Assessment of Thermophysical Properties of Typha Fiber Insulation Panels for Sustainable Buildings

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Abstract. The building sector consumes more energy than any other industry, with heating and cooling alone accounting for over 50% of total use in residential and commercial settings. While conventional insulators such as EPS, XPS, glass wool, and mineral wool deliver low thermal conductivity, their petrochemical origins incur high embodied carbon and poor end-of-life options. This study evaluates Typha angustifolia fiber panels—bonded with a cellulose-dissolved polystyrene binder—as a sustainable envelope material. Composite specimens incorporating coarse (5–10 mm) and fine (≤1 mm) Typha fibers were cast and cured, then characterized for thermal conductivity, specific heat capacity, and bulk density. Coarse-fiber panels achieved the lowest conductivity (0.087 W/m·K) at 236 kg/m³, while fine-fiber panels maximized heat capacity (1168 J/kg·K) at 254 kg/m³. These trends confirm that fiber particle size strongly influences thermophysical behavior. The results demonstrate that Typha-based composites can rival conventional insulators in thermal performance while using renewable, low-carbon inputs. Future work will address bending strength, fire retardancy, and scale-up processing to validate industrial feasibility.

Keywords: Building materials, Typha angustifolia, Thermal property, Natural fibers, EPS-based binder.

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1 Introduction

Rising energy demand and its environmental impacts are driving a global push for more efficient buildings. The construction sector alone consumes nearly 40% of the world's energy and generates a comparable share of CO_2 emissions, largely due to heat losses through poorly insulated envelopes and suboptimal design. As urban populations grow and cooling/heating needs intensify, improving building thermal performance has become essential.
In Morocco's arid and semi-arid regions, summer overheating is severe, prompting widespread use of air conditioning that strains the power grid and deepens energy poverty. Locally produced construction materials typically offer limited thermal resistance and few sustainable insulation options are available [1,2]. Developing affordable, low-carbon alternatives is therefore a national priority.
Bio-based insulators—made from natural fibers or agricultural residues—combine low embodied energy, biodegradability, and competitive thermal properties. Fibers such as hemp, jute, straw, and kenaf have yielded insulation panels with conductivities of 0.035–$0.075\, W/m \cdot K$, comparable to mineral wool and EPS, while supporting circular-economy goals by valorizing local biomass [3 ,4 ,5 ,6]. Recent studies have also highlighted the potential of lesser-known wetland and grassland species for insulation applications, offering new opportunities for regional biomass valorization [7].
This work investigates Typha angustifolia (TA), common cattail, a fast-growing wetland plant abundant across Morocco, as a feedstock for insulation panels. Typha fibers were bonded with a diluted expanded-polystyrene adhesive to produce lightweight composites. We characterize their thermal conductivity, specific heat, density and microstructure, and assess their suitability for building envelopes under local climate conditions.
By demonstrating the performance of TA–EPS (TAE) panels, this study aims to expand the portfolio of sustainable, low-cost insulation materials available for Moroccan construction, reducing energy demand and promoting resource-efficient practices in line with circular-economy principles.

2 Methodology

2.1 Sample preparation

Typh$a$ $a$ngustifolia (TA) fibers were harvested in spring from Anoual wetlands, air-dried to constant weight, then milled into three grades: coarse strands ($\sim 10\, mm$), fine powder (<1 mm), and a 50:50 blend. X-ray diffraction (XRD; $Cu\, K\alpha, 2\theta\, 5-60°$) of these fibers ($Fig.$ 1, right) displayed the characteristic cellulose peaks at the (110), (002), and (004) planes, confirming their high crystalline cellulose content. TA fibers constituted 60 wt% and EPS binder 40 wt% of the total composite mass. Slurries were homogenized, cast into $80\, \times\, 20\, mm$ metal molds, and consolidated by uniaxial pressing to eliminate voids.

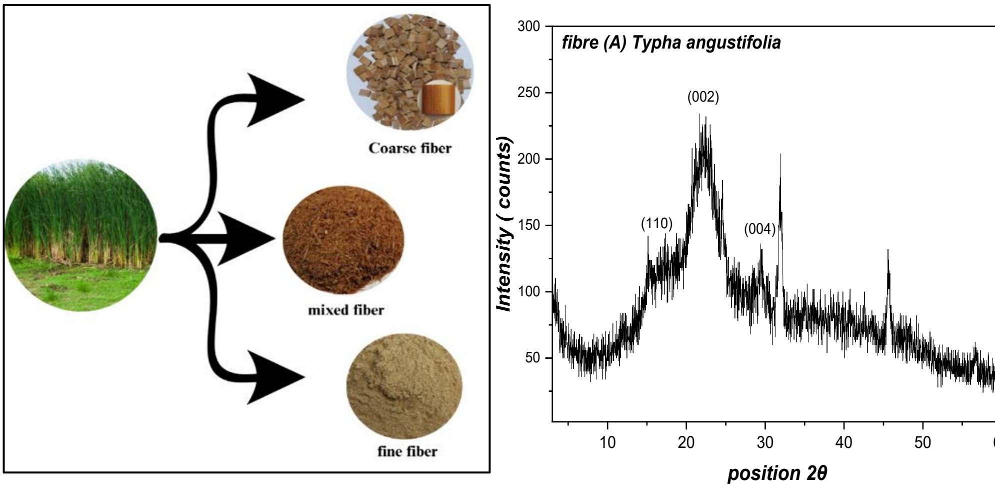

Fig. 1. (left) Processed TA fibers: coarse, mixed and fine grades, (right) XRD diffractograms of the studied TA fibers.

2.2 Hot Disk Method

Thermophysical properties—thermal conductivity (λ), diffusivity (α) and volumetric heat capacity (C_v) −were measured by the transient plane source method on a Hot Disk TPS 2200 (Fig.2) following ISO 22007-2.

- *Sensor & sample setup:* Sensor 8563 ($r = 9.808\ mm$) was sandwiched between two identical $80 \times 20\ mm$ composite disks.
- *Test conditions:* Ambient lab temperature 23 ± 2 °C, 40–60% RH. Power input 20–50 mW, measurement time 160–320 s, data logged every 0.1 s.

Fig. 2. Hot disk setup.

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Data processing: Hot Disk software $v7.3$ used the "infinite sample" model to fit the temperature vs. time curve and extract λ, α, and c_{v}. Specific heat (c_{p}) was calculated as c_{v}/ρ, using densities measured separately.

2.3 Dynamic Heat Transfer Simulation

Dynamic heat-transfer through a five-layer wall ($0.02\ m$ cement plaster, 0.20 m perforated brick, 0.02/0.04/$0.06\ m$ cavity, $0.10\ m$ brick, $0.02\ m$ plaster) was simulated in ANSYS Fluent. The cavity layer was filled with coarse-fiber TA-based insulation, selected for its low thermal conductivity, which effectively reduces heat transfer through the building envelope.

- *Geometry & mesh:* 2D section, $1\ mm$ quad elements near interfaces, up to $10\ mm$ elsewhere.
- *Material properties:* λ, c_{p}, and $\rho\ for$ TAE from experiments; brick/plaster from literature.
- *Solver settings:* Transient energy solver with buoyancy, time step $60\ s, 24\ h\ period\ after\ 48\ h\ initialization$.
- *Boundary conditions:* Exterior: convective $h_{\mathrm{ext}} = 9\ W/m^2 \cdot K$, solar radiation from local weather file; Interior: $h_{\mathrm{int}} = 4\ W/m^2 \cdot K$, no internal gains.
- *Scenarios:* $Reference$ ($2\ cm$ air cavity) vs. TAE cavities ($2, 4, 6\ cm$).
- *Output metrics:* Interior surface temperature, heat flux and U-value over one representative summer day ($July$ 10 2023; $T_{\mathrm{out}} = 24-46\ °C, T_{\mathrm{int}} = 26\ °C$).

3 Results and Discussion

3.1 Thermophysical Properties

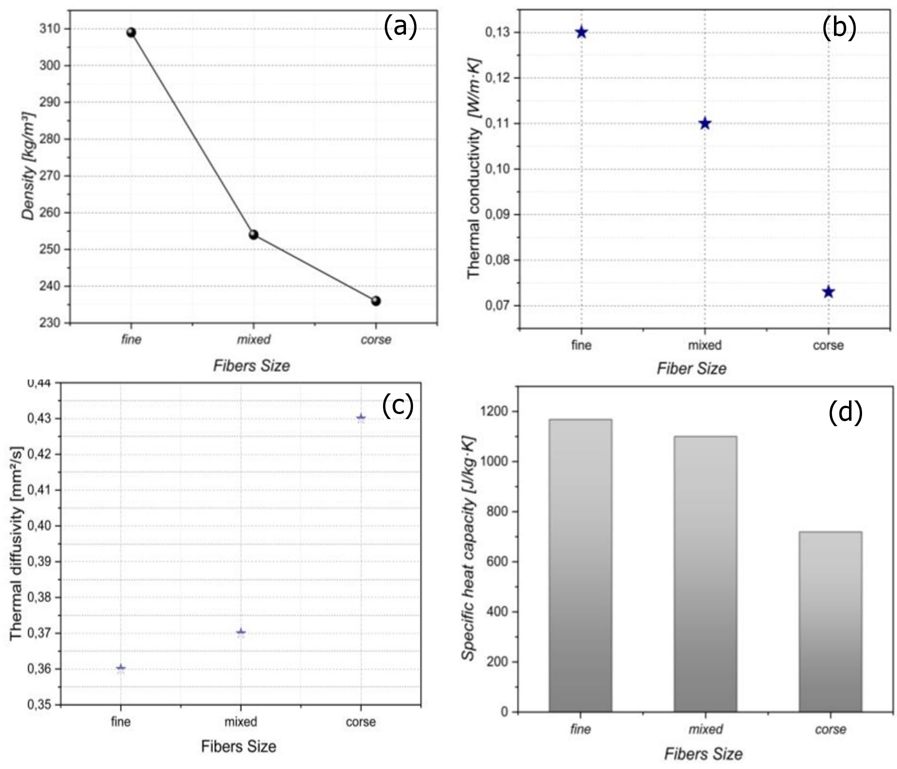

Fig. 3. (a) Density; (b) Thermal conductivity; (c) Thermal diffusivity; (d) Specific heat capacity of TA–EPS panels with coarse, mixed and fine fibers.

Figure 3 shows the influence of Typha angustifolia (TA) fiber grade on the main thermophysical properties of the composite panels. As fiber size increases from fine powder to coarse strands, bulk density decreases from approximately 310 kg/m³ to 235 kg/m³, owing to looser packing and a larger proportion of internal voids. This drop in density directly correlates with reduced solid–solid conduction and improved insulation performance: the coarse-fiber panels achieved the lowest thermal conductivity ($\sim 0.07\, W \cdot m^{-1} \cdot K^{-1}$), whereas fine-fiber panels reached higher values ($\sim 0.13\, W \cdot m^{-1} \cdot K^{-1}$), with mixed-fiber composites falling in between. The lower λ of coarse panels results primarily from increased porosity and greater air entrapment, both of which suppress heat transfer through the solid phase.

Thermal diffusivity ($\alpha = \lambda / (\rho\, c_\mathrm{p})$) exhibited a non-intuitive trend, with slightly higher values for coarse-fiber composites (~0.43 mm²/s) compared to fine ones. Although this might seem contradictory, it can be explained by the sharp reduction in volumetric heat capacity (ρ c_p) associated with the lower density and specific heat of the coarse material. With less thermal mass available to store heat, the transient temperature wave propagates faster even though the overall conductivity is lower. Hence, the apparent increase in α reflects a lower ability to absorb heat rather than improved conduction efficiency.

Specific heat capacity (c_p) indeed confirms this interpretation, decreasing from about 1150 $J \cdot kg^{-1} \cdot K^{-1}$ for fine fibers to 700 $J \cdot kg^{-1} \cdot K^{-1}$ for coarse ones. The fine-fiber composite, being denser and richer in lignocellulosic content, can store more heat, whereas the coarse material—dominated by voids and binder—responds more rapidly to temperature changes.

Overall, these results demonstrate that fiber morphology strongly governs the thermal behavior of bio-based composites. Coarse-fiber panels offer higher thermal resistance and faster response, suitable for lightweight insulation where heat storage is less critical, while fine-fiber composites provide greater thermal inertia, beneficial for moderating indoor temperature swings. The measured conductivities (0.07–0.13 $W \cdot m^{-1} \cdot K^{-1}$) are comparable to other natural insulators such as hemp, flax, and $straw$ ($0.045 - 0.090\ W \cdot m^{-1} \cdot K^{-1}$) [8,9], and though slightly higher than mineral wool or EPS ($0.035 - 0.040\ W \cdot m^{-1} \cdot K^{-1}$) [10], they remain within the range suitable for low-energy buildings. The renewable nature and local abundance of Typha in humid to semi-arid regions reinforce the environmental and economic appeal of these composites for sustainable construction.

3.2 Dynamic Thermal Simulation

$Figure$ 4 $presents$ 24 h indoor surface temperature profiles for wall assemblies with 0 cm (reference), 2 cm, 4 cm, and 6 cm of TA-based insulation under a summer peak of 46 °C outdoors. Compared to the uninsulated case, all insulated configurations exhibited lower maximum indoor temperatures (from ~28.3 °C in the reference to progressively cooler peaks) and a phase shift of approximately $2-3$ $hours$ in the thermal response. This temporal delay indicates that the insulation layer slows down heat transfer through the wall, allowing the indoor surface to reach its maximum temperature several hours after the outdoor peak, which is beneficial for occupant comfort and energy efficiency. Increasing insulation thickness amplified both amplitude damping and time lag, confirming that thicker TA panels enhance both thermal resistance and thermal inertia. This improvement can be attributed to the combined effect of the material's low thermal conductivity and its ability to store heat within its fibrous structure, which reduces the rate of heat penetration and smooths indoor temperature fluctuations. These findings underscore the effectiveness of TA-based insulation in reducing heat gains and stabilizing indoor temperatures in hot, arid climates.

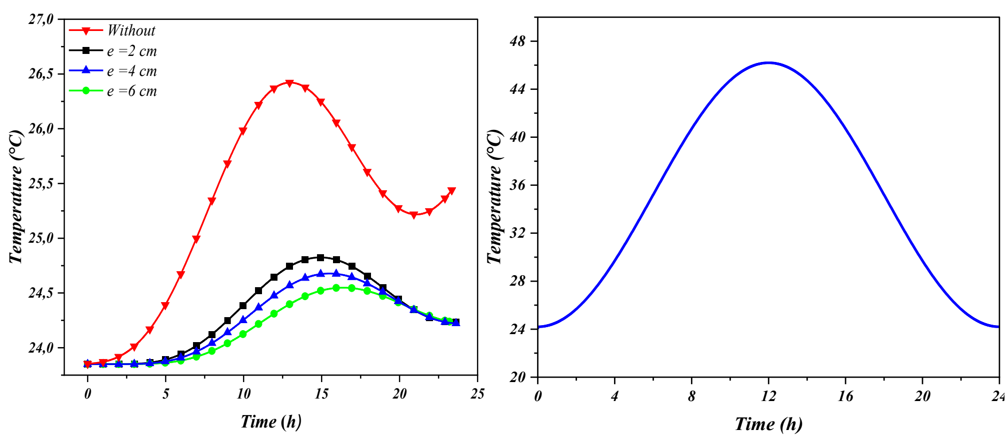

Fig. 4. Indoor surface temperature over a summer day for uninsulated and TA-insulated (2, 4, 6 cm) wall assemblies.

4 Conclusions

The morphology of Typha angustifolia fibers plays a decisive role in defining the thermophysical performance of EPS-bonded insulation panels. Coarse-fiber composites exhibited the lowest thermal conductivity ($\sim 0.07\ W \cdot m^{-1} \cdot K^{-1}$) due to their higher porosity and entrapped air, while fine-fiber panels showed greater density and specific heat capacity, enhancing heat storage but increasing conductivity. Mixed-fiber formulations provided an intermediate behavior, offering balanced insulation and thermal inertia.
These results demonstrate that by adjusting fiber size distribution, the thermal behavior of Typha–EPS panels can be effectively tuned to meet specific building requirements—favoring either high insulation efficiency or greater thermal mass. Beyond their functional performance, these bio-composites capitalize on renewable plant resources and recycled plastics, representing a low-carbon, locally sourced alternative for sustainable and energy-efficient building envelopes.

5 References

[1] A. El-yahyaoui, I. Manssouri, et H. Sahbi, « Effect of Juncus Acutus fibers waste on the technological properties of unfired clay bricks as a construction material », *Mater. Today Proc.*, juin 2023, doi: 10.1016/j.matpr.2023.06.064.
[2] S. Jiang, X. Deng, G. Liu, et F. Zhang, « Climate change-induced economic impact assessment by parameterizing spatially heterogeneous CO2 distribution », *Technol. Forecast. Soc. Change*, vol. 167, p. 120668, juin 2021, doi: 10.1016/j.techfore.2021.120668.
[3] A. Bakkour, S.-E. Ouldboukhitine, P. Biwole, et S. Amziane, « A review of multi-scale hygrothermal characteristics of plant-based building materials », *Constr. Build. Mater.*, vol. 412, p. 134850, janv. 2024, doi: 10.1016/j.conbuildmat.2023.134850.
[4] H. A. MCMANUS, J. L. SEAGO JR, et L. C. MARSH, « Epifluorescent and Histochemical Aspects of Shoot Anatomy of Typha latifolia L., Typha angustifolia L. and Typha glauca Godr. », *Ann. Bot.*, vol. 90, nº 4, p. 489-493, oct. 2002, doi: 10.1093/aob/mcf211.
[5] S. Muntongkaw, S. Pianklang, et N. Tangboriboon, « Modifications to improve properties of gypsum ceiling composites as multifunctional construction by embedding *Typha angustifolia* fiber and natural rubber latex compound », *Case Stud. Constr. Mater.*, vol. 15, p. e00658, déc. 2021, doi: 10.1016/j.cscm.2021.e00658.
[6] D. S. Bajwa, E. D. Sitz, S. G. Bajwa, et A. R. Barnick, « Evaluation of cattail (*Typha* spp.) for manufacturing composite panels », *Ind. Crops Prod.*, vol. 75, p. 195-199, nov. 2015, doi: 10.1016/j.indcrop.2015.06.029.
[7] O. Horma, D. Mohammed, B. Laaouar, S. el Hassani, A. El Hammouti, et A. Mezrhab, « Evaluating the Influence of Alfa Fiber Morphology on the Thermo-Mechanical Performance of Plaster-Based Composites and Exploring the Cost–Environmental Effects of Fiber Content », *Buildings*, vol. 15, p. 1187, avr. 2025, doi: 10.3390/buildings15071187.
[8] B. Laaouar, O. Horma, A. El Hammouti, S. El Hassani, M. A. Moussaoui, et A. Mezrhab, « Evaluating Moroccan Soils for Sustainable Building Applications: An Experimental and Computational Analyses », in *Digital Technology for an Innovative Energy Transition*, F. Latrache, F. Z. Ouariach, S. Ouariach, et N. Jbira, Éd., in Green Energy and Technology. , Cham: Springer Nature Switzerland, 2025, p. 215-225. doi: 10.1007/978-3-031-89657-6_11.

[9] M. El Messiry, S. Y. El-Tarfawy, Y. Ayman, et R. El Deeb, « Development of high-performance thermal insulation panels from flax fiber waste for building insulation », *J. Ind. Text.*, vol. 55, p. 15280837251338160, août 2025, doi: 10.1177/15280837251338160.
[10] L. D. Hung Anh et Z. Pásztory, « An overview of factors influencing thermal conductivity of building insulation materials », *J. Build. Eng.*, vol. 44, p. 102604, déc. 2021, doi: 10.1016/j.jobe.2021.102604.