

Evaluation of Thermal Insulation Performance of Sawdust-Based Composites for Indoor Thermal Comfort

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Keywords:

Sawdust-composite,
Thermal insulation,
Indoor Environment.

ABSTRACT

The demand for indoor thermal comfort is growing by the day due to the impacts of global warming and increasing frequency of heatwaves. This study investigated thermal insulation performance of sawdust-based composites for indoor thermal comfort, with a focus on identifying sustainable insulating materials. Samples of plaster of Paris (POP), laterite, and cement powder were collected and mixed together to form composite powder using sawdust as the primary constituent of the four composites – sawdust-POP, sawdust-cement, sawdust-laterite and sawdust-POP-cement-laterite. The specific heat capacity of each composite powder was determined using the method of mixture, while Lee's disc apparatus was used to determine their thermal conductivity. Results revealed that the sawdust-cement composite recorded the highest specific heat capacity ($5538 \text{ J Kg}^{-1} \text{ K}^{-1}$), followed by sawdust-POP ($3636 \text{ J Kg}^{-1} \text{ K}^{-1}$), sawdust-laterite ($2002 \text{ J Kg}^{-1} \text{ K}^{-1}$), while the sawdust-POP-cement-laterite composite had the lowest value ($1819 \text{ J Kg}^{-1} \text{ K}^{-1}$). For thermal conductivity, the sawdust-POP-cement-laterite composite showed the lowest conductivity value ($0.10 \text{ W/m}\cdot\text{K}$), followed by sawdust-cement composite ($0.17 \text{ W/m}\cdot\text{K}$), sawdust-POP composite ($0.18 \text{ W/m}\cdot\text{K}$), and sawdust-laterite composite ($0.19 \text{ W/m}\cdot\text{K}$). The values of thermal conductivity of these composites are all below the $0.25 \text{ W/m}\cdot\text{K}$ -threshold, indicating their suitability for thermal insulation applications.

Submitted: 01 Sept. 2026

Accepted: 15 Sept. 2026

Published: 27 Oct. 2026

INTRODUCTION

There is a growing demand for thermal comfort, particularly in indoor environments. However, meeting this demand comes with significant environment problems, as increased reliance on fossil fuels for electricity generation is required to power cooling systems such as air conditioners. This demand for thermal comfort is further exacerbated by global warming and the increasing frequency of heatwaves. As a result, heat related illnesses such as heat exhaustion, heatstroke, and cardiovascular complications have become increasingly prevalent. One effective mitigation strategy is the adoption of building materials with very low thermal conductivity to enhance indoor thermal comfort and energy efficiency. Peter (2025) posited that the need for mechanical cooling systems can be reduced by designing buildings with climate responsiveness in mind to provide acceptable thermal conditions for occupants. The World Health Organization (2025) calls climate change one of the biggest threats to global health

in the 21st century that, societies and ecosystems will experience more severe risks without action to limit global warming. This difference in thermal conductivity between metals and non-metals is a fundamental concept in thermal physics and plays a crucial role in material selection for thermal management systems in both engineering and everyday life. This variation in thermal conductivity of materials, including roofing materials is dependent mainly on the type of solid (Berardi & Naldi, 2017). Composite performance depends on the intrinsic properties of its constituents, dispersion, orientation, and matrix-reinforcement adhesion (Pothan et al., 2003; May-Pat et al., 2013; Idris et al., 2013; Rohmat et al., 2021, Tabie, 2025; Idu & Usman, 2025). Rosanna et al. (2018) studied the thermal conductivity of roofing tiles made from recycled materials and other roofing materials, the result showed that the thermal conductivity k of roofing tile made from recycled materials ($0.33 \text{ W/m}\cdot\text{K}$) is much lower than the other constituent elements--zinc sheet ($56.00 \text{ W/m}\cdot\text{K}$), concrete roofing

tile (1.20 W/m. K), and ceramic roofing tile (0.65 W/m. K), respectively. The impact of local materials on the improvement of thermal comfort in building as investigated by Oumarou et al. (2020) showed that the use of local materials in the building design is an option for reducing the heat transfer into the room and the energy consumption. Kuczyński et al. (2025) reported that the high thermal inertia of building materials is an effective solution for reducing excess heat.

Lapisa (2020) study on "thermal effects of roofing materials on indoor temperature and thermal comfort revealed that zinc roofing is less effective than bamboo in reducing solar heat gain. Experimental investigation of the impact of wood sawdust incorporation on the physical and thermal properties of fired clay bricks by Benjeddou (2025) showed that the specific heat capacity of fired clay bricks increases with the addition of wood sawdust while its thermal conductivity significantly decreases. The changes in these thermal properties are partly due to the trapped air within the pores, which serve as a natural thermal barrier that enhance thermal insulation (Benjeddou, 2025). Sawdust has been described as a material of choice due to its cost effectiveness, and biodegradability (Sikhosana et al., 2025). Adeleke et al. (2022) demonstrated that incorporating sawdust into cementitious and polymeric matrices not only improves insulation efficiency but also contributes to reducing the overall carbon footprint of building materials by vaporizing agricultural waste. Robert (2023) posited that composites with sawdust and waste papers have superior thermal insulation compared to conventional materials. Joshua (2009) investigated the thermal conductivity of clay composite with sawdust as additive, the thermal conductivity of clay dropped from 0.250 W/m. K to 0.060 (W/m. K) when mixed with sawdust. According to the data compiled by The Engineering Toolbox (2003a), a broad comparison of the thermal conductivity of natural insulating materials such as wood (including oak), wool, sawdust, and cork confirmed that these materials have relatively low thermal conductivity values compared to many synthetic construction materials. Robert and Ekpote (2022) investigated the specific heat capacity and thermal conductivity of sawdust by methods of mixture and Lee's disc, the results obtained were 549271 JKg⁻¹.K⁻¹ and 0.12 W·m⁻¹.K⁻¹ for specific heat capacity and thermal conductivity, respectively. These results confirm that sawdust with thermal conductivity below 0.25 W·m⁻¹.K⁻¹, qualifies as a low thermal conductivity material, a desirable trait for thermal insulation. Ahmed et al. (2020) explored the thermal performance and physical characteristics of a sawdust-clay composite material aimed at improving building insulation in hot climates, and concluded that such composites, with optimized sawdust content, are promising materials for sustainable and thermally efficient buildings in tropical and arid environments.

Armstrong et al. (2023) investigated the thermal performance of Plaster of Paris (POP) ceilings reinforced with untreated oil palm mesocarp fiber (UOPMF) and treated oil palm mesocarp fiber (TOPMF), aiming to address the environmental challenge associated with the disposal of mesocarp fiber waste. The results showed that specific heat capacities ranged from 1.498×10^3 to 1.825×10^3 J·kg⁻¹.K⁻¹, while thermal diffusivity values ranged from 8.477×10^{-8} to 5.705×10^{-8} m².s⁻¹. UOPMF samples exhibited superior thermal insulation potential compared to TOPMF, with thermal conductivity values decreasing from 0.2245 to 0.1465 W·m⁻¹.K⁻¹.

Hence, this study was carried out to ascertain how sawdust additive influences the specific heat capacity and thermal conductivity of some selected conventional building materials-POP, cement, laterite-with a view to improving indoor thermal comfort.

MATERIALS AND METHODS

Samples of sawdust, laterite, plaster of Paris (POP), and cement were obtained and prepared for investigation of their composite thermal properties. The sawdust was sourced from a local sawmill in Port-Harcourt, Rivers State, Nigeria. The sawdust and laterite were taken to the laboratory where it was dried in an oven at a controlled temperature to eliminate moisture. After drying, the sawdust was allowed to cool and subsequently crushed into fine powder using a manual hand grinding machine to ensure uniform particle size. Plaster of Paris (POP) and cement were purchased from a trusted and certified construction materials supplier in Port-Harcourt. These materials, which are commercially available in powdered form, were used without additional grinding. However, both were further dried in an oven and were weighed precisely using a digital weighing balance and stored separately in air tight containers to maintain their chemical integrity and to avoid moisture absorption.

Composition of Composite: Sawdust and POP composite were mixed in a ratio of 3:2, corresponding to 60% sawdust and 40% POP. The sawdust-cement composite was prepared using a 4:1 ratio (80% sawdust and 20% cement), and the sawdust-laterite composite followed the same 4:1 (80% sawdust and 20% laterite), respectively. For sawdust-POP-cement-laterite composite, 5a total mass of 50.56 g (each sample having a mass of 12.64g) was used. The mixing ratios were adjusted to maintain a uniform thickness of 0.01m across the selected material combinations.

Determination of Specific Heat Capacity (c) of the Selected Composites

The method of mixture was employed for the determination of the specific heat capacities of the samples. The values of *c* for sawdust-POP composite, sawdust-cement composite, sawdust-lateritic composite,

and sawdust-POP-cement-laterite composite were calculated using equation (1). That is the principle of heat lost by a hot material is equal to heat gained by a cold material.

$$\begin{aligned}\text{Heat gained by sample} &= M_{sp} C_s \{(T_3 + q) - T_1\} \\ \text{Heat gained by calorimeter} &= M_c C_c \{(T_3 + q) - T_1\} \\ \text{Heat lost by hot water} &= M_h C_w \{(T_2 - (T_3 + q))\} \\ \text{Heat gained by water} &= M_o C_w \{(T_3 + q) - T_1\}\end{aligned}$$

$$C_{sp} = \quad (1)$$

Where,

$$\begin{aligned}\text{Mass of sample} &= (M_{sp}) \\ \text{Mass of ordinary water} &= M_o \\ \text{Mass of hot water} &= M_h \\ \text{Specific heat capacity of copper} &= C_c = 468 \text{ J kg}^{-1} \text{ K}^{-1} \\ \text{Specific heat capacity of water} &= C_w = 4200 \text{ J kg}^{-1} \text{ K}^{-1}\end{aligned}$$

$$\text{Cooling Correction} = q = \frac{A_1 \times p}{A_2}$$

Specific heat capacity of sample = C_s

Equation (1) was applied to the selected composites to obtain their specific heat capacities.

Determination of the Thermal Conductivity (k) of the Composites

Lee's Disc apparatus was used to determine the thermal conductivity of the respective composites.

The values of k for sawdust-POP composite, sawdust-cement composite, sawdust-laterite composite, and sawdust-POP-cement-laterite composite were calculated using equation (2).

$$k = \quad (2)$$

Where

$$\begin{aligned}\text{Mass of slab (M}_{slab}) &= 1.6 \text{ kg} \\ \text{S.H.C of slab (C}_{slab}) &= 468 \text{ J kg}^{-1} \text{ K}^{-1} \\ \text{Diameter of slab} &= 0.07 \text{ m} \\ \text{Thickness of sample} &= 0.01 \text{ m} \\ \text{The rate of heat loss by the slab} &= 0.006^\circ \text{C/s} \\ \text{Temperature of slab A (T}_1) &= 94^\circ \text{C} \\ \text{Temperature of slab C (T}_2) &= 29^\circ \text{C} \\ \text{Room Temperature} &= 25^\circ \text{C} \\ \text{Difference in temperature of the cylinder A and the slab} &= 94 - 29 = 65\end{aligned}$$

C i.e. $T_1 - T_2 = 94 - 29 = 65$

Substituting these values into equation (1.2) we have,

$$k = 0.18 \text{ W/m.K}$$

Determination of the Thermal Conductivity (k) of Sawdust and Cement Composite

From equation (1.2), the value of k was calculated

$$k = \frac{M_{slab} C_{slab} \frac{d\theta}{dt}}{\frac{\pi D^2}{4} \frac{T_1 - T_2}{L}}$$

Mass of slab (M_{slab}) = 1.6 kg

S.H.C of slab (C_{slab}) = 468 J kg⁻¹ K⁻¹

Diameter of slab = 0.07 m

Thickness of sample = 0.01 m

The rate of heat loss by the slab $\frac{d\theta}{dt} = 0.006^\circ \text{C/s}$

Temperature of slab A (T_1) = 94°C

Temperature of slab C (T_2) = 29.5°C

Room Temperature = 25°C

Difference in temperature of the cylinder A and the slab C i.e. $T_1 - T_2 = 94 - 29.5 = 64.5$

Substituting these values into equation (1.2) above we have,

$$k = 0.17 \text{ W/m. K}$$

Determination of the Thermal Conductivity (k) of Sawdust and laterite Composite

From equation 1.2, the value of k for sawdust and laterite composite was obtained.

$$k = \frac{M_{slab} C_{slab} \frac{d\theta}{dt}}{\frac{\pi D^2}{4} \frac{T_1 - T_2}{L}}$$

k =

Mass of slab (M_{slab}) = 1.6 kg

S.H.C of slab (C_{slab}) = 468 J kg⁻¹ K⁻¹

Diameter of slab = 0.07 m

Thickness of sample = 0.01 m

The rate of heat loss by the slab $\frac{d\theta}{dt} = 0.006^\circ \text{C/s}$

Temperature of slab A (T_1) = 93°C

Temperature of slab C (T_2) = 31°C

Room Temperature = 25°C

Difference in temperature of the cylinder A and the slab C i.e. $T_1 - T_2 = 93 - 31 = 62^\circ \text{C}$

Substituting these values into equation 1.2 we have,

$$k = 0.19 \text{ W/m.K}$$

Determination of the Thermal Conductivity of combined Composite

From equation (2), the value of k for the sawdust-POP-cement-laterite composite was calculated

$$k = \frac{M_{slab} C_{slab} \frac{d\theta}{dt}}{\frac{\pi D^2}{4} \frac{T_1 - T_2}{L}}$$

k =

Mass of slab (M_{slab}) = 1.6 kg

S.H.C of slab (C_{slab}) = 468 J kg⁻¹ K⁻¹

Diameter of slab = 0.07 m

Thickness of sample = 0.01 m

The rate of heat loss by the slab $\frac{d\theta}{dt} = 0.0041^\circ \text{C/s}$

Temperature of slab A (T_1) = 93°C

Temperature of slab C (T_2) = 29°C

Room Temperature = 25°C

Difference in temperature of the cylinder A and the slab C i.e. $T_1 - T_2 = 93 - 29 = 64$

Substituting these values into equation 4.3 we have,

$$k = 0.10 \text{ W/m.K}$$

RESULTS AND DISCUSSION

The values of specific heat capacities and thermal conductivity of the selected composite materials are presented in Tables 1 and 2, respectively.

Table 1: Values of Specific Heat Capacities (C) of the Selected Composites

Composite	Unit (J Kg ⁻¹ K ⁻¹)	Single Material Unit (J kg ⁻¹ K ⁻¹)
Sawdust and POP	3636	1000 (Engineering Toolbox, 2003b)
Sawdust and Cement	5538	840 (Engineering Toolbox, 2003a)
Sawdust and Laterite	2002	499 (Hassan et al., 2020)
Sawdust-POP-Cement Laterite	1819	

The sawdust–cement composite recorded the highest value of specific heat capacity (5538 Jkg⁻¹ K⁻¹), followed by the sawdust–POP (3.636J kg⁻¹K⁻¹), and sawdust–laterite composites (2002Jkg⁻¹K⁻¹ while sawdust-POP-cement-laterite composite had the least value of specific heat capacity (1819 J kg⁻¹ K⁻¹). All composite samples had higher heat-storage capacities than their individual constituents, confirming their suitability as poor heat conductors. For example, Robert and Ekpote (2022) investigated the thermal properties of sawdust, using the method of mixture, the result of specific heat capacity of sawdust obtained was 54927 Jkg⁻¹K⁻¹. Similarly, Emmanuel et al.(2025) study on the determination of the thermal Properties of Some selected materials used as ceilings, the results showed the specific heat capacity of

and thermal conductivity of POP to be 1500J/kg.K and 0.25W/m.K, respectively. Imgba et al. (2022) observed that fine-grained laterite (≤ 1.25 mm) has specific heat values ranging from 0.75 to 1.2 kJ/kg·K. For cement, studies have shown that anhydrous cement typically has specific heat capacity ranges from 0.75 to 0.9 kJ/kg·K, while hydrated cement paste may reach up to 1.2 kJ/kg·K (Neville, 2011).

Conventional materials such as aluminium (887 J/kg·K), glass (792 J/kg·K), brick (841 J/kg·K), and concrete (879 J/kg·K) have moderate specific heat capacities. In contrast, the materials in this study, especially the composites, displayed much higher specific heat capacities. This indicates that they heat up more slowly and retain heat for longer periods.

Table 2: Thermal Conductivity of the Selected Composites Vs Thermal Conductivity of Single Material by Other Authors

Composite	Unit (W/m.K)	Single	Unit(W/m.K)
Sawdust-POP	0.18	POP	0.33 (Cheng et al., 2023)
Sawdust-Cement	0.17	Cement	0.29 (Neville & Brooks, 2010)
Sawdust-Laterite	0.19	Laterite	0.38 (Bouto et al., 2022)
Sawdust-POP-Cement -Laterite	0.10		

In Table 2, the sawdust-POP-cement-laterite composite exhibited the lowest thermal conductivity (0.10 W/m·K). This was followed by sawdust–cement composite (0.17 W/m·K) as against experimental result of 0.29 W/m·K obtained by Neville and Brooks (2010) for cement sample, sawdust–POP (0.18 W/m·K) as against 0.33 W/m·K obtained by Cheng et al. (2023) for POP sample, and sawdust–laterite composite (0.19 W/m·K) as against 0.38W/m·K result for laterite sample obtained by Bouto et al. (2022), respectively. These results show a marked reduction in the thermal conductivity of the selected composites when compared with the thermal conductivity of the individual material. This shows that the presence of sawdust plays a critical role in slowing down the process of heat transfer. More so, when comparing the selected composites in Table 2 with the thermal conductivity of the commonly used building materials such as aluminum, zinc, and iron, the tested composites show significantly lower thermal

conductivity. This means that they transmit less heat and can help regulate indoor thermal conditions more effectively. Studies have shown that materials with low thermal conductivity tend to have higher specific heat capacity than those with higher thermal conductivity. The differences in specific heat capacity and thermal conductivity of these materials can be attributed to the nature or arrangement of their atomic structures.

CONCLUSION

The study revealed that incorporation of sawdust into materials such as POP, laterite, and cement can improve thermal insulation capacity compared to when they are used individually. The low thermal conductivity of these composites make them promising insulating materials for building construction and other engineering applications where thermal insulation and energy efficiency are critical. An environmental waste like sawdust can be gainfully utilized for preparation of composites for

roofing sheets, which is also biodegradable, unlike the asbestos sheet that has been classified as carcinogenic. Sawdust can serve effectively as an additive in block production, reduces cost of production, and promote the thermal insulation performance of walls. Materials that possess thermal conductivity values below 0.25 W/m·K are generally considered effective thermal insulators. All the materials examined in this study fall within this range, indicating that they can exhibit good insulating performance. Hence, the thermal insulating properties of these sawdust composites, if properly harnessed, can enhance indoor thermal comfort and facilitate quicker attainment of the base temperature (T_{base}) which directly offsets the energy required for cooling degree days (CDD), especially in tropical regions such Nigeria.

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