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Bio-Based Plaster Composites Reinforced with *Typha Angustifolia* Fibers: Mechanical and Thermal Behavior for Energy-Efficient Building Envelopes

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ABSTRACT

This study presents the development of sustainable plaster-based composite materials reinforced with *Typha angustifolia* fibers (TAF), aiming to improve thermal insulation and mechanical performance for lightweight wall systems in hot-arid climates. TAF is a regionally abundant wetland plant in Algeria, characterized by low density and high cellulose content, making it a promising natural reinforcement. Composites were prepared by partially replacing sand with 0–2% TAF by weight. Experimental results revealed that TAF incorporation reduced dry density and thermal conductivity, enhancing insulation properties while moderately decreasing compressive strength. Despite this reduction, the composites maintained adequate structural integrity for use in non-load-bearing walls and building partitions. Thermal simulations comparing TAF-based wall assemblies with conventional hollow concrete block systems under the climatic conditions of M'sila, Algeria, demonstrated improved thermal inertia, reduced heat flux, and more stable indoor temperatures. Annual energy analysis showed a relative improvement (reduction) of 21.1% in overall energy performance. These findings suggest that *Typha*-reinforced plaster composites can serve as effective bio-based building materials, supporting sustainable design and construction in arid and semi-arid environments.

摘要

本研究介绍了用香蒲纤维 (TAF)增强的可持续石膏基复合材料的开发，旨在改善炎热干旱气候下轻质墙体系统的隔热和机械性能. TAF是阿尔及利亚一种区域性丰富的湿地植物，其特点是密度低、纤维素含量高，使其成为一种有前景的天然增强剂. 复合材料是通过用0-2%重量的TAF部分替代沙子制备的. 实验结果表明，TAF的加入降低了干密度和导热系数，增强了绝缘性能，同时适度降低了抗压强度. 尽管减少了，但复合材料仍保持了足够的结构完整性，可用于非承重墙和建筑隔墙. 在阿尔及利亚M'sila的气候条件下，将基于TAF的墙体组件与传统的空心混凝土砌块系统进行热模拟比较，结果表明热惯性得到改善，热通量降低，室内温度更稳定. 年度能源分析显示，整体能源绩效相对提高 (降低)了21.1%. 这些发现表明，香蒲增强石膏复合材料可以作为有效的生物基建筑材料，支持干旱和半干旱环境中的可持续设计和施工.

KEYWORDS

Typha angustifolia fibers; plaster composites; thermal insulation; energy-efficient buildings; thermal conductivity; exterior walls; bio-based materials

关键词

狭叶香蒲纤维; 石膏复合材料; 保温; 节能建筑; 导热系数; 外墙; 生物基材料

Introduction

Improving energy efficiency in buildings has become a global priority in the context of climate change and rising urban energy demand. In the European Union, buildings account for approximately 40% of total energy consumption (European Parliament 2012), a trend mirrored in many developing countries. In Algeria, where rapid urbanization intersects with a hot-arid climate, energy consumption for indoor cooling is steadily increasing. This highlights the urgent need for sustainable composite material systems that reduce environmental impact while enhancing indoor thermal comfort.

Thermal discomfort in hot-arid regions is often linked to high solar heat gain and poor thermal inertia in building envelopes. As a result, conventional materials contribute to excessive reliance on air conditioning systems. To address this, there is growing emphasis on materials with low thermal conductivity and high

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specific heat capacity, capable of passively regulating indoor temperatures. The local building energy regulations of Algeria (1997) and international initiatives, such as the International Energy Agency (IEA) (International Energy Agency 2023) Net Zero Carbon Buildings Roadmap both advocate the importance of improving insulation and using bio-based, locally sourced materials.

Gypsum-based materials are widely used for interior finishes due to their low embodied energy, easy application, and reduced carbon footprint compared to cementitious alternatives (Laoubi et al. 2019). However, plaster mortars are typically brittle and mechanically weak, which limits their applicability beyond interior coatings (Naciri, Aalil, and Chaaba 2022). These composites, while lightweight, maintain sufficient strength for use in partition walls and non-load-bearing structural components in low-rise construction, supporting sustainable housing strategies in arid zones.Fiber reinforcement has emerged as a promising solution to overcome these limitations by improving toughness, crack resistance, and importantly thermal performance.

Natural, synthetic, and recycled fibers have been successfully used to reinforce plaster and other building composites (Beddar, Meddah, and Belagraa 2017; Benouadah, Beddar, and Meddah 2017; Djoudi et al. 2014; Guna et al. 2025; Touil et al. 2022). Despite their performance benefits, synthetic fibers are associated with higher costs, greater environmental impact, and chemical incompatibility with gypsum matrices (Agossou and Amziane 2023). Consequently, attention is shifting toward more sustainable alternatives, particularly plant-based fibers that are compatible, cost-effective, and regionally available.

One such alternative is *Typha angustifolia* (TAF), an underutilized wetland plant abundantly found in Northern Africa, especially in Algeria's M'Sila region. Characterized by low density and a high cellulose-lignin content, TAF can be harvested and processed with minimal energy input (Gaye et al. 2023). Previous studies have evaluated its use in cement- and clay-based systems (Barbero-Barrera, Salas-Ruíz, and Galbis-Morales 2021; Kamali Moghaddam 2022; Limami et al. 2021), but its application in gypsum-based composites remains largely unexplored.

While this research focuses on initial thermal and mechanical properties, future investigations will address the durability and fiber – matrix interface performance under environmental exposure conditions typical of arid climates. This study investigates the potential of TAF as a natural reinforcement in plaster composites to enhance thermal insulation and mechanical performance in hot-arid climates. The research aims to:

- Evaluate the influence of TAF incorporation on the physical, mechanical, and thermal properties of plaster composites.
- Assess the thermal performance of TAF-reinforced wall systems through numerical simulations under realistic climatic conditions.
- Quantifying the potential energy savings and improvements in indoor thermal comfort compared to conventional wall construction in a residential-type building of 161 m^2 distributed over two floors.

By transforming a readily available plant into a high-value construction material, this work supports circular economy principles, promotes local resource utilization, and contributes to sustainable development goals, particularly SDG 11 (*Sustainable Cities and Communities*) and SDG 13 (*Climate Action*).

Materials and mix design procedure

Plaster

The plaster used in this study was a commercially available hemihydrate gypsum ($CaSO_4 \cdot 0.5\,H_2O$), commonly used in building finishing applications due to its ease of handling, availability, and setting behavior. According to the technical data sheet of supplier, the plaster had a purity exceeding 95%, a particle size below 100 μm, and an initial setting time ranging from 8 to 14 minutes. Based on the classification established by the CNERIB (CNERIB 1993), the material qualifies as Class I gypsum. The main physical properties are summarized in Table 1.

Sand

Clean dune sand with a specific density of 2596 kg/m^3 was used as the fine aggregate. Its physical characteristics are presented in Table 2, and the particle size distribution curve is shown in Figure 1.

Fibers

Lignocellulosic fibers extracted from TAF, a wetland plant abundant in the M'Sila region of Algeria, were selected as the natural reinforcement for the plaster composites. The plant is characterized by long, flat leaves reaching up to 2 m in length. Fibers were obtained through a conventional water retting process, involving a 21-day soaking period to promote microbial degradation of non-cellulosic components. After retting, the fibers were rinsed, washed with distilled water, oven-dried at 70°C, and manually cut to approximately 3 cm in length.

These local fibers have been recently characterized in detail by Mostefa (Mostefa 2025), who reported their physicochemical and mechanical properties, including density, thermal stability, chemical composition (via FTIR), crystallinity (via XRD), and tensile behavior. The study confirmed that Typha fibers possess a low density (1.21 g/cm^3), moderate tensile strength (300 MPa), and a semi-crystalline lignocellulosic structure. Their thermal degradation profile indicates stability up to approximately 225°C, making them compatible with plaster matrix processing. For a complete description of the characterization methods and results, readers are referred to the cited thesis. These characteristics support the suitability of TAF as a sustainable reinforcement in lightweight plaster composites for building applications.

As observed in Table 3, the Typha angustifolia fibers used in this study exhibit intermediate mechanical characteristics compared to conventional cellulosic fibers such as flax and jute. Their tensile strength (270 MPa) and Young's modulus (≈24 GPa) indicate a moderate reinforcement potential, adequate for enhancing plaster composites while preserving low density (1.25 g/cm^3). Although their strength remains lower than that of flax or jute, Typha fibers combine sufficient stiffness and elongation (≈1.7%) with excellent availability and renewability. This combination makes them particularly suitable for sustainable, lightweight

Table 1. Properties of gypsum.

Setting times [min]			Particle size analysis	
Initial	Final	Apparent density [kg/l]	100 [µm]	200 [µm]
4–6	8–14	0.85–0.95	<20	<10

Table 2. Physical properties of sand used.

property	Apparent density [kg/m^3]	Specific density [kg/m^3]	Porosity [%]	Sand Equivalent [%]
range	1428±14	2596±26	45±0.5	86±0.5

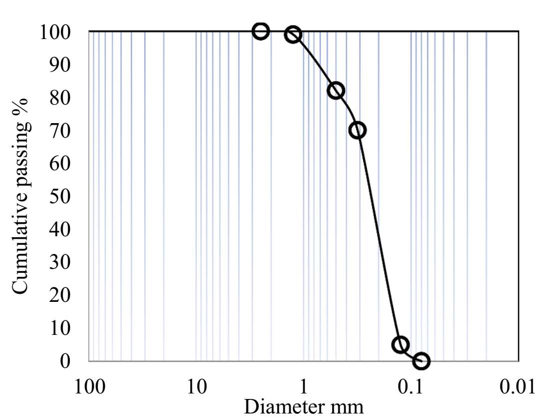


Figure 1. Particle size distribution curve of sand.

Table 3. Comparative physical and mechanical properties of Typha angustifolia and selected natural fibers. Mostefa (2025), Pickering et al. (2016).

Fiber type	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Typha angustifolia (used in this study)	1.25	270 ± 120	24.2 ± 7.8	1.7 ± 0.8
Malva sylvestris	1.12	236.6 ± 113	26.1 ± 8.6	1.3 ± 0.6
Flax	1.50	345–1830	27–80	1.2–3.2
Jute	1.3–1.5	400–800	10–55	1.5–1.8

construction composites where moderate strength and enhanced thermal performance are prioritized over high structural resistance.

Mix design procedure

A constant water-to-binder (W/B) ratio of 0.6 by weight was used for all mixtures. The mix design was based on a binary combination of plaster and sand, with varying fiber additions. The mixing process was carried out as follows:

(1) Dry Mixing: Plaster and sand were dry-mixed for 2 minutes to ensure homogeneity.
(2) Fiber Incorporation: For fiber-reinforced mixes, pre-weighed dry TAF were added to the dry plaster – sand blend and mixed thoroughly to avoid agglomeration.
(3) Water Addition: Water was gradually introduced during mechanical mixing at 400 rpm for 3 minutes.

The fresh mixture was cast into prismatic molds (40 × 40 × 160 mm) and gently vibrated to eliminate entrapped air. Specimens were demolded after 24 hours and cured under ambient conditions (23 ± 2°C, 50 ± 5% RH) for 28 days in a ventilated environment.

Five fiber volume fractions were tested: 0%, 0.5%, 1%, 1.5%, and 2% by weight of plaster. These levels were chosen to evaluate the effect of gradual fiber incorporation on the composite's performance.

Testing methods

The mechanical properties (flexural and compressive strengths) were measured following EN 196–1 standards using 40 × 40 × 160 mm prisms. Flexural strength was determined via a three-point bending test. The resulting halves were used for compressive strength testing, with the load applied axially until failure. Three specimens were tested per mix, and mean values were reported. The thermal conductivity (λ) and thermal diffusivity (α) were measured using the Transient Plane Source (TPS) method, in accordance with ASTM D5334 (2014). This technique provides accurate assessment of the thermal insulation potential of fiber-reinforced composites.

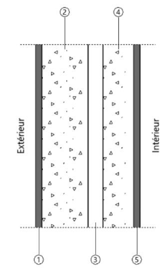
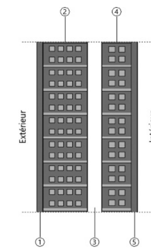
Numerical simulation environment

Simulations were carried out using EnergyPlus v9.4, where each wall system was tested under identical thermal boundary conditions in a 3 × 3 × 3 m^3 cubic test room. Four cardinal orientations were considered: North, East, South, and West. The wall configuration adopted is illustrated in Table 4. The location-specific climate data (M'Sila, Algeria) were integrated to reflect realistic solar radiation and ambient temperature profiles. The following indicators (decrement factor and time lag, respectively) were used to quantify thermal inertia.

$$f = \frac{T_{max}^{(i)} - T_{min}^{(i)}}{T_{max}^{(o)} - T_{min}^{(o)}} \quad (1)$$

$$\varphi = t_{T_{max}^{(i)}} - t_{T_{max}^{(o)}} \quad (2)$$

Table 4. Wall composition details.

		Total Thickness (34 cm)	
Layer Number	Layer description	TAF based	HCB
1	External cement mortar	2	2
2	Plaster block	15	15
3	Air cavity	5	5
4	Plaster block	10	10
5	Internal cement mortar	2	2
			
	Thermal Transmittance (U-value): W/(m^2 ·K)	1.19	1.78

where:

- $T^{(o)}_{max}$ and $T^{(o)}_{min}$: are the maximum and minimum temperatures on the outer wall surface, respectively.
- $T^{(i)}_{max}$ and $T^{(i)}_{min}$: are the maximum and minimum temperatures on the inner wall surface, respectively.

Results and discussions

Physical properties

The progressive incorporation of TAF into plaster composites significantly influences both density and thermal conductivity, revealing a strong interdependence between these two parameters. As shown in Figure 2, the apparent density of the plaster matrix decreases steadily from 1403 kg/m^3 for the reference sample (unreinforced) to 1210 kg/m^3 at 2% fiber content. This reduction is primarily due to the low intrinsic density of TAF fibers (1.21 g/cm^3), and more importantly, to the creation of a porous network within the composite. The fibrous inclusions introduce interconnected micro-voids that reduce mass per unit volume (Labiad, Meddah, and Beddar 2022). The presence of these voids contributes not only to a lower bulk density but also to improved thermal insulation.

Correspondingly, Figure 2 shows also a marked decrease in thermal conductivity, from 0.65 W/m·K in the control plaster to 0.54 W/m·K at 2% TAF content, (i.e., 17% decrease). This trend is consistent with findings reported in the literature for other bio-based materials (Djoudi et al. 2014; Rouf et al. 2025). This decrease can be attributed to two complementary mechanisms: the inherent low thermal conductivity of lignocellulosic fibers (Lian et al. 2024), and the trapped air within the fiber-matrix system (Labiad, Meddah, and Beddar 2022), which further limits heat conduction due to the low thermal conductivity of air.

The relationship between density and thermal conductivity is made explicit in Figure 3, where a strong positive linear correlation is observed, with a coefficient of determination $R^2 = 0.977$. This highlights that as density decreases, thermal conductivity correspondingly reduces. This outcome is consistent with findings of previous studies for other plant fiber reinforced composites. For instance, Benmansour (Benmansour et al. 2014) and Ferrández et al. (Ferrández et al. 2024) noted similar behavior in date palm and hemp fiber gypsum-based composites, respectively, emphasizing the predictable nature of this relationship in porous, lightweight matrices.

From a performance standpoint, this correlation is practically significant. According to RILEM TC 236-BBM (2017) guidelines, efficient bio-based insulating materials should typically exhibit apparent densities near 1200 kg/m^3 and thermal conductivities below 0.6 W/m·K. The 2% TAF-reinforced plaster closely meets these criteria, demonstrating properties (1210 kg/m^3 and 0.54 W/m·K) that make it suitable for non-load-

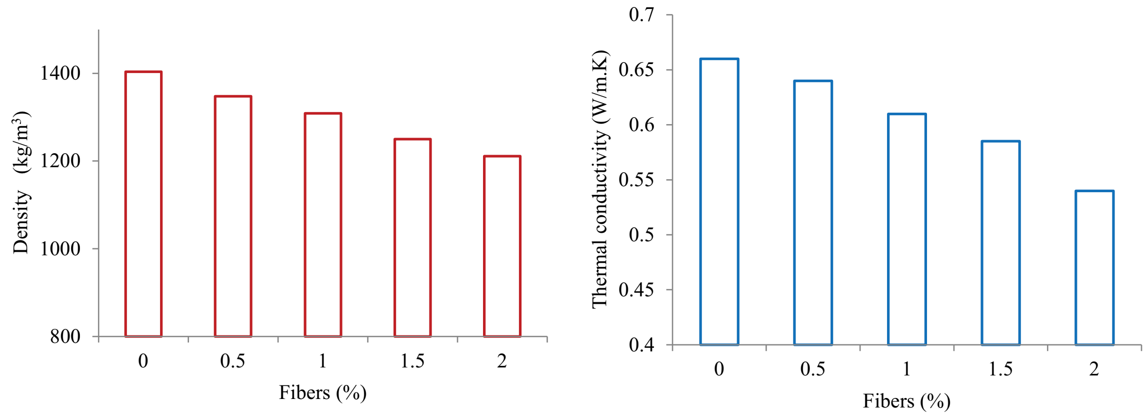


Figure 2. Effect of taf addition on the physical properties of the composite: density (left) thermal conductivity (right).

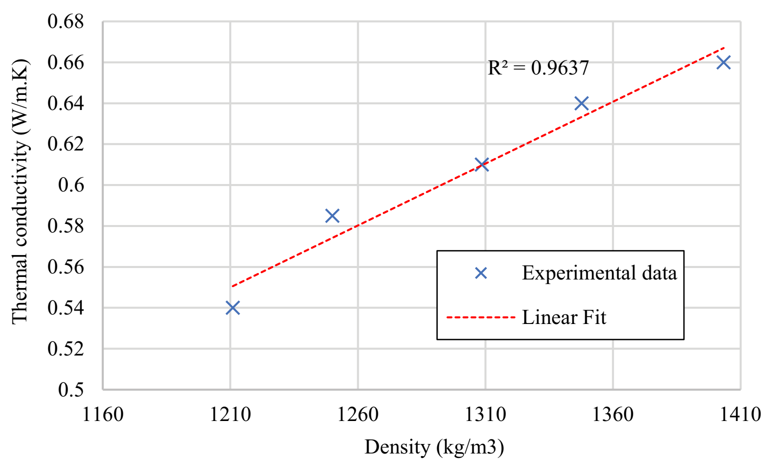


Figure 3. Correlation between apparent density and thermal conductivity.

bearing elements such as interior partitions and insulating layers in building envelopes – especially in hot arid climates where thermal resistance and energy savings are essential.

These findings confirm the potential of *Typha*-based composites as lightweight insulating materials, leveraging the inverse relationship between density and thermal conductivity to improve building energy performance through both material design and functional integration.

From a design and application perspective, this correlation has practical significance. According to the RILEM TC 236-BBM (2017), effective bio-based insulating materials should possess apparent densities of 1200 kg/m^3 and thermal conductivities under 0.6 W/m·K. The 2% TAF-reinforced plaster composite approaches this benchmark, offering performance well suited for non-load-bearing interior partitions, particularly in hot arid climates where thermal resistance and energy efficiency are crucial.

Mechanical properties

The mechanical behavior of TAF-reinforced plaster composites reflects a typical trade-off observed in bio-based systems: decreased compressive strength accompanied with significant gains in ductility and post-peak energy dissipation (toughness). Despite this strength reduction, the composites satisfy the mechanical requirements for non-load-bearing construction, while also offering sustainability and thermal benefits.

The 28-day unconfined compressive strength (UCS) reported in Table 5 and illustrated in Figure 4, show a progressive decrease from 12.88 MPa for the control mix (unreinforced) to 6.45 MPa at 2% fiber addition. Intermediate fiber contents exhibited average UCS values of 10.50 MPa, 9.1 MPa, and 7 MPa for 0.5%, 1%, and 1.5% fiber, respectively. The slightly higher variability observed at 1% and 1.5% fiber (COV > 12%) reflects fiber distribution heterogeneity and localized clustering effects, which are common in bio-based reinforcement systems.This loss of strength is primarily due to increased porosity and disruption of the gypsum crystal network, as well as weak interfacial bonding between untreated lignocellulosic fibers and the mineral matrix. Nonetheless, despite this loss in strength, the 6.5 MPa strength remains well above the minimum thresholds specified in EN 13,279–1 (2008) for Class B4 gypsum plasters (≥6 MPa) and exceeds typical ranges for non-load-bearing components outlined in ASTM C472 (2020) and CNERIB guidelines (CNERIB 1993). To quantify the global statistical relationship, the covariance and correlation between fiber content and UCS were computed using the mean values across all fiber dosages. The sample covariance was −2.04, while the correlation coefficient was −0.98. This strong negative correlation confirms that UCS decreases almost linearly with increasing fiber dosage.

Stress – strain curves (Figure 4) illustrate the transition from brittle to ductile failure modes with increasing fiber content. The control mix exhibited a brittle response with a sharp peak (at $\varepsilon = 0.4\%$) followed by sudden failure, while fiber-reinforced composites showed a more gradual post-peak softening and higher deformation capacity reaching $\varepsilon = 1.1\%$, 2.5%, 1.74% and 2.6% for 0.5%, 1%, 1.5% and 2% fiber composite, respectively. the strain capacity reached 2.7%, compared to only 0.4% for the unreinforced plaster (six times increase. This ductility improvement is attributed to fiber bridging, which delayed crack propagation and promoted energy dissipation. This represents a sixfold improvement in ductility at 2% fiber compared to the control. The enhanced toughness is attributed to fiber bridging and crack-bridging mechanisms, which delay crack propagation, promote gradual stress transfer, and increase fracture energy.

Table 5. Ucs results for different fiber contents.

Fiber content %	UCS MPa Test1	Test 2	Test 3	Mean	Standard deviation	Coefficient of variation COV (%)
0	11.97	12.90	13.85	12.88	0.94	7.30
0.5	9.70	10.51	11.30	10.48	0.80	7.64
1	7.80	9.20	10.50	9.10	1.35	14.83
1.5	6.20	7.05	7.90	7.02	0.85	12.12
2	6.90	6.49	5.98	6.45	0.46	7.15

Table 6. Some compressive strength values of gypsum composite from the literature.

Composite (additives)	USC, MPa	Reference
Gypsum + sand + raw doum fibers (0–0.5–1-1.5–2%)	1.07–3.86	Fatma et al. (2019)
Gypsum + sand + alkali-treated doum fibers (0–0.5–1-1.5–2%)	2–26-4.23	Fatma et al. (2019)
Gypsum +s and + rubber (0,10, 20, 30, 40, 50%)	2–9.95	Meddah, Laoubi, and Bederina (2020)
Gypsum + sand + polystyrene (0,10, 20, 30, 40, 50, 60%)	1.8–7.6	Laoubi et al. (2018)
Gypsum + lime + sand + brick waste	2.06–9.59	Naciri, Aalil, and Chaaba (2022)
Plaster+sand+TAF fibers 0 to 2%	6.5–12.9	This study

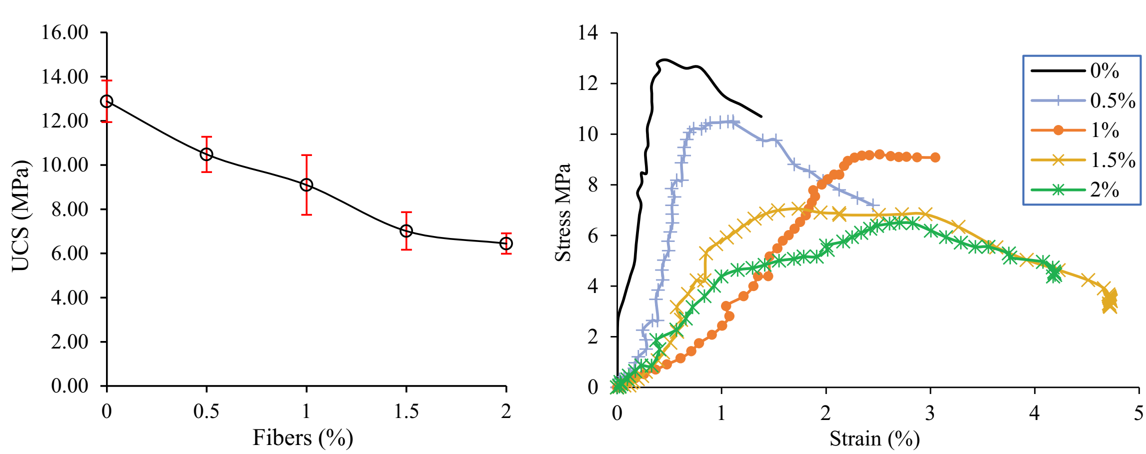


Figure 4. mechanical performance of plaster composites with varying taf content: ucs is shown on the left, while the corresponding stress–strain curves are presented on the right.

These fracture modes transition from brittle cleavage in the control to fiber pull-out and matrix cracking in reinforced mixes, confirming a ductile-to-semi-ductile failure mechanism.

Notably, composites containing 1–1.5% TAF provide an optimal balance, maintaining compressive strengths in the range of 7–9 MPa while achieving significantly higher deformation capacities (> 1.7%), making them promising for lightweight walling systems where cracking resistance, energy absorption and thermal compatibility are benifical. These results align with prior studies on fiber reinforced composites such as doum fibers (Fatma et al. 2019), rubber and polystyrene particles (Laoubi et al. 2018; Meddah, Laoubi, and Bederina 2020). Representative values from prior studies for comparison are summarized alongside other benchmarks in Table 6.

Flexural strength results (Figure 5) show a clear upward trend, rising from 1.7 MPa at 7 days to 3.1 MPa at 28 days (2% fiber). This increase is linked to improved matrix densification and the fiber's ability to delay crack propagation and redistribute tensile stresses. Although the flexural strength decreases with the increase of fiber contents in similar manner to compressive strength due to increased porosity and weak interfacial zones, this behavior is consistent with arguments reported in the literature for similar bio-fiber composites. Importantly, the fiber reinforcement enhanced crack resistance under flexural loading, as fiber-bridging maintained the integrity of the specimens even after failure, with the two halves remaining connected (Figure 5). The final value exceeds the typical requirements of EN 13,279–1 (2008) for non-load-bearing gypsum boards (1.5–2.0 MPa) and is consistent with comparable bio-fiber composites, such as hemp (Fontoba-Ferrándiz et al. 2020) and (Touil et al. 2022).

Figure 6 presents a representative fracture surface of the Typha-reinforced composite after testing. The image clearly shows a visible crack-bridging effect, with several fibers still anchored within the plaster matrix. The failure mechanism is mainly governed by matrix cracking accompanied by fiber slippage and partial pull-out rather than complete fiber rupture. This observation confirms the ductile-to-semi-ductile transition identified in the stress – strain curves (Figure 4), where fiber bridging delayed crack propagation and enhanced post-peak energy dissipation. The fibers act as micro-anchors that redistribute stress along the crack path, improving toughness and maintaining partial integrity even after visible cracking.

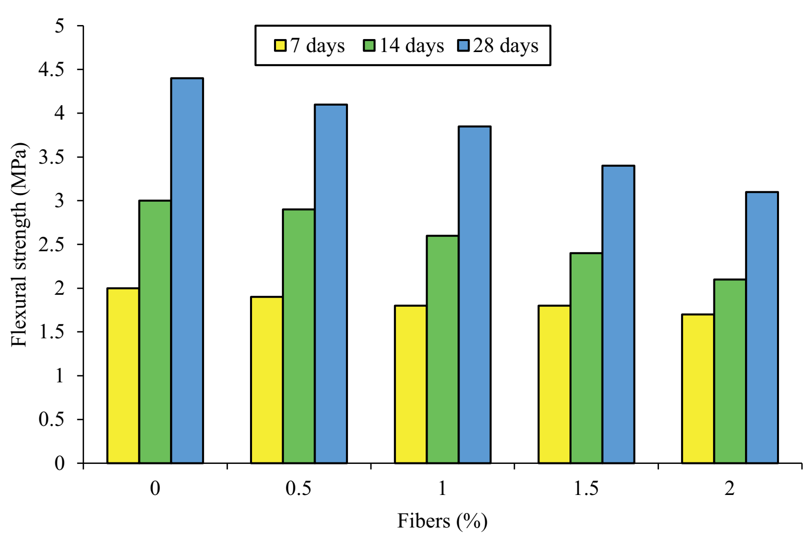


Figure 5. Flexural strength of plaster composites with varying taf content (left to right: 0% to 2% with 0.5% interval).

Figure 6. Fracture surface of Typha angustifolia fiber–reinforced plaster composite after failure.

In summary, TAF-reinforced plaster composites offer a well-balanced mechanical profile for non-load-bearing construction. While compressive strength decreases with fiber addition, ductility and flexural capacity are significantly improved. Combined with low thermal conductivity around (≈0.5 W/m·K), these materials show strong potential for use in lightweight, insulating, and bioclimatic envelopes suited to arid climates. For long-term durability, protective coatings such as hydraulic renders are recommended, in line with (CNERIB 1993) and related technical standards.

Energy efficiency analysis

Figure 7 compares the thermal performance of two wall system, TAF-reinforced plaster composite and the ordinary hollow concrete block (HCB), across four building orientations (South, North, West, and East), using two key thermal indicators: time lag and decrement factor.

The time lag, shown on the left side of the figure, represents the delay between the peak outdoor temperature and the corresponding peak inside the building. A longer time lag indicates greater thermal inertia and improved resistance to rapid temperature changes. In all orientations, TAF-reinforced walls show significantly longer time lags than ordinary HCB walls, demonstrating their superior ability to slow down heat transfer. This delay reduces indoor thermal stress during peak hours, which is especially beneficial in hot-arid climates with intense solar exposure.

The decrement factor, presented on the right side of the figure, measures the extent to which external temperature fluctuations are dampened before affecting indoor spaces. Lower decrement values indicate more effective thermal insulation. TAF walls consistently exhibit lower decrement factors than ordinary HCB walls across all orientations, confirming their superior performance in minimizing indoor temperature variations.

Together, these two indicators demonstrate the thermal advantage of TAF-reinforced plaster composites over ordinary hollow concrete blocks. The TAF system not only delays heat transfer but also reduces its intensity, contributing to better indoor comfort and reduced cooling energy demand. For example, in the South-facing orientation – which typically receives the highest solar exposure in arid climates, the time lag increased by 11%, while the decrement factor decreased by 5.6% compared to HCB walls. These enhancements, although moderate, are significant when achieved using fully bio-based, locally sourced materials, and they support the integration of TAF composites into sustainable, passive building strategies in hot and dry regions.

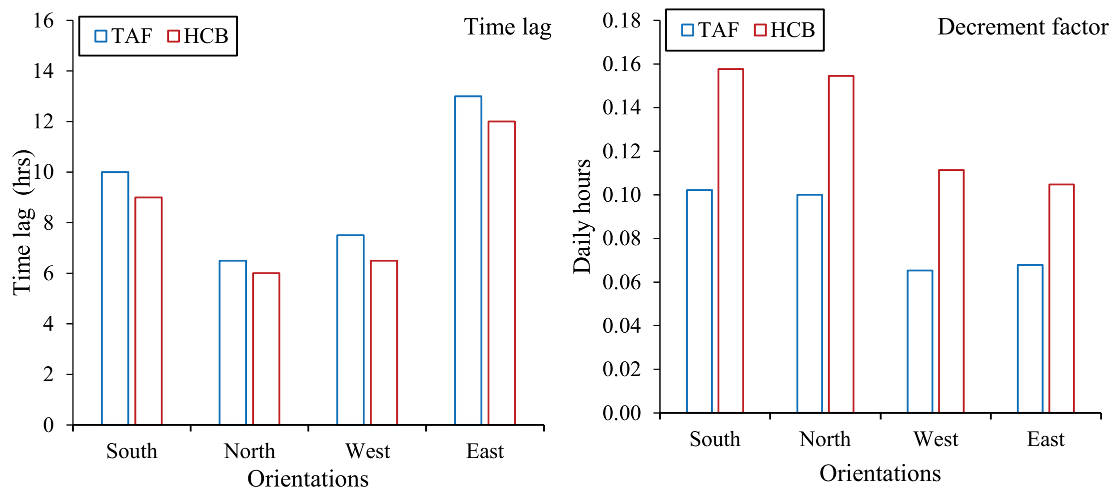


Figure 7. Thermal performance comparison between TAF-reinforced plaster and hollow concrete block (hcb) wall systems across four orientations: time lag (right) and decrement factor (left).

Energy impact estimation

A comprehensive evaluation of thermal performance indicators highlights the clear advantage of the TAF based wall system over conventional cinderblock (HCB) construction. The analysis focused on a two-story residential building with a total floor area of 161 m^2.

The analysis covers critical aspects of building envelope behavior, including partial and total heat transfer coefficients, decrement factor, daily thermal exposure, and annual energy losses – each confirming the technical superiority of TAF in hot, arid environments.

The simulation results reveal a substantial reduction in the annual energy consumption when using the TAF wall system. Specifically, total energy use decreases from 11,083 kWh/year with conventional HCB walls to 8746 kWh/year with the bio-sourced TAF. This corresponds to an annual energy saving of 2337 kWh, or a relative improvement of 21.1% in overall energy performance.

From a transmission coefficient standpoint, TAF façades exhibit a partial heat transfer coefficient (Hi) of 193.60 W/K, compared to 291.29 W/K for cinderblock walls, representing a 33.5% reduction. TAF also contributes only 25.24% to the total building transmission loss (%Htr), versus 33.69% for HCB, demonstrating a more efficient role in the envelope's overall thermal balance.

At the whole-envelope level, TAF further outperforms HCB. The total heat transfer coefficient calculated per EN ISO 13789:2017 is 767.04 W/K for TAF, significantly lower than 864.73 W/K for HCB. This confirms TAF's enhanced insulating capacity and its ability to moderate heat flow across the entire envelope.

The analysis of the annual specific heat loss through a external envelope element further confirms the superior thermal behavior of the TAF-based envelope. The annual energy flow by transmission reaches −7653.94 kWh/m^2.year for the TAF wall system, compared to −8358.28 kWh/m^2.year for the conventional cinderblock solution. This reduction in transmitted thermal energy indicates a lower heat gain into the interior space, which is especially advantageous in arid climates with prolonged cooling periods. These results highlight the capacity of TAF material to reduce overall energy demand and limit thermal loads passively, particularly in summer months.

Supporting these quantitative findings, decrement factor analysis shows that TAF walls consistently attenuate thermal fluctuations more effectively across all orientations. They provide better thermal inertia, reduce indoor heat peaks, and increase comfort stability, key characteristics for passive design in hot climates.

Finally, the TAF wall system presents a robust, technically validated alternative to traditional construction materials. Its lower thermal transmittance, better envelope-level efficiency, and quantifiable energy savings make it an ideal solution for energy-conscious building design in arid and semi-arid regions.

Conclusions

The incorporation of Typha angustifolia fibers into plaster composites has proven to be an effective strategy for developing energy-efficient, sustainable wall materials tailored for arid and semi-arid climates. Through a comprehensive evaluation of thermal, mechanical, and physical properties, this study has confirmed that TAF-reinforced plasters significantly outperform traditional plaster formulations in terms of thermal insulation capacity, environmental performance, and overall sustainability.

The most notable result was the remarkable reduction in thermal conductivity, with TAF-based composites achieving values up to 35–50% lower than conventional plaster. This translates into a substantial improvement in thermal resistance, which directly contributes to reducing indoor heat gain and minimizing reliance on artificial cooling systems, a critical benefit in energy-vulnerable, high-temperature regions. Simultaneously, the lightweight nature of the TAF-modified mixtures led to a density reduction of over 25%, easing the dead load on walls and supporting broader structural efficiency.

Mechanically, although a moderate reduction in compressive strength was observed with increasing fiber content, the values remained within acceptable limits for non-load-bearing wall applications. Importantly, the addition of Typha fibers also enhanced crack resistance and toughness, providing improved ductility and better post-crack behavior, characteristics that contribute to longer service life and improved durability of the walls under thermal cycling.

From an environmental perspective, the use of TAF, a fast-growing and locally available wetland plant, contributes to natural resource conservation and carbon footprint reduction. Its use supports waste valorization, biodiversity management, and the promotion of local green industries. The manufacturing process of TAF-based plaster is simple, low-energy, and compatible with traditional construction practices, making it particularly suitable for rural and low-income housing projects.

In summary, the results of this study demonstrate that TAF-based plasters are not only technically viable but also represent a climate-resilient, affordable, and sustainable solution for improving building performance in hot, arid regions like Algeria. Their adoption could play a pivotal role in national strategies for sustainable construction, particularly in efforts to meet energy efficiency goals and reduce greenhouse gas emissions in the building sector.

Although this study confirms the technical and environmental viability of TAF – reinforced plaster composites for exterior wall applications in arid climates, further research is required to support the scalability and practical implementation of these materials. Future work should investigate their long-term durability under real-world climatic conditions, with particular attention to resistance against humidity, ultraviolet radiation, and freeze – thaw cycles.

In addition, comprehensive life cycle assessments (LCA) and techno-economic evaluations are essential to quantify both the environmental impact and the financial viability of deploying TAF-based solutions on a larger scale. Furthermore, integrating TAF-reinforced plasters into hybrid wall assemblies, combining other bio-based materials or alternative binders such as geopolymers; could enhance the overall multifunctionality of building envelopes by improving acoustic insulation, fire resistance, and mechanical robustness.

RESEARCH HIGHLIGHTS

- Typha angustifolia fibers (TAF), a local wetland plant in Algeria, were valorized as sustainable reinforcement in plaster-based composites.
- Fiber incorporation (0–2% by weight) reduced thermal conductivity and dry density, enhancing thermal insulation and reducing wall weight.
- Despite a moderate decrease in compressive strength, the composites maintained sufficient performance for non-load-bearing interior and exterior walls.
- Thermal simulations under hot-arid climatic conditions showed improved thermal inertia and a 21.1% reduction in annual building energy demand.
- This study supports the use of bio-based materials in green construction and highlights the potential of under-utilized natural fibers for energy-efficient buildings.

Authors' contributions

HL contributed to resources, visualization and draft paper writing; AM contributed to conceptualization, methodology, writing – review and editing and supervision; LP contributed to writing – review and editing.

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Data availability statement

The data supporting the findings of this study are available upon request.

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