Journal Civil Engineering 9[20]1-6: e4920106
Article

Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila

Desarrollo y análisis de un material higrotérmico de un material de construcción ecológico compuesto, optimizado para condiciones semi-áridas: caso de estudio en derramadero, Coahuila

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Classification:

Area: Engineering
Field: Technological sciences
Discipline: Material Technology
Subdiscipline: Clay products

https://doi.org/10.35429/JCE.2025.9.20.4.1.6
History of the article:
Received: October 10, 2025
Accepted: December 30, 2025

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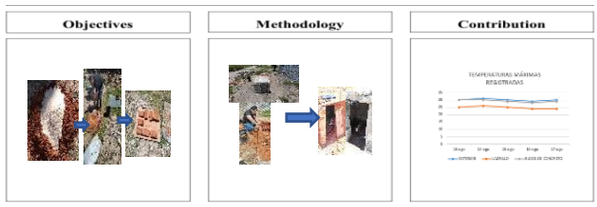
Abstract

This article analyzes the ecological, sustainable, and thermally efficient advantages of adobe brick as a construction material in the rural and semi-arid region of Derramadero in Saltillo, Coahuila. The study is based on the use of endemic materials and the revaluation of traditional building techniques employed for centuries, but currently rejected due to their association with poverty or obsolescence. As noted by Guerrero [2007], earthen architecture possesses widely recognized ecological and cultural qualities, although its application has declined in contemporary society. This work presents the thermal efficiency of an ecological adobe brick made with clay, manure, and silica sand, whose addition enhances the insulating and stabilizing effect of the product. The results show that the modified adobe contributes to thermal comfort in local housing, representing a viable, accessible, and sustainable alternative to the widespread use of concrete blocks.

Adobe brick, thermal efficiency, sustainable construction

Resumen

El presente artículo analiza las ventajas ecológicas, sustentables y térmicamente eficientes del adobe de barro como material de construcción en la región rural y semiárida de Derramadero en Saltillo, Coahuila. El estudio se fundamenta en el aprovechamiento de materiales endémicos y en la revaloración de técnicas constructivas tradicionales utilizadas durante siglos, pero que en la actualidad son rechazadas por asociarse a pobreza u obsolescencia. Tal como lo señala Guerrero [2007], la arquitectura térrea posee cualidades ecológicas y culturales ampliamente reconocidas, aunque su uso ha disminuido en la sociedad contemporánea. En este trabajo se expone la eficiencia térmica de un tabique ecológico elaborado con barro, estiércol y arena sílica, cuya adición permite mejorar el efecto aislante y estabilizante del producto. Los resultados muestran que el adobe modificado contribuye al confort térmico en viviendas de la zona, representando una alternativa viable, accesible y sustentable frente al uso generalizado del block de concreto.



Adobe de barro, eficiencia térmica, construcción sustentable

Area: Dissemination and universal access to science

Citation: Vázquez-Aguilar, Mario Leonardo, Díaz-Silvestre, Sergio Enrique, Correa-Vázquez, Evanivaldo and Chávez-González, Alexis Daniel. [2025]. Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila. Journal Civil Engineering. 9[20]1-6: e4920106.

Introduction

The use of earthen materials such as adobe has been an ancestral practice in Mexico, especially in indigenous communities of Mesoamerica and arid regions where stone or industrialized resources were limited. Its application has been documented since pre-Hispanic times [Gama-Castro, 2012] and has endured through techniques such as adobe, rammed earth, and bahareque, due to its accessibility and thermal insulation capacity [Barahona, 1969].

In recent years, there has been renewed interest in soil-based construction, motivated by global trends toward sustainability, reduction of embodied carbon, and ecological architecture [Villagómez, 2021]. Research reviews highlight that earthen materials often outperform conventional construction materials in environmental indicators when local soil, minimal external binders, and low energy in preparation are used [Zhang, 2024]. The technical viability of stabilizing soil constructions—through mechanical, chemical, or hybrid additives—is also increasingly documented [Ravindran, 2023].

These techniques of improvement are analogous to the proposed method in this study, which uses silica sand as an additive to amplify the insulating and stabilizing properties of adobe. In Latin America there are studies, as in Rivera-Salcedo [2021] which demonstrates that the addition of coarse sand and vegetal fibers significantly improves compressive strength and water absorption properties in adobe masonry units.

Coahuila, and particularly the region of Derramadero, presents an arid to semi-arid climate, with extreme summer temperatures exceeding 35 °C during the hottest months [Secretaría de Medio Ambiente, 2023]. These conditions make thermal comfort strongly dependent on the construction material employed. In contrast, many Latin American countries, informal urban settlements continue to expand along city outskirts, where self-built construction remains the main pathway to home ownership. Nations such as Peru, Bolivia, and Mexico exhibit a significant proportion of dwellings erected without technical assistance or regulatory control, resulting in serious shortcomings in housing quality and comfort.

This issue is even more pronounced in high-altitude areas, where cold and humid climates require specific construction adaptations that are often absent. [Delgado Salazar, 2025]

This research proposes a hybrid adobe brick, made of clay mixed with manure and *silica sand*, which does not require direct-fire baking. This design seeks to improve the thermal insulation and stabilization properties of traditional adobe, becoming a viable, accessible, and sustainable alternative to the widespread use of concrete blocks in Derramadero.

Methodology

For the experimental design, ecological adobe bricks were manufactured using locally available raw materials. The mixture was prepared with the following proportions: 60% red clay soil from the Derramadero region, 20% cattle manure containing crushed corn stalks [*carrizo de milpa*], 10% water, and 10% silica sand [figure 1]. The inclusion of silica sand was intended to enhance thermal insulation and stabilize the composite. The mixture was homogenized manually until a uniform consistency was achieved.

Box 1

Figure 1
Material used
Source [Authors made]

Subsequently, the material was molded into rectangular units measuring 18 cm in width, 25 cm in height, and 2.5 cm in thickness [figure 2]. The specimens were left to set under direct sunlight for two hours, followed by controlled drying in an electric oven [NOVATECH, model HS35-A1A] at 180 °C for three hours [figure 3].

ISSN: 2523-2428.
RENIECYT: 1702902

Vázquez-Aguilar, Mario Leonardo, Díaz-Silvestre, Sergio Enrique, Correa-Vázquez, Evanivaldo and Chávez-González, Alexis Daniel. [2025]. Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila. Journal Civil Engineering. 9[20]1-6: e4920106.
https://doi.org/10.35429/JCE.2025.9.20.4.1.6

This process ensured the elimination of excess moisture without direct firing, maintaining the ecological nature of the material.

Box 2

Figure 2
Molding bricks
Source [Authors made]

In order to evaluate the thermal efficiency of the proposed adobe brick, a comparative analysis was conducted against conventional concrete block construction. For this purpose, two scaled-down housing models were built, simulating the structural layout of a typical dwelling in the region.

Concrete block model**:** Constructed with 15 × 20 × 40 cm blocks joined with a traditional cement-sand mortar, and topped with a lightweight reinforced concrete roof. The dimensions of the model were 95 cm [length] × 90 cm [width] × 64 cm [height].

Box 3

Figure 4
Dried bricks
Source [Authors made]

Box 4

Figure 4
Concrete and bricks house scale model
Source [Authors made]

Bricks model: Built with the proposed hybrid adobe bricks, with final dimensions of 76 cm [width] × 91 cm [length] × 60 cm [height].

Both models were exposed under the same environmental conditions during the hottest season of the year [figure 4]. According to meteorological forecasts from AccuWeather, the period from August 13 to 17, 2025, corresponded to one of the warmest weeks in Derramadero, with maximum daily temperatures between 20 to 31 °C.

Temperature data were recorded inside each model for five consecutive days using memory-registering digital thermometers [UNI-T, model UT330C]. One device was placed in the center of each structure, which was subsequently sealed to avoid external airflow interference. The recorded data allowed the comparison of the diurnal thermal performance between the adobe and concrete block models [figure 5].

Box 5

Figure 5
Thermometers inside scale models
Source [Authors made]

ISSN: 2523-2428.
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Results

The comparative thermal evaluation revealed a consistent difference of approximately 4 °C between the maximum interior temperatures of the adobe and concrete block models. While the interior of the adobe structure remained below the outdoor maximum values, the concrete block model exhibited interior temperatures nearly identical to those of the external environment, demonstrating poor thermal insulation capacity. This result highlights the superior thermal buffering effect of the adobe mixture, which effectively delayed and attenuated heat transfer [figure 6].

Box 6

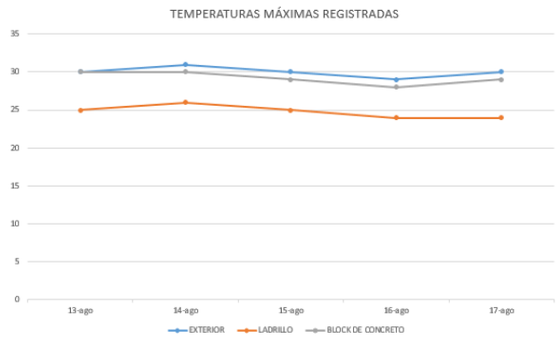

Figure 6
Temperature Comparative graphic
Source [Authors made]

Furthermore, qualitative observations during the testing period indicated that the adobe structure maintained more stable nocturnal temperatures, avoiding abrupt heat loss. In contrast, the concrete block model experienced rapid cooling, reflecting its limited thermal mass behavior.

In addition to thermal performance, permeability characterization was conducted on representative adobe samples to assess moisture absorption and vapor transmission. Techniques such as **capillary water absorption tests** and **vapor permeability measurements** were considered, given their relevance in evaluating construction materials exposed to semi-arid climates like Derramadero. The results indicated that the inclusion of silica sand in the adobe mix contributed to reduced capillary uptake, enhancing dimensional stability under humid conditions. This improvement is critical because high permeability can negatively affect the thermal resistance of earthen materials by facilitating heat transfer through absorbed moisture.

Overall, the findings support the notion that the optimized adobe mixture not only provides superior thermal insulation compared to conventional concrete blocks but also demonstrates improved resistance to environmental factors, thus reinforcing its potential as a sustainable construction material for hot and dry climates.

Development of permeability characterization

As an additional characterization step, the permeability of the adobe–silica brick was evaluated through a **capillary water absorption test**. The evaluation was based on the conceptual framework of **Darcy's law**, expressed as:

$$Q = -K \cdot A \cdot L\Delta h \quad [1]$$

Q = volumetric flow rate [m³/s],
K = permeability coefficient [m/s],
A = cross-sectional area of the sample [m²],
Δh\Delta hΔh = hydraulic head difference [m],
L = length of the sample [m].

In the experimental procedure, a brick specimen was placed in a container where a constant water flow was applied to one of its surfaces. The quantity of water absorbed was recorded over time. Knowing the applied flow rate, the exposed surface area, and the effective length of the sample, the permeability coefficient was calculated.

This approach allowed the characterization of the brick's capillary transport properties, which are crucial in semi-arid climates such as Derramadero, where cyclic wetting and drying can compromise the long-term durability and thermal efficiency of earthen materials [Ma, 2020].

The capillary absorption test indicated that the moisture front required **31 minutes and 58 seconds** to travel across the entire length of the brick specimen, reaching the opposite end.

Characterization Results

This relatively low absorption velocity reflects the contribution of the silica sand additive, which reduces pore connectivity and water uptake compared to traditional adobe [figure 7].

ISSN: 2523-2428.
RENIECYT: 1702902

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Box 7

Figure 7
Permeability test
Source [Authors made]

These results are consistent with previous studies that highlight how the incorporation of stabilizing agents—such as manure and siliceous additives—can improve the moisture resistance of adobe by reducing permeability and enhancing mechanical stability [Sánchez-Calvillo, 2024]. The outcome suggests that the hybrid adobe–silica brick not only improves thermal insulation but also mitigates the main durability limitation of conventional earthen materials: excessive capillary water absorption.

Conclusions

This research demonstrates that adobe-based bricks, when modified with organic and mineral additives, can provide a viable, sustainable, and thermally efficient alternative to conventional concrete blocks [Sánchez, 2012] in semi-arid regions such as Derramadero, Coahuila. The experimental results showed **a temperature difference of up to 4 °C** between the interior of the hybrid adobe model and the concrete block model, highlighting the superior insulating capacity of the proposed material.

Furthermore, the **capillary absorption test** confirmed that the addition of silica sand and manure with vegetal fibers reduced permeability and moisture uptake, addressing one of the main durability limitations of traditional adobe. By improving thermal insulation and lowering water absorption, the hybrid brick combines the ecological advantages of earthen construction with enhanced performance for modern applications.

The findings reinforce the potential of **reintroducing earthen techniques** adapted with contemporary stabilization methods as a countermeasure to climate change, rising energy costs, and housing shortages in rural and peri-urban communities. Future research should extend these results by evaluating **mechanical strength, long-term durability, and scalability** for mass construction.

In conclusion, this work positions the hybrid adobe–silica brick as an accessible and environmentally responsible building material, bridging ancestral knowledge with modern engineering to promote sustainable housing in semi-arid regions.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Vazquez-Aguilar, Mario Leonardo: Contributed to the project idea, investigation, prototypes fabrication, writing –original draft and editing.

Diaz-Silvestre, Sergio Enrique: Contributed to execute permeability test and construction of house scale models

Correa-Vazquez, Evanivaldo: Contributed to the materials analysis and investigation.

Chavez-Gonzalez, Alexis Daniel: Contributed to assist design and fabrication activities.

Acknowledgements

Financied by Universidad Tecnológica de Saltillo

ISSN: 2523-2428.
RENIECYT: 1702902

Vázquez-Aguilar, Mario Leonardo, Díaz-Silvestre, Sergio Enrique, Correa-Vázquez, Evanivaldo and Chávez-González, Alexis Daniel. [2025]. Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila. Journal Civil Engineering. 9[20]1-6: e4920106.
https://doi.org/10.35429/JCE.2025.9.20.4.1.6

References

Antecedents

Gama-Castro, Jorge E, Cruz y Cruz, Tamara, Pi-Puig, Teresa, Alcalá-Martínez, René, Cabadas-Báez, Héctor, Jasso-Castañeda, Carolina, Díaz-Ortega, Jaime, Sánchez-Pérez, Serafín, López-Aguilar, Fernando, & Vilanova de Allende, Rodrigo. [2012]. Arquitectura de tierra: el adobe como material de construcción en la época prehispánica. *Boletín de la Sociedad Geológica Mexicana*, *64*[2], 177-188. Recuperado en 20 de septiembre de 2025.

Basics

Guerrero Baca, Luís Fernando. [2007]. Arquitectura en tierra: Hacia la recuperación de una cultura constructiva. *Apuntes: Revista de Estudios sobre Patrimonio Cultural - Journal of Cultural Heritage Studies*, *20*[2], 182-201. Retrieved September 20, 2025.

Barahona Matamoros, Igor H. [1969]. *La tierra como material de construccion para viviendas*.

Rivera-Salcedo, Hernán, Valderrama-Gutiérrez, Ornar Mauricio, Daza-Barrera, Ángel Andrés, & Plazas-Jaimes, Gerson Santiago. [2021]. Adobe como saber ancestral usado en construcciones autóctonas de Pore y Nunchía, Casanare [Colombia]. *Revista de Arquitectura [Bogotá]*, *23*[1], 74-85. Epub July 07, 2021

Supports

Sánchez, J. L. M., del Carmen Cámara Cabrales, L., Quiroz, C. P., Canepa, J. R. L., & Acosta, O. C. [2012]. ¿un tabique ecológico para construir las casas podría contribuir a la reducción del cambio climático? *Emerging Trends in Education*, *18*[34], 2.

Secretaría de Medio Ambiente. [2023]. Clima de Coahuila. Sistema de Información Ambiental y Ecológica de Coahuila.

Ravindran, G., Bahrami, A., Mahesh, V., Katman, H. Y. B., Srihitha, K., Sushmashree, A., & Nikhil Kumar, A. [2023]. Global Research Trends in Engineered Soil Development through Stabilisation: Scientific Production and Thematic Breakthrough Analysis. *Buildings*, *13*[10], 2456.

Sánchez-Calvillo, Adrià ;Alonso-Guzman, Elia M. ;Navarro-Ezquerra, Antonia ;Ruiz-Mendoza, Melissa ;Martínez-Molina, Wilfrido ;Alvarez-Galindo, José Ignacio et al. "Physical-chemical, mechanical and durability characterization of historical adobe buildings from the State of Michoacan, Mexico". Journal of Building Engineering. 86 2024,

Ma, Q., & Liu, S. [2020]. Effect on Silt Capillary Water Absorption upon Addition of Sodium Methyl Silicate [SMS] and Microscopic Mechanism Analysis. *Coatings*, *10*[8], 724.

Differences

Villagómez Amaro, I. J. [2021]. Estudio y aplicación de la tierra como material sostenible para la bioconstrucción. Universidad Autónoma Metropolitana, Xochimilco.

Discussions

Collazos Bustamante, D. T. V., & Delgado Salazar, F. J. [2025]. Propuesta de mortero para tarrajeo con reemplazo parcial de agregado fino por fibra de bambú para mejorar el confort térmico dentro de las viviendas En Ticlio Chico en el distrito de Villa María del Triunfo [Tesis de ingeniería, UNIVERSIDAD PERUANA DE CIENCIAS APLICADAS].

ISSN: 2523-2428.
RENIECYT: 1702902

Vázquez-Aguilar, Mario Leonardo, Díaz-Silvestre, Sergio Enrique, Correa-Vázquez, Evanivaldo and Chávez-González, Alexis Daniel. [2025]. Development and hygrothermal analysis of an optimized composite ecological construction material for semi.arid condictions: a case study in derramadero, Coahuila. Journal Civil Engineering. 9[20]1-6: e4920106.
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