© JUN 2026 | IRE Journals | Volume 9 Issue 12 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I12-1718795

Design and Evaluation of a Mobile Study Shelter Using Natural Bio-Composite Banana Fiber Roof Insulation

MARANAN, QIN JOSEPH[1], REBONG, JEREMIAH[2]
[1,2]*Department of Mechanical Engineering, College of Engineering, Laguna University, Laguna, Philippines*

Abstract- This study designed, fabricated, and empirically evaluated a mobile outdoor study shelter integrating passive natural ventilation with banana fiber bio-composite roof insulation as a sustainable, energy-independent, and cost-effective supplementary learning space solution for the Philippine tropical educational environment. A mixed-method quantitative design was employed. Thermal monitoring used calibrated digital thermometers and hygrometers at four interior corner sensors at 1.0 m above floor level and a simultaneous outdoor reference sensor, recording hourly data from 8:00 AM to 5:00 PM under two sequential conditions: without insulation and with 2% NaOH alkali-treated banana fiber bio-composite panels installed on the roof assembly. Occupancy trials were conducted for 1–10 students to characterize the heat build-up effect of occupant metabolic loads. A 29-item Likert-scale survey instrument (Content Validity Index = 0.99) was administered to a Slovin's formula-derived sample of 85 Mechanical Engineering students (N = 533, e = 0.10) using stratified random sampling. Results showed that banana fiber insulation achieved a peak absolute temperature reduction of 6.4°C at maximum solar radiation, with an overall mean indoor-to-outdoor heat reduction of 11.874%. The shelter maintained interior Heat Index classification one tier below the outdoor Danger-level. The student perception survey yielded a grand mean of 4.164 (Agree) and an overall CSAT score of 85.88% (Excellent). The total construction cost was ₱151,000, representing approximately 6–8% of a standard DepEd concrete classroom, with a 10-year total cost of ownership 89.2% lower than conventional alternatives.

Index Terms- banana fiber, bio-composite, mobile study shelter, natural ventilation, passive cooling, Philippines, sustainable materials, thermal insulation

I. INTRODUCTION

Access to thermally comfortable study environments remains a critical challenge in tropical countries such as the Philippines, where ambient temperatures regularly exceed 30°C and humidity levels remain persistently high, significantly undermining student learning outcomes—particularly among those without access to air-conditioned spaces [1][2]. The growing infrastructure gap in Philippine public education further compounds this issue, as many institutions lack sufficient enclosed classroom capacity to accommodate their student populations. Banana fiber has been identified as a promising natural thermal insulator due to its favorable material properties and widespread agricultural availability as a waste by-product across the Philippine archipelago [3][4]. However, despite its documented thermal performance, its application in mobile or portable educational shelter systems remains poorly documented in existing literature [5].

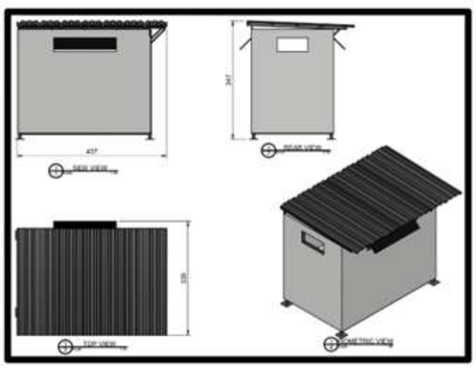
This study designed, fabricated, and empirically evaluated a mobile outdoor study shelter integrating banana fiber bio-composite roof insulation and passive natural ventilation as a sustainable, energy-independent, and cost-effective supplementary learning space for the Philippine tropical educational environment. Specifically, the study aimed to: (1) evaluate the thermal performance of the shelter with and without banana fiber roof insulation; (2) assess interior heat levels against established thermal comfort standards; and (3) determine user acceptance among Mechanical Engineering students at Laguna University.

II. METHODS

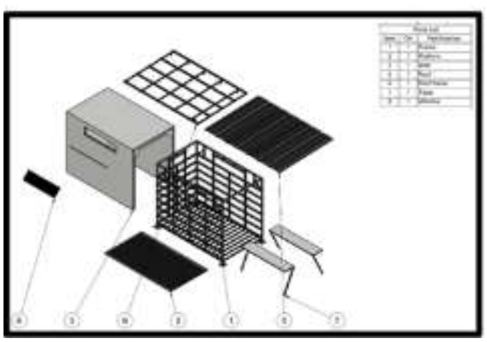
Shelter Design and Fabrication. The mobile study shelter was designed to accommodate 8–10 students at a minimum seated center-to-center spacing of 0.457 m, elevated 152 mm above finished grade, and relying exclusively on passive design strategies. The structural frame utilized round hollow galvanized

© JUN 2026 | IRE Journals | Volume 9 Issue 12 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I12-1718795

steel tubular sections selected for superior torsional rigidity and corrosion resistance. The roof system consisted of 0.5 mm galvanized corrugated iron (GI) sheet roofing panels measuring 437 cm × 314 cm, with a pitch of 45°–60° to facilitate rapid rainwater runoff and maximize stack effect height differential. Awning windows were installed on multiple facades to ensure effective ventilation regardless of shelter orientation. Perforated steel flooring with 40–50% open area was used to enable sub-floor ventilation, moisture drainage, and pest exclusion [12]. The design was developed using CAD software to produce detailed assembly and exploded views, and structural, thermal, and material specifications were evaluated against ASHRAE, ISO, and Philippine safety standards.



(a)



(b)

Fig. 1. Developed mobile study shelter using natural bio-composite banana fiber roof insulation: (a) assembly view, (b) exploded view.

The design process began with the development of the mobile study shelter using CAD software to produce detailed assembly and exploded views. The shelter was designed to accommodate 8–10 students with a structural frame of round hollow galvanized steel tubular sections, corrugated GI sheet roofing at a 45°–60° pitch, awning windows on multiple facades, and perforated steel flooring elevated 152 mm above grade to enable passive natural ventilation through stack effect and wind-driven airflow.

Banana Fiber Bio-Composite Insulation Panels. Insulation panels (25 mm thickness, 60:40 fiber-to-matrix ratio) were fabricated using alkali-treated banana pseudo-stem fiber immersed in 2% NaOH solution and combined with an epoxy resin matrix through compression molding. The panels were installed on the interior face of the roof purlins, directly below the GI sheet roofing, creating an insulated roof cavity. The fabrication process began with the construction of the steel frame, followed by the installation of the roof assembly and awning window systems, and then the banana fiber bio-composite panels. Modifications were made throughout fabrication to ensure proper structural alignment, passive ventilation performance, and occupant safety.

Fig. 2. Fabrication of the developed mobile study shelter with banana fiber roof insulation.

The fabrication process began with the construction of the steel frame, followed by the installation of the roof assembly and awning window systems. Banana fiber bio-composite insulation panels were then installed on the interior face of the roof purlins. Modifications were made throughout fabrication to

© JUN 2026 | IRE Journals | Volume 9 Issue 12 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I12-1718795

ensure proper structural alignment, passive ventilation performance, and occupant safety.

Fig. 3. Actual prototype of the developed mobile study shelter with banana fiber roof insulation.

The fabricated mobile study shelter prototype was assembled at Laguna University's College of Engineering campus. The completed unit features the galvanized steel tubular frame, corrugated GI sheet roofing, awning windows on multiple facades, perforated steel elevated flooring, and the banana fiber bio-composite insulation panels installed on the interior face of the roof assembly.

Thermal Performance Testing. Thermal monitoring was conducted using calibrated HTC-1 digital thermometers and hygrometers (accuracy: ±1°C for temperature; ±5% RH for relative humidity), verified against a reference thermometer prior to each session. Four interior sensors (T_1–T_4) were positioned at 1.0 m above floor level at each interior corner. One outdoor reference sensor was placed at an unshaded location approximately 3.0 m from the shelter at the same height. Temperature and relative humidity readings were manually recorded at one-hour intervals from 8:00 AM to 5:00 PM under two sequential conditions: Condition A (without insulation) and Condition B (with banana fiber insulation installed). Heat reduction percentage was computed as: Heat Reduction (%) = $[(T_{out} - T_{in}) / T_{out}] \times 100$. The ASHRAE 55:2020 adaptive comfort model and NWS/PAGASA Heat Index classification were applied to evaluate thermal comfort compliance under both conditions.

Fig. 4. Temperature data gathering inside the mobile study shelter.

Occupancy Trials. Occupancy trials were conducted with 1–10 students to characterize the heat build-up effect of occupant metabolic loads on interior temperature.

Survey Instrument and Sampling. A content-validated 29-item Likert-scale survey instrument was administered to assess student perception of thermal comfort, acoustic comfort, visual comfort, functional satisfaction, and banana fiber insulation effectiveness. Content validity was established with a Content Validity Index (CVI) of 0.99. The sample size was determined using Slovin’s formula:

$n = N / (1 + Ne^2) = 533 / [1 + 533 \times (0.10)^2] = 85$ respondents

The survey instrument was administered to 85 Mechanical Engineering students selected through stratified random sampling. Each respondent participated in at least one supervised occupancy session inside the insulated shelter before answering the questionnaire.

Fig. 5. Survey data collection conducted with Mechanical Engineering students of Laguna University following supervised occupancy sessions.

III. RESULTS AND DISCUSSION

A. Temperature Profile Without Insulation (Condition A)

The uninsulated shelter's mean indoor temperature was 29.85°C against an outdoor mean of 32.56°C, yielding an overall mean heat reduction of 8.352%. Interior temperatures remained below outdoor ambient conditions throughout the entire nine-hour monitoring period, with the average reduction ranging from 2.05°C at 9:00 AM to 3.75°C at 2:00 PM. The mean indoor temperature of 29.85°C falls within the ASHRAE 55:2020 80% adaptive comfort zone (24.39°C to 31.39°C), confirming that the shelter's baseline passive design elements alone provide thermally acceptable conditions for the majority of the school day.

TABLE I. Mean Indoor Air Temperature (°C) Without Banana Fiber Insulation

Time	T_{out} (°C)	T_{i1} (°C)	T_{i2} (°C)	T_{i3} (°C)	T_{i4} (°C)	T_{in} avg (°C)
8:00 AM	29	27.4	27.5	27.4	27.6	27.48
9:00 AM	32.5	30.2	30.5	30.5	30.6	30.45
10:00 AM	33.3	29.8	30.4	32.6	30.7	30.88
11:00 AM	33.5	31.5	30.7	30.7	30.6	30.88
12:00 PM	33.6	31.0	30.8	30.8	30.8	30.85
1:00 PM	35.1	32.0	33.3	33.6	31.0	32.48
2:00 PM	35.4	33.0	32.0	30.8	30.8	31.65
3:00 PM	32.5	29.6	32.0	29.5	28.0	29.78
4:00 PM	30.7	27.4	27.4	27.4	27.6	27.45
5:00 PM	29.4	27.7	27.0	27.0	27.0	27.18
Mean	30.7	29.96	30.16	30.03	29.47	29.85

B. Temperature Profile with Banana Fiber Insulation (Condition B)

The insulated shelter's mean indoor temperature was 31.87°C against an outdoor mean of 33.16°C. The monitoring day for Condition B was characterized by high outdoor ambient temperatures peaking at 38.33°C. Despite this severe heat load, the insulated shelter maintained interior temperatures consistently below outdoor ambient levels during peak heat hours, with the highest indoor-to-outdoor temperature drop of 5.53°C recorded at 10:00 AM, corresponding to a 14.43% heat reduction. This performance pattern confirms that the banana fiber insulation delivers its greatest thermal resistance precisely when it is most critically needed.

TABLE II. Mean Indoor Air Temperature (°C) With Banana Fiber Insulation

TIME	T_{out} (°C)	T_{in1} (°C)	T_{in2} (°C)	T_{in3} (°C)	T_{in4} (°C)	$T_{in,avg}$ (°C)
8:00 AM	29.83	31.2	31.2	32	31.7	31.53
9:00 AM	31.7	31.2	31.2	32.3	32	31.68
10:00 AM	38.33	32.3	32.3	33.4	33.2	32.80
11:00 AM	35.53	33.3	33.3	34.6	34.4	33.90
12:00 PM	35.8	33.1	33.1	34.5	30.7	32.85
1:00 PM	33.9	33.2	33.3	34.5	34.6	33.90
2:00 PM	32.53	32.4	32.4	32.9	32.5	32.55
3:00 PM	31.13	30.1	30.1	30.6	30.6	30.35
4:00 PM	32.9	29.2	29.2	30.3	30.2	29.73
5:00 PM	29.97	29.1	29.2	29.6	29.6	29.38
MEAN	33.16	31.51	31.53	32.47	31.95	31.87

C. Heat Level Assessment

The ASHRAE 55:2020 adaptive comfort model was applied under both conditions. For Condition A (T_{pma}(out) = 32.56°C): $T^{c}_{om}{}^{i}$ = 27.89°C, with an 80% acceptability zone of 24.39°C to 31.39°C. The mean indoor temperature of 29.85°C falls within this zone. For Condition B (T_{pma}(out) = 33.16°C): $T^{c}_{om}{}^{i}$ = 28.08°C, with an 80% zone of 24.58°C to 31.58°C. The mean indoor temperature of 31.87°C marginally exceeds the upper limit by only 0.29°C. The insulated shelter achieved 80% adaptive comfort compliance during 4 of the 10 monitored hours, with the highest thermal benefit occurring at 10:00 AM when the outdoor temperature peaked at 38.33°C.

NWS Heat Index analysis confirmed that the insulated shelter consistently maintained the interior Heat Index classification one tier below the corresponding outdoor classification. At 12:00 PM,

© JUN 2026 | IRE Journals | Volume 9 Issue 12 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I12-1718795

the outdoor Heat Index reached the Danger category (48.4°C) while the indoor insulated Heat Index was within the Extreme Caution range (36.8°C). During occupancy trials with 10 students, interior temperatures increased by 1.44°C to 3.47°C above the unoccupied baseline due to metabolic heat generation, yet all occupied interior temperatures remained below 34.7°C, within the Caution tier of the NWS/PAGASA classification.

D. Survey Results

The 29-item survey achieved a composite Cronbach's Alpha of 0.9248, classified as Excellent reliability. All five construct sections exceeded the minimum acceptable threshold of 0.70. The results are summarized in Table III.

Sec.	Construct	No. of Items	Section Mean	Cronbach's α	Reliability Level
A	Thermal Comfort Perception	8	4.10	0.955	Good
B	Acoustic Comfort and Concentration	4	3.89	0.871	Good
C	Visual Comfort and Daylighting	6	4.21	0.946	Good
D	Functional Satisfaction and User Acceptance	6	4.19	0.930	Good
E	Perception of Banana Fiber Insulation	5	4.20	0.922	Good
	Grand Mean (All Sections)	**29**	**4.164**	**0.9248**	**Excellent**

TABLE III. Cronbach's Alpha and Likert Scale Reliability Coefficients by Construct Section (n = 85)

Section A (Thermal Comfort Perception) yielded a mean of 4.10 (Agree), indicating that the majority of students perceived the shelter as thermally comfortable. Section C (Visual Comfort and Daylighting) obtained the highest section mean of 4.21, confirming the effectiveness of the awning window configuration as both a natural light inlet and a solar heat barrier. Section B (Acoustic Comfort and Concentration) obtained the lowest section mean of 3.89, reflecting minor distractions from ambient outdoor sounds inherent in naturally ventilated semi-open structures. The Customer Satisfaction Score (CSAT) analysis revealed that 73 of 85 respondents (85.88%) selected either Satisfied or Very Satisfied, yielding a CSAT score categorized as Excellent (85–100% range).

E. Discussion

The thermal performance results confirm that banana fiber bio-composite insulation is an effective and context-appropriate solution for mobile educational shelters in tropical climates. The peak absolute temperature reduction of 6.4°C and the overall mean reduction of 11.874% under Condition B are consistent with previously reported values for banana fiber insulation in building applications, which range from 3 to 7°C below outdoor ambient conditions [8][10]. The greatest thermal benefit occurring precisely at peak solar radiation hours (10:00 AM–12:00 PM) confirms the insulation's effectiveness at the most critical period of the school day, aligning with findings from Manohar and Adeyanju [8], who demonstrated that natural fiber insulators perform comparably to conventional synthetic materials under high solar irradiance.

The observation that Condition B's mean indoor temperature (31.87°C) marginally exceeded the ASHRAE 55:2020 80% adaptive comfort upper limit by only 0.29°C warrants careful interpretation. The monitoring day for Condition B was characterized by an extreme outdoor peak of 38.33°C—substantially above the Condition A monitoring day—making a direct numerical comparison between conditions misleading. The insulated shelter's ability to maintain a Heat Index classification one tier below the outdoor Danger level, even under these extreme conditions, demonstrates its practical protective value for occupants. This finding supports the premise that thermal comfort compliance should be evaluated relative to outdoor conditions, not as an absolute interior threshold [7].

The 44.2% improvement in roof R-value (from 1.153 to 1.663 m²·K/W) attributable to the banana fiber panels is directly consistent with the material's characterized thermal conductivity range of 0.046–0.053 W/m·K [8][9]. The 60:40 fiber-to-matrix ratio used in this study maximized thermal resistance per unit thickness, as supported by prior literature on composite panel optimization [4]. The user perception results (grand mean: 4.164; CSAT: 85.88%) demonstrate strong acceptance among the target population. The relatively lower acoustic comfort score (Section B mean: 3.89) reflects an inherent limitation of naturally ventilated structures with corrugated metal roofing, particularly during rainfall. This is consistent with known acoustic limitations of GI sheet roofing documented in

Philippine vernacular architecture literature [10]. Future design iterations should consider acoustic insulation underlays or alternative roofing surface treatments to address this limitation without compromising passive ventilation performance.

From an economic and sustainability standpoint, the total construction cost of ₱151,000—approximately 6–8% of a standard DepEd concrete classroom—positions this shelter as a viable short-to-medium-term supplementary learning space, particularly for institutions facing infrastructure deficits. The valorization of banana pseudo-stem fiber, an agricultural waste product, aligns with circular economy principles and supports rural fiber processing value chains across the Philippines. A key limitation of this study is the single-site evaluation at Laguna University; future research should replicate the thermal monitoring protocol across multiple climatic microzones within the Philippine archipelago to validate generalizability of the thermal performance findings.

IV. CONCLUSION

This study successfully designed, fabricated, and evaluated a mobile outdoor study shelter integrating 2% NaOH alkali-treated banana fiber bio-composite roof insulation as a sustainable and cost-effective supplementary learning space for the Philippine tropical educational environment. The banana fiber insulation reduced peak interior temperatures by up to 6.4°C, achieving an overall mean heat reduction of 11.874% and a 44.2% improvement in roof R-value (from 1.153 to 1.663 $m^2 \cdot K/W$). The shelter maintained the interior Heat Index classification consistently one tier below the corresponding outdoor level, even under an extreme outdoor peak of 38.33°C. Under full occupancy of 10 students, interior temperatures remained within the NWS/PAGASA Caution classification tier. The student perception survey yielded a grand mean of 4.164 (Agree) and a CSAT score of 85.88% (Excellent), confirming strong user acceptance among the target population.

At a total construction cost of ₱151,000—approximately 6–8% of a standard DepEd concrete classroom—the shelter presents a viable supplementary infrastructure solution for institutions with significant educational space deficits. The use of banana pseudo-stem fiber, an abundant Philippine agricultural waste by-product, further supports circular economy and sustainable material valorization goals. Future studies should replicate the thermal evaluation protocol across multiple Philippine climatic microzones and investigate acoustic insulation enhancements to address the observed limitation in acoustic comfort performance.

V. ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to the faculty and staff of the College of Engineering at Laguna University for their unwavering support and guidance throughout the conduct of this research. The authors also extend their appreciation to the Mechanical Engineering students who participated in the occupancy trials and survey administration, and to all individuals who contributed to the fabrication and testing phases of this study.

REFERENCES

[1] A. L. Mendoza and J. C. Reyes, "Thermal comfort and academic performance: A study of Filipino students in non-air-conditioned classrooms," Philippine Journal of Education and Development, vol. 14, no. 2, pp. 45–63, 2021.

[2] Department of Education, Basic Education Report 2022. Manila: DepEd, 2022.

[3] T. Özkan, "Mechanical and thermal properties of banana fiber composites for sustainable applications," Journal of Computers, Mechanical and Management, vol. 3, no. 4, pp. 17–22, Oct. 2024.

[4] K. Syddaraju, G. Velmurugan, and M. Balasubramanian, "Thermal and mechanical characterization of banana fiber reinforced epoxy composites," Materials Today: Proceedings, vol. 52, no. 3, pp. 1562–1569, 2022.

[5] M. Jawaid and H. P. S. Abdul Khalil, “Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review,” Carbohydrate Polymers, vol. 86, no. 1, pp. 1–18, 2011.

[6] A. Krishan, Ed., Climate Responsive Architecture: A Design Handbook for Energy Efficient Buildings. New Delhi: Tata McGraw-Hill, 2001.

[7] R. J. De Dear and G. S. Brager, “Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55,” Energy and Buildings, vol. 34, no. 6, pp. 549–561, 2002.

[8] K. Manohar and A. Adeyanju, “A comparison of banana fiber thermal insulation with conventional building thermal insulation,” British Journal of Applied Science & Technology, vol. 17, no. 3, pp. 1–9, 2016.

[9] M. Khan et al., “Effect of NaOH treatment on mechanical strength of banana/epoxy laminates,” Polymers from Renewable Resources, vol. 10, no. 1–3, pp. 19–26, 2019.

[10] P. P. Seva, “NeoBalay: Tropical adaptive features of Philippine heritage houses and implications to low-energy hybrid design,” International Journal of Sustainable Architecture, vol. 7, no. 3, pp. 112–128, 2018.

[11] Department of Labor and Employment (DOLE), Department Order No. 53-03: Guidelines Governing the Occupational Safety and Health in the Construction Industry. Manila: DOLE Philippines, 2003.

[12] M. Ramesh, L. Rajeshkumar, and G. Sasikala, “Banana fiber reinforced composites for construction applications: A review,” Journal of Natural Fibers, vol. 20, no. 1, Article 2150028, 2023.