

Thermal Performance of Ricehusk-Sawdust-Waste Carton Fibers Insulation Boards

*¹Ibobe Isaac Hime and ¹Daniel Momngu Tiough

¹Department of Industrial Technology, Faculty of Technology and Industrial Studies, Rev. Fr. Moses Orshio Adasu University, Makurdi

*Corresponding authors' email: himeisaac@gmail.com

Orcid ID: <https://orcid.org/0009.0008.6730-1197>

ABSTRACT

This study evaluated the thermal performance of insulation boards produced from rice husks, sawdust, carton fibers and polyvinyl acetate (PVA) adhesive, focusing on thermal conductivity and thermal resistance. A true experimental research design was adopted to produce four formulations: A (5:3:2:1), B (4:4:2:1), C (3:5:2:1) and D (6:2:2:1), with five specimens per formulation, giving 20 specimens. Laboratory testing was conducted to determine their thermal properties. Data were analysed using mean, standard deviation, one-way analysis of variance (ANOVA) and Tukey's honestly significant difference post hoc test. The results showed mean thermal conductivity values of 0.52, 0.48, 0.39 and 0.50 W/m·K for formulations A, B, C and D, respectively, with an overall mean of 0.47 W/m·K. Formulation C recorded the lowest mean thermal conductivity and was the only formulation within the study-adopted evaluation range of 0.30–0.40 W/m·K. ANOVA revealed a statistically significant difference in thermal conductivity, $F(3,16) = 8.164$, $p = .002$. The reported mean thermal resistance values were 3.03, 3.36, 4.08 and 3.15 m·K/W for formulations A, B, C and D, respectively, with an overall mean of 3.41 m·K/W. ANOVA also indicated a statistically significant difference in thermal resistance, $F(3,16) = 7.860$, $p = .002$. However, the thermal resistance values require verification against the original specimen measurements and thickness calculations. ASTM C518 provides a method for measuring thermal transmission properties, while ASTM C208 is considered only a reference benchmark because the applicability of its scope to the composite boards. The findings identify formulation C as the most promising mixture and demonstrate the potential of waste-derived materials for insulation-board development. Further evaluation of durability, moisture resistance and fire performance is required before practical building applications.

Received: 08 Oct. 2026

Accepted: 23 Oct. 2026

Published: 26 Oct. 2026

Keywords:

Thermal Insulation Boards; Rice Husks; Sawdust; Carton Fibers; Thermal Conductivity; Thermal Resistance

INTRODUCTION

Energy efficiency and environmental sustainability have become increasingly important in the building sector because of rising energy demand, escalating energy costs, and growing concerns about climate change. Buildings consume a substantial proportion of global energy, particularly through heating, ventilation, and air-conditioning (HVAC) systems used to maintain indoor thermal comfort (Okafor et al., 2022). In Nigeria, where high ambient temperatures and limited access to affordable electricity affect building occupants, reducing heat transfer through building envelopes represents an important strategy for improving energy efficiency. Thermal insulation materials help regulate indoor temperatures by limiting heat transfer between the internal and external environments, thereby reducing dependence on mechanical cooling and heating systems (Mbishida, 2020; Singh & Kaur, 2019). However, the effectiveness of an insulation material depends on its thermal properties, particularly thermal conductivity and thermal resistance. Thermal conductivity describes a material's ability to conduct heat, whereas thermal resistance expresses its opposition to heat transfer across a specified thickness. Lower thermal conductivity and higher thermal resistance generally indicate better insulating performance when other relevant conditions are comparable. These properties therefore provide essential measures for evaluating the suitability of materials for

building insulation applications (Buratti et al., 2018; Gowon & Bulama, 2018; Muthuraj et al., 2019; Yu & Sun, 2018). Conventional insulation materials, including fibreglass, polyurethane foam, polystyrene, and mineral wool, are widely used because of their established thermal performance. Nevertheless, concerns about their production costs, energy requirements, dependence on non-renewable resources, and end-of-life disposal have encouraged research into alternative insulation materials (Dauda & Justin, 2020; Gabr et al., 2022). These concerns are particularly relevant in developing countries, where the cost and availability of conventional insulation products may restrict their adoption in affordable housing. Consequently, researchers have increasingly investigated agricultural residues and recycled industrial materials as potential sources of low-cost, locally produced insulation products. Such alternatives may support resource efficiency, waste reduction, and sustainable construction when their performance and environmental implications are adequately established (Aigbomian & Fan, 2013; Buratti et al., 2018; Indwar & Titiksh, 2024; Liuzzi et al., 2023). Agricultural and industrial waste materials are promising candidates for composite insulation boards because their physical structures and material compositions may influence heat transfer. Rice husk, sawdust, and carton fibers are particularly relevant because they are generated through rice milling, timber processing, and the disposal of paper-based

packaging, respectively. When appropriately processed and incorporated into a composite matrix, these materials may provide internal voids and fibrous structures that restrict heat transfer. Research on rice-husk panels and hybrid insulation materials has also highlighted the potential of combining waste-derived constituents in building applications (Buratti et al., 2018; Kumar et al., 2019; Yu & Sun, 2018). Nevertheless, their insulating effectiveness depends on factors such as particle size, fiber distribution, board density, porosity, moisture content, binder characteristics, and manufacturing conditions. Therefore, the potential benefits of these materials cannot be established solely from their individual characteristics; the thermal performance of the resulting composite boards must be determined experimentally.

Rice husk is an agricultural residue produced during rice processing and is available in rice-producing communities in Nigeria. Its composition includes cellulose, lignin, and silica, although the proportions vary according to rice variety and processing conditions (Ajayi & Afolayan, 2020). Its relatively lightweight structure and silica content have attracted research interest in the development of waste-derived construction materials. Previous studies have investigated rice husk as a constituent of composite materials with potential insulating applications (Dauda & Justin, 2020; Muthuraj et al., 2019). Other investigations have examined the thermal, acoustic, and environmental characteristics of rice-husk panels and rice-husk-based insulation products for building applications (Buratti et al., 2018; Gowon & Bulama, 2018; Yu & Sun, 2018). However, the thermal conductivity of a rice-husk-based board depends not only on the properties of the husk but also on the board's composition, compactness, and internal structure. Consequently, the contribution of rice husk to thermal insulation needs to be evaluated within the specific formulation in which it is used.

Sawdust, a by-product of timber processing, is another locally available material with potential for insulation-board production. Its lignocelluloses composition, particle structure, and relatively low bulk density make it a useful constituent in lightweight composite materials. Robert and Ekpote (2022) examined the thermal properties of sawdust, highlighting the relevance of its thermal behaviour to potential applications. Research on wood-based composites produced from sawdust and waste paper has also demonstrated the potential of combining these waste materials to develop building products (Aigbomian & Fan, 2013). Similarly, Kumar et al. (2019) investigated the development and optimisation of hybrid insulation panels involving rice husk, sawdust, and waste carton fibers. Sawdust can also contribute to the internal structure of a composite, although excessive compaction, variations in particle size, and differences in binder distribution may affect the resulting heat-transfer characteristics. Its combination with other waste materials therefore provides an opportunity to investigate how changes in composite composition influence thermal conductivity and thermal resistance.

Carton fibers obtained from discarded cardboard and paper-based packaging provide an additional renewable cellulose-based constituent for composite-board production. Their fibrous structure may contribute to the formation and bonding of the composite matrix, while their arrangement within the board can influence density, porosity, and the continuity of heat-transfer pathways. Research on recycled and natural-fiber composites has demonstrated the potential of waste-derived fibers in construction-related applications (Akinyemi et al., 2016; Oluwole et al., 2021). Aigbomian and Fan (2013) examined the development of wood-crete building materials from sawdust and waste paper, while Liuzzi et al. (2023)

investigated the thermal and acoustical characteristics of sustainable materials produced from waste paper. These studies provide relevant context for considering recycled paper-based materials in building applications.

However, the contribution of carton fibers to insulation performance cannot be determined independently of the other constituents and the manufacturing process. Their interaction with rice husk and sawdust therefore requires experimental investigation to establish the resulting thermal properties. Previous research has examined agricultural residues and bio-based composites for sustainable construction and insulation applications. Muthuraj et al. (2019) investigated rice-husk-based bio-composites, while Arumugam et al. (2015) examined properties of bio-composites reinforced with rice husk and sawdust. Other studies have explored natural-fiber materials and agricultural residues as alternatives to conventional construction products (Muthukaruppan et al., 2021; Serin et al., 2022; Silva et al., 2023). Research on rice-husk insulation panels, hybrid insulation materials, and recycled waste-based products further provides relevant evidence for investigating the thermal performance of these materials (Buratti et al., 2018; Gowon & Bulama, 2018; Kumar et al., 2019; Yu & Sun, 2018). Collectively, these studies provide a basis for investigating waste-derived composite materials and demonstrate the importance of characterising their performance rather than assuming that all natural-fiber composites possess equivalent insulating properties.

Despite this progress, further investigation is required into the combined use of rice husk, sawdust, and carton fibers in thermal insulation boards. In particular, the available literature cited in this study does not adequately establish how variations in the proportions of these three constituents influence both thermal conductivity and thermal resistance under a consistent production and testing procedure. Research involving individual constituents or other combinations of fibers cannot fully resolve this issue because differences in material composition, binder content, compaction, thickness, and test conditions may produce different thermal outcomes. Although previous studies have investigated rice-husk panels, sawdust-based building materials, recycled-paper materials, and hybrid insulation products (Aigbomian & Fan, 2013; Buratti et al., 2018; Kumar et al., 2019; Liuzzi et al., 2023; Yu & Sun, 2018), further evidence is needed to establish the thermal performance of boards produced using the specific combination and proportions of materials examined in this study. The specific research problem is therefore the insufficient experimental evidence on the thermal performance of boards manufactured from this particular combination of agricultural and recycled packaging wastes. Establishing the thermal properties of the resulting boards is necessary to identify promising formulations and determine their potential suitability for building insulation.

The significance of this investigation lies in its potential contribution to sustainable construction, waste valorization, and the development of locally sourced building materials in Nigeria. By examining the thermal performance of composite boards made from rice husk, sawdust, and carton fibers, the study may provide useful evidence for researchers, building-material manufacturers, construction professionals, and institutions concerned with building research and sustainable material development. Previous investigations into the thermal, acoustic, and environmental characteristics of waste-derived building materials provide a basis for further research in this area (Buratti et al., 2018; Liuzzi et al., 2023). The findings may also inform subsequent investigations into formulation optimisation, manufacturing consistency,

durability, and compliance with relevant performance standards. However, practical adoption would require further assessment of factors such as moisture sensitivity, fire behaviour, mechanical integrity, service life, and production costs. The use of waste materials should therefore be considered a promising development pathway rather than proof, in itself, of superior environmental or economic performance.

Accordingly, this study aimed to develop and evaluate thermal insulation boards produced from rice husk, sawdust, and carton fibres, with particular emphasis on determining their mean thermal conductivity and thermal resistance. By evaluating these two parameters across the developed formulations, the study sought to establish their comparative thermal performance and provide experimental evidence on the potential of the selected waste materials for sustainable building insulation applications.

MATERIALS AND METHODS

Research Design

A true experimental research design was adopted to investigate the effects of varying the proportions of rice husks, sawdust and carton fibers on the thermal performance of insulation boards produced using polyvinyl acetate (PVA) adhesive as the binding agent. The materials were selected based on their local availability in Benue State, renewable nature, affordability and potential suitability for thermal insulation applications. Rice husks provided a lightweight lignocelluloses material with relatively high silica content, sawdust served as a porous wood-based constituent, and carton fibers contributed to the fibrous structure and interlocking of the composite matrix. PVA adhesive was incorporated to promote bonding and cohesion among the constituents.

Before production, the rice husks and sawdust were cleaned to remove foreign materials, while the carton fibers were sorted and shredded into suitable sizes. The prepared materials were dried to reduce excessive moisture that could affect bonding, compaction and thermal performance, and then allowed to attain a reasonably uniform moisture condition before weighing and mixing.

The experimental procedure involved systematically varying the proportions of rice husks and sawdust while maintaining the relative proportions of carton fibers and PVA adhesive. The independent variables were the mix proportions of rice husks and sawdust, whereas the dependent variables were thermal conductivity and thermal resistance. Other relevant production and testing conditions were maintained as consistently as practicable to facilitate comparison among the resulting boards and establish the relationship between material composition and thermal insulation performance.

Experimental Procedure

Four formulations, designated Samples A, B, C and D, were prepared using rice husks, sawdust, carton fibers and polyvinyl acetate (PVA) adhesive in weight ratios of 5:3:2:1, 4:4:2:1, 3:5:2:1 and 6:2:2:1, respectively. Each unit of the mix ratio represented 200 g; thus, units 1, 2, 3, 4, 5 and 6 corresponded to 200 g, 400 g, 600 g, 800 g, 1,000 g and 1,200 g, respectively. Accordingly, the mass of rice husks ranged from 600 to 1,200 g and that of sawdust from 400 to 1,000 g, while carton fibres and PVA adhesive remained constant at 400 g and 200 g, respectively. The raw materials were air-dried at temperatures above 35°C until their moisture content was approximately 12%. For each formulation, the measured rice husks, sawdust and carton fibers were thoroughly mixed before the PVA adhesive was incorporated and evenly

distributed. The resulting mixture was placed in a mold measuring 300 mm × 300 mm × 20mm, with a target thickness of 15 mm, and compacted manually. The molded boards were allowed to cure and were subsequently conditioned before thermal testing. Five boards were produced from each formulation, yielding twenty specimens. Thermal conductivity and thermal resistance were the properties evaluated. Thermal conductivity was determined using the heat-flow-meter method in accordance with ASTM C518-21 (ASTM C518, 2021). Each specimen was positioned between the apparatus's hot and cold plates, and measurements were recorded after steady-state conditions had been achieved. The study-adopted evaluation range of 0.30–0.40 W/m·K.

The results from the laboratory test calculated using Thermal Conductivity $\lambda = MC(dT/dt) \div [A(T_2 - T_1)/L]$ (1)

Where λ = thermal conductivity; M = mass of the metallic disc; A = area of the specimen (πr^2), where $\pi = 3.14$ and $r = .055\text{m}$; $T_2 - T_1$ = temperature differences across the specimen L = length/thickness of the metallic disc; $\frac{dT}{dt}$ = Rate of cooling of the metallic disc at T_1

The actual thickness of each specimen was measured for use in the thermal calculations. Where thermal resistance was calculated from thermal conductivity, it was determined using

$$R_t = \frac{L}{\lambda A} \quad (2)$$

Where: R_t = thermal resistance λ = board conductivity L = thickness of specimen 15mm (0.015 m) A = Area of the specimen (πr^2), where $\pi = 3.14$ and $r = .055\text{m}$

The resulting conductivity and resistance values were organized by formulation and compared to assess the influence of the constituent proportions on the thermal insulation performance of the boards.

Material Collection and Preparation

The materials used in producing the thermal insulation boards comprised rice husks, sawdust, carton fibers and polyvinyl acetate (PVA) adhesive. Rice husks and sawdust were obtained from rice-processing mills and sawmills, respectively, within Benue State, Nigeria, while carton fibers and PVA adhesive were sourced from local suppliers. The materials were selected based on their availability, affordability, renewable nature where applicable, and suitability for developing thermal insulation boards. Rice husks provided a lightweight lignocelluloses material with relatively high silica content, sawdust contributed a porous wood-based structure, carton fibers enhanced the fibrous network and interlocking of the constituents, while PVA adhesive served as the binding agent. Before production, the rice husks and sawdust were cleaned to remove dirt, foreign particles and other impurities. The carton materials were sorted and shredded into suitable fiber sizes to facilitate uniform distribution during mixing. The prepared solid materials were dried to reduce excessive moisture that could affect bonding, compaction and thermal performance, then stored in a clean, dry environment until required. All constituents were weighed according to the specified experimental formulations before mixing and board production.

Production of Thermal Insulation Boards

The thermal insulation boards were produced using a dual mould with internal dimensions of 300 mm × 300 mm × 20mm. The inner surfaces of the mould were lined with polythene sheets to minimize adhesion and facilitate the removal of the formed boards. For each formulation, the weighed dry constituent's rice husks, sawdust and carton

fibers were thoroughly mixed before the required quantity of polyvinyl acetate (PVA) adhesive was added. Mixing continued until the binder was evenly distributed throughout the mixture. The prepared mixture was transferred into the mould, spread uniformly and leveled to promote consistent board thickness. The filled mould was then mounted on the compression machine developed for the study and tightened to compact the mixture. Compression was maintained for five minutes, after which the mould was carefully dismantled and the formed board removed. The boards were subsequently cured under ambient conditions for 120 hours and conditioned before specimen preparation and laboratory testing.

The same production procedure was applied to Samples A, B, C and D, with the proportions of rice husks and sawdust varied according to the experimental formulations while the quantities of carton fibers and PVA adhesive remained constant. Five boards were produced for each formulation, giving a total of 20 boards. Following curing and conditioning, specimens were prepared and tested for thermal conductivity and thermal resistance in accordance with the

applicable ASTM procedures. The resulting measurements were used to evaluate and compare the thermal performance of the four formulations. The benchmark used in this study should be understood as an adopted evaluation criterion, rather than a universal ASTM requirement.

The results are presented in accordance with the research questions and objectives of the study.

RESULTS AND DISCUSSION

Research Question 1

What is the mean thermal conductivity value of the developed composite thermal insulation boards? The results from the laboratory test calculated using Thermal Conductivity $\lambda = MC(dT/dt) \div [A(T_2 - T_1)/L]$ (3)

Where λ = thermal conductivity; M = mass of the metallic disc; A = area of the specimen (πr^2), where $\pi = 3.14$ and $r = .055\text{m}$; $T_2 - T_1$ = temperature differences across the specimen L = length/thickness of the metallic disc; $\frac{dT}{dt}$ = Rate of cooling of the metallic disc at T_1

Table 1: Mean Thermal Conductivity Value and Standard Deviation of Thermal Insulation Boards Produced from Rice Husks, Sawdust, Carton Fibers and Polyvinyl Acetate (PVA) Adhesive

Mix Proportions	Specific Category/ Number	λ W/(m.K)	M_1 W/m.K	SD_1	ASTMC208 Benchmark m.k/w(Adopted)	Remarks
5:3:2:1	A01	0.49	0.52	0.03	0.30-0.40	OS
	A02	0.56				
	A03	0.51				
	A04	0.55				
	A05	0.50				
4:4:2:1	B01	0.51	0.48	0.06	0.30-0.40	OS
	B02	0.53				
	B03	0.41				
	B04	0.42				
	B05	0.51				
3:5:2:1	C01	0.46	0.39	0.06	0.30-0.40	WS
	C02	0.33				
	C03	0.36				
	C04	0.45				
	C05	0.37				
6:2:2:1	D01	0.49	0.50	0.02	0.30-0.40	OS
	D02	0.48				
	D03	0.51				
	D04	0.52				
	D05	0.51				
M_T, SD_T			0.47	0.04	0.30-0.40	OS

Lab. Test (2026): λ = Thermal Conductivity (W/m.K), M_1 = Mean Thermal Conductivity (W/m.K), SD_1 = Standard Deviation, M_T =Over all mean Thermal Conductivity (W/m.K), SD_T =Over all Standard Deviation, WS=Within ASTM Specification Adopted Bench Mark

Table 1 shows that the thermal conductivity values of the developed thermal insulation boards ranged from 0.49–0.56 W/(m.K.) with a mean of 0.52 W/(m.K.) for the 5:3:2:1 mix proportion; 0.41–0.53 W/(m.K.), with a mean of 0.48 W/(m.K.) for the 4:4:2:1 mix proportion; 0.33–0.46 W/m.K, with a mean of 0.39 W/m.K for the 3:5:2:1 mix proportion; and 0.48–0.52 W/(m.K.), with a mean of 0.50 W/(m.K.) for the 6:2:2:1 mix proportion. The mean thermal conductivity values and corresponding standard deviations ranged from 0.39–0.52 W/(m.K.) and 0.02–0.06, respectively, across the

four mix proportions. The overall mean thermal conductivity for all four mix proportions was 0.47 W/(m.K.) with an overall standard deviation of 0.04.

Using the study-adopted benchmark range of 0.30–0.40 W/(m.K.), the mean thermal conductivity values for the 5:3:2:1, 4:4:2:1 and 6:2:2:1 mix proportions were above the upper benchmark limit of 0.40 W/(m.K.). This indicates that these formulations did not fall within the adopted evaluation range. However, the 3:5:2:1 mix proportion recorded a mean thermal conductivity of 0.39 W/(m.K.) which fell within the adopted benchmark range. Therefore, only the 3:5:2:1 formulation satisfied the study-adopted thermal conductivity benchmark, while the other three formulations recorded mean values above the specified upper limit.

The findings indicate that the 3:5:2:1 mix proportion demonstrated the most favorable thermal insulation performance among the developed boards because it recorded the lowest mean thermal conductivity. Since lower thermal conductivity indicates less heat transfer through a material under comparable conditions, this formulation showed greater potential for thermal insulation applications than the other formulations investigated. The results further suggest that adjusting the relative proportions of rice husks and sawdust may improve the thermal performance of the composite boards. The benchmark used in this study should

be understood as an adopted evaluation criterion, rather than a universal ASTM requirement.

Research Question 2

What is the mean thermal resistance of the developed composite thermal insulation boards? The results from the laboratory test calculated using $R_t = \frac{L}{\lambda A}$ (3)

Where: R_t = thermal resistance λ = board conductivity L = thickness of specimen 15mm (0.015 m) A = Area of the specimen (πr^2), where $\pi = 3.14$ and $r = .055\text{m}$

Table 2: Mean Thermal Resistance and Standard Deviation of Thermal Insulation Boards Produced from Rice husks, Sawdust, Carton Fibers and Polyvinyl Acetate (PVA) Adhesive

Mix Proportions	Specific Category/ Number	R_t m.k/w	M_1 m.k/w	SD_1	ASTMC208 Benchmark m.k/w(Adopted)	Remarks
5:3:2:1	A ₀₁	3.22	3.03	0.16	3.95	OS
	A ₀₂	2.82				
	A ₀₃	3.10				
	A ₀₄	2.87				
	A ₀₅	3.16				
4:4:2:1	B ₀₁	3.10	3.36	0.38	3.95	OS
	B ₀₂	2.98				
	B ₀₃	3.85				
	B ₀₄	3.76				
	B ₀₅	3.10				
3:5:2:1	C ₀₁	3.43	4.08	0.53	3.95	WS
	C ₀₂	4.79				
	C ₀₃	4.39				
	C ₀₄	3.51				
	C ₀₅	4.27				
6:2:2:1	D ₀₁	3.22	3.15	0.09	3.95	OS
	D ₀₂	3.29				
	D ₀₃	3.10				
	D ₀₄	3.04				
	D ₀₅	3.10				
M_T, SD_T			3.41	0.54		

Lab. Test (2026): R_t = Thermal Resistance (m.K/W), M_1 = Mean Thermal Resistance (m.K/W), SD_1 = Standard Deviation, M_T =Over all mean Thermal Resistance (m.K/W), SD_T =Over all Standard Deviation, WS=Within ASTM Specification Adopted Bench Mark

Table 2 shows thermal resistance of composite thermal insulation boards produced from rice husks, sawdust, carton fibers and polyvinyl acetate (PVA) adhesive. The calculations were based on the measured thermal conductivity of each specimen, a board thickness of 15 mm (0.015 m), and a specimen radius of 0.055 m. The results show that thermal resistance varied among the four mix proportions, indicating differences in their resistance to heat transfer under the adopted test conditions.

The boards produced using the A (5:3:2:1) mix proportion recorded a mean thermal resistance of 3.03 m.K/W, with a standard deviation of 0.18. The B (4:4:2:1) formulation recorded a higher mean thermal resistance of 3.36 m.K/W and a standard deviation of 0.41. The C (3:5:2:1) formulation achieved the highest mean thermal resistance of 4.08 m.K/W, with a standard deviation of 0.59. In contrast, the D (6:2:2:1) formulation recorded a mean thermal resistance of 3.15 m.K/W and the lowest standard deviation of 0.10.

The superior resistance observed in formulation C (3:5:2:1) corresponds with its comparatively lower mean thermal

conductivity of approximately 0.39 W/(m.K). This relationship is consistent with the governing heat-transfer equation: for a constant specimen thickness and area, thermal resistance increases as thermal conductivity decreases. Consequently, formulation C exhibited the greatest resistance to heat flow among the formulations investigated.

The result suggests that the relative proportions of rice husks and sawdust may influence the thermal performance of the developed composite boards. The higher proportion of sawdust in formulation C may have contributed to differences in particle packing, pore distribution and internal air spaces. Such characteristics can influence heat transfer through a composite material.

The variability in the measured resistance values also provides useful information about consistency within each formulation. Formulation C recorded the largest standard deviation (0.59 m.K/W), indicating greater variation among its five specimens. Formulation B followed with a standard deviation of 0.41 K/W, while formulations A and D recorded lower standard deviations of 0.18 and 0.10 m.K/W, respectively. Formulation D therefore demonstrated the most consistent thermal resistance readings among the four groups, although its mean resistance was lower than that of formulation C. This distinction shows that the formulation

with the highest average performance was not necessarily the formulation with the least variation.

The overall mean thermal resistance was 3.40 K/W, with an overall standard deviation of 0.54. This result summarises the resistance measurements across the 20 specimens. In relation to the study-adopted evaluation benchmark of 3.95, formulation C has a mean resistance above the numerical benchmark, whereas formulations A, B and D have means below it. Overall, the findings identify formulation C (3:5:2:1) as the best-performing mix in terms of mean calculated thermal resistance at a thickness of 15 mm. Its

performance, together with its comparatively low thermal conductivity, supports further investigation of rice husk, sawdust and carton fibre composites bonded with PVA adhesive for potential thermal insulation applications in buildings.

Hypothesis One

There is no significant difference in the mean thermal conductivity (W/m.K) of the developed composite thermal insulation boards (from rice husk, sawdust, and carton fibers).

Table 3: Analysis of Variance (ANOVA) for Mean Thermal Conductivity of Thermal Insulation Boards Produced from Rice Husks, Sawdust, Carton Fibers and Polyvinyl Acetate (PVA) Adhesive

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.047	3	.016	8.164	.002
Within Groups	.031	16	.002		
Total	.078	19			

Table 3 shows a statistically significant difference in the mean thermal conductivity of the developed composite thermal insulation boards made from different mix proportions. This means that $F(3,16) = 8.164$, $p = 0.002 < 0.05$. This implies that there was a significant difference in the mean thermal

conductivity of at least two of the different mix proportions of rice husk, sawdust, and carton fibers. In light of the significant difference, a Tukey Post Hoc test was conducted to establish where the difference existed.

Table 4: Tukey Post Hoc Test of Differences in Mean Thermal Conductivity of Thermal Insulation Boards across Mix Proportions

(I) Mix Proportion	(J) Mix Proportion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5:3:2:1	4:4:2:1	.04600	.02784	.379	-.0336	.1256
	3:5:2:1	.12800*	.02784	.002	.0484	.2076
	6:2:2:1	.02000	.02784	.888	-.0596	.0996
4:4:2:1	6:2:2:1	-.02600	.02784	.787	-.1056	.0536
	3:5:2:1	.08200*	.02784	.042	.0024	.1616
3:5:2:1	6:2:2:1	-.10800*	.02784	.007	-.1876	-.0284

Results of the Post Hoc test in Table 4 showed that there was no significant difference between the mean values of the 5:3:2:1 and 4:4:2:1 mix proportions ($p=0.379$). However, there was a significant difference between the mean values of the 5:3:2:1 and 3:5:2:1 mix proportions ($p=0.002$). There was also no significant difference between the mean values of the 5:3:2:1 and 6:2:2:1 mix proportions ($p=0.888$). Furthermore, there was no significant difference between the mean values of the 4:4:2:1 and 6:2:2:1 mix proportions ($p=0.787$). However, there was a significant difference between the mean values of the 4:4:2:1 and 3:5:2:1 mix proportions ($p=0.042$). There was also a significant difference between the mean

values of the 3:5:2:1 and 6:2:2:1 mix proportions ($p=0.007$). Thus, the pairs of 5:3:2:1 and 3:5:2:1, 4:4:2:1 and 3:5:2:1 and 3:5:2:1 and 6:2:2:1 were responsible for the observed differences in the mean thermal conductivity of the thermal insulation boards. The pairs of 5:3:2:1 and 4:4:2:1, 5:3:2:1 and 6:2:2:1 and 4:4:2:1 and 6:2:2:1 did not contribute to the observed differences.

Hypothesis Two

There is no significant difference in the mean thermal resistance of the developed composite thermal insulation boards (from rice husk, sawdust, and carton fibers).

Table 5: Analysis of Variance (ANOVA) for Mean Thermal Resistance of Thermal Insulation Boards Produced from Rice Husks, Sawdust, Carton Fibers and Polyvinyl Acetate (PVA) Adhesive

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3.289	3	1.096	7.860	.002
Within Groups	2.232	16	.0139		
Total	5.522	19			

Table 5 shows a statistically significant difference in the mean thermal resistance of the developed composite thermal insulation boards made from different mix proportions. This means that $F(3,16) = 7.860$, $p = 0.002 < 0.05$. This implies that there was a significant difference in the mean thermal

resistance of at least two of the different mix proportions of rice husk, sawdust, and carton fibers. In light of the significant difference, a Tukey Post Hoc test was conducted to establish where the difference existed.

Table 6: Tukey Post Hoc Test of Differences in Mean Thermal Resistance of Thermal Insulation Boards across Mix Proportions

(I) Mix Proportion	(J) Mix Proportion	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
5:3:2:1	4:4:2:1	-0.3231	0.2360	.535	-0.9982	0.3521
	3:5:2:1	-1.0440	0.2360	.002	-1.7178	-0.3676
	6:2:2:1	-0.1147	0.2360	.961	-0.7899	0.5604
4:4:2:1	6:2:2:1	-0.7197	0.2360	.035	-1.3948	0.0445
	3:5:2:1	0.2083	0.2360	.814	-0.4668	-0.8834
3:5:2:1	6:2:2:1	0.9280	0.2360	.006	-0.2529	1.6031

Table 6 Shows the Tukey HSD post hoc comparisons of mean thermal resistance across the four formulations. Differences were considered statistically significant where the significance value was below 0.05 and the 95% confidence interval did not include zero. The comparison between formulations A (5:3:2:1) and 4:4:2:1 produced a mean difference of -0.3231 ($p=0.535$). This difference was not statistically significant. Similarly, the comparison between formulations 5:3:2:1 and D (6:2:2:1) produced a mean difference of -0.1147 ($p=0.961$), indicating no statistically significant difference between their mean thermal resistance values.

In contrast, the comparison between formulations A (5:3:2:1) and C (3:5:2:1) produced a statistically significant mean difference of -1.0427 ($p=0.002$). The negative difference indicates that formulation A (5:3:2:1) had lower mean thermal resistance than formulation C (3:5:2:1). This suggests that the C (3:5:2:1) formulation offered greater resistance to heat transfer than the 5:3:2:1 formulation under the test conditions.

The comparison between formulations (4:4:2:1) and C (3:5:2:1) also showed a statistically significant difference of -0.7197 ($p=0.035$). This result indicates that formulation C (3:5:2:1) had significantly higher mean thermal resistance than formulation B (4:4:2:1). The finding further supports the comparatively stronger thermal insulation performance of the C(3:5:2:1) formulation.

However, the difference between formulations B (4:4:2:1) and D (6:2:2:1) was not statistically significant (mean difference = 0.2083 , ($p=0.814$)). This indicates that the difference between their observed mean thermal resistance values could not be established as statistically significant.

Finally, the comparison between formulations C (3:5:2:1) and D (6:2:2:1) yielded a statistically significant mean difference of 0.9280 ($p=0.006$). The positive difference indicates that formulation C (3:5:2:1) had higher mean thermal resistance than formulation D (6:2:2:1). This suggests that formulation C (3:5:2:1) was more effective at resisting heat transfer than formulation D (6:2:2:1). Overall, the post hoc analysis shows that formulation C (3:5:2:1) differed significantly from each of the other three formulations, whereas the comparisons among the other three formulations were not statistically significant. The pattern indicates that the C (3:5:2:1) mixture of rice husks, sawdust, carton fibers, and PVA adhesive achieved the highest mean thermal resistance among the formulations examined.

The one-way ANOVA for these derived thermal resistance values gives approximately ($F(3, 16) = 7.864$, $p=0.002$). Since the significance value is below 0.05, the null hypothesis of no significant difference in mean thermal resistance among the four formulations is rejected.

The results therefore indicate a statistically significant difference in mean thermal resistance across the formulations,

with the C (3:5:2:1) formulation demonstrating the highest mean resistance.

The findings showed that the mean thermal conductivity of the thermal insulation boards produced from rice husks, sawdust, carton fibers, and polyvinyl Acetate (PVA) varied across the four formulations. Formulations A (5:3:2:1), B (4:4:2:1), C (3:5:2:1), and D (6:2:2:1) recorded mean thermal conductivity values of 0.52, 0.48, 0.39, and 0.50 W/m·K, respectively, giving an overall mean of 0.47 W/m·K. The individual values ranged from 0.49–0.56 W/m·K for A, 0.41–0.53 W/m·K for B, 0.33–0.46 W/m·K for C, and 0.48–0.52 W/m·K for D. Formulation C recorded the lowest mean thermal conductivity of 0.39 W/m·K, while formulation A recorded the highest mean value of 0.52 W/m·K. Since lower thermal conductivity indicates a lower rate of heat transfer, formulation C demonstrated the most favourable thermal conductivity among the four formulations. The difference in the mean thermal conductivity values demonstrates that changing the proportions of rice husks and sawdust, while maintaining the carton fiber and binder proportions, affected the heat-transfer behaviour of the developed boards. The particularly low value recorded by formulation C can be associated with its 3:5:2:1 composition, which contained the highest proportion of sawdust. The interaction between the sawdust, rice husks and cotton fibers may have produced an internal structure with greater resistance to heat flow. Factors such as fiber arrangement, particle distribution, porosity, internal air spaces, degree of compaction and binder distribution can influence the continuity of heat-transfer pathways within a composite board. Consequently, the thermal conductivity observed in each formulation reflects the combined effect of its constituent materials and the internal structure formed during production.

In practical terms, the mean value of 0.39 W/m·K obtained for formulation C indicates that this formulation restricted heat transfers more effectively than formulations A, B and D under the conditions of the study. The difference between formulation C and the other formulations is particularly important because A, B and D recorded mean values of 0.52, 0.48 and 0.50 W/m·K, respectively. Thus, formulation C was the only formulation that achieved a mean thermal conductivity below 0.40 W/m·K, demonstrating a comparatively superior capacity to reduce heat transfer through the board.

The finding agrees with (Gowon & Bulama, 2018) who reported a thermal conductivity of 0.48 W/m·K for rice husk ceiling boards. The value reported in their study is close to the overall mean thermal conductivity of 0.47 W/m·K obtained in the present study. This similarity provides support for the thermal insulation potential of boards produced from rice husk and other lignocelluloses materials. However, the lower value obtained by formulation C indicates that combining rice husk with a higher proportion of sawdust and maintaining

cotton fibers and binder at the specified levels can produce a formulation with comparatively lower thermal conductivity. The finding also agrees with Kumar, et al (2019), who investigated hybrid insulation panels produced from rice husk, sawdust, and waste carton board fibers and established that the proportions of the constituent materials influenced thermal conductivity. Their finding supports the present observation that the thermal performance of composite insulation boards is dependent not simply on the inclusion of lignocelluloses waste materials, but also on the relative proportions in which the materials are combined. The present result, particularly the superior performance of formulation C, demonstrates the importance of optimizing the constituent proportions when developing waste-derived thermal insulation boards.

Similarly, the finding is consistent with Mbishida (2020), who investigated hybrid composites produced from rice husk, sawdust, and sugarcane bagasse and reported that thermal conductivity varied with material composition. The study demonstrated that an appropriate combination of agricultural waste materials could produce improved thermal insulation characteristics. This agrees with the present finding that formulation C, with its particular combination of rice husks, sawdust, carton fibers, and binder, produced the lowest mean thermal conductivity among the formulations investigated. The finding is further supported by (Yu & Sun, 2018), whose study demonstrated that the incorporation and variation of rice husk fiber in composite insulation wallboards affected thermal conductivity. Their finding reinforces the present observation that changes in lignocelluloses fiber composition can alter the thermal behavior of composite boards. The agreement among these studies indicates that the thermal conductivity of bio-based insulation materials is closely associated with the composition and internal structure of the resulting composite.

The one-way ANOVA revealed a statistically significant difference in mean thermal conductivity among the four formulations, $F(3, 16) = 8.164$, $p = .002$. Since the p -value was less than the 0.05 significance level, the null hypothesis of no significant difference in thermal conductivity among the formulations was rejected. This confirms that the different material proportions produced statistically different thermal conductivity responses. The Tukey HSD analysis further showed that formulation C (3:5:2:1) differed significantly from formulation A (5:3:2:1), $p = .002$, formulation B (4:4:2:1), $p = .042$, and formulation D (6:2:2:1), $p = .007$. However, no statistically significant differences were observed between A and B ($p = .379$), A and D ($p = .888$), or B and D ($p = .787$). These results show that formulation C was responsible for the major statistical separation among the formulations. Its mean thermal conductivity of 0.39 W/m·K was distinctly lower than the values obtained for the other three formulations, whereas A, B and D exhibited statistically comparable thermal conductivity responses.

When compared with the adopted specification range of 0.30–0.40 W/m·K, formulation C, with a mean thermal conductivity of 0.39 W/m·K, satisfied the adopted criterion. Formulations A, B and D, with mean values of 0.52, 0.48 and 0.50 W/m·K, respectively, exceeded the upper limit of the adopted range. Therefore, only formulation C satisfied the adopted thermal-conductivity criterion. This result provides a concrete basis for identifying formulation C as the most favorable formulation for thermal insulation based on thermal conductivity. It is important to clarify that the 0.30–0.40 W/m·K range is the specification adopted for this study and should not be interpreted as a universal ASTM requirement. ASTM C518 provides a test method for determining steady-

state thermal transmission properties rather than establishing a universal acceptable thermal-conductivity limit for all insulation-board products. The comparison in this study is therefore made specifically against the criterion adopted for the investigation.

The findings demonstrated that the formulation of rice husks, sawdust, carton fibers, and binder significantly influenced the thermal conductivity of the developed boards produced from rice husk, sawdust and carton fibers. Formulation C (3:5:2:1) recorded the lowest mean thermal conductivity of 0.39 W/m·K, was statistically different from the other three formulations, and was the only formulation that satisfied the adopted thermal-conductivity criterion. Therefore, based specifically on thermal conductivity, formulation C demonstrated the most favorable heat-transfer performance and represents the most promising formulation for the production of the developed thermal insulation boards under the conditions of the study.

The thermal resistance results indicate that the performance of the insulation boards produced from rice husks, sawdust, carton fibers and polyvinyl acetate (PVA) adhesive varied according to the material proportions. Based on the 20 specimen readings presented in Table 2, formulation C (3:5:2:1) recorded the highest mean thermal resistance of 4.08mk/w, followed by formulation B (4:4:2:1) at 3.36 mk/w, formulation D (6:2:2:1) at 3.15 m.k/w, and formulation A (5:3:2:1) at 3.03m.k/w. The overall mean was approximately 3.41. These findings identify formulation C, which contained a higher proportion of sawdust relative to rice husks, as the most effective of the four formulations in resisting heat transfer under the conditions of the experiment.

The specimen-level values further show that formulation C had the widest range, from 3.43 to 4.79, whereas formulation D ranged from 3.04 to 3.29. The sample standard deviations calculated from the displayed readings are approximately 0.58 for A, 0.42 for B, 0.54 for C and 0.10 for D. Thus, formulation D produced the most consistent resistance values, while formulation C combined the highest mean with greater variation between specimens. This variation may be associated with differences in material distribution, compaction or internal structure, although these explanations would require direct measurements to confirm. The study is consistent with the established physical relationship between thermal conductivity and thermal resistance: for the same specimen thickness and comparable test conditions, lower thermal conductivity corresponds to higher thermal resistance. This agrees with the study's conductivity results, in which formulation C recorded the lowest mean conductivity, approximately 0.39 W/m·K. The agreement between the two measures strengthens the conclusion that formulation C provided the best thermal performance among the mixtures investigated.

A one-way analysis of variance (ANOVA) was conducted using the 20 individual thermal resistance readings. The analysis revealed a statistically significant difference among the four formulations, $F(3, 16) = 7.86$, $p = .002$. Since the probability value was below the .05 significance level, the null hypothesis of no significant difference in mean thermal resistance was rejected. This finding indicates that the tested material proportions were associated with significant differences in the thermal resistance of the developed boards. The Tukey post hoc test identified significant differences between formulation A and C ($p = .002$) formulation B and C ($p = .035$), and formulation C and D ($p = .006$). However, the differences between A and B ($p = .534$), A and D ($p = .960$) and B and D ($p = .815$) were not statistically significant. These results confirm that formulation C's mean thermal resistance

was significantly higher than that of each of the other three formulations. Therefore, the superior performance of formulation C is supported by both descriptive and inferential statistical evidence.

The findings support the established principle that thermal resistance generally increases as thermal conductivity decreases, provided specimen thickness and test conditions remain comparable. Formulation C's highest mean resistance corresponds with its lowest mean thermal conductivity of approximately 0.39 W/m·K. This agreement between the two thermal indicators strengthens the conclusion that formulation C performed best among the mixtures tested. The result also supports the broader direction of research into insulation materials made from agricultural and fibrous residues, where material composition and internal structure are important considerations in thermal performance. In this study, the higher sawdust proportion in formulation C was associated with improved resistance compared with the other tested proportions.

The result is consistent with the empirical findings of Buratti et al. (2018), who investigated rice-husk panels produced by gluing and pressing rice husks for building applications. Their study reported a thermal resistance of 0.59 for the rice-husk panels and demonstrated the potential of agricultural residues for thermal-insulation applications. Although the resistance values from the two studies should not be compared directly without accounting for differences in specimen thickness, composition and testing procedures, both investigations support the potential of rice husks and other agricultural by-products as resources for developing insulation materials.

The findings also confirm with Aigbomian & Fan's (2013) study on Wood-Crete produced from sawdust, waste paper and a lime-based binder. They reported that the composition of the mixture, particularly the addition of waste paper, influenced the composite's structure and thermal conductivity. Their findings are relevant because they demonstrate that the relative proportions of fibrous waste materials can affect the thermal performance of composite building products. In the present study, the superior resistance recorded by formulation C similarly suggests that the balance between rice husks and sawdust influenced the thermal behaviour of the boards.

Studies by Liuzzi et al. (2023), who examined waste-paper-based building materials containing sawdust and biomass residues. They recorded thermal conductivity values ranging from 0.071 to 0.093 W/m·K and observed that sawdust influenced the material's structure and shrinkage. Their findings support the view that the interaction between fibrous constituents and the manufacturing process can affect thermal performance. The conductivity values in their study were lower than those obtained for the present boards, indicating that the two materials do not have equivalent thermal performance. The difference may relate to composition, density, processing and binder characteristics.

Similarly, Abobakr et al. (2025) investigated insulation particleboards made from rice husks and epoxy resin at different densities. They reported thermal conductivity values between 0.064 and 0.076 W/m·K and found that lower-density boards exhibited better thermal performance within their experimental conditions. This study reinforces the importance of composition and physical structure in determining the thermal behaviour of rice-husk-based boards. However, the present study recorded a mean conductivity of approximately 0.39 W/m·K for formulation C. The difference indicates that the developed rice-husk, sawdust, carton-fiber and PVA boards have not demonstrated the same insulating performance as the rice-husk-epoxy boards investigated by

Abobakr et al (2025). The studies therefore support the feasibility of agricultural-waste insulation products while also highlighting the need to evaluate each formulation on its measured properties rather than assume equivalent performance.

CONCLUSION

Based on the findings of the study, it was concluded that the proportions of rice husks, sawdust, carton fibres and polyvinyl acetate (PVA) adhesive influenced the thermal performance of the developed insulation boards. Formulation C (3:5:2:1) recorded the lowest mean thermal conductivity (0.39 W/m·K) and the highest reported mean thermal resistance (4.08 m·K/W), indicating the most favorable thermal performance among the four formulations investigated. The findings demonstrate the potential of utilizing agricultural and industrial waste to develop alternative thermal insulation materials that may contribute to sustainable construction and improved waste management. However, further studies on durability, moisture resistance, fire safety and long-term performance are necessary to establish their suitability for practical building applications.

ACKNOWLEDGEMENTS

The laboratory technologists in the Departments of Civil Engineering and Physics, Joseph Sarwuan Tarkaa University, Makurdi, are gratefully acknowledged for their technical assistance during the laboratory procedures and testing phases of the research.

Declaration of Conflict of Interest

The author declares that there are no known financial or personal relationships that could have inappropriately influenced the research reported in this paper

REFERENCES

- H., Kakou, C. A., Bensalah, M. O., Bouhfid, R., Qaiss, A. E. K., & Raji, M. (2025). Development of lightweight insulation particleboard with superior thermo-mechanical and acoustic properties based on rice husks. *Journal of Building Engineering*, 104, Article 112289. <https://doi.org/10.1016/j.jobbe.2025.112289>
- Aigbomian, E. P., & Fan, M. (2013). Development of Wood-Crete building materials from sawdust and waste paper. *Construction and Building Materials*, 40, 361–366. <https://doi.org/10.1016/j.conbuildmat.2012.11.018>
- Ajayi, O. T., & Afolayan, A. S. (2020). Evaluation of agricultural residues for eco-friendly composite materials. *Journal of Sustainable Materials*, 5(2), 112–120.
- Akinyemi, A. B., Afolayan, J. O., & Ogunji, O. (2016). *Some properties of composite corn cob and sawdust particle boards*. *Construction and Building Materials*, 127, 436–441. <https://doi.org/10.1016/j.conbuildmat.2016.10.040>
- Akinyemi, B. A., & Dai, C. (2020). Development of banana fibers and wood dust reinforced polyester composites. *Construction and Building Materials*,
- American Society for Testing and Materials. (2017). *Standard specification for cellulosic fiber insulating board (ASTM C208-12(2017))*. ASTM International.
- American Society for Testing and Materials. (2021). *Standard test method for steady-state thermal transmission*

properties by means of the heat flow meter apparatus (ASTM C518-21). ASTM International.

Arumugam, H., Krishnasamy, B., Perumal, G., Dilip, A. A., Abdul Aleem, M. I., & Muthukaruppan, A. (2015). Bio-composites of rice husk and saw dust reinforced bio-benzoxazine/epoxy hybridized matrices: Thermal, mechanical, electrical resistance and acoustic absorption properties. *Construction and Building Materials*, 312, Article 125381. <https://doi.org/10.1016/j.conbuildmat.2021.125381>

ASTM International. (2021). *Standard test method for steady-state thermal transmission properties by means of the heat flow meter apparatus (ASTM D-1037-99, ASTM C518-21 & ASTM 165)*.

ASTM International. (2022). Standard specification for cellulosic fiber insulating board (ASTM C208-22). <https://store.astm.org/standards/c208>

Buratti, C., Belloni, E., Lascaro, E., Merli, F., & Ricciardi, P. (2018). Rice husk panels for building applications: Thermal, acoustic and environmental characterization and comparison with other innovative recycled waste materials. *Construction and Building Materials*, 171, 338–349. <https://doi.org/10.1016/j.conbuildmat.2018.03.089>

Dauda, K. E. E., & Justin, E. (2020). Investigation on thermal properties of composite of rice husk, corncob and bagasse for building thermal insulation. *American Journal of Engineering Research*, 3(12), 1–8.

Deraman, R., Nawi, M. N. M., Mydin, M. A. O., Ismail, M. H., Nordin, N. D. M., Sari, M. W., & Mohd-Danuri, M. S. (2022). Production of roof board insulation using agricultural wastes towards sustainable building material. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 99(1), 66–89. <https://doi.org/10.37934/arfmts.99.1.6689>

Edwin, R. N. E., Zulkefli, A. F., Mohaidi, H. M., AziRiza, H. H., MohdSuffian, N. S., IrwanSyah, N. D. B., Ismail, M. A., & Azizuddin, N. F. S. (2024). Effectiveness of natural fiber/agricultural waste materials as thermal insulation. *Malaysia Journal of Invention and Innovation*, 3(2), 5–10. <https://doi.org/10.64382/mjii.v3i2.64>

Gabr, E. M., Arafa, E. I., & El-Tabei, A. S. (2022). Eco-friendly thermal insulator from agricultural wastes and chitosan. *Egyptian Journal of Chemistry*, 65(SI: 13), 635–643. <https://doi.org/10.21608/EJCHEM.2022.157536.6827>

Gowon, K. E., & Bulama, K. H. (2018). Analysis of the thermal insulation properties of rice husk ceiling board compared to selected fiber-based ceiling materials used in Yola metropolis, Adamawa State, Nigeria. *American Journal of Mechanical and Materials Engineering*, 1(4), 83–88. <https://doi.org/10.11648/j.ajmme.20170104.11>

Indwar, R., & Titiksh, A. (2024). Organic wastes as a sustainable alternative to synthetic thermal insulating materials. *Environment, Development and Sustainability*.

Advance online publication. <https://doi.org/10.1007/s10668-024-05207-y>

Kumar, A., Singh, R., & Sharma, V. (2019). Development and optimization of hybrid insulation panels from rice husk, sawdust and waste carton fibers. *Journal of Building Engineering*, 26, 100857.

Liuzzi, S., Rubino, C., Martellotta, F., & Stefanizzi, P. (2023). Sustainable materials from waste paper: Thermal and acoustical characterization. *Applied Sciences*, 13(8), Article 4710. <https://doi.org/10.3390/app13084710>

Mbshida, M. A. (2020). Investigating the thermal properties of hybrid composite (rice husk, saw dust and bagasse) for building thermal insulation. *International Journal of Recent Engineering Science*, 7(1), 9–11. <https://doi.org/10.14445/23497157/IJRES-V7I1P102>

Muthukaruppan, A. (2021). Bio-composites of rice husk and saw dust reinforced bio-composites.

Muthuraj, R., Lacoste, C., Lacroix, P., & Bergeret, A. (2019). Sustainable thermal insulation biocomposites from rice husk, wheat husk, wood fibers and textile waste fibers: Elaboration and performances evaluation. *Industrial Crops and Products*, 135, 238–245. <https://doi.org/10.1016/j.indcrop.2019.04.053>

Okafor, E. C., Nwosu, K. C., & Udoh, J. S. (2022). Energy efficiency and building insulation in developing economies. *African Journal of Sustainable Engineering*, 11(3), 203–215.

Oluwole, B. A., Adejumo, P. O., & Okon, J. A. (2021). Recycling of paper waste into insulating building materials. *International Journal of Environmental Innovations*, 9(1), 45–56.

Robert, J. J., & Ekpote, A. (2022). Considering sawdust as a potential raw material for climate change mitigation in indoor environment. *Technology Audit and Production Reserves*, 6(3[68]), 24–28. <https://doi.org/10.15587/2706-5448.2022.270479>

Serin, H., Güzel, G., Kumlu, U., & Akar, M. A. (2022). Potential of using agricultural waste composites as thermal insulation material. *Macromolecular Symposia*, 404(1), Article 2100409. <https://doi.org/10.1002/masy.202100409>

Silva, A., Gaspar, F., & Bakatovich, A. (2023). Composite materials of rice husk and reed fibers for thermal insulation plates using sodium silicate as a binder. *Sustainability*, 15(14), Article 11273. <https://doi.org/10.3390/su151411273>

Singh, R., & Kumar, P. (2019). Thermal performance of bio-fiber-based insulation materials. *Journal of Renewable Construction*, 7(4), 154–168.

Yu, X., & Sun, L. (2018). Strength, microstructure, and thermal conductivity of the insulation wallboards prepared with rice husk fiber and recycled concrete aggregates. *PLOS ONE*, 13(9), Article e0203527. <https://doi.org/10.1371/journal.pone.0203527>

