

Optimization of Adobe and Sawdust-Based Bricks for Improved Energy Efficiency in Construction

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KEYWORDS

Adobe bricks, Sawdust,
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ABSTRACT

The exploration of bio-based materials for sustainable construction practices, particularly through the use of locally sourced resources like sawdust, is the focus of this study, which evaluates the thermal performance of adobe bricks reinforced with 2% sawdust in small, medium, and large sizes, ranging from 0.3 to 2 cm. The bricks were manufactured using local materials, and the physicochemical properties of the clay were initially analyzed and characterized. The laboratory examined the bricks' thermophysical characteristics, such as their density, thermal conductivity, and heat capacity.

The TRNSYS program was used to conduct annual thermal simulations based on representative meteorological data for a typical building in the semi-arid Moroccan city of Beni Mellal. The results indicate that the energy savings achieved in terms of both heating and cooling were comparable across all configurations of sawdust-reinforced adobe bricks. When compared to a reference concrete building, the heating energy demand was reduced by 59.14% for clay without sawdust, 72.61% for clay with small sawdust, 71.25% for clay with medium sawdust, and 69.88% for clay with large sawdust. Similarly, the cooling energy demand reductions were 45.71%, 58.82%, 57.68%, and 56.62%, respectively, for clay without sawdust, and with small, medium, and large sawdust. These findings suggest that the incorporation of sawdust, regardless of particle size, leads to similar energy savings, offering flexibility in utilizing locally available sawdust from Beni Mellal to optimize energy performance. This research highlights the importance of local clay-based materials and the use of sawdust as a natural reinforcement, to optimize the energy efficiency of buildings. It also offers new perspectives for their integration into sustainable construction practices, contributing to global sustainable development goals.

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التحسين الأمثل للطوب اللبن والطوب القائم على نشارة الخشب لتحسين كفاءة الطاقة في البناء

محمد بنفارس، عبد المنعم عليوي، يونس أزلان، مراد قديري، مصطفى مبروكي.

ملخص: تركز هذه الدراسة على استكشاف المواد الحيوية لممارسات البناء المستدام، لا سيما من خلال استخدام الموارد المحلية مثل نشارة الخشب، حيث تقوم هذه الدراسة بتقييم الأداء الحراري للطوب اللبن المدعم بنسبة 2 % من نشارة الخشب بأحجام صغيرة ومتوسطة وكبيرة تتراوح بين 0.3 و 2 سم. تم تصنيع الطوب باستخدام مواد محلية، وتم تحليل وتوصيف الخصائص الفيزيائية والكيميائية للطين في البداية. فحص المختبر الخصائص الفيزيائية الحرارية للطوب مثل الكثافة والتوصيل الحراري والسعة الحرارية. استخدم برنامج TRNSYS لإجراء محاكاة حرارية سنوية بناءً على بيانات الأرصاد الجوية التمثيلية لمبنى نموذجي في مدينة بني ملال المغربية شبه القاحلة. تشير النتائج إلى أن وفورات الطاقة المحققة من حيث التدفئة والتبريد كانت قابلة للمقارنة في جميع تشكيلات الطوب اللبن المدعم بنشارة الخشب. عند مقارنته بمبنى خرساني مرجعي، انخفض الطلب على طاقة التدفئة بنسبة 59.14 % للطين بدون نشارة الخشب، و 72.61 % للطين مع نشارة الخشب الصغيرة، و 71.25 % للطين مع نشارة الخشب المتوسطة، و 69.88 % للطين مع نشارة الخشب الكبيرة.

وبالمثل، بلغت نسبة الانخفاض في الطلب على طاقة التبريد 45.71 % و 58.82 % و 57.68 % و 56.62 % على التوالي للطين بدون نشارة الخشب ومع نشارة الخشب الصغيرة والمتوسطة والكبيرة. تشير هذه النتائج إلى أن دمج نشارة الخشب، بغض النظر عن حجم الجسيمات، يؤدي إلى توفير مماثل في الطاقة، مما يوفر مرونة في استخدام نشارة الخشب المتوفرة محلياً من بني ملال لتحسين أداء الطاقة. يسلط هذا البحث الضوء على أهمية المواد المحلية القائمة على الطين واستخدام نشارة الخشب كتعزيز طبيعي لتحسين كفاءة الطاقة في المباني. كما يقدم وجهات نظر جديدة لدمجها في ممارسات البناء المستدام، مما يساهم في تحقيق أهداف التنمية المستدامة العالمية.

الكلمات المفتاحية: الطوب اللبن، نشارة الخشب، الأداء الحراري، كفاءة الطاقة، البناء المستدام.

1. INTRODUCTION

Currently, energy consumption is one of the major challenges on an international scale [1]. Indeed, one major factor in the world's energy consumption and CO₂ emissions is the construction industry, contributing to more than 30% of global CO₂ emissions and more than 36% of the world's total energy demand [2]. The construction sector in Morocco mostly uses traditional materials, including fired bricks, whose manufacture has a big influence on the environment. This manufacturing process requires firing temperatures exceeding 1000°C, leading to energy consumption ranging from 0.54 to 3.14 MJ/kg and CO₂ emissions between 70 and 282 g/Kg [3]. Furthermore, these materials generate substantial amounts of waste during construction and demolition phases, estimated at approximately 14×10⁶ t/year in Morocco [4]. This situation highlights the urgent need for a transition towards more sustainable construction practices, where the pursuit of materials that are both thermally efficient and environmentally friendly becomes an essential priority [5]. In this context, the exploration of bio-based construction materials, combining local resources with technical innovations, has become essential to meet the energy needs of buildings while minimizing their environmental footprint. Among these materials, unfired earth bricks stand out as a particularly promising alternative. They offer numerous advantages, including accessibility, low environmental impact, recyclability, and the ability to regulate humidity while enhancing the thermal comfort of buildings. [3], [6]. Moreover, their manufacturing process requires significantly lower energy consumption [3]. However, the thermal performance can be further optimized through the addition of reinforcement natural additives. In this regard, recent research has focused on integrating filler and reinforcement materials to enhance the properties of construction materials [7]. In line with this approach, the present study investigates the thermal effects of incorporating sawdust waste into traditional clay bricks. In addition to improving thermal insulation, this integration promotes the recycling of wood waste as a sustainable building material, reducing landfill disposal and enhancing its valorization. Furthermore, this strategy aligns with Morocco's 2030 Circular Economy Strategy

[8], which aims to minimize environmental impact and encourage sustainable resource management. All of this while adopting an eco-friendly manufacturing process that eliminates high firing temperatures, promoting the production of low-cost, low-energy building structures with significant energy savings.

Numerous studies have highlighted the benefits of incorporating additives into building materials. For instance, M. Giroudon et al. [9] investigated the addition of lavender and barley straw fibers to adobe and found that both types of fibers' thermal conductivity decreased as the fiber quantity increased. M. Boucheffa et al. [10] also examined the impact of doum fibers on the characteristics of earth bricks. They found that the thermal conductivity of compressed earth bricks decreased with an increase in the percentage of doum fibers. Furthermore, M. Babé et al. [11] discovered that the thermal conductivity of adobe bricks decreased as the quantity of neem fibers increased. Building on existing research that highlights the benefits of reinforcing earth bricks with natural additives, this study investigates the impact of sawdust waste of varying particle sizes on the thermophysical properties of materials. It further assesses their thermal and energy performance to demonstrate their potential in reducing energy consumption in semi-arid regions. By focusing on these aspects, this work contributes to the development of sustainable, high-performance building materials suited for energy-efficient construction. The adobe bricks were made by hand utilizing a traditional technique that is common in southern Morocco. To this end, soil samples were collected from the Beni Mellal region, and sawdust fibers of varying sizes (small, medium, and large, with lengths ranging from 0.3 to 2 cm) were incorporated into the formulations. This research extends the work of M. Azalam et al. [12], which focused on the mechanical properties of these adobe bricks. While the earlier research addressed their structural behavior, the present study complements it by exploring the thermal performance and energy efficiency of the same material, providing a more comprehensive understanding of its potential for sustainable construction.

2. MATERIALS AND METHODOLOGY

2.1. Clay

The preparation of adobe bricks in this study relied on clay soil sourced from the Ouled Mbarek village in the north-central region of Morocco. The choice of this material was motivated by its abundant availability in the area, its natural suitability for construction, and its homogeneous composition, which ensures reliable performance in adobe applications.

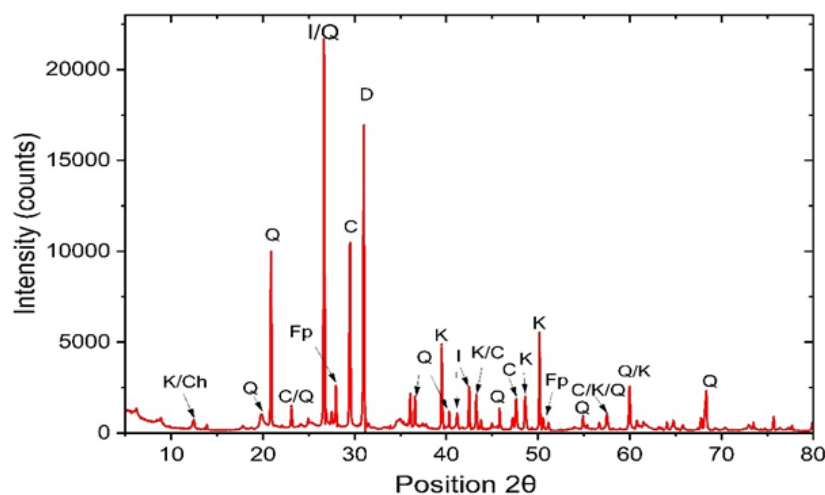


Figure 1: Pattern of X-ray diffraction for the clay sample[38].

To assess the clay's potential for use in adobe brick production, a detailed characterization was performed.

The Atterberg limits and key physical properties of the soil are outlined in Table 1, providing essential insights into its plasticity and workability. Mineralogical analysis was carried out using X-ray diffraction (XRD), with the results depicted in Figure 1, while the chemical composition, critical for understanding its thermal and mechanical behavior, is detailed in Table 2.

This comprehensive analysis not only establishes the suitability of the local clay for construction but also highlights its role as a sustainable and reproducible material for energy-efficient building practices. By leveraging locally available resources, this approach contributes to reducing the environmental footprint of construction while ensuring high-quality material performance.

Table 1: The chemical analysis of the clay sample[12].

Composition	Value (%)	Characteristics	Value (%)
Clay	41.5	Limit of liquidity	30
Sand	27	Limit of Plasticity	16
Gravel	8	Index of Plasticity	14
Silt	23.5	content of water	2.0

Table 2: Soil Composition Analysis[12].

Elements	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	K ₂ O
unfired clay	67.37	12.43	7.18	7	4.13	1.89

2.2. Sawdust

The sawdust was obtained from woodworking wastes in the area in an attempt to lower production costs and encourage the recycling of regional garbage. After collection, a sorting process was carried out to classify the sawdust particles into three categories—short, medium, and long—as indicated in Figure 2.

X-ray diffraction (XRD)[13] analysis revealed that cellulose is the primary chemical component of the sawdust, providing the material with advantageous thermal properties due to its low thermal conductivity. Additionally, scanning electron microscopy (SEM) images highlighted a characteristic porous structure. This porosity plays a crucial role in reducing the bulk density of the bricks, directly influencing their ability to limit heat transfer.

Incorporating sawdust into the adobe bricks significantly enhances their thermal performance by acting as a natural insulator. The pores present in the sawdust trap air pockets, creating an effective thermal barrier that reduces the overall thermal conductivity of the bricks.



Figure 2: Small, medium, and large sawdust particle sizes

2.3. Preparation of Adobe Bricks

The fabrication process of adobe bricks, as illustrated in Figure 3, involves the following main steps:

A. Soil Preparation

The process began with the treatment of soil, the primary raw material. Large aggregates and organic waste (plants, tree leaves) were meticulously eliminated, either manually or through sieving with a hand sieve of suitable mesh size. Following purification, water was progressively added to the soil that had been sieved while being constantly mixed until a uniform paste was achieved. To improve the cohesion and durability of the mixture, the paste was allowed to rest for 72 hours. This resting period facilitated better hydration and integration of the soil particles, improving the adobe bricks' durability and strength[14].

B. Preparation and Integration of Sawdust Fibers

Sawdust, employed as reinforcement, were divided into three groups according to their length:

- **Short fibers (S):** 0.2–0.6 cm
- **Medium fibers (M):** 0.6–1.5 cm
- **Long fibers (L):** 1.5–3.0 cm

A fixed sawdust content of 2% by weight was incorporated into the adobe formulations to optimize thermal performance while ensuring mechanical integrity. This concentration was chosen based on prior studies by M. Azalam et al.[12], which demonstrated that adobe bricks with 2% sawdust exhibited satisfactory mechanical properties. By maintaining a consistent sawdust dosage, the study specifically focused on the impact of fiber size on the thermophysical properties of the material, minimizing variability from concentration differences.

The decision to vary the sawdust size was guided by the findings of M. Limami et al.[15], who observed that thermal conductivity decreases as sawdust size decreases. This relationship was confirmed through experimental measurements using a heat flow meter, in accordance with ASTM D7896-19 standards.

C. Molding

The prepared mixture was molded into standard parallelepiped forms with dimensions of $18 \times 10 \times 5$ cm. To ensure a consistent density and reduce internal flaws, air gaps were removed by manual compaction. The surfaces of the bricks were hand-smoothed to achieve a uniform finish, enhancing their appearance and reducing.



Figure 3: Process of Adobe Brick Preparation[39][40][12]

2.4. Thermal Properties Analysis

After the drying phase, the thermal properties of the sawdust-reinforced adobe brick samples were characterized, concentrating on heat capacity and thermal conductivity. A heat flow meter (HFM Lambda 446) was used to measure these characteristics[16]. The HFM Lambda 446, adhering to ASTM C518 and ISO 8301 standards, is equipped with highly calibrated heat flux sensors, offering a precision of $\pm 1\%$ to $\pm 2\%$.

Each sample was positioned between two heating plates with a Peltier temperature control system, allowing for a regulated temperature gradient. Highly calibrated heat flow sensors were used to continually monitor the heat flux through the samples.

The system's motorized plate movement and thermocouple sensors (type K) enabled precise monitoring of the heat flow through the samples. After thermal equilibrium was achieved, the sawdust fiber-reinforced adobe bricks' heat capacity and thermal conductivity were calculated with thermal conductivity values ranging from 0.001 to 2 W/(m.K) depending on the sample configuration. These measurements were essential for calculating thermal diffusivity, which was derived using the following equation (1)[17], based on the sample's density, thermal conductivity, and heat capacity.

$$a = \frac{\lambda}{\rho \cdot C_p} \quad (1)$$

Where a , λ , ρ and C_p represent the thermal diffusivity, thermal conductivity, density of the sample and heat capacity, respectively.

2.5. Building and Material Properties Overview

A single-story, single-family home with 74 m² of floor space overall and an internal ceiling height of 3 m is the subject of the analysis. It is divided into four separate thermal zones. Figure 4 illustrates the building's geometry, highlighting its functional divisions.

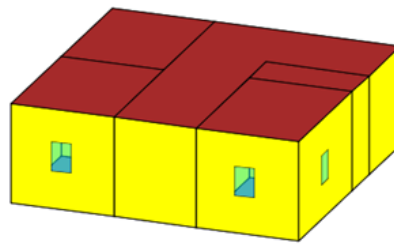


Figure 4: Illustration of the building within the energy simulation model.

Table 3 presents the key thermophysical properties of the building materials, including density, specific heat capacity, and thermal conductivity, to provide a comprehensive understanding of their thermal performance.

To assess and compare the energy efficiency of traditional adobe constructions against conventional cement-based structures, simulations were performed on five distinct building envelope configurations, as specified in Table 3.

The goal of these simulations was in order to quantify the impact of clay walls on the building's heating and cooling energy requirements, providing critical insights into the potential benefits of eco-friendly construction materials.

Table 3: The proposed building envelope's thermal properties.

Exterior wall layers		Thickness (cm)	Density (Kg/m ³)	Thermal conductivity (W/m K)	Thermal capacity (kJ/kg K)	U-value [W/ m ² K]
Reference building	Concrete masonry [18]	20	2076	1.1	0.1	2.84
	Concrete [19]	16	2240	1.7	0.88	3.78
	Cement mortar [20]	2	1800	0.93	1.05	5.22
Clay (0%)		45	1996.67	0.57	0.774	1.04
Clay-Small Sawdust (2%)		45	1877.78	0.331	0.842	0.65
Clay-Medium Sawdust (2%)		45	1865.56	0.348	0.815	0.68
Clay-Large Sawdust (2%)		45	1 800.00	0.364	0.792	0.71

2.6. Energy Transfer Simulation in Buildings: Mathematical and Physical Modeling

This research utilizes the TRNSYS simulation tool to assess the energy performance of a building under realistic conditions. The building's geometric foundation was carefully developed using the SketchUp platform, ensuring an accurate digital representation of its physical structure. This model was subsequently integrated into the TRNSYS Type 56 module (TRNBuild), where detailed specifications related to the building's physical properties, materials, and thermal performance were defined to support precise energy simulations.

Heat transfer in buildings occurs through three primary mechanisms:

A. The transfer of heat through conduction:

The approach utilizing the conductive transfer function, derived from the principles established by Stephenson and Mitalas[21], is employed to analyze the thermal behavior of the building's walls. This method offers an efficient way to model heat conduction through the building envelope, facilitating precise assessment of thermal energy transfer.

The temporal correlations between surface temperatures and heat fluxes are expressed by equations (2) and (3). The time step is indicated by the variable k , where the current hour is denoted by $k = 0$ and the previous hour by $k = -1$. The parameters that control these temporal interactions are determined by the a , b , c , and d coefficients.

Accordingly, the surface heat conduction for any wall can be expressed as follows[22]:

$$\dot{q}_{so} = \sum_{k=0}^{n_a} a^k T_{s,o}^k - \sum_{k=0}^{n_b} b^k T_{s,i}^k - \sum_{k=1}^{n_d} d^k \dot{q}_{s,o}^k \quad (2)$$

$$\dot{q}_{si} = \sum_{k=0}^{n_b} b^k T_{s,o}^k - \sum_{k=0}^{n_c} c^k T_{s,i}^k - \sum_{k=1}^{n_d} d^k \dot{q}_{s,i}^k \quad (3)$$

The terms $\dot{q}_{so}$ and $\dot{q}_{si}$ depict the flow of heat into and out of the wall, respectively. Both the inside and exterior temperatures of the wall are shown by $T_{(s,o)}$ and $T_{(s,i)}$, as illustrated in Fig. 5.

B. The transfer of heat through Convection:

The equations (4,5) depict the heat flows that are transferred by convection at the outside and interior surfaces of the wall[23]:

$$\dot{q}_{c,s,o} = h_{outside} (T_{a,s} - T_{s,o}) \quad (4)$$

$$\dot{q}_{c,s,i} = h_{inside} (T_i - T_{s,i}) \quad (5)$$

The external and interior surfaces' convective coefficients of heat transfer are denoted by h_{inside} and $h_{outside}$ respectively. Meanwhile, $T_{a,s}$ symbolizes the external thermal zone's ambient air temperature, while T_i indicates the indoor temperature within the thermal zone.

C. The transfer of heat through Radiation:

The flux of radiative heat can be calculated using the following formula[24]:

$$\dot{q}_{r,s,o} = \sigma \varepsilon_{s,o} (T_{s,o}^4 - T_{fsky}^4) \quad (6)$$

where:

$\sigma_{theo} = (5.6696 \pm 0.0025) \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$: The constant known as Stefan-Boltzmann[25].

$\varepsilon_{(s,o)}$: The exterior wall surface's emissivity for long-wave radiation.

T_{fsky} : The apparent sky temperature concerning exchange of longwave radiation.

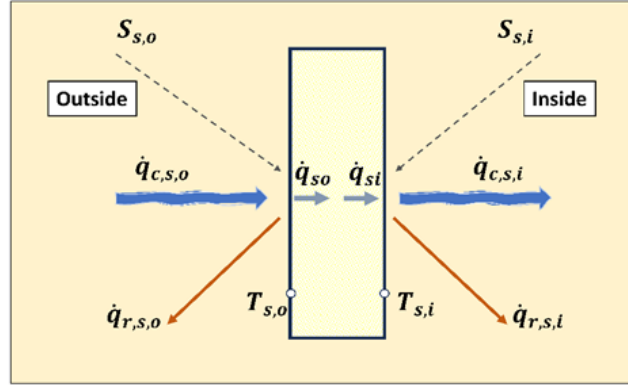


Figure 5: Fluxes of heat and temperatures close to the wall[41]

3. RESULTS AND DISCUSSION

3.1. Thermal Properties Analysis

The thermal characterization of adobe bricks containing varying types of sawdust highlights substantial changes in their thermophysical properties based on the inclusion and particle size (small, medium, large) of the sawdust. These variations are systematically analyzed in terms of density (ρ), thermal conductivity (λ), and specific heat capacity (C_p) as follows:

3.1.1. Density (ρ)

The incorporation of sawdust significantly reduces the density of the adobe bricks regardless of the particle size. The control sample, composed exclusively of clay (0% sawdust), exhibits an average density of 1996.67 kg/m^3 , while bricks with sawdust range from 1800.00 kg/m^3 (large sawdust) to 1877.78 kg/m^3 (small sawdust). This fact is confirmed by the research done by M. Limami et al.[15], which investigated the effect of varying sawdust sizes on bulk density. The results showed a reduction in bulk density for bricks incorporating larger-sized additives. This reduction in density, reaching up to 9.83%, is explained by sawdust's lower bulk density than clay. The substitution of a denser clay fraction with a lighter sawdust fraction effectively decreases the overall mass of the bricks.

3.1.2. Thermal Conductivity (λ)

When sawdust is added, thermal conductivity decreases. Comparable studies have verified that the inclusion of fibers results in a decrease in heat conductivity [26], [27], [28]. Compared to the control brick ($\lambda = 0.57 \text{ W/m}\cdot\text{K}$), bricks incorporating 2% sawdust show reduced conductivity levels between $0.331 \text{ W/m}\cdot\text{K}$ (small sawdust) to $0.364 \text{ W/m}\cdot\text{K}$ (large sawdust). This reduction of up to 41.93% aligns with the increased porosity introduced by the sawdust, which traps air and reduces the material's capacity to conduct heat. Smaller sawdust particles appear to enhance thermal insulation more effectively than larger particles, indicating that granulometry plays a critical role in optimizing thermal performance.

3.1.3. Specific Heat Capacity (C_p)

The inclusion of sawdust moderately increases the adobe bricks' specific heat capacity, with values rising from 0.774 kJ/kg·K for pure clay bricks to a maximum of 0.842 kJ/kg·K for bricks containing small-sized sawdust. This improvement is attributed to the presence of pores within the matrix of the adobe bricks. Studies by M. Ouedraogo et al. have shown that the increase in porosity, resulting from the incorporation of fonio straw into adobe, contributes to a significant reduction in thermal conductivity[29], thereby limiting heat transfer through the material[30]. As a result, the thermal resistance increases due to the reduced efficiency of energy and heat transfer [31]. However, the improvement in specific heat capacity slightly decreases with larger particle sizes, possibly due to uneven thermal distribution within the brick matrix.

3.2. Clay-sawdust thermal behavior

Figure 6 illustrates the internal temperature variations over the coldest seven days of the winter period for different adobe envelope configurations. The results reveal that all four configurations utilizing earthen materials outperform the reference envelope in terms of thermal comfort, even under rigorous outdoor conditions characterized by minimum temperatures reaching as low as 0.25°C.

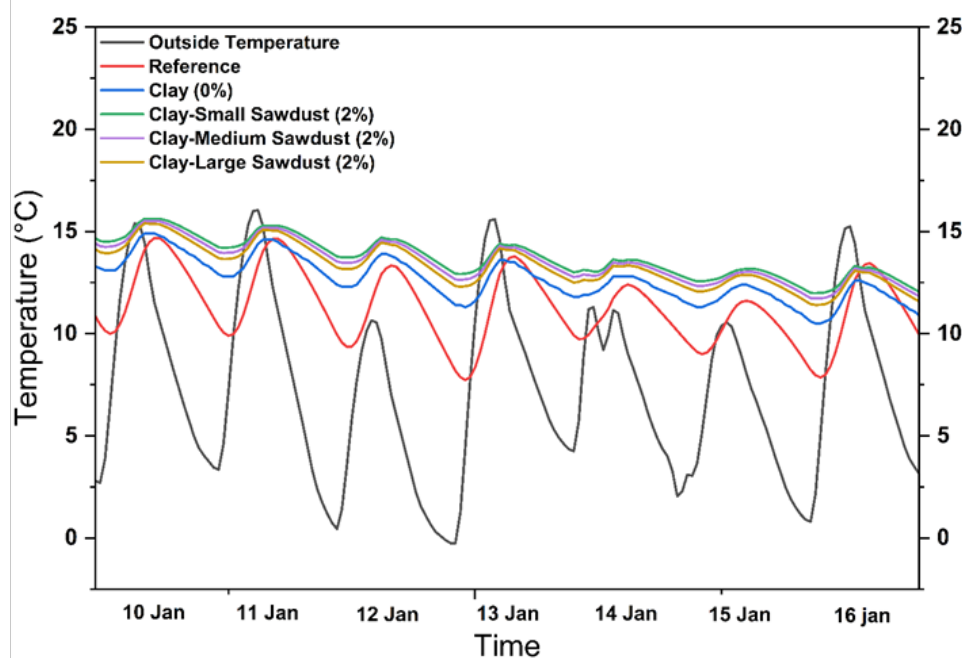


Figure 6: Temperature variations during the coldest seven days of 2024 for the reference building made of concrete and adobe clay bricks with sawdust additives of varying sizes.

Specifically, when the external temperature drops to 0.25°C, the internal temperature for the reference envelope is 8.63°C, while it rises to 11.60°C, 13.08°C, 12.81°C, and 12.50°C For configurations based on pure clay material, clay combined with small sawdust particles, clay with medium-sized sawdust particles, and clay with large sawdust particles, respectively.

These findings demonstrate that the incorporation of organic particles, such as sawdust, into earthen wall compositions significantly enhances their thermal insulation capacity. Sawdust acts as a porous material, increasing the thermal resistance of the envelope and thereby reducing heat losses to the exterior. This aligns with previous studies demonstrating that clay-based walls enriched with organic additives, such as peanut shells, provide superior insulation in winter compared to pure clay constructions[32]. Moreover, the particle size of the sawdust appears

to influence thermal performance: smaller particles maximize efficiency by improving the homogeneity of the mixture and enhancing the internal structure of the material, thus facilitating more effective heat retention.

In comparison, the envelope made of pure clay offers a notable improvement over the reference envelope but is less effective than configurations incorporating sawdust particles. This observation underscores the critical role of material composition and physical properties in governing thermal regulation.

Furthermore, the reduced temperature gradient between the interior and exterior in the earthen configurations demonstrates enhanced thermal stability—a key criterion for occupant comfort. These results are particularly significant in cold climates, where extreme fluctuations in outdoor temperatures can considerably impact the energy demands of buildings.

Figure 7 illustrates the variations in indoor temperature over the seven hottest days of the summer period for different envelope configurations. The results reveal that adobe buildings, whether or not enriched with sawdust, offer noticeably better thermal comfort than the concrete envelope used as a reference, even under extreme climatic conditions characterized by outdoor temperatures exceeding 46°C.

More specifically, when the outdoor temperature reaches 46°C, the internal temperature for the reference concrete envelope is 38.57°C, reflecting its limited capacity to regulate thermal fluctuations. In contrast, adobe envelopes exhibit lower internal temperatures: 37.10°C for the pure earth envelope, 36.12°C for the envelope enriched with small sawdust particles, 36.28°C for the medium-sized sawdust-particle envelope, and 36.52°C for the large-sized sawdust-particle envelope.

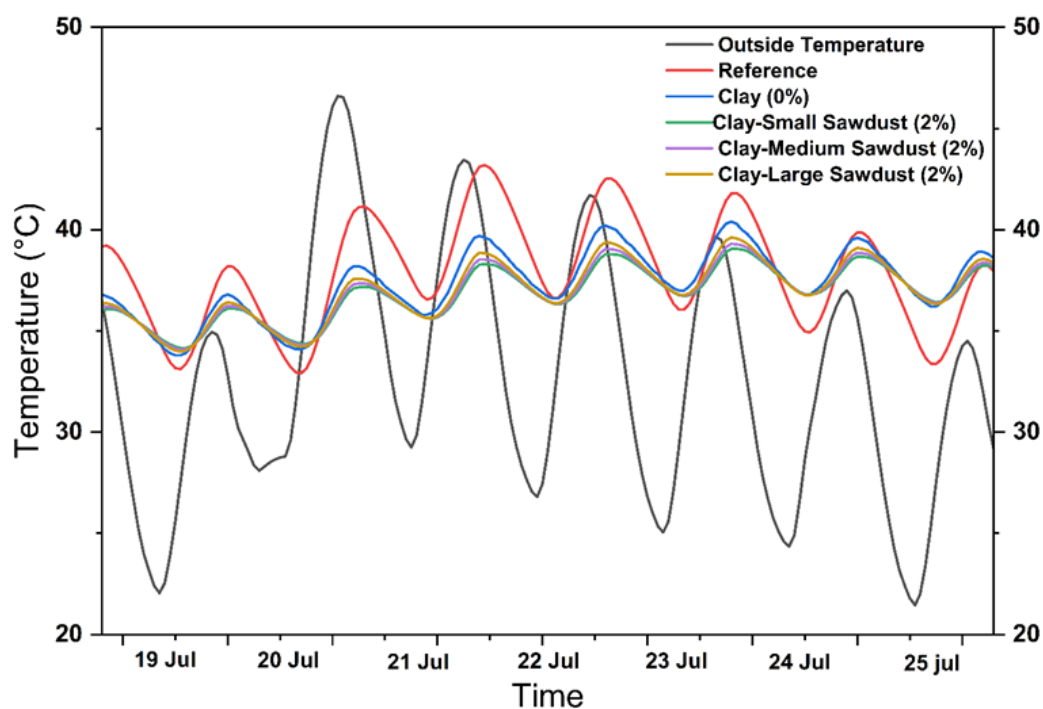


Figure 7: Temperature variations during the hottest seven days of 2024 for the reference building made of concrete and adobe clay bricks with sawdust additives of varying sizes.

These results highlight the superior thermal performance of earth-based materials over concrete. The ability of adobe to mitigate thermal fluctuations is attributed to its intrinsic properties, for example, its high thermal mass and low thermal conductivity, which enable it to limit heat gains and maintain a more stable indoor environment. The addition of sawdust, particularly small

particles, further enhances these thermal performance characteristics.

In comparison, while concrete is commonly used in modern construction, it exhibits notable limitations in thermal regulation under extreme climatic conditions. These results highlight how crucial it is to bring back traditional materials, such as sawdust-enriched adobe, into contemporary building practices to increase buildings' energy efficiency.

Furthermore, these findings support the rising demand for using natural, local building materials in hot climates. The integration of sawdust, an abundant industrial by-product, not only improves the thermal properties of adobe but also contributes to waste valorization, promoting sustainable construction practices.

Figures 8 and 9 illustrate the setups under study's heating and cooling needs, respectively. When comparing the energy performance of the several building configurations under study to a reference concrete building, the analysis of these results shows that the use of adobe bricks formed from clay and sawdust significantly reduces the energy demands for heating and cooling. The indoor air temperature set-points were maintained at 20 °C for heating and 26 °C for cooling. These values comply with the indoor thermal comfort conditions outlined in the Moroccan standard NM ISO 7730[33]. Under these conditions, the results indicate a substantial reduction in energy[33], the results indicate a substantial reduction in energy consumption.

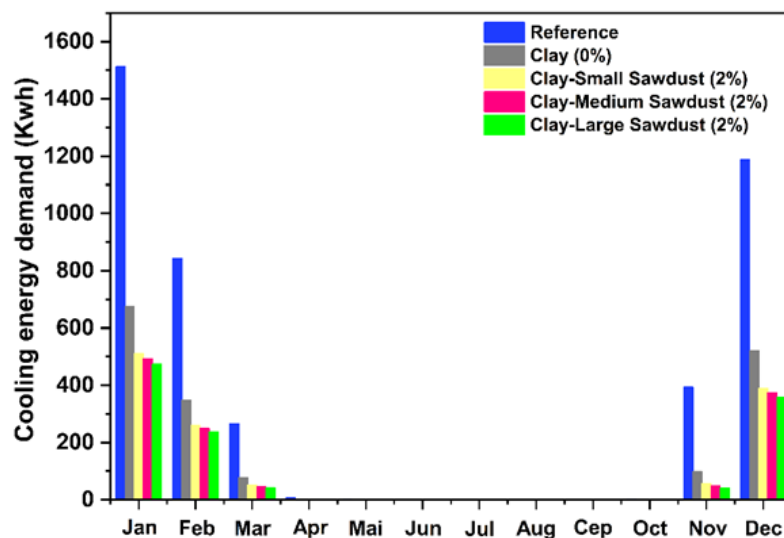


Figure 8: Monthly evolution of the heating needs in 2024 for the reference building made of concrete and adobe clay bricks with sawdust additives of varying sizes.

The simulation results indicate that the concrete building uses 4215.43 kWh of heating energy annually. By contrast, configurations using adobe bricks reduce this demand to 1722.42 kWh for pure clay (a reduction of 59.14%), 1154.60 kWh for clay mixed with fine sawdust (a reduction of 72.61%), 1211.92 kWh for clay with medium sawdust (a reduction of 71.25%), and 1269.68 kWh for clay with large sawdust (a reduction of 69.88%). The fine sawdust configuration stands out, likely due to a more homogeneous distribution of particles, optimizing thermal insulation.

In terms of cooling, the concrete building displays a high annual energy consumption of 9289.94 kWh. The use of adobe bricks reduces this consumption to 5042.08 kWh for pure clay (a reduction of 45.71%), 3824.79 kWh for clay with fine sawdust (a reduction of 58.82%), 3930.73 kWh for clay with medium sawdust (a reduction of 57.68%), and 4029.08 kWh for clay with large sawdust (a reduction of 56.62%). These findings show that because of their thermal inertia, adobe bricks can reduce indoor temperature variations. The integration of sawdust enhances this thermal inertia by limiting incoming heat flux, thereby reducing thermal loads and cooling requirements, with

fine sawdust-enriched bricks showing the highest efficiency.

These findings demonstrate that the use of adobe bricks, particularly those enriched with sawdust particles, significantly improves the energy efficiency of buildings. This optimization results in reduced energy needs for both heating and cooling, while simultaneously providing superior thermal comfort for occupants. Previous studies on energy simulations of building materials have reported similar findings, showing that integrating wool can substantially lower thermal loads compared to conventional clay buildings [34]. Further research has reinforced these findings by exploring the integration of various bioclimatic additives into building materials, such as vegetable matter [35], industrial waste [36], and *Typha Australis* [37] among others.

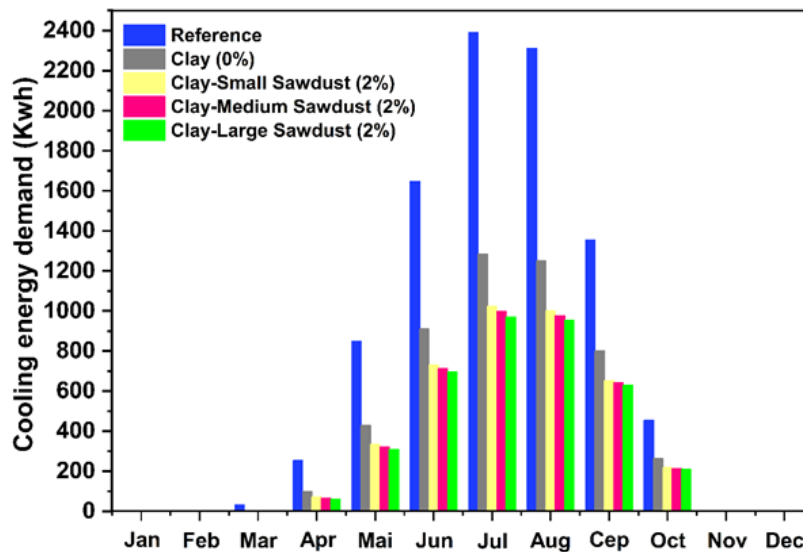


Figure 9: Monthly evolution of the cooling needs in 2024 for the reference building made of concrete and adobe clay bricks with sawdust additives of varying sizes.

4. GENERAL CONCLUSION

This study provides compelling evidence of the superior thermal efficiency of sawdust-enriched adobe compared to traditional concrete, while critically evaluating its performance as a sustainable building material in hot climates. Thermal simulations demonstrate that adobe, whether pure or enriched with sawdust, significantly enhances indoor comfort in both summer and winter. During summer, when external temperatures exceed 46°C, pure adobe maintains indoor temperatures around 37.10°C, whereas sawdust-enriched adobe achieves lower temperatures, ranging from 36.12°C to 36.52°C—up to 2.45°C cooler than concrete, which reaches 38.57°C. Similarly, in winter, when external temperatures drop to 0.25°C, pure adobe maintains an indoor temperature of 11.60°C, while sawdust-enriched adobe ranges from 12.50°C to 13.08°C, compared to just 8.63°C for concrete. These findings underscore the significant thermal efficiency of sawdust-enriched adobe in regulating indoor temperatures, reinforcing its potential as a viable alternative to conventional construction materials.

The results of this study further demonstrate a significant reduction in energy demand for both heating and cooling when sawdust-enriched adobe is utilized. For heating, the configuration with pure clay adobe results in a reduction of 59.14% in energy consumption compared to concrete. When sawdust is incorporated, the reduction ranges from 69.88% to 72.61%, indicating a notable improvement in energy efficiency. In terms of cooling, pure adobe leads to a 45.71% reduction in energy demand, while sawdust-enriched adobe configurations achieve reductions between 56.62% and 58.82%. These findings underscore the positive impact of sawdust incorporation,

regardless of particle size, in contributing to significant energy savings. In addition to its thermal and energy benefits, sawdust-enriched adobe presents economic and environmental advantages. With low production costs and reliance on locally available raw materials, it offers a cost-effective and ecologically responsible alternative to traditional construction materials. However, for its large-scale implementation, clear guidelines on sourcing, processing, and standardization must be developed. Regulatory frameworks should also define technical specifications to ensure its long-term durability, thermal efficiency, and structural integrity.

To facilitate its widespread adoption, collaboration between local governments, construction professionals, and policymakers is crucial. Establishing national and international standards for bio-based adobe formulations will strengthen confidence in its application, encouraging its integration into mainstream construction practices. Additionally, future research should explore its compatibility with other sustainable materials to further enhance the environmental performance of buildings.

Overall, this study contributes to the advancement of sustainable construction by demonstrating the viability of sawdust-enriched adobe as a low-energy, high-performance building material. With appropriate regulatory support and continued research, this innovative material holds great promise for promoting energy-efficient and climate-responsive architecture, particularly in regions with extreme temperatures.

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