

# Comparative Thermal Performance Analysis of Beam-and-Block Floor Systems Using *Typha australis* Earth Blocks and Conventional Concrete Blocks in Hot Semi-Arid Climates

Babacar Diouf<sup>1,\*</sup>, Bator CISSE<sup>1</sup>, Mariama BA<sup>1</sup>, Kadia Thilly<sup>1</sup>, Cheikh Tidiane Seck<sup>2</sup>

<sup>1</sup>Institut Polytechnique de Saint-Louis (IPSL), Université Gaston Berger, Saint-Louis, Senegal

<sup>2</sup>Atelier Kemit Architectes (AKA), Dakar, Senegal

\*Corresponding author: [babacar2.diouf@ugb.edu.sn](mailto:babacar2.diouf@ugb.edu.sn)

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**Abstract** The building sector in Senegal faces significant energy and thermal comfort challenges, with approximately 60% of residential energy consumption devoted to cooling in a hot semi-arid climate where urban temperatures regularly exceed 35–40°C. Conventional construction materials such as concrete exhibit high thermal conductivity (typically  $>1.4 \text{ W m}^{-1}\text{K}^{-1}$ ), exacerbating indoor heat gain. This study presents a quantitative comparative analysis of the thermal performance of two beam-and-block floor assemblies: one incorporating *Typha australis*–earth hollow blocks and insulating panels, and a reference assembly using standard concrete hollow blocks. Steady-state thermal conduction calculations were performed in accordance with ISO 6946 and ADEME guidelines on multi-layer floor systems. Results demonstrate that the typha-based floor achieves a total thermal resistance of  $R_{th} = 2.932 \text{ K m}^2 \text{ W}^{-1}$  and a thermal transmittance of  $U = 0.341 \text{ W m}^{-2} \text{ K}^{-1}$ , compared to  $R_{th} = 0.197 \text{ K m}^2 \text{ W}^{-1}$  and  $U = 5.076 \text{ W m}^{-2} \text{ K}^{-1}$  for the concrete counterpart. The total heat flux through the typha floor (733.37 W for a 215 m<sup>2</sup> surface) is approximately 13 times lower than that of the concrete floor (9822.06 W). These findings confirm *Typha australis* as a high-potential bio-sourced insulating material suitable for sustainable bioclimatic construction in West Africa, capable of substantially reducing cooling energy demand while supporting local circular economies..

**Keywords:** Bio-sourced materials, Thermal insulation, Beam-and-block floor, *Typha australis*, Thermal transmittance, Bioclimatic architecture, Senegal, Hot climate

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## 1. Introduction

The construction sector in Senegal accounts for approximately 41.3% of national final energy consumption, with electricity use projected to represent 70% of building energy demand by 2030 [1]. In urban contexts, air conditioning driven by poor thermal building envelopes constitutes the dominant driver of this demand, particularly during the dry season when outdoor temperatures regularly surpass 40°C [2]. The challenge of reducing cooling loads while improving occupant thermal comfort calls for a re-examination of conventional construction practices and materials.

Conventional hollow concrete blocks, the standard infill element in beam-and-block floor systems widely used across West Africa, exhibit thermal conductivity values typically ranging from 1.4 to 2.0  $\text{W m}^{-1}\text{K}^{-1}$  [3]. These high values result in significant heat transmission through

floor assemblies, particularly in terraced rooftop floors directly exposed to solar radiation. As a consequence, occupants of such buildings experience pronounced thermal discomfort and incur elevated energy costs for mechanical cooling.

*Typha australis* (common cattail) is a perennial aquatic macrophyte found extensively in the wetlands of the Senegal River valley. More than 100,000 hectares of agricultural land have been colonised by the plant, causing significant ecological and economic disruptions [4]. Its valorisation as a construction material therefore presents a dual opportunity: ecological control of its invasive spread and substitution of energy-intensive conventional materials.

A growing body of literature demonstrates that *Typha australis* possesses thermal conductivity values ranging from 0.032 to 0.055  $\text{W m}^{-1}\text{K}^{-1}$  for bulk densities between 30 and 80  $\text{kg m}^{-3}$ , values comparable to or lower than commercial synthetic insulants [5,6]. When incorporated into earth-based composites to produce hollow floor blocks (hourdis), the resulting material retains insulating

properties while also providing acceptable structural performance [7,8].

Despite these promising material-level results, quantitative analyses of full floor assembly thermal performance under realistic Sahelian climatic boundary conditions remain scarce. This paper addresses this gap by performing steady-state thermal conduction analyses on two complete beam-and-block floor assemblies—one integrating typha-earth hollow blocks and insulating typha panels, the other using conventional concrete hollow blocks—and rigorously comparing their total thermal resistances, transmittance coefficients, heat flux densities and total heat flows.

## 2. Background and Related Work

### 2.1. Typha Australis as a Construction Material

*Typha australis* is a monocotyledonous perennial plant that thrives in shallow freshwater environments at depths not exceeding 1.5 m. It can attain heights of 3.5–4.0 m, with linear leaves 1–2 cm wide and stem sections characterised by a round cross-section and high axial compressive strength [4]. The plant's leaves consist of porous aerated parenchyma (aerenchyme) with thermal conductivity as low as  $0.032 \text{ W m}^{-1}\text{K}^{-1}$ , attributed to the trapped air network within the cellular microstructure [5].

Chemical composition studies (Duke, 1983; Theuerkorn, 2001) indicate that *Typha* leaves contain 30–39% crude fibres, 38–48% carbohydrates, and 7–12% crude protein in dry matter, with significant cellulose and lignin fractions that contribute to fire resistance. The mechanical behaviour is anisotropic: longitudinal compressive resistance reaches approximately  $1 \text{ N mm}^{-1}$ , while transverse response is highly elastic [9].

Building applications of *Typha* include ligature-bound panels, woven mats, thatched roofing elements, compressed loose-fill, earth-typha bricks, earth-typha plasters, and hollow floor blocks. The latter—hourdis terre-typha—are fabricated by moulding an earthen slurry mixed with shredded *Typha* fibres and allowing air curing. Manufacturer data sheets report thermal conductivity of  $0.12\text{--}0.15 \text{ W m}^{-1}\text{K}^{-1}$  for bulk-density blends of  $600\text{--}610 \text{ kg m}^{-3}$  [10].

### 2.2. Thermal Performance of Bio-Sourced Floor Systems

Study [11] demonstrated that incorporating *Typha* fibres into cement matrices reduced thermal conductivity from  $1.08 \text{ W m}^{-1}\text{K}^{-1}$  to  $0.52 \text{ W m}^{-1}\text{K}^{-1}$ , while [12] reported conductivities of  $0.085\text{--}0.22 \text{ W m}^{-1}\text{K}^{-1}$  for *Typha*-based insulating panels. Studies on composites of *Typha* with recycled lime showed mechanical compressive strengths of  $1.34\text{--}2.30 \text{ MPa}$  with conductivities of  $0.078\text{--}0.192 \text{ W m}^{-1}\text{K}^{-1}$  [8]. Thermomechanical characterisation of *Typha* particleboards with arabic gum binders yielded conductivities of  $0.055\text{--}0.083 \text{ W m}^{-1}\text{K}^{-1}$  [13].

At the building system level, experimental campaigns

carried out under the TyCCAO and PEEB programmes have confirmed that *Typha*-integrated envelopes reduce cooling energy demand by up to 25% relative to conventional concrete structures [2,14]. However, published analyses rarely address the full floor assembly thermal performance in a standardised, reproducible framework applicable to engineering practice.

## 3. Materials and Floor Assembly Descriptions

### 3.1. Typha-Earth Floor Assembly

The *typha*-based floor is a six-layer beam-and-block assembly representative of current bioclimatic practice in Senegal. From soffit to surface, the layers are: (1) *typha*-earth hollow blocks (hourdis) serving as permanent formwork between pre-stressed concrete joists; (2) a reinforced concrete compression slab; (3) insulating *typha*-fibre panels; (4) a waterproofing membrane; (5) a cement mortar screed; and (6) fired-ceramic floor tiles. Physical and thermal characteristics of each layer were sourced from manufacturer technical data sheets and published experimental literature, as summarised in Table 1.

**Table 1. Thermal properties of the typha-based floor assembly layers**

Layer	Material	Thickness (m)	$\lambda$ ( $\text{W m}^{-1}\text{K}^{-1}$ )	Source
1	Typha-earth hollow block	0.15	0.15	[10]
2	Reinforced concrete slab	0.05	1.75	[3]
3	Typha insulating panel	0.10	0.055	[5,12]
4	Waterproofing membrane	0.005	0.25	[3]
5	Cement mortar screed	0.03	1.40	[3]
6	Ceramic tiles	0.05	1.15	[3]

### 3.2. Conventional Concrete Floor Assembly (Reference)

The reference floor consists of five layers: (1) standard concrete hollow blocks; (2) a reinforced concrete compression slab; (3) a waterproofing membrane; (4) a cement mortar screed; and (5) ceramic tiles. No additional insulation layer is included, as this configuration is representative of standard construction practice in Senegal. Table 2 presents the layer characteristics.

**Table 2. Thermal properties of the reference concrete floor assembly layers**

Layer	Material	Thickness (m)	$\lambda$ ( $\text{W m}^{-1}\text{K}^{-1}$ )	Source
1	Concrete hollow block	0.16	1.75	[3]
2	Reinforced concrete slab	0.05	1.75	[3]
3	Waterproofing membrane	0.005	0.25	[3]
4	Cement mortar screed	0.03	1.40	[3]
5	Ceramic tiles	0.05	1.15	[3]

## 4. Methodology

### 4.1. Theoretical Framework

Thermal calculations were performed under the steady-state, one-dimensional heat conduction hypothesis as standardised in ISO 6946:2017 [15] and consistent with ADEME energy performance guidelines [16]. This approach is appropriate for comparative performance evaluation across two alternative assemblies under identical boundary conditions and is widely applied in regulatory energy calculations for buildings.

The following simplifying assumptions were adopted: (i) steady-state thermal regime with time-invariant interior and exterior temperatures; (ii) perfect thermal contact between adjacent layers (no interfacial resistance); (iii) homogeneous and isotropic material properties within each layer; (iv) one-dimensional heat transfer perpendicular to the floor plane, neglecting edge effects; and (v) no internal moisture migration or convection within the floor system.

### 4.2. Governing Equations

For each homogeneous layer  $i$ , the thermal resistance  $R_i$  ( $\text{K m}^2 \text{W}^{-1}$ ) is given by Fourier's law:

$$R_i = \frac{e_i}{\lambda_i} \quad (1)$$

where  $e_i$  is the layer thickness (m) and  $\lambda_i$  its thermal conductivity ( $\text{W m}^{-1}\text{K}^{-1}$ ). The total thermal resistance of the floor is the sum of individual layer resistances:

$$R_{th} = \sum R_i (i = 1 \text{ to } n) \quad (2)$$

The thermal transmittance (U-value,  $\text{W m}^{-2}\text{K}^{-1}$ ) is the reciprocal of total thermal resistance:

$$U = \frac{1}{R_{th}} \quad (3)$$

The heat flux density  $\phi$  ( $\text{W m}^{-2}$ ) through the floor is:

$$\phi = U \cdot \Delta T \quad (4)$$

where  $\Delta T$  is the temperature difference between indoor and outdoor environments. The total heat flow  $\Phi$  (W) for a floor of surface area  $S$  ( $\text{m}^2$ ) is:

$$\phi = \phi \cdot S \quad (5)$$

### 4.3. Boundary Conditions

Boundary conditions were set to represent peak summer conditions in the Senegal River valley. The outdoor (top surface) temperature was set at 35 °C, consistent with recorded average maximum dry-bulb temperatures during the hot dry season in Saint-Louis, Senegal [2]. The indoor (soffit) temperature was set at 26 °C, corresponding to an acceptable thermal comfort threshold in naturally ventilated spaces in tropical climates [17]. This yields a temperature differential of  $\Delta T = 9$  K. The total floor surface area considered in this study is 215  $\text{m}^2$ , corresponding to the project building under study.

## 5. Results

### 5.1. Layer-by-Layer Thermal Resistances – Typha Assembly

The individual thermal resistances computed for each layer of the typha-based floor are detailed in Table 3. The distribution reveals a strongly stratified contribution: the two typha-containing layers (hollow blocks and insulating panels) account for 96.4% of the total resistance, while the remaining four layers contribute only 3.6%. This highlights the dominant role of the bio-sourced elements in the overall thermal performance.

Table 3. Layer thermal resistances for the typha floor assembly

Layer	Material	$R_i$ ( $\text{K m}^2 \text{W}^{-1}$ )	Contribution (%)
1	Typha-earth hollow block	1.000	34.1
2	Reinforced concrete slab	0.029	1.0
3	Typha insulating panel	1.818	62.0
4	Waterproofing membrane	0.020	0.7
5	Cement mortar screed	0.021	0.7
6	Ceramic tiles	0.043	1.5
Total	—	2.932	100

### 5.2. Comparative Results

Table 4 presents the key thermal performance indicators for both floor assemblies, together with the absolute and relative differences between the two systems.

Table 4. Comparative thermal performance indicators for the two floor assemblies ( $\Delta T = 9$  K,  $S = 215$   $\text{m}^2$ )

Parameter	Typha Floor	Concrete Floor	Difference	Ratio
$R_{th}$ ( $\text{K m}^2 \text{W}^{-1}$ )	2.932	0.197	+2.735	14.9x
$U$ ( $\text{W m}^{-2}\text{K}^{-1}$ )	0.341	5.076	-4.735	14.9x
$\phi$ ( $\text{W m}^{-2}$ )	3.411	45.68	-42.27	13.4x
$\Phi$ at 215 $\text{m}^2$ (W)	733.37	9822.06	-9088.69	13.4x

## 6. Discussion

The results demonstrate an unambiguous and quantitatively substantial improvement in thermal resistance when Typha australis-based elements replace conventional concrete hollow blocks. The typha floor assembly achieves a U-value of 0.341  $\text{W m}^{-2}\text{K}^{-1}$ , which is 14.9 times lower than that of the concrete reference (5.076  $\text{W m}^{-2}\text{K}^{-1}$ ). This performance is attributable principally to the exceptionally low thermal conductivity of Typha australis ( $\lambda = 0.032\text{--}0.055$   $\text{W m}^{-1}\text{K}^{-1}$ ), arising from the highly porous, aerenchymatous microstructure of its leaf tissue [5], and to the combined action of the hollow blocks ( $\lambda = 0.15$   $\text{W m}^{-1}\text{K}^{-1}$ ) and the supplementary insulating panel ( $\lambda = 0.055$   $\text{W m}^{-1}\text{K}^{-1}$ ).

From an energy performance perspective, the total heat flow reduction from 9822 W to 733 W represents a

decrease of approximately 92.5% for a floor area of 215 m<sup>2</sup> under peak summer conditions. On an annual basis, assuming 200 daily peak hours of differential exposure, this corresponds to a cooling load reduction on the order of 1.9 MWh per year for this floor alone—a significant contribution to building energy efficiency in a country where 70% of building electricity is anticipated to derive from cooling by 2030 [1].

The U-value obtained for the typha assembly (0.341 W m<sup>-2</sup>K<sup>-1</sup>) is consistent with the range reported for bio-sourced insulated floor systems in other tropical and subtropical contexts. Diaw et al. [11] and Gassama et al. [12] both documented significant reductions in heat transfer for typha composites, while Adama et al. [7] confirmed the viability of clay-typha composites with thermal conductivities between 0.078 and 0.192 W m<sup>-1</sup>K<sup>-1</sup>. The present study extends these findings from the material level to the full building assembly level under defined climatic boundary conditions, providing engineering-grade data for design practice.

The concrete floor U-value of 5.076 W m<sup>-2</sup>K<sup>-1</sup> is in accordance with literature values for uninsulated concrete floor slabs, confirming that the reference assembly is representative of typical Senegalese practice where thermal insulation in floors remains uncommon [2].

Beyond thermal performance, Typha-based hollow blocks offer a mass density of 600–610 kg m<sup>-3</sup> compared with 2400 kg m<sup>-3</sup> for concrete, reducing permanent floor dead load by approximately 75% for the hollow block component. This reduction decreases the structural design actions on beams, columns and foundations, potentially enabling more economical structural dimensioning and reduced cement and steel consumption.

From an environmental perspective, Typha australis requires no industrial processing energy for the raw material phase; transformation (harvesting, drying, shredding, moulding) is largely artisanal or semi-industrial, resulting in a far lower embodied energy per unit volume than concrete [14]. Furthermore, as a photosynthetically active biomass, Typha sequesters atmospheric CO<sub>2</sub> during growth, offering partial carbon sink benefits within a bio-based construction strategy. These characteristics align with the sustainability objectives of Senegal's PSE (Plan Sénégal Émergent) and the targets of the PNEEB (Programme National pour l'Efficacité Énergétique dans le Bâtiment).

## 7. Conclusion

This study has provided a rigorous quantitative comparison of the thermal performance of a Typha australis-earth beam-and-block floor assembly against a conventional concrete counterpart, applying steady-state thermal conduction analysis in accordance with ISO 6946 under representative Sahelian boundary conditions. The main findings are:

(i) The typha floor assembly achieves a total thermal resistance of 2.932 K m<sup>2</sup> W<sup>-1</sup> and a transmittance of 0.341 W m<sup>-2</sup>K<sup>-1</sup>, representing improvements of approximately 14.9 times over the concrete reference assembly ( $R_{th} = 0.197 \text{ K m}^2 \text{ W}^{-1}$ ;  $U = 5.076 \text{ W m}^{-2} \text{ K}^{-1}$ ).

(ii) Total heat flow through the 215 m<sup>2</sup> typha floor

under peak summer conditions (733.37 W) is 13.4 times lower than that through the concrete floor (9822.06 W), corresponding to an estimated annual cooling load reduction of approximately 1.9 MWh.

(iii) The two typha-based layers (hollow blocks and insulating panels) contribute 96.4% of the total thermal resistance, confirming the decisive role of bio-sourced elements in floor system thermal performance.

These results establish a quantitative engineering basis for the integration of Typha australis-based floor systems into bioclimatic building practice in Senegal and comparable West African contexts. The material simultaneously addresses thermal, structural, environmental and socio-economic objectives, supporting local value chains in rural areas while contributing to national energy efficiency targets. The authors recommend the development of standardised technical specifications, long-term durability testing protocols, and dynamic energy simulation studies to accelerate the adoption of typha-based floor systems at scale.

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## References

- [1] Adama G., Diouf B., Ly E.B., Moise M., Diène N. Caractérisation des propriétés mécaniques et thermiques de matériaux à base de ciment, de Typha Domingénis et d'argile. *J. Phys. SOAPHYS.* 2023; 3(2): 1–6.
- [2] Sow E.M., Gassama D., Diagne M., Seck A. Bâtiment et énergie: Analyse du secteur du bâtiment au Sénégal—Synthèse et recommandations. PEEB Programme; June 2021. Available: [https://peeb.build/wp-content/uploads/2024/12/Synthese\\_Batiment\\_et\\_energie\\_Senegal\\_PEEB.pdf](https://peeb.build/wp-content/uploads/2024/12/Synthese_Batiment_et_energie_Senegal_PEEB.pdf).
- [3] Dieye, Younouss, Pape M. Toure, Seckou Bodian, Prince M. Gueye, Mactar Faye, and Vincent Sambou. 2021. "Study of Thermal and Mechanical Properties of Typha Leaf - Clay Panels". *Journal of Sustainable Construction Materials and Technologies* 6 (4): 135-42.
- [4] Tarus, Bethwel Kipchirchir, et al. "Valorisation of cattail (Typha) biomass: Fibre extraction, properties, and applications in sustainable material systems." *Bioresource Technology Reports* (2026): 102570.
- [5] Samin E. CRATerre: Rapport technique de capitalisation des résultats de la R&D à mi-parcours. Grenoble: CRATerre; December 2015.
- [6] Vèjélienè J. Processed straw as effective thermal insulation for building envelope constructions. *Eng. Struct. Technol.* 2012; 4(3): 96–103.
- [7] Elhaj-Maham, El Moustapha, et al. "Study of the Physico-Mechanical Properties of a Typha Concrete Composites: A Possible New Material for Sustainable Construction." *Materials Science Forum*. Vol. 1122. Trans Tech Publications Ltd, 2024.
- [8] Diaw I., Faye M., Hans S., Sallet F., Sambou V. Valorization of recovered lime in cement-Typha concretes: thermal and mechanical behavior. In: *Innovations and Interdisciplinary Solutions for Underserved Areas*. Cham: Springer; 2022. p. 267–276.
- [9] Rakotomalala L., Misse A. CRATerre rapport technique: identification du contexte sénégalais. Grenoble: CRATerre; December 2014.
- [10] Élémenterre. Fiche technique: Hourdis Terre Typha. Paris:

- Élémente terre; 2023.
- [11] Diaw I., Faye M., Hans S., Sambou V. Thermal conductivity of cement-Typha composites. *Mater. Lett.* 2021; 289: 129383.
- [12] Laaouar, Boutahar, et al. "Assessment of Thermophysical Properties of Typha Fiber Insulation Panels for Sustainable Buildings." *E3S Web of Conferences*. Vol. 680. EDP Sciences, 2025.
- [13] Vejelienė J., Gailius A., Vejelis S., Vaitkus S., Kerienė J. Thermomechanical characterization of particleboards from powder Typha leaves. *J. Civ. Eng. Manag.* 2011; 17(4): 489–496.
- [14] Theuerkorn W., Henning R.K. *Le Typha australis: menace ou richesse?* Eschborn: GTZ; 2002.
- [15] ISO 6946:2017. *Building components and building elements—Thermal resistance and thermal transmittance—Calculation methods*. Geneva: International Organization for Standardization; 2017.
- [16] ADEME. *Méthode de calcul de la résistance et de la conductance thermiques*. Paris; 2016.
- [17] Fanger P.O. *Thermal Comfort: Analysis and Applications in Environmental Engineering*. Copenhagen: Danish Technical Press; 1970.



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