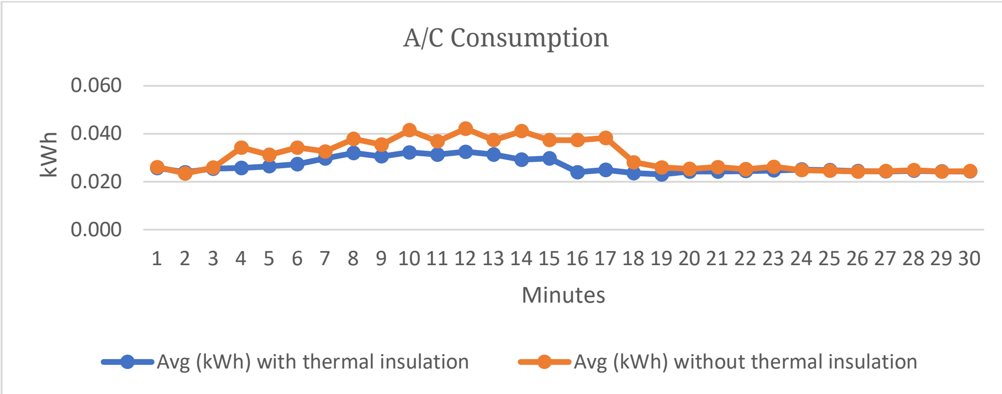

Figure 7. Energy consumption.

Thermal Inertia Analysis

As another point of analysis is the comparison of thermal inertia between conventional reinforced concrete construction and the studied proposal, where it is known that thermal inertia refers to the ability of materials to resist rapid changes in their temperature, thermal inertia describes the tendency of a material to maintain its current temperature even when external heat or cold is applied [27,28]. In other words, materials with high thermal inertia take longer to heat up or cool down than materials with low thermal inertia.

As can be seen in Figure 8 in the reinforced concrete construction system its temperatures vary between 26 °C to 31 °C, while with the proposed one the temperatures vary between 26 °C to 29 °C, this means that the proposed 2 cm rubber insulation panel has higher thermal inertia.

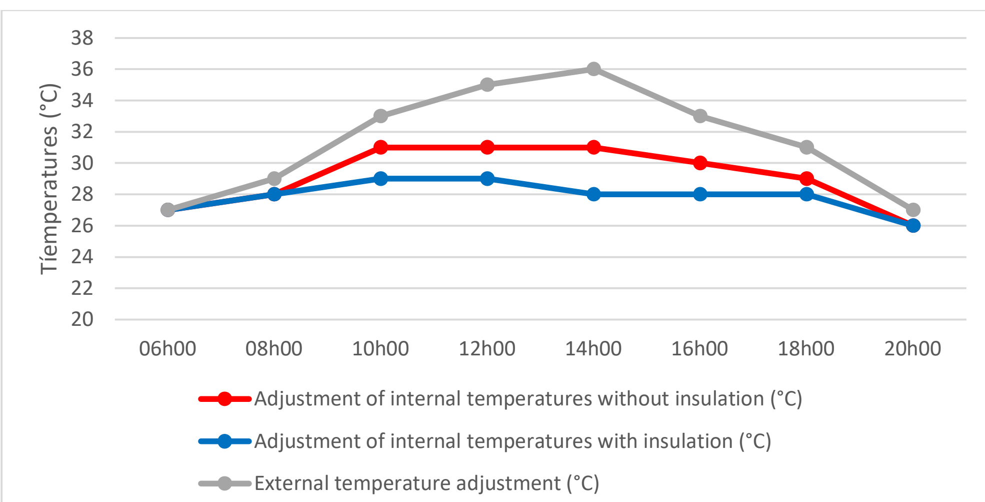

Figure 8. Thermal inertia.

CONCLUSION

The current construction systems of reinforced concrete are more economical due to the short delivery time of the work, but lacking a thermal insulation this will generate discomfort in the occupant of the house or office as it will lack thermal comfort. Even the classic brick constructions have an air insulation system, thus reducing thermal conductivity.

As previously stated, the proposal is to apply a 2 cm thick panel of rubber on the walls with the highest solar radiation, this panel can be generated with different geometric shapes and colors so as not to affect the architecture of the building, it is also necessary to clarify that the insulating panel of rubber does not affect the structural characteristics.

The novelty of this study was to take the experiment to a real situation such as the application of the rubber sheet on two walls of a room built with the reinforced concrete system and determine the actual heat reduction in a room, since in other studies the heat transfer analysis is limited to laboratories, in this analysis it was possible to reduce the internal heat of the room by approximately 40%, which would generate a greater thermal comfort than that provided by the reinforced concrete system. From the above, it is known that the more heat in a room, the higher the energy consumption of the air conditioning equipment, therefore, in addition to determining the reduction of heat transfer, a 13.32% reduction in energy consumption was determined.

In the analysis of thermal inertia, it was demonstrated that the proposed proposal obtained a lower variation in internal temperatures and therefore greater thermal inertia than the reinforced concrete construction system. It is necessary to state that, although it is true that the proposal to place an insulating panel on the walls reduces the transfer of heat from the exterior to the interior during the hours of highest solar radiation, it is not advisable to apply the insulation to all the walls of the room since it would make the transfer of heat from the interior to the exterior at night impossible.

For future research, a comparison can be made between recycled tire rubber and other types of insulation produced from the reuse of waste.

DATA AVAILABILITY

All data generated from the study are available in the manuscript.

AUTHOR CONTRIBUTIONS

Rayner Ricaurte Párraga and Jesús Verdugo Arcos designed the study and the experiments. Jennyffer Yepez Ramirez and Danny Vera Guerrero performed the experiments. Rossana Ricaurte Párraga analyzed the data. Rayner Ricaurte Párraga wrote the paper.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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