Proceedings of the 5th International Conference on Environmental Science and Applications (ICESA 2024)
Lisbon, Portugal- November 18 - 20, 2024
Paper No. 117
DOI: 10.11159/icesa24.117

Regional Bricks Thermal Analysis: A Low-Thermal Conductivity Material to Reduce Carbon Emissions

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Abstract **-** Decarbonizing the building sector is an essential task in accomplishing the goal of Net Zero Emissions by 2050. This sector accounts for a quarter of the global CO_2 emissions. Those emissions are produced during the whole life cycle of the building, which is analyzed from the extraction of the raw materials until the disposal of the waste after it has served its service stage. For this reason, it is vital to study construction materials because they accumulate emissions during production that will become part of the building's carbon footprint; such materials will give their properties to shape the behaviour of the building mechanically and thermally. The local bricks analyzed in this study come as an alternative, as they have shown a very low thermal conductivity (0.33 W/m·K) compared to the ones reported in the literature, which can ultimately be translated to fewer emissions by HVAC. Therefore, emissions could be reduced by two factors: transport emissions are considerably decreased if we consider their local production, and due to their non-cementitious nature, all the energy-related emissions produced for the cement production energy demand are avoided. The determination of the local brick properties impacts the producers, as they can revalue their product and, by knowing their improvement areas, can optimize their process, which can help in their competitiveness in the market. Lastly, understanding the properties of the local brick comes in handy when simulating and planning constructions in the local panorama, as they are necessary to estimate the future energy demand and make decisions to build better-planned and more sustainable communities and homes.

Keywords**:** thermal properties; low-carbon building materials; SDG 8; SDG 9; SDG 11

1. Introduction

1.1. Energy and emissions in the building sector

The building sector significantly impacts the generation of global greenhouse gas emissions, accounting for almost 26% of energy-related emissions. In 2022, 2.5GtCO_2e were associated with building construction, including concrete, steel, and aluminium production [1].

Owing to this, one essential action is the decarbonization of the building sector, as it encompasses the whole life cycle of the building, from obtaining the raw materials, its transformation, the construction process, the use phase, the demolition, and disposal. Depending on the techniques, processes, and design of the building of interest, this life cycle and phases can be subdivided into many. One of the main activities considered for the analysis is between embodied and operational emissions; embodied emissions refer to all the emissions that come as the result of the production of a good or service needed for the construction, maintenance, or disposal of the building. In contrast, operational emissions refer to the ones that result from the energy and water use during the operational phase.

One of the main contributors to energy emissions is cement, which is the main component of concrete and is widespread in the building industry across the world due to its versatility. Reducing cement emissions is a crucial but complicated task, as its production process requires high quantities of energy and reliance on carbon-containing raw materials [2]. These material emissions have stagnated since 2018, with nearly 0.6 tCO_2e per tonne of cement produced. In 2022, it was reported that the world produced 4,160 Mt [2]; this is why, under this panorama, it is decisive to find alternatives for cement-based materials.

Together with cement emissions, transport emissions are embodied in the building sector. In 2022, global transport emissions were reported at just under 8 Gt CO_2 [3]; trucks and buses produce 35% of direct CO_2 emissions from road transport [4]. Indirectly, the construction sector promotes the generation of such emissions by benefiting prefabricated or cement-based materials, which usually have non-local productions.

1.2. Redbrick handcrafting in Durango

Red brick is an extensively used material in Latin America and is highly preferred because it represents local identity and culture [5]; furthermore, it is also perceived as an economical and sustainable component because it is locally manufactured [6].

According to a report by the National Institute of Ecology and Climate Change [7], there are around 17,000 brick factories in Mexico. Such plants work informally and with rudimentary technology, using ovens that burn biomass and waste. In contrast, the supply of substitute products (i.e., extruded materials, mechanized bricks, concrete blocks) is of industrial origin and follows standardized quality processes. However, their processes are usually based on the intensive use of natural or liquefied petroleum gas (LPG).

In México, artisanal brick manufacturing is mainly done by small family groups that build their ovens. Such brick factories use locally sourced clays, generating bricks that significantly differ regionally.

According to an analysis of the impact of concrete blocks, the gases detected in the burning of bricks were CO^2, CO, NO, and SO_2 [8]. Another investigation reported that the production of concrete blocks generates between 0.693 and 0.726 $kgCO_2e$ [9], although the calculation declares emissions from the block production process and emissions related to cement production are not incorporated. On the other hand, this report states that red brick generates between 1.057 and 1.467 $kgCO_2e$.

There are more than 300 producers in Durango's urban area. Nevertheless, the producers face a big problem, as their product has yet to develop significantly in recent years and still lacks the ability to exhibit technical information. In addition, production is not continuous due to a heterogeneous demand; this, accompanied by the fact that its product needs an added value, puts the producers under economic stress. Durango's brick producers are divided into quadrants, with the southeast and southwest quadrants being the most important, with 64% and 29% of the producers, respectively [10]. Their production location is a consequence of the fact that the main material banks are located on the side of the Tunal River, which is located south of the city, approximately 15 km away.

1.3. Materials used in local housing

Brick is one of the materials accepted by the national authorities as a resistant wall material, and it has also been culturally accepted by society. Figure 1 shows an example of traditional red bricks and their employment in housing construction. According to the National Survey of Houses (ENVI) made by the National Institute of Statistics (INEGI), 92.4% of Mexican homes have walls built in a solid material, such as brick, concrete block, stone, or concrete, and 78.4% have ceilings constructed in concrete or joist and vault [11]. In Durango, these percentages are 71% and 74.9%, respectively, representing almost three-quarters of the houses and with a tendency to approach the national trend, according to the governmental goals of embracing houses' material durability.

The physical properties of masonry commonly refer to its ability to withstand compressive stress and its characteristic water absorption percentage (23%, [12]). Other characteristics related to thermal properties, such as conductivity and specific heat, are not commonly determined locally in this type of material. However, it is vital to highlight obtaining these properties to reference these materials in their comprehensive performance in buildings and make them more competitive.


Figure 1. Redbrick construction in Durango, Mexico.

1.4. Heat transfer through building elements

The materials that integrate the wall influence determining the overall heat transfer of a building. The overall heat transfer coefficient (U-value) can be used to describe its thermal performance in a simplified form. The equation for calculating heat transfer is Q=UA(T1-T0) [13], where Q is the heat transfer rate, A is the area, T1 and T0 are the inside and outside temperatures, and U is the total overall transfer coefficient, inverse of the thermal resistance R. When analyzing a wall's thermal resistance, the resistance of the walls' different layers that integrate it is added to determine the wall R-value, but when one layer is compounded by more than one material it becomes necessary to assume isothermal planes normal to the heat flow.

The U-value is mainly affected by the material's width (L) and thermal conductivity ($\boldsymbol{\lambda}$), which are the main factors for determining conduction heat transfer. On the other hand, convective and radiative heat transfer in the exposed surfaces can be incorporated into the internal and external surface conductance (hi and ho). The conductances can be determined through experimentation, or they can be selected from the literature. For example, from the ASHRAE Handbook of Fundamentals [14], values for ordinary and reflective surfaces can be retrieved.

This investigation determined the density, thermal conductivity, and specific heat for three traditional and locally manufactured red bricks. This research comes as a first approach to determine the local brick properties and has the main objective of characterizing the properties of this material in order to understand its potential thermal behavior when implemented into residential buildings. The local redbrick technical description can help label it as a low thermal conductivity material, leading to fewer energy requirements due to low heating and cooling needs in homes. The material could also be promoted as a sustainable construction material as it intrinsically incorporates low transport emissions due to its local production and use.

2. Methodology

2.1. Sampling and material preparation.

This study is the first approach to determine the properties of local brick; in order to accomplish this, three producers were selected due to their location in the quadrant with more producers in the city, southeast, in the suburbs Jardines de Cancun (24.015074, -104.627152) and Valle del Guadiana (24.012937, -104.638331) and because these producers declared that they obtained their clay from the same material bank and employed similar methods to produce their bricks. The artisan producers allowed the collection of samples from different production lots to gather a representative sample.

The sample size for the mean comparison of thermal conductivity (property of interest) between different brick manufacturers was calculated using Minitab 17.3.1.0 software (one-way ANOVA). The power of the test was set to 0.9 and, from the literature, a difference between thermal conductivity means of d = 0.1 is considered to be a practically important difference due to reductions of thermal conductivity of 0.6 [15], 0.1 [16] and 0.18 [17] have shown an impact in the energy consumption. The standard deviation was set to 0.04 because the authors presented values of 0.02 [18] [16], and as a way to ensure the power of the sample, we decided to take a higher value. The obtained sample size was n = 6 bricks. Nevertheless, a sample of n=10 bricks was taken to ensure the reliability of the results. The collection was made by grabbing bricks from different lots in random positions from the pile, with the objective of ensuring that the samples came from different positions during the heating process, securing equal chances of being sampled.

Afterward, the bricks were cut in halves; one half was taken to be analyzed thermally and the other half for the mechanic tests. This decision was made because the equipment required the samples to be smaller than 0.2 m x 0.2 m x 0.05 m and helped us be more efficient when conducting parallel tests. Figure 2 shows the three studied brick samples.

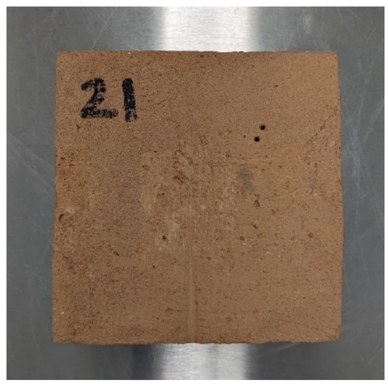
Producer 1	Producer 2	Producer 3
		

Figure 2 Analyzed redbrick images.

2.2. Thermal properties.

The thermal conductivity and specific heat of the samples were determined. The thermal conductivity measurements were conducted with the instrument FOX 200 developed by T.A. Instruments. The FOX 200 equipment complies with ASTM C518 (Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties employing the Heat Flow Meter Apparatus, [19]) and is capable of measuring the thermal conductivity (**λ**) in a range from 0.005 W/m·K to 2.5 W/m·K. The measurements were taken at a mean temperature of 24°C with a temperature differential of 15°C. The specific heat was determined using the Tempos instrument developed by METER Group, using the SH-3 dual needle. This instrument determines values from 0.5 MJ/m³ to 4.2 MJ/m³, with a 0.1 MJ/m³ accuracy.

A one-way analysis of variance and a Tuckey test was used to determine a significant difference between the means of the theq onduc t vit y he trocuctre. Thes as dy e h dF t

ss m and a

3. Results

Table 1 shows the density, thermal conductivity, and specific heat of the local bricks. The determination found that the redbrick densities and specific heat were similar for all producers, and it was around 1330 kg/m^{3,} whereas the mean specific heat was 868 J/kg·K. On the other hand, the observed thermal conductivity of the studied bricks was around 0.33 W/m·K, which was significantly lower than bricks from the literature.

The analysis of the means of the thermal conductivity tests showed that there were no significant differences between the producers. Producer 1 was found to be statistically similar to Producer 2 and Producer 2 similar to Producer 3. This could be interpreted as the producers from this analysis statistically having no significant differences in their thermal conductivity, and technically, a difference of 0.0393 W/m·K has no major impact on the energy consumption due to the thermal behaviour.

Table 1. Properties of studied redbricks.

	Density (kg/m^3)	**Thermal conductivity (W/m·K)**	**Specific heat (J/kg·K)**
Producer 1	1339.9 ± 45.7	0.3106 ± 0.044	870.89 ± 109.43
Producer 2	1381.1 ± 27.7	0.3380 ± 0.0169	839.25 ± 77.24
Producer 3	1370.9 ± 34.8	0.3499 ± 0.0207	893.70 ± 186.75

Figure 3 was made using Flourish [21], a data visualization software. The figure shows the thermal conductivity of this study bricks (local) compared to values from the literature (traditional and modified). In the figure, it is observed that traditional redbrick analyzed by Chavez-Galán et al. were 0.906 W/m·K [22], Borbón et al. had 0.814 W/m·K [17], Sánchez et al. 0.691 W/m·K [23], and the ones examined by Villaquirán et al. were 0.5352 W/m·K [24]. In contrast, modified bricks from the literature had thermal conductivities of 0.212 W/m·K [16], 0.290 W/m·K [25], and 0.267 W/m·K [26].

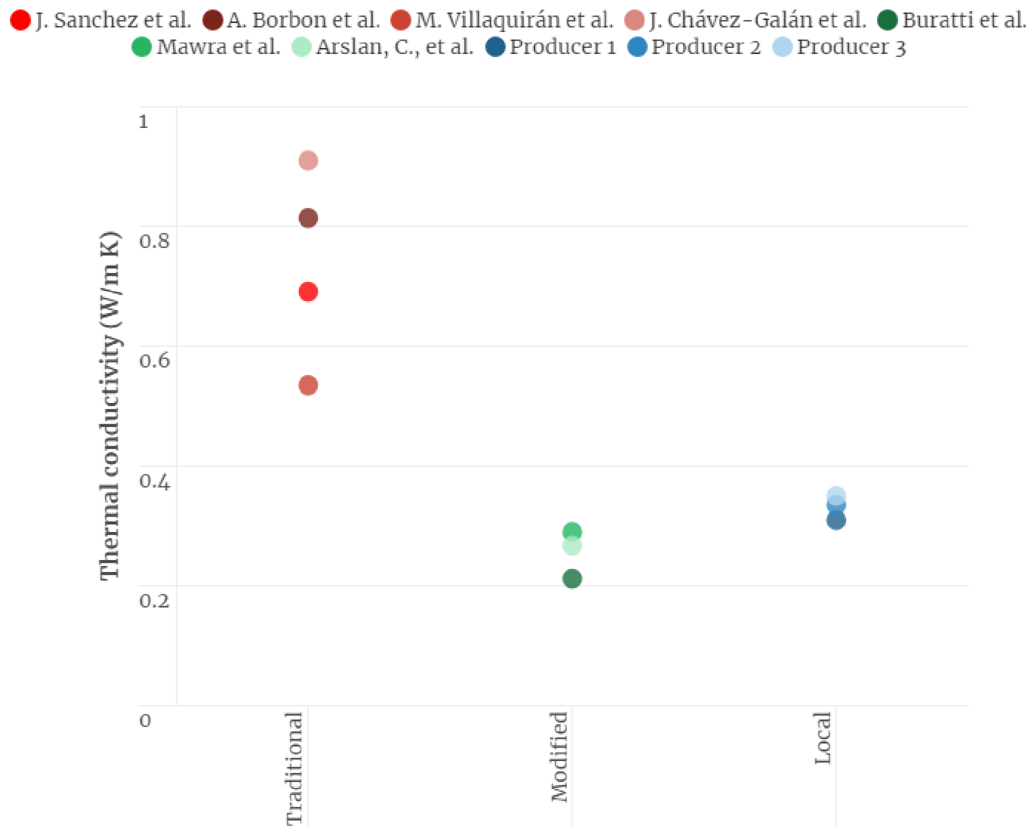


Figure 3. Thermal conductivity (W/m·K) comparative between traditional, modified, and local bricks made with Flourish.

The results from the compressive strength of the samples showed that the bricks have the capacity to resist at least 1,018 MPa. This value is considered to be low when compared to the 11 MPa established as the minimum mean resistance by the NMX-C-404-ONNCCE-2012 (BUILDING INDUSTRY—MASONRY—BLOCKS, BRICKS AND MASONRY UNITS FOR STRUCTURAL USE—SPECIFICATIONS AND TEST METHODS [12]). Consequently, these bricks are only suitable for apparent partition walls, not structural ones.

4. Conclusion

This research is the first step in determining the local brick properties. Its objective is to learn their actual properties to be contrasted with cement-based materials to understand the housing future landscape better.

Transportation emissions related to brick production are significantly lower than cement-based materials. The nearest plants are more than 500 km apart (Saltillo, Coah. and Monterrey, N.L.), and the local redbrick factories and their material banks are within a 15 km ratio. The emissions mentioned above and those emitted during cement production should be considered in the CONAVI analysis of block cement emissions.

The local bricks have shown low thermal conductivity (0.33 W/m·K), which can be ultimately translated into more efficient HVAC energy use in homes. This, combined with the low transport emissions, can decrease the carbon footprint of the construction in the local panorama. Taking the low thermal conductivity mentioned earlier as a starting point, the bricks have a wide range of opportunities to upgrade; this could be through optimizing their geometry regarding structural and thermal functionality or diminishing CO_2 emissions during the production stage.

The revaluation of brick as a non-cementitious alternative with beneficial thermal properties for its use in the building industry will impact a population sector that has been relegated due to the plain nature of its craftsmanship by determining its properties and bringing innovation to the product. It can become a suitable option for planning and developing sustainable communities and homes.

After knowing the benefits of the local brick, it can be said that it is necessary to thoroughly study its emissions and make a life cycle analysis of the product in the local panorama.

Acknowledgements

M.C. Adolfo Ruiz from the Mechanic Test Laboratory of the Universidad Juárez del Estado de Durango (UJED). Also, to MSc. Jorge A. Escobedo and MSc. Luis A. Torres Castañón from the CIMAV-Durango for facilitating working at the Laboratories.

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