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COMPORTAMIENTO TÉRMICO DE TRES PROTOTIPOS EN SALTILLO, COAHUILA (BLOQUES DE TIERRA, CONCRETO Y TAPA DE HUEVO)

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THERMAL BEHAVIOR OF THREE PROTOTYPES IN SALTILLO, COAHUILA (WITH EARTH BLOCKS, CONCRETE AND EGG CARTONS)

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RESUMEN

El cambio climático se ha ido agravando en el siglo XX, genera modificaciones estacionales a nivel global en el hábitat, se observan variaciones importantes en los factores climáticos, aumentando las temperaturas en las ciudades. En México el acondicionamiento térmico de las viviendas repercute en gran medida sobre la demanda de electricidad, siendo mayor en las zonas norte y costeras del país, el rol de la envolvente es mantener un equilibrio entre el exterior y el interior, refiriéndose a las ganancias o pérdidas de calor, que se logran a través de su transferencia producto de las variaciones de la temperatura. El objetivo del trabajo fue comparar el comportamiento térmico de tres módulos ubicados en Saltillo, Coahuila; construidos de tres distintos materiales: uno experimental y dos de uso común en las viviendas de Saltillo, la metodología es de enfoque cuantitativo, se realizaron mediciones del 2018 al 2019, los resultados muestran que el material experimental con respecto a los otros materiales comerciales no tienen diferencias relevantes en los meses más críticos que son enero y mayo, apenas 1 o 2 grados, por lo que es pertinente seguir experimentando y complementar con un sistema pasivo, como un pozo canadiense, con la meta de mejorar el confort en el hábitat construido.

Palabras clave
Bloque, edificación, temperatura ambiental

ABSTRACT

Climate change has been worsening in the 20th century, causing seasonal changes in the habitat at a global level. Significant variations in climate factors are seen, increasing temperatures in cities. In Mexico, thermal conditioning of houses has a major impact on the electricity demand, which is greater in the northern and coastal areas of the country. The role of the envelope, when referring to heat gains or losses that are achieved by their temperature variation transfer, is to maintain a balance between the outside and the inside. The goal of this work was to compare the thermal behavior of three modules located in Saltillo, Coahuila; built using three different materials, one experimental and two commonly used in Saltillo homes. The methodology has a quantitative focus and measurements were made from 2018 to 2019. The results show that there are no relevant differences between the experimental material and other commercial materials in the most critical months, January and May, with just 1 or 2 degrees. Thus, it is relevant to continue experimenting and complementing with a passive system, like a Canadian well, with the goal of improving comfort in the built habitat.

Keywords
Blocks, edification, room temperature

INTRODUCTION

Climate change in the 20th century has generated global seasonal changes in the habitat, with important variations seen in climate factors that directly impact comfort inside dwellings. In fact, climates that were previously considered as template, no longer retain this category, so much so that warm climates are more extreme than before, which as a consequence brings the need to adapt the habitat of dwellings to improve comfort.

In the opinion of Delfin, Gallina and López (2014), the habitat has the responsibility of fulfilling suitable conditions for a species, starting from two angles: real habitat, which refers to the presence of a species in a space, and potential habitat, that implies that a habitat may potentially be built in an area where a species is not present.

The Pan American Health Organization (PAHO, 1999) states that the structure of the dwelling for groups in poverty does not have the necessary conditions to act as a shelter, that provides suitable protection from extreme temperatures, noise, among other factors. Múnera (2011) on the other hand, considers that the habitat and, in particular, the dwelling, become “objects” of intervention and manipulation, becoming merchandise, on standardizing the widespread building of social housing by the private sector.

The Energy Secretariat (SENER and CONUEE, 2011) establishes that:

> In Mexico, the thermal conditioning of dwellings impacts, to a great extent, the peak demand of the electricity system, with it being higher in the Northern and coastal areas of the country, where the use of active systems is more commonplace. (p.1).

Along this line, Herrera (2017) states that technical specifications of an obligatory application are established including, among these, the Mexican Energy Efficiency Standard in Buildings and Building Envelopes for Habitational Use (NOM-020-ENER-2011), whose objective is:

> Limiting the heat gains of buildings for habitational use through their envelope, rationalizing the use of energy in cooling systems and improving the thermal comfort conditions inside the spaces of the dwelling (SENER and CONUEE, 2011, p. 1)

García, Kochova, Pugliese and Sopoliga (2010) suggest that a dwelling is like a breathing box since, as it is based on the climate outside, it activates different mechanisms to regulate the heat; but, also, a construction depends on the design, shape and envelope, giving as a result, comfort or discomfort for two constant parameters: temperature and humidity. Both play an important role in the end result. These authors, along with Costantini, Carro Pérez and Francisca (2016), suggest that:

> The choice of construction materials is key for reaching high comfort levels at a low cost. For example, a ceramic hollow brick has very good insulation properties (or high thermal resistance), but there are other materials like thermal clay that have an even better performance (p. 12).

The National Housing Commission (CONAVI, in Spanish), together with the German Technical Cooperation Agency (GIZ) implemented the country-specific mitigation measures program (NAMA) to develop sustainable housing in Mexico. The problem is the shortage of green label materials, based on the thermal capacity and thermal retardation. The latter refers to the time where the heat or cold passes from the outside to the inside (Morris, 2017). to keep a space comfortable without needing to use an artificial system and, therefore without generating a high energy consumption demand (Roux, 2018).

According to Calderón (2019), it is possible to build a sustainable habitat using recycled low-cost materials, without affecting the budget destined for its construction and, at the same time, improving thermal comfort. Likewise, Herrera (2017) states that suitably using construction materials considering their thermal properties allows dwellings to approach comfort levels in each one of the climate zones, affecting the surrounding area less and demanding less non-renewable energy. He especially recommends evaluating the thicknesses of the thermal mass, even the dimensions of the studied materials.

The role of the envelope is maintaining a balance between the outside and inside, regarding the heat gains or losses achieved through its transference as a result of variations in the outdoor temperature. In winter, heat is generated inside the construction and is lost in spaces with low temperatures or is dispersed outside through openings; in summer, the gain is obtained from the outside, due to a lack of protection or of the materials that are good conductors and of the surrounding conditions that do not help reduce the energy increase indoors.

On the other hand, aiming at reaching thermal comfort indoor temperatures, in all building types, airtightness plays a relevant role in contributing towards a reduction or increase of the indoor temperature (Molina, Lefebvre, Horn & Gómez, 2020). Muñoz, Marino and Thomas (2015) consider the orientation of a construction as a factor for the energy consumption needed for its operation, as such, on assessing its behavior, the contributions of the envelope components must be considered (walls, openings and roofs).

In previous studies made by Molar, Velázquez and Gómez (2018), it is mentioned that:

> In May, the temperatures of dwellings show a thermal behavior that follows the comfort ranges for summer, but in January, there are very low temperatures, with a great thermal amplitude between day and night. As a result, heating is needed to improve indoor conditions (p. 7).

Indoor temperature readings outside these ranges show that heat losses or gains are the result of an unsuitable choice of materials for the envelope. Although, on occasions, this is due to the openings, a given orientation and the materials in general, it has been studied that, by area unit, it is the envelope materials that transfer more heat from the outside to the inside (Huelsz, Molar & Velázquez, 2014; Espinoza, Cordero, Ruiz & Roux, 2017). The heat transfer process happens because of the capture of solar radiation, led inside through the material and released thanks to convection, which affects the environmental thermal behavior inside the building.

In simulation tests using the Ener-habitat program for the climate of Saltillo (Molar & Huelsz, 2017), the total thermal load value of the month of May was compared, following a given thickness. From the different orientations, the one that recorded the highest load was the west. However, in January, under equal conditions, the orientation with the highest load was the north.

Another recommended aspect is annually analyzing a building (Rodríguez, Nájera & Martín, 2018), which means that, if only the summer or winter conditions are studied, it is possible to improve the thermal performance of a single period, which could affect the other, resulting in the neutralization of gains or savings.

Considering this, the Technology in Architecture Faculty Members of the Faculty of Architecture at the Autonomous University of Coahuila's Arteaga Campus, have made a research project with non-toxic and natural industrial waste materials, with the goal of developing sustainable construction systems that improve the thermal comfort conditions of the built habitat. This article presents the results of a project made in this context between 2018 and 2019. It compares the thermal behavior of the envelope of three modules located in Saltillo, Coahuila, built with three different materials: concrete blocks (the most commonly used construction material), compressed earth blocks (typical of the area) and an experimental material that was previously tested as a construction system (Velázquez & Molar, 2016). The objective is to know their results considering given orientations.

METHODOLOGY

The approach of the research is quantitative, performed transversally, with documented work and a field case study. Concretely, measurements were made onsite, following the ASTM Standard Practice for In-Situ Measurement of Heat Flux and Temperature on Building Envelope Components, which states that information must be collected of the surroundings of the analyzed habitat to compare this with the data obtained inside the 3 modules.

Thus, two devices were used:

1. An infrared thermometer was used to measure the temperature of the surfaces, which introduces the type of emissivity depending on the material of the horizonal and vertical envelope, always making sure to take the measurement in the same place at an intermediate height of the surface. The temperature measurements were made on the central part of inside and outside walls. In the case of the roof, only the inside was recorded, in the center of the surface.

2. To measure the environmental temperature and the humidity percentage, two datalogger temperature and relative humidity recorders were used. One for the outside and another inside each module. The measurements were made under the shade on the outside and on the intermediate part of the space on the inside.

During the measurement period, the modules were kept in the same conditions. They were uninhabited. Therefore, there was no internal gain, but a solar gain by conduction and convection through the openings was considered.

The measurements were made regularly from May 2018 to May 2019, for one week a month, on the days closest to solstices and equinoxes, every hour, between 9am and 3pm, period of greatest radiation capture. The outdoor data was then compared against the indoor data of the habitats, recording only the daytime data, as the security conditions would not allow making nighttime measurements. The data was input in a format and then processed. As a result, the most critical months were identified, discarding the rest on being inside the comfort zone. In this case, solely the results of May and January are shown.

For the purpose of comparison, the comfort zone was determined for Saltillo, Coahuila, following the criteria of Szokolay (2014) and the ANSI/ASHRAE Standard 55-2010 which the Luna Excel ASHI ASHRAE COMFORT program (2019) provides for summer and winter.

For the calculation of the neutral temperature, Auliciems' formula is used (Szokolay, 2014, p.20) (equation 1).

Comportamiento térmico de tres prototipos en saltillo, Coahuila (bloques de tierra, concreto y tapa de huevo)
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$$Tn = 17.6 + 0.31\,Tmm \qquad (1)$$

Where Tn is the neutral temperature and Tmm is the mean monthly temperature.

Tn= 17.6 +(0.31*12.1)
Tn=21.4 °C for the month of January and
Tn= 17.6 +(0.31*22.3)
Tn= 24.5 °C for the month of May

The comfort temperature ranges oscillate between (Tn-2.5) °C to (Tn+2.5) °C, as Szokolay (2014 p.21) suggests, which is why, for Saltillo, in the month of January, whose mean temperature is 12.1°C, the comfort range is from 21.4°C to 23.9°C; while in May, with a mean temperature of 22.3°C, the comfort values are between 22°C to 27°C.

DESCRIPTION OF THE PROTOTYPES

The project was run in the facilities of the Autonomous University of Coahuila. The three modules are located within the university area called Camporredondo, in Saltillo, Coahuila (Figure 1).

The city of Saltillo is located 1,600 meters above sea level, with a latitude of 25°22'35" and longitude of 101°01'00". According to CONABIO (National Commission for the Knowledge and Use of Biodiversity, in English), it has a dry template and warm dry climate with little rainfall throughout the year.

The three habitats (Table 1) are similarly sized in length, height and width (by the size of the blocks) and have the same orientation (NE, SE, SW and NW), making sure to have a separation to not generate shade between them, or obstruct air circulation. The envelope (walls and roof) of each module corresponds to each type of material: compressed earth block (CEB), concrete block (CB) and egg carton block with Thermolite and cement (ECB) (Table 2). None of the modules has a coating on the outside or inside, but they do have two openings, a small window and a door, in a SW orientation (Figure 2).

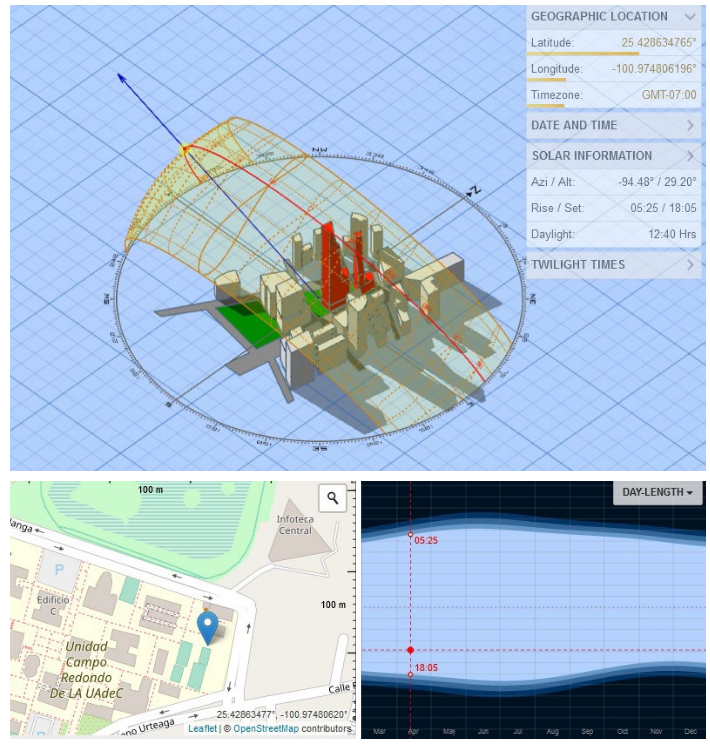

Figure 1. Location of the modules. Source: Andrewmarsh.com. PD: 3D Sun Path.

Figure 2. View of the modules (from left to right: egg carton blocks with Thermolite and cement – ECB, concrete block – CB, and compressed earth block – CEB). Source: Preparation by the author.

Module	Size m
	(width, length, and height)
Compressed earth block module (CEB)	1.4 x 2.20 x 2.36
Concrete block module (CB)	1.47 x 2.26 x 2.50
Egg carton block module with Thermolite and cement (ECB)	1.57 x 2.21 x 2.45

Table 1. Module size
Source: Preparation by the authors.

Material	Size cm
	(width, length, and height)
Compressed earth block module (CEB)	20 x 40 x 12
Concrete block (CB)	14.5 x 39.5 x 19
Egg carton block with Thermolite and cement (ECB)t	10 x 69 x 35

Table 2. Sizes of the blocks.
Source: Preparation by the authors.

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The experimental ECB prototype, comprising light materials like Thermolite, Portland cement, sand and egg cartons, was tested in 2015 by Raúl Ernesto Canto Cetina, PhD and Porfirio Nanco Hernández, PhD, obtaining a Conductance of 2.59W/m2°C, with a Thermal Resistance of 386m2°C/W (Velázquez & Molar, 2016).

RESULTS AND DISCUSSION

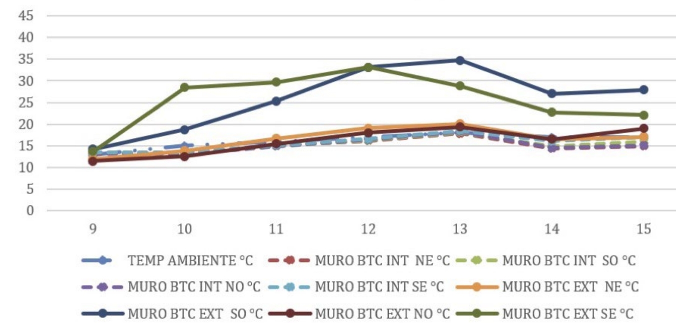
Graphs 1 to 5 correspond to the data obtained in January 2019. It can be seen that the maximum temperature is reached between 12pm and 1pm in the SW orientation. In general, the indoor surface temperature registers around a 10 to 15°C difference compared to the outdoor surface, even with the openings open.

The maximum temperature on the outdoor surfaces, on the compressed earth block module (CEB) (Graph 1), appears on the SE and SW orientation at 12pm and 1pm, reaching 34°C and 35°C, respectively. This is a difference of 15°C regarding the indoor surfaces. The readings of the NE and NW orientations present a similar behavior of the indoor faces, on not having direct radiation. At 2pm, it is seen that, even though the outdoor surface does NOT see a temperature increase on receiving radiation, its indoor face does not increase in temperature, seeing a difference of 4°C between them. At 11am, the temperature increase of the indoor surfaces was 5°C and at 1pm, they began to fall again.

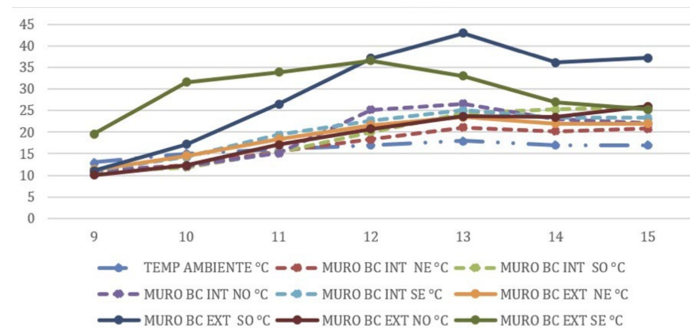
The maximum temperature of the outdoor surface on the concrete block wall module (CB) (Graph 2) is seen in the SW orientation at 1pm, with 43°C, that is to say, a difference of 20°C regarding its indoor surface. In this module, the temperatures of the indoor faces of the surfaces had an increase of 5° to 10°C difference compared with the outdoor environmental temperature at 11am. The NW and NE outdoor surfaces were 5 to 8°C more than the outdoor temperature, even when shaded, reaching 25°C.

The temperature of the module built with egg carton blocks with Thermolite and cement (ECB) (Graph 3) shows that the maximum temperature on the outdoor surface is generated in the SW orientation at 1pm, with 45°C and 20°C of difference regarding the indoor face. The indoor temperatures of the surfaces remained above the outdoor environment temperature, with a difference of between 5°C and 7°C. Meanwhile, the outdoor NW and NE surfaces recorded a difference of 5°C to 9°C, even though there was no direct radiation. However, the indoor temperature of these surfaces stayed 3°C lower.

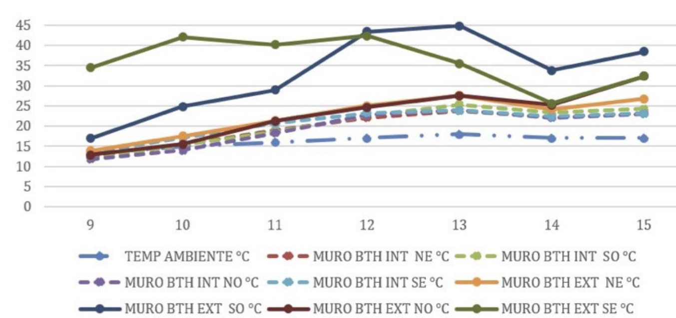
According to Graph 4, in this season, the high temperatures on the roofs are not reached due to contact with the cold air that tends to absorb heat from exposed surfaces. The maximum temperature was



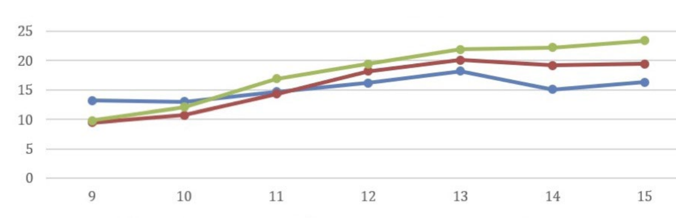
Graph 1: Behavior of indoor and outdoor temperatures of the CEB module (January 2019) Source: Preparation by the authors.



Graph 2. Behavior of indoor and outdoor temperatures of the CB module (January 2019). Source: Preparation by the authors.



Graph 3. Behavior of indoor and outdoor temperatures of the ECB module (January 2019). Source. Preparation by the authors.



Graph 4. Behavior of indoor temperature of the roof of the three modules (CEB, CB and ECB), January 2019. Source: Preparation by the authors.

reached by the roof with ECB and was 24°C. The lowest of 18°C was achieved with the CEB roof. The CB and ECB begin with the same temperature at the beginning of the recording.

ANSI/ASHRAE 55:2010		
JANUARY		
80% ACCEPTANCE		
LOWER L.	NT	UPPER L.
19.50	22.00	24.50

Figure 3. Comfort limits in January. Source: ANSI ASHRAE COMFORT Program.

Limits were set in the diagram to analyze the results obtained from the measurements, based on the comfort limit corresponding to January, according to Szokolay, 21.4°C to 23.9°C, and what is obtained from the ANSI ASHRAE COMFORT program.

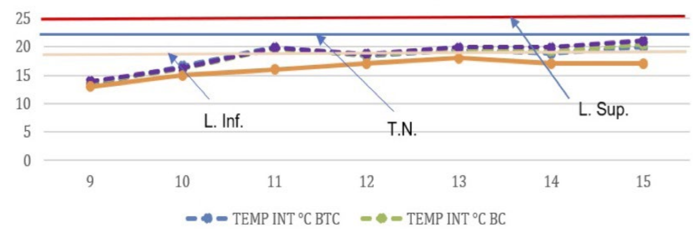
Even though the envelopes of the three modules (Graph 5) have variations in the surface temperatures, the resulting behavior of the three modules was similar to the environmental temperature, reaching the lower limit (Figure 3). Starting from 11am, they capture energy through the envelope, although in the case of the ECB, slightly higher values were obtained, while in the CEB much lower values were recorded.

Graphs 6 to 8 belong to data of May 2019. The maximum temperature of the outdoor surfaces is seen in the SE orientation, at 11am.

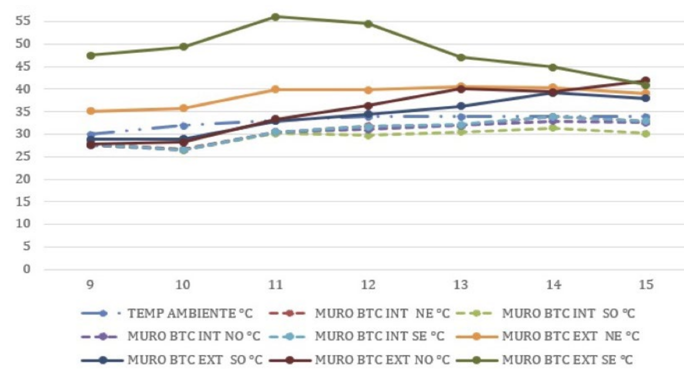
In the compressed earth block wall module (Graph 6), the maximum outdoor surface temperature was recorded on the SE orientation at 11am, with 56°C and 25°C of difference compared with the indoor surface. The temperature of the indoor surfaces increased gradually at 10 am, but remained below the environmental temperature.

In the CB module (Graph 7), the maximum temperature of the outdoor surfaces appears on the SE orientation at 11am, at 56°C, with 20°C of difference compared to the indoor surface. The indoor temperature of the surfaces increased at 10 am, with a difference with the outdoor temperatures of between 1°C and 8°C. At 11am, the NW and SW outdoor surfaces increased their temperature gradually, presenting a difference of between 8°C and 10°C compared to the outdoor temperature, with an oscillation of 5°C compared with the indoor surface.

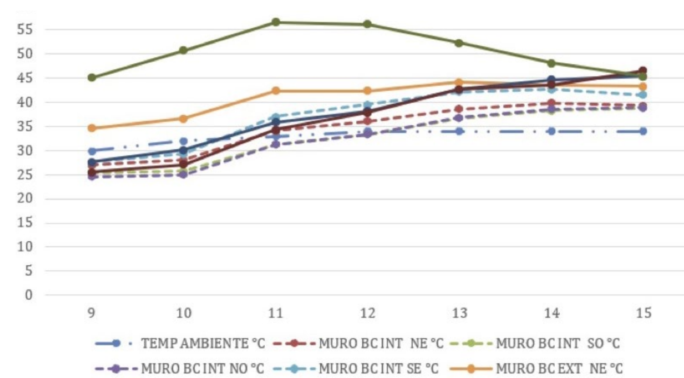
In the ECB module (Graph 8), the maximum temperature of the outdoor surfaces is seen on the SE orientation at



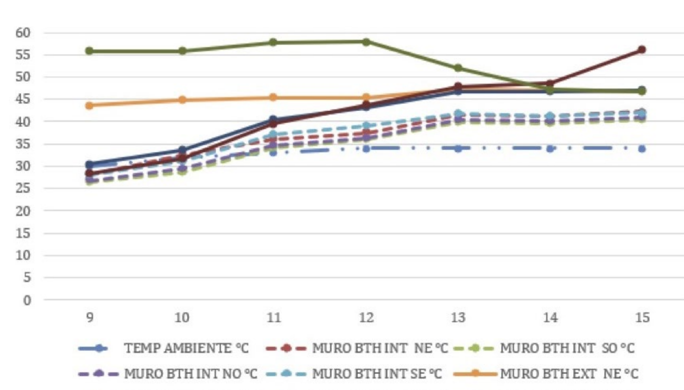
Graph 5. Indoor thermal behavior of the three modules (January 2019). Source: Preparation by the authors.



Graph 6. Indoor and outdoor temperature behavior of the walls of the CEB module (May 2019). Source: Preparation by the authors.



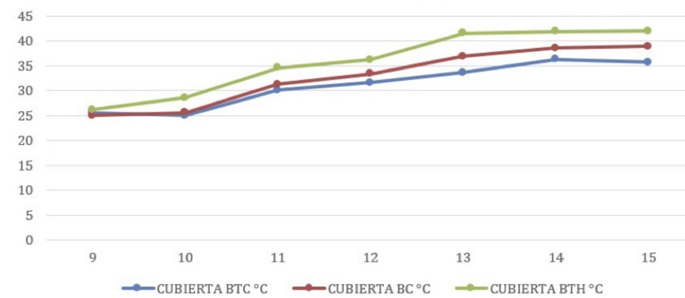
Graph 7. Behavior of the wall indoor and outdoor temperatures of the CB module (May 2019). Source: Preparation by the authors.



Graph 8. Behavior of outdoor and indoor temperatures of the ECB module (May 2019). Source: Preparation by the authors.

11am and 12am, at 57°C with 18°C difference compared to the indoor surface. The indoor temperature of the surfaces increased from 10am on, recording a difference of 1°C to 7°C compared to the outdoor temperature. It was also seen, that the external NW and SW surfaces increased at 10am, maintaining a difference of 5°C to 20°C compared to the outdoor temperature, with an oscillation of 5°C with their respective indoor temperature.

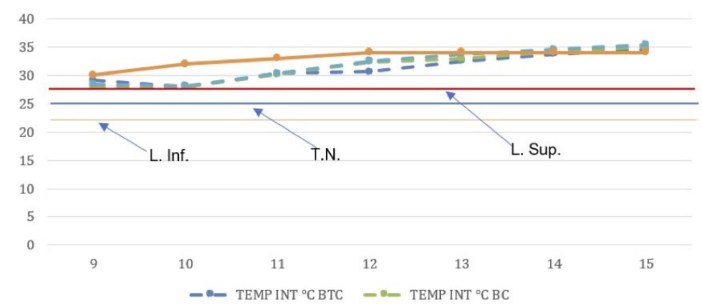
In Graph 9, it is seen that the maximum temperature appears on the ECB roof at 43°C, and the lowest on the CEB is 36°C. In this period, the three roofs begin with similar temperatures at 9am, while at 3pm they keep a difference of 7°C between the lowest and highest value.



Graph 9. Behavior of the indoor surface temperatures of the roofs of the three modules (CEB, BC and ECB) (May 2019). Source: Preparation by the authors.

MAY		
80% ACCEPTANCE		
LOWER L.	NT	UPPER L.
22.70	25.20	27.70

Figure 4: Comfort limits in May Source: ANSI ASHRAE COMFORT Program.



Graph 10. Indoor thermal behavior of the three modules (May 2019). Source: Preparation by the authors.

The limits were defined in the diagram to analyze the results obtained from the measurements, based on the comfort limit corresponding to May, according to Szokolay, 22°C to 27°C, and that obtained with the ANSI ASHRAE COMFORT program.

The resulting indoor temperature of the three modules (Graph 10) has a similar thermal behavior, although at 12pm, the temperatures of the ECB and CB are slightly higher than those of the CEB. The three were outside the upper limit, maintaining a temperature below the outdoor temperature in the first hours.

According to what is said by García et al. (2010), an active envelope activates its regulation mechanisms according to the properties of the material and its exchange with the outside. A key aspect, as Huelsz et al. (2014), Espinoza et al., (2018) and Muñoz et al. (2015) suggest, is the affectation generated by the openings that affect, to a great extent, the heat transfer gain or loss inside the construction. The airtightness is the key to reducing or increasing the indoor temperature (Molina et al., 2020).

CONCLUSIONS

On comparing the thermal behavior in winter of the three modules located in Saltillo, Coahuila, starting from the NE, SE, SW and NW orientations of the walls, it is identified that, in winter, the southwest maintains the highest values during the morning-afternoon, as it receives a higher amount of solar radiation at this time of the day. Likewise, given the composition of the blocks, and starting from the same orientations, the southeast, in summer, has the highest energy transmitted during the morning-afternoon, between 11am and 1pm, period where the surfaces capture the highest amount of radiation. This constitutes an area of opportunity to consider, given that in winter, heat needs to be taken advantage of and, in summer, the intention is having less capture, which would allow proposing some alternative in the design of both orientations.

When comparing the environmental indoor temperatures of January of the three modules with comfort ranges, starting from Szokolay (2014) and the Luna program (2019), the readings begin with values below the comfort ranges, although at 3pm they are found within the comfort ranges. On the other hand, in May, the three modules were above the comfort ranges, which means that the greatest problem to work on would arise in summer.

Regarding the comparison between the surfaces of the experimental materials (CEB and ECB) and the commercial concrete block (CB), these show relevant differences in January and May, which is why it is possible that the thickness of the experimental block is too thin to contribute to the improvement of the indoor conditions. Even so, it is important to continue working on new alternatives and improvements of the material to implement it in building low income dwellings and to improve the built habitat.

The envelope with the CEB in both seasons always keeps temperatures below or similar to the environmental temperature, while the CB and ECB tend to increase the temperature incrementally from 10 and 11am onwards compared to the outdoor temperature. However, the final result was similar to the indoor temperature in the three materials. It is worth stating that the behavior of the surfaces on their indoor faces was diverse, which offers the option to continue working on improvements.

These results may be associated to the lack of protection on the openings, to the thickness of the blocks both on walls and on the roof, or, to the lack of some outdoor and indoor filler that reduces the increase of the environmental temperature inside the construction. This is why it is pertinent to continue making tests with other geometries in the experimental blocks, closing the openings and complementing with a Canadian well as an auxiliary passive system which is viable, according to the mathematical calculations of Molar, Ríos, Bojórquez and Reyes (2020), given the properties of the earth in this location, to help obtain a suitable thermal behavior inside the space. The contribution of this research is focused on improving the habitat inside dwellings of the 20th and 21st centuries, especially in those traditional and vernacular constructions of the location studied here.

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